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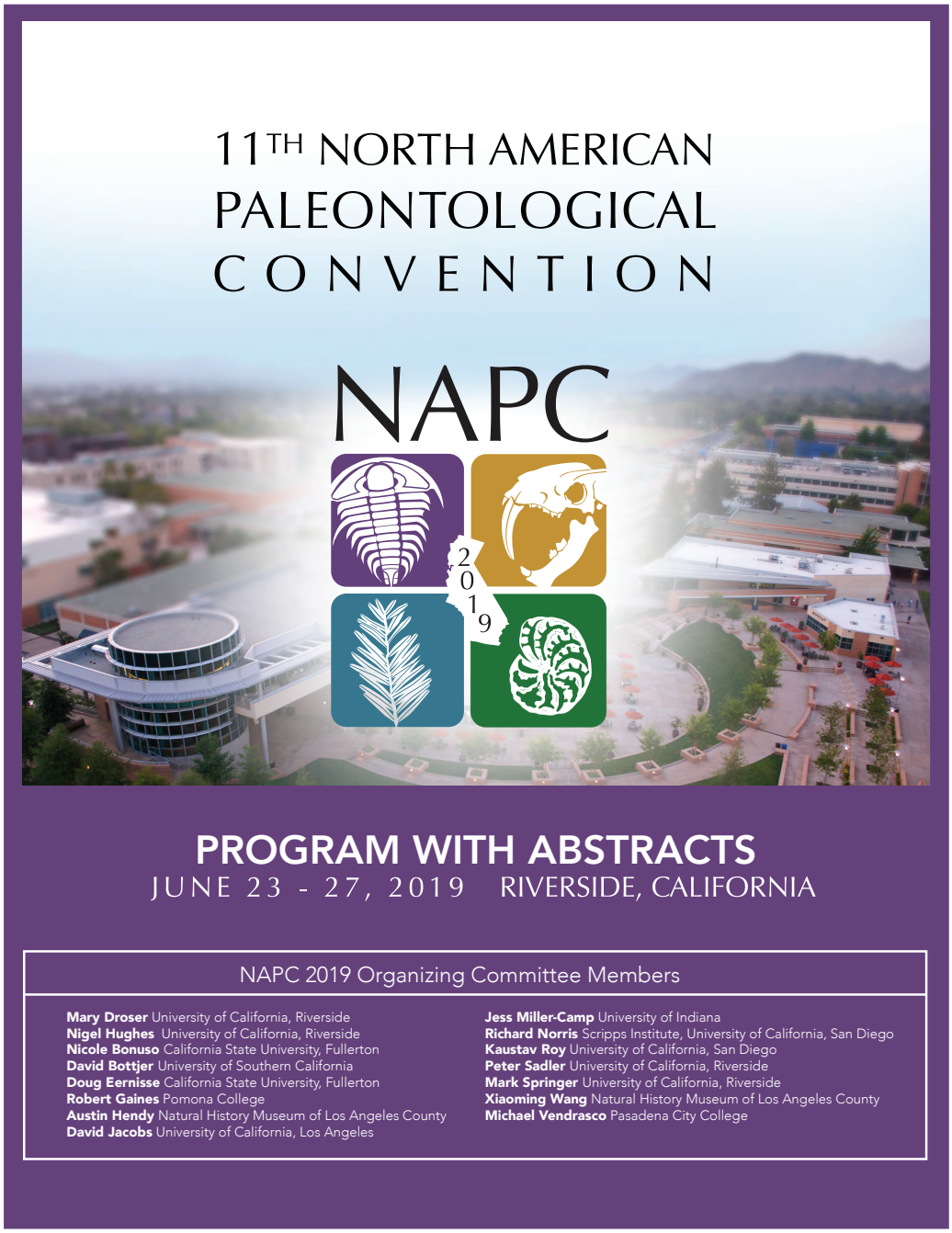

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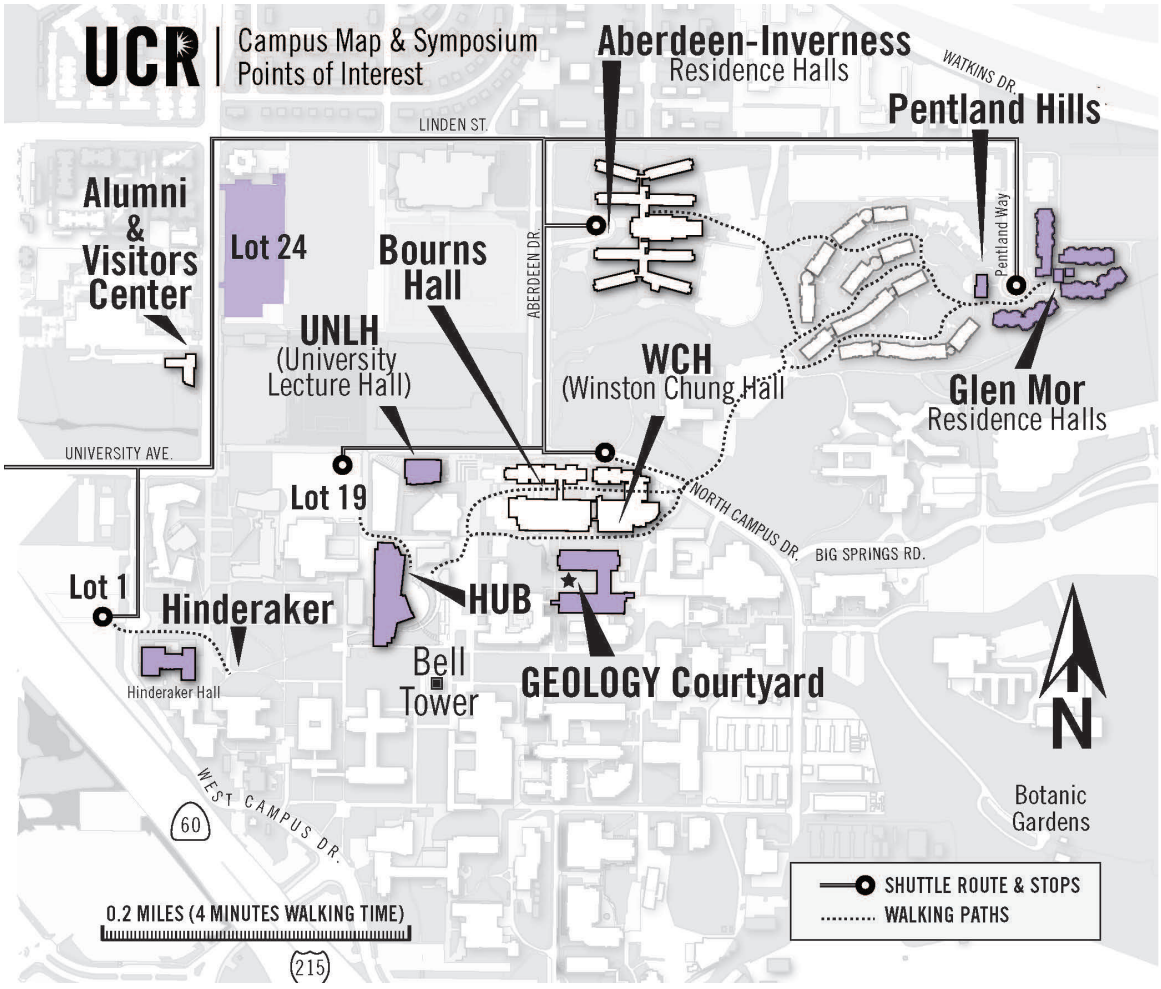
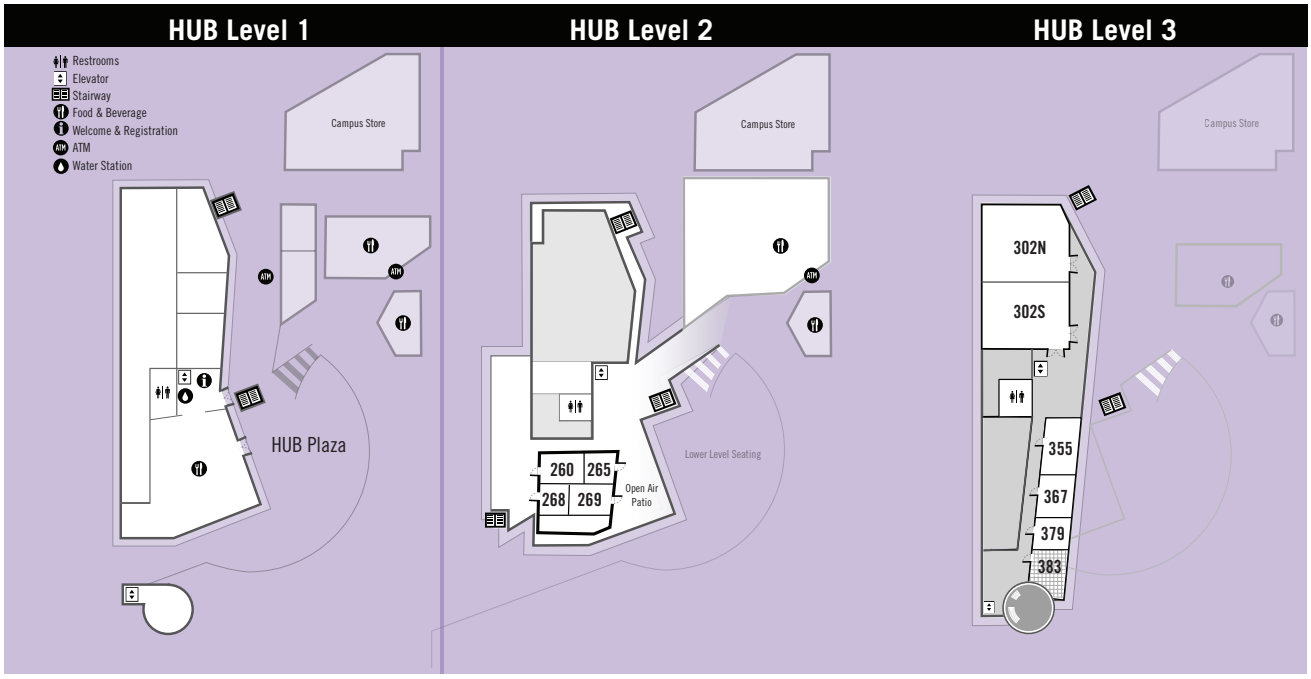
MAP OF UNIVERSITY OF CALIFORNIA-RIVERSIDE





NAPC 2019 ORGANIZING COMMITTEE

- **Mary Droser**, University of California, Riverside
- **Nigel Hughes**, University of California, Riverside
- **Nicole Bonuso**, California State University, Fullerton
- **David Bottjer**, University of Southern California
- **Doug Eernisse**, California State University, Fullerton
- **Robert Gaines**, Pomona College
- **Austin Hendy**, Natural History Museum of Los Angeles County
- **David Jacobs**, University of California, Los Angeles
- **Jess Miller-Camp**, University of Indiana
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- **Peter Sadler**, University of California, Riverside
- **Mark Springer**, University of California, Riverside
- **Xiaoming Wang**, Natural History Museum of Los Angeles County
- **Michael Vendrasco**, Pasadena City College

11th NORTH AMERICAN PALEONTOLOGICAL CONVENTION

JUNE 23–27 RIVERSIDE, CALIFORNIA

NAPC 2019 SCHEDULE OF EVENTS

Saturday, June 22

2:00pm	Dorm check-in begins at Glen Mor apartments.
4:00 – 8:00pm	Glen Mor guest early conference registration and guest reception with refreshments. Pizza and Beer pool party for residents.

Sunday, June 23

7:00– 9:00am	Registration and refreshments
8:20 – 10:20am	Welcome/Plenary Session—UNLH
11:00am – 12:00pm	Symposia and Topical Sessions
12:00 – 1:00pm	Lunch—HUB Plaza
12:00 – 1:00pm	Essentials of Publishing Workshop—HUB 367
1:00 – 5:00pm	Symposia and Topical Sessions
1:00 – 6:00pm	Poster Session
5:30 – 6:45pm	Graduate Student Wine Tasting and Cheese Reception—Geology Courtyard
7:00 – 9:00pm	Opening Reception with dinner - street taco buffet with Mariachi band—HUB Plaza

Monday, June 24

7:00 – 8:00am	Registration and Refreshments
8:00am – 5:00pm	Mission Inn tours for guests—family event
8:00am – 12:00pm	Symposia and Topical Sessions
8:00am – 12:00pm	Poster Session
12:00 – 1:00pm	Lunch—HUB Plaza
12:00 – 1:00pm	Student Equity, Inclusion & Diversity Event—Finding your community and building a support network
1:00 – 5:00pm	Symposia and Topical Sessions
1:00 – 6:00pm	Poster Session
5:00 – 6:00pm	NSF Town Hall—HUB 355
5:00 – 6:00pm	Public Lands—Panel Discussion—HUB 269
6:00 – 9:30pm	Raffle and Dinner—casual mixed buffet—HUB 302

Tuesday, June 25

7:00 – 8:00am	Registration and refreshments
8:00am – 5:00pm	Local field trips, museum trips, and workshops

NAPC 2019 SCHEDULE OF EVENTS

Tuesday, June 25 (cont.)

8:00am – 5:00pm	K-12 Teacher STEM Workshop—Riverside STEM Academy
8:00am – 7:00pm	Disneyland—family event
12:00 – 1:00pm	Lunch—HUB Plaza
5:00pm – 6:30pm	Beer and Pretzels for workshop participants—Geology Courtyard
6:30 – 8:30pm	Casual BBQ dinner—HUB Plaza

Wednesday, June 26

7:00 – 8:00am	Registration and refreshments
8:00am – 12:00pm	Symposia and Topical Sessions
8:00am – 12:00pm	Poster Session
12:00 – 1:00pm	Lunch—HUB Plaza
12:00 – 1:00pm	Equity, Inclusion & Diversity Event—Using your Power and Privilege for Good
1:00 – 5:00pm	Symposia and Topical Sessions
1:00 – 6:00pm	Poster Session
6:30 – 10:00pm	Banquet—Hinderaker Hall Lawn

Thursday, June 27

7:00 – 8:00am	Registration and refreshments
8:00am – 12:00pm	Symposia and Topical Sessions
8:00am – 12:00pm	Poster Session
12:00 – 1:00pm	Lunch—HUB Plaza
1:00 – 5:00pm	Symposia and Topical Sessions
1:00 – 6:00pm	Poster Session
6:00 – 8:00pm	Refreshments

Friday, June 28

8:00 – 11:00am	Check out. Post-meeting field trips depart.

NAPC 2019 EXHIBITORS/SPONSORS

METROLINK

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IUGS UNESCO Project 668
Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics

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NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23

Plenary Session (UNLH)	Presenter	Testament of Time - N. Hughes (*keynote)
8:00 am	**M. Droser, N. Hughes**	Welcome and opening remarks
8:20	R. Ahmed*	Natural history and the future
8:50	P. Crane*	Ginkgo: An evolutionary and cultural biography
9:20	R. Fortey*	Writer versus scientist: compromise and comprehension
9:50	S. Sumida*, E. Rega	The power of paleontology and the arts as collaborative forces
10:20		**Coffee Break**

Symposium #3 (HUB 355)		Plankton and Earth System Evolution - P. Hull, S. Kirkland Turner
11:00 am	S. Trubovitz	Tropical and polar plankton demonstrate contrasting sensitivities to climate change throughout the Late Neogene
11:15	D. Lazarus	Diversity dynamics and climate change in Cenozoic marine siliceous plankton
11:30	H. Jones	Delayed calcareous nannoplankton boom-bust successions in the earliest Paleocene Chicxulub impact crater
12:00 - 1:00 pm		**LUNCH**

Symposium #2 (HUB 355)		Tiny fossils, big questions, big data - M. Yasuhara, A. O'Dea, E. Sibert, J. Williams
1:00 pm	S. Kahanamoku	Building big data with AutoMorph: A high-throughput imaging, morphometrics, and machine learning pipeline accelerates macro- and microfossil paleoecological research
1:15	D. Lazarus	NSB and Mikrotax: Databases and software tools for fossil and living plankton research
1:30	C. Belanger	Path analyses of faunal change: Deconvolving environmental drivers of benthic foraminiferal community change to demonstrate similarities at intermediate and abyssal depths in the Pleistocene Gulf of Alaska
1:45	Y. Zhao	The evolutionary history of fusulinids reconstructed by using GBDB and CONOP
2:00	M. Yasuhara	Deep-sea biodiversity in space and time: What high time resolution microfossil records tell
2:15	H. Huang	The relationship between tectonics and ostracods: ostracods faunal changes under a subduction initiation system in the Tasman Sea

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23 (cont.)

Symposium #2 (HUB 355)	Presenter	Tiny fossils, big questions, big data - M. Yasuhara, A. O'Dea, E. Sibert, J. Williams
2:45 pm		**Tea Break**
3:15	Y. Wang	Climate drives stability of vegetation biomes after the last glaciation in North America
3:30	J. Williams	Building big data and open science from the long tail: Community-curated data resources, Neotoma Paleoecology Database, and the Earth-Life Consortium
3:45	R. Dunn	Forest canopy response to greenhouse warming at the Paleocene-Eocene Thermal Maximum
4:00	S. Punyasena	Improving the taxonomic accuracy and precision of fossil pollen identifications
4:15	L. Morais	Siliceous VSM tests and the origin of protist biomineralization in Neoproterozoic oceans
4:30	E. Sibert	A mass extinction of open-ocean sharks 20 million years ago

Symposium #7 (HUB 302)		Cambrian Konservat-Lagerstätten and the emergence of modern-style marine ecosystems - R. Lerosey-Aubril, R. Gaines, X. Zhang (*keynote)
11:00 am	J-B. Caron*	The Marble Canyon Burgess Shale fossil deposit – British Columbia, Canada: New field discoveries, geologic setting, prospects and significance
11:30	F. Zhao	The Chengjiang-type fossil assemblages from the lower Cambrian Yu'anshan Formation of Qujing, eastern Yunnan and its taphonomic and paleoecological significance
11:45	M. B. Meyer	Understanding exceptional preservation through comparative micro-analysis of fossils from the Cambrian Kinzers Formation (~514–509 Mya) of central Pennsylvania, USA
12:00 - 1:00 pm		**LUNCH**
1:00 pm	Z. Zhang	Brachiopods with soft parts from the early Cambrian Wulongqing Formation (Series 2, Stage 4) of Yunnan, southern China
1:15	S. Hsieh	Bright and early – Trends in cognition among Phanerozoic marine ecosystems
1:30	J. Ortega-Hernández	The Xiaoshiba Konservat-Lagerstätte: overview, significance and future directions
1:45	D. Fu*	The Qingjiang biota – An extraordinary new Burgess Shale-type fossil Lagerstätte from the early Cambrian of South China

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23 (cont.)

Symposium #7 (HUB 302)	Presenter	Cambrian Konservat-Lagerstätten and the emergence of modern-style marine ecosystems - R. Lerosey-Aubril, R. Gaines, X. Zhang
2:15 pm	L. E. Babcock	Three-dimensional preservation of nonbiomineralized tissues in Cambrian concretionary Lagerstätten of North America
2:30	Q. Tang	The Hetang biota: A taphonomic window into the Cambrian explosion
2:45		**Tea Break**
3:15	K. Nanglu	Diversity and structure of the Burgess Shale palaeocommunity with new insights from Marble Canyon, British Columbia
3:30	Y. Liang	Shell structure and affinity of the problematic early Cambrian brachiopod *Heliomedusa orienta* Sun and Hou, 1987
3:45	X. Ma	Why is the Chengjiang Biota exceptionally well preserved?
4:00	H. Qiu	Preservation and microstructures of small shelly fossils from the Cambrian Terreneuvian Yanjiahe Formation
4:15	J. Kimmig	The middle Cambrian Spence Shale (Miaolingian: Wuliuan) Lagerstätte: Improving our understanding of a key Cambrian ecosystem

Topical #38 (HUB 269)		Macroevolutionary Dynamics - L. Lassiter, T. Smiley
11:00 am	P. Smits	How predictable is extinction? Forecasting species survival at million-year timescales
11:15	J. Lipps	The Signor-Lipps Effect in paleobiology, paleoecology and evolution
11:30	J. Crampton	Synchronous changes of speciation and extinction in mid-Paleozoic zooplankton: “instantaneous” coupling of macroevolutionary dynamics
11:45	L. Lassiter	Revisiting Romer: Eurypterid influence on early vertebrate evolution
12:00 - 1:00 pm		**LUNCH**
1:00	E. Doughty	Cenozoic environmental change shapes North American ungulate communities through within- and among lineage evolution
1:15	T. Smilely	Basin and Range tectonics drive diversification dynamics in North American mammals
1:30	G. Smith	Phylogenetic conservatism of biotic crises in North American mammals

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23 (cont.)

Topical #38 (HUB 269)	Presenter	Macroevolutionary Dynamics - L. Lassiter, T. Smiley
1:45 pm	T. Htun	How did mammoths and mastodonts grow and become dwarfed? Ontogenetic long bone growth compared to island dwarfing in Pleistocene Proboscidea.
2:00	A. Kocsis	The R package divDyn for quantifying diversity dynamics using fossil sampling data

Topical #41 (HUB 269)		Taphonomy - A. Tomasovych, T. Selly
2:15 pm	T. Selly	Establishing a new protocol for decay experimentation using x-ray tomographic microscopy
2:30	A. Tomašových	The formation of permanent fossils records: Estimating post-mortem disintegration, burial, and mixing from shell-age frequency distributions in sediment cores
2:45		**Tea Break**
3:15	J. Hou	Mathematic modeling to reconstruct the taphonomic history of the Burgess Shale-type fossils
3:30	F. Saleh	Preservation bias in the Fezouata Shale
3:45	P. Vayda	Exceptionally preserved fossils from the Silica Shale Lagerstätte (Middle Devonian) of Ohio, Michigan, and Indiana: XCT reveals detailed anatomical information
4:00	D. Friend	Preservation potential of rocky intertidal molluscs in temperate and tropical environments
4:15	N. Seiden	Determining the impacts of the Anthropocene through time-calibrated taphonomic grading
4:30	N. Soto-Contreras	Testing the influence of human interference on land snail richness and composition from temperate forests in Ohio

Symposium #37 (HUB 268)		Engaging Diverse Communities in Paleontology: Innovative educational initiatives that connect culture to natural history - G. Santos, S. Mills, I. Magallanes
1:00 pm	R.M. Dahl	More than numbers, beyond diversity: Re-centering the conversation on equity and inclusion
1:15	C.C. Visaggi	Teaching at the intersections of paleontology and culture: bringing new meaning to the study of the fossil record

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23 (cont.)

Symposium #37 (HUB 268)	Presenter	Engaging Diverse Communities in Paleontology: Innovative educational initiatives that connect culture to natural history - G. Santos, S. Mills, I. Magallanes
1:30 pm	M.F. Miller	Nashville discovers Paleozoic fossils: Programs and field trips at an urban historical park
1:45	L. Taylor	Building collaborations with local community colleges to increase diverse students' access to paleontology
2:00	H.T. Chase	Treating Science Outreach as Exchange Rather than Bestowal
2:15	S.S. Sumida	Partnering Vertebrate paleontologists with local Native American students: Lessons from The Pueblo of Jemez, northwest New Mexico, USA
2:30	I.D. Browne	Increasing American Indians pursuing STEM careers through paleontology and culture
2:45		**Tea Break**
3:15	B.S. Dooley	I.C.E. AGE Project: Fostering global mindedness
3:30	G.-P. Santos	The Alf Museum and the Institute for the Study of Mongolian Dinosaurs: An international collaboration for paleontology education
3:45	L.D. White	Leveraging natural history collections, online media, and field experiences to create a network of engaged geoscientists
4:00	B. de Pastino	Reaching a diverse audience for paleontology on YouTube
4:15	M.M. Barboza	Reaching communities through Cosplay: A study in paleontology and pop culture
4:30	A. Rudenko	Prehistoric Body Theater: bringing paleontology narratives to global contemporary performance audiences

Symposium #16 (HUB 367)		Climate and Environmental Change in High-Latitude Fossil and Modern Ecosystems - K. Cronin, S. Walker (*keynote)
1:00	J. McClintock*	The impacts of climate warming and ocean acidification on the marine ecology of the Antarctic Peninsula
1:30	C. Meadows	High-latitude benthic bivalve biomass and recent climate change: Testing the power of live-dead discordance in the Pacific Arctic
1:45	K. Chin	Warm Arctic temperatures and the structure of Cretaceous marine ecosystems

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23 (cont.)

Symposium #16 (HUB 367)	Presenter	Climate and Environmental Change in High-Latitude Fossil and Modern Ecosystems - K. Cronin, S. Walker (*keynote)
2:00	A. Fiorillo	Comparison of paleoenvironmental and paleoclimatological parameters of correlative dinosaur-bearing Late Cretaceous (Campanian - Maastrichtian) rock units across Alaska, USA: A regional perspective
2:15	X. Wang	Dental caries on a primitive bear, *Protarctos abstrusus*, from the Pliocene of Canadian Arctic suggest a high sugar diet of berries and possible hibernation
2:30	L. Buatois	Is climate an overlooked factor in marine ichnology?
2:45		**Tea Break**
3:15	R. Aronson*	Climate, trophic structure, and the evolving demeanor of the Antarctic benthos
3:45	R. Whittle	Benthic invertebrate community ecology in the Cenozoic of Antarctica
4:00	S. Bowser	Population dynamics in the Antarctic benthos: inter-annual fluctuation of foraminiferal, tunicate, and scallop abundances in Explorers Cove, Western McMurdo Sound
4:15	A. Perez-Huerta	Biomineralization in extreme environments: the case of Antarctic scallop shells
4:30	K. Cronin	Trace elements and interstrial distances as environmental and anthropogenic proxies in the Antarctic scallop, *Adamussium colbecki*
4:45	A. Raymond	Evolutionary rates at high latitudes and the equator during the Late Paleozoic Ice Age

Symposium #27 (HUB 379)		New frontiers in paleobotany: tools, techniques, insights - J. Wilson, C. Looy
1:00	C.V. Looy	The Pteridological Collections Consortium: An integrative approach to pteridophyte diversity over the last 420 million years
1:15	B. Muddiman	Coal ball meta-analysis of paleowildfire in Pennsylvanian coal swamps
1:30	J.P. Wilson	Hydraulic conductivity and constraints among Paleozoic plants
1:45	W.J. Matthaeus	The physiological landscape of the Carboniferous: Finding the frontier of frost tolerance

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23 (cont.)

Symposium #27 (HUB 379)	Presenter	New frontiers in paleobotany: tools, techniques, insights - J. Wilson, C. Looy
2:00	X. Zhang	Late Triassic flora of the Xiaoping Formation and palaeoenvironmental significance in central Guangdong, China
2:15	Z. Jiang	*Zhangoxylon* gen. nov., a new coniferous wood genus of Sciadopityaceae from the Juriassic of western Liaoning, NE China
2:30	X. Zhang	Reconstruction of *Tricalycites*, an early winged fruit type from the Cretaceous of the Gulf coastal and eastern coastal plains of North America
2:45		**Tea Break**
3:15	P. Wilson	Seafood Salad: A Diverse Florule from the Late Cretaceous-age Hell Creek Formation of Montana

Symposium #19 (UNLH)		Paleozoic Extinctions: Environmental Call and Biotic Response - D. Boyer, P. Cohen (*keynote)
11:00	L. Sallan*	The rise and fall of the 'Age of Fishes': Vertebrate Responses to Paleozoic Extinctions
11:30	S. Shen	A high-resolution marine invertebrate biodiversity trajectory from Cambrian to Early Triassic
11:45	S. Finnegan	A simulated selectivity framework for evaluating the relative plausibility of marine extinction scenarios
12:00 - 1:00		**LUNCH**
1:00	T. Vandenbroucke	Global marine anoxia as a forcing mechanism for zooplankton colonisation and diversification
1:15	J. De Weirdt*	Synchrotron XRF elemental mapping of metals in Paleozoic palynomorphs
1:45	A. Bush	The Frasnian-Famennian (Late Devonian) extinction event in New York and Pennsylvania: stratigraphic and paleoenvironmental context
2:00	A. Martinez	Intermixed Messages: integrated geochemical and paleontological analysis of end-Devonian marine communities in the Appalachian Basin, USA
2:15	P. Cohen	Carbon isotopic analyses of single organic-walled microfossils across the Late Devonian Kellwasser Intervals in New York State reveal a strong biological pump
2:30	D. Boyer	Lilliput in the Late Devonian: a post Hangenberg recovery fauna from the uppermost Cleveland Shale

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Sunday, June 23 (cont.)

Symposium #19 (UNLH)	Presenter	Paleozoic Extinctions: Environmental Call and Biotic Response - D. Boyer, P. Cohen (*keynote)
2:45		**Tea Break**
3:15	K. Liang	Biotic interactions between corals and stromatoporoids from the upper-uppermost Famennian (Devonian) Etoucun Formation, Huilong, South China: Implications for the recovery of reefal environments after the F-F crisis
3:30	S. Carmichael*	A trigger mechanism for the Late Devonian Hangenberg Crisis, as recorded by mercury anomalies in carbonate sediments in Viet Nam and elsewhere: we're not saying it was volcanoes… but it was volcanoes
3:45	S. Brisson	Extinction Selectivity and Paleoecological change along an onshore-offshore Gradient in the Late Devonian Appalachian Basin
4:00	K. Pippenger	Exploring the microfossil record of the late Devonian Hangenberg event in the Cleveland Shale, Ohio

Monday, June 24

Symposium #31 (HUB 269)		Paleontology on Public Lands: Research, Outreach and Resource Management - K. Springer, V. Santucci (*keynote)
8:00	K. Johnson*	Fossils and the Future: The role of paleontology in the 21st Century
8:45	A. McDonald	New Upper Cretaceous Vertebrates from the Menefee Formation in New Mexico: Blending Field Work, Research, and Outreach to Promote Paleontology on BLM Land
9:00	D. Debleux	Building out North America's most compete lower Cretaceous terrestrial fossil records across a mosaic of Utah State, Bureau of Land Management (BLM), and National Park Service lands
9:15	A. Marsh	New specimens of *Acaenasuchus geoffreyi* (Archosauria) from Petrified Forest National Park (Arizona) support evidence for a new Triassic clade of armored pseudosuchians in North America
9:30	W. Parker	Examining late Triassic (Norian-Rhaetian) terrestrial faunal assemblage compositions in the Chinle Formation of northeastern Arizona
9:45		**Coffee Break**
10:15	G. Retallack	Oregon has two dinosaurs
10:30	T. Nyborg	Fossil fishes of Death Valley National Park, California: reconstructing the origins and historical biogeography of western North American freshwater fishes

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #31 (HUB 269)	Presenter	Paleontology on Public Lands: Research, Outreach and Resource Management - K. Springer, V. Santucci
10:45	K. Springer	Linking paleoclimate research and Pleistocene vertebrate faunas in desert wetlands on public lands in the American southwest
11:00	D. Bustos	Preserving fossil prints in an ephemeral landscape
11:15	E. Scott	Fossils of late Pleistocene *Bison* from public lands in the Colorado and Mojave Deserts: Implications for the diversity and biography of bison in southwestern North America
11:30	K. Prassack	Hagerman's PET dog: Current research by the Hagerman Paleontology, Environments, and Tephrochronology Project
12:00 - 1:00		**LUNCH**
1:00	A. Bell	The Gnatalie Quarry: Ten years of outreach and education at a dinosaur quarry on public lands
1:15	V. Santucci	Celebrating the paleontological heritage of Grand Canyon National Park during the park's centennial
1:30	B. Breithaupt	Dinosaur tracking with citizen scientists: Discovery, documentation, and stewardship
1:45	A. Farke	High school paleontologists and public lands: From the outcrop to the classroom
2:00	T. Lepore	The role of field paleontology high school experiences in shaping science stewardship on public land
2:15	A. Dooley	Promoting paleontology: Western Science Center outreach using fossils from public lands
2:30	J. Irving	The Ediacara Fossil Site at Nilpena, South Australia: Finding new ways to manage a new national park
2:45		**Tea Break**
3:15	S. Foss	A MAP to Managing Paleontology
3:30	B. Schumacher	New paleontological permits and perceptions on Forest Service lands
3:45	K. Hollis	Stewarding over 100 years of USGS paleontological research into the 21st century
4:00	P. D. Polly	Paleontology and US National Monuments: Why downsizing Grand Staircase Escalante and Bears Ears is bad for science
		Break

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #31 (HUB 269)	Presenter	Paleontology on Public Lands: Research, Outreach and Resource Management - K. Springer, V. Santucci
5:00-6:00	**K. Johnson, V. Santucci, S. Foss, B. Schumacher, K. Springer**	Panel Discussion (led by Smithsonian, NPS, BLM, USFS, USGS)

Symposium #1 (HUB 260)		Behavioral Innovations and Environmental Feedbacks: Insights from the Trace Fossil Record and Other Archives - L. Tarhan, D. Hembree, J. Smith, J. Gehling (*keynote)
8:00	S. Darroch	The Ediacaran trace fossil record from Namibia, and implications for drivers of the Ediacaran-Cambrian transition
8:15	A. Cribb	Cambrian-type metazoan ecosystem engineering in the terminal Ediacaran Nama Group, Namibia
8:30	Z. Chen	Trace fossil complexity in the terminal Ediacaran Period
8:45	S. Jensen*	Treptichnid trace fossils as examples of Geon 5 behavioral innovations
9:15	M. Gingras	The importance of behavioral niches in invertebrate evolution
9:30	Y. Hu	Coprolites in Cambrian Stage 4 Guanshan biota and their ecological implications
9:45		**Coffee Break**
10:15	K. Marenco	Missing the big (bedding plane) picture: small samples do not always capture the lateral heterogeneity of bioturbation
10:30	M. Mangano	Behavioral innovations in space and time: insights from the trace-fossil record
10:45	M. Clapham	Phanerozoic trends in bioturbation intensity and consequences for benthic organisms
11:00	S. van de Velde	Export efficiency of the biological carbon pump limited burrowing behavior in the early Paleozoic
11:15	R. Twitchett	Bioturbators, global warming and shrinking seafood: implications for ecosystem functioning in hothouse oceans
11:30	M. Zill	Constraining Paleocene-Eocene Thermal Maximum carbon cycling using the record of bioturbation
11:45	K. Broach	Epifaunal ecosystem engineers control shallow benthic bioturbation and the sedimentary record under multi-year sea ice, McMurdo Sound, Antarctica

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #1 (HUB 260)	Presenter	Behavioral Innovations and Environmental Feedbacks: Insights from the Trace Fossil Record and Other Archives - L. Tarhan, D. Hembree, J. Smith, J. Gehling (*keynote)
12:00 - 1:00		**LUNCH**
1:00	K. Parsons Hubbard	Microbial infestation of shell carbonate: The micrite envelope as an environmental indicator
1:15	R. Plotnick	The taphonomy of behavior
1:30	D. Hembree	Neoichnological evidence of predatory behavior recorded by soil arthropod trace fossils
1:45	J. Smith	Life in the Dead Zone: A diverse ichnofossil assemblage preserved in volcanic ash, Ashfall Fossil Beds State Historical Park, Nebraska, USA
2:00	A. Martin	The evolution underground: How burrows changed the world
2:15	K. Chin*	The evolution of complex coprophagous behavior: Ichnofossil evidence of brood provisioning and dung relocation by dung beetles in the Late Cretaceous

Topical #39 (HUB 268)		Advances in understanding of Precambrian and Paleozoic life and environments - Q. Tang, M. Betts
8:00	Q. Tang	Do perforations on Proterozoic organic-walled microfossils represent predation traces?
8:15	S. Willman	Acritarchs and small carbonaceous fossils from Finland
8:30	G. O'Neil	A new terminal Ediacaran vermiform body and trace fossil assemblage from Ancient Bristlecone Pine Forest, Inyo County, CA
8:45	M. Betts	A multiproxy chronostratigraphy for the early Cambrian of Antarctica
9:00	B. Slater	The Cambrian Explosion without the hard-parts
9:15	D. Murdock	The first vertebrate skeletal tissues and the 'biomineralization toolkit'
9:30	A. Nielsen	Cambrian sea level changes: A Scandinavian perspective
9:45		**Coffee Break**
10:15	C. Brett	Revised Upper Ordovician, Cincinnatian (upper Katian) Sequence stratigraphy in the Cincinnati Arch: Implications for the tempo and patterns of biotic change
10:30	Z. Wistort	Community analysis of the Gerster Limestone: Reevaluation of the late Permian marine fauna in the western USA
12:00 - 1:00		**LUNCH**

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #28 (HUB 260)	Presenter	Growth, development, and evolution in the fossil record - M. Hopkins (*keynote)
1:00	B.M. Gee	Histological skeletochronology of the early Permian stem lissamphibian *Doleserpeton*
1:15	D.E. Barta	Bone histology reveals high individual variation in growth among a population of early dinosaurs
1:30	A.R. Reynolds	Osteohistological growth curve reconstruction in *Smilodon fatalis*
1:45	J.J. El Adli	Secular changes in life history traits of female woolly mammoths
2:00	D.K. Moss	Paleobiology meets sclerochronology (again): using growth increments in fossil bivalves to answer evolutionary questions
2:15	J.D. Holmes	Ontogeny of the trilobite *Estangia bilobata* from the Cambrian Series 2 (Stage 4) Emu Bay Shale, South Australia
2:30	M.J. Hopkins	Comparison of growth rates in the trilobites *Elrathia kingii* (Meek, 1870) and *Aulacopleura koninckii* (Barrande, 1846)
2:45		**Tea Break**
3:15	J.E. Burke	Growth rate dynamics underlying planktonic foraminiferal morphology
3:30	S.E. Leventhal	The evolution of phenotypic plasticity in *Stylopoma*
3:45	S.J. Carlson	The role of ontogenetic transformations of the loop in the classification and phylogeny of Terebratellidina (Brachiopoda)
4:00	L.E. Holmer	Ontogenies and attachment strategies of early Palaeozoic brachiopods
4:15	J.L. Moore	Early ontogeny of the Cambrian hyolith *Parkula Esmeraldina* and its paleobiological implications
4:30	G.E. Budd*	The evo-devo of the Cambrian explosion: an integrated approach

Symposium #35 (HUB 367)		Broadening horizons of broader impacts - J. Orcutt, S. Jacquet (*keynote)
8:00	J.D. Orcutt	Kumtuks Illahie and the role of paleontology in place-based outreach
8:15	L. Soul*	Reaching new audiences through established and experimental digital formats
8:30	D. Moscato	Podcasting paleontology with the "Common Descent Podcast"
8:45	J.E. Bauer	Promoting visibility and participation of diverse scientists through a digital science communication platform
9:00	G.A. Brock	Using Instagram to communicate paleobiology and the history of life to the general public

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #35 (HUB 367)	Presenter	Broadening horizons of broader impacts - J. Orcutt, S. Jacquet (*keynote)
9:15	A.E. Marcy	DIY Go Extinct!: game design inspires student advocacy of biodiversity
9:30	R.C. Martindale	"Taphonomy: Dead and fossilized": a new board game designed to teach players about the process of fossilization
9:45		**Coffee Break**
10:15	S. Elshafie	What paleontologists can learn from artists in entertainment
10:30	M.A. Stegner*	Legal and political mechanisms for paleontology advocacy: the battle for Grand Staircase-Escalante and Bears Ears National Monuments
10:45		Discussion
11:00		Discussion
11:15		Discussion
11:30		Discussion
11:45		Demonstration Setup

Symposium #14 (HUB 355)		Ecosystem recovery in the aftermath of the end-Permian mass extinction in the marine and terrestrial realms - A. Huttenlocker, D. Bottjer (*keynote)
1:00	J. Botha*	The Permo-Triassic mass extinction on land: A review of Karoo Basin studies
1:30	A. Huttenlocker	An adult specimen of *Scaloposaurus* (Therapsida: Theriodontia: Therocephalia) from South Africa and size-age structure in Lilliputian assemblages of the Triassic recovery
1:45	C. Kammerer	Convergent, geographically-regionalized occupation of herbivore niches by eutheriodont therapsids following the Permo-Triassic mass extinction
2:00	C. Looy	Plant mass extinction and recovery? Inferring the nature of ecological upheavals at the base of the terrestrial food web
2:15	B. Allen	Tetrapod spatial biodiversity patterns across the end-Permian mass extinction and recovery interval
2:30	R. Irmis	The importance of geochronology for interpreting non-marine recovery from the end-Permian mass extinction
2:45		**Tea Break**
3:15	D. Bottjer	Biosedimentology of the Early Triassic
3:30	B. Burger	Stratigraphy and paleontology of the nearshore marine Late Permian and Early Triassic rock units in the Uinta Mountains of Utah and Colorado.

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #14 (HUB 355)	Presenter	Ecosystem recovery in the aftermath of the end-Permian mass extinction in the marine and terrestrial realms - A. Huttenlocker, D. Bottjer
3:45	W. Foster	"Deadly trio of carbon dioxide" leaves a selective extinction record during the end-Permian mass extinction

Symposium #20 (HUB 355)		Stratigraphic Paleobiology - S. Holland, E. Jarochowska, M. Patzkowsky
8:00	T. Womack	Resolving the shallow marine Cenozoic fossil record of New Zealand: understanding variations in biodiversity and patterns of community evolution at different spatial scales.
8:15	N. Hohmann	Quantifying the effects of changing deposition rates and hiatuses on the stratigraphic distribution of fossil occurrences
8:30	J. Zimmt	Exploring the impact of stratigraphic architecture on the pattern and timing of Late Ordovician extinction events
8:45	M. Patzkowsky	Climate change and species response: an unfulfilled promise of stratigraphic paleobiology
9:00	J. Sclafani	Morphology in time and space: how does shape change with sequence stratigraphic architecture?
9:15	E. Jarochowska	Testing for the effects of depositional rates in multiproxy models of environmental and faunal change: the Silurian Lau δ13C excursion
9:30	S. Danise	Environmental drivers of faunal change in the Jurassic Sundance Seaway, western United States
9:45		**Coffee Break**
10:15	D. Scarponi	Using regional stratigraphic context of the Po-Adriatic system (Italy) to infer biotic response of *Chamelea gallina* to Holocene environmental change
10:30	R. Nawrot	Environmental and taphonomic controls of diversity patterns across a depositional sequence: Holocene benthic mollusks of the Po Plain, Italy
10:45	M. Zuschin	Palaeoenvironmental distribution of Terebratula (Brachiopoda) in the early Pliocene of SE Spain
11:00	L. Tarhan	The Evolution of bioturbation: Timing and geobiological consequences
11:15	S. Holland	Predictions for the stratigraphic paleobiology of continental systems
11:30	K. Loughney	Regional patterns of mammal diversity through Basin and Range extensional history, 36 Ma to present
11:45	S. Peters	Does the Earth have a kill switch? Macrostratigraphic predictions for atmospheric oxygen concentration over the past 3 billion years
12:00 - 1:00		**LUNCH**

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #23 (HUB 367)	Presenter	Evolution of Flight - M. Habib, C. Chuong
1:00	C. Chuong	The evolution of the flight feather
1:15	W. Dong	Cladistic analyses of some Pleistocene mammalian faunas from China for biochonological interpretation
1:30	E. Ghezzo	High-resolution multispectral images for fossil detection: applications of spectral properties of fossils to remote field surveys
1:45	J. Samuels	The Gray Fossil Site of Tennessee: A unique record of mammalian life in the Early Pliocene of eastern North America
2:00	A. Guerrero	Endocranial anatomy of the tube-crested dinosaur *Parasaurolophus* (Ornithischia, Hadrosauridae) from the Kaiparowits Formation (Upper Cretaceous) of Utah, USA
2:15	W. Gearty	Energetics drives convergent gigantism in marine Crocodyliformes
2:30	M. Raveloson Tantely	New information on the Madagascan Middle Jurassic sauropod *Lapparentosaurus madagascariensis*: towards to the Cetiosauridae confirmation

Symposium #25 (HUB 302)		The Evolutionary Transition from Non-avian Dinosaurs to Birds - C. Chuong, L. Chiappe (*keynote)
8:00	**C. Chuong***	Introduction - Evo-Devo of integumentary organs during Dino-avian transition
8:30	C. Sullivan*	The Early Cretaceous Jehol Biota of northeast China as a unique window on the dinosaur-bird transition
9:00	J. DiGildo	Comparative analysis of niche occupation between Mesozoic and extant avifauna
9:15	T. Holtz	Scales, fuzz or both? Remaining difficulties in determining the ancestral integumentary state in Dinosauria
9:30	P. Wu	Combination of multiple novel regulatory modules is required for the scale-feather transition
9:45		**Coffee Break**
10:15	F. Serrano	Evolution of powered flight in Mesozoic stem birds
10:30	H. Chase	Bird to the bone: trabecular structure in the wing varies across flight modes
10:45	S. Wang	The origin of avian beak from toothed dinosaur ancestors
11:00	D. Rashid	Spinal nerve, the immune system and evolution of the avian tail
11:15	M. Pittman	Illuminating the evolution of birds using laser-stimulated fluorescence imaging

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #25 (HUB 302)	Presenter	The Evolutionary Transition from Non-avian Dinosaurs to Birds - C. Chuong, L. Chiappe (*keynote)
11:30	N. Carroll	Feather paleogenome insights from high fidelity fossil preservation
11:45	**L. Chiappe***	Conclusion- Dinosaur-avian transition: current and future research
12:00 - 1:00		**LUNCH**

Symposium #15 (HUB 379)		Scales of Ecological Development in the Mesozoic - K. Ritterbush, L. Tackett, Y. Pan, J. Sha (*keynote)
8:00	S. Maccracken	Mesozoic Acarodomatia reveal the antiquity of plant-mite mutualisms
8:15	S. Chang	New age constraints on the Yixian Formation and its implications for the Jehol Biota
8:30	A. Demers-Potvin	A recently expanded palaeocommunity of plants and insects from the Late Cretaceous (Cenomanian) of Labrador, Canada
8:45	D. Contreras.	Forest structure during the ecological expansion of flowering plants; evidence from the southern Western Interior
9:00	P. Olsen*	The end-Triassic mass extinction (ETE) on land and the role of high-latitudes in dinosaur dominance
9:30	J. Kirkland	Constraining the Jurassic–Cretaceous terrestrial biotic crisis in North America: New data from Utah helps close the gap
9:45		**Coffee Break**
10:15	V. Roden	The role of liberation lagerstätten as windows into past biodiversity
10:30	E. Larina	Uppermost Triassic phosphorite deposits from Willison Lake, Canada: An indicator of perturbed conditions preceding the end-Triassic mass extinction.
10:45	L. Tackett	High-latitude predation patterns during the Late Triassic and implications for evolutionary escalation in the early Mesozoic
11:00	J. Huntley	Escalating parasitism of bivalve mollusks in the Mesozoic
11:15	P. Monarrez	Testing the role of environmental conditions on promoting ecological escalation: Middle Jurassic Carmel Formation, central Utah, U.S.A.
11:30	Z.Tao	Taphonomy of fish concentrations from the Upper Jurassic Solnhofen Plattenkalk of Southern Germany
12:00 - 1:00		**LUNCH**

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Monday, June 24 (cont.)

Symposium #30 (HUB 268)	Presenter	New insights into functional morphology: Microstructures, Modeling, and Experimental approaches - C. Pietsch, B. Anderson, K. Ritterbush, N. Hebdon (*keynote)
1:00	J. Esteve	Gaits modelling and computational fluid dynamic simulation suggest multiple functional behaviors in trilobites
1:15	J.H. Nebelsick	The echinoid skeleton. An exemplary source of adaptations and their potential usefulness in technical applications
1:30	G.A. Janevski	The history of motility in comatulid crinoid evolution
1:45	N. Hebdon	Spiraling consequences: Characterizing hydrodynamic impact of single parameter shape change in ammonoids
2:00	B.M. Anderson	Applications of 3-D printing to testing functional hypotheses of turritellid gastropod shell morphologies and sculpture
2:15	M. Chipman	Computational fluid dynamics of archaeocyathan sponges from the Cambrian Forteau Formation of southern Labrador
2:30	C. Pietsch	Testing convergence and function of extreme parietal callus in marine gastropods
2:45		**Tea Break**
3:15	M. Habib*	Giant flyingjaws: Aerodynamic effects and constraints on cranial hypertrophy in pterosaurs
3:45	A.V. Chochinov	Using digitally constructed endocasts to examine the relationship between diet and neuroanatomy in phyllostomid bats
4:00	B. Shirley	Shedding synchrotron light on the architecture and evolution of conodont feeding apparatuses.
4:15	R. Short	Predicting paleoenvironment from community morphology of artiodactyl limbs to understand change through time
4:30	Z.J. Tseng*	Progress and challenges in deciphering complex structure-function mapping in the fossil record: Examples from the mammalian jaw model system

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Tuesday, June 25

Tuesday, June 25
No Scheduled Talks

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Symposium #8 (HUB 379)	Presenter	Symposium in honor of Michael A. Murphy - K. Springer, S. Finney, J. Matti (*keynote)
8:00	**K. Springer, J. Matti, S. Finney, M. Murphy**	Opening remarks by co-convenors and Michael A. Murphy
8:30	G. Klapper*	Mike Murphy's impact
9:00	J. Valenzuela-* Rios	Applying Murphy's 1977 time-stratigraphic concepts to subdivide the Lochkovian (Lower Devonian) in the Spanish Pyrenees and test its global value
9:15	K. Springer	The Las Vegas Formation as the linchpin for understanding the response of desert wetlands to abrupt climate change
9:30	J. Matti	The Imperial Formation in San Gorgonio Pass, southern California: implications for paleogeography at the northwest head of the late Miocene Gulf of California
9:45		**Coffee Break**
10:15	S. Finney	Stratigraphic paleontology: the key to recognizing major tectonic and paleoenvironmental events recorded in Paleozoic stratigraphic successions of north-central Nevada
10:30	J. Dunham	Continental Subduction as a mechanism for emplacement of the Roberts Mountains Thrust in Nevada
10:45	L. Edwards	Range charts as chronostratigraphic hypotheses, four decades later
11:00	S. Gouwy	Updating the Lower and lower Middle Devonian time-rock chart for the Mackenzie Mountains, NWT (Canada) based on conodont biostratigraphy
11:15	J. Valenzuela-Rios	The role of Spanish conodonts in the redefinition of the base of the Emsian Stage (Lower Devonian)
11:30	J. Day	Upper Devonian (Upper Frasnian-Lower Famennian) Biostratigraphy and Kellwasser extinction signatures in the Iowa Basin-Central North America (Western Subtropical Euramerica)
11:45	G. McGavin	THANKS Mike!
12:00 - 1:00		**LUNCH**
Symposium #29 (HUB 269)		**Environmental change and the evolution of form and function - S. Huang, S. Edie, K. Collins (*keynote)**
1:00	P. David Polly*	Assessing form-function-environment interactions using ecometric analysis of functional traits
1:30	S. M. Edie	Phylogenetic, ecological, and geographic effects on morphology: Analysis of 3D ornamentation shape in marine bivalves

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Symposium #29 (HUB 269)	Presenter	Environmental change and the evolution of form and function - S. Huang, S. Edie, K. Collins (*keynote)
1:45	R.V. Dievert	The performance space: A new way of viewing evolution's theatre
2:00	J. Sime	Testing the ecological "rules" that govern trait plasticity using bony fishes (Osteichthyes)
2:15	K.S. Collins	Breaking new ground: form, function and the fossil record of the repeated evolution of rock-boring in the marine Bivalvia
2:30	A. Dineen	Food web dynamics during the Marine Mesozoic Revolution (MMR)
2:45		**Tea Break**
3:15	S.K. Lyons*	Schrödinger's mammoth – ecological assembly in the age of humans
3:45	N.A. Heim	Respiratory and circulatory anatomy supersede ecological escalation in driving size increase in marine animals
4:00	S.A. Singh	The ecomorphology and macroevolution of the Synapsida through the Permo-Triassic.
4:15	S. Huang	Macroevolution of body size and dietary preference in Neogene large mammals
4:30	A. Halling	Complex multicellularity as an evolutionary response to viscous Snowball Earth Oceans
4:45	M. Munoz	Strong mechanical relationships bias the tempo and mode of morphological evolution.

Symposium #5 (HUB 355)		Arthropod Evolution Through Deep Time: a tribute to Richard A. Fortey - J. Ortega-Hernandez, J. Esteve, J. Moysiuk, A. Lopez (*keynote)
8:00	D. Briggs*	From 'weird wonders' to molecular methods – resolving the early radiation of arthropods
8:30	J.M. Wolfe	What defines crustaceans? Insights from the Cambrian fossil record and from phylogenomics
8:45	L. Lustri	A new horseshoe crab from the early Ordovician Fezouata Biota and its relationship with Herefordshire synziphosurines
9:00	M.A. Pulsipher	Refining arthropod evolutionary history: Investigation of an undescribed crustacean-like fossil from the Waukesha Lagerstätte, Wisconsin
9:15	P. Gueriau	Soft part preservation clarifies the affinities of the large bivalved arthropods from the Fezouata Biota (Early Ordovician, Morocco)
9:30	C. Labandeira	The long-proboscid insect pollination mode of the mid-Mesozoi: its discovery, biology, and implications for understanding gymnosperm reproductive biology
9:45		**Coffee Break**

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Symposium #5 (HUB 355)	Presenter	Arthropod Evolution Through Deep Time: a tribute to Richard A. Fortey - J. Ortega-Hernandez, J. Esteve, J. Moysiuk, A. Lopez (*keynote)
10:15	J. Luque	Phylogenetics of true crabs, and the early origins of crab-like forms
10:30	L. Laibl	Post-embryonic development of Fritzolenellus reveal ancestral morphology of early developmental stages in trilobita
10:45	J.C. Lamsdell	What's the deal with chasmataspidids?
11:00	V. Baranov	Chironomidae – an updated overview of the palaeobiology and geological history of non-biting midges
11:15	A.D. Chipman	The evolution of arthropod segmentation and tagmatization – linking embryological data with the fossil record
11:30	B. Schoenemann	A look into the eyes of trilobites
11:45	C. Aria	Fossils from South China redefine the ancestral euarthropod body plan
12:00 - 1:00		**LUNCH**
1:00	S.A. Rosbach	Morphological analysis of enigmatic arthropods of the Silurian Waukesha Lagerstätte, WI
1:15	K.K. Pearson	Experimental biomechanics of trinucleid fringe pits (Trilobita)
1:30	H. Zeng	Macroevolution of anomalocarids and its implications for the Cambrian explosion
1:45	J. Moysiuk	Hurdiid radiodontans and the exploitation of Cambrian infaunal food sources
2:00	F. Perez-Peris	Morphology and evolution of basal Cheirurina (Trilobita) from the Fezouata Biota (Lower Ordovician, Morocco)
2:15	A. Izquierdo Lopez	A cladoceran-like arthropod from the Burgess Shale; benthic niches in Cambrian bivalved arthropods
2:30	P.G. Pazinato	Evolution of eumalacostracan grasping appendages from an extraordinarily preserved crustacean from the Tithonian of Germany
2:45		**Tea Break**
3:15	A. Corrales	Synchronized molting behavior in early Cambrian trilobites
3:30	J. Esteve	Morphological variation as consequence of abiotic factors in early trilobites
3:45	A.C. Daley	New hurdiid specimens with paired endites reveal new interrelationships within Radiodonta
4:00	R. Lerosey-Aubril	Evolution of the digestive system in Cambrian trilobites
4:15	J.R. Paterson	Trilobites in cruise control: clocking their evolutionary rates and the end of the Cambrian explosion
4:30	G.E. Budd*	Richard Fortey: an unauthorised biography

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Topical #42 (HUB 269)	Presenter	Paleoenvironments and Paleobiology - B. Kelly, J. Millercamp
8:00	C. Congreve	The impact of environmental preference and geographic occupation on diversification and survivorship during the Ordovician Mass Extinction
8:15	A. Clement	Depositional Environments and Paleoecological Assemblages of a Common Late Triassic Shell Bed-Forming Bivalve (*Monotis*) in New Zealand
8:30	P. Milla Carmona	Allometric variation in the genus *Steinmanella* (Trigonioida, Bivalvia) from the Lower Cretaceous of the Neuquén Basin (west-central Argentina)
8:45	J. Miller-Camp	Deposition, climate, and diversity: Alligatorines as a case study of the common cause hypothesis
9:00	A. Du	Comparing the accumulation of large mammal species in Amboseli National Park, Kenya over increasing temporal and spatial scales, with implications for the composition of time-averaged communities
9:15	G. Gully	Tooth microwear of the extinct Australian Vombatiformes
9:30	M. Macias	Whales n' snails: a potential Miocene shallow marine whale fall community
9:45		**Coffee Break**
10:15	B. Kelly	Encrusters on the fossil oyster *Hyotissa hyotis*: Examining the biodiversity of sclerobionts on a hard substrate community from the California Miocene
10:30	L. Farrar	Nine morphotypes of biotic traces found on fossil and recent echinoids
10:45	S. Sinha	Comparison of early Paleocene ichthyofaunal diversity from Croc Pot and Roche Percee localities, Ravenscrag Formation, southern Saskatchewan, Canada
12:00 - 1:00		**LUNCH**

Topical #43 (HUB 367)		Systematics and Phylogeny - B. Long, L. Anderson
1:00	I. Kerr	A unique articulated fossil sheds light on the taxonomy of two Pleistocene species of giant kangaroo from the genus *Protemnodon*.
1:15	J. van Zoelen	Resolving the taxonomic validity of the giant extinct Australian marsupial *Nototherium* (Diprotodontidae) and its relationship to *Zygomaturus*
1:30	J. Jung	Anatomical Redescription And Phylogenetic Analysis Of The Materials Assigned To The Taxon "*Captorhinikos*" Chozaensis

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Topical #43 (HUB 367)	Presenter	Systematics and Phylogeny - B. Long, L. Anderson
1:45	S. Wiedrick	Molecules meet Morphology: Evolution, biogeography, and the fossil record of a speciose predatory snail genus *Paciocinebrina* Houart, Vermeij & Wiedrick, 2019
2:00	A. Adams	New slender-snouted crocodylians from the Neogene of North and East Africa and resolution of the Gharial debate
2:15	P. Mocho	Gnatalie Quarry, a window to understand the dinosaurian paleodiversity of the Late Jurassic of Southeastern Utah (Morrison Fm., USA)
2:30	X. Wang	Black Hole Effect: Pattern of mistakes in botany
2:45		**Tea Break**
3:15	R. Ng	Phylogeny of an enigmatic and distinct clade of Cambro-Ordovician trilobites from Laurentia with new and revised species of *Clelandia*
3:30	R. Fortey	The best of two worlds - the Late Ordovician trilobites of the Taimyr Peninsula, Arctic Russia
3:45	J. Loch	*Lotagnostus* species from the Cambrian (Furongian) Windfall Formation, Nevada, and their significance regarding on the GSSP for Cambrian Stage 10
4:00	N. Lopez Carranza	Testing species designations in extant and fossil *Laqueus* (Brachiopoda, Terebratulida) through the quantitative analysis of shell outlines and machine learning
4:15	E. Altier	Updated Systematics of Plio-Pleistocene *Turritella* of Florida and the Atlantic Coast

Symposium #34 (HUB 367)		Exploring eLearning in the paleosciences: Visualizing the past and inspiring learners through the use of digital technologies - W. Taylor, R. Ross, G. Bruce, J. Hendricks (*keynote)
8:00	M. Pittman*	Immersive and engaging e-learning experiences: insights from an e-course on dinosaurs
8:30	M. Davis	Virtual reality, augmented reality, and real reality: thinking holistically about the spectrum of immersive technologies in museums
8:45	S. Jacquet	Augmenting traditional methods of teaching carbonate sedimentology with micro-CT and 3D segmentation
9:00	F. Oboh-Ikuenobe	Fossils3D and PaleoApp: new interactive and user-friendly learning tools in paleontology
9:15	L. Soul	Engaging family groups in learning about evolution with 3D digitized fossils in hands-on activities and VR
9:30	J. Hendricks	Virtual Teaching Collections in Paleontology
9:45		**Coffee break**
10:15	R. Ross	Virtual fieldwork experiences for online exploration of Cenozoic Pacific coast fossil localities for the EPICC project

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Symposium #34 (HUB 367)	Presenter	Exploring eLearning in the paleosciences: Visualizing the past and inspiring learners through the use of digital technologies - W. Taylor, R. Ross, G. Bruce, J. Hendricks
10:30	G. Bruce	Gamifying virtual environments to explore the past 350 million years
12:00 - 1:00		**LUNCH**

Symposium #17 (HUB 302)		Conservation Paleobiology: natural systems in a human world - S. Kidwell, R. Terry, W. Parker, Y. Yanes, M. Zuschin (*keynote)
8:00	P. Albano*	The collapse of native biodiversity on the Israeli Mediterranean shallow shelf: patterns and causes
8:15	J. Miller*	Antlers of the Arctic National Wildlife Refuge: Baselines of biological variability from bones on the tundra
8:30	K. Cramer*	Integrating paleoecological, historical, and ecological data to assess the timing and causes of the loss of acroporid corals in the Caribbean
8:45	M. Stegner	Identifying causes of abrupt change and resilience loss in paleoecological records of grassland-woodland systems
9:00	P. Harnik*	Life history variation in response to anthropogenic eutrophication: using live-dead analysis to understand adaptation in a human world
9:15	M. Kemp*	Perching on a precarious future: a conservation paleobiology perspective on understanding and sustaining lizard diversity in the Anthropocene
9:30	J. Pandolfi	The rise and fall of novel ecological communities
9:45		**Coffee Break**
10:15	J. Cybulski	The past, present, and future of Hong Kong corals: hope for marine ecosystems found in an unlikely place
10:30	K. Johnson	Can turbid-water habitats serve as reef refugia in the Coral Triangle? Insights from the fossil record.
10:45	A. O'Dea	Fossils define natural variation in a Caribbean coral reef ecosystem and reveal an unexpected bright spot
11:00	E. Dillon	Dermal denticle assemblages can reflect changes in shark abundance on coral reefs over time
11:15	M. Zuschin	Regional-scale collapse of benthic baseline communities in the northern Adriatic Sea
11:30	Y. Edelman-Furstenberg	Application of dead molluscan assemblages to the assessment of the ecological quality of the Eastern Mediterranean
11:45	D. Killam	Potential nitrate aerosol fertilization in Red Sea giant clams recorded in δ15N of shell organic material
12:00 - 1:00		**LUNCH**
1:00	B. Kokesh	Quality over quantity: Bivalves as taxonomic surrogates of entire benthic community in coastal pollution assessment

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Symposium #17 (HUB 302)	Presenter	Conservation Paleobiology: natural systems in a human world - S. Kidwell, R. Terry, W. Parker, Y. Yanes, M. Zuschin
1:15	S. Kidwell	If we built it, would they come? New insights into natural baselines for southern California shelf macrobenthos and the role of land use in their decline
1:30	W. Parker	Using the archaeological record to assess resource overexploitation in the Canary Islands, Spain
1:45	Y. Yanes	Fossil land snails suggest human influence on present-day communities in the eastern islets of the Canary Islands
2:00	S. Pineda Munoz	Human landscape impacts have shaped North American mammal niches
2:15	R. Terry	The small mammals of Paisley Caves: disentangling climate-driven environmental change from prehistoric human impacts on diversity dynamics
2:30	J. McGuire	A paleontological perspective to conserving for change
2:45		**Tea Break**
3:15	L. Wingard	The Role of Conservation Paleobiology in Restoration of the Greater Everglades Ecosystem
3:30	K. Kusnerik	The Tale of Two Rivers: Fossil Mollusk Assemblages of the Wakulla River Document Ecological Consequences of Climate Change, Invasive Species, and Hurricane Michael
3:45	J. Smith	Restoring the bivalve community in the Colorado River estuary: Just add water?
4:00	G. Dietl	Bridging the Research-Implementation Gap in Conservation Paleobiology: Lessons Learned from the SEACAR (Statewide Ecosystem Assessment of Coastal and Aquatic Resources) Project
4:15	M. Kowalewski	Multi-millennial stability of benthic communities recorded in surficial mollusk shell accumulations
4:30	M. Pruden	Can we use the past to save the future? Testing the projective power of ecological niche models using the paleontological record
5:00–6:30	**F. Flessa**	Conservation paleobiology panel discussion: Welcome to the real world

Symposium #24 (HUB 260)		Recent advances in Central American and Mexican mammalian paleontology - E. Jimenez-Hidalgo, B. Lander
8:00	E. B. Lander	Revised (earliest late Duchesnean) age, Lower Rancho Gaitan local fauna, Prietos Formation, northeastern Chihuahua, Mexico
8:15	E. Jiménez-Hidalgo	The early Oligocene Iniyoo local fauna of northwestern Oaxaca, southern Mexico

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Symposium #24 (HUB 260)	Presenter	Recent advances in Central American and Mexican mammalian paleontology - E. Jimenez-Hidalgo, B. Lander (*keynote)
8:30	R. Guerrero-Arenas	Unusual vertebrate fossil burrows in the Oligocene of tropical North America
8:45	O. Carranza-Castañeda*	The late Neogene faunas of Central Mexico: new records of *Gomphotherium hondurensis*
9:15	J. Arroyo-Cabrales	New Mexican Pleistocene mammal findings
9:30	G. Oñate-Angulo	Late Quaternary environmental changes in the Valley of Mexico inferred from small mammal assemblages
9:45		**Coffee Break**
10:15	B.W. Schubert	Underwater caves of the Yucatán shed light on Late Cenozoic biodiversity and faunal interchange in Middle America
12:00 - 1:00		**LUNCH**

Symposium #22 (HUB 260)		Fossil Marine Tetrapods of the Eastern Pacific - J. Parham, A. Valenzuela-Toro, J. Velez-Juarbe (*keynote)
1:00	P. Noble	Insights from new records of Late Triassic ichthyosaurs, Mineral County, Nevada
1:15	J. Parham	An overview of marine turtle evolution with an emphasis on new data from Eastern Pacific fossils
1:30	K. Matsui	Juvenile specimen reveals unexpected dental morphology of early desmostylians
1:45	M. Uhen	Fossil cetaceans of the Eastern Pacific: A comparison of the Northern and Southern Hemispheres
2:00	C. Peredo	A new desmatophocid (Pinnipedia) from the early Miocene of Oregon sheds new light on the origins of the extinct lineage.
2:15	A. Valenzuela Toro	From beach bones to fossils: taphonomic insights from a northern elephant seal breeding colony
2:45		**Tea Break**
3:15	J. Velez-Juarbe*	Overview of the Neogene marine mammal faunas of the North Eastern Pacific

Symposium #32 (HUB 268)		Two to tango: amateur-professional interactions in advancing paleontological knowledge - J. Kallmeyer, D. Meyer
8:00	V.J. Perez	Public-Professional Partnerships in Paleontology Research: Serendipity vs. Strategy
8:15	T.E. Bantel	Discoveries in the Silurian of Indiana: Four Decades of Collaboration between Avocational and Professional Paleontologists

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Wednesday, June 26 (cont.)

Symposium #32 (HUB 268)	Presenter	Two to tango: amateur-professional interactions in advancing paleontological knowledge - J. Kallmeyer, D. Meyer (*keynote)
8:30	L. Cone	Amateur and Professional Relationships: Hobby collecting meets scientific research
8:45	W. Heimbrock	Unidentified fossils in the enigmatic phosphatic Steinkern Layers of the Cinncinnati Arch Region (Ordovician, Katian) lead an amateur paleontologist into multiple collaborations
9:00	M.K. Pankowski	How a family of amateur paleontologists is finding fossils online and helping scientists discover new species
9:15	L.J. McCall	Collaborations Between Amateurs, Professionals and Yes, Even Fossil Dealers…a Personal Perspective
9:30	J.W. Kallmeyer	Amateur/professional collaboration – A personal journey
9:45		**Coffee Break**
10:15	R.L Manning	Dallas Paleontological Society: An Example of Amateur – Professional Cooperation in Paleontology
10:30	K.R. Hartshorn	Roadcuts After Dark: Adventures in Avocational Stratigraphy on the Cincinnati Arch
10:45	B.J. MacFadden	Scientist-Teacher Partnerships in Paleontology
11:00	R. Meyer	The relationship between amateur collectors and professional paleontologists in collecting fossil lagerstätten
11:15	M.A. Smith	Bridging the gap: Outreach and research contributions of the North America Research Group
11:30	D.L. Meyer*	The Dry Dredgers of Cincinnati: A history of outreach and collaboration
12:00 - 1:00		**LUNCH**
1:00	A.R. Lam	Twelve to tango: Avocational and professional partnerships to increase public understanding of paleontology through informational pages, blogs, and social media platforms
1:15	S.L. Sheffield	Advances in echinoderm paleobiology: collaborations with avocational paleontologists
1:30	P.G. Scoggins	The Arlington Archosaur Site: An amateur discovery leads to a amateur – professional collaboration in paleontology
1:45	J. Pirlo	Montbrook Fossil Site Discoveries: An impossibility without volunteers
2:00	S. Haugrud	Getting by with a skeleton crew in the Volunteer State

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27

Symposium #4 (HUB 355)	Presenter	Avalon to Zaris: A Global Perspective on the Ediacaran Biosphere - E. Mitchell, C. Kenchington, C. Hall (*keynote)
8:00	M. Droser*	Environment, succession and who's on first: controls on Ediacara bed diversity and abundance structure at the National Heritage Site, Nilpena, South Australia
8:30	H. Agić	Ediacaran from a protistan point of view: assessing microfossil diversity changes during the rise of macroscopic life
8:45	F. Dunn	A new cnidarian from the Late Ediacaran (562 – 557 Ma) and its implications for the diversity of early animal communities
9:00	R. Surprenant	A Tale of Tube Cities: The role of *Funisia dorothea* in preserving short-term community succession in Ediacara assemblages
9:15	I. Bobrovskiy	Analysis of biomarkers from the Ediacara biota fossils: the oldest case of ventriloquism
9:30	D. Segessenman	A Macrostrat Approach to the Ediacaran of North America
9:45		**Coffee Break**
10:15	S. Xiao*	Fossils and redox geochemistry in the terminal Ediacaran Shibantan Member
10:45	R. Wood	Phased origin of biomineralisation, habitat expansion, and the rise of heterotrophy
11:00	J. Leme	Paleoenvironment and fossil distribution on an Ediacaran-Cambrian mixed carbonate ramp (Tamengo Formation, Brazil)
11:15	J. Han	Dwarfed frondlike metazoans from the Cambrian Kuanchuanpu Formation in South China
11:30	S. Darroch	Ancient life in moving fluids - what fluid dynamics can (and can't) tell us about the Ediacara biota
11:45	B. Gibson	Gregarious suspension feeding in a modular Ediacaran organism
12:00 - 1:00		**LUNCH**

Symposium #12 (HUB 355)		Environmental change and the dawn of animal life: Integrating geochemical and paleontological data - C. Diamond, S. Evans (*keynote)
1:00	E. Sperling*	Considering all the ingredients of an 'Explosion'
1:30	T. Boag	Oxygen, temperature, and the deep-marine stenothermal cradle of animal evolution
1:45	D. Jacobs	Cold cradles and warm graves - Towards a synthetic view of temperature, oxygen and diversity
2:00	D. Erwin	Developmental novelties, the rise of O2 and the early evolution of animals

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Symposium #12 (HUB 355)	Presenter	Environmental change and the dawn of animal life: Integrating geochemical and paleontological data - C. Diamond, S. Evans (*keynote)
2:15	S. Evans	Stretched, wrinkled and ripped: Unexpected structural integrity and extensibility in *Dickinsonia* provides new insight into environmental change and diversity loss in the Ediacara Biota
2:30	J. Schiffbauer	Soft-tissue preservation in cloudinomorphs from the terminal Ediacaran of Nevada may provide clues onto phylogenetic position
2:45		**Tea Break**
3:15	M. Prokopenko	Redox state of the marine nitrogen cycle and evolution of eukaryotes during late Neoproterozoic
3:30	A. Shore	Phosphorus drawdown drove redox stabilisation and metazoan diversification in the terminal Ediacaran Nama Group, Namibia
3:45	K. Pehr	Late Ediacaran marine shelf environments: evidence for nutrient control on local community structure and productivity
4:00	X. Zhang	The Ediacaran-Cambrian transition of North China
4:15	R. Gaines*	Can Burgess Shale-type environments inform our understanding of the Cambrian world?

Topical #40 (HUB 367)		Advances in understanding of Mesozoic and Cenozoic life and environments - A. Buczek, A. Hendy
8:00	D. Chure	A rich body and trace fossil record in the Nugget Sandstone (late Triassic) of NE Utah provides insight into biological diversity and ecological segregation in an ancient eolian ecosystem.
8:15	A. Lam	Forams of coastal Utah: A record of Oceanic Anoxic Event 2 (~94-93 Ma) along the western edge of the US Western Interior Sea
8:30	J. Sankey	Latest Cretaceous vertebrate diversity from microvertebrate sites prior to the Cretaceous/Paleogene (K/P) boundary, Hell Creek Formation, North Dakota
8:45	L.F. Opazo	Faunal turnover and changes in ecological complexity across the end-Cretaceous mass extinction in California
9:00	J. Smith	Tertiary Caribbean mollusks and the ancient Gulf of California
9:15	L. Zhu	Calcareous Algae from the Well Xike-1 in Xisha Islands and their paleoecological implications
9:30	A. Buczek	Constraining the age of Californian Plio-Pleistocene formations using strontium isotope stratigraphy
9:45		**Coffee Break**
10:15	T. Grun	*Echinocyamus*: a model organism for Cenozoic predation

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Topical #40 (HUB 367)	Presenter	Advances in understanding of Mesozoic and Cenozoic life and environments - A. Buczek, A. Hendy
10:30	X. Cui	Study on the foraminiferal assemblages and paleoenvironment of reef facies since the Quaternary in the Xisha Islands, South China Sea
10:45	A. Hendy	Winners and losers: Revisiting the quality of California's Fossil record
12:00 - 1:00		**LUNCH**

Symposium #6 (HUB 367)		Paleobiology of Cephalopods - L. Chang, B. Linzmeier, M. Yacobucci (*keynote)
1:00	D. Jacobs*	Can we escape our history and update our focus on fossil cephalopod shell function(s)
1:30	A. Ippolitov	Size matters? A new relict megateuthidid belemnite from the Oxfordian of Wyoming (USA)
1:45	K. Ritterbush	Squid or falcon? Evaluating convergent evolution in beaks of cephalopods and birds
2:00		Discussion
2:15	C. Thompson	How distinct is distinct? *Aturia* (Aturiidae: Cephalopoda) from the early Oligocene of Florida
2:30	C. Whalen	The paleoecological dimension of Paleozoic ammonoid evolution
2:45		**Coffee Break**
3:15	D. Peterman	Sexual dimorphism in scaphitid ammonoids: differences in hydrostatic properties revealed by virtual 3D modeling
3:30	C. Ji	New Anisian (Middle Triassic) ammonoids from British Columbia (Canada): Biochronological and palaeobiogeographical implications
3:45	L. Chang	Linking geographic range and background extinction in ammonoids across the Cretaceous
4:00	M. Yacobucci	Controls on cephalopod survivorship through Ocean Anoxic Event 2 within the Cenomanian-Turonian Western Interior Seaway
4:15		Discussion
4:30		Discussion

Symposium #10 (HUB 268)		Deep Time Paleogenomics - D. Gold, J. Thompson
8:00	K. Moore	The ancient evolution of cyanobacteria and plastids
8:15	D. Gold	Sterol genomics and the assignment of *Dickinsonia* as an animal

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Symposium #10 (HUB 268)	Presenter	Deep Time Paleogenomics - D. Gold, J. Thompson (*keynote)
8:30	D. Eernisse	A sunken-wood dwelling chiton (Mollusca: Polyplacophora) is not a direct link to the Paleozoic
8:45	L. Anderson	Holocene marine lakes as refugia: Morphometric and phylogenetic analyses of Bahamian Lake *Ctena* (Bivalvia: Lucinidae) and their endosymbionts
9:00	G. Dolby*	Speciation by neutral and adaptive forces: evolutionary pseudocongruence within geo-climatically complex regions
9:15	J. Thompson	Morphological and genomic evolution of the echinoderm skeleton
9:45		**Coffee Break**
10:15	N. Mongiardino Koch	The phylogenetic and macroevolutionary history of sea urchins: a combined genomic, phenomic and paleontological approach
10:30	A. Butler	Brachiopod phylogenomics: Implications for the evolutionary history of biomineralization and the Cambrian explosion.
10:45	P. Donoghue	The timescale of early land plant evolution
11:00	D. Erwin*	Evolutionary dynamics of metazoan gene regulation
12:00 - 1:00		**LUNCH**

Symposium #9 (HUB 268)		Ancient DNA and Fossil Proteins - J. Drake, D. Jacobs
1:00	A. Vershinina	Evolution and extinction of caballine horses in Ice Age Beringia
1:15	X.T. Wang	Nitrogen isotopes of ancient proteins: New analytical capabilities and potential applications in paleobiology
1:30	T. Zhao	Morphological degradation of feathers: results from experimental maturation
1:45	J. Drake	Toward sequencing ancient stony coral skeletogenesis proteins
2:00	J. Pandolfi	Broadening the taxonomic scope of coral reef paleoecological studies using ancient DNA
2:15	J. Buckner	How ancient DNA allowed two dead ducks to tell their tale

Topical #45 (Rm. 4)		Paleobiology and Climate Change in the Fossil Record - W. McLaughlin, R. Twitchett
8:00	M. Steinbauer	The legacy of past climates in climate-related extinction risk
8:15	E. Landing	Climate and life in earth history: CO_2 or other factors?
8:30	R. Twitchett	Body size change in Chalk Sea animals during the Cenomanian-Turonian warming event

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Topical #45 (HUB 302)	Presenter	Paleobiology and Climate Change in the Fossil Record - W. McLaughlin, R. Twitchett
8:45	C. Hall	Hyperthermal hide and seek: patterns of changing ostracode abundance during early Cenozoic warming events
9:00	CANCELLED ~~A. Weiss~~	~~Recovery of reefs on the Adriatic Carbonate Platform following the Paleocene-Eocene Thermal Maximum~~
9:15	E. Bullard	Temporal trends in shell calcification in marine bivalves: paleontological baselines for understanding species-specific responses in a changing ocean
9:30	I. Magallanes	Stable carbon and oxygen isotopes provide new insights on climate and paleoecology during the Miocene of northern New Mexico
9:45		**Coffee Break**
10:15	W. McLaughlin	Hawk Rim: An Oregon ecosystem on the cusp of the Mid Miocene Climatic Optimum
10:30	D. Prothero	How do birds evolve in response to climate change? Data from the long-term record at La Brea tar pits
10:45	S. Walker	Mollusk forensics in Antarctica: Do epibenthic scallops exhibit predatory shell repair?
11:00	N. Fox	Identification and analysis of small mammal fossils at Rancho La Brea elucidate responses to late Quaternary environmental change in southern California
11:15	W. Kiessling	Paleontology and the Intergovernmental Panel on Climate Change: A call for action
11:30	A. Ivkic	A comparison of MIS5e and modern coral reefs in the Red Sea
11:45	M. Viteri	Using habitat-level variation in modern small mammal communities to reconstruct past environments
12:00 - 1:00		**LUNCH**

Symposium #18 (HUB 302)		The Sixth Extinction: Integrating Paleobiological, Ecological, and Physiological Perspectives - N. Heim, J. Payne
1:00	J.L. Payne	Body size and extinction risk in the fossil record and the modern world
1:15	S.R. Cole	Phylogenetic perspectives on the selectivity of background extinction
1:30	W.J. Foster	Resilient marine invertebrate communities along the US Gulf Coastal Plain during the Early Cenozoic hyperthermals
1:45	M. Balisi	Recent ecomorphological selectivity of North American canid extinction

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Symposium #18 (HUB 302)	Presenter	The Sixth Extinction: Integrating Paleobiological, Ecological, and Physiological Perspectives - N. Heim, J. Payne (*keynote)
2:00	R. Lockwood*	Bay of the living dead: A paleontological perspective on Chesapeake oysters
2:30	E. Lindsey	Regional patterns of Late-Quaternary extinctions in South America: towards a more realistic model of extinction dynamics
2:45		**Tea Break**
3:15	E.A. Orzechowski	Thermal niche tracking over the last 120,000 years: Comparing modern and Late Pleistocene coastal marine environments and molluscan communities in southern California
3:30	A.G. Simpson	Does dispersal mechanism impact the ability to respond to rapid, intense climate change? A case study in trees of the Younger Dryas
3:45	A.M. Mychajliw	Holocene arrival and historic loss of the California grizzly bear: Bridging timescales of decline in the 6th mass extinction
4:00	M.A. Kosnik	Tales from a harbor downunder: How the modern molluscan community differs from the pre-colonial community
4:15	K.M. Barclay	Modern experiments and fossil perspectives: The effects of ocean acidification on two gastropods
4:30	J. Vendetti	Terrestrial gastropod diversity decline in the Modern: Endemic species and the consequences of habitat loss

Symposium #21 (HUB 269)		Evolution, communities and ecosystems: systems approach to paleoecology - P. Roopnarine, A. Dineen
8:00	R. Norris	Rise of oxygen in the Phanerozoic world: from grey sediments to white in the Early Mesozoic
8:15	L. Na	Understanding biogeography during the Cambrian through eco-evolutionary process
8:30	J. Shaw	The spatial diversification of Evolutionary Faunas
8:45	B. Kröger	The constructive growth of Phanerozoic marine biodiversity
9:00	C.L. Tyler	Changes in paleocommunity structure associated with the Mesozoic Marine Revolution in the western Tethys
9:15	C.M. Selles	Survival of the sharpest: Community trends in ornamentation as a proxy for predation in Devonian strophomenate brachiopods
9:30	E. Petsios	Escalation of echinoid-associated predatory and parasitic drilling during the Mesozoic marine revolution

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Symposium #21 (HUB 269)	Presenter	Evolution, communities and ecosystems: systems approach to paleoecology - P. Roopnarine, A. Dineen
9:45		**Coffee Break**
10:15	G.S. Antell	No patterns of ecological release in brachiopod and bivalve distributions over the Phanerozoic
10:30	L. Sallan	Capturing convergence and innovation in fish ecomorphology across time and space
10:45	A.K. Behrensmeyer	It's about time! Paleontological contributions to understanding terrestrial community ecology
11:00	P.D. Roopnarine	The emergence and ecological stability of geologically persistent paleocommunities
12:00 - 1:00		**LUNCH**

Symposium #36 (HUB 379)		Past, Present, and Future of the FOSSIL Project - J. Bauer
8:00	**K. Crippen**	Session Introduction
8:15 - Talk	K. Crippen	FOSSIL: Building a community of practice via social paleontology
8:30 - Panel	**S.M. Mills, L.M. Lundgren, E.Gardner**	FOSSIL: Building a community of practice via social paleontology
8:45 - Discussion	**S.M. Mills, L.M. Lundgren, E.Gardner, K. Crippen, B.J.MacFadden**	FOSSIL: Building a community of practice via social paleontology
9:00 - Talk	B.R. Hunda	FOSSIL community connections: Strengthening professional-avocational partnerships for the future of paleontology
9:15 - Panel	**D.B. Cone, J. Kowinsky, L. McCall, T.J. Lepore**	FOSSIL community connections: Strengthening professional-avocational partnerships for the future of paleontology
9:30 - Discussion	**B.R. Hunda, D.B. Cone, J. Kowinsky, L. McCall, T.J. Lepore**	FOSSIL community connections: Strengthening professional-avocational partnerships for the future of paleontology
9:45		**Tea Break**

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Symposium #36 (HUB 379)	Presenter	Past, Present, and Future of the FOSSIL Project - J. E. Bauer
10:15 - Talk	S.M. Mills	FOSSIL accomplishments and outcomes: Harnessing digital platforms and in-person events to foster community relationships
10:30 - Panel	C. Lockner, J.Pirlo, D. Porcello, G.-P. Santos	FOSSIL accomplishments and outcomes: Harnessing digital platforms and in-person events to foster community relationship
10:45 - Discussion	S. Mills, C. Lockner, J.Pirlo, D. Porcello, G.-P. Santos	FOSSIL accomplishments and outcomes: Harnessing digital platforms and in-person events to foster community relationship
11:00am - Talk	J.E. Bauer	FOSSIL future and sustainability: myFOSSIL eMuseum and mobile app
11:15 - Panel	G. Carr, W.D. Heim, J. Kallmeyer, M. Speights	FOSSIL future and sustainability: myFOSSIL eMuseum and mobile app
11:30 - Discussion	J.E. Bauer, R.T. Bex II, G. Carr, W.D. Heim, J. Kallmeyer, M. Speights	FOSSIL future and sustainability: myFOSSIL eMuseum and mobile app
12:00 - 1:00pm		**LUNCH**

Symposium #26 (HUB 269)		Paleontological history of the Indian subcontinent - D. Chattopadhyay, S. Manchester
1:00	S. Chakravorti	Life from land to water– A Triassic rendezvous of Indian Temnospondyls
1:15	S. Das	Jurassic gastropod of Kutch: a study on diversity and palaeoecological interaction.
1:30	D. Mukherjee	Immigrant taxa, speciation events and niche stability: the Jurassic brachiopod diversity of western India
1:45	D.P. Sengupta	Fossil vertebrates of India; major Players and minor absentees
2:00	G.P. Wilson	Mammalian faunas from the Deccan Volcanic Province and the Cretaceous-Paleogene transition in India

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Symposium #26 (HUB 269)	Presenter	Paleontological history of the Indian subcontinent - D. Chattopadhyay, S. Manchester
2:15	S. Manchester	India's lost flora: Distinctive fruits and seeds of the Deccan Intertrappean beds lacking close living relatives
2:30	S.Y. Smith	Plant response to environmental change: a case study of macrofossils from the Deccan Intertrappean Beds of India
2:45		**Tea Break**
3:15	J.H. Hartman	Continental molluscan conflict resolution? India subcontinent refugia during Deccan volcanism
3:30	P. Barden	Ants of Cambay amber illuminate biogeographic affinities of early Cenozoic India
3:45	D. Chattopadhyay	Oligocene-Early Miocene bivalve fauna of Kutch (Western India) and its paleobiogeographic implication
4:00	A.M. Jukar	Late Quaternary extinctions in India
4:15	K. Halder	*Glyptoactis* (Carditidae) flourished as the pioneer and opportunist genus in early Eocene marginal marine basins of western India

Symposium #13 (HUB 260)		The end of Cambrian "boom and bust" and the onset of the Great Ordovician Biodiversity Event (GOBE): diversity patterns, paleoecology, and paleobiogeography - IGCP 653-668 combined symposium - A. Stigall, S. Pruss, R. Freeman, S. Wernette
8:00	S. Peng	Discovery of a new exceptional preserved Cambrian biota from the Longha Formation in southeastern Yunnan
8:15	C.M.O. Rasmussen*	The Middle Ordovician shift in the state of the Earth
8:45	R. McKenzie	Assessing records of environmental stress and mass extinctions during the early Paleozoic
9:00	L.E. Holmer	Glendonite occurrences in the Tremadocian of Baltica: first Early Palaeozoic evidence of massive ikaite precipitation in temperate latitudes
9:15	P. Myrow	Depositional dynamics in the Inner Detrital Belt of North America and implications for biomere extinctions
9:30	J.M. Adrain	Two Laurentian Tremadocian (Early Ordovician) mass extinctions
9:45		**Coffee Break**

NAPC 2019 TECHNICAL SESSIONS - Oral Presentations

Thursday, June 27 (cont.)

Symposium #13 (HUB 260)	Presenter	The end of Cambrian "boom and bust" and the onset of the Great Ordovician Biodiversity Event (GOBE): diversity patterns, paleoecology, and paleobiogeography - IGCP 653-668 combined symposium - A. Stigall, S. Pruss, R. Freeman, S. Wernette
10:15	Q.-J. Li	The Early Ordovician lithistid sponge-microbial reefs, Tarutao Islands, Thailand: a prelude to the recovery of metazoan reefs
10:30	J.-H. Lee	Marine oxygenation and the early development of Paleozoic reefs
10:45	Y. Deng	Constructing the high-resolution evolutionary history of Ordovician marine animals in South China
11:00	X. Fang	Paleontologic and paleobiogeographic studies of Lituitida (Mollusca: Cephalopoda): based on new materials from South China
11:15	F. Franeck*	House by the sea or skyscraper? – Prime estate during the Great Ordovician Biodiversification
11:30	A.L. Stigall	Timing the GOBE: Coordinated biotic and geochemical changes during the Darriwilian in Laurentia
12:00 - 1:00		**LUNCH**
1:00	R.G. Stockey	Moving from correlation to mechanism: testing the role of oxygen and temperature change in the Great Ordovician Biodiversification Event
1:15	A.W. Hunter	A new somasteroid from the Fezouata Lagerstätte in Morocco and the Early Ordovician origin of Asterozoa
1:30	D.F. Wright	Fossil phylogenies reveal the timing, magnitude, and duration of the largest radiation of marine animal life
1:45	S. Wernette	Improved biostratigraphy for the Tarutao Group, Thailand and its global significance

NAPC 2019 TECHNICAL SESSIONS - Posters

Sunday, June 23

Poster Number	Poster Sessions	
#3 Plankton and Earth System Evolution		
1	S. Westacott	Radiolarians increased test size across the PETM at Mead Stream, New Zealand
#41 Taphonomy		
2	F. Varejoa	Exceptional preservation of shrimp soft tissues by microbial entombment: Cretaceous Crato konservat-lagerstätte, Araripe Basin, Brazil
3	M. Rodrigues	Sedimentary dynamics of an internally complex bakevelliid-dominated shell bed: event condensation and taphonomic feedback in muddy bottoms
4	S. Zille	Encrustation patterns of *Clypeaster rosaceous* tests from San Salvador, The Bahamas
5	T. Grun	Comparative taphonomy of deep-sea and shallow-marine echinoids of the genus *Echinocyamus*
6	M. Nielsen	Selective transformation and ontogenetic biases of phosphatised soft tissues in the Sirius Passet Lagerstätte, North Greenland
7	W. Zhan	Origin of large, 'Orsten'-type carbonate concretions in the Huron Shale Member of the Ohio Shale (Devonian) of Ohio
8	S. Galavez	Age-mortality profiles in La Brea bison: Insights into population dynamics and taphonomy
9	B. Burgy	Taphonomy of an adolescent male mastodon from a Pleistocene kettle lake deposit in northeastern Ohio
10	J. Thomka	Pirasocrinid anal sac spines with multiple planes of regeneration in the Upper Pennsylvanian of eastern Ohio
11	I. Bobrovskiy	Sediment rheology explains the Ediacara biota preservation
#44 Marine Paleobiology		
12	R. Beltracchi	Community changes in shallow benthic invertebrate ecology in the Early Danian
13	I. Smith	Polished slabs or thin-sections? Examining the consistency of alpha diversity estimates across different mediums
14	J. Nebelsick	Animal-plant interactions in the marine realm: Echinoid-coralline algal dominated ecosystems in the Miocene of Sardinia
15	P. Gorzelak	*Holocrinus* – the oldest stem-group isocrinid with stalk shedding and crawling abilities: Evidence from taphonomy, microstructure and trace fossils

NAPC 2019 TECHNICAL SESSIONS - Posters

Sunday, June 23, (cont.)

Poster Number	Poster Sessions	
Marine Paleobiology (cont.)		
16	A. Hawkins	Breaking down the lithification bias through time: Did vulnerability to lithification state related methodological bias change through the Phanerozoic?
17	K. Matsui	Inferences on aquatic adaptation of fossil mammals based on cranial characteristics with an example of the enigmatic fossil clade Desmostylia (?Afrotheria: Mammalia)
18	L. Taylor	Isotopic analysis of fossil coronulid barnacles as a means of understanding prehistoric whale migration
#46 General Session		
19	D. Lofgren	Algal structure from the upper member of the middle Miocene Barstow Formation, California
20	C. Hohman	Irvingtonian and Rancholabrean small mammals from the Harveston locality, southwestern Riverside County, California
21	P. Hong	Digitization of three-dimensional surface morphology of millimeter-scale fossil specimens through focus stacking and photogrammetry techniques
22	T. Grun	Deposition and bioinfestation patterns of *Spirula* shells
23	S. Tennakoon	Morphological disparity of Cenozoic cassids (Mollusca: Gastropoda)
24	A. Gause	Intervertebral variation of *Heterodon* and *Farancia* (Serpentes: Dipsadinae) and the reassessment of fossil holotypes using geometric morphometric analysis
25	P. dePolo	A spatially-constrained Paleocene mammal assemblage from the San Juan Basin, New Mexico, USA
26	K. Estes-Smargiassi	Allow us to reintroduce ourselves: Revitalizing the Invertebrate Paleontology collection at the Academy of Natural Sciences
27	R. Guerrero-Arenas	Towards a Mexican protection of paleontological resources
28	J. Samuels	A new large kangaroo rat-like rodent from the early Miocene of Oregon and the phylogeny of early heteromyids
29	D. Curry	Variation and ontogenetic change in the humerus of *Triceratops* (Dinosauria: Ceratopsia)
30	A. Bush	Searching for outcrops using LiDAR data (when you can't see the rocks for the trees)
31	F. Varriale	Jaw translation and dietary differences in marginocephalian dinosaurs inferred from quantitative dental microwear

NAPC 2019 TECHNICAL SESSIONS - Posters

Sunday, June 23, (cont.)

Poster Number	Poster Sessions	
#46 General Session (cont.)		
32	J. Claytor	Earliest Puercan 1 (Pu1) faunas from Montana with high-resolution insights on mammalian faunal recovery after the K-Pg mass extinction event
33	S. Trubovitz	New census of radiolarian communities in the eastern equatorial Pacific reveals unprecedented biodiversity throughout the Late Neogene
#19 Paleozoic Extinctions: Environmental Call and Biotic Response		
34	N. Marshall	Tracking the evolution of the Silurian marine biosphere using lipid biomarkers and stable isotope geochemistry
#7 Cambrian Konservat-Lagerstätten and the emergence of modern-style marine ecosystems		
35	M. Valent	Hyolith taphonomy: decay patterns
36	J.R. Foster	Comparative trilobite taphonomy of the Pioche Formation lagerstätte and other formations along a nearshore to outer shelf transect, latest early Cambrian (Stage 4; late Dyeran) of the southern Great Basin, USA
37	R. Lerosey-Aubril	New non-trilobite arthropods from the Drumian 'deep Wheeler' Lagerstätte of the House Range (Utah, USA)
38	Y. Liang	Exploration of Cambrian fossils by micro x-ray fluorescence spectrometer
39	W. Liu.	Biolamination structures from Guojiaba Formation (Cambrian Stage 3) in Hanzhong area, South China
40	H.C. Olson	Review of the Middle Cambrian trilobites of the *Bathyuriscus-Elrathina* biozone of Montana: Taphonomy and taxonomic information
41	A.C. Daley	New radiodonts from the Drumian (Miaolingian) Marjum Formation of Utah, USA
42	X. Yang	Early Cambrian phosphatized microbial pseudomorphs preserving non-mineralized animals

NAPC 2019 TECHNICAL SESSIONS - Posters

Sunday, June 23 (cont.)

Poster Number	Poster Session	
#37 Engaging Diverse Communities in Paleontology: Innovative educational initiatives that connect culture to natural history		
43	P.A.Cohen	A gender analysis of the Paleontological Society: Trends, gaps, and a way forward
44	A.N. Michels	Guided dissection of primary paleontology research as a tool to build science literacy in high school students

Monday, June 24

Poster Number	Poster Sessions	
#1 Behavioral Innovations and Environmental Feedbacks: Insights from the Trace Fossil Record and Other Archives		
45	W. Leibach	Leaving a mark: Horseshoe crab trace fossils of the Pony Creek Shale Lagerstätte, uppermost Pennsylvanian, Kansas
46	S. Grove	Dancing on the dunes: An ichnological examination of the Aztec Sandstone and the Jurassic paleoecology of the southern Nevada region
47	S. Chakravorti	Stromatolite? First report on biologic trace organisms preserved on an Early Triassic temnospondyl substrate
48	C. Savrda	Shipworm bioerosion of lithic substrates in a freshwater setting, Abatan River, Philippines: Ichnologic, paleoenvironmental and biogeomorphical implications
49	C. Kenchington	Diverse and dense trace fossil assemblages from the Ediacaran of Namibia

#14 Ecosystem recovery in the aftermath of the end-Permian mass extinction in the marine and terrestrial realms		
50	A. Cribb	Early marine ecosystem engineering recovery after the end-Permian mass extinction
51	T. Stone	Quantitatively assessing reef mound communities within the Upper Triassic carbonates along the eastern Panthalassic Ocean
52	L. Mosqueda	Characterizing Middle Triassic sponge-microbialite mid-ramp deposits during the recovery from the end-Permian mass extinction
53	R. Meyer	Regional variability of the recovery of shallow marine invertebrates during the Early Triassic

NAPC 2019 TECHNICAL SESSIONS - Posters

Monday, June 24 (cont.)

Poster Number	Poster Sessions	
#31 Paleontology on Public Lands: Research, Outreach and Resource Management		
54	B. Stoneberg	New remains of middle Miocene equids from the Cajon Valley Formation, San Bernardino National Forest, San Bernardino County, California
55	T. Nyborg	Fossil vertebrate tracks of Death Valley National Park: Indication of a large mammal and bird population in Death Valley during the Pliocene
56	M. Hodges	Fossil resources of Shellabarger Pass, Denali National Park and Preserve, Alaska
#28 Growth, development, and evolution in the fossil record		
57	J. Stack	The repeated evolution of skull elongation in ray-finned fishes (Actinopterygii)
58	L. Laibl	Post-embryonic stages of a Moroccan arthropod suggest direct development in Marrellomorpha
59	E.E. Vargas-Parra	Exploring variation in late Cambrian trilobite *Dikelocephalus* pygidia using landmark-based geometric morphometrics
CANCELLED 60	A.P. Cossette	~~A morphometric analysis of the crocodylian skull table; tracking allometry and predicting ecology~~
#39 Advances in understanding of Precambrian and Paleozoic life and environments		
61	J. Thomka	An *Iocrinus* 'logjam' from the Upper Ordovician Kope Formation of southwestern Ohio: Paleoecological and taphonomic significance
CANCELLED 62	P. Parkhaev	~~Meso- to Neoproterozoic Lakhanda Lagerstätte (Siberia, Russia): Progress and prospects~~
63	X. Shi	A comparative study of armoured palaeoscolecids from the Chengjiang Biota
#30 New insights into functional morphology: Microstructures, Modeling, and Experimental approaches		
64	A. Srinivas	Constraints and adaptations in crocodilian skull form and function
66	P.M. Peragine	Ungual nndressed: Comparing the bone and keratin sheath of claws across extant raptors

NAPC 2019 TECHNICAL SESSIONS - Posters

Monday, June 24 (cont.)

Poster Number	Poster Sessions	
#35 Broadening horizons of broader impacts (cont.)		
67	K. Keillor	Connecting non-museum goers to paleontology using art and rock n' roll
68	M.K. Macias	Fossils at the landfill: interactive tools for public education
69	L. White, A. Williams, A. Dineen	From the field to the fossils: Eastern Pacific invertebrate communities of the Cenozoic (EPICC)
#15 Scales of Ecological Development in the Mesozoic		
70	A. Godbold	Spatial differences in taxonomic composition amongst Upper Triassic patch reef deposits within the Gosaukamm Reef
71	P. Maxeiner	Early Jurassic Spiculites: Glass ramp deposits of Peru in the micro and macro scale

Tuesday, June 25
No Scheduled Posters

NAPC 2019 TECHNICAL SESSIONS - Posters

Wednesday June 26

Poster Number	Poster Sessions	
#5 Arthropod Evolution Through Deep Time: a tribute to Richard A. Fortey		
72	S. Losso	Taphonomy of the phacopid trilobites Cerausus pleurexanthemus and Flexicalymene senaria from the Walcott-Rust Quarry (Upper Ordovician)
73	K.J. Eaton	Patterns of lethal and sublethal predation on Cambrian Stage 3-Drumian Stage trilobites from the Great Basin, USA
74	P. Gueriau	Well-preserved 3-segmented chelicerae in a 478-million-year-old horseshoe crab (Fezouata Biota, Morocco)
75	R.J. Knecht	The end of the trail; A lobopodian mortichnia.
#42 Paleoenvironments and Paleobiology		
77	J. Bauer	Paleoecology and paleobiogeography of Eublastoidea (Blastozoa: Echinodermata)
78	A. Lam	Paleobiogeography of the Neogene planktic foraminiferal genus *Globoconella* to interpret long-distance dispersal mechanisms
79	M. Asgharian Rostami	Extinction pattern and paleoenvironmental reconstruction across the Cretaceous/Paleogene boundary in the eastern Tethys, northern Alborz: Using benthic foraminifera
80	B. Balmaki	Microfossil-based reconstruction of paleoclimate and paleo-seismic activity in a Southern California coastal marsh
81	G. O'Neil	Statistical approaches to identifying the origin of undocumented paleontological collections: A Mazon Creek example
#24 Recent advances in Central American and Mexican mammalian paleontology		
82	P.G. Butron Xantopica	The postcranial skeleton of the basal ruminant *Nanotragulus* (Artiodactyla: Hypertragulidae) from the Iniyoo Local Fauna, early Oligocene (Arikareean) of southern Mexico.
83	V.M. Bravo-Cuevas	Taxonomy, ecology, and biochronological implications of *Bison* (Artiodactyla, Bovidae) from the late Pleistocene of Hidalgo and Puebla, central Mexico
84	M.L. de Robles-Muro	A skull of *Canis lupus* from the Pleistocene of the state of Chihuahua, Mexico
85	C.D. Hannold	Isotopic evidence for diets and environments of late Miocene mammals in Yepómera, Mexico
86	E. Jiménez-Hidalgo	The Late Pleistocene equids from southern Mexico
87	V.A. Pérez-Crespo	Pleistocene mammal fauna migration at Laguna de las Cruces, San Luis Potosí, México

NAPC 2019 TECHNICAL SESSIONS - Posters

Wednesday June 26 (cont.)

Poster Number	Poster Sessions	
# 8 Symposium in honor of Michael A. Murphy		
88	M. Murphy	*Belodella* versus cavidonts and conodonts, taxonomy and biostratigraphy
#32 Two to tango: amateur-professional interactions in advancing paleontological knowledge		
89	T.E. Bantel	Conodont biostratigraphy and δ13Ccarb chemostratigraphy of the golden Brassfield of Indiana: A successful collaborative effort with two members of the Dry Dredgers
#43 Systematics and Phylogeny		
90	B. Long	Molecular vs. morphologic phylogenies in Neogene and Quaternary Lucinidae (Bivalvia) of the Western Atlantic
91	A. Bradley	*Politicurus* and related genera of hintzecurine trilobites from the late Skullrockian (Tremadocian: Early Ordovician) of western Utah and southeastern Idaho
92	P. Brady	Chasing a more complete mammalian phylogenetic tree: A pseudoextinction analysis
93	J. Randall	Relaxed selection on tooth genes suggests a two-step model for tooth loss in baleen whales
94	A. Saha	Neither a rodent nor a lagomorph: *Gomphos* as the most successful basal Glires (Class:Mammalia) in the early Eocene of China
95	M. Rubin	The examination and placement of a new specimen in Alligatorine evolutionary history
#29 Environmental change and the evolution of form and function		
96	K. Reed	Community changes during times of orogeny; examples from the Upper Devonian of Pennsylvania
97	S.V. Robson	Dental microwear of North American Taeniolabidoid multituberculates indicates niche expansion after the end-Cretaceous mass extinction

Thursday June 27

Poster Number	Poster Sessions	
#4 Avalon to Zaris: A Global Perspective on the Ediacaran Biosphere		
98	J. Hawco	New insights into the Ediacaran taxa *Beothukis* & *Culmofrons* – a combined morphometric and statistical analysis approach

NAPC 2019 TECHNICAL SESSIONS - Posters

Thursday June 27 (cont.)

Poster Number	Poster Sessions	
#4 Avalon to Zaris: A Global Perspective on the Ediacaran Biosphere (cont.)		
99	E. Mitchell	Using intra-specific variations to detect sexual reproduction in Ediacaran organisms
100	S. Jensen	*Cloudina*-microbial reefs in an unstable Cadomian retro-arc basin of the Iberian Peninsula
101	K. Turk	The earliest complex trace fossils from the terminal Neoproterozoic of Namibia
102	C. Kenchington	Constraining morphological disparity in rangeomorphs
103	A. Dhunghana	Resolving Ediacaran discoidal fossils
104	R. Taylor	A reappraisal of *Hapsidophyllas flexibilis*, a complex rangeomorph organism from the Ediacaran biota of Mistaken Point, Newfoundland, Canada
#26 Paleontological history of the Indian subcontinent		
CANCELLED 105	G. Singla	~~Uniform geochemical characters of Batal and Kunzum La Formation and question on existence of Batal Formation~~
106	R. Toor	Validation of *Psammichnites gigas* Ichnozone (Cambrian Series 2/ Stage 4) in Tethyan Himalaya
#13 The end of Cambrian "boom and bust" and the onset of the Great Ordovician Biodiversity Event (GOBE): diversity patterns, paleoecology, and paleobiogeography - IGCP 653-668 combined symposium		
107	A. Penny	Measuring ecosystem engineering in Cambrian and Ordovician reefs
108	F. Perez-Peris	New nektaspid arthropod from Lower Ordovician of Morocco
109	A. Hunter	Exceptionally preserved Late Ordovician 'starfish beds' from the Tafilalt area, Morocco: Implications for the Great Ordovician Biodiversification Event
#12 Environmental change and the dawn of animal life: Integrating geochemical and paleontological data		
110	C. Chang	Nitrogen isotope evidence for an oligotrophic shallow ocean during the Cambrian Stage 4
#40 Advances in understanding of Mesozoic and Cenozoic life and environments		
111	F. Varejoa	SpectacularAptian stromatolite fields and associated biofacies in the RomualdoFormation, Araripe Basin, northeastern Brazil

NAPC 2019 TECHNICAL SESSIONS - Posters

Thursday June 27 (cont.)

Poster Number	Poster Sessions	
#40 Advances in understanding of Mesozoic and Cenozoic life and environments		
112	S. Matos	First record of *Silesunionina* (Order Unionida) bivalves in South America: Aptian Crato Formation, northeastern Brazil
113	Q. Li	Untangling Lower Miocene reef frameworks: A case study from the Xisha Islands, South China Sea
114	S. Matos	Tracking benthic faunal changes in a monotonous oxygen-deficient lithofacies: A study case in the Early Cretaceous Romualdo shales, Araripe Basin, northeastern Brazil
115	M. Rodrigues	The "Bakevelliidae Sea" of the Romualdo Formation: A short-lived Aptian marine ingression in the northeastern Brazil
116	A. Hendy	Evolving biodiversity and paleoecology of marine communities across the end-Cretaceous mass extinction in California
117	D. DeMar	New vertebrate records from the Late Cretaceous (Campanian) Ellisdale Site of New Jersey
118	S. Allen	How tall were Eocene forests in western North America?
119	L. De Bortoli	Preliminary study about calcareous nannofossils from Burdigalian/Langhian boundary interval in the Paratethys area, referred to the reworked specimens
#45 Paleobiology and Climate Change in the Fossil Record		
120	I. Román Moreno	Evaluation of the ecosystems of the Western Mediterranean through paleoecological studies
121	B. Allen	The impact of the end-Permian mass extinction on the global distribution of marine invertebrates
122	A. Ricker	Laying the groundwork for utilizing isotopes to understand reptilian response to climate change
123	A. Jones	Paleoecology of the Mid-Miocene Tonopah Local Fauna of southwestern Nevada
124	T. Boag	Exploring the role of ecophysiology and metabolism in governing marine latitudinal biodiversity gradients during past icehouse and greenhouse climates
#21 Evolution, communities and ecosystems: systems approach to paleoecology - P. Roopnarine, A. Dineen		
125	Y. Huang	Contrasting community dynamics of terrestrial ecosystems in three mass extinctions through the Paleozoic–Mesozoic transition

NAPC 2019 TECHNICAL SESSIONS - Abstracts

NEW SLENDER-SNOUTED CROCODYLIANS FROM THE NEOGENE OF NORTH AND EAST AFRICA AND RESOLUTION OF THE GHARIAL DEBATE

ADAMS, Amanda, and BROCHU, Christopher, The University of Iowa, Iowa City, IA; @amanda-adams-1@uiowa.edu

Phylogenetic analyses made using molecular and morphological datasets yield conflicting results for placement of the modern Indian gharial (*Gavialis gangeticus*) and false gharial (*Tomistoma schlegelii*) among other crocodylians. Morphological analyses indicate they are distantly related, last shared a common ancestor more than 80 million years ago, and are similar because of evolutionary convergence. Molecular analyses instead support a close relationship and a divergence within the past 40 million years, with similarities resulting from common ancestry. Both arguments are well supported, keeping the debate unresolved for decades. The continued disagreement limits our ability to use Crocodylia as a model clade for the integration of the earth and life sciences. Numerous undescribed Neogene slender snouted crocodylians from Libya and Kenya, along with described specimens from Uganda, reveal a substantial diversity of gharials in the region until the Pliocene. They preserve derived characters unique to both lineages; the basioccipital is anteroposteriorly broad, and there is a long, broad descending ramus of the exocciptal along the basioccipital tuber, and the orbits are broadly upturned in a manner reminiscent of true gharials, but cranial sutural patterns are more similar to those of tomistomines. Present phylogenetic analyses draw some of these close to *Gavialis* and others close to *Tomistoma*, but this may reflect incompleteness in some forms and insufficient character sampling. Further phylogenetic work on these fossils holds great promise in reconciling modern gharial relationships using traditional morphological methods.

TWO LAURENTIAN TREMADOCIAN (EARLY ORDOVICIAN) MASS EXTINCTIONS

ADRAIN, Jonathan, University of Iowa, Iowa City, IA; jonathan-adrain@uiowa.edu

The presence of three significant Laurentian mass extinction events during the late Cambrian has long been recognized. They terminate intervals now recognized as the Laurentian Marjuman, Steptoean, and Sunwaptan stages. Once thought to be restricted in scope to the Laurentian craton, recent evidence from trilobite taxic data indicates that they were global events, with a signal obvious on every paleocontinent. Measured as proportional loss, the extinctions rank among the most severe of the Phanerozoic.

While the Laurentian Cambrian has seen extensive study, the Early Ordovician has been poorly documented. The main works to appear are the nearly seventy year old monographs of Ross and Hintze. Nevertheless, Laurentia features the richest and most complete record of Tremadocian trilobites known from anywhere in the world. Full documentation of these faunas reveals that the late Cambrian pattern of "boom and bust" diversification and extinction continued well into the Ordovician.

Stitt proposed a "Symphysurinid Biomere" based on the faunas of Oklahoma. New data from the Great Basin confirm that a fourth extinction-bound interval - the Laurentian Skullrockian Stage - has biotic patterns nearly identical to the Cambrian stages. It features a suite of mostly unique trilobites (including Hintzecurinae, *Symphysurina*, *Bellefontia*-group asaphids, and *Clelandia*) which almost entirely disappear in a mass extinction which terminates the stage.

In addition, a fifth such interval event clearly follows, corresponding to the Laurentian Stairsian Stage. This interval has its own unique fauna, including Hillyardininae and several presently unnamed family-group clades. Almost all terminate in a mass extinction which marks the base of the Tulean Stage. No further significant events are known in Laurentia until the great end-Ordovician extinction.

While evidence for a global signal for the Cambrian events is strong, that for the Ordovician extinctions is equivocal. There is potential signal that they are present in tropical continents and terranes (particularly North and South China) but none in high latitude regions. A particular problem is that the global Tremadocian is poorly sampled and the Stairsian Stage is narrow. Nevertheless, obvious "Stairsian"-style faunas have been documented from North China and Australia.

Taken as a whole, the five cycles of diversification and extinction record extraordinarily high evolutionary rates punctuated by extinctions which consistently

removed 70–90% of the trilobite faunas. The effect on global diversity was a steady erosion from the Marjuman to the end-Tremadocian, followed by sustained diversification as the extinctions ended and the "Whiterock Fauna" trilobites participated in the Ordovician Radiation. Hence, the timing of the Great Ordovician Biodiversification Event may largely reflect cessation of the extinctions following an approximately 20 million year global period of "start and stop" diversification and decimation.

EDIACARAN FROM A PROTISTAN POINT OF VIEW: ASSESSING MICROFOSSIL DIVERSITY CHANGES DURING THE RISE OF MACROSCOPIC LIFE

AGIĆ, Heda, and PORTER, Susannah, University of California Santa Barbara, Santa Barbara, CA; hagic@geol.ucsb.edu

Terminal Neoproterozoic is marked by severe low-latitude glaciations, oxygenation of the oceans, the first appearance of abundant macroscopic eukaryotes, and emergence of complex ecosystems. The Ediacara-type biota occurs shortly after a negative carbon isotope excursion and a short-lived glaciation (Gaskiers). However, in the early Ediacaran, the fossil record of complex eukaryotic life is dominated by organic-walled microfossils (OWM) and carbonaceous compressions. Early Ediacaran OWM are characterized large cell size (>200 μm) and elaborate processes (Doushantuo-Pertatataka acanthomorphic acritarchs). These taxa have a global distribution but their stratigraphic range is poorly understood. Through 3 case studies of OWM diversity from early, middle, and late Ediacaran, and a database compiling published OWM data, the macroevolutionary patterns of Ediacaran protists were analyzed.

OWM were extracted from shales, siltstones, and diamictites of the Vestertana Group (Arctic Norway), St. John's Group (Newfoundland), and the Nama Group (Namibia). To minimize bias in comparing the microfossil record from shales and glaciogenic diamictites, a modified acid maceration technique was used.

In the Vestertana Group, eukaryotic biodiversity is highest in the pre-Gaskiers Nyborg Formation including large acanthomorphs. Eukaryotes decline during the glacial interval (Mortensnes diamictite), which hosts abundant bacteria. The overlying macrofossil-bearing Stáhpogieddi Formation is nearly devoid of microfossils, containing scarce smooth-walled OWM (leiosphaerids). The Trinity Diamictite and the post-Gaskiers Fermeuse Formation on Newfoundland, contain abundant prokaryotic microfossils but no acanthomorphs. Diamictite facies are rich in cellular aggregates, and younger shales host an assemblage of filamentous bacteria and leiosphaerids. In the late Ediacaran Spitzkopf Member of the Nama Group, protistan fossils are restricted to leiosphaerids and envelope-bearing taxa (including the first occurrence of *Granomarginata* in Namibia).

These results, accompanied by a compilation of Ediacaran OWM occurrences, indicate that although stratigraphic range of acanthomorphs extends up to the Ediacaran-Cambrian boundary, they are rare after the short-lived glaciation, and OWM assemblages contemporary with diverse macroscopic faunas are depauperate and dominated by leiosphaerids and bacteria. Novel protistan taxa (acanthomorphs) that evolved in the aftermath of Cryogenian glaciations are complex and diverse, but mostly go extinct during or after the Ediacaran glaciation. Coincident with the decline of acanthomorphs is the appearance of bedding-plane fossils interpreted as macroscopic protists. Protistan diversity slightly increases in the terminal Ediacaran, and includes envelope-bearing acritarchs (*Granomarginata*) and large-sized microfossil problematica, e.g. *Cochleatina*, *Redkinia*. Cells size, however, remains small (10-20 μm) and acanthomorphs are absent until the Cambrian.

NATURAL HISTORY AND THE FUTURE

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Unlike any other living organism, only our species can ask "where do we come from?" and "what things matter in life?" Society's answers to these questions have evolved along with understanding of our planet and our place in it – we now have the ability to explore the arts, science, philosophy, music, and theology. We can pursue societal and cultural concerns such as ethics, law, or education, in order to improve the human condition, and we routinely enjoy the benefits of science-based discovery in easing human existence. The speed of change and progress within the last few hundred years has changed the zeitgeist of our time like no other. But at the same time, our species has also proven we can be stubborn and stupid; we can resist change; we can destroy ourselves for the most irrational, blind, and implausible beliefs. Many remain blind to climate change even as it wreaks havoc in front

of our eyes; we have created abysmal inequality while managing to accumulate unprecedented wealth; we question womens' right to choose; some of us even do not hesitate to kill only because someone dares to question our irrational beliefs. Rationalism is increasingly at risk worldwide, with threats ranging from the shockingly evident to the dangerously insidious. Paleontologists have played a critical role in shaping the philosophy of both biological and physical science by shaping the understanding of our place in Earth history. You chronicle and interpret the way our planet and life upon it has co-evolved, and share the stories of deep time. And we know our species loves good stories! The role of the storytellers in our societies has become more critical than ever before. Now is a time for experts from all walks of life to come together to promote the story nature itself tells of our origins, existence, and future so that decisions about our collective future are based on an informed view of our planet's natural history.

THE COLLAPSE OF NATIVE BIODIVERSITY ON THE ISRAELI MEDITERRANEAN SHALLOW SHELF: PATTERNS AND CAUSES

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The Levantine basin in the easternmost Mediterranean Sea is well known for hosting hundreds of non-indigenous species introduced after the opening of the Suez Canal in 1869 (the so-called Lessepsian invasion). A still insufficiently recognized but equally dramatic phenomenon is the disappearance of native species: the large-sized native molluscan fauna on intertidal and subtidal rocky reefs was reported to be highly impoverished.

We here quantify the decline of native mollusks on the Israeli Mediterranean soft-substrate shelf based on sampling along two transects off Atlit and Ashqelon (northern and southern Israel, respectively) in autumn 2016 and spring 2017 from 10 to 40 m depth. We compared the living assemblages with 1) a comprehensive literature-based checklist of Israeli mollusks filtered by appropriate substrate and depth, and 2) the composition of the death assemblage collected with the living organisms. We used a small mesh size (0.5 mm) to retain small sized and juvenile individuals and deployed an intense identification effort, including tracing the morphology of early ontogenetic stages.
Our sampling intercepted only 24% of the historically recorded species notwithstanding a sample coverage of 99.4%. At individual sites, the living assemblage native richness is between 2.9% and 18.5% of the death assemblage native richness (coverage standardized). In contrast, we intercepted 42% of the historically recorded non-indigenous species (54% after removal of the casual or unconfirmed records from the checklist), with a sample coverage of 99.6%. At individual sites, the living assemblage non-indigenous richness ranges between 7.1% and 80.2% (mean 42%) of the death assemblage (coverage standardized), with lower values in deeper stations.

The abundance of native species peaks in spring (80%, 934 individuals) but drops in autumn to only 15% (279 individuals, notwithstanding two additional replicates were collected) suggesting a mass mortality during summer. Abundant native species like Abra alba and Corbula gibba, present in the hundreds in spring, collapse although they are reported to be pluriennial species. The comparison of size-frequency distributions of seven native and nine non-indigenous species (those with sufficient sample size) from living and death assemblages showed that most native species have small living individuals but do not reach the large sizes of the past, suggesting that while recruitment does occur, death occurs prematurely, for some species possibly before maturity. In contrast, for most non-indigenous species the size range of living individuals overlaps with the dead ones. These two results combined suggest that current environmental conditions (likely including the locally rapid climate warming) disproportionally favor non-indigenous species and that native species reproduction may be hindered, with recruitment potentially coming from deeper waters or other sectors of the basin.

TETRAPOD SPATIAL BIODIVERSITY PATTERNS ACROSS THE END-PERMIAN MASS EXTINCTION AND RECOVERY INTERVAL

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The modern-day latitudinal diversity gradient (LDG) is a general trend of increasing biodiversity from the poles to the equator. However, our understanding of the underlying processes that drive it is limited, and it remains unclear whether this pattern was consistent throughout the Phanerozoic. One approach to

answering these questions is to examine spatial biodiversity patterns in the geologic past, across different global climate regimes and continental configurations.

The Late Permian–Middle Triassic (~260 – 237 Ma) represents an ideal time interval for investigating whether the LDG has been consistent throughout deep time. It is characterized by large-scale volcanic episodes, extreme greenhouse temperatures and mass extinctions and recoveries, including the most severe mass extinction event in Earth history at the end of the Permian (~250 Ma). Continental configuration was also markedly different from today, with most of the major landmasses coalesced into the supercontinent Pangea.

Previous work on Permo-Triassic geochemical proxies and climate models has suggested that extremely high equatorial temperatures may have rendered the lower latitudes uninhabitable, producing a bimodal LDG with temperate peaks. In order to test this hypothesis, we downloaded and reviewed tetrapod occurrences from the Paleobiology Database across this time window, adding additional occurrences from the literature to increase coverage, and used shareholder quorum subsampling (SQS) to reconstruct LDGs for both terrestrial and marine tetrapods.

Sampling was sufficient to compare gradients from the Late Permian (prior to extinction), Early Triassic (during recovery) and Middle Triassic (post-recovery), but was consistently poorer in the Southern hemisphere. During the Late Permian and Early Triassic, peak terrestrial tetrapod diversity moved from tropical to temperate latitudes, resulting in a bimodal richness distribution. However, in the Middle Triassic, highest tetrapod diversity is found in equatorial regions. These results indicate that extreme equatorial temperatures drove tetrapod extinction and migration at low latitudes in the wake of the end-Permian mass extinction, while subsequent ecological recovery and cooling temperatures in the Middle Triassic produced a more modern-like LDG.

THE IMPACT OF THE END-PERMIAN MASS EXTINCTION ON THE GLOBAL DISTRIBUTION OF MARINE INVERTEBRATES

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While mass extinction events represent times of hardship for most of Earth's ecosystems, shallow marine reef communities have often been hardest hit during periods of extreme environmental change. This is particularly true of the end-Permian mass extinction (~250 Ma), the most severe in Earth history, when up to 96% of marine species became extinct. High rates of taxonomic turnover across this event represent the transition between Sepkoski's 'Palaeozoic' and 'Modern' marine faunas.

However, the environmental changes which occurred during the Late Permian–Middle Triassic (~260 – 237 Ma) are complex. Large-scale volcanic episodes drove extreme greenhouse temperatures, peaking in the late Early Triassic, alongside widespread ocean acidification and anoxia, compounded by feedbacks associated with the presence of the supercontinent Pangea. As such, the variation of climate with latitude may have driven spatially heterogeneous patterns of extinction severity and selectivity. Several recent studies have suggested that high latitude faunas suffered higher extinction rates during the end-Permian mass extinction than their counterparts at lower latitudes.

In order to examine the spatial nuances of the end-Permian mass extinction and recovery for marine invertebrates, we downloaded and reviewed Late Permian to Middle Triassic occurrence data for brachiopods and bivalves from the Paleobiology Database, with additional occurrences added from the literature in order to increase coverage. We then calculated changes in origination, extinction and extirpation rates with latitude, and reconstructed the latitudinal diversity gradients (LDGs) of brachiopods and bivalves, with shareholder quorum subsampling (SQS) applied to compare richness between latitudinal bands. These results highlight the role of extreme climate change and continental configuration in driving spatial biodiversity patterns at this time.

HOW TALL WERE EOCENE FORESTS IN WESTERN NORTH AMERICA?

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Three Eocene localities with a fossil wood record were examined to estimate tree height. Blue Rim, the oldest site (~49 Ma), is preserved in the Bridger Formation of southwestern Wyoming. The wood flora is not very diverse and dominated by angiosperms. Sites in the middle Eocene Clarno Formation (~44 Ma) of central Oregon, including the Nut Beds and Hancock Canyon floras, preserve a diverse wood flora. The

youngest site (34 Ma) is the Florissant Formation in central Colorado. Unlike the angiosperm-dominated dendrofloras of the Bridger and Clarno Formations, the petrified stumps at Florissant are primarily gymnosperms, specifically *Sequoioxylon pearsallii.*

Tree heights were estimated using multiple regression equations based on actual or estimated stem diameter. Many fossil wood specimens are not full stumps or logs, so it is impossible to estimate tree height for all taxa at a site.

At Blue Rim, measured diameters from *in situ* stumps and a large allochthonous log fragment (n=10), most of which were not adequately preserved to be identified, were used to estimate tree heights of 16–28 m. In the field, *in situ* stumps were small and widely spaced. It is not clear if they represent the original landscape (e.g., an early successional forest) or if taphonomic effects played a role.

Stem diameters from the Hancock Canyon and Nut Beds localities in the Clarno Formation were either measured directly or estimated based on the curvature of the growth rings from smaller hand samples. Measurements or estimates below 10 cm were excluded in order to limit the potential for including branches. At Hancock Canyon (n = 28), all trees averaged 17.4 m tall with the tallest specimens over 26 m. At the Nut Beds locality, angiosperm specimens (n=93) averaged 13.7 m tall. The largest specimens had estimated heights over 37 m. The gymnosperm component (n=8) had estimated average tree heights of 13.0 m and the tallest specimen exceeded 19 m.

Measured diameters from stumps in the Florissant Formation (n=10) ranged from 0.5 to 4.9 m. All but one of these (the smallest) were redwood stumps. Using the mixed taxon regressions, height estimates for the redwoods ranged from 55 to 90 m. Height estimates for the redwood specimens were also calculated using a regression based on a managed stand of redwoods. This taxon specific method estimated an average redwood height of 63.5 m with a range of 58–70 m. Based on both of these approaches, the tallest redwood specimens at Florissant were at least 60 m tall.

Data from the woods and other proxies suggests that the Bridger and Clarno Formations were deposited during warm temperate to subtropical conditions with limited seasonality. In contrast, paleobotanical evidence from the Florissant Formation suggests a cooler, drier climate and more seasonality. The forest at Florissant was also dominated by tall conifers, which is not supported by the dendroflora at either of the sites earlier in the Eocene.

UPDATED SYSTEMATICS OF PLIO-PLEISTOCENE *TURRITELLA* OF FLORIDA AND THE ATLANTIC COAST

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Turritelline gastropods are abundant and diverse in the Plio-Pleistocene deposits of Florida and the Atlantic coastal plain. Past researchers described numerous species over more than 150 years, frequently with inadequate attention given to ranges of variation and details of shell ornamentation, especially associated with the apex and protoconch. As a result, numerous overlapping names were assigned. In an attempt to better represent the actual variation of turritelline species in this region and time interval, SEM imaging and diagrammatic morphometrics were employed to reexamine all described species. We recognize 32 distinct species, instead of the 42 that were originally described. Several species, including *Turritella bipertita* Conrad, *T. apicalis* Heilprin, *T. acropora* Dall, and *T. cookei* Mansfield represent especially interesting cases of overlapping naming and misunderstanding of morphology. Improved systematics allow for more effective use of fossils in determining biostratigraphy and, together with concurrently researched genetic data, improved phylogenies of these Plio-Pleistocene forms.

APPLICATIONS OF 3-D PRINTING TO TESTING FUNCTIONAL HYPOTHESES OF TURRITELLID GASTROPOD SHELL MORPHOLOGIES AND SCULPTURE

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Turritellid gastropods are a common component of the marine macroinvertebrate fossil record from the Jurassic to Recent. Prominent aspects of turritellid shell morphology include whorl profile (the shape of each whorl and how it relates to the prior and subsequent whorls) and spiral sculpture (ornamentation on the whorl). Some features of shell morphology occur

repeatedly in probable independent lineages (in different basins and time periods), suggesting a role for selection. Selective hypotheses proposed in the past for the function of sculpture have frequently related directly to predation, but results have been ambiguous.

An alternative hypothesis is that sculpture is related to the semi-infaunal habit of most turritellids. Burial can take several minutes, leaving an exposed animal at risk of detection by predators, and maintaining sediment cover is a potential function of shell shape and sculpture. Testing hypotheses relating to burial and exhumation using a flume or wavetank is potentially damaging to fossil or Recent shells, however 3-D printing permits repeated testing without damaging collected specimens. Six extant and fossil species (*Mesalia brevialis*, *Turritella abrupta, T. acuticarinata, T. banksii, T. duplicata,* and *T. montañitensis*) representing a variety of morphologies were micro-CT scanned and models were printed using an ObJetPro 3-D printer. Experiments were performed with these models in both a flume and a wavetank to assess differences in sediment retention under both unidirectional and oscillatory flow.

3-D printing not only allows replication of natural shells, but also the generation of physical models of simplified or idealized forms. The creation of artificial morphologies permits the disentanglement of sculpture from whorl profile, further refining our ability to test the adaptive significance of each component of morphology. Nine models were generated representing all combinations of straight-sided, rounded, and carinate whorl profiles with zero, one, or two spiral cords.

While preliminary results based on naturally occurring forms showed a potential role for strong sculpture in sediment retention in wave-influenced environments (but not environments with consistent unidirectional flow), tests with the theoretical morphologies examined did not find significant differences in sediment retention among tested morphologies. It is therefore probable that these differences in sculpture relate to other selective pressures, such as crushing predation.

HOLOCENE MARINE LAKES AS REFUGIA: MORPHOMETRIC AND PHYLOGENETIC ANALYSES OF BAHAMIAN LAKE *CTENA* (BIVALVIA: LUCINIDAE) AND THEIR ENDOSYMBIONTS

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Lakes are often viewed as cradles of diversity, especially when they persist over evolutionary time scales, have distinct environmental conditions, and their biota represent either a non-random sample of the regional biota and/or show evidence of endemic speciation. An analysis of multiple dimensions of biodiversity (morphologic, molecular, and functional) for abundant *Ctena* inhabiting anchialine lakes in San Salvador, the Bahamas, reveals a complex evolutionary history for the bivalve hosts, as well as for their thiotrophic chemosymbionts. These lakes were flooded during the Holocene transgression and maintain some connectivity to the ocean through karst conduits. Each lake is distinct geochemically and sedimentologically. In addition, an evolutionary radiation of endemic pupfish (*Cyprinodon*) among these lakes has been documented by previous authors.

For *Ctena*, molecular phylogenetic work of others has documented a species complex for members of the genus in the western Atlantic and eastern Pacific. Currently, two morphologically similar abundant taxa are recognized from the Western Atlantic: *C. orbiculata* and *C. imbricatula*, with *C. imbricatula* a sister species to the eastern Pacific *C. mexicana*.

We investigated *Ctena* from three anchialine lakes on San Salvador, as well as marine populations from San Salvador, the Florida Keys, and southwest Florida. Phylogenetic trees of 28S rRNA and cyt*b* genes produced using a Bayesian analysis indicate that specimens from Florida are *Ctena orbiculata*, as expected, but all specimens from the Bahamas (both from lakes and from a marine lagoon) are more closely related to *C. mexicana* than *C. imbricatula*. Metagenomic analyses produce similar results. Geometric morphometric results are consistent with these molecular data, with the shell morphology of Bahamian lake specimens more similar to *C. mexicana* than to either accepted western Atlantic taxon. Host genetic profiles, however, do not match those of their endosymbionts, as lake endosymbionts were more genetically variable and at least one strain showed 100% identity to lucinid endosymbionts from Florida. These results are surprising because published reports indicate that *C. imbricatula* can acquire symbionts from the environment throughout their life. As such, we would expect symbiont diversity

to reflect local sediment microbial communities.

The close phylogenetic relationship with *C. mexicana* indicates that lake *Ctena* represent a long-lived taxon that evolved before closure of the Central American Isthmus. Therefore, marine lakes of San Salvador may represent a refugium for the species, as it is present but not abundant in coastal areas of the island and has not been reported in other areas of the western Atlantic and Caribbean.

NO PATTERNS OF ECOLOGICAL RELEASE IN BRACHIOPOD AND BIVALVE DISTRIBUTIONS OVER THE PHANEROZOIC

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Geographic range size interacts with traits at every level of the biological hierarchy, from individuals to ecosystems, and may link ecological interactions to evolutionary outcomes. The assumption that biotic pressures limit species' distributions forms a keystone in many fundamental evolutionary theories, such as adaptive radiation, ecological saturation, and species selection. However, until now empirical studies have tested this assumption almost exclusively at the fine scale of living populations. Contention remains about the effect size of competition over the large spatial scale of entire species' distributions and the large temporal scale of extinction and speciation. Moreover, most modern evidence is derived from vertebrates in terrestrial systems, which may not be representative of invertebrates in the marine realm, where currents aid dispersal. Our study sought to quantify the dominant relationship between number of competitors and breadth of geographic distribution, in brachiopods and bivalves over all oceans throughout the Phanerozoic. In particular, we tested the expectation from ecological release that distributions expand after competitors go extinct, and the expectation from competition exclusion that distributions contract after more competitors enter a region. As a preliminary step we formulated a subsampling procedure to control for heterogeneous spatial preservation of fossil occurrences through time, within environments. We then investigated (1) the correlation through time between the number of species in regional marine assemblages and the geographic distributions of constituent species in those regions, and (2) changes in survivors' range area as a function of changes in the number of species present in a region. We conducted analysis at different taxonomic scales (species and genera) and spatio-temporal scales (global Phanerozoic and Northwestern Atlantic Neogene—Quaternary). Contrary to the expectations derived from hypotheses of release and exclusion, geographic range size varied independently (rather than inversely) with species count. Similarly, analysis of survivors indicated that range size dynamics are not diversity-dependent, although factors other than species count do influence per-species likelihood of contraction. Taxa that were narrowly distributed, near the end of their duration, or specialized on substrate composition carried greater risks of range contraction and thence extinction. Surprisingly, brachiopods were predicted to expand in range more than bivalves when suitable habitat was present. This last result contradicts the assumption that bivalves were more fit than brachiopods in general; it is more congruent with the interpretation that the clades "passed like ships in the night." On evolutionary scales of geologic stages and ocean basins, environmental filtering rather than biotic pressure seems predominantly to control the size of marine animals' distributions.

FOSSILS FROM SOUTH CHINA REDEFINE THE ANCESTRAL EUARTHROPOD BODY PLAN

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Early Cambrian Lagerstätten from China have greatly enriched our perspective on the early evolution of animals, particularly arthropods. However, recent studies have shown that many of these early fossil arthropods were more derived than previously thought, casting uncertainty on the ancestral euarthropod body plan. In addition, evidence from fossilized neural tissues conflicts with observations based on external morphology, in particular regarding the identity of the frontalmost appendage. Here we redescribe the multisegmented megacheirans *Fortiforceps* and *Jianfengia* and describe a new genus with more than thirty

atypically ornamented trunk segments. We show that the frontalmost appendage is homologous between radiodontans and megacheirans, refuting the claim that the dinocaridid "great appendage" evolved into the euarthropod labrum and questioning its protocerebral identity. These taxa also show that the ancestral euarthropod head shield was three-segmented and that the plesiomorphic endopod had seven podomeres. Our phylogeny resolve multisegmented megacheirans as the earliest euarthropods, providing a new perspective on the origin of the largest animal phylum.

CLIMATE, TROPHIC STRUCTURE, AND THE EVOLVING DEMEANOR OF THE ANTARCTIC BENTHOS

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Shell-crushing (durophagous) teleosts, elasmobranchs, and decapod crustaceans have been functionally absent from benthic food webs in Antarctica for millions of years. Their ecological importance declined with declining temperatures in the Southern Ocean after the Eocene, driving the shelf-benthos toward the archaic community structure that is manifested in the living communities. Shelf habitats in Antarctica are currently dominated by assemblages of ophiuroids nemertean worms, asteroids, pycnogonids, brachio pods, thin-shelled mollusks, and other sessile and slow-moving, epifaunal invertebrates. This retrograde Paleozoic-style ecology can be especially pronounced on the sea-floor beneath the ice shelves. In contrast durophagous predators exert top-down control on benthic communities in shelf environments at tropical temperate, and Arctic latitudes.

Climate change now threatens to change the structure of benthic-shelf communities in Antarctica. Because marine ectotherms tend to be stenothermic at the poles, polar faunas are vulnerable to the deleterious physiological impacts of climatic warming: rapidly rising ocean temperatures off the western Antarctic Peninsula (WAP) in particular could soon outstrip the thermal tolerances of many endemic invertebrate taxa. Warming in Antarctica is also breaking up the ice shelves and simultaneously may be facilitating the reappearance of durophagous predators in benthic communities on the continental shelf.

King crabs (Lithodidae), which inhabit the slightly warmer waters of the upper bathyal zone off the WAP, appear to be the vanguard of a reinvasion of durophagous predators in Antarctic-shelf habitats. The lithodid *Paralomis birsteini* is the most abundant durophagous predator in those deep waters. Biomechanical analysis showed that the claws of *Paralomis* are as thick, as hard (or harder) and as invested with calcium carbonate as durophagous crabs from temperate-coastal environments—despite the fact that the *Paralomis* live in an undersaturated environment. Analysis of mitochondrial DNA sequences of a population of *Paralomis* off Marguerite Bay, WAP suggests this population has expanded twice over the last 120,000 years. Those expansions appear to have coincided with previous episodes of climatic warming in Antarctica and elsewhere. Continued warming off the WAP could drive a third episode of population expansion in *Paralomis*, onto the continental shelf. Taken together with the likelihood of geographic-range expansion by predatory brachyuran crabs from southern South America, a bathymetric-range expansion of lithodids could increase durophagous predation substantially on the Antarctic shelf on a multidecadal to centennial scale. Substantially increased durophagous predation could 'remodernize' the Antarctic-shelf benthos and homogenize community structure with benthic-shelf communities in other parts of the world.

NEW MEXICAN PLEISTOCENE MAMMAL FINDINGS

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Renewed interest in search for early human sites in Latin America, and especially in Mexico, has allowed the finding of an extended record for the Pleistocene Mammals in the last 20 years. Nowadays Mexican Pleistocene terrestrial mammals account for 12 orders 43 families, 135 genera, and 272 species, including several species that have been extirpated or become extinct, while recent Mexican terrestrial mammal fauna includes 11 orders, 39 families, 173 genera, and 508 species, accounting Pleistocene mammals for a 54.8% of the recent species, more than half the known recent species and certainly above the 10% considered the average faunal preservation rate in the fossil record. Localities include mountain-top cave (Chiquihuite Cave, Zacatecas), several deep water holes (*cenotes* in Quintana Roo), fluvial and lacustrine deposits (Chazumba, Oaxaca), to mention the more representatives. Also the revision of ancient collections where there are

mammal remains overlooked, like those from Chapala Lake, Jalisco, and Valsequillo, Puebla. Furthermore, interest in Cenozoic Vertebrate Paleontology has steadily growth recently, increasing the number of paleontologists in universities and centers all over the country, e.g. Instituto de Historia Natural (Chiapas), Universidad del Mar (Oaxaca), Universidad Michoacana de San Nicolás Hidalgo (Michoacán), Universidad Autónoma de San Luis Potosí (San Luis Potosí). Finally, most recently, a federal Paleontological Council was renewed in order to study, protect, conserve, and disseminate the Mexican paleontological heritage. It is managed by INAH, which has helped to initiate coordination with the different paleontologists all over the country.

New extinct species have been described, surprisingly including large and medium-sized mammals, like several ground sloths, which almost increased twice the number that previously was known, and more specimens are still under study. This points out about the fact that research has expanded in the Mexican tropical region, where few localities were known in the past, mostly in the state of Yucatan, but now there have been a steady increase in its knowledge, again for both archaeological and paleontological studies. Also, long-term research has allowed the naming of the local fauna (*Vico Vijin*), as well as securing new findings in old and new localities. Many new state records are reported, as well as presence of taxa previously unknown in the country. Radiometric control has improved with new dating techniques, and although still lacking dates for many localities, some recent ones have systematic programs for radiocarbon datings. Finally, further studies are been undertaken, including biogeochemical or morphofuncional techniques for understanding diet and habitat of mainly herbivorous mammals, and ancient and environmental DNA studies for identification and phylogenetic studies. In a near future, a better knowledge of Mexican Mammal Pleistocene fauna will be accomplished.

EXTINCTION PATTERN AND PALEOENVIRONMENTAL RECONSTRUCTION ACROSS THE CRETACEOUS/PALEOGENE BOUNDARY IN THE EASTERN TETHYS, NORTHERN ALBORZ: USING BENTHIC FORAMINIFERA

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The extinction patterns, as well as paleobathymetric and paleoenvironmental changes, of benthic foraminifera were investigated across the Cretaceous/Paleogene (K/Pg) boundary at the Galanderud section (Northern Alborz, Iran), which contains one of the most continuous and expanded K/Pg transitions in the eastern Tethys. Changes in the benthic foraminiferal assemblages, morphotypes, diversity, heterogeneity, and benthic foraminiferal oxygen index (BFOI), coupled with statistical analyses, defined three intervals. In the first interval (uppermost Maastrichtian *Plummerita hantkeninoides* Zone), benthic foraminiferal assemblages are well preserved and highly diverse, with a combination of epifaunal and infaunal taxa indicating stable, mesotrophic to weakly eutrophic, normal marine conditions. However, in the second interval (basal Danian *Guembelitria cretacea* and lower part of *Parvularugoglobigerina eugubina* Zones), benthic foraminifera assemblages experience a major change across the K/Pg boundary that is marked by a decrease in the infaunal morphogroups, including buliminids, as well as a decrease in diversity, heterogeneity, and genus and species richness. This interval denotes highly oligotrophic conditions, and a collapse in productivity and food availability due to the extinction of primary producers. Indeed, high abundance of BFOI is in contrast with low oxygen conditions inferred at many K/Pg boundary sections and sites around world. Benthic foraminifera do not show significant extinction at the end of the Cretaceous at this section, with only about 4% loss of the species. However, marked change and temporary disappearance of some taxa are observed at this interval. Additionally, high abundance of some opportunistic species, including *Cibicidoides pseudoacutus* and *Tappanina selmensis*, might reflect instability in the benthic foraminiferal assemblages. The third interval (middle part of *Pv. eugubina* to the *Parasubbotina pseudobulloides* Zones) is characterized by the dominance of epifaunal morphogroups in up to 70% of the assemblages with a partial recovery of infaunal groups. The characteristics of the benthic foraminiferal assemblages indicate that the flux of food to the benthos had not fully recovered during the lower Danian.

THREE-DIMENSIONAL PRESERVATION OF NONBIOMINERALIZED TISSUES IN CAMBRIAN CONCRETIONARY LAGERSTÄTTEN OF NORTH AMERICA

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Concretions have long been recognized as invaluable sources of information about the morphology of ancient organisms. Concretions of various dimensions are pervasive features of some Cambrian Konservat-lagerstätten, particularly ones of Drumian and Guzhangian age. Apart from large, 'Orsten'-type concretions, concretions in Cambrian strata have remained largely underappreciated as a source of biological and taphonomic information. Concretionary material has the potential to add substantially to our understanding of the anatomy, paleoecology, and taphonomy of some Cambrian organisms, and it often has the added benefit of providing three-dimensional preservation and details about skeletal articulation.

Concretions in Cambrian strata vary in mineralogy, and include carbonates and silica, depending on the organic source material. In addition, some coprolites, cololites, and trace fossils in sediment can be construed as being preserved as concretions. If so, other mineral compositions, including pyrite or limonite and calcium phosphate, can be added to the list of major constituents. Non-invasive analytical tools such as XCT can be used to extract detailed morphologic information from the organisms preserved inside the concretions. The most familiar form of concretion, typified by the small cone-in-cone concretions in the Wheeler and Marjum formations of Utah, is relatively small and encloses a macrofossil, such as an articulated trilobite, that extends nearly to the margin of the concretion. Digestive systems of trilobites are often preserved, and appendages are occasionally preserved. Presumably this reflects differences in the timing of decay, disarticulation, and early mineral replication of these different tissues. Siliceous concretions, such as those from the Conasauga Formation of Georgia and Alabama, show, among other things, excellent three-dimensional morphology of articulated hexactinellid sponges.

Concretions from Cambrian Lagerstätten can reveal interesting paleoecological relationships, and some links to taphonomy. Experimental evidence and SEM analyses suggest that the concretions formed within days from when the ancient organisms became sedimentary particles. The size and shape of the small concretions were determined by the configurations of biofilm 'decay halos' surrounding organic remains.

RECENT ECOMORPHOLOGICAL SELECTIVITY OF NORTH AMERICAN CANID EXTINCTION

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Modern mammal ecosystems are bottom-heavy and depauperate of apex predators. Most regions except Africa harbor few coexisting large carnivores; extant North American communities include at most two, the gray wolf and mountain lion. This current paucity of large predators—and the threatened conservation status of many of them—might suggest that the demands of large body size and carnivory make diverse predator assemblages unsustainable. To resolve the roles of intrinsic risk and extrinsic drivers in the survival of large predators, and to provide deep context to the extinction dynamics of large predators, I use the fossil record of North American canids (Mammalia: Carnivora: Canidae), which preserves a long history of large-bodied mammalian carnivores and bone-crackers.

How typical is the extant predator assemblage compared to paleontological baselines? Previous work has shown repeatedly that late Pleistocene predator guilds were exceptionally diverse compared to today, with North American ecosystems including as many as four more species: the extinct dire wolf and three large cats. Analysis of the North American canid record further shows that this high predator diversity was the rule rather than the exception over the last 40 Ma. While most of the 132 examined canid species are small to medium-sized non-predators, a quarter of them have occupied the large-predator niche in continuous succession over the past 30 million years. Furthermore, many of these large predators bear no-analogue hypercarnivorous and bone-cracking ecomorphologies surpassing those of extant canids.

Have large predators been more prone to extinction than other ecomorphologies in deep time? Earlier studies have illustrated costs associated with carnivory that may aggregate over long timescales to impact extinction risk. However, comparing extinction victims and survivors over 17 time slices, I find no difference in body size and degree of carnivory between victims

and survivors for most of the past 40 Ma. Continuous diversification rates corroborate this result. While extinction rates for the two extinct canid subfamilies increase after the first appearance of lineages leading to large predators, extinction rates for large predators themselves are not significantly elevated over those for smaller non-predators across the three canid subfamilies. These dynamics persist until the end-Pleistocene 10,000 years ago: the lone time-point that records an ecomorphological difference between victims and survivors. At this time, three large canid predators became extinct or extirpated from North America and left behind a radiation of foxes, laying the foundation for the modern assemblage of largely mesocarnivorous canids.

Contrary to studies focusing on modern species alone, these results show minimal selectivity in canid extinction. Instead, unique external challenges at the end-Pleistocene likely have exacerbated the intrinsic risks of large predators.

MICROFOSSIL BASED RECONSTRUCTION OF PALEOCLIMATE AND PALEO-SEISMIC ACTIVITY IN A SOUTHERN CALIFORNIA COASTAL MARSH

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Microfossils are commonly used and widely applied in paleoenvironmental reconstructions of coastal settings because their surface assemblages accurately reflect the relative elevation of the marsh with respect to tidal level. In this research, pollen, benthic foraminifera, diatoms, grain size, and organic matter content from a 230-cm long-AMS dated piston core (Core SB-51B) were used to reconstruct paleoenvironmental changes and paleoclimatic evolution of the Seal Beach Wetland, southern California (USA), during the last ~ 2000 years. A Q-mode cluster analysis based on diatom and foraminiferal data revealed three distinct units: 1) the lowest sandy to silty-sand unit from 230 to 150 cm in depth (deposited earlier then 1761 Cal years. B.P.) is devoid of microfossils; 2) the intermediate unit between 150 to 52 cm (1761 and 391 Cal years. B.P.) is primarily composed of clay and dominated by brackish and brackish-marine diatoms and foraminifera; and 3) the uppermost unit from 52 cm to the surface (deposited after391 Cal years. B.P.) is enriched in clay and microfossils, particularly diatoms, which typify a high salt marsh environment. Unit 2 contains strata at 105 cm, 82 cm, and 75 cm with fresh-water and salt-tolerant diatoms indicating that fresh water flowed into the wetland. This may have come from the flooding of a nearby stream, which overflowed into the marsh. Pollen analysis of the core indicates a shift in the lower portion of the core from dominance by saltmarsh plant species to increased abundance of terrestrial plant species, probably from around the marsh. The *Artemisia*/Chenopodiaceae (A/C) ratio reflects both the shift to more terrestrial species during the record. In particular, pine pollen production increases upward suggesting mean cooler and wetter climate conditions during the last 300 years. These changes share similarities with other regional pollen records that shifted from drier conditions during the last 1,800 years to the cooler, more mesic conditions of the Little Ice Age. The analyzed sedimentary sequence reveals three seismic events during the late Holocene: E3, E2 that occurred before1761 cal. yrs. B.P. and E1 occurred prior to 391 cal. yrs. B.P. This research was indicated Late Holocene coastal paleoenvironmental changes related to paleoclimate variability and to paleo-seismic activities in Seal Beach Wetland.

DISCOVERIES IN THE SILURIAN OF INDIANA: FOUR DECADES OF COLLABORATION BETWEEN AVOCATIONAL AND PROFESSIONAL PALEONTOLOGISTS

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In 1979, amateur collectors from the Dry Dredgers fossil club discovered a huge assemblage of Silurian Age Massie Shale (formerly Osgood Shale) echinoderms in the New Point Stone commercial stone quarry near Napoleon, Indiana. The discovery was shared with Harrell Strimple (University of Iowa). We donated hundreds of echinoderm samples for study, and led him on field trips to the quarry. Thus began four decades of collaboration between avocational and professional paleontologists at this locality.

In our frequent collecting trips to the quarry every year, we have not only saved thousands of echinoderms from destruction by the quarrying operation, but also made other discoveries and observations. We are willing to share those specimens and our

knowledge of the quarry for further studies. The new specimens and findings have led to several additional studies done in collaboration with Professors Carlton Brett (University of Cincinnati), James Thomka (University of Akron), and Sarah Sheffield (University of South Florida). Examples of these new studies follow:
* Discovery of a large grouping of "cystoid" holdfasts on hard ground;

* Discovery and quantitative analysis of parasitic borings on echinoderm tests;

* Collection of echinoderm columnals for estimation of echinoderm population numbers;

* Donation of rare juvenile cystoid specimens for study of changes with growth;

* Depositional studies based on collected cystoid specimens;

* Identification of anemone trace (Conostichus) fossils from the Massie Shale.

Over the years, many oral presentations, posters, graduate theses, and peer-reviewed publications have arisen from the collaborations. And in a time when access to commercial quarries is problematic due to liability concerns, the close relationship that the avocational collectors have nurtured with the quarry personnel has allowed collection and study to proceed unhindered for forty years. That has led to other professional collaborations:

* Brassfield Limestone conodont studies with Dr. Mark Kleffner (Ohio State University at Lima);

* Brachiopod studies by Texas A&M University (Dr. Ethan Grossman);

* Field trip stop by professional paleontologists;

* Field trips by local university geology classes.

CONODONT BIOSTRATIGRAPHY AND $\delta^{13}C_{carb}$ CHEMOSTRATIGRAPHY OF THE GOLDEN BRASSFIELD OF INDIANA: A SUCCESSFUL COLLABORATIVE EFFORT WITH TWO MEMBERS OF THE DRY DREDGERS

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Golden Brassfield is an informal designation for the golden-colored unit disconformably overlying Ordovician strata in southeastern Indiana and north-central Kentucky. The thickest complete section of that unit is exposed in the Napoleon Quarry of the New Point Stone Co. at Batesville, Indiana. Although I had visited the quarry previously during conference field trips, I thought gaining access to the quarry and collecting samples from the quarry for a research project on the golden Brassfield would be facilitated by visiting with others who had a greater familiarity with the stratigraphical layout of the quarry and had an established rapport with the quarry owners. Two members of the Dry Dredgers, Tom Bantel and Don Bissett, turned out to be the ideal collaborators for the project. The research project began in 2015 when Stig Bergström, Parrish Gebhart, and I met Tom and Don at the quarry to collect samples for conodonts and $\delta^{13}C_{carb}$chemostratigraphy from a location in the quarry that exposed the thickest complete section of the golden Brassfield. Tom, Parrish, and I returned in 2016 to collect samples from a location in the quarrywhere a much thinner golden Brassfield was found to be superjacent to mounds of Ordovician strata interpreted as sea stacks. I was unable to collect as many samples as I had hoped during that visit, and due to a concern that the quarry operators might remove the section at that location before I could return again, Tom and Don collected numerous additional samples for the project and stored those samples in their garages until I was able to pick them up. Results from samples collected in 2015 and 2016 for $\delta^{13}C_{carb}$chemostratigraphy prompted a need for additional sampling for $\delta^{13}C_{carb}$chemostratigraphy at reduced intervals from the thickest complete section of the unit. I was unable to schedule a return visit to the quarry in 2017, but Tom and Don followed a list of instructions I provided them to collect the samples for that purpose. Tom helped Parrish and me to collect samples for conodontsfrom the upper part of the golden Brassfield in 2018. Tom also took numerous photographs of the sections collected all four years to document the research we were doing. At locations in the quarry where the formation overlies sea stacks, it is entirely within the middle Aeronian *Pranognathus tenuis* Zone. At locations lacking sea stacks, the golden Brassfield is thickest (3.0+ meters), and also within the *Pr. tenuis* Zone, except forthe uppermost portion, whichis within the early Telychian *Pterospathodus eopennatus* Superzone. $\delta^{13}C_{carb}$ values in the golden Brassfield vary between +1.30‰ to +2.40‰, typically less than +1.7‰ in the lower third and greater than +1.90‰ in most of the rest of the formation, although $\delta^{13}C_{carb}$ values in the uppermost 0.3 meters are typically less than +1.8‰.

CHIRONOMIDAE – AN UPDATED OVERVIEW OF THE PALAEOBIOLOGY AND GEOLOGICAL HISTORY OF NON-BITING MIDGES

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Our world seems to be dominated by the flying representatives of the group Insecta. This is at least true for terrestrial ecosystems and if we focus on the animal part of a biota. Among the myriads of representatives of Insecta, there are four groups that have been described as "hyperdiverse", also known as the "big four": Hymenoptera (sawflies, bees, wasps, ants), Coleoptera (beetles, weevils), Lepidoptera (butterflies, moths), and Diptera (midges, mosquitoes, flies). Within Diptera, a very diverse lineage is that of Chironomidae, the group of non-biting midges. More than 6200 formally described species are known in the extant fauna. Also, more than 400 species have additionally been described based on fossils. The oldest fossil representatives have been recorded form the upper Triassic. In younger deposits, especially in amber, non-biting midges occur in astonishing numbers.

Most modern non-biting midges possess aquatic larvae and are an important part of the freshwater fauna. This seems to have been similar in the past. We here review the fossil record of non-biting midges with an emphasis on recent findings in amber. This includes aspects of their developmental biology, survival of morphotypes and new unexpected forms. Given the importance of non-biting midges in the modern fauna these new finds increase our knowledge about a group that must have played an important ecological role in the past as well.

REACHING COMMUNITIES THROUGH COSPLAY: A STUDY IN PALEONTOLOGY AND POP CULTURE

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The Cosplay for Science Initiative is a science-communication project that uses cosplay, the practice of dressing up in costume as a popular fictional character, to help break down barriers between audiences and scientists, making science relatable and scientists approachable. An audience insecure about their knowledge in science may feel intimidated by the idea of speaking to a scientist, but that same audience jumps at the chance to ask questions about evolution to a Pokemon trainer, learn about extinct dire wolves from Game of Thrones characters, and discuss dinosaurs with a paleontologist from Jurassic Park. These pop culture characters and their worlds pull at an already established, deeply cherished connection in an audience with strong and often expansive knowledge about these pop culture worlds, which can be used to show connections to paleontology and other STEM fields in our world. A key component of Cosplay for Science is exposing audiences to educational content and natural history programming in spaces not traditionally associated with learning, such as comic book conventions, social media posts, blogs, and podcasts. Through these new experiences, the initiative can better explore learning and develop best practices for informal science communication. Opening a conversation about science starting with pop culture, rather than a scientific topic that an audience perceives as too complex allows for engaging conversation with communities that might not otherwise find the opportunity to delve deep into STEM topics. The Cosplay for Science initiative sparks interest in paleontology and STEM fields by connecting science not just to an audience secure in their knowledge of science, but to any audience with access to movies, TV, and popular culture.

MODERN EXPERIMENTS AND FOSSIL PERSPECTIVES: THE EFFECTS OF OCEAN ACIDIFICATION ON TWO GASTROPODS

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The integration of fossil and modern data has become an increasingly recognized tool for conservationists faced with the implications of human-induced climate change. In particular, modern taxa with extensive fossil records may be of interest to conservationists. Ocean acidification (OA) is known to have negative effects on calcifying organisms, but our understanding of the relationship between organismal and ecosystem effects (e.g., changes to predator-prey interactions) is limited. The fossil record provides a natural laboratory for exploring how OA has and could affect predator-prey relationships through time. Here, we conduct a modern experiment to determine

the effects of OA on the growth and shell-strength of two species of gastropods; the long-term intention is to use the results as a baseline for examination of OA on the lineages of these two gastropods through time.

Two species of common northeast Pacific intertidal gastropods, *Tegula funebralis* (the black turban snail), and *Nucella ostrina* (the striped dogwhelk) were selected because of their long fossil records (the genus *Tegula* first appears in the Jurassic, *Nucella* in the Miocene), the fact that they live in the same environments and have the same shell-crushing predators (crabs), yet have different trophic roles and distinct shell composition/structure. *T. funebralis* is an herbivore with a globose shell made of nacre (aragonite) and a periostracum, whereas *N. ostrina* is a barnacle/mussel driller with a more elongate shell that has an outer layer of homogenous calcite and an inner layer of cross-lamellar aragonite. Before examining these species' fossil records relative to OA, it is essential to establish their modern responses. The two species were experimentally exposed to decreased seawater pH and predation cues. Juveniles of both species were kept for 185 days under one of the following treatments: 1) ambient pH, no cue, 2) ambient pH, predation cue, 3) low pH, no cue, and 4) low pH, predation cue ($n = 40$ per treatment). Measurements of shell growth and strength were used as a proxy for resistance to shell-crushing predation.

T. funebralis was severely impacted by pH, with shell growth decreasing by 83% ($p < 0.001$), and shell strength, regardless of size, reduced by 50% ($p < 0.001$) in low pH treatments. In contrast, shell growth of *N. ostrina* was unaffected by pH. However, low pH exposed shells of *N. ostrina* were still 10% weaker than control specimens ($p = 0.012$), indicating that shell integrity can be compromised by OA, even if growth is unaffected. Overall, our results indicate that both species will be negatively affected by OA, potentially leading to shifts in trophic balances between predators and prey in this system. Potential differences among species in responses to OA must be considered when examining fossil lineages. Such baselines can be integrated with fossil data to examine and better predict the effects of environmental change on these organisms and their ecosystems.

ANTS OF CAMBAY AMBER ILLUMINATE BIOGEOGRAPHIC AFFINITIES OF EARLY CENOZOIC INDIA

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As ubiquitous members of most terrestrial environments worldwide, ants provide a high-resolution window into post-Mesozoic biogeographic patterns. Many extant ant lineages are narrowly distributed and well defined. In addition, the nearly 700 described Cenozoic fossil species which span over 50 deposits allow for better estimations of lineage-specific shifts in distributions over time. Representing over 10% of all arthropod inclusions, fossil ants preserved in early Eocene "Cambay" amber offer insight into the biogeographic history of the Indian subcontinent more specifically. Formed prior to the Paleocene Eocene Thermal Maximum and during putative age ranges for collision with Asia, Cambay amber is a window into a clearly dynamic time for the fauna of the Indian subcontinent. A collection of over two hundred Cambay amber ant specimens prompts comparison with other contemporaneous fossil insect deposits in Europe and Asia. Remarkably, many Cambay ants fall within well-characterized extant genera and thus can be linked with the present-day distributions of their modern congeners. The high-fidelity preservation of fossil amber, along with access to imaging technologies such as X-ray based microCT-scanning and laser confocal microscopy further improves our ability to link the ants of Cambay amber with our understanding of modern and fossil distributions. Results demonstrate instances of stasis among Early Eocene and modern Indian fauna, along with ancient long-distance dispersals. Moreover, we find significant extinctions in some lineages, underscoring the dynamic nature of the Indian subcontinent throughout the Cenozoic.

BONE HISTOLOGY REVEALS HIGH INDIVIDUAL VARIATION IN GROWTH AMONG A POPULATION OF EARLY DINOSAURS

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Developmental plasticity is exemplified by a high degree of body size variation within a given age class. It is traditionally considered a hallmark of ectothermy among extant reptiles, but is not common among birds with highly-canalized development and single-year maturation. This suggests that a reduction of plasticity may be associated with a metabolic transition to endothermy and/or rapid maturation. However, it is hard to assess developmental plasticity in fossil taxa, owing to a lack of specimens. An exceptional case is the

*Coelophysis*bone bed from the Upper Triassic (~200 Ma) Chinle Formation at Ghost Ranch, New Mexico. This bone bed preserves hundreds of individuals of the early-diverging theropod dinosaur *Coelophysis bauri* representingmultiple body size classes and ontogenetic stages, thought to have died nearly synchronously.

To assess individual variation in bone microstructure and determine the age distribution of this population, we conducted one of the largest single-element histological studies of a theropod dinosaur to date. Twenty-one tibiae and 15 adhering fibulae were thin-sectioned and surveyed for annual growth marks and histological indicators of growth rate and relative age, such as bone fiber type, vascular arrangement, and degree of remodeling.

All *Coelophysis*age classes show fairly uniform woven to parallel fibered bone and longitudinal to reticular vascular canals within primary osteons. Growth marks reveal that the sampled specimens span a range of less than a year to at least four years of age. None exhibit an external fundamental system (closely spaced growth lines in the outer cortex indicating greatly slowed growth at somatic maturity). Therefore, none of the *Coelophysis*specimens were somatically mature at death. This suggests, as has been found in other dinosaurs, that the population distribution was right-skewed, with young individuals predominating. Size (based on long bone dimensions) and age (based on growth mark count) are poorly correlated among Ghost Ranch *Coelophysis*. The presence of relatively small older individuals and relatively large younger individuals in a single population is typical of extant reptiles, but not most birds. The presence of rapidly growing bone tissue together with a relatively high degree of individual variation in growth suggests that growth rate and developmental plasticity were decoupled during early dinosaur evolution.

Graphing the age and size data against maturity scores derived from external morphological indicators (e.g., muscle scars, bony fusions) further reveals that these three commonly utilized proxies for ontogenetic age are poorly correlated. Relative ages derived from body size and skeletal morphology do not always match numerical ages derived from bone histology. Therefore, any hypothesized body size or external morphological indicator of ontogenetic stage for early dinosaurs and their relatives should be tested with bone histology before being widely applied.

FOSSIL FUTURE AND SUSTAINABILITY: MYFOSSIL EMUSEUM AND MOBILE APP

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Part 4 of the FOSSIL Project symposium describes the future plans for sustaining a community driven platform and how the introduction of a mobile app has altered the community.

The future of the FOSSIL project contains two primary aspects: the eMuseum and mobile app. The vision for the eMuseum is to promote and facilitate public participation in scientific research through allowing personal fossil specimens to become vouchered museum specimens publicly available through data aggregators. In order to do this we have developed a workflow with three volunteer assistant curators with two-year terms to aid in curation of site specimens. The curation team will evaluate data associated with specimen occurrences and identify research grade specimens. This allows for fossil uploads to be elevated to research quality material and ensures the content of the eMuseum contains credible fossil material. The high quality data will be ingested by iDigBio and will be available for researcher across the globe to access the information. This team will also facilitate digital rotating exhibits containing specimens on the myFOSSIL eMuseum portal.

The myFOSSIL mobile app, an extension of the myFOSSIL website, was first developed in 2018 as a partnership between researchers at the Florida Museum, University of Florida, and a private software development firm, Atmosphere Apps. The primary goals of this App were to: (1) engage a younger, more diverse demographic with the science of paleontology (2) generate valuable paleontological data in order to contribute to scientific research (3) make the practice of science more accessible. This mobile app affords users the ability to rapidly document fossil discoveries as well as connect and converse with others about paleontological finds, methods, and activities. Through iterative design, the myFOSSIL team has been soliciting input from the community through user testing, focus groups, and community feedback in order to improve the myFOSSIL app's capacity for achieving its design

goals. Since its launch, over 300 individuals have begun using the App and the activity on myFOSSIL has dramatically shifted towards this mobile platform. The App has also influenced how individuals participate in the myFOSSIL community, as demonstrated by the change in assortment of images being uploaded to myFOSSIL.

The subsequent panel discussion will involve the assistant curators and another active member of the myFOSSIL community. The goal will be to discuss previous challenges, how we will work to overcome them, and where they hope the platform will be in the coming years.

PALEOECOLOGY AND PALEOBIOGEOGRAPHY OF EUBLASTOIDEA (BLASTOZOA: ECHINODERMATA)

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The paleobiogeographic patterns of Paleozoic echinoderms have been assessed by both time periods and taxonomic groups on several occasions over the last fifty years. Many of these analyses were descriptive rather than quantitative, but provided the baseline data to begin exploring biogeographic patterns in more detail. I am particularly interested in examining the biogeography of a long-lived Paleozoic clade: the Eublastoidea. The eublastoids are temporally expansive, ranging from the middle Silurian to the end Permian. Eublastoids have been found on nearly every continent and they inhabited a variety of paleoenvironments. These factors make Eublastoidea an excellent model clade to begin examining macroevolutionary patterns and drivers of dispersal and speciation in the Paleozoic.

The long temporal range of this group spans several major climate shifts from the Devonian to the late Carbonifierous. The Devonian was marked by a warm global climate with associated high sea levels, whereas the Carboniferous is characterized by glaciation events and global sea level regression. Species have been described from a range of lithologies, indicating varied potential environmental conditions including: low energy microbial mud mounds in the Devonian to high-energy carbonate platforms of the Mississippian. Recently, I examined this lithological information of eublastoid-bearing localities in the context of the evolutionary patterns of these organisms and few to no discernable patterns arose. These results indicate that variation in inhabited environments and sedimentology may not be evolutionarily driven.

In order to further explore the patterns and processes of dispersal and speciation within the eublastoids further, I have added a biogeographical component to this study. I used data culled from the literature on the geographic and stratigraphic ranges of species represented in an inferred phylogenetic hypothesis of eublastoids. Species geographic and temporal occurrence data was used in the R package BioGeoBEARS to assess biogeographic patterns in the Eublastoidea. This summary provides an updated paleobiogeographic history of the eublastoids and allows for comparison to paleobiogeographic patterns of other Paleozoic blastozoan groups. These data will shed light into the drivers of connectivity, dispersal, and speciation within the blastozoans across major climate events during the Paleozoic and future work will include a comparison to published geochemical records to elucidate biotic responses to specific recorded events in the geologic record.

PROMOTING VISIBILITY AND PARTICIPATION OF DIVERSE SCIENTISTS THROUGH A DIGITAL SCIENCE COMMUNICATION PLATFORM

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Time Scavengers is an educational blog that aims to provide easy-to-digest scientific content surrounding climate change and evolution through the lens of deep time. Time Scavengers is curated by two main site developers (JEB and ARL) and maintained by many other collaborators, including two avocational paleontologists, an educator, and an editor. Through monthly features we promote and highlight diverse scientists and their research, outreach activities, and journey through science. A topic of interest in the informal learning research community is STEM or science identity, broadly meaning, how an individual sees themselves fitting into a specific role in a given situation. Someone with a strong science identity may influence decisions into the future, even if this individual is not a professional scientist. To aid in increasing visibility of scientists, Time Scavengers showcases diverse scientists and science, to ensure our community understands that anyone, regardless of background, identity, etc. can become a successful scientist. These scientists are featured through our 'Meet the Scientist blog', with a new person highlighted every other week. To date, we have featured over 49

individuals: 16 identified as students, 15 faculty, 10 other professionals (e.g., museum staff or sciences and postdoctoral associates), 5 avocational scientists, 1 National Park Service park interpreter, 1 project engineer, and 1 archaeologist.

More recently, we worked to encourage and support a young avocational paleontologist and Time Scavengers collaborator, Cam Muskelly, to attend and present at the Southeastern Geological Society of America meeting in Charleston, South Carolina. Cam is a strong advocate for paleontology education online and in his communities in Georgia. He is still uncovering his path to becoming a professional paleontologist, thus him engaging and networking with professionals in a formal setting is essential to his career development. Through crowdsourced funding on social media platforms, we were able to provide a fully funded experience for Cam. Cam presented on using hashtags for gaining community engagement on social media. This was Cam's first academic conference and an excellent networking opportunity. Into the future, Time Scavengers will continue our efforts to help individuals participate in local and national conference to engage with their science community and broaden participation of underrepresented groups in science.

IT'S ABOUT TIME! PALEONTOLOGICAL CONTRIBUTIONS TO UNDERSTANDING TERRESTRIAL COMMUNITY ECOLOGY

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Systems paleoecology looks for emergent properties in ancient communities, such as the persistence of different life modes and the resilience of diversity to environmental perturbations. Datasets for exploring community ecology through geological time depend on samples of fossil organisms that represent paleocommunities. In ecology, a community is an interacting assembly of species in one place and time (alpha diversity) but includes ongoing dispersal from the surrounding metacommunity. In paleoecology, where it is often impossible to sample ecological time scales, communities are defined by the constraints of preservation and represent a wide range of temporal scales. Paleoecologists now understand many taphonomic processes and sampling biases and can better calibrate temporal scales represented in different types of paleocommunity samples. Meanwhile, ecologists realize the importance of historical contingency and are compiling evidence for community change over decades to centuries. Although the temporal scales of paleoecological and ecological samples usually differ, recent emphasis on metacommunities in both fields provides a common basis for investigating community structure and dynamics. The fossil record offers samples from temporal scales otherwise unavailable because of two unique properties of the fossil record: taphonomic time-averaging, e.g., over 10^2-10^4 years, within restricted locales (taxon lists from specific sites) that captures metacommunity species richness (alpha and beta diversity), and analytical time-averaging of multiple assemblages from longer time intervals, which provides larger scale censuses (beta and gamma diversity). Fossil assemblages thus represent metacommunity "censuses" across time that can record long-term associations between taxa and environments and interactions between taxa (e.g., habitat filtering, competitive exclusion). Examples of recent insights from analysis of paleocommunity samples include: 1) the proportion of significantly aggregated pairs of species in communities remained stable for 300 million years and then shifted to a new state around 6000 years ago when significantly segregated species became dominant, 2) biotic interactions in Late Pleistocene-Holocene North American mammal communities were lost as a result of size-biased extinctions, 3) Late Pleistocene biotic homogenization of North American mammal communities began before modern anthropogenic impacts, 4) habitat filtering in palynofloras decreased significantly across the K-Pg extinction, suggesting that biotic interactions or other factors were important in the early recovery phase of those floral communities. Although modern ecological thinking has been slow to incorporate fossil data, our research indicates that community-based analyses of paleontological data can synergize new multi-scale understanding of past and future terrestrial communities.

PATH ANALYSES OF FAUNAL CHANGE: DECONVOLVING ENVIRONMENTAL DRIVERS OF BENTHIC FORAMINIFERAL COMMUNITY CHANGE TO DEMONSTRATE SIMILARITIES AT INTERMEDIATE AND ABYSSAL DEPTHS IN THE PLEISTOCENE GULF OF ALASKA

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Multiple environmental factors simultaneously affect communities of organisms, which can confound our ability to use them as proxies for past environmental change and to determine the primary controls of past faunal changes. Covariation between environmental variables and mediating effects among sets of variables makes it additionally difficult to identify the drivers of faunal change. Structural equation modeling, or path analysis, however, allows us to account for hypothesized directions of cause and effect between variables and the interactions among variables and, thus, more confidently attribute faunal changes to environmental drivers.

Here we test whether the environmental drivers of changes in the composition of benthic foraminiferal communities are consistent between two ~50,000 year sedimentary records from the Gulf of Alaska at ~200 year resolution. Site U1419/EW0408-85JC is located at 692 m water depth within the upper oxygen minimum zone (OMZ) and is influenced by changes in North Pacific Intermediate Water; previous work has shown geochemical and faunal evidence of OMZ intensification during the last deglacial at this site. Site U1418/EW0408-87JC is at 3667 m water depth, well below the extent of the modern OMZ, and is bathed in Pacific Deep Water. Each faunal sample has accompanying geochemical proxies that partially reconstruct oceanographic variables including surface productivity, organic carbon remineralization, and sedimentary oxygenation ($\delta^{18}O$ and $\delta^{13}C$ of planktonic and benthic foraminifera, redox sensitive metals).

We find that faunas at both sites are primarily and directly associated with changes in redox sensitive elements during the last deglacial despite site differences. However, preliminary results suggest changes in primary production and carbon export were most closely associated with low-oxygen conditions at the deep site whereas changes in proxies related to temperature were more associated with redox changes at the shallow site. We further find that the timeframe of examination can affect perceived drivers of changes in overall faunal composition as different oceanographic processes operate at different time scales and are dominant processes at different time intervals. Despite differences in the primary drivers of overall faunal composition, changes in the relative abundance of species typically used as indices for low-oxygen environments and for seasonal fluxes of phytodetritus remain related to the expected geochemical proxies after accounting for the interactions between environmental variables.

THE GNATALIE QUARRY: TEN YEARS OF OUTREACH AND EDUCATION AT A DINOSAUR QUARRY ON PUBLIC LANDS

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Discovered in 2008 during an expedition led by the Natural History Museum of Los Angeles County (NHMLA), the Gnatalie Quarry is a multitaxic bonebed in the Upper Jurassic Morrison Formation on Bureau of Land Management (BLM) land in southeastern Utah. Since its discovery, the NHMLA has worked with the BLM to excavate the site in a manner that provides educational opportunities for undergraduate and graduate students, educators, and museum personnel as well as facilitating international research collaborations and public outreach through both the museum's community in Los Angeles and local communities in Utah. The Gnatalie Quarry has served as the centerpiece of experiential learning programs targeting underserved undergraduate students from the Los Angeles area, many of whom have gone on to graduate studies or careers in Earth Sciences. The NHMLA has also developed field learning opportunities for education professionals at the museum, providing valuable first-hand experiences to volunteers, gallery interpreters, and education program developers who interact with many of the museum's 1.3 million annual guests either directly or through the NHMLA's Dino Lab, a fossil conservation public viewing laboratory. The Gnatalie Quarry is unique among the museum's field sites in being easily accessed, thus presenting opportunities for people who might not be able to participate in physically demanding field work, enabling them to experience field paleontology firsthand. Novel programs are currently being developed with the newly-created Bears Ears Education Center (Bluff, UT) to provide local community outreach in southeastern Utah. Given the recent controversy over Bears Ears National Monument, which is just to the west of the Gnatalie Quarry, the NHMLA feels public education regarding the significance of paleontological resources in the area is especially important. Through multiple programs over the past decade, the NHMLA's work at the Gnatalie Quarry serves as an example of how paleontological field research programs can work in concert with public land management to maximize

opportunities for education and outreach at a variety of scales.

COMMUNITY CHANGES IN SHALLOW BENTHIC INVERTEBRATE ECOLOGY IN THE EARLY DANIAN

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The study of mass extinction events contributes finer understanding of ecosystems and their potential responses to extreme stresses, and is therefore applicable to today's global biotic crisis brought on by anthropogenic climate change. The Cretaceous-Paleogene (K/Pg) mass extinction event, roughly 66 million year ago, is a well-known time of taxonomic and ecological change for both terrestrial and marine communities.

Two great disturbances to the Earth System at the time of the K/Pg are documented in the geologic record. The first is intense volcanic outgassing from the Deccan Traps, in present day India, which may have produced global warming, sluggish ocean circulation, and anoxia in a similar manner to the Siberian Traps and CAMP flood basalts at the end-Permian and end-Triassic mass extinctions, respectively. The second event is the impact of a ~10km extraterrestrial bolide 66 million years ago which lead to a dust-filled atmosphere that blocked sunlight, likely reducing primary productivity and possibly resulting in biotic collapse at all trophic levels. The role of these two events as kill mechanisms is still debated, but they are hypothesized to cause different patterns in extinction, recovery rates, and ecology of surviving communities. Previous studies of benthic macroinvertebrates immediately after the K/Pg boundary have shown preferential survival based on ecospace occupation, including consistent shifts towards a higher proportional abundance of detritivores over suspension feeders. This study examined longer-term patterns of ecological changes throughout the recovery interval to allow a better understanding of ocean conditions; and demonstrating the rates of these changes.

To refine this interpretation bulk samples of shallow-shelf marine invertebrates were collected from the early Danian (2 My) of the Darting Minnow K/Pg boundary section in Texas. Analysis of taxonomic richness and abundance was used to examine turnover in recovery communities. For each sample, the number of specimens in each taxonomic family is tallied and assigned an ecological life-mode (feeding, motility, and position relative to the substrate) for a comparison of proportional abundance changes throughout the recovery interval.

Changes in benthic macroinvertebrate assemblages after mass extinction events also commonly include reduction in body size of surviving organisms, regardless of the extinction mechanism. Shell volume was approximated using a combination of length, width, and height for complete fossils in order to assess changes in average and maximum body size for each family and fossil assemblage through the section.

A MULTIPROXY CHRONOSTRATIGRAPHY FOR THE EARLY CAMBRIAN OF ANTARCTICA

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During the early Cambrian, South Australia and Antarctica were sutured together forming an integral part of East Gondwana. Lower Cambrian rocks of the Ross Fold Belt in the Transantarctic Mountains share abundant sedimentary and faunal similarities with Cambrian-aged deposits in Australia. Several studies have described lower Cambrian rocks from Antarctica and their shelly faunas, though most are from spot localities or allochthonous clasts. The arduous nature of collecting and sampling in Antarctica has precluded detailed systematic investigations, and understanding of the palaeontologic, stratigraphic and tectonic relationships of this key Cambrian terrane remains relatively poorly known as a consequence. In an effort to refine Antarctic early Cambrian chronostratigraphy and correlation, new work integrates shelly fossil and trilobite biostratigraphy, carbon isotope chemostratigraphy and lithologic data from several systematically logged stratigraphic sections through an authochthonous succession (oldest to youngest) including the upper Shackleton Limestone, Holyoake Formation, Starshot Formation and Douglas

Conglomerate. Results demonstrate close faunal links with South Australia, and shared fauna including the problematic *Cambroclavus absonus*, brachiopods such as*Schizopholis yorkensis* and a diverse mollusc assemblage suggest correlation with the new early Cambrian shelly fossil biostratigraphic scheme for South Australia. The shelly faunas equate, at least in part, with the *Dailyatia odyssei* Zone in South Australia (equivalent to Cambrian Stage 4), though the package of rocks may extend into younger intervals. Preliminary chemostratigraphic results capture the AECE interval which correlates well with faunal data. These data place lower Cambrian Antarctic successions into a robust chronostratigraphic context for the first time, and provide new information about the distribution of organisms that evolved during this critical phase of the Cambrian Explosion.

OXYGEN, TEMPERATURE, AND THE DEEP-MARINE STENOTHERMAL CRADLE OF ANIMAL EVOLUTION

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Ediacaran fossils document the early evolution of complex macroscopic life, contemporaneous with geochemical evidence for widespread marine anoxia. This suggests that early animals experienced frequent hypoxia. As such, research has focused on the concentration of molecular oxygen (O_2) required by early animals, while also considering the impacts of climate. One hypothesis is that the Ediacaran biota originated in cold, shallow-water environments due to increased O_2 solubility in such regions. Instead, the fossil record suggests the Ediacara biota first occur as early as 571 Ma in deep-water slope facies, before appearing in shelf environments ~555 Ma. We propose an ecophysiological underpinning for this pattern. Using respirometry physiology experiments, we show that in the shallow mixed layer where seasonal temperatures fluctuate widely, thermal and pO_2 effects are highly synergistic. The result is that temperature change away from species-specific optima impairs tolerance to low pO_2. We hypothesize that deep and particularly stenothermal environments in the Ediacaran ocean were a physiological refuge from the synergistic effects of temperature and low pO_2.

EXPLORING THE ROLE OF ECOPHYSIOLOGY AND METABOLISM IN GOVERNING MARINE LATITUDINAL BIODIVERSITY GRADIENTS DURING PAST ICEHOUSE AND GREENHOUSE CLIMATES

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In modern icehouse oceans the unidirectional trend of increasing biodiversity from the poles to the equator is one of the most well-established biological patterns. Despite these empirical observations and the development of numerous explanatory evolutionary hypotheses, there remains little consensus regarding mechanistic drivers which can explain the underlying causes. This issue with yielding process from pattern has critical implications for understanding the geographic component of biodiversity loss in future global change scenarios. Of use perhaps is the study of deep-time latitudinal biodiversity gradients (LDGs). The marine paleontological record corroborates equatorial biodiversity peaks during past icehouse periods, consistent with thermodynamic hypotheses describing the relationship between ectotherm biodiversity and environmental temperature. Crucially however, emerging studies of fossil diversity data during greenhouse intervals in deep-time suggests a very different form of LDG, with diversity peaking instead in the mid-latitudes.

In this study we expand upon this work, analyzing the global record of Mollusca along continental shelves across multiple icehouse and greenhouse intervals using data from the modern and fossil records spanning the Cretaceous and Cenozoic. For each time interval, we combine existing marine and terrestrial proxies to reconstruct global temperature gradients and compare these against age-equivalent fossil occurrence data from the Paleobiology Database. Together, we assess the impact of paleo-latitude on marine diversity across various climate states. We find strong evidence reinforcing the positive relationship between temperature (and latitude), and diversity during other icehouse periods in the geological record. However, results from greenhouse periods indicate that this relationship is not universal, as diversity tends to sharply decrease at temperatures just slightly beyond those experienced in modern equatorial oceans. To explore this pattern, we apply a mechanistic framework which integrates the effects of temperature on aerobic requirements of invertebrates to determine metabolic viability of habitats during greenhouse climates. Our results suggest

that the aerobic habitat of mollusks may have critical thermal limitations at temperatures closely exceeding the present-day ocean, overcoming mechanisms which normally produce equatorial-peaking LDGs in the modern. These results therefore suggest that current hotspots of marine biodiversity in equatorial oceans (e.g. the coral triangle), may be an exception rather than a rule of marine habitats in deep-time, and are some of the most threatened by climate warming-events both in the past and into the future.

ANALYSIS OF BIOMARKERS FROM THE EDIACARA BIOTA FOSSILS: THE OLDEST CASE OF VENTRILOQUISM

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The emergence of modern animal phyla in the Cambrian was preluded by the appearance of large architecturally complex organisms, the Ediacara biota (571 to 539 Ma). These fossils might hold clues to the history of the animal lineage and the evolution of complex multicellular life on Earth. However, most of them have evaded taxonomic classification, with interpretations ranging from marine animals or giant single-celled protists to bacterial colonies and terrestrial lichens.

A technique of analysing biomarkers from individual fossils opens a new dimension in the study of the Ediacara biota. Instead of looking at their morphology, it allows to analyse remains of organic molecules of these enigmatic organisms. Biomarkers represent skeletons of biomolecules produced by living organisms; as different groups of organisms possess different lipids, biomarkers can be used to unravel their biological origins. Thus, based on morphology, Ediacaran fossils *Beltanelliformis* have been variably interpreted as bacterial colonies, planktonic algae, benthic algae, fungal colonies, jellyfish bodies, sponge-like animals and sedentary coral polyps. Biomarker analysis showed that *Beltanelliformis* contain abundant hopanes and long-chain *n*-alkanes with odd-over-even predominance, indicating that these fossils represent large spherical colonies of cyanobacteria similar to modern *Nostoc*. Biomarkers from the most iconic Ediacaran macrofossil *Dickinsonia,* along with two other dickinsoniid genera, *Andiva* and *Yorgia*, indicate that they were not lichens or giant protists, but in fact belong among the oldest animals preserved in the rock record.

The biomarker technique has yet broader applications than uncovering the biological origins of ancient organisms. In addition to membrane lipids, animals may contain molecules of what they have eaten. Using biomarkers, we were able to detect the presence of a gut in some of Ediacaran macroorganisms and distinguish the lipid composition of their last meal. Gut content analysis is one of the most powerful tools for deciphering trophic structure of ancient ecosystems and ecology of their members. Biomarkers provide a new dimension to these studies, allowing to analyse the gut content of ancient macroorganisms even when it is not fossilized.

SEDIMENT RHEOLOGY EXPLAINS THE EDIACARA BIOTA PRESERVATION

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The Ediacara biota (571-539 Ma) represents the oldest complex large organisms in the fossil record, providing a bridge between largely microbial ecosystems of the Precambrian and the animal dominated world of the Phanerozoic. However, the nature of most Ediacaran organisms remains unclear, not least due to their enigmatic non-actualistic preservation.

We show that Flinders-style fossilization of Ediacaran organisms was promoted by unusually prolonged conservation of organic matter, coupled with differences in rheological behaviour of the over- and underlying sediments. In contrast to accepted models, cementation of overlying sand was not critical for fossil preservation, which is supported by the absence of cement in unweathered, unmetamorphosed White Sea specimens and observations of soft sediment deformation in both White Sea and South Australian specimens. This model has been confirmed by laboratory simulations, which produced Ediacaran-like negative hyporelief impressions at the base of sand layers.

The rheological model implies that Ediacaran fossils do not necessarily reflect the external shape of the organism. In many cases, the impressions repeat the morphology of a soft external or internal organic

'skeleton'. This mechanism provides new constraints on biological interpretations of the Ediacara biota.

THE PERMO-TRIASSIC MASS EXTINCTION ON LAND: A REVIEW OF KAROO BASIN STUDIES

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The Permo-Triassic Mass Extinction, which occurred approximately 252 Ma, was the most catastrophic biotic crisis in Phanerozoic history. It affected both marine and terrestrial ecosystems, substantially changing global community structure in a series of phases. Much research has been conducted on the marine strata recording this event, but its terrestrial record has not been as extensively studied due to the perceived lack of complete non-marine Permo-Triassic sequences. However, the past three decades have seen the discovery of several complete terrestrial Permo-Triassic boundary (PTB) sequences around the world, especially within the Karoo Basin of South Africa. Studies on the Karoo Basin have identified the Permo-Triassic boundary interval based on sedimentological, biostratigraphical and geochemical data and associated it with increasing aridity, floral and faunal turnovers, and increased temperatures. Examination of the vertebrate turnover reveals a complex pattern of extinction/origination events, with most of the large herbivorous parareptiles and dicynodonts and their attendant carnivores disappearing during the main extinction phase followed by the appearance of mostly insectivorous theriodont therapsids and the dominance of the herbivorous dicynodont species *Lystrosaurus declivis* and *L. murrayi*. A Lilliput effect appears to have taken place with decreased body sizes in most Early Triassic taxa compared to their Permian counterparts, even in the few boundary-crossing taxa. Life history changes across the boundary include truncated development and shortened life expectancies that in conjunction with high mortality rates led to an earlier onset of reproduction in many Early Triassic taxa. However, several recent studies have argued against the current placement of the PTB in South Africa, especially the associated aridification and faunal turnover. These studies have questioned the synchroneity of the main extinction event between the marine and terrestrial realms. New sedimentological, biostratigraphical and geochemical data on a recently rediscovered terrestrial PTB site in the Karoo Basin provide insight into South Africa's PTB debate and address the issue of whether the boundary sequences in the Karoo Basin record the cataclysm itself, or merely the prelude to the major event.

BIOSEDIMENTOLOGY OF THE EARLY TRIASSIC

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A major aspect of biosedimentology focuses on biological processes that produce sedimentary structures and fabric. In marine environments this includes reefs as well as microbial structures and bioturbation. Mass extinctions exert a profound influence on biosedimentological processes. That mass extinctions are defined by their effect upon metazoans implies they can have a strong affect upon reefs and bioturbation. The marine microbial record has been documented through the sedimentary structures which they produce, such as stromatolites in carbonates and wrinkle structures in siliciclastics. Marine environmental processes that cause mass extinctions and thus affect biosedimentology include changes in seawater temperature, carbonate chemistry and oxygen content. Changes in marine bioturbation due to mass extinctions are more likely caused by the negative affects of environmental changes that restrict bioturbators than extinction of bioturbators. Mass extinction processes that restrict marine bioturbators can affect development of the surface mixed layer and thus lead to changes in biogeochemical cycling. If there are changes in normal marine carbonate microbialites as well as siliciclastic wrinkle structures, then biosedimentological changes for a particular mass extinction are not just due to changes in ocean carbonate chemistry. Biosedimentological processes are much less well-known in terrestrial environments. However, in terrestrial environments changes affecting microbial features and bioturbation are commonly the greatest biosedimentological outcome of mass extinctions. Early Triassic biosedimentological features due to the end-Permian mass extinction were caused by the environmental effects of a large igneous province. Biosedimentological changes in marine environments for microbial structures and bioturbation are extensive in the Early Triassic after the end-Permian mass extinction. For this mass extinction metazoan framework reefs were devastated, but the growing recognition of the presence of metazoans in Early Triassic microbial constructions has led to a more refined synthesis for this time. Intensive studies on biosedimentology of Early Triassic terrestrial environments are at the beginning phase. Reported evidence to date shows an

increase of wrinkle structures and related features in siliciclastic facies. Similarly, these early studies also indicate that terrestrial environments were less well bioturbated after the end-Permian mass extinction only to recover to pre-extinction levels by the Middle Triassic. Continued work on understanding how past episodes of environmental stress affected interacting biosedimentological processes in both marine and terrestrial environments will help to manage for future environmental change.

POPULATION DYNAMICS IN THE ANTARCTIC BENTHOS: INTER-ANNUAL FLUCTUATION OF FORAMINIFERAL, TUNICATE, AND SCALLOP ABUNDANCES IN EXPLORERS COVE, WESTERN MCMURDO SOUND

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To understand whether or how climate change will drive changes in Antarctic marine benthic ecosystems, one must first understand baseline population dynamics of the system. Species abundances may change seasonally, annually, or on decadal scales, for example, or due to rare cataclysmic events unrelated to a changing climate.

We used SCUBA to collect foraminiferan protists in Explorers Cove, McMurdo Sound in austral spring in 1986 to 2016. Our research involved the cell biology and molecular evolution of large (>1mm), early-evolving, agglutinated members of this assemblage, but during the course of this work we also charted changes in their populations from bulk surface sediment collection and semi-quantitative 0.25-m^2 to 1-m^2 quadrat sampling. We focused on two species of *Astrammina,* two species of *Crithionina*, *Notodendrodes hyalinosphaira*, larger calcareous species (*Pyrgo peruviana*, *Cornuspira* sp., *Glandulina* sp.), as well as *Gromia* cf. *oviformis*.

During the 1990s, we noted that relative species abundances fluctuated substantially on an inter-annual basis. For example, *Astrammina rara* was very abundant in 1990 (75.9% of the total assemblage), dipped in 1993 and 1994 (54.9% and 58.7%, respectively), and rebounded in 1998 and 1999 (65% and 67%). By contrast, *Astrammina triangularis* abundances were low in 1990 (0.3%), peaked in 1993 (18.3%) and declined to 6.5% of the total assemblage in 1998. During the 2000s, we began tracking numerical densities quantitatively by taking 7.4cm-diameter cores and wet-picking specimens recovered from the top cm of sediment. Similar fluctuations were observed in target species. Most notable was the rapid increase in a "silver saccamminid" species, first recognized at low abundance in 1998. In 2005 there were 412/m^2 and since that time their numbers have increased to become the dominant species in the area (186,732/m^2 in 2016).

Over our study period, we also noted changes in meio- and macrofauna. In particular, we noted a dramatic increase in the numerical density of small epifaunal and infaunal tunicates (360/m^2 in 2005 to 11,379 in 2016). We also observed a dramatic, qualitative reduction in the population of the Antarctic scallop *Adamussium colbecki* along the Explorers Cove ice wall, prompting us to examine the extent of their decrease by re-sampling the six stations reported by Stockton in 1982 using his methods. The results were surprising: The average scallop population had decreased 74%. Similar results were obtained in 2015 and 2016. Although the cause of the reduction remains unknown, we noted new recruits on the seafloor in 2016, indicating initial recovery from this event.

Clearly, the Antarctic benthos is anything but static. Standardized, long-term environmental monitoring is necessary to uncover changes attributable to climate change. Explorers cove, with its proximity to McMurdo Station and the Taylor Dry Valley LTER site, is a prime candidate for such an endeavor.

LILLIPUT IN THE LATE DEVONIAN: A POST HANGENBERG RECOVERY FAUNA FROM THE UPPERMOST CLEVELAND SHALE

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The Hangenberg extinction event was the last of several large extinction pulses through the end of the Devonian Period that contributed to a protracted interval of significant diversity loss and dramatic ecological turnover. A diminutive, pyritized fauna recognized in the immediate aftermath of this global extinction event is identified and described at two localities in northern Ohio, in the uppermost Cleveland shale. The moderately diverse fauna, while locally abundant, is geographically restricted and is dominated by brachiopods with less common bivalves and rare gastropods. Fossils are rarely greater than 1 cm along the greatest axis and preservation ranges from highly fragmented

to butterflied and some individuals with delicate spines preserved, and nearly all are pyritized. This recovery fauna is distinct from the well-established Bedford fauna in the overlying units in diversity, composition and size of individuals. Trace metal geochemistry indicates that conditions were not persistently anoxic at the time of deposition at these localities, and conspicuous burrows that are several cms in length and greater than 1mm in burrow diameter support oxic to fluctuating dysoxic conditions. The diminutive size of this fauna is recognized as an expression of the Lilliput Effect and is consistent with prolonged stress associated with the mass extinction event.

POLITICURUS AND RELATED GENERA OF HINTZECURINE TRILOBITES FROM THE LATE SKULLROCKIAN (TREMADOCIAN: EARLY ORDOVICIAN) OF WESTERN UTAH AND SOUTHEASTERN IDAHO

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Exceptionally well preserved silicified fossils from the Great Basin of the western United States provide an unusually detailed record of Laurentian trilobite diversity from the late Cambrian to the Middle Ordovician. The hintzecurine trilobite genus *Politicurus* Adrain et al., 2003, is currently represented in the literature only by its type species, *P. politus* (Ross, 1951). Undescribed material from the House Formation (Skullrockian: Tremadocian) of western Utah and the coeval Garden City Formation of southeastern Idaho includes at least five new species of *Politicurus* as well as one belonging to a new, closely related genus.

Members of *Politicurus* are large (sclerites are commonly greater than 1 cm in size) compared to other hintzecurines. Their sclerites are nearly, and sometimes completely, effaced. Cranidia bear a prominent posteriorly directed occipital spine and librigenae have long, curved genal spines. The thorax features a long axial spine on the sixth thoracic segment. These trilobites also have semicircular pygidia with a postermedian embayment visible only in posterior view. Variations in the robustness, length, direction, and curvature of genal and occipital spines, extent of tuberculate sculpturing, degree of vaulting of the cranidium, number of pygidial segments, and overall relative dimensions distinguish species of this genus. The unnamed new genus is more strongly dorsally tuberculate and lacks an occipital spine altogether, bearing instead an elongate, shelf-like occipital ring. It demonstrates a suite of characters intermediate between those of *Politicurus* and other hintzecurine genera such as *Ibexicurus*.

A preliminary cladistic analysis resulting in seven most parsimonious trees depicts the unnamed new genus, represented by a single species, as sister to *Politicurus*, united by subdued cranidial sculpture, a relatively flattened cranidium, and a relatively long pygidium with at least three axial rings. Four species of *Politicurus*, including *P. politus*, form a clade united by a relatively slender and long genal spine, and effaced pygidial axis. Ingroup relationships are here determined by morphology alone but are congruent with sampled stratiraphic order.

CHASING A MORE COMPLETE MAMMALIAN PHYLOGENETIC TREE: A PSEUDOEXTINCTION ANALYSIS

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Phylogenetic analyses of extant taxa are often based solely on molecular data without any contribution from morphological characters. Phylogenomic data sets have become increasingly common with the low cost of Next Generation Sequencing. However, morphological characters are the only data that are available for most fossil taxa, which comprise the vast majority of species that have lived on Earth. To incorporate the wealth of extinct species in phylogenetic analyses, it is therefore necessary to include a partition for morphological characters. Unfortunately, homology and homoplasy are often conflated in morphological cladistic analyses. It is therefore critically important to assess the reliability of morphology-based trees.

To investigate this problem, we employed molecular scaffolds for robustly supported molecular clades with the largest available mammalian morphological dataset from O'Leary et al. (2013). This data set is comprised of > 4500 characters for 46 extant species and includes at least one representative of every placental order. Individual species, orders, and superorders were sequentially treated as pseudoextinct in parsimony analyses by exempting them from the scaffold and recoding their soft morphological characters as missing. We then used Robinson-Foulds distances and qualitative assessments of topological shifts to evaluate the accuracy of phylogenetic analyses when these taxa were treated as pseudoextinct. Finally, successive reweighting of morphological characters was applied to access its value in recovering molecularly-supported

phylogenetic relationships.

Our results suggest that morphological characters can accurately place taxa in some situations. Thirty out of the 46 individual species retained their molecularly-supported topological placements based on osteological characters only. The other 16 species moved to a different position on the tree. When the 19 placental orders were sequentially treated as pseudoextinct only seven retained an interordinal placement that was consistent with the molecular scaffold. Three orders were also rendered polyphyletic in these analyses. Only one superorder (Xenarthra) was recovered as monophyletic when treated as pseudoextinct and no superorders maintained a topological position that was consistent with the molecular scaffold. We also examined the effect of reweighting characters on the phylogenetic placement of placental orders that moved to a different position of the tree when pseudoextinct. In some instances, these orders returned to their molecularly-supported positions with character reweighting. For example, Chiroptera was recovered as the sister group to other therian mammals without reweighting but returned to its molecularly-supported position inside of Laurasiatheria with character reweighting. These results suggest morphological cladistics analyses for fossil taxa can be improved with character reweighting and a molecular scaffold for extant taxa.

TAXONOMY, ECOLOGY, AND BIOCHRONOLOGICAL IMPLICATIONS OF BISON (ARTIODACTYLA, BOVIDAE) FROM THE LATE PLEISTOCENE OF HIDALGO AND PUEBLA, CENTRAL MEXICO

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The genus *Bison* is one of the index fossils that define the Rancholabrean North American Land Mammal Age. Fossil remains referable to this bovid have been reported from numerous Mexican localities, although in many instances their species identity is unknown. Recent paleontological information has shown that *Bison antiquus* (the ancient bison) was the most common and widespread species of bison in the country during the late Pleistocene, including areas in northern (Baja California), central (Estado de México, Jalisco, Puebla, San Luis Potosí, and Michoacán), and southern (Oaxaca) Mexico. An important collection of fossil remains belonging to bison has been recovered from fluvial-lacustrine sedimentary deposits that outcrop in southeastern Hidalgo and central Puebla, central Mexico. The sample consists of a skull fragment, a horn core fragment, a mandibular fragment, isolated teeth, several vertebrae, and a scapula. The size and morphology of the horn core fragment, as well as the width of the occipital condyles of the skull fragment (ca. 135 mm), are similar to those of the species *B. antiquus*. Parsimoniously, the associated dental and postcranial remains have been considered in the same species. Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotope analysis were performed on 11 tooth enamel samples from Hidalgo and one sample from Puebla. In the samples from Hidalgo, the $\delta^{13}C$ values range from – 7.18 ‰ to + 1.42 ‰ with an average value of – 3.58 ‰ [± 2.96 ‰ (SD)], whereas the $\delta^{18}O$ values range from – 5.76 ‰ to – 0.77 ‰ with an average value of – 4.07 ‰ [± 1.43‰ (SD)]. The $\delta^{13}C$ values of the samples from Hidalgo indicate a variable trophic regime consisting of C3 and C4 plants. On the other hand, the $\delta^{13}C$ value of – 0.05 ‰ in the sample from Puebla is related to a diet with emphasis for C4 plants. In both cases, the $\delta^{18}O$ values (ca. – 4 ‰) suggest that members of the ancient bison from Hidalgo and Puebla were able to roam open and/or closed habitats. The known biochronological range of *B. antiquus* is from 60 ka to 11.7 ka. Hence, the age of the considered localities from Hidalgo and Puebla should be not older than 60 ka. The presented record supplements the evidence of the ancient bison in the Mexican territory. It seems that was the common bison species in areas of central Mexico at the end of the Pleistocene. Furthermore, it is reported the first occurrence of *B. antiquus* from the state of Hidalgo.

DINOSAUR TRACKING WITH CITIZEN SCIENTISTS: DISCOVERY, DOCUMENTATION, AND STEWARDSHIP

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The well-known occurrences of dinosaur fossils in the Rocky Mountain West provide an excellent opportunity for the collaboration with and the development of citizen scientists. Federal mandates for the inventory, monitoring, and educational use of paleontological resources on public lands can often be difficult to accomplish due to the vast amount of public lands in the western United States and limited staff and resources. Collaborative efforts with federal

partners, the scientific community, and the general public can ensure that new discoveries, as well as existing resources, be managed, monitored, and preserved using scientific principles and expertise. To that end, associations between researchers, land managers, and the public are cultivated through a variety of avenues including volunteer and site stewardship programs. These opportunities allow eager volunteers with a diversity of backgrounds, talents, and capabilities to interact with academics and other members of the public at interpreted sites and on research projects. Paleontological research partnerships are effective means of inventorying and data gathering. These activities also increase the understanding and appreciation of fossil resources and the values of preservation and protection, while also fostering an awareness of the significance of paleontological resources on public lands.

As paleontological resources on Bureau of Land Management-administered lands belong to the American public, it is important to utilize a management approach that supports both the collection of fossils for scientific purposes, as well as ensuring the preservation and protection of in-situ resources, especially those interpreted to the public. Dinosaur tracksites in Wyoming (e.g., Red Gulch Dinosaur Tracksite) and Utah (e.g., Mill Canyon Dinosaur Tracksite and Moccasin Mountain Tracksite) have served as excellent venues for the use of citizen scientists over the years. At these sites, enthusiastic, trained, and motivated volunteers engage in a wide variety of activities. Their contributions range from paleontological resource discovery, cleaning, preparation, maintenance, and monitoring to documentation, data gathering, and mapping. Volunteers are encouraged to share the knowledge they acquire by leading interpretive tours and serving as site stewards. Data gathered by citizen scientists not only consists of traditional ichnological measuring, mapping, and surveying, but also includes utilizing state-of-the-art photogrammetric techniques to capture detailed 3D information. Data collected by volunteers of all ages can be used by BLM resource managers and scientists to track new discoveries, observe changes to sites, and bring an energy, enthusiasm, and unique perspective to the field of paleontology. Dinosaur paleontology provides for a unique synergy that combines the public's interest in science with the mandate to increase public awareness about the significance of paleontological resources.

REVISED UPPER ORDOVICIAN, CINCINNATIAN (UPPER KATIAN) SEQUENCE STRATIGRAPHY IN THE CINCINNATI ARCH: IMPLICATIONS FOR THE TEMPO AND PATTERNS OF BIOTIC CHANGE

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The Upper Ordovician(upper Katian) Cincinnatian strata of the Cincinnati Arch (OH, KY, IN) formed a criticalreference succession for the establishment of stratigraphic paleobiology. This succession was previously subdivided into six depositional sequences (C1 to C6). Recent documentation of previously unrecognized erosion surfaces and revised regional correlations have led to recognition of eight 3rd-order Cincinnatian sequences, designated C1 to C8, about 254th-order subdivisions.This high-resolution framework provides new insights into the timing and patterns of expression of bioevents. Incursions in the well known "Richmondian Invasion", occurred abruptly, with many of the invading taxa first appearing, locally in abundance, in the basal transgressive limestones of 4th-order sequence C5C (Clarksville Member of the Waynesville Formation), probably representing no more than a few thousand years. A second wave of new taxa, mainly of mollusks, occurs in the lower 1–2 m of C7A (Whitewater Formation). These two events account for much of the net change in the Richmondian invasion, suggesting that these were also unusual times in terms of climate, current patterns, or other conditions. Moreover, high-resolution correlations permit the assessment of gradients in constrained time slices that represent portions of small scale (4th order) systems tracts. For example, correlation of the basal transgressive limestones of the lowest portion of sequence C5C shows that most new taxa appeared in mid ramp settings, while both deeper ramp (offshore) and peritidal/lagoonal biofacies showed little change. Conversely, a few colonial coral taxa appear in shallow shelf/shoal settings prior to the main phase of the Richmondian invasion, in sequence C3. Purported earlier invasions of more offshore taxa in sequence C4 were actually epiboles, abortive, short term incursions followed by local extermination. Such epiboles are common throughout the Cincinnatian and form important stratigraphic markers. For

example, nearly all occurrences of the Richmondian brachiopods *Rhynchotrema dentatum* and *Retrosirostra carleyi* in the Arnheim Formation are restricted to just a few beds, typically representing less than a meter of section. Hence, the taxa involved were only successful for a geologically brief interval (10^2-10^4 years). These occurrences were not successful invasions, as the taxa involved do not become parts of persistent associations, although they do provide important insights into ecological processes. Similar epiboles occurred at other times during the Cincinnatian but comparative study reveals that they were more frequent in certain intervals. Based on the revised sequence stratigraphy we suggest that a majority of epiboles, as well as successful invasions, occurred during transgressions. This may be the result of expanding low sedimentation/turbidity, shallow water conditions that were conducive to temporary insurgence and proliferation of normally excluded taxa.

FROM 'WEIRD WONDERS' TO MOLECULAR METHODS – RESOLVING THE EARLY RADIATION OF ARTHROPODS

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New discoveries and approaches in the thirty years since the 1989 publication of Stephen Jay Gould's *Wonderful Life*, the book that put the Burgess Shale on a pedestal, have revolutionized how we view the Cambrian radiation. Gould offered his own interpretation of the Cambrian explosion, reflecting on the disparity of form – the 'weird wonders' – among Burgess Shale taxa. He recognized 'at least twenty unique designs of arthropods', the most diverse group in the fauna, in addition to the major arthropod clades represented today. Gould's hypothesis of maximum Cambrian disparity prompted others to test his ideas by generating character matrices and using them to analyse relationships and quantify morphological distances between taxa. The Cambrian database has increased substantially since. New arthropods have been discovered in Konservat-Lagerstätten that were already known (e.g., Chengjiang, Emu Bay Shale, Sirius Passet, Burgess Shale, Utah) and many new exceptionally preserved biotas (e.g., Marble Canyon, Kaili, Guanshan, Balang) have been found. New taxa have been reported: e.g., *Ayshaeia* and *Anomalocaris* are now embedded in a remarkable diversity of early Paleozoic lobopods and radiodontans, respectively. Younger Lagerstätten (Fezouata formations of Morocco, Herefordshire Lagerstätte of England, Hunsrück Slate of Germany) have informed our view of arthropod diversification. The opportunity provided by new discoveries has been enhanced by new approaches. Additional morphology is accessible through tomography and a fuller understanding of taphonomy and diagenesis allows anatomical features to be recognized through EDS elemental mapping. Phylogenetic analyses have become ever more sophisticated through Bayesian and other methods. Our understanding of the relationships of living forms has been revolutionized by molecular data which, together with fossils, provide molecular clock estimates for the origin of groups. The arthropods remain a key to understanding the nature of the Cambrian radiation but much remains to be discovered and interpreted.

EXTINCTION SELECTIVITY AND PALEOECOLOGICAL CHANGE ALONG AN ONSHORE-OFFSHORE GRADIENT IN THE LATE DEVONIAN APPALACHIAN BASIN

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The Frasnian-Famennian (F-F) extinction in the Late Devonian was one of Raup & Sepkoski's "Big 5" mass extinctions of the Phanerozoic. Consisting of two pulses, the Lower and Upper Kellwasser extinction events (LKW and UKW), the extinction is often linked with carbon cycle disruption, global cooling, and ocean dysoxia/anoxia. The F-F impacted numerous marine clades, including brachiopods, ammonoids, rugose and tabulate corals, and stromatoporoids. Upper Devonian strata exposed in present-day Pennsylvania and New York represent an onshore-offshore paleoenvironmental gradient spanning both extinction pulses. Our work in this field area indicates that the LKW was more severe than the UKW, with atrypid and strophomenid brachiopods affected most strongly. Here, we analyze changes in brachiopod species distributions along this onshore-offshore transect, patterns in extinction selectivity, and the immigration/origination of new species all resulting from the LKW. We collected bulk samples from the Wiscoy Formation (pre-LKW) and Canaseraga Formation (post-LKW) from localities in New York and north-central Pennsylvania. We identified ~8000 brachiopod fossils from each formation and assessed variation in species composition among samples using non-metric multidimensional scaling (NMDS). Extinctions occurred across the habitat gradient during the

LKW, and the extinct species (largely warm water taxa) were disproportionately replaced by productids. The taxonomic selectivity and broad environmental spread of the extinction, combined with the differential success of the productids in its aftermath, resulted in a dramatic faunal turnover. However, surviving species appear to have maintained their habitat preferences.

EPIFAUNAL ECOSYSTEM ENGINEERS CONTROL SHALLOW BENTHIC BIOTURBATION AND THE SEDIMENTARY RECORD UNDER MULTI-YEAR SEA ICE, MCMURDO SOUND, ANTARCTICA

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Antarctic benthic marine faunas in Explorers Cove (EC), western McMurdo Sound, inhabit shallow seafloor habitat characterized by absence of fast predatory crabs and fish, abundant medium sand substrate, and persistent sea ice that dampens water movement. Because sea ice of this area rarely melts, it thickens and accumulates wind-blown sediment, reducing light transmittance and diminishing growth and flux of sea ice algae to the seafloor under these quiet water conditions.

Sea ice algae is the main food source of the suspension-feeding scallop *Adamussium colbecki*, and though the limited organic matter in EC sediment (0.63%) is highly degraded, it is also important in the diet of the deposit-feeding ophiuroid *Ophionotus victoriae*. Diver observations and photos of seafloor transects indicate that *A. colbecki* and *O. victoriae* are the most abundant free-living epifaunal animals in EC and are frequently observed residing in centimeter-scale divots and body imprints of the seafloor microtopography. These two abundant organisms were observed under laboratory conditions using time-lapse photography to evaluate the styles and rates of bioturbation and the impact on sediment appearance. The animals were transported to McMurdo Station and established in aquaria with sediment from Explorers Cove prior to recording.

Scallops resuspended surface sediment with water jets generated by valve clapping, resulting in conical divots similar to those on the seafloor. Mean sediment displacement from divot formation was 48.4 cm^3 d^{-1} per scallop and 80-113 cm^3 m^{-2} d^{-1} for scallop population densities observed in EC. Ophiuroids bioturbated sediment by twisting and burying their discs with sweeping arm motion. Mean sediment disturbance per ophiuroid was 861 cm^3 d^{-1} and 97-113 cm^3 m^{-2} d^{-1} for EC ophuiroid population densities. Combined, these rates far exceed rates of sedimentation and reworking by physical processes.

Rapid bioturbation rates suggest the scallop and ophiuroid in EC control microtopography, sediment stability, pore water chemistry, and distribution of limited food resources, thus effectively controlling the ecosystem in EC under multi-year sea ice as ecosystem engineers. Use of food resource near the sediment-water interface removes it at depth, inhibiting infauna and precluding discrete biogenic structures. Flushing of near-surface pore water enhances high rate of carbonate dissolution, possibly stimulating bacterial growth to provide an additional food source. Concentration of settling fine sediment in divots allows for easy resuspension, reserving scallop energy. These diffuse bioturbation styles are consistent with massive structureless stratigraphy observed in EC sediment cores (~10 cm deep) despite paucity of infaunal animals, including burrowers and trace producers.

USING INSTAGRAM TO COMMUNICATE PALEOBIOLOGY AND THE HISTORY OF LIFE TO THE GENERAL PUBLIC

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Instagram (IG) is an image-based social media platform that in 2018 hit 1 billion users. Whilst the cult of celebrity and the duck-faced selfie are undoubtedly manifest, it is also true that a growing number of research scientists, early career researchers, science communicators and large scientific institutions are actively using this platform to promote and share science in engaging, relatively simple and effective ways. Palaeobiology, founded on the fossil record and the history of life, provides exquisitely preserved organisms (sometimes down to cellular level) that can be captured with increasingly sensitive imaging equipment, including 3D tomographic x-ray and synchrotron beamlines. These spectacular fossil images (and videos) provide a perfect means to educate, illuminate and fascinate the general public about the importance and relevance of fossils in resolving important questions related to evolutionary theory, ecology and paleoecology, behavior, taphonomy, biogeochemistry, biogeography, stratigraphy and a vast array of other interdisciplinary applications.

Since January 2015, in response to a wager with a colleague who thought that outreach on IG was "a waste of time" with no worthwhile outcome, I created my @palaeobiologist feed with the express aim of

taking IG followers on "educational journeys through deep time" to inform, inspire and educate the general public about the wonders of the fossil record and the importance of the history of life to our modern world. Whilst dinosaurs have clear appeal to the wider community, I wanted to focus on a much wider spectrum of the history of life, especially those fossil groups that are less well known, but provide interesting educational vignettes or stories that engage and fascinate the reader. In so doing, I have built an ever-growing group of followers (~ 25k) who enjoy learning about the pages of "archive earth" and interacting with me and other like-minded followers. This outreach stream has enabled me to advertise and promote my own (and colleagues) research to a much wider audience and even provided a means to contact, interact with and even recruit postgraduate students into paleobiological research. In this presentation I will outline some of my successful (and unsuccessful) strategies in posting about palaeontology on IG and recall some of the beneficial, detrimental and humorous outcomes of running an educational outreach page on social media.

INCREASING AMERICAN INDIANS PURSUING STEM CAREERS THROUGH PALEONTOLOGY AND CULTURE

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The multifaceted perspectives that underrepresented groups bring to STEM fields represent an untapped human resource that is staged to strengthen the capabilities and reach of scientific advancements in the United States (US) and beyond. The challenge of recruiting and retaining minority members, such as American Indians (AI) in STEM careers continues to confront the nation's academic community and society. One of the greatest barriers in developing a diverse STEM workforce is the paucity of employees who are people of color. A unique program at Oklahoma State University, Native Explorers (NE), is addressing the lack of AIs in this workforce through its partnerships with tribal nations, federal agencies, museums, and universities. The program provides opportunities in basic STEM research while connecting students of different ethnicities, sovereign nations, and rural-urban backgrounds across the US with one another and with the natural world. The program helps them envision their place in nature while absorbing concepts such as geologic time, evolution, extinction, human resilience, and environmental sustainability alongside their attendant social challenges. It also helps them validate their own cultures, histories, and traditional knowledge in society, and find ways to direct their passion to revitalize it and themselves to the benefit of all. According to past program participants, their joint effort after their field experiences often evokes creativity and previously unrealized passions (and thus social well-being and health) that have been described as "life-changing"; it invokes further networking, opens doors and educational possibilities that were previously considered beyond their reach.

The NE team is a diverse group of Native and non-Native STEM researchers and educators, public school administrators, and tribal education advocates, who are dedicated to training the next generation of AI STEM researchers and educators. By addressing the specific needs of AIs, the NE provides an important national model for wider application in promoting the success of AIs. The NE will continue to build on established relationships with educators, administrators, tribal leaders, and other AI leaders to expand its impact and student support through outreach to vital community-based colleges and universities. The NE will ensure an increase in the number of AI undergraduate and graduate students in STEM fields. Past participants are pursuing STEM careers and/or degrees at universities (public and private) across the United States. These young AI scientists will positively impact society through their rural communities across Oklahoma; as the project expands, other tribes, rural communities, and sectors of our society beyond Oklahoma could benefit similarly.

IS CLIMATE AN OVERLOOKED FACTOR IN MARINE ICHNOLOGY?

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In contrast to terrestrial ichnology, which has a much longer tradition of assessing climatic controls on trace-fossil distribution in paleosols, the potential role of climate as a controlling factor on marine trace fossils has not been thoroughly investigated. As a result, there has been a tendency to extrapolate models based on temperate, mid-latitude settings to high- and low-latitude settings. Early work proposed the existence of three climatic zones: (1) tropical and subtropical characterized by the presence of *Ophiomorpha*, also

including echinoid trace fossils and other ichnotaxa, (2) temperate with echinoid trace fossils and *Thalassinoides,* and (3) arctic dominated by molluscan and worm trace fossils. In addition to these broad trends, specific environments tend to display differences in patterns of bioturbation along the depositional regime in response to climatic conditions. For example, high-energy foreshores of high- to mid-latitude settings commonly host extremelly high density, monospecific occurrences of deep-tier biogenic structures (*Macaronichnus*) produced by ophellid polychaetes. However, recent research has documented the presence of these structures also in tropical settings affected by upwelling in both the modern and the fossil record. The upper intertidal zone of tidal flats usually displays high temperatures, long time of subaerial exposure and abnormal salinities, all these conditions being detrimental for the marine benthos. Therefore, the highest density and diversity of biogenic structures in tropical tidal flats is in the lower-intertidal zone, as shown by many Carboniferous trace-fossil assemblages of the American mid-continent. On the contrary, tidal flats from high-latitude settings tend to exhibit evidence of higher density and diversity of biogenic activity in the upper-intertidal zone. In addition, tidal flats subjected to regular winter freeze contain lower trace fossil diversity than their lower-latitude counterparts. Research on the ichnology of fjords is providing some insights on how marine organisms cope with stresses associated with high-latitude ecosystems. Some of these stressors include extreme salinity dilution, high rates of sedimentation, variable degree of substrate consolidation, oxygen depletion, high water turbidity, and intense storms. In addition, seasonal light restriction and floating ice masses contributing to ice-rafted debris are stressors in polar regions. Neoichnologic observations indicate substantial differences between fjords in the Canadian Arctic and those from more temperate regions (e.g. Baltic), with oxygen depletion becoming a limiting factor in the latter. Applying this knowledge to the fossil record is not without challenges, but integration of sedimentologic and ichnologic evidence to the study of late Paleozoic successions of Gondwana is providing valuable information to delineate trace-fossil distribution in ancient fjords and related high-latitude environments.

HOW ANCIENT DNA ALLOWED TWO DEAD DUCKS TO TELL THEIR TALE

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Here we describe how phylogeny reconstructions based on ancient DNA from recently extinct lineages can substantially inform our understanding of deeper time evolution. In this particular case we recovered full mitochondrial sequence from, *Chendytes lawi*, an extinct large flightless duck from California midden deposits but persisted until about 3000 years ago. We also similarly sampled museum material including the extinct Labrador duck which succumbed to market hunting in the 19th century. These data allow the generation of an improved true-duck phylogeny where the placement of these extinct lineages was informative. Although long thought to be a “sea duck”, *Chendytes*proved to be a deeply divergent sister to the dabbling ducks such as mallards, indicating the relatively recent departure of a deeply divergent presumptively relictual lineage in the face of early human predation. Such interesting relict lineages are often eliminated prior to Western scientific collecting and ancient DNA provides an efficient mechanism for reconstructing the nature of these lineages.

Placement of the Labrador duck was also informative as it proved to be sister to, Stellar’s eider, perhaps the rarest sea duck. This sister relationship may help clarify where Labrador ducks went to breed as they were never recovered in their breeding territory. This sister relationship may also it inform us about the potential perils that stellar's eider faces as both species appear to depend on breeding habitat controlled by permafrost.

Time tree reconstructions where the molecular phylogeny is informed by the duck fossil record allow divergence of Chendytes to be placed in the early Miocene. Perhaps more intriguingly the general duck tree resulting from the inclusion of these data suggests that duck diversification is associated with climate change. Non-migratory forest forms from Southern continents such as Africa appear to give rise seasonally vagile forms initially associated with the generation of open landscapes and variable monsoonal climates in the late Miocene. Further diversification appears associated with the evolution of migratory boreal forms in association with the development of polar biomes in the Pliocene and Pleistocene. Overall recovery of ancient DNA proves important as recently extinct forms are often deeper time relicts that are unusually informative relative to phylogeny reconstruction and paleo-environmental interpretation. Thus, ancient DNA applications significantly inform broader

reconstructions of group evolution based on fossil and modern data, in this case revealing responses to changing Tertiary climates.

CONSTRAINING THE AGE OF CALIFORNIAN PLIO-PLEISTOCENE FORMATIONS USING STRONTIUM ISOTOPE STRATIGRAPHY

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The late Pliocene warm period (3.5–2.5 mya) is heralded as one of the best analogues for modern climate change and offers a chance to examine the response of Earth systems to a similar warming as that predicted for the future. The fossiliferous San Diego Formation (San Diego, CA), Pico Formation (Valencia, CA), and Careaga Sandstone (Santa Maria, CA) of Southern California have all been proposed to be of late Pliocene Age. Further, the presence of warm, extralimital mollusks (currently distributed in tropical climates south of California) within these formations has been cited as evidence of warmer ocean currents in the Northeastern Pacific during the Pliocene than in the modern. However, none of these formations have been absolutely dated; their age assessment relies on the presence of marine fossils proposed to be indicative of Pliocene age, correlation with terrestrial mammal biochronology, and magnetostratigraphy. Here I use the marine strontium (Sr) record to determine whether these formations contain late Pliocene age molluscan assemblages that can be used to analyze the response of nearshore marine communities to late Pliocene warming and subsequent cooling thereafter. Strontium isotope stratigraphy relies on the presence of aragonitic or calcitic deposits, such as mollusk shells, which record seawater chemistry at the time of shell formation. I analyzed the $^{87}Sr/^{86}Sr$ of 40 well-preserved aragonitic bivalve and gastropod shells from newly collected material from the San Diego Formation (21 specimens), Pico Formation (10 specimens), and Careaga Sandstone (9 specimens). Results from aragonitic specimens from the Careaga Sandstone place the formation in the early Pleistocene (1.85–2.00 mya). Strontium isotope ratios from Pico Formation species suggest an early Pliocene (5.65–4.65 mya) age, while Sr isotope ratios from two localities of the San Diego Formation indicate an early-mid Pliocene (4.95–4.5 mya) age. All specimens from the Pico and San Diego Formation record anomalous Sr values relative to their previously established ages. Calcitic fossils from one locality are being additionally analyzed to determine if anomalous values from aragonite fossils were a product of diagenetic overprinting. The results of this study constrain the age of the Careaga Sandstone to the Gelasian stage (now the earliest Pleistocene in the revised geological time scale), but the ages of the Pico and San Diego Formations remain unresolved in an absolute sense. These ongoing efforts to establish absolute ages assigned for Pliocene formations of Southern California are critical to providing temporal context to past and future studies on the marine communities preserved within these formations.

RICHARD FORTEY: AN UNAUTHORISED BIOGRAPHY

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Richard Fortey, whose career has (so far) spanned five decades, is widely regarded today as the greatest living trilobite scientist. Here I briefly review his contributions, with emphasis on their broader palaeobiological significance. His pioneering work ranges from its origins in classical faunistics into the thoroughly modern fields of biogeography, cladistics and molecular clocks. In addition, his limpid writing style has brought creatures dead for hundreds of millions of years back to life and made them accessible to the broadest possible public; an achievement that has been augmented in recent years by an extensive broadcasting career. Scientist and naturalist, he has united penetrating scientific insight with an exuberant pleasure in Darwin's 'tangled bank', thus perpetuating the 17–18thcentury tradition of White and Ray into the 21stcentury.

THE EVO-DEVO OF THE CAMBRIAN EXPLOSION: AN INTEGRATED APPROACH

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Nearly all evolution takes place within extinct stem groups, and thus cannot be accessed directly by investigating modern organisms. This applies even to developmental and molecular evolution, even if the pattern of such change can be reconstructed to a certain extent. Can the "unreliable narrator" that is the fossil record be harnessed to assist? Here I outline

two approaches we have employed in recent years, from classical comparative *in situ*hybridization in ecdysozoans to investigating phenotypic modularity and integration in evolving Cambrian arthropod lineages. Just as important, however, is an understanding of what it is we are trying to explain: and thus I will also discuss what our "null hypothesis" of rates of evolutionary change in the fossil record should be, with particular reference to the Cambrian explosion. I shall argue that nothing we have learnt about the fossil record around the Precambrian-Cambrian boundary requires unusual developmental or evolutionary mechanisms to explain. Rather, our distant perspective creates certain distortions in the patterns we see that need to be discounted before subsuming them in one or other explanatory evolutionary theory.

TEMPORAL TRENDS IN SHELL CALCIFICATION IN MARINE BIVALVES: PALEONTOLOGICAL BASELINES FOR UNDERSTANDING SPECIES-SPECIFIC RESPONSES IN A CHANGING OCEAN

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Utilizing the fossil record as a baseline to understand the impacts of climate change on species and communities is a new and promising field. While considerable work has been done to assess the fidelity of species abundances in live-dead assemblages in order to understand how communities are impacted by anthropogenic impacts and climatic change, much less is known about how traits within these communities change. Trait-based ecology is becoming increasingly important for predicting species' responses to environmental change but temporal spans of such analyses remain limited. Better information about trait variations across different temporal scales is essential for modeling species responses to environmental change. Anthropogenic ocean acidification is potentially a major threat for marine calcifiers and paleontological data can be used to quantify levels of plasticity and the potential for adaptation in calcification related traits. Here, we use Pleistocene (MIS 15 and MIS 5e) fossil assemblages in conjunction with historical data from multiple time periods (1930's-1970's and 2010) to assess how intraspecific investment in shell carbonate has changed over time in three species of common marine bivalves in California. Calcification index (CI), defined as thickness per unit size, of two closely related species *Chione californiensis* and *Chione undatella*, differed significantly between the Pleistocene, historical and living populations, but in opposite directions, suggesting that phylogenetic relatedness is not a good predictor of temporal changes in calcification in this group. CI of *Mytilus californianus*, a foundation species in the rocky intertidal communities, showed a significant thickening of the shell from Pleistocene to present (2017-2018). In addition to CI, shell mineralogy, specifically the calcite/aragonite ratio of the shell, is another trait that is expected to respond to ocean acidification and warming. Comparison of living populations of *M. californianus* with those from the 1950's show that the proportion of calcite in the shell has increased significantly over half a century, consistent with predictions about responses to anthropogenic ocean acidification. Overall our results show that both CI and shell mineralogy vary substantially over time in response to environmental perturbations, implying considerable plasticity in these traits. However, the nature and magnitude of the responses are species-specific and may not be phylogenetically conserved.

A COMPARATIVE STUDY OF FORAMINIFERAL ASSEMBLAGES ALONG THE EAST AND WEST COAST OF INDIA

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The present study examines the taxonomy, abundance and diversity of the foraminiferal population along the east and west coast of India within the latitudinal domain of 20^0N to 22^0N. Surface sediment samples were collected from sixteen stations over a year from both the regions. A total of thirtyfive species from the west coast and twenty species from the east coast have been identified. The most dominant species of the west coast are *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica*, *Eponides repandus*, *Cibicides refulgens*, *Quinqueloulina seminulum*, *Nonion*. cf. *commune, Ammonia tepida* and minor occurences of *Elphidium advenum, Ammonia beccarii* and *Haynesina germanica* were recorded. The east coast is dominated by *Cribroelphidium* spp., *Asterorotalia trispinosa*, *Ammonia dentata*, *Haynesina germanica, H. depressula*, *Nonionella* sp., *Quinqueloculina seminulum, Ammonia beccarii, A. tepida* and the abundance of *Rotalidium annectens, Quinqueloculina seminulum and Nonion*. cf. *commune is very less.* The agglutinated species such as *Trochammina spp.* and *Haplophragmoides* sp. are present in the east coast whereas the west coast

lacks agglutinated species. The taxonomic comparison between both the coasts show that only seven species are common. They are *Quinqueloculina seminulum, Rotalidium annectens, Nonion*. cf. *commune, Ammonia beccarii, A. tepida, Elphidium advenum* and *Haynesina germanica*.

Total Foraminiferal Number (TFN) was standardized to one gram for the study of relative abundance. TFN shows overall higher abundance of foraminiferal assemblage in the west coast. The size of the benthic foraminifera are greater in diameter on the west coast (>125 μm) when compared to the east coast (<125). The foraminiferal assemblages in the west coast are more diverse. Various physical parameters such as salinity and temperature, sediment type and load are taken into consideration to observe the role of abiotic factors on the abundance and diversity of the foraminiferal assemblages. Lots of terrigenous sediment, typically siliciclastic sediments drain into the east coast by major rivers such as Ganga and Brahmaputra, but very few minor rivers such as Vramji and Kapila are present in the carbonate dominated west coast. The abundance of reworked foraminifera from the west coast indicates the higher energy condition as compared to east coast.

This study of seasonal variation of the foraminiferal assemblage will help to improve our knowledge in the distribution pattern of recent benthic foraminifera along the coastal settings.

STUDY OF TAPHONOMIC ATTRIBUTES AND MECHANICAL PROPERTIES OF BIVALVE (MOLLUSCAN) SHELL STRUCTURES

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It is the natural selection over millions of years, which make molluscs shells to develop their unique shell structure and mechanical properties to protect themselves from attack by predators. The mechanical function of shell depends upon its ability to resist deformation and failure under imposed environmental stresses. In addition the shell also plays an important role in the burrowing and boring processes. Even after its death, the taphonomic processes acts differently on molluscs shells. The shell is predominantly made up of $CaCO_3$. The effect of shell microstructure, bonding strength calcite crystals and intercalations with organic of portion, on overall mechanical behaviour is significant towards its adaptation with time. These were contemplated and investigated by researchers in recent past but still the understanding is modest.

A field work was conducted along the coastal regions of Chandipur, Odisha,India. Three dominant genera *Donax*, *Mactra* and *Meretrix* were collected in substantial numbers and some major mechanical properties of individual shell structures such as compressive strength by ‚Nano Indentations Method' i.e. 'Vickers Hardness'; Centerline (*L,* where *L* is the length of the centerline from commissure line to umbo) thickness and density variations along the centerline (*L*) were estimated.

All the related experimental measurements were carried out at M.L. Dastur School of Material Science, IIEST, Shibpur. Some interesting trends and correlations were observed between the tested mechanical behaviors of examined bivalve shells. The correlation plots of the variation of centerline thickness, Vickers Hardness and density variation along the Centerline are estimated for all three species and it was noted that the weakest zone of all the species lies in between 0.7*L* to 0.9*L*. Though it is also clear from the plots of them mechanical characteristics for individual species which shows a specific range of variations and significantly differs from species to species.

These are an obvious output of internal arrangement of constituting crystals of the shells. This study may be related to the causes for unique behaviour of molluscs and possible functional significance of the shell structures.

STRATIGRAPHY AND PALEONTOLOGY OF THE NEARSHORE MARINE LATE PERMIAN AND EARLY TRIASSIC ROCK UNITS IN THE UINTA MOUNTAINS OF UTAH AND COLORADO.

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The Uinta Mountains of northeastern Utah and Colorado compose a high elevation east-west mountain range south of the southern border with Wyoming. As a result of recent Cenozoic uplift, the mountain range exhumed older late Paleozoic and early Mesozoic rock units. These rock units enable study of the recovery of the end-Permian extinction in a shallow marine depositional environment along the equatorial western edge of Pangea. Marine rock units are composed of the latest Permian Park City Formation

and earliest Triassic Dinwoody Formation, which represent a major transgression of the Panthalassic Ocean into northeastern Utah. Presence of the conodont *Merrillina divergens* indicates that the upper Park City Formation is earliest Wuchiapingian to late Changhsingian in age, while *Hideodus typicalis* and *Isarcicella isarcica* in the Dinwoody Formation indicate an early Griesbachian age. The Permian-Triassic boundary has been identified based on geochemical evidence along the northern edge of the Uinta Mountains in Sheep Creek Valley between the Park City and Dinwoody Formations. Biostratigraphic studies were carried out during the 1930s to 1960s, but recent investigations of the fossil record are lacking, especially in regard to the recovery of the end-Permian extinction. Cephalopod diversity was high during the deposition of the late Permian Park City Formation, with ammonites *Stacheoceras*, *Gastrioceras*, *Goniatites*, and *Waagenoceras* and the nautiloid *Coelogasteroceras* known from the unit. Brachiopods were diverse with the occurrence of 22 genera, and 10 genera of bivalves and 4 genera of gastropods reported from these late Permian rock units. Crinoid and bryozoan fossils are also known indicating a healthy phosphate-rich carbonate platform in equatorial warm waters. In contrast, fossils in the overlaying Triassic Dinwoody Formation are exceedingly rare, with no observed evidence of bioturbation in the lower portions of the rock unit. The lower ~10 meters of the Dinwoody Formation appears to be unfossiliferous, but above this lower barren-zone is the middle *Lingula*-zone of the Dinwoody Formation, characterized by the rare presence of the brachiopod genus *Lingula.* The upper most *Claraia*-zone of the Dinwoody Formation represents an early Triassic recovery fauna characterized by the bivalve *Claraia*, but also contains 3 genera of brachiopods, as well as 9 genera of bivalves, indicating a change from a brachiopod dominated environment to a bivalve dominated environment. Three genera of ammonites are known from the upper Dinwoody Formation *Otoceras*, *Discophiceras*, and *Metophiceras*, while 2 reported gastropods are known from these upper beds. The end Permian extinction indicates a major shift in the marine fossil record in northeastern Utah, indicating a protracted recovery during the earliest Triassic. The rock record of the end-Permian extinction event is exceptional in the Uinta Mountains and represents an understudied region within the United States.

TAPHONOMY OF AN ADOLESCENT MALE MASTODON FROM A PLEISTOCENE KETTLE LAKE DEPOSIT IN NORTHEASTERN OHIO

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The skeleton of an adolescent male mastodon ("Little Horatio") was recovered from a small, isolated kettle lake deposit within a Pleistocene glacial outwash plain in Fairlawn, Summit County, northeastern Ohio. Although initially discovered in 1966 and offhandedly estimated to be approximately 60% complete, no detailed taphonomic research on this material has hitherto been conducted. Approximately 55% of recovered elements, though disarticulated, represent complete bones or identifiable incomplete bones; the rest represents unidentifiable fragments and broken shards. Attempts to incorporate the proportion of the skeleton consisting of unidentifiable pieces yields a completeness estimate of roughly 40%. The left side of the skeleton is more complete than the right side, presumably reflecting orientation of the skeleton prior to burial. The medial portion of the skeleton is over-represented compared to the anterior and posterior regions, though this likely reflects the size and thickness of bones in these areas as well as damage induced by heavy machinery to the cephalic region during discovery of the skeleton. Interestingly, epiphyses (vertebral disks) are significantly more abundant than vertebrae in spite of the fact that these elements are smaller and thinner, making them more prone to both biostratinomic destruction and being overlooked during collection. Surprisingly, elements of the distal appendages (tarsals, metatarsals, carpals, metacarpals) are under-represented and show evidence of more severe physical processing relative to other portions of the skeleton. Collectively, taphonomic analysis of this mastodon resulted in detection of some patterns that are fitting with expected biostratinomic interpretations for kettle lake environments; some patterns that are unique owing to the specific discovery and collection history of this material (an under-studied aspect of an organism's post-mortem history); and some patterns that remain enigmatic and may be looked for, and hopefully deciphered, in future studies of proboscidean taphonomy.

GROWTH RATE DYNAMICS UNDERLYING PLANKTONIC FORAMINIFERAL MORPHOLOGY

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Planktonic foraminifera--microscopic marine organisms with calcareous tests--grow by adding new chambers onto their tests, modifying their surface area, volume, and ornamentation with each addition. This process creates a wide variety of adult morphologies while also preserving all previous chambers. With high resolution three-dimensional imaging techniques, precise measurements can be made on parameters like surface area and volume on all chambers, recreating patterns of ontogenetic growth and allowing variation within and among species groups to be characterized. Here, we use three-dimensional images (microCT scans) of extant planktonic foraminifera from plankton tows, sediment traps, and core tops to measure and compare the variation in chamber and whole test volume within and between eleven species. We explored the extent of interspecific and intraspecific variation in whole-test and chamber dimensions and growth rate dynamics through ontogeny. We found that these species exhibit one of three different ontogenetic trajectories as evidenced by trends in growth rates. Some species maintain a relatively constant growth rate throughout ontogeny, others change growth rate at the transition from the juvenile to the neanic stage, and still others change growth rate two or more times through ontogeny. We also measured multiple specimens from six species for intraspecific variation, and we find variation in cell size and timing of growth that was at times as large as that observed between species, specifically in the size of a given chamber number, indicating that overall size and chamber number are not related or even consistent within species.

THE FRASNIAN-FAMENNIAN (LATE DEVONIAN) EXTINCTION EVENT IN NEW YORK AND PENNSYLVANIA: STRATIGRAPHIC AND PALEOENVIRONMENTAL CONTEXT

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The Lower and Upper Kellwasser (LKW and UKW) Events comprise the Frasnian-Famennian mass extinction, one of the "Big 5" extinctions of the Phanerozoic. The Appalachian foreland basin preserves a thick package of Upper Devonian sediments in which these events can be examined along a paleoenvironmental transect thanks to revised correlations based on biostratigraphy and carbon isotope stratigraphy. Here, we review these correlations and the facies changes observed during the Frasnian-Famennian boundary interval in the relatively shallow-marine settings of the Southern Tier of New York and north-central Pennsylvania. The KW-equivalent beds are separated by ~60 m of strata and consist of dark gray silty shales, interpreted as representing deposition in offshore settings. Coarser-grained, shallower-water sediments precede and follow each event. Prior ichnological and trace metal studies of more distal sections in western NY indicated dysoxic to intermittently anoxic conditions during the deposition of the KW-equivalent beds. Similar analyses in our field area have detected no evidence of anoxia, although dysoxic conditions were often present. At some localities, body and trace fossils are present within the Kellwasser beds. Thus, oxygen levels increased along the offshore-onshore transect during KW times. Many macrofossil species went extinct in the LKW Event in this region, including all extant strophomenid and atrypid brachiopods and large, shallow-water rugose corals. In contrast, the UKW event only claimed a couple of victims, including the last species of atrypid brachiopod, which migrated into the basin after the Lower Kellwasser, and no new species of brachiopod appeared in its immediate aftermath.

SEARCHING FOR OUTCROPS USING LIDAR DATA (WHEN YOU CAN'T SEE THE ROCKS FOR THE TREES)

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There are many ways to locate outcrops for paleontological sampling – published descriptions, word of mouth, satellite photographs, geological maps, etc. Finding new, unstudied outcrops can be difficult in wooded landscapes, however, because satellite photographs are not as informative and searching on foot is time consuming. Here, we discuss the use of LiDAR for locating potential outcrops before commencing field work. LiDAR is a technique used to make high-resolution digital elevation maps, essentially through 3D laser scanning of the Earth's surface from an aircraft. Critically, LiDAR data can often be processed to produce a "bare earth" model even if tree cover is

present. LiDAR data sets are becoming increasingly available for download from government agencies, with resolution often on the order of one meter. We examined LiDAR data sets from several areas in New York, Pennsylvania, and Connecticut, converting them to slope maps in ArcGIS. Areas of high slope should include rock outcrops, which often have higher slopes than other surfaces in the landscape.

Many road cuts and stream exposures were identifiable in slope maps, even under fairly dense tree cover. Other high-slope features include man-made structures like retaining walls and dams, but given high enough quality LiDAR, these appeared more regular than most outcrops. Not surprisingly, some outcrops could not be distinguished in slope maps. Some were too small to be evident given the resolution of the data, and some were simply not high-slope features (e.g., flat or sloping bedding plane exposures; strata exposed in stream beds but not along banks). In some cases, the stratigraphic position of an outcrop could be inferred from the topography of the landscape surrounding the outcrop. For example, the alternation sandstone- and mudstone-dominated formations/members can be evident in the alternation of zones of higher and lower slopes. This information can supplement geologic maps in locating outcrops ahead of time that expose a desired stratigraphic interval.

PRESERVING FOSSIL PRINTS IN AN EPHEMERAL LANDSCAPE

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The Tularosa Basin of New Mexico has provided a snap shot in time of incredible ichnofossils. Beginning in 1931, with what was first thought to be footprints of a "big-foot" and later identified as those of a giant ground sloth. A large diversity of Late Pleistocene soft sediment gypsum ichnofossils have been found in the lake beds that created White Sands National Monument (WHSA) and the world's largest gypsum dune field. In recent years, thousands of ichnofossils of extinct Rancholabrean fauna have been found, including prints of Proboscidea (mammoth), Pilosa (ground sloth), Carnivora (canid and felid), and Artiodactyla (bovid and camelid) as well as humans. What sets the prints within the boundary of White Sands National Monument (WHSA) apart is not only the sheer number of prints, with densities often >10 per square meter, and but the spatial area over which they are distributed. At WHSA individual humans and animals can be tracked over kilometers and seen in many places interacting. The prints have been referred to as ghost prints because they can be seen only under specific moisture conditions and once exposed they are often destroyed by the elements in just a few years. It is the mission of the National Park Service to preserve cultural and natural resources for future generations, but how can this be done with resources that are so ephemeral and so elusive? This talk will focus on the work, collaboration, and techniques that have been develop to locate, preserve the prints (through documentation and data collection), persevering the impossible, capturing this incredible story for future generations.

BRACHIOPOD PHYLOGENOMICS: IMPLICATIONS FOR THE EVOLUTIONARY HISTORY OF BIOMINERALIZATION AND THE CAMBRIAN EXPLOSION

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Within Lophotrochozoa, brachiopods and allied clades are among the first biomineralized Cambrian metazoans to appear and represent a major component of the oldest known fossil record of animals. While the brachiopod fossil record is ultimately the key to determining character homology and polarity during the evolution of the brachiopod body plan, reading this record has been clouded by disagreement about relationships among the crown clades. Specifically, the monophyly of brachiopods with respect to phoronids, and the relationships of the calcitic to phosphatic-shelled brachiopods. Much of this phylogenetic uncertainty stems from difficulties in rooting the brachiopods and their sister groups within Lophotrochozoa.

Consequently, we have conducted the first extensive phylogenomic investigation with broad taxon sampling of Brachiopoda/Phoronida with analyses that combine novel sequence data with all publicly available brachiopod and phoronid transcriptomes in addition to a broad range of protostome outgroups.

Analyses were run under best fitting evolutionary models (LG) utilizing both published lophotrochozoan ortholog sets and novel brachiozoa specific orthologs. Preliminary results (of a ~20k amino acid partitioned alignment with 75% occupancy) strongly (>99% bootstrap) support a monophyletic Brachiopoda with Phoronida as sister group within Lophotrochozoa. High bootstrap support (>90% bootstrap) is also found for Inarticulata under Maximum Likelihood. Preliminary Bayesian results are consistent with this topology.

In addition, we are also generating a set of best-practice molecular clock calibration points. This encompasses *a priori* evaluation of relevant paleontological, phylogenetic, stratigraphic and geochronological data, all of which are critical to establishing effective and well supported time calibration points.

This combined dataset will allow us to test, under a Bayesian analytical framework, the hypothesis that the Cambrian explosion was a synchronous period of rapid molecular evolution, in addition to the rapid appearance of high-level morphological disparity. Testing the relationship between molecular and morphological evolution in the Cambrian has important implications for arbitrating between potential driving mechanisms including ecological opportunism, body size evolution, and changes to gene regulation, also for understanding how evolutionary rates vary across geologic and clade history. Combining fossil and molecular data in this integrated framework provides novel insight into brachiopod biomineralization and evolutionary patterns during the Cambrian radiation. With an excellent fossil record and well-resolved phylogeny, brachiopods also provide a rich empirical dataset to test for potentially significant 'push of the past' artefacts in the fossil record, a possibly confounding effect on existing macroevolutionary models. (e.g. the fossilized birth-death process).

THE POSTCRANIAL SKELETON OF THE BASAL RUMINANT NANOTRAGULUS (ARTIODACTYLA: HYPERTRAGULIDAE) FROM THE INIYOO LOCAL FAUNA, EARLY OLIGOCENE (ARIKAREEAN) OF SOUTHERN MEXICO

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The genus *Nanotragulus* (Artiodactyla: Hypertragulidae) is an extinct basal ruminant with a chronological range from the early Oligocene to the early Miocene of North America (Whitneyan-Arikareean), and is a typical mammal for the Arikareean. The skeleton of this genus was previously described by Loomis (1933) from Porcupine Creek in South Dakota, with other known occurrences of fragmentary skeleton remains in the states of Oregon, Nebraska, Texas and Florida. Here we present the postcranial skeleton of *Nanotragulus*, collected from early Oligocene fluviolacustrine sediments that crop out in the surroundings of Santiago Yolomécatl, in Northwestern Oaxaca, Mexico. We describe the postcranial bones that consist of vertebrae, radius-ulnae, carpal bones (Scaphoid), metacarpals, metatarsals, humeri, tibiae, calcanea, astragali, phalanges and partial broken ribs. Several bones show differences in size, suggesting the presence of two morphotypes in our sample. *Nanotragulus* represents the only genus of the Hypertragulidae family in Yolomécatl, where it is associated with a diverse Paleogene mammal fauna. The study of the *Nanotragulus* postcranial skeleton provides a broader insight of the metric and morphological variations between the Oaxaca and North American specimens. Previous U-Pb zircon dating of a sandstone bed that overlies the fossiliferous beds dated the fauna as a maximum of 30.6 Ma, and by mammalian biochronology the faunal assemblage is 28-29 Ma in age, making it the southernmost land mammalian assemblage of early Arikareean (early Oligocene) age in North America. The geographic distribution of the genus is expanded by 1,400 km south and constitutes the southernmost North American record of the genus *Nanotragulus*.

A CIRCUM-TROPICAL DISASTER BED IN THE EARLY AFTERMATH OF THE END-ORDOVICIAN MASS EXTINCTION

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The end-Ordovician glaciation and mass extinction was associated with unusual inorganic carbonate production and preservation through wide expanses of contemporaneous shallow seas in Earths tropical zone. This resulted in widespread ooid formation and locally in botryoidal cements, a post-extinction carbonate production change only well studied in the earliest Triassic of the Tethys Realm. High-resolution correlation by means of stable carbon isotope stratigraphy reveals a late early Hirnantian (stage slice Hi1 and the early *Metabolograptusperscuplptus* chron)

peak of calcareous ooid formation giving rise to a few metres thin but globally recognizable 'oolite disaster-bed', marking the extreme loss of shell-bearing taxa, ecosystem collapse and thus reduced carbonate production in shallow seas. We use own and published records of the Hirnantian Isotope Carbon Excursion (HICE) as a stratigraphic ruler to study the degree of synchroenity of oolite formation across the American Midwest (Oklahoma, Arkansas, Missouri, Illinois), through multiple localities in Norway, Sweden and the East Baltic area, and further on to South China (the Kuanyinchiao Bed in the Hirnantian Global Stratotype Section and Point at Wangjiawan section corresponds to this oolite disaster bed), together representing three continents in the contemporaneous tropical zone. The combined effect of a strongly reduced biological sink for carbonate ions due to mass extinction of shell-bearing organisms, widespread anoxia and CO_2 release during post-glacial transgression across shallow platforms was the likely trigger for the anomalous carbonate production, which represents a short-lived but significant change in sea-floor substrate composition in the early aftermath of the event. Similar unusual environmental conditions and carbonate production turnovers, with seemingly strong ecological impact in carbonate platforms, developed also during mid and late Silurian biocrises that were related to global climate change but that was far less significant in terms of taxonomic loss.

THE ROLE OF ONTOGENETIC TRANSFORMATIONS OF THE LOOP IN THE CLASSIFICATION AND PHYLOGENY OF TEREBRATELLIDINA (BRACHIOPODA)

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The long mineralized loop in terebratellidine brachiopods is a geometrically and ontogenetically complex structure; it has played a significant role in constructing terebratulide classification and hypotheses of phylogeny. For over a century, long loops present in all Paleozoic and post-Paleozoic terebratulides have been considered to be homologous, originating from Middle Devonian mutationellids, from which all subsequent terebratellidines evolved. In the 2006 *Treatise on Invertebrate Paleontology*, the classification of terebratulide brachiopods was thoroughly revised, largely on the basis of patterns of loop ontogeny via resorption and mineralization, as documented in extant terebratellidines. Extant long loop geometry transforms through a series of identifiable ontogenetic stages, resulting in a variety of extant adult loop geometries. As a result of these more recent studies of loop ontogeny: (1) nine superfamilies are recognized, each with at least one extant representative, replacing three superfamilies previously recognized, only one of which included extant taxa; (2) .the evolutionary origin of the long loop crown clade is placed in the Triassic, not the Devonian. This suggests that Paleozoic long loops could be analogues, not homologues, to extant long loops. Moreover, this interpretation is in conflict with molecular clock analyses that place the divergence of crown short loop and crown long loop clades in the Devonian. Did the long loop evolve once or twice within Terebratulida, through which morphological transformations, and by what combination of ontogenetic and evolutionary mechanisms?

Extant terebratellidines develop long loops from both the cardinalia and a septal pillar emerging from the center interior of the dorsal valve. Long loops in Paleozoic terebratellidines appear to develop only from the cardinalia; a septal pillar appears to be absent throughout ontogeny. In some extant adult long loop geometries, the septal pillar resorbs completely later in ontogeny, resulting in an adult geometry that is indistinguishable from Paleozoic adult long loops. Finding evidence for stages of ontogenetic development in extinct terebratellidines is a challenge; it is thus difficult to test hypotheses of the existence of a septal pillar in extinct terminal geometries in which it may have resorbed and vanished completely in adults.

Two ontogenetic pathways appear to have evolved in this clade: one lacking a septal pillar throughout, and one with a septal pillar. The septal pillar may represent an evolutionary innovation, as an addition to the Devonian terebratellidine developmental trajectory. We argue that these two ontogenetic pathways are homologous, but at a deeper level of homology. As wings of birds and bats are homologous as forearms but evolve independently as wings, long loops of Paleozoic and post-Paleozoic terebratulides appear to be homologous as elongated crural extensions but evolve independently as long loops.

A TRIGGER MECHANISM FOR THE LATE DEVONIAN HANGENBERG CRISIS, AS RECORDED BY MER-

CURY ANOMALIES IN CARBONATE SEDIMENTS IN VIET NAM AND ELSEWHERE: WE'RE NOT SAYING IT WAS VOLCANOES… BUT IT WAS VOLCANOES

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The Hangenberg Crisis is a complex ocean anoxia event coupled with a drastic regression in sea level that occurred just prior to the Devonian - Carboniferous biodiversity crisis at 359 Ma, and has been documented throughout Euramerica, Gondwana, the Central Asian Orogenic Belt and South China. The trigger mechanism(s) for the Hangenberg Crisis have long been debated, and deciphering the expression for these mechanisms has been complicated by unconformities, mixed lithologies, tectonic overprinting, and problems with biostratigraphic correlation. Associations between mass extinctions and intensive volcanism are well established for many of the other major Phanerozoic mass extinction events. Mercury (Hg) chemostratigraphy can be used to tentatively identify volcanic emissions via atmospheric deposition, although its use must be constrained by paleoenvironmental setting, lithology, and local redox conditions.

The Cat Co 3 section of the Pho Han Formation in Viet Nam represents an ideal location to test the volcanic trigger hypothesis for the Devonian-Carboniferous extinction, as it represents a sediment-starved, isolated carbonate basin on the South China platform. At this section, a marked enrichment in Hg is just below the stratigraphic location of the Devonian-Carboniferous boundary, corresponding to the onset of the Hangenberg Crisis. There is no evidence for any detrital input nor any regressive sequences in the section, indicating that Hg enrichment likely represented atmospheric deposition rather than terrestrial runoff. Furthermore, the section records sustained dysoxic to anoxic conditions throughout the Famennian and becomes anoxic to euxinic at the Hangenberg Crisis, indicating that the enrichment in Hg at the Hangenberg Crisis is not solely due to a major change in redox conditions.

Although there are no definitive large igneous provinces associated with the Devonian-Carboniferous extinction at this time, there are similar Hg enrichments associated with the onset of the Hangenberg Crisis in both Germany (Euramerican paleocontinent) and Uzbekistan (Central Asian Orogenic Belt). Hg enrichments associated with the Hangenberg Event are therefore global in scope and need to be further studied in a variety of paleoenvironments to parse out local vs. global signatures of Hg enrichment and refine (or refute, or confirm) the hypothesis for volcanism as a trigger mechanism for the Hangenberg Crisis and Devonian-Carboniferous mass extinction event.

THE MARBLE CANYON BURGESS SHALE FOSSIL DEPOSIT – BRITISH COLUMBIA, CANADA: NEW FIELD DISCOVERIES, GEOLOGIC SETTING, PROSPECTS AND SIGNIFICANCE

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Discovered in 2012 in northern Kootenay National Park (British Columbia), Marble Canyon represents the most significant new Burgess Shale locality since the discovery of the Walcott's original quarry site in 1909. Surface collecting and quarrying operations in 2012, 2014 and 2016 have so far yielded over 23.000 specimens representing about 75 species, including fish (*Metaspriggina*), hemichordate (*Oesia*), lophophorate (*Haplophrentis*), a new annelid (*Kootenayscolex*), new arthropods (*Tokummia, Yawunik* and *Surusicaris*), including two new naraoiid species (*Misszhouia canadensis* and *Naraoia magna*) and a new hurdiid radiodontan arthropod. Most recently, the phylogenetic relationship of agnostids, a problematic group of Cambro-Ordovician euarthropods, was elucidated in part thanks to specimens from Marble Canyon showing exceptional preservation of limbs. In addition to its contribution to evolutionary studies, the great abundance of fossils has allowed detailed quantitative analyses and comparisons with other well-sampled Burgess Shale sites (including the Walcott Quarry), suggesting both local and regional differences in community structure. Body and trace fossils, combined with sedimentological, micropalaeontological, taphonomic and geochemical data also provide critical context for understanding the Marble Canyon ecosystems.

New field explorations, including quarrying operations, along Tokumm Creek, north of Marble Canyon, have revealed dozens of rich new fossiliferous

horizons near the top of the Stephen Formation, extending the Marble Canyon biota northward by at least 7 km. These discoveries suggest that the depositional environment and conditions responsible for the burial and exceptional preservation of the fossils were extensive in space (at least tens of square kilometers) and persisted for at least tens of thousands of years. By comparison, all previously-known Burgess Shale sites were confined to small outcrops. Marble Canyon and Tokumm Creek thus offer great prospects for refining our understanding of the Burgess Shale community and its paleoenvironmental settings across a much wider geographic area. In addition, the new area holds promise more generally for understanding how early metazoan ecosystems were structured along environmental gradients and for increasing our knowledge of body plan evolution and marine diversity that existed during the middle Cambrian.

THE LATE NEOGENE FAUNAS OF CENTRAL MEXICO: NEW RECORDS OF GOMPHOTHERIUM HONDURENSIS

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The oldest proboscideans in Central America were discovered in the Gracias Formation, Honduras, in deposits of early Hemphillian age of the Tapasuma locality; the first jaw of gomphotheriids was assigned to the new species *Blickotherium blicki,* the only know with the presence of enamel band. Shortly after, a second jaw was referred to *Aybelodon hondurensis,* with an absence of enamel in the tusks (Frick 1933).

In the revision of the taxonomy of *Rhynchotherium*, Lucas and Morgan (2008) established that the Central American gomphotheriid (*Blickotherium blicki = Aybelodon hondurensis*), are not *Rhynchotherium* species, concluding that all gomphotheriids from Gracias fauna are referable to *Gomphotherium hondurensis.* Its restricted geographical distribution was determinant to assume that Central America was a center of diversification of proboscideans, and the possible origin of *Rhynchotherium*.

As a result of the research in central México, a large collection of gomphotheriids from early-late and late Hemphillian were collected. These represent the first records of *Gomphotherium hondurensis* known outside Central America.

The material consists of: Juchipila basin, a palate, jaw fragment, upper and lower tusks. In the state of Querétaro, a palate and almost complete jaw. In Tecolotlán basin, skull fragment, complete jaw lower and upper tusks. The age was determined as Hh2, and analyses of the ash from La Cofradía gave an age of 6.53 ± 0.11 Ma, and the upper ash resulted in 5.59 ± 0.11 Ma.

The jaws present the diagnostic character of a symphysis in an angle of 33° and the absence of enamel in the lower tusks. However, in the tusk from the late Hemphillian of Tecolotlán, the enamel band and dentine are present in a slight clockwise torsion that reminds the upper tusk of *Rhynchotherium*.

Previous records of *Gomphotherium* from Mexico are from Oaxaca and Chiapas, referred to the late-early Barstovian age, which have been considered as a continuation of the Coalinga records in the west coast of USA, contemporaneous, and geographically separated by 3000 km, which implies an extremely efficient dispersion to southern Mexico from the north.

The *Gomphotherium hondurensis* records collected in early-late and late Hemphillian faunas, central region of México, are the first known outside Central America, and constitute the largest collection of this species in North and Central America. These records show that Central America was not a diversification center of proboscideans and *Rhynchotherium* did not originate in Central America, its origin is in late Hemphillian-Blancan faunas of North America and Mexico, where *Rhynchotherium tlascalae* was described.

The jaw of late Hemphillian of Tecolotlán, is the youngest record known in Central Mexico and Central America. PAPIIT Project IN102817

FEATHER PALEOGENOME INSIGHTS FROM HIGH FIDELITY FOSSIL PRESERVATION

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Recent advances in the field of feather research have revealed much about the microstructural and three-dimensional components of modern feathers, as well as the genetic and molecular signaling that controls their morphogenesis. The temporal and taxonomic origin of feathers is informed by a growing number of well-preserved fossils, largely preserved as compression fossils in lake deposits. These fossils reveal informative macro structures of feathers such as the main supporting rachis and branching barbs but features in the microstructural range (10-100 μm) are difficult to interpret in these fossils. This study utilizes exceptionally preserved feather specimens from a Late

Cretaceous coprolite and mid-Cretaceous amber which display three-dimensional contiguous macro to nanoscale structures. Three-dimensional cross sections of the feather shaft and rachis-calamus transition, the presence or absence of medullary pith, and details of barb and barbule morphology were examined with a combination of optical and micro computed tomography imaging. The high-fidelity preservation of these feather structures allows for comparisons with modern feather components for which the morphogenetic regulatory modules are known. Although some feathers in the Cretaceous display features remarkably similar to those produced by the modern suite of regulatory modules, others may have been made through limited integration and coordination of distinct regulatory modules. The preservation of morphogenetically informative feather characters in amber and coprolites at multiple scales can provide insight into extinct and extant feather development.

LIFE FROM LAND TO WATER– A TRIASSIC RENDEZVOUS OF INDIAN TEMNOSPONDYLS

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Triassic of Indian Gondwana is preserved as continuous sequence through Early, Middle and Late Triassic in the Pranhita – Godavari (P-G), Satpura, Rewa and Damodar basin. The Triassic temnospondyls have their bizarre records in India but are understudied. They are important being the first to conquer the land on their long journey through time from water. India preserves a complete sequence of temnospondyl record throughout Triassic Gondwana. The Panchet Formation has bulk of temnospondyl assemblage viz trematosaurids, plagiosaurids, rhytidosteids and benthosuchids among which trematosaurids are most abundant represented by fragmentary skulls parts and mandibles. Recent work shows that Indian trematosaurids fall within the sub-family Lonchyrhonchinae. Outline morphometric analysis and comparison with other global lonchorhynchine bring forth two taxa in India. The first resembles closely to *Aphaneramma givaliamis* from Madagascar and the other lies in between *Wantzosaurus* and *Trematosaurus.* Acomplete Rhytidosteid skull was also recovered from this formation. Analysis shows that the skull is abiotically deformed and suffered a combination of brittle and ductile deformation. Early reconstruction of the skull was thus incorrect. Impression of skin is preserved in some areas of the skull which is a rare and important find. The Middle Triassic is represented by the presence of *Stanocephalosaurus rajaredyyi* from Yerrapalli Formation in P-G Valley and an array of capitosaurids like *Cherninia denwai* and *stanocephalosaurus crookshanki*from Denwa Formation in Satpura Basin. Denwa is also home to a new short-faced brachyopid having vaulted palate, large orbits and unusually long retroarticular process of the mandible. It has an external mandibular fenestra and large openings at its cheeks. These combinations of characters are similar to *Vigilius*of North America. India also records having the youngest lonchorhynchinae from the Anisian Denwa Formation. The Late Triassic of India is represented by the Maleri Formation of P-G Valley with its unique assemblage of Laurasian metoposaurids and Gondwanan chigutisaurids found within the same formation. Detailed study on morphology of Indian metoposaurids, biometric studies, morphospace analysis, elliptical Fourier analysis, PCA along with phylogeny reveals that Indian taxon *Panthasaurus gen. nov.maleriensis* is distinct from other metoposaurid taxa. The Indian Late Triassic Chigutisaurids are represented by *Compsocerops cosgriffi* and *Kuttycephalus triangularis.* Newer worksreveal*Kuttycephalus triangularis* is a juvenile and deformed *C. cosgriffi* contributing to an ontogenetic series.With all the above researches, it can be concluded that the Indian Triassic temnospondyl fauna was cosmopolitan presenting high diversity and disparity in Early Triassic with niche sharing transgressing to low diversity but high disparity in the Middle Triassic to low diversity and low disparity (but a unique assemblage) in Late Triassic.

STROMATOLITE? FIRST REPORT ON BIOLOGIC TRACE ORGANISMS PRESERVED ON AN EARLY TRIASSIC TEMNOSPONDYL SUBSTRATE

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The Early Triassic in India is well preserved in the Panchet formation of Eastern India. One of the main faunal elements in this formation is the temnospondyl amphibians. This work presents the first report of biological traces preserved in a temnospondyl humerus about 5 cm in length along with the study of surface topography of the bone excavated from argillaceous sandstones of the area. It occurred in the lag deposits along with the pebbles within the sandstone. Detailed study of the surface topography of the bone in hand held microscope showed linear marks and

conspicuous cluster of tears drop shaped traces. SEM analysis of this bone surface reveals structures having close resemblance to cyanobacterial filaments (Stromatolites) and another ring-shaped organismic trace whose identity is still questionable. These ring-shaped organisms were formed around circular pits approximately measuring 72.75 um to 71.68 um in diameters. Zones with different electron densities revealed by SEM on the thin layer of stromatolite corresponded to carbonated structures (whitish) and the surrounding bone surface greyish in colour. EDS analysis shows these whitish areas to be rich in calcium carbonate and having a high percentage of potassium. Stromatolites are carbonated structures which are built by microbial community. Their structures are associated with both physical and biological processes of mineral deposition. Generally, cyanobacteria are the most common element in this kind of structures. Stromatolites can grow in a variety of environments like fluvial, marine or lacustrine. Panchet formation has been suggested by many workers as deposits of fluvio-lacustrine environment. Results obtained from SEM also reveals pits and perforations within the network laminae whose origin is uncertain. However, there are voids or spaces which lack any biological structures. These voids may be due to the diffusivity and adsorption capacity within the stromatolites allowing storage of gasses and nutrients. This suggests to their functional adaptivity in quasi extreme conditions like lack of nutrients or high temperature. A few circular pits ranging from 36.74 um to 62.43 um have been found in array which can be concluded as probable bite marks. The humerus examined is extremely well-preserved with minimal taphonomic abrasion. SEM analysis reveals that most of the linear marks apart from filaments have a V-shaped profile which suggests that they were formed by inorganic processes. Linear marks with V shaped cross-section on bone are produced by objects which are harder than bone, and the agent can be the movement of rock against bone during abrasion, or movement of the bone against a hard object, for instance during trampling or transport. Hence it can be concluded that stromatolite traces found in fossil substrate are preserved in harsh environment.

NITROGEN ISOTOPE EVIDENCE FOR AN OLIGOTROPHIC SHALLOW OCEAN DURING THE CAMBRIAN STAGE 4

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To figure out the variation of N supply and elucidate the combined effect of O_2 and N availability on the extinction event, this study presents the first set of high-resolution N isotope data from two shallow-water Cambrian Stage 4 drilling sections on the eastern Yangtze Platform. The results indicate that the sections are characterized by highly negative $\delta^{15}N$ signatures during the lowermost and uppermost Cambrian Stage 4, which are indicative of strong NH_4^+ assimilation in an anoxic shallow ocean. During the rest of the Cambrian Stage 4, both of the studied sections show stable $\delta^{15}N$ values close to 0. This phenomenon can be best explained by enhanced N_2 fixation in an oxic shallow ocean characterized by strong N limitation, resembling the low-latitude oligotrophic regions in the modern ocean. The oligotrophic environment was likely caused by enhanced denitrification/anammox as well as elevated P input associated with eustatic changes, and could be widespread in the global shallow ocean during the Cambrian Stage 4. Our results lend new support to the traditional view that anoxia contributed to the mass extinction event. More importantly, it is emphasized that the oligotrophic environment could have played an important role in the prolonged decline of metazoan diversity during this stage.

LINKING GEOGRAPHIC RANGE AND BACKGROUND EXTINCTION IN AMMONOIDS ACROSS THE CRETACEOUS

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Geographic range size has been identified as one

of the most consistent predictors of extinction risk across taxonomic groups. In fossil marine ecosystems, this relationship has been most extensively explored using the benthic invertebrate record. Ammonoids are generally known to exhibit rapid rates of evolution, high turnover, and broad geographic ranges, attributes that make them valuable for biostratigraphic studies. Despite these broad characterizations, ammonoid genera may also span several stages, and endemic faunas have been recognized, particularly in conjunction with the presence of epeiric seas. Ammonoids are therefore an ideal group with which to test the strength of selectivity on geographic range size in non-benthic organisms at a global scale during background extinction times. Here, I use a dataset of Cretaceous ammonoid genera, their stratigraphic ranges, and regions of known occurrences to investigate the relationship between geographic range size and background extinction selectivity in Cretaceous ammonoids. Using logistic regression, I model extinction at both global and regional scales to identify spatial heterogeneity in the magnitude of extinction and in selectivity and compare Early Cretaceous extinction dynamics with those of the Late Cretaceous, when epeiric seaways were widespread.

NEW AGE CONSTRAINTS ON THE YIXIAN FORMATION AND ITS IMPLICATIONS FOR THE JEHOL BIOTA

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The fossils of the Jehol Biota are magnificent, exquisitely preserved and extraordinarily diverse. Since formal study of the Jehol Biota began in the 1990s, abundant terrestrial plant and animal fossils, have been discovered from the Dabeigou Formation, the Yixian Formation and the Jiufotang Formation (and their correlative strata) in Northeastern China. Although strata interpreted to be correlative with the classic Jehol localities occur throughout Eastern China, as well as in Korea, Japan, Mongolia, and Siberia, most fossils of the Jehol Biota have been discovered from classic outcrops of the 225-4000 meter-thick Yixian Formation in Western Liaoning Province. Fossils from the Yixian Formation provide unique insight into Cretaceous terrestrial ecosystems and their influence on the emergence or radiation of angiosperms, insects, dinosaurs, mammals and birds. Despite voluminous research on the Jehol fossils, critical uncertainties remain. Based on assemblages of vertebrate fossils, the Yixian Formation is generally divided into the Lujiatun Unit, Lower Lava Unit, Jianshangou Unit, Upper Lava Unit, Dawangzhangzi Unit and Jingangshan Unit (from bottom to top). This stratigraphic column for the fossil-rich Yixian Formation has been widely accepted in the past three decades. However, previously reported age data obtained through a range of methods and applied to different units of the Yixian Formation do not consistently integrate with this commonly accepted stratigraphic interpretation. In this study, I summarize previous age data for the Yixian Formation and recalibrate previously reported $^{40}Ar/^{39}Ar$ ages by using new age interpretations for the same standard. I also present new high-precision $^{40}Ar/^{39}Ar$ ages of 125.8 ± 1.0 Ma and 126.0 ± 0.8 Ma for two basaltic samples from the Lujiatun Unit. This study refutes the widely accepted stratigraphic correlations for the Yixian Formation. The age result indicates that the Lujiatun Unit was deposited contemporaneously with the Jianshangou Unit. This study provides significant clues for reconstructing sedimentary environment for the fossil-rich Yixian deposits. The results will further strengthen the regional correlations and chronostratigraphic framework of Cretaceous nonmarine strata in East Asia and resolve fundamental biologicalquestions concerning dinosaurian evolution and paleobiogeography.The research may thus have fundamental implications for biologic evolution and the geologic circumstances that influenced major cladogenetic events.

TREATING SCIENCE OUTREACH AS EXCHANGE RATHER THAN BESTOWAL

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Engaging underrepresented communities in STEM is a two-fold challenge- we must find effective ways to engage while also ensuring that to become and stay engaged, minority students are able to maintain an active relationship with their community. Leading literature on increasing diversity in STEM describes the agenda as justified by the fact that science requires teams of people with diverse backgrounds and perspectives. To successfully enter and stay in the STEM "pipeline," however, many minority students must largely assimilate and conform to the cultural and cosmological perspectives of western science. This is not only harmful for these students, but invalidates the stated goal of nearly every initiative to increase diversity in the sciences. Similarly, approaches and attitudes that often accompany typical science outreach to underserved

communities may work against communicating the scientific concepts themselves- concepts which, on average, are often already understood via different structures of knowledge or tradition within these communities. To effectively engage and serve these communities, it is therefore necessary to not only teach, but empower people to integrate their own perspectives on knowledge and understanding of the natural world.

To engage underserved communities and students, many new initiatives are using storytelling, communal activities, and kinaesthetic learning. But as we move forward in using these "new" techniques, it is important to recognize these approaches as far from novel for many communities. It is thus salient to root these approaches in what many communities have practiced for generations, to which western pedagogy has only recently caught up. Integrating these principles with the local practices of a given community via active collaboration with community members can be highly effective- treating science outreach as an exchange rather than a bestowal.

To this end, I have been working with local outreach groups in MT to run activities for kids from local Native reservations. The activities integrate their knowledge of local species with movement exercises that promote a focus on homology, structure-function, and relatedness to other animals. I am also developing an interactive exhibit of wear-able "exoskeletons," allowing a diverse range of participants to directly experience the movements of other vertebrates. Finally, I am in the early stages of creating a program to involve local tribal communities with active paleontological field sites on their land, as a means to encourage science education while simultaneously addressing the lack of indigenous land sovereignty and seeking to assuage the often-negative relationship paleontology has with indigenous peoples. Based on feedback and observations from outreach activities and the early stages of these projects, it appears this integrative approach is effective at creating an exchange which enriches both underserved, diverse communities and scientists alike.

BIRD TO THE BONE: TRABECULAR STRUCTURE IN THE WING VARIES ACROSS FLIGHT MODES

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To understand the evolution of avian flight, it is necessary to resolve the functional morphology of the flight stroke. Recent success in this approach on wing bones has focused solely on the cross-sectional geometry of cortical bone at the midshaft. However, a full understanding of the functional morphology of flight (i.e. joint loading, kinematics, structural adaptation) requires a more holistic approach. Though birds have long been admired for having "lightweight" bones with specialized "reinforcements," very little work has been done to investigate the substructure of the avian wing. This substructure is mainly represented by a spongey matrix called trabecular bone, which has a turnover rate four times higher than cortical bone and has been shown to structurally adapt to an organism's function throughout its lifetime. It can thus reflect subtler and more kinematically-specific functional signals that correlate with behavior. While this approach has led to major discoveries in mammalian biomechanics and fossil interpretation, trabecular morphology in relation to avian flight has yet to be explored. We used existing kinematic and mechanical data from various species to model the loading regime for different flight modes. We then collected high-resolution microCT scans of the humerus across a broad, comparative set of avian museum specimens (51 species) including four corvid species (n=5-6) which vary in flight mode on a continuum from flapping to soaring. Segmentation was performed on whole bones and trabecular parameters were measured for the humeral head. A new parameter (Trabecular Extent, Tb.Ex) was developed to holistically assess the relative extent of reinforcing substructure in the humerus. Across corvids, increases in trabecular thickness (Tb.Th), Ellipsoid Factor (EF), and the degree of anisotropy (DA) significantly covary with increases in gliding/soaring behavior. The same patterns were found in a preliminary analysis across the phylogeny, though Tb.Th was surprisingly high in Galliformes. Tb.Ex measurements and anatomical observations across the phylogeny suggest there may be a structural trade-off between cortical and trabecular bone which scales allometrically. Overall, our results show strong functional signals in the trabecular matrix of the proximal humerus, which are congruent with expected differences in joint loading between more flap-based and more glide-based flight modes. Future work will continue to explore flight-related functional signals in the avian humerus and will more deeply explore the mechanical relationship between cortical and trabecular bone. Elucidating the relationship between trabecular structure and flight mechanics in the avian shoulder provides both significant insight

into extant avian flight and a fundamental resource for fossil interpretation across the avian lineage with regard to flight evolution.

OLIGOCENE-EARLY MIOCENE BIVALVE FAUNA OF KUTCH (WESTERN INDIA) AND ITS PALEOBIOGEOGRAPHIC IMPLICATION

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Kutch Basin preserves one of the most complete Cenozoic marine records of western India. The faunal record of Oligocene-Early Miocene formations is especially diverse and are characterised by numerous shellbeds. Biogeographically, the fauna belongs to the Western Indian Faunal province (WIP) that demarcates the eastern extent of Tethyan seaway during Aquitanian. In the late Burdigalian (~19Ma) the Tethyan seaway went through a closure near Arabian Peninsula, separating the WIP from the proto-Mediterranean fauna of the west. Hence, the faunal character during Oligocene-Miocene of Kutch is of great interest to document the faunal response of WIP to a closing seaway.

Late Oligocene-Early Miocene of Kutch is represented by three formations, Maniyara Fort (Bermoti Member - Chattian), Khari Nadi (Aquitanian) and Chhasra (Burdigalian), each consisting of multiple fossil rich units. Using the Sr isotopic values of calcitic shells, we determined the age of multiple shellbeds spanning these three formations. The Sr-based age of Maniyara Fort confirms a Chattian age (~24.4Ma) and Chhasra shows age range of Burdigalian (~17.3Ma). Upper shellbeds of Chhasra, however, shows an age of ~ 15.3Ma placing it to Langhian (Middle Miocene).

The carbonate rich units of these three formations yield a variety of marine fauna including foraminifera, molluscs, arthropods, corals, echinoderms and mammals. The bivalve fauna dominating the shellbeds consists of 22 species representing 12 families including arcidae, pectinidae, spondylidae, anomiidae, placunidae, ostreidae, lucinidae, carditidae, veneridae, limopsidae, pholadidae and teredinidae. The most abundant genera include *Ostrea*, *Amusiopecten*, and *Talochlamys*. The shellbeds of Maniyara Fort contain abundance of *Kuphus* which is absent from the rest. Three genera, *Crassostrea*, *Spondylus* and *Centrocardita* appear only in Chhasra. *Amusiopecten* is most abundant during Oligocene and declines sharply in the Early Miocene units. Although we observed a drop in bivalve diversity in the Khari Nadi, this might have been affected by small sample size. Both sedimentary features and the faunal assemblage indicate a reefal nature of Oligocene formation in contrast to the Early Miocene formations that shows shallow marine deposits with frequent siliciclastic input. The faunal composition did not change drastically during this interval, neither does it show any difference in the geographic range of the constituent taxa.

The Kutch fauna showed a relatively low taxonomic diversity as compared to coeval tropical localities, that might be a result of the inherent bias of our studied biota towards calcitic preservation and larger body size. Although we cannot completely rule out the influence of preservational artefact, our observation points to a steady endemic faunal composition of Kutch that remained unchanged for a span of 9 Ma (24 – 15 Ma) indicating to a relatively small influence of Tethyan closure on this fauna.

TRACE FOSSIL COMPLEXITY IN THE TERMINAL EDIACARAN PERIOD

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Trace fossils offer an independent line of evidence to evaluate the tempo and mode of animal diversification and ecosystem evolution at the Neoproterozoic–Paleozoic transition. Traditionally, Ediacaran trace fossils are thought to be typically horizontal, unbranched trails and burrows, which were made close to the sediment-water interface by simple animals grazing on microbial mats. In contrast, earliest Cambrian trace fossils show a substantially increase in diversity, disparity, and complexity, representing a wide variety of animal behavioral patterns. This perception, however, is being revised following several recent discoveries.

Abundant trace fossils and Ediacara-type body fossils have recently been found in limestone of the terminal Ediacaran Shibantan Member of the Dengying Formation (551–541 Ma) in the Yangtze Gorges area, South China. Our study shows that these trace fossils were produced by animals with various behavior patterns. Most Shibantan traces are simple horizontal or sub-horizontal burrows and trails, including forms that can be identified as *Helminthoidichnites*,

Torrowangea, *Planolites*, and *Palaeophycus* that represent relatively simple behaviors. However, more complex trace fossils have also been found in the Shibantan Member. These include (1) trackways produced by animals with paired appendages, (2) uniserially chained and aligned burrows, (3) screw-like traces similar to *Streptichnus narbonnei*, and (4) horizontal or sub-horizontal burrows connected with short vertical burrows. The latter group of trace fossils include *Treptichnus*, *Lamonte*, and an unnamed form of tadpole-like trace fossils. These trace fossils indicate that vertical burrows first emerged in the terminal Ediacaran Period. Together with recent discoveries of cloudinids in basal Cambrian strata and Cambrian-style tubular fossils in terminal Ediacaran strata, as well as a recent study showing relatively high ecological complexity in benthic Ediacaran communities, the Shibantan trace fossils indicate that the evolutionary and ecological divide at the Ediacaran-Cambrian boundary is less remarkable as traditionally thought.

WARM ARCTIC TEMPERATURES AND THE STRUCTURE OF CRETACEOUS MARINE ECOSYSTEMS

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The concept of temperate Arctic environments during Cretaceous greenhouse climate intervals is hard to comprehend since we live in an interglacial environment characterized by frigid polar temperatures. Warmer paleotemperatures would have played a role in shaping polar Cretaceous ecosystems, but only within the evolutionary context of the existing biota and available nutrients. Recent paleoclimatic constraints from organic biomarker proxies, including those based on glycerol dialkyl glycerol tetraethers (GDGTs), can be correlated with fossils from the Upper Cretaceous Kanguk Formation of Devon Island in the Canadian Arctic. Analyses of GDGTs extracted from marine and terrestrial sediments as well as marine coprolites suggest that sea surface temperatures (SST) in the Devon Island area ranged from ~12.6–20.6°C and terrestrial mean annual air temperatures (MAAT) were ~11.7–16.9°C during the Late Turonian/Early Coniacian to Late Campanian. Though these estimates may be skewed to warm month temperatures, it was considerably warmer than today's Arctic which can have average SSTs of ~-1°C and MAATs of ~-15°C.

Micro- and macrofossils from the Kanguk Formation include abundant, diverse marine diatoms, dinoflagellates and terrestrial palynomorphs, numerous coprolites and wood fragments, small numbers of sponges, lingulids, and decapods, and relatively few skeletal fossils of fishes, marine reptiles, and birds. Taphonomic biases limit preservation of calcareous and soft-bodied taxa, but the fossil assemblage offers insights on trophic interactions. It is notable that coprolites are abundant at the site despite the paucity of vertebrate fossils. Coprolite contents reveal two major feeding habits that indicate short food chains: planktivory and benthic feeding on invertebrates. The disparity in abundance of phosphatic coprolites and skeletal fossils may reflect seasonal influxes of non-resident taxa that traveled north to exploit flushes in primary productivity. In addition, *Teredolites* borings in wood reflect a transfer of resources from forested terrestrial habitats to the ocean.

In modern Arctic environments, cold temperatures slow growth and decomposition, inhibit the vertical growth of trees, and foster the growth of sea ice. However, photoperiodic extremes are the primary drivers of seasonality in polar ecosystems. Thus, fossils from the Kanguk Formation suggest that the surprisingly warm temperatures of the Cretaceous Arctic primarily influenced Cretaceous ecosystems by increasing the stature of terrestrial vegetation (and terrigenous input to the sea) and preventing development of sea-ice communities. Within this environmental setting, high levels of seasonal sunlight plus adequate nutrients apparently supported sizeable diatom blooms in the Devon Island area. Such episodic pulses in primary productivity anchored short marine food chains and likely supported a variety of resident and migratory heterotrophs, much like today's Arctic ecosystems.

THE EVOLUTION OF COMPLEX COPROPHAGOUS BEHAVIOR: ICHNOFOSSIL EVIDENCE OF BROOD PROVISIONING AND DUNG RELOCATION BY DUNG BEETLES IN THE LATE CRETACEOUS

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Most analyses of fossilized feces focus on reconstructing the diet of the fecal producer. However, it is also useful to examine evidence for consumption of the dung itself in order to gain a more comprehensive view

of ancient food webs. Fossil evidence for coprophagy can be subtle, but herbivorous dinosaur coprolites from the Two Medicine Formation of Montana are highly burrowed, and preserve portions of ancient dung-sediment interface. As such, they offer a rare opportunity to study patterns of terrestrial coprophagy in the Late Cretaceous. These specimens reveal numerous 1–30 mm diameter burrows within and below the dung deposits. Previous work concluded that the backfilled burrows were made by dung beetles because they resemble modern dung beetle burrows and because dung relocation is archetypal dung beetle behavior. New analyses of the specimens now show varied dung relocation patterns and evidence for nesting activities that reflect active and complex dung beetle communities in the Cretaceous.

The dung-filled burrows in the Two Medicine coprolites are distinct from Cenozoic *Coprinisphaera* ichnofossils that are also attributed to dung beetles. *Coprinisphaera* are rounded to pear-shaped chambers that are not associated with fossilized fecal matter. In contrast, the Two Medicine ichnofossils are meniscate, backfilled burrows packed with selected fecal particles or a mixture of dung and sediment. Many of these are isolated dung-filled burrow casts that are interpreted as individual provisioned brood chambers. The discovery of cavities within some of the brood masses suggests the presence of egg chambers or dung loss due to larval feeding. Other dung-filled burrows are partially or wholly emplaced within the dung mass itself. Most of the dung relocation patterns are similar to those displayed by extant dung beetles, but others do not appear to have modern analogs and may represent early behaviors that were subsequently abandoned.

Body fossil evidence for the earliest dung beetle activity is inconclusive because behavior cannot always be correlated with morphology. Hence, early discussions about the ecological importance of dung beetles often focused on the presumption that they co-evolved with mammals. However, the burrowed Two Medicine Formation coprolites indicate that dung beetles had established mutualistic relationships with dinosaurs by the Late Cretaceous, and had already developed different brood mass preparation strategies. The Cretaceous evidence for extensive dung burial also indicates that dinosaur feces were valued resources that warranted protection from other coprophages by sequestration within the sediments. The compound trace fossils from the Two Medicine Formation thus document the emerging role of dung beetles as ecosystem engineers in the Cretaceous landscape. Development of this sophisticated coprophagous behavior represented a key evolutionary step in the utilization and dispersal of large vertebrate dung.

THE EVOLUTION OF ARTHROPOD SEGMENTATION AND TAGMATIZATION – LINKING EMBRYOLOGICAL DATA WITH THE FOSSIL RECORD

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The segmented body plan is one of the hallmarks of arthropod structure. Morphological segments are formed during insect embryogenesis, through a complex procedure involving the activation of a series of gene regulatory networks. Our understanding of the genetics of this process originally stems from work on *Drosophila melanogaster*from the late 1970s and onwards. In *Drosophila,* there is a relatively detailed model for the network of gene interactions that proceeds in a sequential-hierarchical fashion to define the main features of the body plan. Over the years, we have a growing understanding of the gene regulatory networks involved in defining the segmented body plan in an increasing number of arthropod species. Despite the homology of segments across all arthropods, there are significant differences in the way they are formed. It is now becoming possible map the conserved and divergent aspects of segment generation and to try to reconstruct the evolution of the process. For example, in many species, anterior segments are generated simultaneously during an early developmental stage, whereas posterior segments are generated sequentially from a posterior growth zone during the germband stage. Furthermore, the different modes of segment generation are often linked to specific morphological tagmata, and may be at the core of some of the morphological differences among higher level taxa within the arthropods. Intriguingly, despite this difference in segmentation mechanism, many of the same genes are involved in both processes. Thus, the evolution of segment generation mechanisms within arthropods is based not on novel genes, but on differential regulation of conserved genes.

The early arthropod fossil record provides evidence for a sequential acquisition of segmental characteristics as well as a sequential differentiation of specific tagmata. These gradual evolutionary changes were driven by changes in the developmental processes defining them. By surveying the conserved and variable aspects of the segmentation process in different

tagmata over a range of arthropod taxa it is possible to highlight potential developmental transitions that could be linked to key events in the evolution of the arthropod body plan.

COMPUTATIONAL FLUID DYNAMICS OF ARCHAEOCYATHAN SPONGES FROM THE CAMBRIAN FORTEAU FORMATION OF SOUTHERN LABRADOR

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During the early Cambrian (530 Ma), the archaeocyathans emerged and became one of the earliest animal reef builders before slowly declining to extinction by the end of the Cambrian. These calcareous filter feeders provide an opportunity to study early animal reef ecosystems dominated by sponges rather than the diverse array of corals that currently dominate our modern oceans, and further provide us with insight into the evolution of filter feeding in reef-building organisms. Toward the end of their prevalence as reef builders, a collection of reef mounds constructed of Irregulares archaeocythans were preserved in the pink cliffs from the Forteau Formation located on the coast of the Strait of Bell Isle in southern Labrador. These represent some of the best preserved examples of Cambrian reef mounds in the world. Uniquely, these reef mounds are created almost entirely by a single species of archaeocyathan, *Metaldetes profundus*, which show a great variety of growth morphology ranging from branching sticks to flat plate-like forms. We use computational fluid dynamics (CFD) of 3-dimensional models to describe how fluids moved through these organisms, to examine their filter feeding techniques, and to explore why this single species dominated its ecosystem, and why its morphology was so diverse.

USING DIGITALLY CONSTRUCTED ENDOCASTS TO EXAMINE THE RELATIONSHIP BETWEEN DIET AND NEUROANATOMY IN PHYLLOSTOMID BATS

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New World leaf nosed bats (Phyllostomids) are a diverse family with members exhibiting many specialized skull morphologies to accommodate a variety of diets, including insectivory, frugivory, nectarivory, and hematophagy. This project examines the influence of diet on the evolution of the Phyllostomid brain through a comparative analysis of insectivorous species with those practicing herbivorous diets. The skulls of fourteen species were chosen from the 12 subfamilies of Phyllostomidae, as well as the families Mormoopidae and Pteropodidae to act as outgroups. All specimens were borrowed from the mammalogy collection of the Smithsonian Natural History Museum and scanned using the micro CT at Vanderbilt University. In order to quantify the variation in the olfactory bulbs the scans were used to produce digital models of the endocranial space. Accurate linear and volumetric measurements of the olfactory bulbs and brain can be gathered from these models for comparison between the selected species. By examining the variations of the olfactory bulb in Phyllostomids we will better understand how different diets can influence the evolution of the brain. We predict the olfactory bulbs to be larger in nectivorous and frugivorous phyllostomids as their diets rely heavily on the sense of smell. These methods can later be applied to fossil bats, as the construction of digital endocasts is often used to accurately analyze the brain morphology of prehistoric animals.

THE EVOLUTION OF THE FLIGHT FEATHER

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The successful evolution of flight from feathered dinosaurs to early birds took millions of years. At the core is the architecture of flight feathers, featuring hierarchical branches of rachis, barbs and barbules. We take molecular approach to study the development of these branches in chicken and other birds. One major feature is the bilateral asymmetric feather vanes. Through morphology analysis, transcriptome profiling and functional perturbations in regenerating chicken feathers, we show that mesenchyme-derived *GDF10* and *GREM1* are major controllers for the topologies of rachidial and barb generative zones. Their

interactions with the anterior-posterior WNT gradient establish the bilateral-symmetric vane configuration. Additionally, combinatory effects of *CYP26B1*, *CRABP1* and *RALDH3* establish dynamic retinoic acid (RA) landscapes in feather mesenchyme, which modulate *GREM1* expression and epithelial cell shapes. Incremental changes of RA gradient slopes establish a continuum of asymmetric flight feathers along the wing, while switch-like modulation of RA signaling confers distinct vane shapes between feather tracts. Another major feature is the formation of pennaceous feather vanes versus plumulaceous barbs branches. This is because of the formation of hooklet in the barbules. We show the formation of barbule types is controlled by the dermal papilla. In addition, we show how the topology of cortex and medulla in the rachis can be modified along the proximal distal axis and the consequence of the weakening of rachis by the loss of medulla in the frizzled mutant chicken. Integrating three levels of branches, the flight feather forms the unit for the evolution of the flight, accompanied by the changes of the whole remige tracts, wing skeleton, etc. to evolve different modes of flight.

A RICH BODY AND TRACE FOSSIL RECORD IN THE NUGGET SANDSTONE (LATE TRIASSIC) OF NE UTAH PROVIDES INSIGHT INTO BIOLOGICAL DIVERSITY AND ECOLOGICAL SEGREGATION IN AN ANCIENT EOLIAN ECOSYSTEM

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Although generally considered poorly fossiliferous, an intensive 15-year study of the Nugget Ss eolianite in NE Utah has yielded a diverse vertebrate and invertebrate fauna. The most widely represented record is of ichnofossils,but vertebrate body fossils, such as at the Saints and Sinners Quarry (SSQ), can be, locally, extraordinarily abundant (over 20K bones and fragments).

Arthropod traces dominate the dunefield fossil record. Trails and burrows of diverse size and complexity record the presence of scorpions, spiders, insects, and unidentified tracemakers. *Brasilichnium*, tracks made by small therapsids, are the only vertebrate ichnofossils in the dunefields, but can be locally abundant with 400+ tracks on one small exposure of a dune slip face.

In contrast, the interdunal trace fossil record is dominated by the tracks of theropod and prosauropod dinosaurs. They occur in moist, interbedded interdunal sandstone and siltstone intervals showing extensive dinoturbation. Many hundreds of tracks can be present at one site. Extensive carbonate lake beds, associated with large carbonate spring mounds, contain invertebrate traces and natural molds of small gastropods.

The SSQ, an interdunal lake deposit, has produced more vertebrate body fossils than all other sites in the Nugget Ss erg (and its equivalents the Navajo and Aztec Ss). It is overwhelmingly dominated by carnivorous forms. The remains of more than 120 individuals have been recovered to date, belonging to theropod (but not prosauropod) dinosaurs, pterosaurs, sphenosuchians, sphenodonts, procolophonids, and drepanosaurs, most new to science. While the first three could wander easily, the last three are of low vagility and indicate that the lake endured for a time and was not ephemeral.

Clearly the Nugget erg was a hostile environment but one far from devoid of life. Nugget Ss exposures (like those of its equivalents) are often of immense extent and challenging to prospect for fossils. Searches for fossil vertebrates should focus on interdunal deposits. These are horizontally bedded, in contrast to the large-scale crossbedding of the dune deposits. Interdunal beds range from mudstones to pure, well sorted sandstones. They often occur at bounding surfaces or sandwiched between dune deposits. Fortunately, these interdunal beds can often be seen from a distance and targeted for investigation.

Our experience in the Nugget Ss indicates that an astounding fossil record is present in a formation classically viewed as very poorly fossiliferous. We fully expect that bone beds like the SSQ are more common than suspected in the Nugget and its equivalents. Persistent, targeted field work will greatly improve our knowledge of the diversity and evolution of the creatures that lived and thrived in an erg ecosystem that covered up to 2.2 km^2 of the western United States for tens of millions of years.

PHANEROZOIC TRENDS IN BIOTURBATION INTENSITY AND CONSEQUENCES FOR BENTHIC ORGANISMS

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Bioturbation introduces water into the substrate, which makes the seafloor softer and less hospitable to sessile surface-dwelling organisms. Modern marine sediments are pervasively bioturbated, and bioturbation was effectively absent prior to the Phanerozoic, but trends during the Phanerozoic are poorly constrained. Ichnofabric index and shell-bed thicknesses suggest an increase in bioturbation in the Cambrian and early Paleozoic and another increase in the mid-Mesozoic. But did bioturbation actually increase in a two-stage pattern? To evaluate bioturbation intensity, we performed text mining of the published literature with GeoDeepDive to extract mentions of ichnogenera that could be associated with named stratigraphic units. We categorized the reworking mode represented by the ichnogenus and matched stratigraphic names to units in Macrostrat to measure trends in average reworking mode through time. Average reworking mode exhibited the same two early Paleozoic and mid-Mesozoic increases inferred from ichnofabric and sedimentological evidence, but with little trend in the Devonian-Jurassic or after the Cretaceous. These results suggest a two-stage increase in bioturbation intensity, with modern levels not reached until the Cretaceous. Increases in bioturbation contributed to declines in sessile marine organisms and morphological adaptations in surviving groups. Brachiopods were especially affected, largely disappearing first from siliciclastic and later from carbonate substrates during the Jurassic and Cretaceous. During this time, terebratulide brachiopods also evolved from an unattached, reclining lifestyle to morphologies suggesting closer pedicle attachment to hard substrates. The two-stage increase in bioturbation was a major pressure on macroevolution, contributing to the pronounced shift from epifauna- to infauna-dominated marine ecosystems.

EARLIEST PUERCAN 1 (PU1) FAUNAS FROM MONTANA WITH HIGH-RESOLUTION INSIGHTS ON MAMMALIAN FAUNAL RECOVERY AFTER THE K-PG MASS EXTINCTION EVENT

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The Cretaceous-Paleogene (K-Pg) mass extinction was a pivotal event in mammalian evolution. All three North American clades (multituberculates, metatherians, and eutherians) survived the event, but eutherians became the numerically and taxonomically dominant clade within one million years (Ma). The Hell Creek area of eastern Montana is an excellent study system to resolve local fine-scale patterns of the K-Pg recovery and eutherian radiation. It has a sequence of fossil localities in the Hell Creek and Tullock formations within a high-resolution temporal framework spanning the last ~2 Ma of the Cretaceous and the first ~1.2 Ma of the Paleogene. Here, we track changes in taxonomic composition and diversity within earliest Paleogene mammalian faunas from the Hauso Flats and Hell Hollow areas of Garfield County, MT. We recovered mostly isolated mammal teeth via surface collection and underwater screenwashing of the Herpijunk, Morales 1, and Carrie Padgett localities. The first two localities are from a channel complex that cuts through the K-Pg boundary clay layer, and the third is from a channel complex that in places cuts through the Hell Hollow channel and the K-Pg boundary clay layer. The localities are bracketed in time by the IrZ-Coal and HFZ-Coal and fall within the first ~80 Ka of the Paleogene. Stratigraphic mapping implies Herpijunk and Morales 1 are older than the Carrie Padgett localities. The assemblages from Herpijunk and Morales 1, the multituberculate *Mesodma* spp. and cimolestid *Procerberus formicarum* have the highest relative abundances. Other typical Pu1 species present include the multituberculate *Cimexomys minor*, metatherian *Thylacodon montanensis*, cimolestid *Puercolestes simpsoni*, and the archaic ungulates *Baioconodon nordicum* and *Mimatuta* sp. In comparison, a sample from the Carrie Padgett localities has similar relative abundances of *Mesodma* spp., but higher relative abundances of the metatherian *Thylacodon montanensis* and the archaic ungulate *Oxyprimus erikseni*. Other eutherians present in the sample include *Procerberus formicarum* and *Protungulatum donnae*. Our results support a mammalian recovery model in which older Pu1 localities have high relative abundances of disaster taxa (*Mesodma* spp.) and low richness and relative abundances of archaic ungulates. High temporal resolution analysis of post-K-Pg mammalian faunas will continue to shed light on this faunal recovery and radiation and, more broadly, models of ecosystem recovery.

DEPOSITIONAL ENVIRONMENTS AND PALEOECOLOGICAL ASSEMBLAGES OF A COMMON LATE

TRIASSIC SHELL BED-FORMING BIVALVE (MONOTIS) IN NEW ZEALAND

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Late Triassic shell-beds from New Zealand are unique not only for their paucispecific density but also for their frequency at certain localities especially in the North Island, commonly composed of *Monotis* or *Manticula*. However, in the South Island, the highly abundant genus *Monotis* is observed in assemblages that vary significantly with regard to diversity and abundance. Here we report on the lithology, fossil assemblage, and preservation of several Late Norian *Monotis* deposits from localities in the North and South Islands of New Zealand in order to yield insights into shell bed-forming processes and ecological dynamics.

Monotis is a genus restricted to Late Norian strata (Late Triassic, ~220-228 Ma). At least five subgenera and eighteen species are recognized from Late Norian marine deposits in New Zealand. The hyperabundance of *Monotis* in shell beds and fossiliferous deposits can obscure the surprising diversity of species and shell morphologies both within the genus and within samples.

Samples collected from across the southern South Island and western North Island of New Zealand indicate that the *Monotis*-dominated assemblages exhibit a variety of preservation modes, within-genus diversity, and abundance; however, the assemblages are frequently found in deposits with highly consistent sedimentary features. These environments occur primarily as lenses in Warepan strata and preservation styles vary across the study area. Similar environments of deposition for *Monotis* shell beds and non-shell beds is suggested by very fine to fine sandstone lithology of both deposits. Development of shell beds and abundant *Monotis* deposits in Warepan sandstones are not consistent across the study area indicating that these environments were not laterally extensive. These results suggest that *Monotis* populations may have been controlled by biotic or geochemical factors that varied within a fairly consistent depositional environment range and could yield important insights into Late Triassic ecological dynamics of competition and predation.

CARBON ISOTOPIC ANALYSES OF SINGLE ORGANIC-WALLED MICROFOSSILS ACROSS THE LATE DEVONIAN KELLWASSER INTERVALS IN NEW YORK STATE REVEAL A STRONG BIOLOGICAL PUMP

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The vast majority of carbon isotope measurements are done on bulk samples measuring either total inorganic or organic carbon. While these data have illuminated vast intervals of Earth's history, they provide a time- and community-averaged view of the carbon pool. This lack of resolution limits our ability to use these measurements to reconstruct short-term carbon cycle dynamics and to fully probe the structure of ancient ecosystems. Organic carbon isotope analyses of single microfossils are one approach that can provide a window into short-term environmental variability and can reveal ecological data about enigmatic organic fossil groups. We have developed new analytical techniques that allow us to measure individual organic microfossils with less than 20 nanomoles of carbon using a modified elemental analyzer coupled to a stable isotope mass spectrometer. Here, we apply this new technique to organic-walled microfossils (OWMs) and chitinozoans from the Upper and Lower Kellwasser events in Upstate New York, which are black shale intervals associated with the Late Devonian Biotic Crisis.

The difference between the microfossil and kerogen values, $\Delta^{13}C$, varies between sections and between samples, but microfossil values are consistently heavier than bulk. We see no differences in $\delta^{13}C$ between different morphological groups of OWMs. Instead, our data suggests that all OWMs are sampling a pool of DIC with a distinct isotopic signal and are ecologically distinct from the organisms that supplied most of the bulk organic matter. Chitinozoans have values in between OWM means and bulk. We hypothesize that the offsets we observe could be the results of a strong biological pump leading to a large $\delta^{13}C_{org}$ gradient with shallow ^{13}C-enrichment and ^{13}C-depetion at depth. If OWMs were assimilating carbon in the surface ocean, they will have an enriched $\delta^{13}C_{org}$value, whereas chinitozoans, perhaps living in deeper waters, would be more ^{13}C-depleted. The bulk $\delta^{13}C_{org}$value would be lighter still because it represents the averaging of carbon fixed in the entire water column, including lighter carbon from deeper in the water column and also perhaps biomass produced by processes with highly depleted signatures such as methanotrophy. Coupled with trace element, total organic carbon, and fossil abundance data, we suggest high productivity,

as evidenced by a strong biological pump, may have contributed to deleterious environmental conditions, including low oxygen, which played a role in the end-Devonian extinction.

A GENDER ANALYSIS OF THE PALEONTOLOGICAL SOCIETY: TRENDS, GAPS, AND A WAY FORWARD

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Gender disparities still exist in many STEM fields, including paleontology, despite decades of efforts to attract and retain women into STEM fields. These disparities are often more pronounced at the level of senior researchers. One way to identify both progress and continuing problems is by looking at trends in data. This study focuses on gender, inferred using the GenderizeR.io database from first names of Paleontological Society (PS) members, awardees, officers, and committee members for the years 2000-2018. Our results show that while the proportion of PS members with female-gendered names has remained relatively constant over our time interval of analysis, there has been a significant lag in PS awards to women, despite a constant pool of potential women awardees. We also find a notable increase in the proportion of PS committee and officer participation by women over the study interval. While increased participation by women is a positive trend, we note that many of committees in which women are proportionally over-represented relate to education, outreach, and diversity, yet they remain under-represented in other positions, most notable society President. We discuss the many factors leading to this trend including over-burdening of service for the relatively small number of senior women. This study does not address the persistent under-representation of people of color, LGBTQ people, and other dimensions of identity, but we hope that it serves as a focal point for future conversations within the discipline and the society.

PHYLOGENETIC PERSPECTIVES ON THE SELECTIVITY OF BACKGROUND EXTINCTION

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Species loss during both background and mass extinctions typically results in nonrandom, selective patterns of extinction, although different reasons may underly these patterns. During intervals of selective extinction, certain traits may buffer species from extinction and enhance survivorship, resulting in increased taxonomic longevity. As a result, identifying traits that contribute to extinction risk is useful for understanding the mechanisms driving differential extinction rates and heterogeneity in taxonomic durations. To this end, numerous studies have implicated factors like geographic range, larval dispersal, and environmental tolerance as common contributors to extinction risk, which has increased our understanding of modern and ancient extinctions. However, although correlations between single traits and taxonomic durations are informative, they likely underestimate the complexity of extinction risk. Notably, the effects of multiple, interacting factors and phylogenetic autocorrelation should be considered when studying extinction selectivity.

Here, I explore a variety of ecological, biological, and phylogenetic controls on genus longevity in the global fossil record of diplobathrid crinoids (Ordovician–Mississippian). A suite of analytical methods are employed using both taxic and phylogenetic approaches to (1) quantify the contributions of multiple, interacting variables to genus duration and (2) evaluate how interpretations differ when phylogeny is considered. Notably, it is often assumed that accounting for phylogenetic non-independence simply weakens the correlation between variables of interest, but comparatively few studies have applied phylogenetic approaches to extinction selectivity in the fossil record, so this may not hold true. To investigate empirical support for this assumption, I also present a compilation of studies using both taxic and phylogenetic approaches to assess the ways in which phylogeny can change interpretations of extinction selectivity.

By quantifying effect sizes, I identify species richness as the primary predictor of diplobathrid genus duration and lithologic environment as a significant secondary predictor. All traits considered as well as genus duration are found to have phylogenetic signal, indicating phylogenetic structure of traits in at least part of the diplobathrid tree. Although results are broadly similar between taxic and phylogenetic approaches, accounting for phylogenetic structure dramatically alters interpretations for some analyses. Contrary to common assumptions, I find incorporating phylogeny does not consistently weaken correlations between traits and duration; instead, both the strength and the direction of the relationship can change. These results show interpretations of extinction selectivity can be altered in unpredictable ways when phylogeny

is accounted for and highlight the importance of a comparative approach when investigating correlates of extinction risk.

BREAKING NEW GROUND: FORM, FUNCTION AND THE FOSSIL RECORD OF THE REPEATED EVOLUTION OF ROCK-BORING IN THE MARINE BIVALVIA

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It is an intuitively logical biological observation that related species often live in the same way, and that species very seldom change their fundamental life habits. This view is formalized as the principle of phylogenetic niche conservatism – related species tend to occur in similar habitats, and lineages track niches. Related species are also often morphologically similar, and morphology to a varying extent is related to life habit. But some species must, and demonstrably do, colonize new niches. The degree to which morphology constrains an organism to remain in its ancestral niche despite changing environmental conditions is a question of vital interest to biologists, policymakers, and the wider global community, especially given the current pace of climate change and the predictions of the IPCC.

A striking example of an autecological shift in an economically important group of animals is the repeated evolution of the rock-boring habit in the marine Bivalvia from a variety of infaunal and epifaunal ancestors, a transition that has occurred at least 10 unique times in the post-Paleozoic. This radical shift requires a suite of morphological alterations, some of which are potentially maladaptive for non-boring life-strategies, impeding reversals. It has been hypothesized that the resurgence of corals to serve as substratum, and pressure from the rise of durophagous predators, promoted evolution of boring bivalves. Both corals and high predator abundances are associated with warm climates.

To investigate the timing and magnitude of transitions to the boring habit in the Bivalvia, we use a phylomorphospace built from a database of 3D micro-CT shell scans, published molecular phylogenies, and occurrence data from the fossil record. Using this approach, we can evaluate the evolutionary consequences for disparity and diversification of colonizing the boring niche. In literally breaking new ground and escaping their various ancestral niches, boring lineages shift in morphospace, repeatedly but not universally converging on a cylindrical shape disadvantageous for most bivalve lifestyles, which may indicate boring to be an evolutionary dead-end. In no case does the species richness of a clade of borers exceed that of their non-boring sister group, indicating that this new niche, however advantageous in the short run, does not open opportunities for more prolific taxonomic diversification, and perhaps pointing to elevated extinction and/or damped speciation rates following the transition. However, many boring lineages are ancient and have survived extensive environmental changes and extinction events, including the end-Cretaceous extinction. New colonizations of the boring niche have arisen through geological time, and once established, boring lineages persist, despite low diversity.

AMATEUR AND PROFESSIONAL RELATIONSHIPS: HOBBY COLLECTING MEETS SCIENTIFIC RESEARCH

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Research at the professional level can pose challenges that require enormous amounts of time and energy beyond that which the paleontologist can handle individually. When such an event occurs, creative partnerships can solve the logistical problem and simultaneously serve to benefit both the amateur and the professional. Amateur collectors share a passion for fossils, and many are very good at the skill of finding, identifying, and collecting specimens. By organizing and utilizing the skills of the amateur collector, professionals can maximize their time in the field, as well as exponentially increase the number of specimens that a particular site might yield to research.

The University of Florida (UFL) Paleontologists have long championed the use of amateur collectors, and in 2018 the Special Friends of the Aurora Fossil Museum (SFAFM) teamed with the FOSSIL Project to search Miocene sediments from the Belgrade Formation at the Martin-Marietta Mine in Maysville, NC. The mine officials cooperated in this venture, and selectively removed and safely set aside 160 tons of the sandy Belgrade Formation from the Belgrade stratigraphic layer. Twenty volunteer collectors spent 6 hours digging and sifting (¼ inch mesh) for 100% visual size fossil removal from the piles. The project participants,

involving citizen scientists from five states, were aware in advance that all finds would be the property of the UFL, and willingly donated 100% of the screened fossils. A number of buckets of the screened material were taken back to UFL for microfossil analysis. Those participating in the project were required to log on to a pre-collecting webinar hosted by UFL and the FOSSIL Project. The viewers were introduced to:

1. The purpose for the study
2. Geological stratigraphy of the mine
3. Methods for collecting
4. Safety issues
5. Procedures for labeling and bagging specimens

Preliminary results have indicated that over 1500 fossils were found on site.As expected most of the specimens were marine, but terrestrial fossils were also discovered and identified. Only a small percentage of the Belgrade Formation material was processed, and the remaining material has been protected by the mine officials, so that going forward, future collecting by SFAFM and select volunteer organizations will continue to produce educational research material for years to come.

THE IMPACT OF ENVIRONMENTAL PREFERENCE AND GEOGRAPHIC OCCUPATION ON DIVERSIFICATION AND SURVIVORSHIP DURING THE ORDOVICIAN MASS EXTINCTION

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The Late Ordovician mass extinction was the second largest mass extinction in the history of the Earth in terms of the percentage of species lost. Despite the high rates of extinction, few large clades were lost and recovery taxa were distributed broadly across the evolutionary tree, suggesting that the extinction may have had minimal impact on ecological interactions. However, phylogenetic studies of brachiopods, trilobites, and crinoids suggest that the Late Ordovician had a long-term impact on the shape of the evolutionary tree. While clades containing species that were ecologically abundant during the Ordovician survived the extinction event, they diversified at a much lower rate and were replaced by new or sister clades that originated in the Ordovician but were not as diverse or abundant. One possible explanation for this pattern could be that surviving taxa became restricted to a few environments or biogeographic provinces, and were unable to move or adapt as their preferred environment shifted throughout the Silurian. To test this hypothesis, we conducted a phylogenetic study of the Strophomenoidea, a diverse brachiopod group that was a major component of Ordovician ecosystems. We time-calibrated our phylogeny and used lithological locality data and geographic occurrence data to investigate the impact of environmental affinity and biogeographic occupation on survivorship patterns for the clade. Environmental affinity was estimated for each taxa using equations modified from Simpson and Harnik (2009) to generate a proportional variable that estimates the strength of environmental affinity for each taxon. These affinities were mapped onto the topology of the tree to investigate correlations between survivorship patterns and preferences in water depth or substrate. Biogeographic shifts through time using the R package BiogeoBEARS. Our results suggest that there may be some correlation between tropical distribution and evolutionary responses to the Late Ordovician mass extinction. Several diverse clades during the Ordovician originated in tropical/subtropical environments and remained within those environments throughout their entire history. These tropical/subtropical clades preferentially went extinct during the Late Ordovician, though the clade that ultimately diversified after the event also originated in these tropical/subtropical environments. Cosmopolitan taxa (whose ranges extend from high latitude to the tropics) survived the event but were restricted to higher latitudes until later diversifying in the Devonian. Our results corroborate previous studies showing increased extinction in tropical faunas during the Late Ordovician, but they also illustrate the importance of clade independent processes in shaping how life responds to mass extinctions and recovery events.

FOREST STRUCTURE DURING THE ECOLOGICAL EXPANSION OF FLOWERING PLANTS; EVIDENCE FROM THE SOUTHERN WESTERN INTERIOR

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The rise of flowering plants (angiosperms) in the Cretaceous transformed terrestrial ecosystems. The major patterns in the timing of diversification of angiosperm lineages and their increases in species richness within plant communities are fairly well known based on information from fossil floras. The patterns of their

ecological expansion and concordant changes in forest structure and functioning, however, are not well understood. This study generates new insights into an important interval in the spread of angiosperms and the turnover of plant communities, by providing a quantitative reconstruction of a diverse late Campanian (74.6 Ma) fossil flora from south-central New Mexico. This fossil flora is preserved in a 1.2 km long bed of fine-grained recrystallized volcanic ash, representing deposition from airfall on a floodplain. The flora is uncommonly diverse, with over 200 leaf morphotypes (~species) recognized from the deposit, of which 166 were recovered in quantitative censuses. The overwhelmingly majority (>84.0%) are non-monocot angiosperms ('dicots'). Censuses of 26 quarries spanning the deposit (totaling over 7,362 specimens and 34,606 2-cm line increments) show that angiosperms are the most abundant plant group across the landscape (74.3% of specimens, 83.4% cover), followed by conifers, and low abundance cycads and ferns. Although dicots represent a significant proportion of the flora overall (48.9% specimens, and 39.6% cover), the two most abundant individual taxa are a sequoioid conifer (redwood) and *Zingiberopsis*-type monocot (ginger), resulting in a strong dominance structure in the community. Other common elements include the costapalmate palm *Sabalites*, a *Brachyphyllum*conifer, and the dicots *Platanites*and *Dryophyllum*. Most other taxa in the flora have localized distributions, with over 84% of species occurring in less than three quarries. As a result, the flora exhibits high spatial heterogeneity. Overall, the flora is one of the most diverse leaf macrofloras known from the Cretaceous, with species richness similar to the hyper-diverse Castle Rock paleo-rainforest from Colorado (63.8 Ma). It is the oldest leaf macroflora to quantitatively demonstrate angiosperm dominance by both species richness and relative abundance across a floodplain.This early occurrence of angiosperm dominance in the megathermal belt of the southern Western Interior is consistent with previously suggested trends of angiosperm radiation from lower latitudes and warmer climates. The floral reconstruction demonstrates that angiosperms coexisted with conifers in highly heterogeneous mixed vegetation. This no-analog flora therefore provides novel insights into the structure of forests in warm-wet climates during an important transitional period in Earth's history, one that captures the early phases of the taxonomic and ecological radiations of major animal and plant groups that account for modern biodiversity.

SYNCHRONIZED MOLTING BEHAVIOR IN EARLY CAMBRIAN TRILOBITES

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Currently, there are many studies focus on the molting procedures in social and semi-social groups of modern animals (e.g. arthropods). Such studies mainly deal with the causes behind the associated behaviors and metabolic processes. One of the most significant social molting adaptations is the synchronized molting, where a large group shed the carapace periodically at the same time.

The study of molting behavior in the fossil record is relatively well known in arthropods and this is especially true in trilobites. Nevertheless, very few works deal with molting adaptations in deep time. This is likely as consequence of a taphonomic and/or sampling bias. We can tackle this problem with a large fossil assemblage which allow us to carry out a quantitative analysis.

Here we report a trilobite assemblage from the Tsinghsutung Formation in the early Cambrian of South China. Around 850 specimens were used for this study from three different levels in two sections near Balang (SE Guizhou Province, South China). These three levels present trilobite clusters in some cases with about 400 specimens. Clusters have two species, although one of them is predominant and sometimes one additional species can be found within the clusters. The specimens are well preserved as external or internal molds. Trilobite clusters show a high percentage of articulation, *ca*. 90 per cent. However, free checks and segments are in some cases slightly dislocated. This supports that they are not carcasses but molts. No preferable flow direction was found on the clusters. This is associated with a very quiet water conditions followed by rapid burial events; prior to scavenger disturbance. Since the trilobite assessable seems to be in situ, the large number of exuviae suggests a local place of migration. This was triggered by the need of a group protection while molting, which is suggesting a gregarious behavior likely synchronized.

These trilobites from the Stage 4, Cambrian Series 2 constitute the earliest known gregarious community of arthropods in the fossil record. This has important implications to understand ecology during the early

Cambrian since they could represent the first synchronized molting adaptation in the fossil record.

INTEGRATING PALEOECOLOGICAL, HISTORICAL, AND ECOLOGICAL DATA TO ASSESS THE TIMING AND CAUSES OF THE LOSS OF ACROPORID CORALS IN THE CARIBBEAN

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Since the systematic monitoring of Caribbean coral reefs began in the late 1970s, researchers have documented a mass mortality of the previously-dominant staghorn (*Acropora palmata*) and elkhorn (*Acropora cervicornis*) corals that has transformed these reefs from coral- to macroalgal-dominated habitats. The loss of *Acropora* has been variously attributed to coral disease and bleaching caused by anthropogenic climate change, sea urchin disease, overfishing, and land-based pollution, but the relative influence of these factors is unresolved due to the dearth of pre-1970s data. We used paleoecological, historical, and ecological survey data to track *Acropora* presence and dominance throughout the Caribbean from the pre-human period (Late Pleistocene Epoch, approximately 125,000 ya) to present (2011 AD) to assess the initial timing and root cause(s) of the loss of these corals. Declines in dominance from pre-human values first occurred in the 1950s for *A. palmata* and the 1960s for *A. cervicornis*, decades before outbreaks of acroporid disease or bleaching or sea urchin disease. We compared trends in *Acropora* dominance since 1950 to proxies of regional and local potential drivers of coral loss, and found that declines in dominance were related to human population density andfertilizer use for agriculture. The earlier timing and local roots of *Acropora* loss demonstrate the urgency of mitigating the local stressors that threaten Caribbean reefs, particularly land-based runoff.

SYNCHRONOUS CHANGES OF SPECIATION AND EXTINCTION IN MID-PALEOZOIC ZOOPLANKTON: "INSTANTANEOUS" COUPLING OF MACROEVOLUTIONARY DYNAMICS

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Temporal and causal relationships between extinction and speciation are key to understanding macroevolution. These relationships are difficult to study because they manifest on multi-millennial time scales that lie between the short-term, highly resolved time series available to biologists, and the long-term but low-resolution data available in the fossil record. Here we report on long (~60 myr) and relatively high resolution (~25-50 kyr) time series of speciation and extinction rates for globally distributed, Ordovician-Silurian graptoloid zooplankton that go some way towards bridging this disconnect between paleontological and biological data.

Using these data, a recent study (Foote et al., 2018 Proc Royal Soc B) demonstrated negative diversity-dependence in macroevolutionary rates, such that net diversification in the graptoloids responded to standing diversity, with maximum response at a temporal lag of 1 myr and approximately equal effects in speciation and extinction. This finding is inferred to reflect the roles of competition and other biotic interactions in shaping total diversity amongst ecologically similar species.

In addition to this relatively slow linkage between diversity and macroevolutionary rates, we now find that there was also rapid and positive coupling between speciation and extinction rates that was, in geological terms, almost "instantaneous"— with a response time of less than 25 kyr. This correlation explains approximately 16% of the variance in each time series and is highly significant statistically ($p < 0.001$, accounting for the effects of autocorrelation).

We infer that this result may indicate a common and more-or-less synchronous response of speciation and extinction to environmental forcing. Abiotic forcing is implied by records of carbon-isotope fluctuations (Cooper et al., 2014 Geol. Mag) and the recognition of Milankovitch-frequency variations in macroevolutionary rates (Crampton et al., 2018 PNAS). We hypothesise that following environmental change, and over a time lag of ~1 Myr, many newly evolved species were preferentially driven to extinction by diversity-dependent biotic interactions. This diversity dependence may explain the observed, background

age-dependent extinction bias against newly evolved species (Crampton et al., 2016 PNAS), since these species will tend to have smaller geographic ranges and thus higher extinction probabilities than old species, and may lack the benefits of ecological incumbency.

These interpretations require testing in other groups but, if correct, may suggest short characteristic time scales (< 25 kyr) of adaptive, evolutionary response to environmental change and, in contrast, relatively long time frames of diversity-dependent response, at least in the case of widespread plankton at the spatial scale of entire ocean basins.

GINKGO: AN EVOLUTIONARY AND CULTURAL BIOGRAPHY

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Ginkgo biloba is a botanical oddity and one of the world's most distinctive trees. It is the last living species of a group of plants that was diverse and widespread in both northern and southern hemispheres through much of the Mesozoic. However, the Late Cretaceous and Cenozoic history of ginkgo is one of progressive restriction, beginning with the loss of ginkgo-like plants from the Southern Hemisphere in the early Cenozoic, and then, within the last few million years, regional extirpation from Europe, North America and most of Asia. Evidence from molecular biology suggests that after the last glaciation ginkgo survived only in relictual populations, in central, eastern and southern China. The subsequent resurgence and global spread of ginkgo has been driven by cultural processes, which are first recorded about a thousand years ago. Initial human interest in ginkgo focused on its edible seeds and since then the consumption of ginkgo 'nuts' has spread to other parts of eastern Asia. At the same time, ginkgo became beloved for the elegance of its leaves, revered for its longevity, and also has a strong presence in the temples and shrines of China, Japan and Korea. In the twentieth century ginkgo has become one of the world's most widely planted street trees, as well as a source of a popular herbal medicine.

The longevity of the ginkgo lineage, its near extinction, and its resurgence in association with people raises interesting issues about contemporary approaches to managing the future of plants – including the practice of ex situ plant conservation and current international biodiversity policy. In a very real sense ginkgo is gift of China to the world. Equally, however, the paleontological history of ginkgo shows that this remarkable plant is also a gift of the world to China. Ginkgo is part of a deep evolutionary heritage to which human-made boundaries are irrelevant. Similarly, the timescale of ginkgo's life story - hundreds, thousands, millions, tens of millions, hundreds of millions of years - while not easy for us to grasp, is most certainly relevant to the way we should think about ourselves, and our place in the world. These timescales help calibrate the speed of current environmental change, reminding us to consider the environmental legacy that we received and that we will leave. Trees, especially long-lived trees like ginkgo that also connect us to the deep history of our planet, ask us to reflect more often and think more carefully about all we lose when the short view rules our world and everything in it.

EARLY MARINE ECOSYSTEM ENGINEERING RECOVERY AFTER THE END-PERMIAN MASS EXTINCTION

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The End-Permian mass extinction has been recognized as the most severe extinction of the Phanerozoic and is associated with a recovery interval which may have been delayed until the start of the Middle Triassic. Previous work on the timing and pattern of biotic recovery in the Early Triassic has given much attention to the body and trace fossil record, but, to date, less focus has been given to analyzing patterns in ecosystem engineering behaviors preserved in the trace fossil record during the recovery interval. However, the timing of recovery of bioturbating animals as ecosystem engineers may be a critical factor in understanding the full recovery of marine ecosystems after the mass extinction event. For this study, we created a dataset compiled of trace fossils reported from previously published literature and in the Paleobiology Database to study changes in ecosystem engineering patterns across the Permian-Triassic boundary. We utilize two different methodologies to characterize these changes. One analysis focuses on characterizing potential biogeochemical effects which result from changes in the type and amount of sediment disturbance, while the other analysis focuses on quantifying the number of ecosystem engineering behaviors present at different tiers in the sediment. The results of both of these analyses show a bioturbation depth collapse which persists into the Middle Triassic, but complex ecosystem engineers recover more rapidly

in the Early Triassic. The persistence of ecosystem engineering behaviors which have high impact on sediment chemistry and biogeochemical cycling suggests the potential for burrowing animals in the Early Triassic to ameliorate the environmental conditions caused by the extinction.

CAMBRIAN-TYPE METAZOAN ECOSYSTEM ENGINEERING IN THE TERMINAL EDIACARAN NAMA GROUP, NAMIBIA

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The Ediacaran Period (635 – 538.5 Ma) represents one of the most important intervals for life in Earth history, marking the first appearance of ecosystems dominated by large, complex multicellular eukaryotes known as the Ediacara biota. Moreover, the evolution of the earliest metazoan ecosystem engineers occurs with the advent of bioturbation during the Ediacaran. During the Cambrian, the diversification of burrowing behaviors resulted in the Cambrian substrate revolution, where substrate rheology and sediment geochemistry were altered globally. However, the timing of the evolution of ecosystem engineering behaviors during the Ediacaran Period is currently less well understood. The Nama Group in southern Namibia is a mixed siliciclastic-carbonate succession of the terminal Ediacaran with a diverse trace fossil record. Using point-counting techniques to estimate bioturbation intensity and two different ecosystem engineering analysis frameworks to characterize impact and complexity, we find that the Nama Group trace fossil record exhibits three key patterns. First, bioturbation intensity gradually increases towards the Cambrian boundary, but the most substantial increase occurs in the Cambrian. Second, trace fossils representing complex ecosystem engineering behaviors are present during the Ediacaran and increase in abundance towards the Cambrian boundary. Third, the level of complexity and environmental impact of ecosystem engineering exhibited in the Cambrian is present (in the Nasep Member) below the Ediacaran-Cambrian boundary. These results suggest that bioturbation-induced changes to substrates which would affect ecosystems and influence biogeochemical cycling began during the Ediacaran, prior to the Cambrian substrate revolution. Furthermore, these results have implications for both the extinction of the Ediacara biota and the subsequent diversification of metazoan life during the Cambrian.

TRACE ELEMENTS AND INTERSTRIAL DISTANCES AS ENVIRONMENTAL AND ANTHROPOGENIC PROXIES IN THE ANTARCTIC SCALLOP, *ADAMUSSIUM COLBECKI*

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The Antarctic scallop *Adamussium colbecki* may be a crucial paleoenvironmental proxy for coastal Antarctica. For example, two highly seasonal environmental parameters, glacial melt and productivity, were linked to trace elemental concentrations in a previous bulk shell analysis and a transect spanning ~ 3 months of juvenile growth. However, neither study examined seasonal variation in trace elements or tied variation to distances between small ridges (striae) on valve surfaces, which may also vary seasonally. Striae and interstrial growth between them are expressed as alternating narrow and wide groups (presumably winter and summer growth, respectively). If tied to trace elemental concentrations, striae could provide high-resolution sclerochronological proxies for seawater conditions. Here, we evaluate whether trace elements archived in *A. colbecki* striae can be used as seasonal indicators of glacial influence and nutrients over *A. colbecki* ontogeny.

We examined trace elements from an adult and juvenile *A. colbecki* (shell height, 80.2 mm and 17.1 mm, respectively) collected live by divers from ~ 12 m water depth in Explorers Cove, western McMurdo Sound (2008 and 2016, respectively). Trace elements linked to glacial melt (Mg/Ca, Mn/Ca, Fe/Ca, and Pb/Ca), metabolism (Mg/Ca), and productivity (Ba/Ca) were sampled with an LA-ICP-MS on each stria along the central growth axis of lower (right) valves from umbo to growing margin. Distances between sampled striae were measured along the central margin (FIJI). Interstrial distances (ISDs) and trace elements were compared using wavelet coherence analysis (WaveletComp 1.1) and cross-correlation. Coherence and correlations that exceeded 95% significance are reported here. Coherence identifies areas of covariance between ISD and trace elements over ontogeny; cross-correlation describes the direction (±) of correlation between

ISDs and trace elements where coherence exists. We expected trace elements that increase with glacial melt (Fe, Mn, Pb), productivity (Ba), and altered metabolism (Mg) to be coherent and correlate positively with ISD (highest concentrations at wide summer striae) throughout ontogeny.

Preliminary results mostly do not conform to predictions. Though correlation remains consistently positive or negative under strong coherence, most elements are only coherent with ISD for short strial sequences (~ 8 striae) and only during adult growth. Of the elements associated with glacial melt, only Mn correlates positively with ISD and may be a potential proxy for seasonality. Other indicators of glacial melt (Pb/Ca, Fe/Ca) and productivity (Ba/Ca) correlate negatively with ISD. Mg/Ca correlates positively with ISD, indicating seasonal effects on metabolism. Ontogenetic variation in coherence urges cautious use of ISDs as proxies, but Pb/Ca (anthropogenic in Antarctica) is coherent with ISD throughout ontogeny; further analysis might illuminate seasonal effects of human activities on Antarctic ecosystems.

STUDY ON THE FORAMINIFERAL ASSEMBLAGES AND PALEOENVIRONMENT OF REEF FACIES SINCE THE QUATERNARY IN THE XISHA ISLANDS, SOUTH CHINA SEA

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As a kind of special carbonate platform, reef reservoirs have attracted much attention in petroleum exploration. The reefs, which were formed since Neogene, are widely developed in Xisha Islands. However, the research on the foraminiferal assemblages and paleoenvironment of reef facies during the Quaternary are still in infancy. High-resolution foraminiferal biostratigraphy sequences in the Xisha Islands are needed to be established, which is of great significance to the stratigraphic division and correlation of these reef facies and the reconstruction of their paleoenvironment.

A quantitative analyse of foraminiferal assemblages from well XK-1 in the Xisha Islands, South China Sea are carried out and 110 species in 55 genera of foraminifera from 76 samples are identified, including 90 species in 48 genera of benthic foraminifera and 20 species in 7 genera of planktonic foraminifera, which provide critical evidence for foraminiferal biostratigraphy and palaeoenvironmental interpretation of reef carbonate since the Quaternary. Based on that, four foraminiferal assemblages are recognized, respectively labelled as FA_1, FA_2, FA_3 and FA_4 in descending order. The abundance of foraminifera in FA_1 (0-7.25m) ranges from 1690 to 8981 individuals/25g and the simple diversity ranges between 28-65. *Amphistegina madagascariensis* d'Orbigny, *Calcarina calcarinoides* (Cheng & Zheng) and *Elphidium crispum* (Linnaeus) are the dominant species. FA_2 (7.25-22.30m) is remarkably increased compared with FA_1, the abundance of foraminifera mostly between 4490 and 10075 individuals/25g and the simple diversity generally ranges 42-58. The foraminiferal assemblages are dominated by *Dendritina striata* Hofker, *Amphistegina madagascariensis* d'Orbigny, *Heterolepa dutemplei* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny) and *Globigerinoides sacculifer* (Brady). In FA_3 (22.30-60.30m), the abundance of foraminifera mostly less than 300, and simple diversity less than 40, usually dominated by *Amphistegina madagascariensis* d'Orbigny, *Calcarina calcarinoides* (Cheng & Zheng) and *Calcarina hispida* Brady.FA_4 (60.30-213.35m) has relatively low abundances (mostly<100) and simple diversity (<20) and composed dominantly of *Elphidium crispum* (Linnaeus), *Amphistegina madagascariensis* d'Orbigny and *Pyrgo* sp.

These foraminiferal assemblages are well correlated to that in wells Xichen-1 and Xiyong-2 in Xisha Islands. Base on the lithofacies and distribution characteristics of foraminifera, FA_1 is interpreted as an assemblage from lime-sand-island facies because of the present of *Amphistegina madagascariensis* d'Orbigny and *Calcarina calcarinoides* (Cheng & Zheng), FA_2 is an assemblage from forereef shelf facies for the appearance of *Amphistegina radiata* (Fichtel and Moll), *Globigerinoides ruber* (d'Orbigny) and *Globigerinoides sacculifer* (Brady), FA_3 is an assemblage from reef frame facies and FA_4 is an assemblage from reef flat facies.

VARIATION AND ONTOGENETIC CHANGE IN THE HUMERUS OF *TRICERATOPS* (DINOSAURIA: CERATOPSIA)

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Although *Triceratops* fossils are abundant in latest Cretaceous rocks of western North America, including an increasingly large sample of juvenile and subadult material, many aspects of ontogenetic, and

morphological variation in this taxon remain poorly known. The postcrania in particular are incompletely documented relative to the more taxonomically diagnostic skull. Here, we examined shape variation in *Triceratops* humeri, to address two questions. First, how does *Triceratops* humerus anatomy vary with size (i.e., across individuals of presumably different ages)? Second, does this variation recapitulate overall evolutionary changes in ceratopsians? Studying the humerus of *Triceratops* in particular allows us to understand potential changes in function and size in *Triceratops* and compare these observations with those for other ceratopsians. We used geometric morphometrics to document shape variation in a sample of *Triceratops* humeri from the Frenchman, Lance, and Hell Creek Formations of western North America, representing a wide range of sizes (211 mm to 906 mm in maximum length). Landmarks were documented on 2D images of humerus specimens in dorsal view, intended to capture details of limb robusticity, deltopectoral crest proportions and changes in the size of the condyle. Tpsdig and Tpsrelw were used to digitize landmarks and analyze shape and size differences between sampled specimens, using relative warps. Between juvenile (small) and adult (large) specimens, the distal condyles become more robust and pronounced, and the deltopectoral crest also becomes more broader and more elongated. The central shaft of the humerus thickens, potentially in response to a growing deltopectoral crest and increased body size. Within large (presumed adult) specimens, there is variation in the width of the humeral head and the spacing of the distal condyles, unrelated to size variation. We suggest that more robust humeral features in the largest individuals relative to the smallest individuals is related to increased body mass as the animal grew. A similar trend of increasing robustness in the humerus has been previously documented across ceratopsian postcrania on a macroevolutionary scale, between smaller species and larger species.

THE PAST, PRESENT, AND FUTURE OF HONG KONG CORALS: HOPE FOR MARINE ECOSYSTEMS FOUND IN AN UNLIKELY PLACE

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Coral ecosystems are degrading worldwide. Regional anthropogenic and global climate stressors are decreasing both live coral cover and coral diversity at an alarming rate. Without assisted migration and/or restoration, certain coral ecosystems may be lost forever. But what goals do we set for ecosystem restoration? Can natural ecosystem functioning be restored or will we simply return it to a previously degraded state? Kidwell et al. 2015 has shown that restoration efforts benefit from historical baselines that illustrate the diversity and persistence of an ecosystem through time. In light of this recommendation, we present the first paleoecological study to investigate coral assemblages in southeast China, focused on Hong Kong during the Holocene. Results show that coral composition has shifted from an Acroporiid-dominated community in the past to a modern dominance of massive morphology with significant species diversity decline in southern Hong Kong. Water parameters in this southern region are dominated by the outflow of the Pearl River, the most rapidly developing river in the world. Conversely, eastern Hong Kong communities constitute an oceanic- rather than river-driven water system and exhibit greater resilience to these diversity shifts through time. We discovered that in the modern era, coral community composition is driven by local anthropogenic stressors derived from highly degraded water quality. Furthermore, our study highlights potential historical impacts dating back hundreds to thousands of years, uncovered by various archaeological efforts. For centuries, local Hong Kong miners dredged surrounding waterways for both live and dead coral to produce exportable slaked lime. We discuss the effects that this ancient lime industry had on local assemblages and together, our findings constitute the first known quantitative comparison of modern and historical baselines of a coral ecosystem in this region. This story illustrates that the marginal coral communities of Hong Kong, impacted by the physical extraction of mining, eutrophication, high sediment loads and turbidity for hundreds if not thousands of years, constitute useful analogs for the futures of other

similarly impacted reef ecosystems.

Our story concludes with our present efforts to restore these communities, utilizing our "inferred restoration" methods in conjunction with local government. Through our historical-modern community comparisons, we identify what species have been lost and with population genetics coupled with coral fragmentation, have implanted new coral communities. With local government efforts to improve water quality, we show improved success for coral restoration. This model of inferred restoration gives hope in a frequently depressing outlook for the future of our coral reefs.

MORE THAN NUMBERS, BEYOND DIVERSITY: RE-CENTERING THE CONVERSATION ON EQUITY AND INCLUSION

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The "diversity problem" in the geosciences is well documented. Using NSF metrics, Bernard and Cooperdock (2018) showed that there has been no significant increase in the ethnic and racial diversity of earned doctorates in the geosciences over the past 40 years. Women now account for a greater percentage of earned doctorates than they did 20 years ago, but there is still high attrition of women at each stage in geoscience careers like academic faculty and geotechnical industries. Furthermore, federal statistics fail to paint a complete picture of the diversity problem. Many minoritized groups, such as members of the LGBTQ+ community and persons with disabilities, are not even measured in federal statistics and are rarely included in the discussion. And because federal statistics measure demographic characters separately, there is little mechanism for measuring complex or multifaceted identities. Ultimately, "solving" the diversity problems requires much more than simply counting the types of people earning degrees or advancing in careers. It requires a deeper understanding of why diversity in geoscience matters. Re-centering the conversation about diversity on equity and inclusion allows for a deeper analysis of why the diversity problem exists and how we, as a community, can address it.

NEW HURDIID SPECIMENS WITH PAIRED ENDITES REVEAL NEW INTERRELATIONSHIPS WITHIN RADIODONTA

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Early arthropods from Cambrian fossil localities occupy a wide range of morphologies, with some of the most distinct belonging to a diverse clade of large predators known as Radiodonta, including the reknowned *Anomalocaris*. Radiodonts were originally described from the Burgess Shale and the Chengjiang biota, but recent discoveries have shown that the clade had a wide geographic distribution and a range of feeding modes including raptorial predation, sediment sifters, and filter feeders. Four families are known. Anomalocarididae and the closely related Amplectobeluidae have frontal appendages that are elongated and bear paired short ventral spines on most podomeres, whereas Hurdiidae consists of taxa with shorter frontal appendages characterized by single elongated ventral blades on only five proximal podomeres. Tamisiocarididae is a family of filter-feeding taxa that have highly spinous frontal appendages, and have usually been recovered in phylogenetic analyses close to Hurdiidae. Owing to their highly variable morphology, and the lack of transitional taxa, it has been difficult to resolve the trajectory of character evolution within Radiodonta, and the interrelationship and membership of the four main families. Here we describe recent new discoveries of hurdiid specimens that clarify the basal character condition in this family, and resolve its relationships to other radiodont families. New hurdiid appendages from the early Cambrian Guanshan biota (China) and the middle Cambrian Mount Cap Formation (Canada) and Jangle Limestone (USA) have frontal appendages with paired ventral spines, in opposition to all other known hurdiids, which have single unpaired ventral spines. Otherwise, the morphologies of these frontal appendages are comparable to previously described hurdiids, in particular that the ventral spines are confined to five of the more proximal podomeres. These new specimens allow us to define the order of character acquisition in the early evolutionary stages of Radiodonta, and comparison with new hurdiid material from the Early Ordovician Fezouata Biota (Morocco), including appendages, oral cones, and carapaces, reveals the later stages of evolution of this group. A new phylogenetic analysis recovers a monophyletic Hurdiidae that includes these new fossils, as well as new interrelationships with the other three radiodont families. Specifically, this

new analysis reveals that the family of filter-feeding radiodonts Tamisiocarididae is more closely related to Anomalocarididae + Amplectobeluidae than to Hurdiidae. In addition, Radiodonta itself is recovered as monophyletic. By clarifying the interrelationships between the families within Radiodonta, this work sets the stage for revealing more about the importance of radiodonts during early arthropod evolution.

NEW RADIODONTS FROM THE DRUMIAN (MIAOLINGIAN) MARJUM FORMATION OF UTAH, USA

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Our understanding of the taxonomic, morphological, and ecological diversities of radiodonts, a clade of stem euarthropods including the iconic Burgess Shale apex predator *Anomalocaris canadensis*, has been dramatically improved over recent years. This group is now known to include over 25 species from four major families, with members occupying trophic positions from raptorial predators to filter feeders. Most of our knowledge of these extinct organisms comes from the Burgess Shale, Emu Bay Shale, and Chengjiang biotas, however recent work on the Cambrian Lagerstätten of Utah has substantially extended the known spatial and temporal ranges of various representatives, along with describing a fair number of new taxa. As a continuation of this work, we report here the discovery of two radiodont fossils in the upper Drumian Marjum Formation of the House Range of Utah.

The first specimen is an isolated frontal appendage of *Caryosyntrips serratus*, which represents the youngest occurrence of this genus, which was previously known from the Wuliuan Burgess Shale and lower Drumian Wheeler Lagerstätten. The second specimen is an almost complete body of a new species of *Hurdia*, a rare find considering that only eight articulated body specimens of *Hurdia* have been described previously, all from the Burgess Shale. Its hurdiid affinities are indicated by the presence of a tetraradial oral cone and subequal blade-like endites on its frontal appendages. The new taxon is easily differentiated from congeneric species by its oral cone – unusually large relative to the size of the body and apparently devoid of internal tooth rows – and its frontal appendages equipped with long, particularly stout auxiliary spines. This unique morphology suggests that it fed on tougher and larger prey items than its Burgess Shale counterparts. Possibly occurring in the underlying Wheeler Formation, this new species provides the youngest occurrence of the genus *Hurdia*.

The radiodontan fauna from the Marjum Formation is composed of the youngest representatives of three genera: *Caryosyntrips* (*C. serrata*), *Hurdia* (new species), and *Peytoia* (*P. nathorsti*). The discovery of the new taxon brings the total number of radiodontan species reported from the exceptional Cambrian deposits of Utah to 13 (in ascending stratigraphic order: the Spence Shale and shallow Wheeler, deep Wheeler, Marjum, Weeks Lagerstätten) – more than half of them are endemic to the state. The fossil record of radiodonts in Utah perfectly illustrates how these American Lagerstätten contribute to a more accurate depiction of the complexity of Cambrian ecosystems.

ENVIRONMENTAL DRIVERS OF FAUNAL CHANGE IN THE JURASSIC SUNDANCE SEAWAY, WESTERN UNITED STATES

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Environmental gradients are among the primary drivers of change in ecological communities through time and space. However, quantitative analyses of the relationship between paleoecological data and independently measured environmental data are rare, largely because many environmental variables are difficult to measure in the fossil record.

In this study we integrate quantitative abundance estimates of benthic macroinvertebrates with a multivariate dataset of paleoenvironmental proxies to potentially estimate the environmental drivers of faunal change through the 13 m.y. history of the Middle–Late Jurassic Sundance Seaway, western United States. The Sundance Seaway was a shallow epicontinental sea that extended nearly 2000 km from southern Utah northward to its open-ocean connection near the border of British Columbia and the Yukon Territory. Because of its elongated shape and its north–south orientation with a single entrance located at a high latitude, the Seaway was likely prone to pronounced latitudinal temperature and salinity gradients, which likely affected patterns of faunal diversity, distribution, and immigration into the Seaway.

Faunal censuses of macroinvertebrates were obtained from marine rocks of the Gypsum Spring, Sundance and Twin Creek formations at 21 localities in Wyoming, Montana and South Dakota. From the same localities, calcitic shells of selected species (*Gryphaea planoconvexa*, *Gryphaea nebrascensis*, *Liostrea strigilecula*, *Deltoideum* sp.), were analysed for stable isotope (carbon and oxygen) and elemental (Mg/Ca, Sr/Ca, Na/Ca, Ba/Ca) geochemistry. The studied interval was subdivided into seven third-order depositional sequences representing carbonate ramp, wave-dominated, siliciclastic shelf, siliciclastic tidal coast, and mixed evaporite-siliciclastic desert systems. Of these, five depositional sequences were fossiliferous.

Ordination of paleoecological data shows that the shift from carbonate to siliciclastic depositional systems at the Middle–Late Jurassic transition is the main factor controlling faunal change through time (axis 1 of the ordination). Ordination of geochemical data strongly mirror paleoecological change and shows that this is linked to an increase in productivity (increase of $\delta^{13}C$) and a decrease in temperature (decrease of Mg/Ca ratio) through time. Such a result is consistent with evidence of the gradual northward migration of the North American Plate, which would have moved the study area from subtropical latitudes with an arid climate, into progressively more humid conditions, and possibly also by global cooling at this time. Variations across the axis 2 of the ordination can be linked to changes in salinity in the Seaway, as shown by variations of $\delta^{18}O$ and Ba/Ca ratio, suggesting a strong salinity gradient, with decreasing salinity moving from the craton towards the foredeep.

ANCIENT LIFE IN MOVING FLUIDS - WHAT FLUID DYNAMICS CAN (AND CAN'T) TELL US ABOUT THE EDIACARA BIOTA

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The paleobiology and -ecology of many Ediacaran organisms are not understood, largely as a result of their non-analogue body plans that in many cases have no modern counterparts. Despite these challenges, digital modeling techniques such as computational fluid dynamics have begun to shed new light on these fossils, and are helping to reconstruct their paleobiology and evolutionary history. This research begins with the question: how may the bizarre morphologies of Ediacaran organisms have evolved to interact with moving fluids? Although this may seem an unconventional approach, it is supported by several key observations: 1) the Ediacara biota are, without exception, found in marine settings. 2) Many taxa – especially some of the more iconic and bizarre-looking taxa from the White Sea assemblage – are preserved in shallow-water facies that preserve evidence for moderate- to strong and variable water currents. And, 3) in modern marine settings, a wide variety of invertebrate groups have evolved morphologies that help them move, feed, and disperse (or collect) gametes in a dynamic fluid environment. Thus far, examining the Ediacara biota in this context has shed crucial new light on several bizarre and problematic Ediacaran fossils and is helping to re-assess the complexity of Ediacaran ecosystems.

Here we review what fluid dynamics can tell us about the Ediacara biota, highlight key questions that need to be addressed, and introduce some new avenues of research that promise to shed new light on the functioning of Ediacaran ecosystems, as well as changing ecological dynamics across the Ediacaran-Cambrian transition.

THE EDIACARAN TRACE FOSSIL RECORD FROM NAMIBIA, AND IMPLICATIONS FOR DRIVERS OF THE EDIACARAN-CAMBRIAN TRANSITION

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The Ediacaran–Cambrian transition marks one of the most important geobiological revolutions of the past billion years, including the Earth's first crisis of macroscopic eukaryotic life (the extinction of the 'Ediacara biota'), and, shortly afterwards, its most spectacular evolutionary diversification - the Cambrian Explosion. However, the driver(s) of this these two events are still poorly understood, with competing models proposed. The 'biotic replacement' model ties together these two phenomena - Ediacaran extinction and Cambrian explosion - in suggesting that the appearance of metazoan and Cambrian-type 'ecosystem engineers' drove the extinction of soft-bodied Ediacaran organisms, ushering in the Paleozoic. Although this model has received some support, many key questions and predictions of 'biotic replacement' remain untested. Here, I review the trace fossil record of the Nama Group of southern Namibia, which preserves late Ediacaran to Cambrian-aged sediments in unparalleled extent. I describe some new trace fossil assemblages, document the appearance of key metazoan and

ecosystem engineering behaviors, and discuss their importance in a potential 'biotic replacement' scenario for the Ediacaran-Cambrian transition.

JURASSIC GASTROPOD OF KUTCH: A STUDY ON DIVERSITY AND PALAEOECOLOGICAL INTERACTION

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The Jurassic rocks of the Kutch basin in India are particularly famous for its fossil treasure. The ammonite biozonations suggest that the Jurassic rocks range from the Bathonian to the Tithonian. The Kutch basin formed due to Gondwana fragmentation while India drifted away from Africa and it hosted a thick pile of sediments (about 3000 m.) ranging from the Bathonian (Middle Jurassic) to Aptian (Early Cretaceous). We have been studying Jurassic gastropods since last two decades and described many groups based on about 15000 specimens.

So far 120 species belonging to 27 families have been described. The study of diversity pattern and evolutionary tempo suggests that the diversity increases from the late Bathonian to Oxfordian and majority of the members of the gastropod community (Archaeogastropoda) showed strong Tethyan affinity but were distinct at lower taxonomic level.

Both ammonites and gastropods constitute marked endemic community and for this reason many workers suggested distinct palaeobiogeographic province for ammonites and subprovince for gastropods.

Recently, we reported the oldest occurrences of two important caenogastropod groups which are turritellines and naticids. Turritellines are found in the Oxfordian beds and are both diverse and highly abundant. We studied about 13,000 specimens and the community was represented by turritelline-dominated assemblage. Like other gastropods turritellines are distinct at species level.

Interestingly, we also recently reported the oldest record of another important gastropod group i.e. Naticidae from the same horizons. We recognized three naticid species from this Jurassic beds of Kutch. They belong to two existing naticid subfamilies i. e. Gyrodinae and Polinicinae

Naticid and turritelline gastropods constitute an important ecological relationship i. e. predator-prey interaction since the Early Cretaceous. We presently investigate what was the nature of interaction between oldest turritelline and naticid communities. We found many drilled shells of turritelline gastropods and corbulid bivalves from the same Oxfordian assemblage. We will address the following objectives:

1. Drilling intensity (DI) will be estimated to know whether the predators were escalated right from the beginning.
2. Prey effectiveness (PE) and multiple drill holes (MULT) will also be calculated to know prey's adaptability against drilling predation.
3. Size and site stereotypy will be studied to understand the efficiency of the predators.
4. DIs in other species (both gastropods and bivalves) are also to be studied in order to know whether turritellines are preferred prey in the early history of naticid predation.
5. Reasons for variation of DIs among turritelline species will be explored.
6. Did a recurrent community of the turritelline prey and naticid predator evolve during the Jurassic?

VIRTUAL REALITY, AUGMENTED REALITY, AND REAL REALITY: THINKING HOLISTICALLY ABOUT THE SPECTRUM OF IMMERSIVE TECHNOLOGIES IN MUSEUMS

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Augmented reality (AR) and virtual reality (VR) are often presented as panaceas to museums, futuristic yet inevitable technologies that will excite visitors, raise much needed funds, and educate underrepresented youth. But where is the evidence to back up these claims? How can museums tell which of ever changing buzzworthy systems (Oculus, Magic Leap, HoloLens, mixed reality, hyper reality, etc.) represent effective education tools instead of expensive vaporware?

The Natural History Museum of Los Angeles County is one of the leaders in actively investigating the utility of immersive technologies in an informal learning environment. We recently collaborated on and hosted the award winning, commercial VR series The Blu and are currently in the midst of two NSF funded projects to examine the financial and educational efficacy of AR (Grants are co-led with Perceptoscope and the University of Southern California, respectively). Additionally, the Museum's location in Los Angeles, the heart of America's entertainment industry and burgeoning experience economy, uniquely positions us to collaborate and learn from a talented pool of professionals.

We provide a brief overview of immersive technologies before presenting best practices, preliminary results, and open questions gleaned from our research and experiences. Firstly, museums need to set realistic expectations around VR and AR projects and have clear, testable goals. Knowledgeable, unbiased academic and industry partners are key for effectively evaluating these potential technologies and outcomes. However, in the pursuit of AR/VR technologies, museums should not forget what they do well when thinking holistically about unique and immersive visitor experiences. Far from a blanket solution, the costs and benefits of immersive technologies have to be evaluated carefully on a case by case basis depending on the specific goals of each institution.

UPPER DEVONIAN (UPPER FRASNIAN-LOWER FAMENNIAN) BIOSTRATIGRAPHY AND KELLWASSER EXTINCTION SIGNATURES IN THE IOWA BASIN-CENTRAL NORTH AMERICA (WESTERN SUBTROPICAL EURAMERICA)

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Upper Devonian strata from in the Iowa Basin (central United States) provide one of the best-documented and complete Upper Frasnian to Lower Famennian successions in and condensed basinal facies in North America. New conodont sample series document a continuous conodont sequence identifying all five Upper Frasnian and three Lower Famennian zonal boundaries and intervals, the stepped Lower and Upper Kellwasser Extinction Bioevent (LKE & UKE), and Frasnian-Famennian boundary intervals in offshore facies, and most Upper Frasnian zones in platform facies. Offshore Sweetland Creek and Grassy Creek facies feature a continuous conodont sequence spanning Frasnian Zone 11 through the Early Famennian *Palmatolepis platys* Zone interval. Deep subtidal ramp facies of the Amana Beds (Lime Creek Formation) record the LKE extinction evidenced by stepped extinctions of brachiopod taxa, all echinoderms, and two of three ammonoid species just below the base of Frasnian Subzone 13a. The LKE record in platform facies in the upper Cerro Gordo and Owen Member of the Lime Creek Formation document extinctions of brachiopod faunas of the lower-Middle *Elita inconsueta* Zone with upper Frasnian Zone 12 conodonts, succeeded by low diversity shelly mollusk-dominated assemblages of the *Iowatrypa owenensis* Zone with Frasnian Subzone 13a conodonts.

PRELIMINARY STUDY ABOUT CALCAREOUS NANNOFOSSILS FROM BURDIGALIAN/LANGHIAN BOUNDARY INTERVAL IN THE PARATETHYS AREA, REFERRED TO THE REWORKED SPECIMENS

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Our project is focused on the processes in the Burdigalian/Langhian boundary interval in the non-oceanic realm. The base of Langhian has not been standardized yet and remains one of the key objectives of the Neogene Subcommission of the International Commission of Stratigraphy. Candidates for stratotypes are situated in the Mediterranean area that directly communicated with Paratethyan realm. This fact speaks in favour of Paratethys area to test applicability of proposed stratigraphical markers in extra-Mediterranean non-oceanic area. The Burdigalian/Langhian boundary is recently proposed at 15.974 Ma, which is the top of polarity Chron C5Cn.1n. Calcareous nannoplankton Zone boundary (NN4/NNS Zones) astronomically calibrated at 14.91 Ma positioned it, in fact, within the Langhian. Therefore, several different calcareous nannoplankton events have been proposed as biostratigraphic markers of the Burdigalian/Langhian boundary: the Highest Common Occurrence o*f Helicosphaera ampliaperta* and the paracme of *Sphenolitus heteromorphus.* The abundance peak of *H. ampliaperta* is slightly younger. However, all proposed events occurr probably only locally in the Mediterranean area, reflecting local paleoenvironmental condition and cannot be used for interregional correlation. In the Central Paratethys area, no clear calcareous nannoplankton events have been defined yet in this interval. The interval is less known and no detailed quantitative biostratigraphical data exist. Because of the composition of calcareous nannoplankton assemblages reflects quality of superficial water and paleooceanographic circumstances (circulation regime), we expect events recording effect of climatic and paleogeographic evolution on calcareous nannoplankton assemblages. The influence of Middle Miocene Climatic Optimum and Mi-2 and Mi-2a global cooling events is expected. Also influence of significant paleogeographical event - closure of Indic-Mediterranean gateway (14.5-16 Ma) as well as changes in Mediterranean-Paratethyan gateway due to intensive tectonic (Styrian phase) is expected. In this moment, following material has

been analyzed: Central Paratethys area: 1) Croatian samples, Langhian/Burdigalian boundary indicated from foraminiferal assemblages; 2) Carpathian Foredeep - IH borehole, Czech Republic localities, 3) Estern Paratethys (Crimea), 4) Southern Italy samples (Campania region). Preliminarily detailed quantitative analysis of calcareous nannoplankton assemblages was undertaken, morphometrical study of problematic taxa, paleoecological interpretations and multivariate statistical classification. We observed abundance of *Reticulofenestra* spp. and *Coccolithus pelagicus*, with the presence of *Helicosphaera* cf. *waltrans*; a lot of reworked specimens coming from older Meso-Palaeogenic material is also present with high percentage in the assemblage, especially in the Eastern Paratethys. Further studies will shed light on the connections of the three areas during the Neogene.

A SKULL OF *CANIS LUPUS* FROM THE PLEISTOCENE OF THE STATE OF CHIHUAHUA, MEXICO

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The fossil records of the genus *Canis* in Mexico are very scarce, and known taxa include *Canis ferox* Miller and Carranza-Castañeda 1998, from the late Miocene-early Pliocene of the state of Guanajuato; *Canis lepophagus* Johnston 1938 and *C. edwardii* Gazin 1942, from the Gulf of Santa Clara, in the state of Sonora; *Canis cedazoensis* Mooser and Dalquest 1975, from the late Pliocene of the state of Aguascalientes, and the dire wolf *C. dirus* Leidy 1858, grey wolf *C. lupus* Linnaeus 1758, and coyote *C. latrans* Say 1823 for the late Pleistocene in several states of Mexico.

During the Pleistocene, grey wolves are generally more rare than dire wolves or coyote. This is especially true in the southern part of North America, including Mexico, and thus presence of a new grey wolf record is worhty of note.

The specimen reported in the present work was collected in a deposit located near the comunity of Sainapuchi (La Garita), municipality of Riva Palacio, in the state of Chihuahua. It consists of a parcial skull, and a fragment of a left mandibular ramus, preserved in a red, semi-consolidated sand matrix, whose age has not been established but is speculated to belong to the Pleistocene. The skull preserves the rostrum (maxilla and nasal bones), top of skull (frontal bones), sagital crest, anterior portion of the right zygomatic arch, basioccipital bone, part of the right tympanic bulla and the right P4-M2. The segment of the mandibular ramus preserves the base of the fractured canine, the alveolus of p1, the complete p2, the p3 is fractured and missing the cusp of the tooth, and the base of p4. The preliminary analysis of the right M1 of the specimen shows synapomorphic characters with *Canis lupus,* such as the hypertrophy of paracone with respect to metacone. Comparisons with dental measurements of *C. dirus*, *C. lupus*, and *C. latrans* from the Rancho la Brea Tar Pits are also consistent with the new Chihuahua specimen being that of a grey wolf. We thus assign the Chihuahua canid material to the grey wolf. *Canis lupus* has been reported for the states of Jalisco, Estado de México, Nuevo León, Puebla, San Luis Potosí, Yucatán and Chihuahua, however, its presence in the latter state is controversial. Therefore the material reported here constitutes the first confirmed record of this taxon in the state of Chihuahua and adds an important record of the family Canidae in the Pleistocene of Mexico.

SYNCHROTRON XRF ELEMENTAL MAPPING OF METALS IN PALEOZOIC PALYNOMORPHS

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The Ordovician-Silurian was one of the most dynamic intervals in the Earth's climatic and biologic evolution featuring a series of abrupt, short-lived events that radically reorganized global climate-ocean chemical systems and changed the trajectory of life on Earth. These episodes are marked by dramatic stable isotope excursions that reflect major disturbances of oceanic C, O and S cycles. Reconstructing these ancient

environments and climates requires a range of indirect proxies, including chemical and physical imprints archived in (micro)fossils. In pilot studies, we observed dramatic increase of metals (Fe, Mo, Pb, Mn, As) in microfossils and their host rocks during these events. We suggested that large-scale paleo-ocean redox cycling of metals was a mechanism for ocean poisoning that has affected Ordovician-Silurian life, and left a record of extinction and pollution. In this context, the non-destructive technique of hard X-ray fluorescence (XRF) scanning imaging in a synchrotron facility provides, with a high sensitivity, unique insights in the elemental distribution of metals in microfossils. A total of 40 Paleozoic individual palynomorphs (organic-walled microplankton) from Midwestern USA (Katian), Canada (Hirnantian) and Northern Africa (Pridoli) were analyzed at the Nanoscopium 155m-long beamline of Synchrotron Soleil (France) [1], using a fast-scanning and highly sensitive imaging technique ("*flyscan*", at 20 ms/pixel) within the 5-20 keV energy range. The XRF images unveil qualitative and semi-quantitative signatures of a wide range of major and trace elements (K and L shell emissions) at a high spatial resolution (300 nm).

[1]A. Somogyi et al., "Optical design and multi-length-scale scanning spectro-microscopy possibilities at the Nanoscopium beamline of Synchrotron Soleil" (2015). Journal of synchrotron radiation, 22(4), 1118-1129.

BUILDING OUT NORTH AMERICA'S MOST COMPLETE LOWER CRETACEOUS TERRESTRIAL FOSSIL RECORD ACROSS A MOSAIC OF UTAH STATE, BUREAU OF LAND MANAGEMENT (BLM), AND NATIONAL PARK SERVICE LANDS

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The 40-million-year record of the Lower to earliest Upper Cretaceous Cedar Mountain Formation (CMF) extends across parts of Emery, Grand, and Wayne Counties of east-central Utah. The discovery of its rich basal Cenomanian microvertebrate sites and of *Utahraptor* in 1993, led to extensive explorations of these strata by many institutions. Land management in Utah is complex given the mosaic of private, state, tribal, and federal lands. Initially, in Utah, 4 sections in each 36-section township were designated state school sections. Unfortunately, many, if not most, researchers did not have Utah state paleontology permits (issued by the Utah Geological Survey), informed by BLM after the fact that some of their sites are actually on Utah state lands. Utah State Paleontological Permit requirements may be found at: https://geology.utah.gov/?p=6606

We found that the basal Yellow Cat Mbr. of the CMF preserves the two oldest North American Cretaceous dinosaur faunas only in Grand Co., due to local subsidence resulting from salt tectonics in the Paradox Basin around Arches National Park. A massive paleosol that separates these faunas marks the first evidence of a rain shadow from the Sevier orogeny at ~136 Ma (detrital zircons). These Wealden "style" faunas include taxa supporting the continuation of a Euro-North American biota beyond the terminal Jurassic extinction. The overlying Barremian or basal Aptian Poison Strip Mbr. preserves a Lakota "style" biota and the final evidence of European connections in the first strata deposited outboard along the entire Sevier orogenic belt. These first three dinosaur faunas are dominated by turiasaur and broad-toothed brachiosaurid sauropods, polacanthine ankylosaurs, and basal styracosternan iguanodontians. Overlying this coarse clastic wedge, the Cloverly "style" fauna in the Aptian portion of the Ruby Ranch Mbr. follows a middle Aptian extinction and is characterized by endemic fauna dominated by nodosaurids, slender-toothed basal titanosauroid sauropods, and primitive tennontosaur-grade iguanodonts. The latest Albian Ruby Ranch strata dates to~104-102 Ma (ash and detrital zircons) and preserve a similar dinosaur fauna composed of mostly related taxa. Stable oxygen isotope studies of tooth enamel reveal the first evidence of a spring snow melt from the Sevier orogenic belt in these foreland basin strata along the San Rafael Swell and at Dinosaur National Monument. A basal lag overlying an unconformity includes the first lower Paleozoic quartzites derived from the Sevier highlands, and separates the overlying 97-99 Ma (ash dates) basal Cenomanian Mussentuchit Mbr. in the foreland basin. With more than 90 taxa recognized, the Mussentuchit fauna reveal the first Asian immigrants into North America, such as the abundant derived hadrosauroid iguanodont *Eolambia*, overlapping with the last evidence of endemic basal titanosauroid sauropods and tennontosaur-grade iguanodonts marking the origin of an Alaskan landbridge.

NEW VERTEBRATE RECORDS FROM THE LATE CRETACEOUS (CAMPANIAN) ELLISDALE SITE OF NEW JERSEY

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Terrestrial and freshwater vertebrate faunas of the Late Cretaceous of eastern North America (Appalachia) are rare and invariably associated with coastal marine environments and faunas. Consequently, our understanding of those non-marine faunas is relatively poor when compared to the richly fossiliferous coeval deposits of the Western Interior of the continent (Laramidia). Discovered in 1980, the Campanian-age Ellisdale Site of the Marshalltown Formation, Monmouth County, New Jersey remains the sole vertebrate fossil assemblage of Appalachia to have produced adequate sample sizes of small, non-marine taxa including frogs, salamanders, non-marine lizards, and mammals via bulk sediment sampling and underwater screen-washing techniques. Past and ongoing work indicate that these taxa differ at the generic level from their Laramidian counterparts, supporting previous suggestions of broad regional distinctions between Appalachia and Laramidia. Fossiliferous sediment samples collected in 2018 from a previously unsampled area of the Ellisdale Site ('92 Pit) are yielding the expected faunal assemblage (mostly cartilaginous and bony fishes with a few turtles, crocodylians, and dinosaurs) as well as new and exciting discoveries of non-marine vertebrates. These include a proximal femur that is possibly the oldest mammalian postcranial specimen from Appalachia. Although this femur is incomplete, it possesses a subtrochanteric tubercle, a large, proximally-projecting greater trochanter, a ventrally positioned lesser trochanter, and a post-trochanteric fossa; all features that are diagnostic of multituberculates. The element is relatively robust, with a basally broad neck and well-developed lesser trochanter. Other novel discoveries include the oldest Appalachian record of a chelydroid turtle, based on a nearly complete peripheral from the carapace. This element exhibits several ridges that extend perpendicular to the major sulcus on the dorsal surface of the bone and a transversely oriented medial pit ventrally; it either represents a chelydrid (snapping turtle) or a kinosternid (e.g., mud turtle). An indeterminate but morphologically distinct shed tooth of an atoposaurid-like mesoeucrocodylian also has been identified. The tooth is extremely labiolingually compressed, with what appears to be weakly developed denticles along the thin mesial and distal carinae. These new elemental and taxonomic records expand the known terrestrial and freshwater assemblage of the Ellisdale vertebrate fauna, adding to our knowledge of the unique land life of the Appalachian "Island Continent" and filling in a major gap in the worldwide biogeographic record of the early- to mid-Campanian stage of the Late Cretaceous.

A RECENTLY EXPANDED PALAEOCOMMUNITY OF PLANTS AND INSECTS FROM THE LATE CRETACEOUS (CENOMANIAN) OF LABRADOR, CANADA

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The Redmond Formation is one of the rare Mesozoic exposures known from the Quebec-Labrador Peninsula, and is only found in an abandoned iron ore mine located near Schefferville. This ferruginous argillite deposit of probable lacustrine origin and Cenomanian age has been known to contain semi-complete to fragmentary leaf and insect impression fossils for most of the time since its discovery in the late 1950s. However, only 5 insect species have been formally described, along with mentions of genera belonging tentatively to Blattaria, Schizophoridae, Cupedidae, and Haliplidae.

Fieldwork undertaken in the Redmond Mine in 2013 and 2018 has resulted in a significant expansion of the species richness and functional diversity of this mysterious palaeocommunity. More fossil angiosperm, conifer and fern leaves were recovered from the site. New angiosperm morphotypes were brought together with species known from historical specimens to produce the first absolute palaeoclimate estimate for Cretaceous eastern Canada. Our results suggest a mean annual temperature of 15°C and confirm the initial hypothesis of a warm temperate to subtropical climate, which is as expected for a particularly warm episode of the Cretaceous.

The expedition was most successful in expanding the known insect diversity: the specimens we present here are assigned to families or orders that were insofar not represented in the Redmond Formation. The hypothesis of a lacustrine depositional setting is strongly supported by the discovery of the first relatively complete representatives of mayfly nymphs (Ephemeroptera), belostomatid hemipterans

and hydradephagan coleopterans known from this site. We also report the first occurrences of a basal mantis (Mantodea), a lacewing (Osmylidae), a hairy cicada (Tettigarctidae), planthoppers (Fulgoromorpha), leafhoppers (Cicadellidae), orthopterans, and hymenopterans. Together, these new specimens contribute substantial information on insect evolution and biogeography at a pivotal time in the evolution of terrestrial ecosystems for a poorly represented region of the Cretaceous world.

CONSTRUCTING THE HIGH-RESOLUTION EVOLUTIONARY HISTORY OF ORDOVICIAN MARINE ANIMALS IN SOUTH CHINa

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Biodiversity pattern based on accumulated data is a major pursue in the macroevolution study, which can be used to investigate those major biological events such as originations, radiations, turnovers and extinctions. The Ordovician is considered as a significant period during the Phanerozoic Eon, containing two major biological events in Earth's history—the Great Ordovician Biodiversification Event (GOBE) and the end-Ordovician mass extinction event. These two events are also evident in South China based on previous research works. However, more precise analyses on big dataset are still necessary to fully disclose the diversity change during the Ordovician.

Constrained Optimization (CONOP) has been widely adopted as one of the most efficient, accurate and high-resolution methods that can conflate all sections in a multidimensional space at one time to gain the optimal composite bio-sequence, and thus is used here. The employed data for the present study are from the Geobiodiversity Database (GBDB, http://www.geobiodiversity.com/), which is an integrated platform for the integration, management and sharing of stratigraphical and paleontological legacy data. The raw dataset contains over 10000 species from ~1800 sections in South China, which includes all major marine fossil groups in the Ordovician such as graptolites, trilobites, brachiopods, conodonts, cephalopods, corals, and so on. During the quality control procedure, we excluded those low-quality sections either of a few fossil records or less sampling effort, and the taxonomic names of open nomenclature. The taxonomic names were then updated to a uniform systematic paleontological framework. The final dataset with quality control contains at least over 49000 bioevents (FADs or LADs) of 3375 species. The data were run repeatedly on the supercomputer - TianHe II with the parallel computing version of the CONOP program designed by the GBDB team. The result, the optimal composite bio-sequence, was calibrated by the ICS geological time scale to construct a high-resolution Ordovician marine biodiversity patterns of species, genus and even higher-rank taxon. Compared with previous biodiversity analyses which were generally of only about 6-10Ma temporal resolution, the present research provides a much higher temporal resolution of at least 30Ka, which gives more details of the biodiversification history, and sheds new lights for fully understanding the Ordovician marine world in South China.

A SPATIALLY-CONSTRAINED PALEOCENE MAMMAL ASSEMBLAGE FROM THE SAN JUAN BASIN, NEW MEXICO, USA

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The Paleocene Nacimiento Formation in the San Juan Basin (New Mexico, USA) preserves one of the most detailed records of mammal faunas during the time immediately following the Cretaceous-Paleogene mass extinction. The Nacimiento Formation is composed of alternating siltstones, sandstones, and redbeds from alluvial floodplain deposits. Generally speaking, fossils in this region weather out of steep cliffs and accumulate in topographic lows such as shallow pans. One such pan (L-1079), located a few meters below the upper black mudstone near the top of the overlying Ojo Encino Member in biostratigraphic zone Torrejonian 6 (Tj6) on the East Flank of Torreon Wash, is notable its abundance of fossils. L-1079 was discovered in the late 1970's and has been repeatedly visited for additional surface collection.

166 teeth were studied to characterize the mammalian fauna of the site. The minimum number of individuals (MNI) for the quarry is 24. The most common taxa are *Pantolambda bathmodon* and *Tetraclaenodon puercensis* with a MNI of 4 and 5 individuals respectively. The next most abundant taxa are *Mimotricentes subtrigonus* and *Promioclaenus lemuroides* (MNI=2

individuals). Other taxa present include *Acmeodon secans, Mioclaenus turgidus, Dissacus navajovius, Periptychus carinidens,* and *Conoryctes comma*. Several multituberculate teeth and an isolated tooth of the marsupial *Swaindelphys encinensis* give evidence of non-eutherian mammals. In addition to mammalian teeth and bones, isolated crocodilian vertebrae and osteoderms, squamate vertebrae, and platysternoid turtle shell fragments indicate that these reptiles were minor components of the fauna. While the majority of the material recovered is from terrestrial animals, gar scales have also been found and indicate some fluvial influence on the assemblage.

Based on its stratigraphic position and taxa present, this site belongs to the *Mixodectes pungens* biostratigraphic zone (M zone), the youngest within the Nacimiento Formation. However, the relative abundances of the taxa at this site are not congruent with those of the overall M zone. *Pantolambda bathmodon* is overrepresented in the L-1079 assemblage while taxa like *T. puercensis* and *M. subtrigonus* are underrepresented.

The bluff over L-1079 ranges from 5–10 m high and erosion of this steep surface samples across this stratigraphy. Thus, this assemblage, while spatially constrained, is somewhat time-averaged and can be regarded as mixed. However, the abundant teeth and postcranial bones of *P. bathmodon* at L-1079 originate from a <1 m thick horizon approximately 3–4 m above the pan. The abundance and variety of postcranial elements in particular indicate that there were minimal transport processes acting on these individuals after death. *P. bathmodon* is generally rare within the M zone, but locally abundant (with individuals grouping close together spatially and temporally). Such groupings may indicate that these pantodonts exhibited gregarious behavior.

BRIDGING THE RESEARCH-IMPLEMENTATION GAP IN CONSERVATION PALEOBIOLOGY: LESSONS LEARNED FROM THE SEACAR (STATEWIDE ECOSYSTEM ASSESSMENT OF COASTAL AND AQUATIC RESOURCES) PROJECT

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Conservation paleobiology is an explicitly goal-oriented field, but examples of the application of paleontological data and techniques on the ground in conservation and habitat management are uncommon, and viable paths for conservation paleobiologists to produce actionable science are not always obvious. Thus, success stories describing how this "research-implementation gap" was bridged may be instructive for helping conservation paleobiology practitioners achieve the field's full potential. Here we present an example of a successful partnership between academic conservation paleobiologists and state agency scientists and managers to contribute to a specific data need for a specific statewide habitat management project in Florida. The Statewide Ecosystem Assessment of Coastal and Aquatic Resources (SEACAR) is a project being implemented by the Florida Coastal Management Program within the Florida Department of Environmental Protection (DEP). This five-year project aims to aggregate monitoring data from state agencies and their federal, academic and non-governmental partners collected within areas managed by DEP in order to assess the current status and historical trends in status for five submerged habitat types: seagrasses, coral reefs, oyster reefs, coastal wetlands and the water column. During the early stages of the project, it became clear that there was relatively little historical data on oyster body size, one of the metrics chosen to assess oyster reef habitat status. This data need led to the development of a collaborative project focused on gathering historical oyster body size data from buried death assemblages around the state. We will present preliminary results as well as the history and lessons learned from this collaboration to help facilitate additional integration of more salient, credible, and legitimate conservation paleobiology science into habitat management and policy, highlighting the mutual benefits of the SEACAR project for both science and management.

THE PERFORMANCE SPACE: A NEW WAY OF VIEWING EVOLUTION'S THEATRE

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Morphology has traditionally been used as a proxy for functionality, however, measuring the performance of part or all of an organism using biomechanical tests is a novel and potentially powerful method of evaluating functional morphology more directly. The goal of our study is to construct, use, and evaluate a 'performance space'. The space is made using biomechanical tests as measures of performance to evaluate

functionality. Similar to how a 'morphospace' might use a growth vector for each axis[1], each axis of the space represents one functional variable, measured quantitatively. For example, when evaluating brachiopods, possible axes within the 'performance space' could represent functional variables such as transport velocity, percent water volume of soft substrates tolerated before sinking, or ambient flow through the mantle cavity. Sessile suspension feeders –such as brachiopods- make ideal subjects for testing the performance space because hydrodynamic performance is critical to their autecology.

To demonstrate an example of the performance space, we have selected productide genera from the Late Pennsylvanian and Early Permian of the North American Mid-Continent. Unlike most modern rhynchonelliform brachiopods, productides lacked the pedicle which is used for attachment and in some cases, reorientation; thus external morphology was the only means for a productide to influence hydrodynamic stability. For example, the spines found on all productides functioned at least in part as a means of achieving stability, such as anchorage in high velocity currents (2) or as a means of increasing surface area (snowshoe strategy) when on soft substrates (3). Further, our taxa have been studied extensively within a paleo-environmental framework; associations of specific brachiopod communities with lithologies, hydrological regimes, and an onshore-offshore gradient have been established (4). Our study constructs accurate models using 3D imaging and printing, evaluates the models through biomechanical tests, and places each genus within the 'performance space'. Here we present the preliminary results for several common genera (including *Parajuresania, Pulchratia, Echinaria, Linoproductus, Retaria, Hystriculina* and *Reticulatia*) on two of the performance axes: velocity at which the model is transported on sand, and the percent water volume at which a model sinks into a soft substrate. By comparing functional performance to environmental/lithological distribution, it is possible to evaluate the performance space.

[1]Raup, DM. 1966. Geometric analysis of shell coiling. J. Paleo. 2. Alexander, RR. 1984. Comparative hydrodynamic stability of brachiopod shells on current scoured arenaceous substrates. Lethaia. 3. Grant RE. 1966. Spine arrangement and life habits of the productoid brachiopod Waagenoconcha. J. Paleo 4. Olszewski TD and Patzkowsky ME. 2001. Measuring Recurance of Marine Biotic Gradients. Palaios.

COMPARATIVE ANALYSIS OF NICHE OCCUPATION BETWEEN MESOZOIC AND EXTANT AVIFAUNA

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Neornithes are the most diverse clade of extant vertebrates, a diversity that arose during the Mesozoic among an abundant pre-Neornithes avifauna. Modern birds inhabit an extensive array of ecological habitats and have specific and diverse foraging strategies. Understanding the degree to which the observed morphological and ecological diversity of modern birds can be correlated, providing a useful tool for interpreting the ecology of extinct Mesozoic birds. The goal of this study is to first identify phylogenetic signal in modern morphological and ecological data, and then to infer possible ecological niche occupation for extinct Mesozoic birds. A large database of morphometric and ecological data of modern birds was corrected for phylogeny by independent contrasts to evaluate the significance of the correlation between morphology and ecology, followed by comparison of modern and fossil taxa. Results highlight the importance of including phylogenetic considerations in assessments of morphometric data.

DERMAL DENTICLE ASSEMBLAGES CAN REFLECT CHANGES IN SHARK ABUNDANCE ON CORAL REEFS OVER TIME

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Many coastal shark populations have declined steeply over the last several decades, but longer records of change are unavailable. This hinders our ability to determine baseline shark abundance, understand natural variation in shark assemblages over time and space, and interpret sharks' functional roles on coral reefs in natural and human-impacted systems. Here, we explore the use of dermal denticles, the small tooth-like scales that cover the bodies of sharks and rays, as a new tool for reconstructing historical shark assemblages on coral reefs. We first conducted

a fidelity study on Palmyra Atoll, central Pacific and found that denticles accumulating in the surficial sediments of low-energy reef habitats correlated well with estimated shark abundances across sites. We then compared denticle assemblages extracted from mid-Holocene (~7ka) fossil reefs in Bocas del Toro, Panama with modern reefs in the same area to investigate how shark assemblages have changed over time. Preliminary data suggest that denticle accumulation rates (number of denticles per amount sediment per unit of time) were, on average, five-fold higher on the fossil reefs than on the modern reefs, implying that these reefs supported many more, or larger sharks, 7000 years ago. Furthermore, we observed a significant shift in the relative abundance of denticle morphotypes over time. "Abrasion strength" denticles belonging to demersal sharks (e.g. nurse sharks) increased in relative abundance on the modern reefs, whereas "drag reduction" denticles, which are associated with fast-swimming species (e.g. requiem and hammerhead sharks), decreased in relative abundance, suggesting an ecological shift in shark assemblages on these reefs. These new data can provide insight into pre-human shark assemblages on coral reefs and can help guide management targets.

FOOD WEB DYNAMICS DURING THE MARINE MESOZOIC REVOLUTION (MMR)

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The Mesozoic Era (250–66 mya) was a period of major ecological reorganization in marine ecosystems, driven by the radiation of predators in conjunction with an increase of anti-predatory adaptations, and a decrease of the relative abundance of epibenthic sessile, suspension feeding organisms. These associations support the Mid-Mesozoic Marine Revolution (MMR) theory, which states that predation was a major driver of these eco-evolutionary changes. Furthermore, increasing predator diversity, predation intensity, motility, and ecospace utilization, suggest that the complexity of marine systems has increased over time as more specialized morphologies and functions have evolved. The examination of ancient food webs presents an opportunity to determine whether trophic organization has also changed, and to understand the evolutionary mechanisms that have contributed to historical patterns of community structure. Here we present results of a large-scale project examining the changing dynamics of the western Tethyan marine ecosystem, spanning the Triassic to Cretaceous. We present three large (1000+ species) marine food webs from the Triassic (Anisian), Jurassic (Bathonian), and Cretaceous (Aptian) of western Tethys, comparing the trophic structures of those webs. The trophic relationship of a species to its community was measured as network trophic position (ntp), a measure more appropriate to network structure than hierarchically aligned trophic levels. The ntp of a species is the average chain length of its prey to the nearest primary producer, and we summarized these relationships as the mean ntp of guilds of species.

Species-level network analysis revealed that guild trophic relationships were dynamic, with guilds shifting their ntps within the system as other guilds became extinct, and new guilds were added. Guilds that did not transition from one stage to the next were significantly biased toward higher ntp, as were new guilds. E.g., Anisian durophagous placodonts were absent in the Bathonian, but durophagous fish introduced in the Bathonian were of similar ntp. In the Anisian-Bathonian transition, guilds whose ntp increased significantly in the Bathonian were of high Anisian ntp, whereas low Anisian ntp guilds remained unchanged. In contrast, in the Bathonian-Aptian transition, low ntp guilds increased their ntp in the Aptian while high ntp guilds decreased their ntp significantly. Therefore, the Tethyan trophic network expanded significantly in the Bathonian and contracted in the Aptian in terms of food chain length, with the expansion and contraction being due to high trophic position species. An open question then is whether the MMR was anomalous because marine trophic network structure is conservative, or if that network structure is dynamic and fluctuates frequently.

SPECIATION BY NEUTRAL AND ADAPTIVE FORCES: EVOLUTIONARY PSEUDOCONGRUENCE WITHIN GEO-CLIMATICALLY COMPLEX REGIONS

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How new species form is central to evolutionary theory and to understanding what factors control the distribution of biodiversity on Earth today and over deep time. It is well established within phylogeography and paleontology that geologic and climatic (geo-climatic) processes shape diversification and

adaptation of species by mediating population connectivity and varying selection pressures over time. Studying Earth-life evolution on the modern landscape enables a detailed evaluation of the cause-effect relationship between geo-climatic forces and evolutionary consequences. This is achieved by combining whole-genome data with geologic models of how the physical paleo-landscape changed and statistically testing which aspects of that change best explain genomic variation among individuals living on the landscape today.

Such neontological approaches generate mechanistic and predictive knowledge of how individual geo-climatic factors shape diversification and adaptation. From this knowledge we can ultimately deduce which processes most diversify life over deep time and potentially in other geological systems, such as other planets. Achieving this insight, however, requires considering the major ways the physical landscape has changed over evolutionary time and considering that multiple geo-climatic processes may produce similar evolutionary effects (i.e. evolutionary pseudocongruence). Overlooking 'true' geo-climatic complexity risks limiting hypothesis space and biasing our most fundamental understanding of how geological forces shape life on Earth.

I present work from the warm deserts of the southwestern United States. Recent results from geologic models and genetic data of 33 desert-adapted animals reveal that the Colorado River has been a leaky barrier since its inception (5.3 vs. 4.8 Ma for 'early' vs 'late' river initiation models). Channel avulsions, periodic lava dams, as well as climate-induced changes in flow may have facilitated cross-river dispersal, challenging the longstanding hypothesis that the Colorado River is the leading driver of southwestern divergence. Population analyses of whole-genome data collected from desert tortoise species indicate that monsoon-driven rainfall asynchrony may have additionally or primarily driven southwestern divergence via differential ecological adaptation. This setting is unusual in that two disparate, co-occurring geo-climatic forces have operated over the same time and yield appreciably different evolutionary predictions. They differ in the expected patterns of divergence recorded in the genome, as well as the implied mode of speciation proposed by theory. Quantifying river versus monsoon influence on southwestern divergence embraces intermediate levels of geobiological complexity. Yet, more work and advances in pseudocongruence theory are needed to better understand Earth-life evolution and the geologic controls on speciation through time.

CLADISTIC ANALYSES OF SOME PLEISTOCENE MAMMALIAN FAUNAS FROM CHINA FOR BIOCHONOLOGICAL INTERPRETATION

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There are many localities yielding the Pleistocene mammalian fauna in China. It offers excellent material for the study of mammalian evolution, biochronology, paleoecology, paleoenvironment, paleozoogeography, etc. Faunal assemblage characters and taxonomic extinction rates were widely used for determine the fauna ages in biochronology. Faunal binary similarity coefficients sequenced according to Brainerd-Robinson's rule and antiquity coefficients were further developed methods in biochronology for dating the ages of the faunas. The faunal binary similarity coefficients are based on the presence or absence of a taxon in a fauna. It is similar to the presence or absence of a character of a species in cladistic analyses for phylogeny in mathematic sense. The present work is an attempt to find the relationship of the faunas with cladistic analyses by selecting three groups of faunas sequenced by faunal binary similarity coefficients according to Brainerd-Robinson's rule and antiquity coefficients, to compare the results with different methods, and then to estimate the ages of the faunas not yet dated by physical or chemical methods. The resulted estimations are as follow: Gulongshan in Dalian, Liaoning Province: 16–20 ka; Shanchengzi at Benxi, Liaoning Province: 20–30 ka; Hualongdong at Dongzhi Man site, Anhui Province: 150–400 ka; Xinghuashan at Nanzhao Man site, Henan Province: 150–400 ka; Donghe at Luonan Man site, Shaanxi Province: 500-700 ka; Bailongdong at Yunxi Man site, Hubei Province: 500-850 ka; Meipu at Yunxian, Hubei Province: 500-850 ka; Mohui at Tiandong Man site, Guangxi Autonomous Region: 1.2–1.8 Ma; Juyuandong at Liucheng, Guangxi Autonomous Region: 1.2–1.5 Ma; Chutoulang at Chifeng, Nei Mongol Autonomous Region: 1.6–1.9 Ma; Renzidong at Fanchang, Anhui Province: 1.9–2.4 Ma.

THE TIMESCALE OF EARLY LAND PLANT EVOLUTION

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Establishing the timescale of early land plant evolution is essential to testing hypotheses on the co-evolution of land plants and Earth's system. The sparseness of early land plant megafossils and stratigraphic controls on their distribution make the fossil record an unreliable guide, leaving only the molecular clock. However, the application of molecular clock methodology is challenged by the current impasse in attempts to resolve the evolutionary relationships among the living bryophytes and tracheophytes. Here we establish a timescale for early land plant evolution that integrates over topological uncertainty by exploring the impact of competing hypotheses of bryophyte-tracheophyte relationships, among other variables, on divergence time estimation. We codify 37 fossil calibrations for Viridiplantae following best practice. We apply these calibrations in a Bayesian relaxed molecular clock analysis of a phylogenomic dataset encompassing the diversity of Embryophyta and their relatives within Viridiplantae. Topology and dataset sizes have little impact on age estimates, with greater differences among alternative clock models and calibration strategies. For all analyses, a Cambrian origin of Embryophyta is recovered with highest probability. The estimated ages for crown tracheophytes range from the Early Ordovician to close to the Silurian-Devonian boundary. This timescale implies an early establishment of terrestrial ecosystems by land plants that is in close accord with recent estimates for the origin of terrestrial animal lineages. Biogeochemical models that are constrained by the fossil record of early land plants, or attempt to explain their impact, must consider the implications of a much earlier, late Cambrian–Early Ordovician, origin.

I.C.E. AGE PROJECT: FOSTERING GLOBAL MINDEDNESS

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The Western Science Center launched its International Collaborations for Education (I.C.E.) AGE Project in the spring of 2018. Beyond the creation of new exhibits, the goal of the I.C.E. AGE Project is to raise students' level of global mindedness. A sixth-grade science class in Hemet, California was partnered with a high school English-language class in São Paulo, Brazil. The classes collaborated through Google Docs to create exhibit text about guided research they did concerning the Ice Age fossils from each location. They video conferenced using Google Hangouts to learn more about each other. The collaboration resulted in a four-panel exhibit that included 3D prints of specimens, artwork and photographs by the students, and exhibit text created by the students and edited by museum staff. A second collaboration involved 7th and 8th grade students from Murrieta, California and a high school class in São Paulo, Brazil. Students were heavily engaged in communication via video conferencing but there were scheduling difficulties that provided the students inadequate time to conduct and share their research. A third collaboration in the fall of 2018 between a school in Ontario, California and one in Martinsville, VA followed the same format. There were technical and weather issues that resulting in students only video conferencing twice, but they were able to communicate through Google Docs to create the text collaboratively.

Future collaborations will have students take the modified Global mindedness survey (Hett, 1993; Cook, 2016) to enable a quantitative measure of changes in global mindedness. The survey was not presented to the first three groups, but anecdotal evidence was collected. Teachers indicated students made gains in their communication skills as well as learning about their local natural history. Two of the first three projects successfully created museum exhibits; one of these is on exhibit currently. Any changes in global mindedness were subtle and not commented on by the teachers.

PROMOTING PALEONTOLOGY: WESTERN SCIENCE CENTER OUTREACH USING FOSSILS FROM PUBLIC LANDS

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Few scientists would dispute the axiom that a necessary component of scientific research is the dissemination of the results of scientific endeavors. This is generally taken to mean the publication of peer-reviewed technical papers and the presentation of observations and results at professional meetings. We hold the view that public outreach is as vital as any other form of dissemination and that it should be considered a component of the research process. This is especially true of fossils from public lands, which are held in the public trust and for which recovery and study are often conducted using public funds.

The Western Science Center (WSC) currently holds fossil collections from National Park Service, National Forest Service, and Bureau of Land Management lands, and these collections are used in a variety of public outreach activities. Original specimens are frequently placed in rotating exhibits, sometimes within 1–2 months of arrival at the museum. These may be used to teach about the particular localities and faunas, or they may be incorporated into larger themed exhibits on broad topics (for example, evolution or paleoecology) that also make use of specimens from other locations.

In addition to exhibits, WSC regularly features fossils from public lands in our online and social media activities. This includes Fossil Friday posts on the WSC blog *Valley of the Mastodons*, as well as on the museum's Facebook, Twitter, and Instagram accounts.

About 40% of WSC's visitation occurs at off-site venues. In order to protect the fossils, specimens are not typically removed from the museum. Instead, WSC makes extensive use of 3D-printed plastic models, hand-painted to resemble the original specimens. These prints are used in traveling displays, "show-and-tell" events, and classroom teaching activities. Visitors are able to touch and handle the prints, allowing them to engage more fully with the specimen. In directed activities students can take measurements off prints for data analysis, without risk to the original specimen. To increase public accessibility even further, whenever possible WSC makes digital 3D models freely available through accounts with Sketchfab and MorphoSource, and strives to make any technical publications involving WSC specimens completely open-access.

CENOZOIC ENVIRONMENTAL CHANGE SHAPES NORTH AMERICAN UNGULATE COMMUNITIES THROUGH WITHIN- AND AMONG LINEAGE EVOLUTION

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Body mass is intertwined with organismal physiology, morphology, life history, and both microevolutionary and macroevolutionary dynamics. Accordingly, the evolution of mammalian body mass has seen considerable attention, particularly with in the context of climate and environmental change throughout the Cenozoic. Prior analyses document persistent increases in body mass among numerous groups of mammals, and have attempted to relate them to environmental changes. Revealing the drivers of these trends, and the precise mechanisms by which they drive body mass evolution requires more detailed quantitative analysis.

Here, we statistically detect shifts between intervals of stasis (i.e., statistically indistinguishable distributions) in North American mammalian ungulate (orders Artiodactyla and Perissodactyla) community structure, as measured by their body mass distribution, throughout the Cenozoic (56 to 5 Ma). We estimate body mass from dental measurements of nearly every North American ungulate species (n=919). Our results corroborate previous findings of a persistent increase in both the median and lower bound of body mass throughout the Cenozoic. Five distinct shifts in body mass distribution coincide with the early diversification of the ungulates (50 and 46 Ma), the initial opening of habitats in the Middle Eocene (40 Ma), Late Oligocene warming (26 Ma), and the Middle Miocene Climatic Optimum (16 Ma).

Ultimately, body mass distributions and shifts among them are determined by both trait evolution (i.e., evolution within lineages).and taxonomic evolution (i.e., lineage origination and extinction). To address trait evolution, we use phylogenetic comparative methods to estimate the rates of body mass evolution of ungulates. Abiotic drivers of body mass evolution are expected to place similar selective pressures on distantly related lineages (e.g., horses and camels). Using a phylogenetic framework, we fit Brownian motion models of increasing complexity to determine the number and timing of significant rate shifts across all coeval ungulate lineages. We found a marked shift at the global cooling event at the E/O (34 Ma), which led to lower rates of body mass evolution afterwards.

We then tested the influence of taxonomic evolution on ungulate body mass distributions by comparing the body masses of species originating or going extinct within an interval from those of the previous or following interval, respectively. Of the five shifts in body mass distribution we determined (above), two (at 50 and 40 Ma) may be explained by both significant differential origination and extinction. Similar to trait evolution, the E/O boundary is straddled by significant differential extinction and origination events. Collectively, our results underscore interplay of within- and among-lineage macroevolution in shaping mammalian community structure in response to environmental changes.

TOWARD SEQUENCING ANCIENT STONY CORAL SKELETOGENESIS PROTEINS

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Biomolecules, especially those preserved in ancient material can provide unusual insight into evolution. Unfortunately, DNA, the most common biomolecule used to reconstruct phylogenies and interrogate evolutionary history, is unlikely to be retained in fossil skeleton in a useable (i.e., non-degraded) form. In contrast, proteins, particularly those embedded in mineral crystals, are potentially available in fossil skeletons going back hundreds of millions of years. Before these fossil proteins can be used for phylogenetic analysis or other assessments of evolutionary process, protocols must be established to isolate and describe these biomolecules under conditions of minimal contamination by modern proteins. Here, we describe the extraction and characterization of coral (Order Scleractinia) skeletal proteins ranging from modern to Eocene ages (i.e., 16-20 million years). We first used pristine modern and fossil corals obtained from the Los Angeles Natural History Museum (LANHM) to establish a clean-work pipeline to extract and characterize proteins by amino acid racemization analysis, protein imaging, and liquid chromatography-tandem mass spectrometry protein sequencing. Next, we showed that proteins of appropriate racemization ages are retained not only in pristine Pleistocene corals (Key Largo Formation; approximately 120,000 years) but also in both partially and totally recrystallized Pleistocene specimens, also obtained from LANHM. We are currently in the process of sequencing these fossil proteins in the most promising samples. Finally, we confirmed the presence of non-modern proteins in primary aragonite coral skeletons aged ~2-20 million years obtained from the American Museum of Natural History and Harvard Museum of Comparative Zoology. Our work lays the foundation for carefully extracting and characterizing fossil coral skeletal proteins. It will aid in understanding the evolutionary history of biomineralization in these marine organisms.

ENVIRONMENT, SUCCESSION AND WHO'S ON FIRST: CONTROLS ON EDIACARA BED DIVERSITY AND ABUNDANCE STRUCTURE AT THE NATIONAL HERITAGE SITE, NILPENA, SOUTH AUSTRALIA

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Patterns of origination and evolution of early complex life on this planet are interpreted largely from the fossils of the Precambrian soft-bodied Ediacara Biota. Excavation and reconstruction of beds of the Ediacara Member of the Rawnsley Quartzite at the National Heritage Ediacara fossil site Nilpena, in the Flinders Ranges of South Australia has exposed nearly 300 square meters of fossiliferous bedding planes. As a result, the taphonomy and sedimentology of the succession are well-constrained, rendering it possible to disentangle ecological from taphonomic signals. The excavation and reconstruction of beds at Nilpena yields an exceptional and unique opportunity to examine not only the taxonomic composition of Ediacara communities but also their ecological character at various stages of development. Preserved ecological 'snapshots' of fossil assemblages range from immature communities associated with poorly developed organic mats to communities characterized by a high diversity of macrofaunal taxa, range of body sizes and the presence of dense textured organic surfaces. NMDS ordination of 11 beds of the Oscillation Ripple Facies separates two clusters along the first axis: three beds dominated by *Plexus*, Aulozoon and *Phyllozoan* along with *Dickinsonia* are distinct from the others suggesting possible subtle environmental differences within this facies. The second axis separates three beds dominated by *Aspidella*, with a substantial gradient among the remaining beds. We hypothesize that the second axis captures two different short-term successional pathways: immature surfaces are either quickly colonized and dominated by *Funisia* and *Aspidella* or they are colonized by *Dickinsonia*, *Rugoconities* and

other taxa.

COMPARING THE ACCUMULATION OF LARGE MAMMAL SPECIES IN AMBOSELI NATIONAL PARK, KENYA OVER INCREASING TEMPORAL AND SPATIAL SCALES, WITH IMPLICATIONS FOR THE COMPOSITION OF TIME-AVERAGED COMMUNITIES

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Virtually all fossil communities are time-averaged relative to the time scale at which modern communities are studied. Yet, much work remains on understanding how time-averaging affects the quality of ecological information that can be obtained from fossil assemblages, especially in terrestrial mammal systems. It has been hypothesized that time-averaging results in a community composition that also is spatially averaged, suggesting that time-averaging and spatial averaging may be interchangable. Here, we directly test this hypothesis by analyzing taphonomic data from repeated sampling of a large mammal death assemblage in Amboseli National Park, Kenya, which represent ~50 years of cumulative mortality. We use these data to compare the order by which species are accumulated with increasing temporal scale versus the order of species accumulation with increasing spatial scale. Results show that for any given sampling plot, there is a positive relationship between temporal and spatial species accumulation order, and across all plots, this relationship is quite robust (Kendall's tau=0.4). Furthermore, we find that the order of species spatial/temporal accumulation is directly related to species abundances, such that common species are sampled first followed by increasingly rarer species. We also find that common species possess functional traits that are more indicative of the local Amboseli habitat (e.g., grass-dominated diets), whereas rarer species possess traits that presumably reflect habitats found in the larger region outside of Amboseli (i.e., its metacommunity). Together, these three results demonstrate not only a direct correspondence between the taxonomic composition of increasingly time-averaged and spatially averaged communities, but also how this relationship is manifested in the functional makeup of increasingly averaged communities. Our findings emphasize the distinct nature of modern versus time-averaged fossil communities, and highlight the pitfalls related to the incautious application of small-scale modern theory and methods to large-scale paleoecological questions.

CONTINENTAL SUBDUCTION AS A MECHANISM FOR EMPLACEMENT OF THE ROBERTS MOUNTAINS THRUST IN NEVADA

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The Antler orogeny was a significant Paleozoic tectonic event in Nevada that emplaced deep-water mudstones and volcanic rocks on top of shallow-water carbonate-platform sediments. The contact between the dissimilar rock masses is called the Roberts Mountains Thrust, originally described by Merriam and Anderson in 1942, in the era before the concepts of plate tectonics.

Nearly 40 years later in 1981, Jess Johnson of Oregon State University hypothesized that the Antler orogeny involved subduction of continental crust at an oceanic trench. Johnson interpreted that the deep-water assemblage was an accretionary wedge composed of sediments scraped off the descending plate and piled up above a basal detachment surface that strikes parallel to the axis of the subduction trench and dips down in the direction of the descending plate. The carbonate assemblage was a continental-shelf carbonate platform that originally grew along the edge of a passive continental margin. As the former passive-margin descended into the trench, the shallow-water carbonate platform basically slid-under the base of the accretionary prism. The detachment surface separating these rock masses was the Roberts Mountains Thrust. The timing of emplacement of shallow-water carbonate below deep-water mudstone was constrained by Mississippian fossils recovered from the Webb Formation which overlaps the toe of the Thrust. Yet, continental crust is much less dense than ocean crust, so some workers questioned the possibility that continental crust could be subducted into a trench.

Nearly 40 years after Johnson's interpretation, modern geophysical methods and global-imaging systems provide clear evidence for decent of continental crust and continental-shelf sediments into subduction zones. My presentation will compare the size and shape of Recent subduction zones to the Roberts Mountains allochthon. Modern seismic sections offer compelling analogs for Johnson's interpretation. Continental crust of the western Australian plate is descending into the Banda Trench of Indonesia. Exploration

wells document a thick Tertiary carbonate platform that is being subducted into the trench. A basal detachment surface marks the boundary between underlying shallow-water carbonate sediments and overlying deep-water mudstones in an imbricately thrusted accretionary prism. Everything is driven by gravity. Nothing is really "thrusted" on top of anything else.

Johnson was able to mentally visualize these tectonic constructions by studying geologic maps and biostratigraphic data; including maps and publications by Professor M.A. Murphy of U.C. Riverside in the eponymous Roberts Mountains. Mike is a renowned field geologist as well as a biostratigrapher. Mike was one of the people that Johnson asked to read and criticize the early versions of his paper. It is hoped that Johnson would have enjoyed seeing these modern data. They support concepts that he saw only in his mind.

A NEW CNIDARIAN FROM THE LATE EDIACARAN (562–557 MA) AND ITS IMPLICATIONS FOR THE DIVERSITY OF EARLY ANIMAL COMMUNITIES

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Deep-water Ediacaran communities of the Avalon biotic assemblage are dominated by frondose organisms, in particular rangeomorphs and arboreomorphs. However, other taxa, not referable to any currently defined Ediacaran morphogroup, are also present as rare components. While there is broad consensus that at least some of these organisms may represent the remains of animals, few have been examined in detail. We here present a new taxon from the turbiditic succession of Charnwood Forest (U.K.) which had a non-biomineralized skeleton constructed of a pair of equi-sized tetraradial goblets, each bearing a dense crown of tentaculate structures. The organism stood at least 20cm high, with the goblets branching (?bifurcating) from a point near their base, leading us to infer a colonial organisation. Phylogenetic analysis, and subsequent statistical tests, resolve this species as a total-group cnidarian.

The new taxon lacks a preserved holdfast structure, and is preserved in a different orientation to the closely aligned co-occurring frondose fossils (interpreted to have been anchored in place at the time of burial), suggesting that it is allochthonous. This is consistent with the well-documented offshore export to the deep of anchored shallow water organisms in the modern marine environment (e.g. algae), and other potential evidence for 'washed-in' organisms in Avalonian deposits. Furthermore, the appearance of classical 'White Sea' taxa in shallow-water White-Sea deposits (~558 Ma) indicates an earlier, Avalonian-age, origination of these forms, which has important implications for the evolutionary versus environmental nature of Ediacaran assemblages. We conclude that the classical deep-water Avalonian deposits record only a subset of contemporary Neoproterozoic diversity and cannot, therefore, be used as the foundation of an Ediacaran evolutionary trajectory. This is, perhaps, no more than we might expect, given that modern-day deep marine ecosystems are markedly distinct from their shallower water counterparts. The current model of Ediacaran evolution posits a deep-water initial radiation of macro-organisms. However, together, these data suggest that this assumption may need to be recast; initial radiations for most extant animal phyla took place in the shallows, where there was greater energy and opportunity – could the same not be true in Ediacaran times?

FOREST CANOPY RESPONSE TO GREENHOUSE WARMING AT THE PALEOCENE-EOCENE THERMAL MAXIMUM

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At the current rate of greenhouse gas emissions, atmospheric carbon dioxide (pCO_2) levels will increase to values not known on Earth in the last 50 million years. How will vegetation, more specifically, primary productivity respond to this exponential increase in pCO_2 and the associated climate changes? Much of our present knowledge about the effects of pCO_2 on plant growth comes from modeling studies and small-scale experimental work. How whole ecosystems will be affected on longer temporal scales remains largely unknown.

This study tests how increased pCO_2 and temperature during the Paleocene-Eocene Thermal Maximum (PETM ~ 56 million years ago) affected forest ecosystems from new sections identified in the Hanna Basin, south-central Wyoming, USA. We present data from

three geologic sections where the negative carbon isotope excursion (CIE) of the PETM interval is present. We demonstrate that canopy density, quantified as Leaf Area Index (LAI–foliar area/area of ground) can be reconstructed using light-dependent cellular morphology of leaf epidermis in modern environments. We then present a reconstructed LAI record from fossilized dispersed leaf cuticles from mid to late Paleocene–early Eocene strata using the newly developed proxy. Our preliminary results show moderately dense forests existed consistently throughout most of the Paleocene, with an abrupt increase in LAI immediately before PETM onset. Following PETM onset, forests abruptly opened prior to the deposition of a large, stacked fluvial channel system. Through the body of the PETM, LAI values are highly variable. In the PETM recovery zone, LAI values again increase to pre-PETM levels and higher. Absolute LAI values vary across each of the sections indicating heterogeneity across the landscape; conditions were more forested at the basin margin compared to the basin center where the fluvial/paludal system was most pronounced.

Similar to other areas (e.g. the Piceance Creek Basin), the Hanna Basin contains sedimentological evidence for increased fluvial discharge, sediment flux and enhanced erosion of surrounding rock units during the PETM. Our LAI record suggests that reduced vegetation cover altered the basin's hydrologic system during the climatic perturbation. LAI is controlled by temperature, precipitation, precipitation seasonality and pCO_2. While pCO_2 is expected to have a fertilizing effect on forest canopies, the interplay between pCO_2, temperature and precipitation regime is complicated. Our data are consistent with models of anthropogenic greenhouse warming that show enhancement of hydrologic extremes, and they suggest that the fertilizing effect of pCO_2 is only beneficial to primary productivity during wet periods.

PATTERNS OF LETHAL AND SUBLETHAL PREDATION ON CAMBRIAN STAGE 3-DRUMIAN STAGE TRILOBITES FROM THE GREAT BASIN, USA

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Changes in predator-prey systems through the early and mid-Paleozoic are hypothesized to have played a major role in early animal evolution and transforming ecological relationships in early marine ecosystems. Differences in interpretation of the evidence of carnivorous activity from fossils can lead to substantially different models of paleoecologic interactions. Using an array of characteristics, improvements have been made to the criteria used to distinguish lethal and sublethal predation from other types of damaged surfaces (such as molting injuries) on the exoskeletons of Paleozoic trilobites. Healed injuries are separated into predation scars and injuries of uncertain origin (which includes molting injuries). Non-healed injuries are separated into those of biologic and non-biologic origin. Injuries of biologic origin can be distinguished as having an origin with either lethal predation or scavenging.

Study of fossils from a variety of Cambrian Konservat-lagerstätten ranging from provisional Stage 3 through the Drumian Stage of Utah and Nevada, show that most trilobites are represented by fragmented remains. Healed sublethal injuries are relatively rare, indicating that Cambrian predators were more commonly successful than unsuccessful. Among fossils showing sublethal predation scars, there appears to be considerable variability in the number of specimens showing such scars. Olenellines (Stage 3-Stage 4) tend to have low incidences of sublethal predation scars. Some Drumian Age taxa, such as Elrathia and Asaphiscus, have higher incidences of sublethal predation scars. Other common trilobites of the Drumian, such as Modocia, tend to have few preserved sublethal predation scars. This preliminary evidence suggests that some trilobite clades evolved more efficient predation-resistant structures or behavioral strategies through time. Lethal predation or scavenging appears to be commonly represented through the Cambrian Stage 3-Drumian interval by unhealed, broken sclerites, in coprolites, and in cololites. Incomplete, partly disrupted exoskeletons interpreted as scavenged remains are common in Cambrian Lagerstätten.

APPLICATION OF DEAD MOLLUSCAN ASSEMBLAGES TO THE ASSESSMENT OF THE ECOLOGICAL QUALITY OF THE EASTERN MEDITERRANEAN

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The EU has established monitoring directives to preserve and protect marine environments around the Mediterranean Sea in response to increasing

anthropogenic stress. The directives standardize the ecological health state of water systems by defining an 'ecological quality status' (EcoQS) that quantifies the deviation from pre-impacted reference conditions. However, in many cases information on pre-impacted conditions is incomplete or missing, leading to potential bias in evaluation of environmental quality.

Long-term accumulation of shells on the sea floor average out short-term variations in the community and can be used for a more complete definition of the ecological system. These death assemblages serve as a baseline for the composition and structure of live communities. This study compares live and dead molluscan assemblages across eutrophication gradients in the highly oligotrophic Israeli shallow shelf (40 m water depth). Over 10,600 bivalve individuals were collected and identified. Bentix and Shannon-Wiener indices were calculated for live and dead assemblages from polluted and control stations near the Dan Region Wastewater Project (Shafdan), to evaluate their utility as indicators of EcoQS in the Eastern Mediterranean.

The Bentix and Shannon-Wiener indices show a significant decrease in ecological conditions over time, from a moderate EcoQS in the dead- to a poor EcoQS in the live assemblage. Although Bentix was developed specifically for Eastern Mediterranean living taxa, it failed to show a significant difference in the live assemblage between the polluted and control stations of the Shafdan, highlighting the importance of applying the death assemblage as a baseline recorder of multiannual time scales. Adjustments to the Bentix index concerning naturally abundant pollution-tolerant benthic fauna, e.g *Corbula gibba* of the oligotrophic Israeli coast improves its utility in monitoring shallow shelves around the Mediterranean.

The Shafdan case study showed that live-dead comparisons of molluscan assemblages are valuable in evaluating ecological conditions before the onset of human activity and should be applied in future monitoring procedures.

PHYLOGENETIC, ECOLOGICAL, AND GEOGRAPHIC EFFECTS ON MORPHOLOGY: ANALYSIS OF 3D ORNAMENTATION SHAPE IN MARINE BIVALVES

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An organism's external phenotype is its primary interface with the ambient environment. Consequently, extrinsic pressures from a mixture of biotic and abiotic factors are expected to impose strong selection on that phenotype, but intrinsic factors such as evolutionary history can restrict access to morphologies suited for certain ecologies and life habits. Here, we assess the extent to which external phenotypes are predicted by extrinsic and intrinsic factors in two faunas of modern marine bivalves—a tropical assemblage of 358 species from the Florida Keys and a boreal assemblage of 63 species from Cape Cod.

We quantified the surface shape of the bivalve shell—i.e. ornamentation, a feature with anti-predatory and life-habit implications—by flattening the reconstructed surface topography of microCT scans to a unit square using an ad-hoc proportional slicing sampler, and then mapping point-wise distances between the shell's exterior and interior surfaces. Resulting intensities of the ornamentation "images" (40,200 pixels) were rescaled 0-1 using the inner 98% quantiled distances to buffer the influence of outlying measurements. Images were ordinated using PCA and the first 100 PC axes (92% cumulative explained variance) were retained for predictive analyses by qualitatively assessing the congruence of full-resolution images to those from ordination subspaces.

We used a permutation-based multivariate analysis of variance to assess the geometric partitioning of variance across the ornamentation space in response to taxonomic family membership, infaunal vs. epifaunal lifestyles, and mode of attachment to the substratum. Family membership most strongly affected the partitioning of variance in this ornamentation space, with ecological factors including substrate use and mode of attachment explaining relatively less variance. Geography has little explanatory power, where the centroid and variance of the ornamentation in the boreal Cape Cod fauna cannot be distinguished from that of the tropical Florida Keys fauna, even though the species with true shell spikes are absent from Cape Cod. Shell ornamentation is not associated with total body size or shell thickness either, even when controlling for the effect of family membership, indicating a minimal tradeoff between total shell material and the shape of exterior ornament. Overall, phylogeny appears to have the tightest control on shell ornamentation, for the entire data set or when considering only those families with multiple ecological functions (N=20 of 56). However, within ecological functions, epifaunal lifestyles have the most disparate ornamentation shapes, buoyed by taxa with spikes, ribs, and flanges, whereas the less disparate (though more speciose)

infaunal lifestyles are relatively inornate. Thus, bivalve ornamentation appears to evolve hierarchically: under tight phylogenetic control but with distinct effects derived from coarsely grouped ecological modes.

RANGE CHARTS AS CHRONOSTRATIGRAPHIC HYPOTHESES, FOUR DECADES LATER

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In the early 1970s, I took an advanced stratigraphy course from Mike Murphy. He turned us loose with the data for hundreds of occurrences of conodonts, brachiopods, and graptolites collected and compiled by Mike and co-authors from multiple sections across the Silurian-Devonian boundary in Nevada. Over several months, we taught ourselves Shaw's method of graphic correlation, mostly by trial and error. I was hooked. By the end of the class, I knew that I wanted to do my dissertation on the theory and practice of getting from individual fossil occurrences in multiple sections to the big-picture of total fossil ranges. I ended up doing exactly that, using fossil dinoflagellate cysts from the Eocene and Oligocene of the Gulf Coast.

The best part of my UCR experience was the freedom Mike gave me pursue my goal. He didn't always understand what I was doing and he certainly didn't know my fossil group, but he gave me an amazing amount of leeway. My final year at UCR had me writing the computer code to run Shaw's method in real time (via teletype to a computer in UCLA). Mike saw that I could do in 3 hours what it took our graduate class a month or two to do. He also saw the new method I had developed. Next thing I knew, Mike and I were writing a paper. I was running the computer program with Mike's data while simultaneously completing the various drafts and defense of my own dissertation. There were a lot of late nights, but I can't think of a better way to have your advisor understand every limitation and advantage of your new method than to see it applied to both your own and his very different sections and species lists.

The first paper I ever published was Murphy and Edwards [1] on the Silurian-Devonian in Nevada. You can now get the whole volume (used copy in good condition) on Amazon for about $80.

Both Mike and I have a penchant for proper nomenclature. I have served on the North American Commission for Stratigraphic Nomenclature for over three decades, being Chair three times. Mike served on the International Subcommission on Stratigraphic Classification of the IUGS International Commission on Stratigraphy, including as Chair. Both of us contributed to the current International Stratigraphic Guide.

I've spent my whole career on fossil dinoflagellate cysts: starting, of course, with biostratigraphy but also treating morphology, taxonomy, paleoecology, and taphonomy. I've spent a lot of time in Atlantic Coastal Plain geologic mapping and drilling. Along the way, I helped discover the buried Chesapeake Bay impact crater. Different fossil group, different geologic setting, but built on the foundation I got from Mike.

[1]Murphy, M. A., and Edwards, L. E., 1977, The Silurian-Devonian boundary in central Nevada, *in* Murphy, M. A., Berry, W. B. N., and Sandberg, C. A., eds., Western North America: Devonian:University of California, Riverside Campus Museum Contribution, v. 4, p. 183-189, 3 figs., 2 tables.

A SUNKEN-WOOD DWELLING CHITON (MOLLUSCA: POLYPLACOPHORA) IS NOT A DIRECT LINK TO THE PALEOZOIC

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Since the genus, *Ferreiraella* Sirenko, 1988, was introduced for rather odd chiton species (Lepidopleurida: Ferreiraellidae) that live in deep water as sunken-wood specialists, its author has subsequently cited biogeographic data and its wood dwelling habit to propose these extant species are the direct descendants of a well-known and well-preserved examples of five species of the Pennsylvanian (Carboniferous) genus, *Glaphurochiton* Raymond, 1910. The latter was argued to also inhabit the abundant sunken land plant remains of the Pennsylvanian because these often fully-articulated fossils are associated with dark shales thought to have originated from muddy habitat rich in organic plant remains. Although the chitons were claimed to have similar shape and tegmental sculpturing of their valves, no specific derived valve features were cited and, in general, valves from extant lepidopleurids are simple and smooth with mostly plesiomorphic attributes. The claimed biogeographic evidence for the link has to do with the presently known worldwide distribution of species of *Ferreiraella*, concentrated in three oceanic regions, which was interpreted as due to the joining of Pangaea in the Permian, followed by its Jurassic breakup. An appealing aspect of this hypothesis is that sampling of molecular data across the major lineages of Lepidopleurida could support the hypothesis if *Ferreiraella* was found to be the sister lineage of all other Lepidopleurida, or

even all other extant chitons. Calculation of molecular clock date estimates should also support an ancient divergence for *Ferreiraella*. Using a combination of partial gene region data coding for nuclear 18S/28S or mitochondrial 16S ribosomal RNA, selected fossil calibrations for other chitons, and representatives of most genera of Lepidopleurida and selected outgroups, we have instead rejected the supposed ancient connection between *Ferreiraella* and *Glaphurochiton*. Two species of *Ferreiraella* were included in the analysis, one from a Museum National D'Histoire Naturelle expedition to the western Pacific, and a recently discovered new species from off California. *Ferreiraella* appears to be unremarkably nested inside the crown group of Lepidopleurida, which itself was estimated to be much younger than the Pennsylvanian. Because the association with sunken wood is also known for at least two other lepidopleurid genera, besides *Ferreiraella*, we would interpret this ecological association to be labile and recently derived.

SECULAR CHANGES IN LIFE HISTORY TRAITS OF FEMALE WOOLLY MAMMOTHS

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Tusks of proboscideans are enlarged incisors that contain an almost complete record of growth spanning an individual's life from near birth (recorded near the unworn tusk tip) until death (recorded at the pulp cavity). This record is accessed through analyses of compositional and/or structural variation in tusk growth increments within dentin. These increments form with a consistent periodicity and vary in thickness and composition based on nutritional input and aspects of life history.

Dentin increments have been shown to record seasonal patterns of growth, which has permitted identification of boundaries between years. Using a combination of stable isotope data and analysis of weekly dentin increments, several studies have shown that the transition from winter to spring is marked by a distinct shift from high to low X-ray attenuation. Identification of these annually-forming density features permits nondestructive analysis of tusks, often yielding multiple decades of growth data.

Several complete or nearly-complete tusks of adult and subadult female woolly mammoths from northern Siberia were imaged using a high resolution industrial microCT scanner. Measurements of annual increment areas were taken from curved slices following the longitudinal axis. In general, annual increments representing juvenile, subadult, and early adult years show successive increases in increment area through time followed by a gradual decline in area into old age. Over periods of three to five years, adult female tusks record a pattern of decrease and then increase in both increment area and extensional length. This pattern was not observed in extensional increments of male mammoths and was not found in either area or extensional length measurements of increments formed during sub-adult years in females. The appearance of this pattern only in adult females, and not in adult males or young individuals of either sex, suggests that it reflects some aspect of female reproductive life history. Given the similarity in the periodicity of this pattern to that of calving intervals in modern elephants, it seems reasonable to interpret these cycles of change in annual increment area as representing calving intervals.

The two main competing mechanisms for extinction in mammoths, climate change and hunting by humans, would have had antithetical effects on age of maturation and length of calving intervals. This suggests that life histories of female mammoths should show secular changes, approaching the time of extinction, that reflect the dominant cause of extinction and provide a test for hypothesized causes. We document lengths of calving intervals and ages of maturation in female mammoths in the latter part of the Pleistocene in order to assess changes through time and thereby test the cause of extinction.

WHAT PALEONTOLOGISTS CAN LEARN FROM ARTISTS IN ENTERTAINMENT

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Paleontology has long enjoyed wide public appeal thanks to dramatic depictions of dinosaurs and other fossil animals in popular media. But this appeal is often not sufficient to guarantee funding for jobs or grants in Paleontology. Amidst increasingly competitive funding and challenging political landscapes, paleontologists must be vigilant and creative in how we present our material in order to gain public support. One of the best ways we can do this is to learn from artists in entertainment industries. For many years,

we have been working with artists in entertainment to understand how to make science not just informative, but meaningful for diverse audiences. These efforts resulted in a workshop series led by the lead author,"Science Through Story," that adapts storytelling approaches from the film industry for use in science communication, as well as a symposium that the authors organized, "Science Through Narrative: Engaging Broad Audiences," with presentations from both scientists and artists, many of them paleontologists and paleoartists.

From these endeavors, we have arrived at several shared conclusions. 1) Both artists and scientists distill complexity to reveal truth. Both start with a large amount of material and must distill the most cogent and compelling story from it for a given audience in a given context. 2) When communicating with broad audiences, relatability must take precedence over volume of information. The communicator must get the audience invested in the story in order for any information to stick. 3) To engage an audience, you must find the right balance between accuracy and believability. Greater precision will not necessarily make a story more compelling. Often what you lose in resolution, you gain in power.

These initiatives have already reached over 2,300 participants, generated content available to the public and the academic community (in a volume of papers that is now published in the peer-reviewed journal *Integrative and Comparative Biology*), and can serve as models of collaboration for other institutions. Effective public engagement with science will require scientists and artists to learn from and support each other's efforts, and paleontologists can especially benefit from these opportunities.

DEVELOPMENTAL NOVELTIES, THE RISE OF O2 AND THE EARLY EVOLUTION OF ANIMALS.

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The changes in cellular gene regulation and development associated with the origin and early evolution of animals occurred during an interval of highly variable environmental conditions in particular very low and unstable oxygen levels. Increasing levels of oxygen have been invoked as causal drivers for the origin of Metazoa (~750 million year ago (Ma)), the origin of bilaterian animals (~650 Ma), the origin of crown groups of major metazoan clades with their characteristic morphologies, and increases in body size near the Ediacaran-Cambrian boundary (539 Ma). But the course and stability of oxygen levels in shallow marine environments between 800-500 Ma have been highly contentious, with different geochemical proxies providing sometimes conflicting evidence, and modeling studies indicating that oxygen levels may have been spatially heterogeneous and temporally unstable. Comparative studies of living animals and their closest relatives have now provided a wealth of data on deep homologies in developmental genes and processes including novelties associated the formation of genome control mechanisms, developmental tools and developmental patterning. Understanding the forces responsible for the origin of these novelties and their initial function requires acknowledging the conditions in which they arose. I explore how developmental potential changed through the late Neoproterozoic by the expansion of the regulatory genome and how the realization of this potential may have been constrained environmental conditions, and particularly by oxygen levels in shallow marine settings. Although comparative data remains sketchy, the origin of Metazoa corresponds with the generation of novel genomic control mechanisms in opisthokonts and others near the base of metazoans, such as increases in the number of transcription factors (TFs), TF families, Type I and III promoters, distal enhancers and expansion of the multi-factor complexes which control gene activity. These elements provided a scaffold for the generation of new cell types, and eventually the foundation upon which structured dGRNs for spatial and temporal control of the developing embryo were established. These patterns suggest that the original role of many of these developmental tools was associated with spatial and temporal control of *cell types* rather than the complex morphogenetic patterning found today.

EVOLUTIONARY DYNAMICS OF METAZOAN GENE REGULATION

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Since the 1970s macroevolutionary research has pursued two different avenues. The dominant path over much of that time has been investigations of the differential success of species and clades through time, and understanding how events such as mass extinctions influence the success or failure of taxa. The second path has been to focus on sources of variation, and whether microevolutionary processes reflect different origins than macroevolutionary phenomena,

which would support decoupling between macro- and micro-evolution at a genomic or developmental level. Gould's *Ontogeny and Phylogeny* (1977) was a major motivator for such work in the 1980s but lacked sufficient mechanistic grounding. The spread of comparative evolutionary developmental biology since the mid-1990s has provided just such a grounding. There is now a wealth of data on the evolution of developmental processes associated with a wide variety of evolutionary outcomes, from adaptive divergence within species to novelties such as the origin of limbs in vertebrates and arthropods. A variety of approaches have been pursued in exploring the evolutionary dynamics of gene regulatory networks (GRNs) and the larger regulatory genome. These include focusing on particular components such as enhancers or transcription factors, exploring the processes responsible for generating particular aspects of morphology, such as eyes, neural crest, or flowers. Other work has focused on particular processes, such as gene co-option or duplication. Each of these approaches is informative, depending on the questions of interest.

From a conceptual perspective we can identify distinct aspects of evolution of the regulatory genome: First, the introduction of new regulatory tools, such as distal enhancers in Metazoa, which expand the regulatory capacity of a clade. Second, the expansion of existing regulatory controls, particularly among transcription factor families. Third, repatterning of regulatory networks, particularly through co-option of subcircuits has been a common theme. Finally, microevolutionary changes in regulatory control are frequently generated via changes in enhancer specificity. I will focus on the variety of mechanisms of GRN change associated with different types of morphological evolution, largely drawing on examples from animals. I want to assess claims made by Davidson and I that microevolutionary changes may be more common in the periphery of a GRN while macroevolutionary changes may be largely confined to the core of a GRN or otherwise involve distinct mechanisms (Davidson and Erwin, 2006), and whether there is a mechanistic difference in the types of GRN evolution associated with larger-scale evolutionary changes (macroevolution) and the origins of morphological novelties versus small-scale adaptive or microevolutionary changes.

ALLOW US TO REINTRODUCE OURSELVES: REVITALIZING THE INVERTEBRATE PALEONTOLOGY COLLECTION AT THE ACADEMY OF NATURAL SCIENCES

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The Academy of Natural Sciences, Philadelphia of Drexel University (ANSP) is the oldest natural history museum in the Western Hemisphere, and its Invertebrate Paleontology collection dates to the founding of the museum in 1812. The collection is heavily dominated by mollusks, primarily from the US Atlantic and Gulf Coastal Plains and from the U.K., while also reflecting an 19th century perspective of having representation of all macro-invertebrate phyla. Unfortunately, the collection has been operating without dedicated staff for the last two decades. No data from this collection of approximately one million invertebrate fossils, including 5000 type specimens, is available online at this time, and no data has been shared with any modern data aggregators (e.g. iDigBio, GBIF). The recent merger of the Academy with Drexel University has seen a commitment to the revitalization of this world-class collection, with the hirings of a curator, a position that has gone unfilled for forty years, and the first full time collection manager in twenty years. Drexel has also allocated funding for two undergraduate co-op students to work in the collection in 2019. A partnership has been established between the Invertebrate Paleontology department and Drexel's Louis Stokes Alliance for Minority Participation, an NSF funded initiative that provides various modes of support for historically underrepresented minority undergraduate students in STEM-disciplines to increase funding for these students. The co-op students spend 32 hours per week for six months as collections assistants and are working on a complete collection inventory. Additionally, the Academy has granted the department four years of collections improvements funding to assist with the physical curation of the collection. Following inventory, a major goal for the new staff is to begin a robust digitization program and start contributing data to the wider biodiversity and paleontology research community via NSF funded digitization grants.

The purpose of this poster is to re-introduce the ANSP Invertebrate Paleontology collection to the greater paleontology community. Using the information gathered from an ongoing inventory of the collection, we will present the contents of the collection and their potential for use in research.

GAITS MODELLING AND COMPUTATIONAL FLUID DYNAMIC SIMULATION SUGGEST MULTIPLE FUNCTIONAL BEHAVIORS IN TRILOBITES

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Unlike two, four, six and eight legged animals, multilegged animals have been largely overlooked in the computer graphics literature. Only a couple of cases deal with multilegged arthropods (i.e. myriapods) and none with extinct animals. Here we focus on trilobites, a successful arthropod group with a one-to-one relationship between biramous appendage pairs and tergites. Trilobites not only provide an outstanding fossil record but also an outstanding ichnofossil record (e.g.*Rusophicus*, *Cruziana* or *Diplichnites*). However, understanding of trilobite walking and its relationship with sediment and water flows is far to be understood. In order to understand such relationships, we present a mathematical and virtual model framework for modelling these multilegged trilobites and animating their locomotive behaviour over regular surfaces using different velocities and consequently different flow behaviours in real time with compelling physical and biological realism.

Our results using two benthic Ordovician trilobites (*Placoparia* and *Neseuretus*) show two different ways of locomotion. Tripod legs can meet in the distal ends (on the seafloor) or in the proximal part (close to the trilobite body). This is consistent with locomotion in multilegged arthropods (e.g. myriapods). The adaptation of the type of locomotion could be related with the type of substrate. A minimum surface on the seafloor, which means less tripod legs, prevents the sinkage of the trilobites into unconsolidated substrates. On the other hand, the Computational Fluid Dynamic (CFD) simulations of the flow around the exoskeleton, under laminar and transitional flow conditions, shows a high positive pressure in the rear part of the trilobite body in both trilobite species. Given this positive pressure, the rear trilobite legs are unlikely touching the seafloor while walking. This has an important implication in trace fossils understanding and could explain the variation seen in some ichnofossils such as *Diplichnites*. CFD shows that the position of the trilobite head had different functions depending of its position: i) gills protection; ii) increase the drag, iii) assist feeding and iv) increase the lift. Protection of the gills is fundamental against sediment hits or high flows. *Placoparia* has a very short anterior pleural tips (suitable for enrollment but unsuitable to protect the gills) and its head protects against high flows. *Neseuretus* increases the drag by moving down the head which prevents getting out of the seafloor in a high energy event in transitional flow conditions. However, moving the head up, *Neseuretus* increases the lift, which first increases the flow currents toward the mouth (beneath the hypostome) and afterwards swims freely for potentially short distances.

Further work is needed to understand relationships between shape, flows and sediment. But this first attempt shows very promising results to understand the evolution of shape within a realistic environment framework.

MORPHOLOGICAL VARIATION AS CONSEQUENCE OF ABIOTIC FACTORS IN EARLY TRILOBITES

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Environmental factors can drive morphological plasticity in animals making difficult in some cases the delimitation between species. This is especially true in some early arthropods, as trilobites. However, analyse the implication of abiotic factors within the shape variation in the fossils record is not a simple task. Secular isotopic variations ($\delta^{13}C$ and others) are well recognized as the major cause of many excitation during the Phanerozoic. But a relationship between morphological variation and isotopic variation throughout the geological record is unknown. We tackle this duty analysing the shape variation of a well-known species from South China and elsewhere (i.e. *Bathynotus kuichouensis*) during its whole stratigraphically record before its extinction in the "Redlichiid-Olenellid Extinction Carbon isotope Excursion" (ROECE). Geometric morphometric analysis shows a clear trend to increase the glabella width and palpebral lobe surface and partial least squares analysis shows a clear relationship between shape and secular $\delta^{13}C$ and $\delta^{18}O$ variation. A clear reaction is here seen in the shape variation of *Bathynotus kuichouensis* since the shape of its glabella increase when there is an organic matter reduction and the eye surface increase in a more turbiditic environment before the ROECE. These results suggest that the environmental degradation related to the ROECE was not a sudden process in South China, but gradual enough to be

distinguishable for the isotopic signal of sediments and influence in the variation of some morphological traits of contemporaneous benthic trilobites.

STRETCHED, WRINKLED AND RIPPED: UNEXPECTED STRUCTURAL INTEGRITY AND EXTENSIBILITY IN DICKINSONIA PROVIDES NEW INSIGHT INTO ENVIRONMENTAL CHANGE AND DIVERSITY LOSS IN THE EDIACARA BIOTA

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The Ediacara Biota is a suite of soft-bodied taxa that represents the earliest multicellular, community forming organisms in the fossil record. Recently, it has been documented that this group likely records the earliest extinction(s) of macroscopic fossilized organisms. Whether these represent changes in preservational conditions or true extinctions remains debated. If they are extinction events, potential drivers are also controversial, although replacement by more advanced Cambrian forms or environmental change have been proposed. Importantly, exceptional preservation allows detailed investigation into the biology and ecology of these enigmatic forms. Here we present new data on *Dickinsonia,* an iconic, abundant, modular, bilaterally symmetrical Ediacaran organism, preserved under variable taphonomic conditions. In spite of a lack of hard parts, *Dickinsonia* are found as lifted, transported, folded, rolled, ripped, and expanded or contracted individuals, while maintaining diagnostic morphology. This suite of characters indicates that *Dickinsonia* was composed of a material that was flexible, difficult to rip and capable of elastic and plastic deformation. While none of these characters are diagnostic of a single biomaterial component, we find many similarities with modern biopolymers. Significantly, the maintenance of relief following complete tearing suggests that *Dickinsonia* was composed of relatively thick tissues, indicating higher-oxygen requirements than previously hypothesized. The ability to be transported considerable distances and still preserve recognizable fossils is unique amongst the Ediacara Biota and demonstrates that *Dickinsonia* was a taphonomic elite. Combined with discovery in multiple environmental settings, this indicates that the absence of *Dickinsonia* represents the extinction of this organism prior to the Nama assemblage, possibly due to a decrease in the global availability of oxygen in the latest Ediacaran.

PALEONTOLOGIC AND PALEOBIOGEOGRAPHIC STUDIES OF LITUITIDA (MOLLUSCA: CEPHALOPODA): BASED ON NEW MATERIALS FROM SOUTH CHINA

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The ontogeny of *Lituites* (Lituitida Starobogatov, 1974) is studied and discussed based on the measurements of the well-preserved specimens from the Middle Yangtze Platform, South China. Analytic geometry is adopted to explain ranging developmental stages using the polar coordinates method to describe different forms. Then three characteristic ontogenic stages in the species lifespan have been recognized, i.e., juvenile, rapid growth and mature stages. On this basis, a cladistic analysis was conducted for several significant species of Family Lituitidae and Sinoceridae, belonging to Order Lituitida, with the aim of elucidating the origin and phylogenic evolution of the group. Thirteen taxa, including lituitids and the related forms and outgroups, and 16 characters were selected for the analysis. The results suggest that the lituitids share a likely common ancestor, the orthocerids. The orthocerids gave rise to two lineages, one of which was the *Rhynchorthoceras* and *Ancistroceras* lineage, and the other was the *Lituites*, *Cyclolituites* and *Sinoceras* lineage. *Sinoceras* was the stem group from which *Lituites* and *Cyclolituites* were derived. Furthermore, weighted networks approach has been used to explain paleobiogeographic patterns of Lituitida near the northeastern peri-Gondwana region during the Middle to Late Ordovician.

HIGH SCHOOL PALEONTOLOGISTS AND PUBLIC LANDS: FROM THE OUTCROP TO THE CLASSROOM

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Paleontology is more than a gateway science on the path to other destinations—it is a vibrant and socially relevant field of inquiry in its own right, which offers opportunities for virtually anyone to make a major

scientific contribution. The educational program of the Raymond M. Alf Museum of Paleontology at The Webb Schools involves students in grades 9 through 12 in the study of life's history, through field trips, volunteer opportunities, and coursework. Fossils from public lands play a critical part in this effort, combining the resources of a museum on a high school campus along with the extensive public lands accessible throughout the western United States.

Students at Webb, in collaboration with professional paleontologists from the Alf Museum, participate in every facet of the museum experience. As 9th graders, all students have a paleontology unit in their evolutionary biology class, culminating in a field trip to collect fossils in the Barstow Formation (Miocene) under permit from the US Bureau of Land Management. While in the field, students learn how to identify and collect a fossil in the field, as well as the basics of outdoor ethics.

As 10th graders, interested students can take Honors Paleontology and Honors Museum Research classes. Honors Paleontology features units on the ethics and legalities of fossil collecting, including PRPA (Paleontological Resources Preservation Act) and science stewardship on public lands. Here, students see the broader societal interactions of paleontologists and learn about principles of civic engagement, by studying the federal rule-making process associated with PRPA. Students compare and contrast public comments from various stakeholders about proposed rules and see how the final rule addressed these comments. Students also learn about the permitting process, the roles of repositories, and how all of these contribute to the science of paleontology. As 11th and 12th graders, many students undertake original research on fossils collected from public lands, presenting their results at professional conferences and publishing within the peer reviewed literature. Additionally, student volunteers in the museum's after school program work under the supervision of museum staff to learn about best practices of collections stewardship.

Field experience during extended summer and weekend trips offers another opportunity for Webb students to interact with paleontology on public lands. Under permits from the US Forest Service and US Bureau of Land Management held by staff at the Alf Museum, Webb students help collect fossils relevant to ongoing research projects. These projects have helped to better characterize fossil resources in previously understudied areas, identify species and faunal assemblages new to science, and educate a new generation in the sciences and stewardship of public resources.

NINE MORPHOTYPES OF BIOTIC TRACES FOUND ON FOSSIL AND RECENT ECHINOIDS

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Although a variety of traces are found on Recent and fossil echinoids, attributing traces to specific trace makers remains contentious due to a lack of diagnostic criteria. Rigorous characterizations and descriptions of a broad range of traces observed on echinoid tests could improve our ability to identify and interpret ecological interactions between echinoids and their predators and parasites in the fossil record.

Here we describe and characterize traces of biotic interactions observed in 8,693 specimens that represent 131 species of echinoids and range in age from Jurassic to Recent. The 587 distinct biological traces observed were grouped into nine categories: circular, figure-eight, irregular, linear, notched circle, oblong, rectangular, slit, and subcircular. We used SEM images to investigate and document exemplars of those nine trace types. To assess long-term changes in the diversity of traces (and associated ecological behaviors), morphological trace diversity was evaluated in terms of a null model simulating random distribution of trace types through time. All traces were pooled and randomly reassigned to each time bin based on the number of specimens per time bin (1,000 iterations per time bin).

Circular traces were most common (n=286), followed by subcircular (n=110) and oblong (n=78) traces, interpreted as being produced by either predation or parasitism. Traces surrounded by a dissolution halo (n=31) were interpreted as the product of acid etching during gastropod predation. Cumulative trace diversity increases in the late Eocene, much later than predicted by the null model. This suggests that biotic interactions may have intensified through evolutionary time, particularly during the Mesozoic and early Cenozoic, as predicted by several macroevolutionary hypotheses, previously only evaluated using mollusks.

The trace categorizations proposed here may promote a more consistent identification of traces on fossil echinoids across individual case studies. A more

comprehensive and rigorous categorization of trace types should ultimately enhance our ability to identify evolutionary trends in biotic interactions archived in the fossil record of echinoids.

A SIMULATED SELECTIVITY FRAMEWORK FOR EVALUATING THE RELATIVE PLAUSIBILITY OF MARINE EXTINCTION SCENARIOS

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Because many marine extinction events coincide with interrelated changes in climate, oxygenation, seasonality, productivity, and seawater chemistry, it is not always clear which specific environmental changes were most responsible for causing species extinctions. Selectivity patterns can in principle help to fingerprint the principal drivers of extinction, but *a posteri* interpretation of selectivity predictions is complicated by uncertainty about what selectivity patterns are expected under a given global change scenario. We outline a simulation framework for evaluating expected selectivity patterns under different global change scenarios. We begin by using a combination of global circulation and Earth system models to simulate global geographic and bathymetric distribution and seasonal variations of seawater temperature, productivity, dissolved oxygen, and carbonate saturation state under a range of assumptions about atmospheric $CO_2$and O_2concentrations. We select a model to represent a hypothetical global starting state, and use niche modeling to simulate the geographic distributions of species with a wide range of niche parameters, dispersal abilities, and centers of origin in this world. We then select an alternative global state model and predict the geographic and bathymetric distributions of the previously simulated species in this new global state. Species that are not able to disperse to cells that have environmental conditions within their niche parameters become extinct. This approach allows us to generate expected extinction selectivity patterns for a variety of hypothetical global state transitions and for ecologically and physiologically diverse lineages, and thus to determine which scenario best matches empirical extinction patterns. Although necessarily simplistic, our simulation framework has potential to aid in solving the inverse problem of inferring extinction drivers from patterns of extinction selectivity. We illustrate this approach by comparing predicted and observed selectivity patterns for several different scenarios that have been suggested for the Late Ordovician Mass Extinction.

STRATIGRAPHIC PALEONTOLOGY: THE KEY TO RECOGNIZING MAJOR TECTONIC AND PALEOENVIRONMENTAL EVENTS RECORDED IN PALEOZOIC STRATIGRAPHIC SUCCESSIONS OF NORTH-CENTRAL NEVADA

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Improvements in methods of radiometric dating, chemostratigraphy and magnetostratigraphy and the development of cyclostratigraphy and astrochronology have greatly enhanced the practice of stratigraphy. Where these methods can be applied, they offer high-resolution, long-distance correlation of stratigraphic intervals and horizons that record major events and distinctive periods in Earth history. However, they generally cannot be applied to stratigraphic successions that have not been correlated first with biostratigraphy. Furthermore, chemostratigraphy and magnetogratigraphy cannot be applied to stratigraphic successions that have suffered significant diagenetic and thermal alteration. Radiometric dates from volcanic ash beds can allow for high-resolution correlation and astronomical tuning, butbstratigraphic successions of great duration in many depositional basins lack volcanic ash beds. As a result, major events recorded in these successions can be recognized and correlated only with the long-established, yet fundamental, methods of stratigraphic paleontology. Such is the case for the thick Paleozoic successions in the Great Basin, specifically those in north-central Nevada, where Mike Murphy devoted much of his career. Recognized sole by stratigraphic paleontology are: the Roberts Mountains thrust and Antler orogeny, imbricated thrust plates in the lower part of the Roberts Mountains allochthon, the original stratigraphic succession of the Ordovician Vinini Formation, a thick submarine-fan complex in the Vinini Formation that is correlative with the sea-level low stand that corresponds to the boundary between the Sauk and Tippecanoe Sloss Sequences, the Late Ordovician global sea-level low stand and mass extinction, and a duplication of the structural-stratigraphic succession in the Roberts Mountains allochthon.

COMPARISON OF PALEOENVIRONMENTAL AND PALEOCLIMATOLOGICAL PARAMETERS OF CORRELATIVE DINOSAUR-BEARING LATE CRETACEOUS (CAMPANIAN - MAASTRICHTIAN) ROCK UNITS ACROSS ALASKA, USA: A REGIONAL PERSPECTIVE

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The Late Cretaceous of Alaska now records a remarkably diverse fossil vertebrate fauna across much of the region. Hadrosaurs and ceratopsians are the most commonly found either as skeletal remains, or as footprints. As the largest-bodied herbivores, these two dinosaurs were likely keystone species and played a role in structuring this ancient ecosystem. The richest rock units in terms of dinosaur remains are the Prince Creek Formation (PCF), North Slope, Alaska, the lower Cantwell Formation (LCF), Denali National Park, Alaska, and the Chignik Formation (CF), Aniakchak National Monument, Alaska, and together provide an unparalleled opportunity to examine an ancient high-latitude terrestrial ecosystem from a regional perspective.

The PCF consists primarily of small distributary channels, crevasses splays, small ponds and abundant paleosols. Large trunk channels fed this delta plain distributary network. Paleosols are weakly to moderately developed and indicate generally poorly drained conditions punctuated by periods of drying that were probably related to the seasonal light regime. Megafloral remains are uncommon, but paleosols contain an abundant palynoflora. A rich dinosaur record is known largely from skeletal remains. PCF, located at 75-85 ^{o}N paleolatitude, had a MAT of ~ 5-6 ^{o}C. An average MAP value of 1318 +/- 181 mm/yr was obtained from paleosol geochemical calculations. MAP estimates calculated from d^{13}C data yield a low range of 350-1200 mm/yr and a high range of 1000-3900 mm/yr.

The LCF consists primarily of axial braided rivers, alluvial fans, floodplains, ponds and small lakes. Paleosols exist but they are uniformly poorly developed. Abundant plant megafossils are present but fossil pollen recovery is poor. A rich invertebrate and dinosaurian ichnofauna is known from the LCF. The LCF, located at a paleolatitude of 65-75 ^{o}N, had a MAT of ~ 7–8 ^{o}C. MAP estimates calculated from d^{13}C data yield a range of 168-470 mm/yr during the MME, 353-1050 mm/yr before the MME, and 475-1451 mm/yr after the MME.

The CF is a cyclic succession of sedimentary rocks representing shallow marine environments in the lower part and predominantly non-marine conglomerate, sandstone, mudstone and coal.

The CF, located at a paleolatitude of 56–57 ^{o}N, had a MAT of ~ 15°C. Plant megafossils and a dinosaurian ichnofauna are contained within the CF. Woody fragments from the CF were measured for their carbon isotopic composition to relate d^{13}C to mean annual precipitation. The sample analyzed from the Chignik Fm. was -24.0‰ vs. VPDB. The CF sample suggests a MAP value of 822 mm/year.

Relative abundances of hadrosaurs and ceratopsians vary somewhat along this north-south transect and different environment. Both dinosaurs are abundant from the PCF and LCF, but the CF is dominated by hadrosaurs. We suggest that the paleoclimatic and paleoenvironmental variances observed played a role in the large-bodied herbivore ecological structure of the ancient North.

WRITER VERSUS SCIENTIST: COMPROMISE AND COMPREHENSION

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I recently chaired the panel to choose the popular science book of the year for The Royal Society. This allowed me oversight of the challenges scientists face in communicating the excitement of discovery to a lay audience in writing. I shall review some of the common pitfalls and challenges. Most professional scientists are interested in theory, but most readers are concerned with narrative. Discovery is best communicated as an intellectual adventure. Although we all know that human foibles are part of the scientific life they are sometimes edited out in popular accounts in favour of a less nuanced approach. Scientists like to present progress as a straight line leading to our present enlightenment rather than the complex process it really is. Often the failures make as interesting stories as the successes. We are fortunate in paleontology to have a science rooted in fieldwork and real objects – fossils. The story of discovery of fossils that changed our understanding of the history of life is endlessly fascinating to readers who know little of the process. More challenging is integrating our science with breakthroughs in genetics and molecular biology, although the congruence is more than we

could have imagined a few years ago. In my view one of the challenges is keeping the broad view – we cannot have only books about dinosaurs and hominines. This tendency is reflected in the decreasing numbers of specialists 'behind the scenes' in museums in the USA and elsewhere. Web resources are generally helpful, but there is no substitute for the individual voice of a writer communicating directly with a committed reader. I shall illustrate some of these ideas drawing on my own experience with publishing in the USA and Europe. Like many scientists I regard communicating with a wider public to be a duty at a time when there is so much misinformation. In particular, paleontologists are able to explain the long biological history of our planet at a time when humans are wreaking such profound damage.

THE BEST OF TWO WORLDS - THE LATE ORDOVICIAN TRILOBITES OF THE TAIMYR PENINSULA, ARCTIC RUSSIA

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Important occurrences of Late Ordovician trilobites of the Taimyr Peninsula, Arctic Russia have been known for nearly 70 years through the work of Balashova (1959/1960) but have been neither well-understood nor revised. A study and revision of 56 Sandbian-Katian species from the Peninsula including new and previous described material, gives a clear picture of their diversity and distributionfor the first time. The new material is well-preserved and constrained stratigraphically, while the original Balashova specimens are more incomplete and from isolated finds made during mapping in the 1950's. A new monorakine subgenus and seven new species are recognized in press. Previously thought to be an endemic, *Taimyraspis*is shown to be an ityophorid close to *Effnaspis*, *Yumenaspis*, *Ityophorus*, and *Frognaspis* from Laurentia, Baltica and China. The monotypic *Goldillaenoides* is shown to be close to*Failleana*. The remopleuridid*Pararemopleurides*is recognized for the first time in Taimyr, a genus with other possible occurrences including China, North-eastern Russia and Australia. The genus may be closely related to *Robergiella* Whittington. Two new species of *Robergia* prompted a re-investigation of the type species which revealed the presence of a narrow anterior border. This finding suggests that the concepts of *Roberga* and *Pugilator* Nikolaisen must be revised. A new species of *Dionide* is exceptional in having about 30 axial rings on the pygidium. It is found in dark sediments suggestive of a depletion of oxygen at the sea floor, and the high number of segments with accompanied limb pairs and gills may reflect an adaption to such an environment. Eight species of monorakines are described, but while *Ceratevenkaspis* dominates *Monorakos* is apparently absent from the Taimyr Peninsula. Seven species of isoteline asaphids are recognized, but with the exception of *Homotelus* only very fragmentary material is available. Our study clearly distinguishes between two biofacies in the Upper Ordovician. The first is a widespread raphiophorid association found in marginal shelf areas of low latitude Ordovician palaeocontinents. Taxa include *Ampyxella*, *Ampxyina*, *Failleana*, *Pararemopleurides*, *Raymondella*, *Remopleurides*, *Robergia*, *Stygina*, *Taimyraspis*, and *Toernquistia*. The second biofacies is the shallow shelf monorakine-cheirurid-illaenid association with *Carinopyge*, *Ceratevenkaspis* and *Evenkaspis*, endemic to the Siberian Platform, as well as seven isoteline taxa, *Achatella*, *Ceraurinus*¸ *Denella*?, *Whittakerites*, and *Xylabion* otherwise typical of inshore Laurentia. From a biogeographical and palaeogeographic point of view, Taimyr is placed marginally to the Siberian Platform during the later Ordovician.

A MAP TO MANAGING PALEONTOLOGY

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Managing paleontology requires the development of a program that fits the needs of science and society. Here, I present a road map, or MAP, to manage paleontology that should fit any bureaucracy or governing structure. This involves a mission (M) that articulates the purpose for managing paleontological resources. The mission might be simple or complex, but it always must be consistent and attainable. The mission must also be framed in a legal context of authorities (A). Authorities include statutes, laws, written rules, and policy. The primary statute that authorizes the BLM paleontology program is the Paleontological Resources Preservation Act of 2009 (PRPA), but there are many other statues and policies that also authorize and guide the program. Finally, managing paleontology requires a detailed structure or program (P). A paleontology program must have a mission that is consistent with applicable authorities (and not in violation of other authorities) in order to be successful and should also

consist of all of the following program components: Inventory & Monitoring; Planning & Mitigation; Collection & Curation; and Education & Protection. The MAP presented here provides a rational structure for developing a paleontological management program that can be transposed to any governing structure.

COMPARATIVE TRILOBITE TAPHONOMY OF THE PIOCHE FORMATION LAGERSTÄTTE AND OTHER FORMATIONS ALONG A NEARSHORE TO OUTER SHELF TRANSECT, LATEST EARLY CAMBRIAN (STAGE 4; LATE DYERAN) OF THE SOUTHERN GREAT BASIN, USA

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Burgess Shale-type preservation of soft-bodied taxa is rare in the early Cambrian of the western United States but does occur in the late Dyeran levels of the Pioche Formation in eastern Nevada, in taxa from the Ruin Wash locality such as *Anomalocaris pennsylvanica*, *Tuzoia nitida*, *T. polleni*, and *Ottoia* sp. Unlike in the Burgess Shale where they comprise a relatively low proportion of the preserved biota, trilobites are relatively common in deposits of this age across the paleoshelf of southwestern Laurentia in what is now the Great Basin. Analysis of a sample of more than 2600 fossil specimens from fine-grained siliciclastic deposits of the *Nephrolenellus multinodus* trilobite zone of the latest Dyeran (Stage 4), across a nearshore-to-outer shelf transect of the Cambrian passive margin wedge of southwestern Laurentia, demonstrates several patterns from shallow, proximal settings to those of deeper, offshore environments. The faunas from the Bright Angel, Pioche, Carrara, and Emigrant formations of Nevada and California are dominated by olenellid and biceratopsid trilobites such as *Olenellus terminatus*, *O. gilberti*, *O. fowleri*, *O. chiefensis*, *Nephrolenellus multinodus*, *N. geniculatus*, *Mesonacis fremonti*, and *Biceratops nevadensis*. Patterns preserved in the four formations across the transect include: 1) a decrease in overall fossil abundance from nearshore to shelf settings; 2) higher diversity (effective richness) on the inner and middle shelves compared to nearshore and lowest diversity by far on the outer shelf; and 3) low degree of articulation of trilobites across all environments (~1% of identifiable trilobite specimens), with fragmentation of sclerites increasing offshore and highest degrees of fragmentation and disarticulation on the outer shelf. Trilobite cephalon size and compass orientation (measured on glabella axis) show no discernible pattern across the shelf; trilobites sclerite up-down orientation (measured on cephala) varies by site and shows no clear pattern. These results suggest that sclerite burial and sedimentation rates were higher in proximal settings, that possibly fluctuating abiotic conditions in nearshore settings limited taxonomic diversity relative to the open shelf, and that long bottom-exposure times, and possibly scavenging, near or below storm wave base were more responsible for the disarticulation and breakage of trilobite remains than mechanical transport (current action) in more distal settings.

"DEADLY TRIO OF CARBON DIOXIDE" LEAVES A SELECTIVE EXTINCTION RECORD DURING THE END-PERMIAN MASS EXTINCTION

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The end-Permian mass extinction event was the most catastrophic biodiversity crisis in Earth's history, with extinctions in the oceans hypothesized to have been caused by the combined role of deoxygenation, high temperatures, and ocean acidification, i.e., the "Deadly Trio of Carbon Dioxide". The role of these environmental factors in the extinctions is, however, controversial, and there are several inconsistencies: geochemical evidence for ocean acidification does not correlate with the mass extinction; presumed sedimentological proxies for ocean acidification have been associated with other processes; rapid warming is recorded as occurring after the main extinction pulse; and anoxic conditions did not occur in shallow water aerated settings that suffered extinctions.

The ecological selectivity of mass extinctions reveals critical information on the traits of life as key determinants of extinction and, crucially, critical information on the causes of extinction. To better understand the ecological selectivity of the end-Permian mass extinction we compiled a high-resolution dataset of fossil occurrences spanning the Permian-Triassic transition in South China. The dataset includes marine invertebrates, calcareous algae, and Problematica, with each taxon characterized according to ten ecological attributes (skeletal mineralogy, physiological buffering capacity, body size, carbonate load, ornamentation,

tiering, motility, respiratory protein, reproduction, and habitat). We find that extinction risk was greater for genera that were limited to basinal habitats, had a stationary mode of life, possessed a siliceous skeleton or, less critically, had calcitic skeletons. These selective losses can be directly linked to the environmental effects of rapid injections of carbon dioxide into the ocean-atmosphere system, specifically expanded oxygen minimum zones, rapid warming, and potentially ocean acidification, i.e., the "Deadly Trio of Carbon Dioxide".

RESILIENT MARINE INVERTEBRATE COMMUNITIES ALONG THE US GULF COASTAL PLAIN DURING THE EARLY CENOZOIC HYPERTHERMALS

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Climate change is one of the five biggest threats to global biodiversity today. Early Cenozoic hyperthermals (i.e., the Paleocene-Eocene Thermal Maximum, Early Eocene Thermal Maximum, Early Eocene Climatic Optimum, and Middle Eocene Climatic Optimum) provide an opportunity to investigate how climate warming has altered the ecological structure and composition of marine ecosystems in the past. Here, we investigated changes in the diversity and composition of Cretaceous to Eocene (Maastrichtian to Priabonian) molluscan communities from the US Gulf Coastal Plain. Our own collections include 421 samples collected from 95 localities along the Gulf Coastal Plain (Texas, Louisiana, Mississippi, and Alabama). Each sample was collected at the bed-level and fossils were collected exhaustively until no new specimens were found. In total, 109,100 mollusk specimens were identified to the species-level. Together with a newly compiled database of previously recorded molluscan fossil abundances from the US Gulf Coastal Plain, we explored the changes in sample diversity and composition through the study interval. Our data show that the early Cenozoic hyperthermals did not leave a lasting impact on the composition of molluscan marine communities. We propose that these communities were resilient to environmental change because mollusks are better adapted to high temperatures than other taxa, as demonstrated by their evolutionary history. In comparison to more sensitive ecosystems, such as coral reefs, mollusk communities are relatively tolerant to thermal stress.

IDENTIFICATION AND ANALYSIS OF SMALL MAMMAL FOSSILS AT RANCHO LA BREA ELUCIDATE RESPONSES TO LATE QUATERNARY ENVIRONMENTAL CHANGE IN SOUTHERN CALIFORNIA

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Paleontological excavation and research have been conducted at Rancho La Brea (RLB) in Los Angeles, California, for over a century. Despite this, there is no consensus on the environmental conditions and changes that occurred there during the late Quaternary. We examined small mammal (<3kg body size) fossils from four RLB deposits (Project 23 Deposits 1, 7B, 13 and 14) spanning >50,000 to ~30,000 calibrated years before present (cal BP) and evaluated changes in their faunal composition, diet, and size through time. Those changes are proxies for interpreting responses to past environmental change since small mammals are sensitive to natural perturbations due to their small home ranges and limited mobility. We evaluated taxon-specific presence, absence, and abundance through time by randomly sampling and identifying fossils from each Project 23 deposit and compared those occurrences with small mammal occurrences from RLB Hancock Collection deposits that frequently yield post-glacial dates. Dietary niches were tracked in a subset of taxa via stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis of individually radiocarbon-dated dentaries. For several taxa, size changes were quantified from linear and geometric morphometric measurements of species-identifiable fossils and analogous elements of their extant representatives in California. Results show similar sets of taxa among P23 deposits, though taxon-specific abundances vary considerably. Further, there are compositional differences between Project 23 deposits and Hancock Collection deposits. For example, some xeric-adapted taxa including *Lepus californicus* and *Notiosorex crawfordi*

are present in several Hancock Collection deposits but absent from all sampled Project 23 deposits. $\delta^{15}N$ and $\delta^{13}C$ become more positive and more constrained through time respectively in some radiocarbon-dated taxa including *Otospermophilus beecheyi* and *Sylvilagus audubonii*. Finally, measured elements of *Sylvilagus audubonii*, *Sylvilagus bachmani*, and *Microtus californicus* from Project 23 are significantly smaller than those of their extant representatives. Together, these data suggest that the baseline small mammal community has shifted through time, particularly across the last glacial transition, setting the stage for further baseline shift in contemporary times. These compositional changes may be due to environmental changes including aridification and/or increased seasonality that occurred over the past 50,000 years, but we are also exploring whether changes in the small mammal fauna can be attributed to perturbations of the broader mammal-vegetation food web that occurred with the late Pleistocene megafaunal extinctions.

HOUSE BY THE SEA OR SKYSCRAPER? – PRIME ESTATE DURING THE GREAT ORDOVICIAN BIODIVERSIFICATION

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The Great Ordovician Biodiversification (GOBE) refers to a sharp increase of taxonomic richness during the Middle Ordovician. Although global analyses of many taxonomic groups show a similar temporal pattern of the main increase in taxonomic richness, the onset of this increase seem to have been earlier in some groups, such as plankton, graptolites, and crinoids. Despite a continuously improving understanding of the timing of the GOBE, globally, regionally and in taxonomic groups, we lack an understanding of its ecological dynamics. Regardless of the taxonomic affinity of an organism, those that live in the same environment may benefit or suffer in a similar way from changing conditions in this particular environment. There is also a greater opportunity for taxa living in the same habitat to interact ecologically with one another and hence have their fates linked during environmental change. Here, I want to explore whether there were any 'beneficial positions' in the water column or around the water/sediment interface during the GOBE, in terms of diversification rates. To do so, I establish diversification dynamics on genus level for five different ecological groups: non-motile epifaunal, motile epifaunal, erect epifaunal, nektobenthic, planktonic. I hope to get a better understanding of when these groups reacted to drivers of the GOBE, whatever these may be. Finding out which groups benefited to which degree and at which time, may give us new insights into the dynamics behind the GOBE.

My preliminary results suggest that most of the investigated groups follow the overarching global diversification dynamics pattern, with a peak in origination rates at the Dapingian/Darriwilian boundary. Only genera of the erect epifaunal group do not follow this pattern but instead show increased origination rates already at the Floian/Dapingian boundary, one boundary prior to all other groups represented in the dataset.

PRESERVATION POTENTIAL OF ROCKY INTERTIDAL MOLLUSCS IN TEMPERATE AND TROPICAL ENVIRONMENTS

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Previous studies concerning the fossilization potential of rocky shore communities agree that inclusion in the rock record is an unusual occurrence and that most ancient rocky shores are represented in the geologic record on unconformity surfaces. The depositional settings that likely create such fossil assemblages is restricted to rocky shores within lagoons or highly faulted coast lines. These investigations, however, utilized either in-situ fossil assemblages or the living communities themselves, but never sub-fossil death assemblages. Additionally, due to the paucity of examples, the effect of latitude on preservation potential has not been addressed. The possibility of preserving intertidal species as parautochthonous assemblages was explored by analyzing the compositional fidelity obtained in a live-dead-dead comparison from in-situ communities, sandy subtidal flats, and beach shell accumulations. Using samples collected on two islands (San Salvador, Bahamas and Appledore Island, Maine), we compared (1) living intertidal mollusc communities; (2) death assemblages; and (3) their preservation potential.

Transects spanned the entire intertidal vertically and represented all intertidal biozones of tropical or temperate rocky coasts. Transect methods to capture the living community differed between islands – on San. Salvador, 2m wide transects were marked from the highest spray zone down to the lowest intertidal zone possible. Within each intertidal zone in

the transect, a 0.5m2 transect was thrown and all organisms within its boundaries were collected for identification and measurement. Appledore Island has semi-permanent transect locations marked with metal pins to facilitate repeated transect studies. A line from the pin to the waterline guided placement of quadrats along it. The complete dataset by Shoals Marine Lab interns dates back to 1986 but the overabundance of questionable data led us to use only 3 consecutive years of data (1999-2001) in subsequent analyses. Samples from sandy sub-tidal flats and beach shell accumulations yielded ca. 10,000 shells and shell fragments. All identifiable specimens were assigned a taphonomic grade (0-3) based on the degree of fragmentation. Death assemblages from beaches or sandy subtidal flats were dominated by subtidal bivalve and gastropod fragments; Intertidal species accounted for only a small proportion of specimens in the death assemblages. Yet the compositional fidelity of the rocky intertidal communities was high: approximately 70% of intertidal species were represented in the death assemblages regardless if identifiable fragments were included or not. Results suggest that it may be possible to gather information on rocky intertidal community composition from sub-tidal fossil assemblages. The influence of latitude on preservation potential is linked to important habitat and community differences between temperate and tropical rocky coasts.

THE QINGJIANG BIOTA – AN EXTRAORDINARY NEW BURGESS SHALE-TYPE FOSSIL LAGERSTÄTTE FROM THE EARLY CAMBRIAN OF SOUTH CHINA

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Our understanding of the Cambrian explosion and of the fundamental structure of the tree of animal life rests in large part on evidence from a dramatically enhanced fossil record, characterized by the preservation of entire assemblages of soft-bodied fossils. In the one hundred years since Walcott's original discovery of the Burgess Shale, exceptionally preserved fossil assemblages have been reported from Cambrian strata of almost every paleocontinent. Nevertheless, only the early Cambrian Chengjiang biota of Yunnan Province has matched the Burgess Shale in total diversity of soft-bodied taxa and fidelity of exceptional preservation. Here, we report the discovery of an extraordinary new early Cambrian Burgess Shale-type (BST) fossil Lagerstätte from the Changyang area of South China, which is characterized by high taxonomic diversity (101 metazoan taxa plus 8 algal forms), an unexpectedly large proportion of new taxa (53.2%), and exquisite preservation of fine aspects of labile tissue anatomy. The taxonomic richness of soft-bodied taxa (85%) approaches the top tier of BST deposits, presently occupied only by the Burgess Shale and Chengjiang biotas. Rarefaction analyses suggest that diversity may surpass all other BST biotas. Novel aspects include high abundance of cnidarians, including both medusoid and polypoid forms, new taxa resembling extant kinorhynchs, and abundant larval or juvenile forms. While approximately coeval to the Chengjiang biota, the Qingjiang biota (518 Ma) appears to have occupied a more distal environmental setting, in which a different early Cambrian ecosystem flourished. The uniqueness of the Qingjiang biota in the taxon composition and preservation quality holds special potential to provide new insights into the evolution of early metazoans and the structuring of Cambrian ecosystems across environmental gradients.

CAN BURGESS SHALE-TYPE ENVIRONMENTS INFORM OUR UNDERSTANDING OF THE CAMBRIAN WORLD?

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Burgess Shale-type biotas form the foundation of our understanding of the Cambrian explosion. Historically, the Burgess Shale and other Fossil Lagerstätten have been considered the products of atypical, highly localized environments in which the constraints of the typical fossil record were circumvented. It is now clear, however, that the record of Cambrian Series 2-3 is replete with Burgess Shale-type deposits, with multiple occurrences on most paleocontinents. While special circumstances were most certainly required to facilitate exceptional preservation, the widespread and frequent instances of Burgess Shale-type preservation are unique among Phanerozoic Lagerstätten, and may offer insights into the nature of Earth's surface environments in which the Cambrian explosion unfolded. This presentation focuses on examples from the Burgess Shale, Chengjiang, and the newly discovered early Cambrian Qingjiang Lagerstätte from Hubei Province, South China. These deposits and others like them occur characteristically in outer shelf and slope environments. The frequency of these environments in the rock record is indicative of large-scale continental flooding and a profound expansion of shallow marine

habitats. In the water column, Cambrian Lagerstätten are associated with a sharp chemocline that juxtaposed anoxic and oxygenated benthic environments. Geochemical data indicate that anoxia in these settings was driven by different forcings in different settings, with elevated productivity typical of South China, and stagnation under lower productivity regimes, presumably driven by poor circulation and thermal stratification, dominant elsewhere. These observations are congruent with emerging global geochemical data, suggesting pronounced swings in atmospheric oxygen concentration during the Cambrian. In particular, they underscore the susceptibility of benthic habitats to oxygen deficiency under far lower rates of productivity than required in today's oceans. Bottom water anoxia in outer shelf environments imposed an environmental barrier to benthos, and suggests that environmental instability and habitat fragmentation were significant features of Cambrian marine habitats on the continents. The mineralogy and geochemistry of outer shelf sediments include prominent early marine carbonate cements and Fe-rich authigenic clays. The former indicates elevated alkalinity of bottom waters and the latter requires simple (Al-rich) detrital clay mineral precursors: both are indicative of intensive continental weathering, and an elevated supply of nutrients from the continental crust to the oceans. Burgess Shale-type environments suggest that metazoan evolution during the earliest Phanerozoic occurred in marine settings characterized by habitat instability and fragmentation, as well as nutrient loading of epicratonic seaways.

AGE-MORTALITY PROFILES IN LA BREA BISON: INSIGHTS INTO POPULATION DYNAMICS AND TAPHONOMY

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In population dynamics, age-mortality profiles (a histogram showing the mortality in each age class) are powerful tools for interpreting ecology. A typical living population has its highest mortality rates among juveniles, and mortality declines among the older age classes. In a fossil assemblage, this is interpreted as a catastrophic death assemblage. Another common pattern is an attritional death assemblage, with high mortality rate among the youngest and oldest age classes, but the healthy adults have a very low mortality rate. Jefferson and Goldin (1989) reconstructed the age-mortality profiles for Ice Age *Bison antiquus* from Rancho La Brea, using the wear stages in lower jaws. They found a unimodal distribution, with a very high number of older juveniles, but few in the other age classes. This seems to suggest taphonomic or presevational distortion of the original biological population sample. For comparison, we measured all the juvenile and adult limb bones (humerus, radius, femur, tibia) using the length of the diaphysis to see what kind of profile they produced. Surprisingly, they gave a bimodal pattern, with a large number of older juveniles (as seen by Jefferson and Goldin), but also a large mode among adults in their prime. This pattern bears no resemblance to the expected patterns for known processes, and must reflect some sort of taphonomic bias in the tar pits. Apparently, individuals of these age classes are more likely to be trapped, or their bones are less likely to be destroyed during the pit wear and churning within the pit.

INTERVERTEBRAL VARIATION OF HETERODON AND FARANCIA (SERPENTES: DIPSADINAE) AND THE REASSESSMENT OF FOSSIL HOLOTYPES USING GEOMETRIC MORPHOMETRIC ANALYSIS

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Snake vertebrae are common throughout the Cenozoic fossil record, but identification of isolated vertebrae often proves difficult due to inter- and intra-columnar variability. Most fossil identifications are based on comparisons with disarticulated modern specimens, with a focus on mid-trunk vertebrae. One focus of this study was to determine the necessity of identifying a true mid-trunk vertebra prior to identification and to develop a method of locating the columnar position of an isolated vertebra for both modern and fossil identifications. Colubrid genera *Farancia* and *Heterodon* were chosen for the analysis because they share distinct morphological similarities, articulated modern specimens were available, and fossil species in these genera need to be reassessed. Every third pre-cloacal vertebra was selected from each specimen to undergo geometric morphometric analysis on its anterior face. Relative warp analyses detailed the inter-columnar variation of each specimen and found that the only significant difference in the column was between the anterior most vertebrae, which are already identifiable, and the remainder of the pre-cloacal vertebrae. Despite concern, the convention

of using mid-trunk vertebrae for identification may prove accurate for these genera. Due to *Farancia* and *Heterodon*'s vertebral similarities, a discriminant function analysis was utilized to distinguish the two genera from one another. To evaluate this method's utility in paleontology, vertebrae of two extinct species, *Heterodon brevis* and *Paleofarancia brevispinosus,* will undergo identical morphometric and discriminant analyses. This study also emphasizes the need for more modern snake skeletons in collections and the necessity of stringing the vertebral column prior to disarticulation.

ENERGETICS DRIVES CONVERGENT GIGANTISM IN MARINE CROCODYLIFORMES

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Twenty-four species of crocodile populate the globe today, but this richness represents a minute fraction of the diversity and disparity of Crocodyliformes since their origin early in the Triassic. While modern crocodiles have sprawling postures and are semi-aquatic, fossil forms are more varied, spanning from erect, fully terrestrial species to fusiform and flippered, fully marine species. Differences in the physical and chemical conditions on land versus in water have the potential to cause differing selective pressures on diversification and morphology for terrestrial versus marine lineages. For example, differences in buoyancy, habitat size or structure, protein availability, thermoregulation, or oxygen availability may cause selective pressures on the body size of Crocodyliformes living on land or in the ocean. In this study, our goal was to quantify the influence of a marine lifestyle on the directionality, rate, and variance of evolution of body size in Crocodyliformes in the hopes of identifying physiological or ecological mechanisms for these changes. To achieve the study goal, we compiled a database of body sizes for 265 fossil and modern species of Crocodyliformes covering terrestrial, semi-aquatic, and marine habitats, and we time-scaled a pre-existing supertree using the known stratigraphic ranges of those species. We find significant increases in body size following the evolution into marine habitats which have been systematically coupled with increases in strength of selection and decreases in variance. Such changes do not occur in association with shifts from terrestrial to semi-aquatic lifestyles, suggesting that selective pressures on size evolution associated with aquatic habitats are only fully expressed when lineages become fully marine. Lung volume, which has long been proposed as the main constraint on diving time in marine crocodiles, is an important constraint at sizes greater than 10 kg, whereas the rate of cooling is the more important constraint on diving time at sizes less than 10 kg. A model that combines constraints from thermoregulation and lung capacity provides a physiological basis for the larger minimum and average sizes of marine Crocodyliformes. Marine Crocodyliformes have not evolved to sizes larger than their largest non-marine relatives, suggesting that constraints on maximum size are shared across all crocodiles, perhaps through factors such as the allometric scaling of feeding rate versus basal metabolism with body size. These findings, coupled with related findings for marine mammals, suggest that broad scale patterns of body size evolution and the shapes of body size distributions within higher taxa are often determined by physiological constraints more than by ecological interactions or environmental fluctuations.

HISTOLOGICAL SKELETOCHRONOLOGY OF THE EARLY PERMIAN STEM LISSAMPHIBIAN DOLESERPETON

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The amphibamid temnospondyl *Doleserpeton annectens* from the early Permian karst deposits of Richards Spur, Oklahoma is widely accepted as one of the most closely related taxa to lissamphibians under hypotheses supporting either a batrachian or a lissamphibian origin from the clade. Although the cranial anatomy of the taxon has been extensively studied with respect to morphological features such as the dentition, less attention has been directed toward the postcranial skeleton or to ecological aspects of its paleobiology. In particular, the appendicular skeleton offers great opportunities for advancing our understanding of both small terrestrial temnospondyls and the greater issue of lissamphibian origins.

Here we present a histological growth series of long bones of *Doleserpeton annectens* that provide new insights into the ontogeny and paleobiology of the taxon. The abundance of available material of this small amphibamid at the Richards Spur locality permits broader histological sampling and more detailed ontogenetic studies than have been performed for

any other fossil amphibian. By sampling 60 femora, we were able to provide qualitative and quantitative constraints on intraspecific variation in ontogeny. The general predicted pattern of correlation between age, indicated by lines of arrested growth (LAGs), and various parameters of femur size holds true, but a high degree of variation is noted in the sample. Testing correlation of size with another physiological proxy, osteocyte lacunar density (OLD), revealed the same pattern of variability. This could be induced by ecological factors and supports the inference of marked developmental plasticity in this stem lissamphibian. We also conducted sensitivity analyses of our dataset by subsampling in sample size bins more typical of paleohistological studies of extinct tetrapods. These analyses revealed that limited sample size, a widespread limitation of paleohistology, can inadvertently produce artificially strong and thus misleading correlations between osteological features and age, an important consideration when studying non-amniotes in which developmental plasticity is well-documented.

Our detailed histological examination of *Doleserpeton* also provides additional information on the inferred paleoenvironment of the locality. Spacing between LAGs remains relatively constant throughout ontogeny, indicating a constant rate of cyclical growth throughout the animal's lifetime that could reflect consistent, repetitive seasonal patterns at the locality. However, closely paired LAGs (double LAGs) are found in the vast majority of specimens. By comparison with extant lissamphibians, this is interpreted to be indicative of a higher range of seasonal environments that results in two cessations of growth within a single temporal cycle. This histological analysis contributes new information on the ecology and development of this stem lissamphibian in the context of the unique Richards Spur locality.

HIGH-RESOLUTION MULTISPECTRAL IMAGES FOR FOSSIL DETECTION: APPLICATIONS OF SPECTRAL PROPERTIES OF FOSSILS TO REMOTE FIELD SURVEYS

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Properties of light are used to recognize some standardized patterns on the surfaces of fossils. In particular, UV light makes it possible to detect specific characteristics, like fossilized feathers and stomach contents, and short wavelength lamps are commonly used during restoring activities.

The same generalized concept can be applied to paleontological field surveys. The main goal is to detect new fossils exposed on the surface, while also increasing the surface available for "prospecting" at a regional scale. This larger scale analysis entails a larger variability of objects and a consequent higher degree of uncertainty. Therefore, it is essential to increase the pixel resolution of each image and enlarge the range of wavelengths recorded through each band.

In our analyses, we tested this approach in remote, arid, regions (i.e. John Day Fossil Beds, Pisco Basin, Wadi el Hitan, Gadoufaua, and Petrified Forest) where fossils of Eocene and Miocene mammals, dinosaurs, large crocodiles, and wood trunks had been previously reported.

We sampled fossils from each locality, and we analyzed them with a spectrometer, obtaining a collection of signatures that correspond to the mineral and spectral properties of these fossils. Then, we applied the signatures to the correspondent image, also testing spatial algorithms to match the location of known fossils to our signatures.

We tested the results under several conditions, altering pixel resolution and sources to include multispectral satellite images and RGB photos recorded from drones and hand-held cameras.

Our method potentially allows researchers to analyze the fossiliferous region before organizing any field expeditions, strongly increasing the potential effectiveness of each campaign, i.e. detecting new fossils and pre-organizing their recovery, with consequent reduction of the risk of lost specimens, the danger for people involved in the field, and the expenses related to fieldwork.

We present our ongoing results, explaining how fossils reacted to the spectral analyses and how their signature can be interpreted as a signal for their mineral content and, more importantly, the effective possibility of applying remote sensing algorithms to distinguish the fossils from their matrix in the selected localities.

GREGARIOUS SUSPENSION FEEDING IN A MODULAR EDIACARAN ORGANISM

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The Ediacara biota are a paraphyletic group of macroscopic eukaryotes (including some animals) that represent the first radiation of structurally complex life. Reconstructing their paleoecology is therefore pivotal to understanding origins of the modern, animal-dominated biosphere. In particular, reconstruction of feeding mode provides fundamental information for assessing nutrient cycling and quantifying ecosystem engineering in the latest Ediacaran. Here, we combine new fossil data from southern Namibia with computational fluid dynamics (CFD) testing between competing feeding models for the Ediacaran taxon *Ernietta*. In addition, we perform simulations for multiple individuals, allowing us to analyze hydrodynamics of living communities. We show *Ernietta* lived gregariously, forming shallow marine aggregations in the latest Ediacaran, 548-539 Ma. We demonstrate enhanced vertical mixing of the water column above aggregations, and preferential redirection of current into body cavities of downstream individuals. These results support reconstruction of *Ernietta* as a macroscopic Ediacaran suspension feeder, and moreover provide a convincing paleoecological advantage to feeding in aggregations analogous to those recognized in many extant marine metazoans. These results provide some of the oldest evidence of facilitation by macroscopic eukaryotes yet recognized in the fossil record.

THE IMPORTANCE OF BEHAVIORAL NICHES IN INVERTEBRATE EVOLUTION

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Jean-Baptiste Lamarck postulated that "More frequent and continuous use of any organ gradually strengthens, develops and enlarges that organ, and gives it a power proportional to the length of time it has been so used; while the permanent disuse of any organ imperceptibly weakens and deteriorates it, and progressively diminishes its functional capacity" His efforts were among the first modern attempts to identifying evolutionary mechanisms to explain morphological evolution. Nonetheless, Darwin's gradualism and then punctuated equilibrium became the foundations of evolutionary theory. It is now accepted that the establishment of peripheral isolate populations greatly enhance morphological drift. Peripheral isolates are generally presented as geographically isolated populations, for which gene flow (with other populations) is severely limited or even stopped. However, fascinating examples of behavioural niching are represented by the ichnofossils of marine invertebrates: *e.g.* deposit feeding, grazing, filter feedingand even oxygen mining. In modern settings, analogues to these trace fossils are commonly made by animals whose ecospace is limited by substrate consistency, food resource availability and salinity and oxygen conditions that may isolate marine invertebrate populations in disconnected oases.

Presumably throughout time behavioural isolationism has been important. The first (hypothetical) bilaterian animal, "Ubilateria" learned to systematically foraged for food: over time feeding strategies became increasingly sophisticated. Before the Cambrian, it appears that most of the major crown-group animal lineages had emerged (*i.e.*, annelids, arthropods, chordates, echinoderms, molluscs and priapulids). Their colonization of the seafloor, motility and search for nutrition is preserved as a rapid diversification and increased abundance of trace fossils in upper Ediacaran and L. Cambrian sedimentary successions. Notably, there is little evidence of morphological diversity among the body fossils of recognizably bilaterian animal groups until the Cambrian Explosion, yet the trace-fossil record shows a diversity of forms, even in the upper Fortunian. If this behavioral diversification (as recorded by trace fossils) preceded morphological diversification (as recorded by body fossils), invertebrate behaviours leading to infaunal niching can in part explain the apparent decoupling of the Ediacaran–Cambrian bilaterian trace and body fossil records. Importantly, behavioural niches may have subsequently rewarded certain morphological attributes over others, effectively guiding early morphological evolution in invertebrate animals. Even though Lamarck was incorrect in saying that through a lifetime of activity, physical attributes refined in the course of an animal's survival could be passed on to their offspring, the trace fossil record suggests a certain truth to his hypothesis: behaviour is an understated driving force in animal evolution.

SPATIAL DIFFERENCES IN TAXONOMIC COMPOSITION AMONGST UPPER TRIASSIC PATCH REEF DEPOSITS WITHIN THE GOSAUKAMM REEF

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During the Late Triassic, the Northern Tethys Ocean was a semi-enclosed ocean basin with numerous large carbonate platforms and thick reefs composed of scleractinian corals and hypercalcified sponges. Gosaukamm is one of the best studied Triassic reef localities in the Northern Calcareous Alps. The reef framework at Gosaukamm is restricted to patch reefs that are irregularly distributed across a vast spatial range. The aim of this study is to compare the spatial differences in taxonomic composition amongst Gosaukamm patch reefs deposited during the middle Norian. A total of three quadrats (10m x 10m) were constructed and samples were collected every two metres. Samples were processed to create polished slabs that were used for equal area quadrat counts in order to quantify the diversity and abundance of reef building organisms. Accumulation curves were used to determine how many views would need to be examined in order to capture the complete diversity of each sample. Bray-Curtis dissimilarity index was used to compare the taxonomic composition amongst patch reefs. Results from this study allows us to evaluate the spatial variability of patch reefs and the importance of local environmental conditions on the taxonomic composition. Since the Norian was a time of optimal reef growth, the dataset generated from this study allows us to establish a baseline for healthy reefs that can be compared with reefs growing during times of environmental stress.

STEROL GENOMICS AND THE ASSIGNMENT OF DICKINSONIA AS AN ANIMAL

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The Ediacaran fossil*Dickinsonia* has a contentious history, with nearly as many taxonomic assignments as there have been scientists who study it. Although a consensus has not been reached, a growing body of evidence supports the hypothesis that *Dickinsonia* and its relatives represent some of the oldest animals in the fossil record. In particular, a 2018 study published in *Science*reported remarkably preserved examples of *Dickinsonia* that contained cholesteroid lipids, which the authors consider a hallmark of animals. In this talk, I take a comparative genomics approach to study how cholesterol became the dominant sterol lipid in animals, and how elucidating this evolutionary history provides additional insight into where*Dickinsonia* fits into the tree of life. My work demonstrates that cholesteroids alone cannot be used to classify *Dickinsonia* as an animal, although they provide an important line of evidence supporting this assignment. Additionally, sterol biosynthesis has a complex history in animals, having been gained and lost multiple times within this group. If we accept the hypothesis that *Dickinsonia* is in fact an animal, the presence of cholesteroids constrains the placement of this organism into several positions among the "higher" animal clades. Ultimately, this work provides a new example on how genetics and paleontology can be combined to better understand the evolution of complex life.

HOLOCRINUS – THE OLDEST STEM-GROUP ISOCRINID WITH STALK SHEDDING AND CRAWLING ABILITIES: EVIDENCE FROM TAPHONOMY, MICROSTRUCTURE AND TRACE FOSSILS

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Holocrinids (Holocrinida) are among the oldest post-Paleozoic crinoids, which are considered stem lineage leading to isocrinids (Isocrinida). Although holocrinid stalk is similar to that of fossil and living isocrinids, it lacks flat synostosial articulations at the distal facet of nodals, which represent sites of autotomy. Holocrinids were thus long considered fully sessile. Over the years, however, there has been growing morphologic and taphonomic evidence (e.g., lack of holdfast, presence of well-developed muscular articulations in the arms and callus overgrowths, specific pattern of preferred disarticulation of the stalk at the distal facet of nodals) suggesting stalk shedding and crawling abilities in these crinoids. It has been argued that these traits evolved in response to increased benthic predation pressure during the so-called Mesozoic marine revolution. The ability to stalk shedding, allowing active relocation, in these crinoids is supported by microstructural data: the stereom type observed at the distal symplexial nodal

facet strongly resembles synostosial stereom in living isocrinids, that is associated with short ligaments designed for autotomy. Motility in holocrinids is further corroborated by ichnological findings. In particular, holocrinid-bearing beds sometimes yield trace fossils in the form of horizontal traces composed of median trails and lateral short tracks. Very similar traces were observed during neoichnological experiments using the shallowest species of living stalked isocrinoid *Metacrinus rotundus*.

UPDATING THE LOWER AND LOWER MIDDLE DEVONIAN TIME-ROCK CHART FOR THE MACKENZIE MOUNTAINS, NWT (CANADA) BASED ON CONODONT BIOSTRATIGRAPHY

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The Lower Devonian and lower Middle Devonian in the Mackenzie Mountains (Northwest Territories, Canada) and adjacent areas is a succession of dolostone, limestone breccia and massive limestone with minor basal sandstone. Based on new field data and a restudy of Geological Survey of Canada conodont collections, the time-rock chart for this succession is updated to the current conodont biozonation.

The Lower Devonian is represented by a peritidal carbonate platform. The basal Delorme Group onlaps underlying Lower Silurian dolostones with a locally angular unconformity. The Tsetso Formation quartzarenite, a transgressive peritidal sandstone, represent the onset of the Devonian transgression in the study area and is locally followed by the brecciated dolomudstones and interbedded anhydrites of the Camsell Formation. In the southern Mackenzie Mountains, facies equivalence includes the calcareous Vera, Root River and Cadillac formations.

Conodont material from the Delorme Group and lateral equivalents is rare, especially in the Northern Mackenzie Mountains, and gives a Lochkovian to Pragian (*woschmidti* to *kindlei* zones) age estimate. The Delorme Group is separated from the overlying Bear Rock Assemblage by an abrupt change to clean limestone and dolostone.

In the Bear Rock Assemblage (Bear Rock, Arnica and Landry formations), the crystalline banded Arnica dolostone and the overlying crystalline Landry limestone pass eastward into the brecciated limestone and dolostone of the Bear Rock Formation and westward in the shaly Road River Group, Funeral Formation or Mount Baird Formation. In the southern Mackenzie Mountains, the calcareous Sombre, Grizzly Bear and Natla formations can be distinguished as lateral facies of the Arnica Formation. The Bear Rock Assemblage conodont data set allows the identification of the *dehiscens* to *serotinus* zones (Emsian) for the Arnica Formation and lateral equivalents and the *costatus* to *australis* zones (Eifelian) for the Landry Formation and lateral equivalents. The subtidal variously argillaceous and richly fossiliferous limestone of the Eifelian Hume Formation has been sampled at four sections. Graphic correlation on these data provides a high-resolution correlation between the sections, and a conodont range chart that can be subdivided into local faunal units linked to the *australis* to *ensensis* zones[1]. This allows correlation with sections in the Headless and Nahanni formations in the southern Mackenzie Mountains. The drowning of the Hume platform is marked by the onset of the black shales of the Bluefish Member (Hare Indian Formation) in the *ensensis* Zone.

[1]Uyeno, T. T., Pedder, A. E. H. and Uyeno, T.A. 2017. Conodont biostratigraphy and T-R cycles of the Middle Devonian Hume Formation at Hume River (type locality), northern Mackenzie Mountains, NWT, Canada. *Stratigraphy*, 14:391-404.

DANCING ON THE DUNES: AN ICHNOLOGICAL EXAMINATION OF THE AZTEC SANDSTONE AND THE JURASSIC PALEOECOLOGY OF THE SOUTHERN NEVADA REGION

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In recent years multiple fossil trackways have been reported across the Southern Nevada Region within the eolian dune deposits of Jurassic Aztec Sandstone. These wind-blown sand-dune deposits are correlative to the fossiliferous Nugget and Navajo Sandstones, but had previously been deemed unproductive in prior paleontological studies. However, since 2007 with the first reports of trackways made by the therapsid-ichnogenus *Brasilichnium,* and 2010 when reports of tridactyl dinosaur trackways captured the minds of enthusiastic hikers and scientists, there has been a dramatic increase in the number of sites reported (Rowland et al., 2014). These ichnofossils occur in Red Rock Canyon National Conservation Area (RRCNCA), Valley of Fire State Park (VFSP) and Gold Butte National Monument (GBNM). In addition to trackways, we recently discovered two structures that we are tentatively interpreting to be preserved

burrows in VFSP that are similar to the Type I structures described by Riese et al. in 2011 in the Navajo Sandstone. The presence of a lenticular carbonate lens near the two separate burrow sites reinforces the existence of pluvial intervals during the Early- to Middle-Jurassic Period (Winkler et al. 1991, Loope et al. 2001). With multiple previously-reported track sites and this first report of potential burrows in the Aztec Sandstone, evidence indicates that the pluvial-supported ecosystems that are well-documented in the Navajo and Nugget Sandstones were also present in the Aztec dunefields.

DEPOSITION AND BIOINFESTATION PATTERNS OF SPIRULA SHELLS

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Shells of the coleoid cephalopod *Spirula* are frequently washed ashore of continental islands, such as the Canary Islands and New Zealand, and the shelf of South Africa. The chambered and spirally coiled shells are gas filled and air-locked due to their morphological design, which promote that shells can float for a long period of time and may travel long distances before being beached. During this journey, *Spirula* shells are habitats for various organism including sessile bryozoans and crustaceans. The close association between an attached individual and the shell, however, also determines the life span of the attached organisms. In terms of fitness, this means that encrusters need to reproduce before their host shell strands.

In this study, a total of 336 *Spirula* shells from Fuerteventura, Canary Islands, Spain, are examined for preservation, deposition and bioinfestation patterns. Bioinfestation analysis include the position, abundance and size of encrusting organisms. The position of encrusting organisms can either be in the phragmacone opening, or, on the outside of the remaining shell. For size assessment, cirripeds are assigned into one of four categories: (I) early post-settlement state before first molting (cypris); (II) post-settlement state after molting, shell length < 1 cm; (III) shell length between 1 and 2 cm; (IV) shell length > 2 cm.

Spirula shells accumulate along the waterline and are generally well-preserved, even though the depositional areas are affected by tidal activity with high-energy waves and strong currents. The accumulation and deposition along the waterline and the high preservation potential of the shell are interpreted as the result of shell floating. Results also show that the majority of *Spirula* shells are infested by cirripeds, with up to 17 of these encrusters on a single shell. Cirripeds mostly settle in the phragmacone of the host's shell. This area is lined by a nacre layer and holds up to four cirripeds. Although many *Spirula* shells are encrusted by large cirripeds over 1 cm in length, most cirripeds are in the cypris state. This result indicates that many of the attaches cirripeds died before reaching maturity and can thus not contribute to gene-pool of the next generation.

ECHINOCYAMUS: A MODEL ORGANISM FOR CENOZOIC PREDATION

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The sea urchin genus *Echinocyamus* is an extant echinoid known back to the Eocene. This minute bottom-dweller occupies habitats from shallow waters to the deep sea, and, from tropical to cold regions. In its habitat, *Echinocyamus* has an important function e.g. as a bioturbator and food source for many taxa. Previous research on mostly recent material of *Echinocyamus* dealt with drilling predation by cassid gastropods. It has been shown that cassids can account for high mortality rates and are thus considered to exert pressure on echinoid populations. In modern ecosystems, predator-prey systems can be analyzed in real-time and at high temporal resolution. Major changes in such co-evolutionary affected predator-echinoid systems, however, usually occur on much larger time-scales. Comparative analyses through geological times are thus imperative to identify changes in the predator-echinoid system and interpret evolutionary signals. The wide spatial and temporal distribution thus make *Echinocyamus* a model organism for comparative analysis.

In this study, fossil *Echinocyamus* from two Oligocene localities in Northern Germany (Doberg and Astrup) were analyzed for test dimensions and predatory traces. Tests were examined for length and width. Holes in the tests were interpreted as predatory drillings when the hole morphology resembles those of recent drillings based on size, circularity, shape, and hole profile. Recognized drill holes are analyzed for their position on the test, as well as for their length and width. Test dimensions, drilling frequencies, position, size and morphologies are compared between the two localities and to findings from *Echinocyamus* from both recent and fossil environments.

Results indicate that *Echinocyamus* tests from

Doberg are in average larger than tests recovered from Astrup. Similarly, drill holes in tests from Doberg are in average larger than those found in tests from Astrup. The two localities can thus be separated and interpreted as separate populations with drilling frequencies of 23.1% for Doberg, and 15.4% for Astrup. Drill hole morphologies are, however, similar. The drill hole is of the *Oichnus* type with with a cylindrical or asymmetric paraboloid profile. In some cases, the outer margins are dissolved indicating an acid supported drilling. Site selectivity of the predator is present with most drill holes placed on the aboral site. Size selectivity is not present in both localities. The drill hole morphology is similar to that from recent samples, but can differ in the profile. Whereas recent drill hole profiles are typically straight or convex, the Oligocene samples can also show asymmetric pits around the penetration. This morphological modification can be due to taphonomic alteration or handling effects of the predator which changed through time.

COMPARATIVE TAPHONOMY OF DEEP-SEA AND SHALLOW-MARINE ECHINOIDS OF THE GENUS ECHINOCYAMUS

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Knowledge of the ecological, spatial and temporal interactions between deep-sea communities and the environmental conditions supporting these interactions is embryonic when compared with the detailed view of shallow-marine ecosystems. However, such knowledge is crucial for the conservation of these deeper environments, which already are under anthropogenic stress. A confounding factor that limits the progression of our knowledge is that deep-sea benthos samples are obtained mostly though dredging during which spatial and temporal mixing of samples may occur. A first step forward is a better understanding of the relationships between live-collected samples (biocoenosis) and associated dead assemblages (thanatocoenosis) within a dredge. To better understand the early post-depositional taphonomy and diagenetic processes in deep-sea environments we compared taphonomic alteration observed on the tests of the burrowing echinoid, *Echinocyamus* from both deep-sea and shallow-marine environments. The comparison showed that the fundamental taphonomic processes, such as abrasion, fragmentation, and encrustation, are similar in both environments. However, their timing and prevalence differ as a result of different biological and physical conditions between the two environments. For example, abrasion of echinoid tests is higher in deep-sea settings than in shallow-marine environments, whereas test fragmentation and encrustation are lower. Moreover, encrusting fauna in deep-sea settings differs from those in shallow-marine environments. The echinoid genus *Echinocyamus* has proven to be a good model organism for comparative taphonomy across both bathymetric and latitudinal gradients.

SOFT PART PRESERVATION CLARIFIES THE AFFINITIES OF THE LARGE BIVALVED ARTHROPODS FROM THE FEZOUATA BIOTA (EARLY ORDOVICIAN, MOROCCO)

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The Early Ordovician Fezouata Biota (late Tremadocian, ca. 478 Ma) from Morocco has yielded a diverse arthropod fauna, including basal stem-lineage arthropods such as Radiodonta and Lobopodia, the oldest examples of horseshoe crabs, and new informative specimens of enigmatic taxa such as marrellomorph arthropods. The Fezouata Biota also contains abundant remains of bivalved arthropod carapaces, with lengths ranging from a few millimeters to several centimeters. Absence of soft parts has so far precluded their assignment to any specific arthropod group, as bivalved carapaces evolved in a wide range of arthropod groups homoplastically, and are seen in ostracod, diplostracan, phyllocarid and thylococephalan crustaceans, as well as in a series of large Cambrian 'bivalved arthropod taxa' such as *Branchiocaris*, *Canadaspis* and *Odaraia*. Here, we describe new bivalved arthropod specimens with soft parts from the Fezouata Biota. The new anatomical details highlighted using optical photography and contrast-enhanced UV-near-infrared imaging show anteriorly directed appendages associated with an elongated, narrowing backwards bivalved carapace, reminiscent of thylacocephalan crustaceans. Isolated carapaces further display a well-defined anterior notch similar to the anterior optic notch present in most thylacocephalans. Another specimen, dorsoventrally flattened with suboval valves in 'butterfly position', displays part of the trunk

including six segments, the last one being longer than the others. A third specimen preserves two segments and a tapering telson with unsegmented articulated furca, which strongly suggest phyllocarid affinities for these forms. These new specimens clearly reveal that different bivalved arthropod taxa were present in early Ordovician marine communities along West Gondwanan margin, and we can expect that new fossil finds and/or the use of new imaging techniques may provide further insights into the affinities and diversity of these organisms. Finally, we investigate on their preservation using synchrotron-based X-ray fluorescence major-to-trace elemental mapping and X-ray absorption spectroscopy.

WELL-PRESERVED 3-SEGMENTED CHELICERAE IN A 478-MILLION-YEAR-OLD HORSESHOE CRAB (FEZOUATA BIOTA, MOROCCO)

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Chelicerata is the second most species-rich clade on Earth today after the hexapods (insects), and is comprised of Pycnogonida (sea spiders) and Euchelicerata, which includes arachnids (the iconic scorpions and spiders) and their closest relatives (xiphosurans, eurypterids and chasmataspidids). The principal autapomorphy of Euchelicerata is the modification of the first pair of head appendages into chelate or clasp-knife structures referred to as the 'chelicerae', which are used for food manipulation and predation. The origin and early evolution of this structure is widely debated. While xiphosurans represent a small fraction of euchelicerate diversity today, encompassing only four species, they were much more diversified in the fossil record. Recent discoveries from the Lower Devonian and Middle Ordovician revealed the ground plan of xiphosurans, eurypterids and chasmataspidids, such that a good overview of the relationships within Euchelicerata is emerging. By contrast, little is known about the origin and early evolution of Chelicerata because there is no clearly defined stem-lineage. Molecular clock analyses estimate a late Ediacarian or early Cambrian origin for the Chelicerata, yet their fossil record only starts in the late Cambrian with Chasmataspidida-like trace fossils and a putative pycnogonid larva, but body fossils are not recovered until the Ordovician. It is only recently that Early and Middle Cambrian fossils have been identified as stem-lineage representatives of Chelicerata or Euchelicerata, and these are difficult to align with modern groups because they do not possess chelicerae and median ocelli, and display differences in segmentation. However, more familiar chelicerates are known from the Early Ordovician Fezouata Biota, which yields at least two xiphosuran taxa. Here, we describe the well-preserved chelicerae of a xiphosuran (characterized by a fused opisthosoma) from the Fezouata Biota. A dozen specimens preserving the chelicerae in great detail show that it was composed of three segments, confirming the hypothesis that a 3-segmented chelate chelicerae represents the early condition in euchelicerates, and dates back to at least 478 million years ago.

ENDOCRANIAL ANATOMY OF THE TUBE-CRESTED DINOSAUR PARASAUROLOPHUS (ORNITHISCHIA, HADROSAURIDAE) FROM THE KAIPAROWITS FORMATION (UPPER CRETACEOUS) OF UTAH, USA

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Parasaurolophus was a tube-crested hadrosaur dinosaur known for its extraordinary cranial ornamentation, and an increasingly large sample of skulls from throughout western North America provides substantial information on its osteology. Yet, little is known about the neuroanatomy of this genus, other than a partial endocast described for a juvenile. In 2011, the partial skull of an adult-sized *Parasaurolophus* was collected within the Kaiparowits Formation (late Campanian, ~75.5 Ma) of Grand Staircase-Escalante National Monument, southern Utah, USA. The braincase of the skull (RAM 17000, reposited at the Raymond M. Alf Museum of Paleontology) was CT scanned, and a 3D reconstruction of the endocast was generated using Slicer 4.10.1. Total endocast volume, including pituitary fossa and olfactory bulbs, was 235 cm^3. The morphology of the endocast is similar to that of other hadrosaurids in being elongated anteroposteriorly, and strongly expanded mediolaterally at the cerebral region. Compared to the condition in other hadrosaurids, the endocast of RAM 17000 is relatively deeper along its long axis. The olfactory bulbs are strongly depressed relative to the cerebral region, to a degree not seen in any other known hadrosaurid endocast. A similar depression of the olfactory bulbs occurs in juvenile *Parasaurolophus*, although less pronounced

than in RAM 17000. The angle between the dorsal profiles of the cerebral and postcerebral regions is more strongly pronounced in *Parasaurolophus* than in any other lambeosaurine. Uniquely among known lambeosaurines, the cerebral region is very strongly arched and bulbous. These features of endocranial shape likely are the result of the unique skull roof configuration that supports the crest in *Parasaurolophus*. Significant differences in endocasts across hadrosaurids suggests a complex relationship between cranial ornamentation and neuroanatomy in this clade.

UNUSUAL VERTEBRATE FOSSIL BURROWS IN THE OLIGOCENE OF TROPICAL NORTH AMERICA

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Vertebrate fossil burrows are poorly recorded in tropical North America. Several burrow systems were discovered few years ago in fossiliferous outcrops from southern Mexico. The objectives of this contribution are to describe these burrows, to compare them with others previously reported, and to discuss their ecological implications.

The lithostratigraphic units represent a fluviolacustrine succession with several paleosol horizons. This sedimentary sequence is part of the early Oligocene Chilapa Formation of northwestern Oaxaca. Besides vertebrate burrows, the paleosols also contain insect trace fossils, such as *Fictovichnus gobiensis*, *Teisseirei barattinia* and *Celliforma* ispp. They represent the *Celliforma* Ichnofacies, suggestive of xeric vegetation under arid or semiarid climate in the study area.

The complex burrows system is composed of two types of chambers, shafts and tunnels. Large to medium-sized superior chambers are connected to descending, radiating and inclined shafts, or to horizontal tunnels; smaller secondary chambers may be present at the end of these burrows or lateral to them. Horizontal burrows may be straight, sinuous, or may show “C” or “H” paths, meanwhile vertical to sub-vertical burrows may be straight, curved, sinuous or showing consecutive arches resembling roughly a helical design. Surface morphology of some tunnels includes short, straight, paired traces on the external surface of the burrow fill, attributable to rodent incisor marks.

Architecture and morphology of these burrows system are not comparable to other previously reported produced by invertebrate or vertebrate producer. Trace makers of this unique burrows are not unequivocal, although they are attributed to fossorial rodent gophers (Geomyidae) found inside them, mainly by the presence of the bioglyphs and their size.

These burrows systems represent the only evidence of fossorial vertebrates in tropical North America during the early Oligocene. It is possible that these fossorial organisms exploited open habitats of xeric vegetation. This tendency agrees with evidence in another temperate North America localities. Even when the producer’s identity is not entirely known, burrowers could be considered as engineers ecosystems during Oligocene.

TOWARDS A MEXICAN PROTECTION OF PALEONTOLOGICAL RESOURCES

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The aim of this contribution is to relate the current status of protection of the paleontological remains in Mexico by federal agencies. The Instituto Nacional de Antropología e Historia (INAH) has been the federal agency responsible for conservation and protection of fossil heritage in Mexico since 1986. In 1994, the Consejo de Paleontología (“Paleontology Council”) was established in order to safeguard the Mexican paleontological remains; later, the council was disintegrated. After a period of stillness, the council has been settled in 2017 and is composed by INAH’ and paleontological researches of several Mexican institutions. These plurality focuses on the knowledge and experiences of outstanding professionals in Paleontology.

The first actions of the Paleontology Council were the settlement of the norms and guidelines for paleontological research projects and exploration activities, as well as the design of effective strategies and actions, in order to safeguard the Mexican paleontological heritage.

Nowadays, the council has reached several goals, as the creation of a Code of Ethics for their members, the constant regulation of diverse paleontological activities in Mexico, and the evaluation of these activities through the analysis and opinions of the members of the council. Also, the council is currently working

on the procedures for the exportation and reintegration of paleontological materials deposited in foreign institutions.

A particular issue is the development of procedures for the conservation and preservation of the Mexican paleontological heritage, considering the extensive territory and the vision of the fossil by the local people. Since the trading of Mexican fossils is forbidden, a solution is necessary for the communities that use paleontological remains as an economical source for their survival.

Future work of the council will be the outstanding balance of their first period and the awareness promotion of paleontological researches in order to follow the procedures to improve the preservation and understanding of Mexican fossil record.

TOOTH MICROWEAR OF THE EXTINCT AUSTRALIAN VOMBATIFORMES

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The Australian landscape and vegetation have changed dramatically through the Cenozoic. Climatic influences and tectonic movement north have largely transformed the mesophyllic, closed temperate rainforest of the Middle Miocene into the arid deserts, open sclerophyll forests, and grasslands that dominate the continent today. By the late Pleistocene, the dominant herbivore order, the Diprotodontia, had within it two now-extinct families, Diprotodontidae and Palorchestidae. Species within these families had evolved very large body size, and they may have had a role as keystone species in various ecosystems. To understand their dietary affiliations, and therefore their ecological significance and evolution, we scanned and analysed the microwear signature of ~200 fossil tooth specimens from these families, as well as the teeth of other older but related members of the Vombatiformes. We compared the microwear signatures of the extinct taxa with those of extant kangaroos with established dietary niches. The microwear signature is tending toward decreasing complexity and increasing anisotropy over the past 15 million years, which correlates to a shift in feeding niche from softer browse to grasslands and/or harder browse, echoing the development of aridity in Australia. This mirrors evolutionary patterns seen on other continents, such as those of equids in North America.

GIANT FLYING JAWS: AERODYNAMIC EFFECTS AND CONSTRAINTS ON CRANIAL HYPERTROPHY IN PTEROSAURS

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Pterosaurs are most well-known for their expanded and altered forelimbs, which supported muscular membrane wings. Indeed, pterosaurs possessed one of the most derived hand morphologies of any vertebrate animal. However, several pterosaur lineages also possessed enormously expanded cranial and cervical proportions. The most extreme cases occur within ornithocheiroid and azhdarchoid pterosaurs, for which the cranial length, even excluding display crests, regularly exceeded 3.5 times the shoulder to hip distance.

The enlarged heads and necks of many pterosaurs had implications for their flight and ecology. Understanding the costs and mechanisms of cranial hypertrophy in pterosaurs also has implications for understanding the evolution of the vertebrate skull, more generally. Investigating this problem is made particularly challenging by the fact that pterosaurs have no living descendants. A numerical modeling approach, using first principles, is likely the most effective way to investigate the evolution of cranial hypertrophy in pterosaurs.

I addressed the performance impacts of cranial expansion in pterosaurs through a modeling approach based combining aeromechanics and beam mechanics. I focused particularly on azhdarchids. These include some of the most extreme cases of cranial hypertrophy and possessed cervical anatomy amenable to beam theory applications (azhdarchids possessed highly derived cervical vertebrae with an elongate, tubular morphology). I used CT imaging to resolve cortical bone thickness in key elements. I created updated soft tissue reconstruction estimates, and I then applied both volumetric and scaling methods to estimate body masses and mass distribution.

While the skulls were relatively light, the neck of azhdarchoid pterosaurs may have been much more robust than previously suggested. The Relative Cantilever Failure Force (RCFF) values of the cervical vertebrae range from roughly equal to nearly double that of the humeri. The expanded skull and neck of azhdarchid pterosaurs did have a substantial impact on center of mass (COM). To align the center of lift with the forward center of mass, a forward sweep of the wings was required. Rather than being a costly

wing position, this would have improved low speed performance by delaying stall of the wingtip. Stability could be achieved dynamically through leading edge adjustments of the propatagium. Passive stability was likely achievable through a dihedral and reflex camber. Pterosaurs therefore may have obtained flight advantages from their expanded cranial and cervical proportions, in addition to any advantages to signaling or feeding. I suggest that cranial hypertrophy in pterosaurs is best explained as a case of constraint release, rather than unusual selective pressures. Other flying animals would probably also obtain advantages from a forward center of mass, but developmental, anatomical, or ecological constraints may prevent extreme increases in head size in other flying taxa.

GLYPTOACTIS (CARDITIDAE) FLOURISHED AS THE PIONEER AND OPPORTUNIST GENUS IN EARLY EOCENE MARGINAL MARINE BASINS OF WESTERN INDIA

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Several pericratonic basins along the west coast of the Indian subcontinent started to receive Cenozoic marine sediments with the transgression of the sea during the Paleocene-Eocene. There were a few contemporaneous intracratonic basins also. Most of these basins, in their initial stage, show features of restricted depositional condition. Lignite/coal deposits were formed in minable quantity in many of these basins. The successions in all these basins, in their early development stage, are characterized by plane-laminated grey, red, green and black shales. Mollusc bearing shell beds appear intermittently in this succession. Commonly these shell beds produce low diversity faunas, characterized by huge abundance of a single or few species. These faunas are often dominated by one or another species of *Glyptoactis* (family Carditidae). Apparently, this genus was successful in invading the newly opened basins. There, they flourished under low selection pressure. Sheltered nature of these coastal basins with rapidly fluctuating environmental factors made these ecosystems unsuitable for most of the marine mollusks. There are evidences of fluctuation in oxygen availability, terrigenous influx and sea-level. *Glyptoactis* overcame these adversities and was able to flourish opportunistically as the pioneer taxon in such non-conducive environment. Later, with further transgression, the basins became open. Consequently, mollusk diversity increased and dominance of the *Glyptoactis* lineage was suppressed.

HYPERTHERMAL HIDE AND SEEK: PATTERNS OF CHANGING OSTRACODE ABUNDANCE DURING EARLY CENOZOIC WARMING EVENTS

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Investigating the rapidly changing climate of the early Cenozoic, when there was a sudden addition of carbon to the atmosphere and oceans, is one way we can begin to understand how changes like this might impact life on earth in the future. Climatic conditions in the late Paleocene and early Eocene were marked by multiple hyperthermal events that have been identified globally by rapid temperature increases and negative carbon isotope excursions. The largest and most well-known of these is Paleocene-Eocene Thermal Maximum (~56 Ma); however, several other hyperthermal events followed in the next several million years. Eocene Thermal Maximum 2 (ETM2) was the next hyperthermal event, occurring about 2 million years after the PETM. It was characterized by about half of the magnitude of carbon and oxygen isotope excursions that have been observed for the PETM. Like the PETM, ETM2 has been identified in marine and terrestrial records from around the world. Many studies have investigated the impact of these hyperthermal events on single-celled organisms, such as foraminifera, identifying noticeable changes in abundance, and even a benthic foraminifera extinction event at the PETM. Ostracodes (small, bivalved crustaceans) represent an opportunity to conduct comparable investigations that evaluate how multicellular animals were impacted by these changing environmental conditions.

Here we compare patterns of ostracode diversity and abundance across ETM2 at IODP Site U1409 off the coast of Newfoundland and ODP Site 1258 in the equatorial Atlantic, both with paleodepths of about 3000 m. Using isotopic proxies for temperature and carbon cycle indicators, we evaluate the effect of these environmental changes on this group of multicellular animals. In these cores ETM2 has been identified based on the carbon and oxygen isotope excursions using bulk carbonate and benthic foraminifera records. The sites preserve similar ostracode taxa. At both of these sites, ostracode abundance and diversity decrease at

ETM2, but recover to pre-ETM2 conditions within the recovery period of the isotope excursions (within ~100 kyr). While the ostracode abundance and diversity patterns at the two sites are similar, the observed trends are stronger at the north Atlantic site.We then compare these records to a new PETM ostracode record from ODP Site 1261 as well as published records of ostracode abundance and diversity from the PETM.

COMPLEX MULTICELLULARITY AS AN EVOLUTIONARY RESPONSE TO VISCOUS SNOWBALL EARTH OCEANS

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Animals, fungi, and algae with complex multicellular bodies all evolved independently from unicellular ancestors. The early history of these multicellular groups, if not their origins, co-occur with an extreme phase of global glaciation known as the Snowball Earth. Instead of going extinct, life emerged from the Snowball Earth large, diverse, and complex. Across the globe, Snowball Earth oceans would have been cold, saline, and viscous. For small single-celled organisms, changes in viscosity directly impact their ability to feed and move within the water. I propose that by evolving large multicellular bodies, organisms can counter the effects of high viscosity seawater. Warm, low viscos ity seawater returns with the melting of the Snowbal glaciers and with it, by virtue of large multicellula. bodies, new ways of life are unveiled.

DWARFED FRONDLIKE METAZOANS FROM THE CAMBRIAN KUANCHUANPU FORMATION IN SOUTH CHINA

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Ediacaran frondlike organisms remain problematic in affinity and feeding behavior. Here we report a few of microscopic specimens of frondlike forms from the early Cambrian Kuanchuanpu Formation in south China (535Ma). The exceptional Orsten-type preservation reveals isomeres exhibit left-right asymmetry along the middle ractis, resembling to that of *Yorgia*. The ventral groove of these fossils is flanked by two alternative rows of canal openings different from both cnidarians and ctenophores, thus probably responsible for feeding on microscopic food particles. The specimens exhibit a single undifferentiated body encapsulated by a two-layered body wall consisting of an inner stiff layer and an outer thin fragile membrane that can hardly being preserved. Current findings support a sessile metazoan hypothesis for these frondlike organism which show a close affinity with *Dickinsonia*-type organisms. The dwarfism of the descents of Ediacaran organisms are ascribed to the competition of bilaterians or environmental changes at the Ediacaran-Cambrian transition interval.

ISOTOPIC EVIDENCE FOR DIETS AND ENVIRONMENTS OF LATE MIOCENE MAMMALS IN YEPÓMERA, MEXICO

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The late Miocene brought a sudden increase in the biomass of C4 plants that resulted in an expansion of grassland habitat and markedly changed the diets of vertebrate fauna in many places around the world. Concurrently, early pulses of Great American Biotic Interchange (GABI) migrations are evidenced by early first appearances of immigrant taxa in the fossil record. Whether through island hopping or an early land bridge, Central America was the center of exchange between the Americas making it a crucial area to understanding the ecology of the exchange. Vertebrate fossils from Yepómera, western Chihuahua, represent one of the richest assemblages in Mexico and offers a broad insight into the environmental conditions of this region between 6 to 4 Ma, just after the arrival of C4 plants in North and South America and before the first major migration of GABI. This assemblage also offers insights into paleoecology of northern Mexico before the dispersals in an area from which the southward migrations would likely have originated. In this study, we use stable carbon and oxygen isotope ratios of tooth enamel samples from this fauna to reconstruct

the diets and environments in the Yepómera area in the late Miocene. The enamel carbon isotope data suggest a shortgrass prairie environment with a strong C4 vegetation component and a moderate annual precipitation of 660 mm/yr. Four species of horses—*Dinohippus mexicanus*, *Nannippus aztecus*, *Astrohippus stockii*, and *Neohipparion eurystyle*—coexisted in this region with no evidence of niche partitioning between the species. While the larger equids (*D. mexicanus* and *N. eurystyle*) did exploit a wider range of vegetation, the groups overlapped in isotopic range and all species were shown to be strictly C4 consumers (grazers). Pure C3 consumption was rare to absent in all other genera analyzed except for the genus *Camelops*, for which C3 vegetation was the dominant diet. Samples from *Hemiauchenia* varied between pure C3 diet and a mixed diet depending on the individual. The other genera in this study site (*Gomphotheriidae, Hexobelomeryx fricki, and Platygonus*) were primarily mixed feeders. Assuming a carnivorous life habit (based on dentition), *Agriotherium schneideri*, an immigrant large ursid, appears to have consumed primarily camelids. However, there is no way to exclude the possibility of an omnivorous life habit from the enamel isotopes. Through adaptation to this ecosystem, these taxa would be well prepared to exploit and compete for the grassland habitats proposed to have developed on the Panama Isthmus. This could explain how equids, peccaries, gomphotheres, and short-faced bears related to these taxa had such success in arriving and diversifying in the South American mainland, where a similar habitat is believed to have expanded around the time of the exchange.

LIFE HISTORY VARIATION IN RESPONSE TO ANTHROPOGENIC EUTROPHICATION: USING LIVE-DEAD ANALYSIS TO UNDERSTAND ADAPTATION IN A HUMAN WORLD

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Evolutionary theory offers predictions for how changing resource availability will affect the life histories of aquatic organisms. Increased resource availability is expected to relax life history trade-offs, giving individuals that produce many small eggs a fitness advantage over those that invest equivalent energy in fewer, larger eggs. If these conditions are sustained over time this will result in a reduction in mean egg size. Although these predictions have been observed in some experimental manipulations, whether they are borne out in natural ecosystems is largely unknown because data on life history variation over evolutionarily-meaningful time scales are sparse and it is challenging to disentangle the effects of other environmental factors that co-vary with primary productivity and may also affect life history (e.g., temperature, hypoxia). Bivalve mollusks offer an unparalleled system for investigating environmental drivers of life history variation at different spatio-temporal scales because the diameter of the earliest larval shell is correlated with egg size and preserved through ontogeny, and the stable isotope chemistry of bivalve shells can record the environmental conditions in which organisms lived. Thus a time series of life history and environmental proxy data can, at least in principle, be derived from the same biomineralized tissues, enabling us to investigate the environmental drivers of life history variation over time scales that extend greatly beyond recent biomonitoring. The temporal scale of live-dead analyses offers an opportunity to investigate rates of trait evolution at a temporal resolution that is not typically possible with older fossil material, and insights specifically into species adaptation to anthropogenic environmental change. For this study, we focus on the effects of enhanced primary production on the life histories of two bivalve species, *Nuculana acuta* and *Ameritella versicolor* in the northern Gulf of Mexico, with an emphasis on coastal Alabama. First, we compare live-dead data on the sizes of bivalve larval shells in order to test the hypothesis that increased primary production has led to reductions in egg size over time. We then compare data for these two species to assess whether differences in larval duration affect the magnitude of live-dead shifts in life history. We predict that species with shorter planktonic larval durations will show greater evidence for local adaptation in life histories, whereas species with longer planktonic larval durations and greater dispersal ability will show weaker evidence for local adaptation.

CONTINENTAL MOLLUSCAN CONFLICT RESOLUTION? INDIA SUBCONTINENT REFUGIA DURING DECCAN VOLCANISM

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The origin of the infra- and intertrappean continental molluscan faunas in precollision India sedimentary deposits is a mystery. The conflict with the vicariance

model is the apparent independent evolution of Late Cretaceous snails and mussels from a pre-Gondwanan separation (at various times) of the Indian subcontinent from Africa, Antarctica, and Madagascar between 160 and ~88 Ma. Although still under study, Indian caenogastropod, pulmonate, and unionoid fossils appear consistent with current taxonomy. An alternative resolution is the capture of incipient fauna(s) through pre- or early Indian subcontinent-Laurasia collisional events. Precollision includes serendipitous low- and high-venture historical dispersal (e.g., land bridges, aerial transport). Most scenarios, however, isolate ar end-Cretaceous proto-India and its emerging volcani pile in the middle of a Neo-Tethys Sea. The "greater subducted proto-India is generally interpreted as bearing marine sediments. A Late Cretaceous (~70 Ma) early interaction with Laurasian island arcs or an African pathway may have provided into-India dispersal opportunities.

Similar to the fossil vertebrate "out-of-India" hypothesis, the disembarkation of Paleocene and Eocene continental mollusks could have provided the stem stock for subsequent speciation. Postcollision Paleogene continental mollusks, however, have not been kind to paleontologists. Only one low-diversity freshwater microgastropod faunule is known from palynomorph-dated Paleocene strata (Lalitpur Formation, Papro Locality, Uttar Pradesh).

Over 20 continental mollusk taxa occur in Cretaceous infratrappean sediments (generally referred to as the Lameta Formation in central India) below the Deccan traps in Maharashtra and Madhya Pradesh. Surprisingly, the onset of basalt flows did not diminish the molluscan record, with at least 22 taxa observed post-Lameta. The faunal turnover with the commencement of continental basalt flows, however, is significant, with current studies showing only three taxa in common with pretrap life. Although any extensive correlation of trap flows and intertrappean sediments is risky, multiple horizons above the first mollusk-bearing sediment record at Intertrappean 1 (post-Lameta) Nagpur (e.g., Takli) localities indicate the immigration of mollusks from refugia, presumably from eastern and southern parts of proto-India, in a water-encompassed model. These short-term reintroductions retain aspects of the previous lacustrine Intertrappean 1 fauna but vary in richness and content, and are diminished in size (compared to the infratrappean fauna). The life expectancy of the intertrappean habitats must have been brief, but repopulation did occur, if not expeditiously, from nearby allopatric populations. Thus the origins and dispersal of the infra- and intertrappean faunas remain enigmatic and their role, if any, in later post-Cretaceous radiation of continental mollusks in the Indotropics is similarly mysterious.

ROADCUTS AFTER DARK: ADVENTURES IN AVOCATIONAL STRATIGRAPHY ON THE CINCINNATI ARCH

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Avocational geology is not restricted to paleontology. While fossil hunting often provides an exciting introduction to the science, the interests of serious collectors may evolve as they look beyond individual specimens and ask deeper questions about phylogeny, paleoecology, taphonomy, biogeography, structure, and stratigraphy. The latter is particularly seductive as it is ever-present in the field, inherently manifest in the fossiliferous outcrops themselves. A dedicated amateur paleontologist spends many a weekend exploring roadcuts and creek beds, perhaps more than some professionals. With proper guidance, the observations made during such casual expeditions can be refined into crucial data to support regional stratigraphic studies.

The present authors have partnered in stratigraphic and paleontological fieldwork for over six years, largely centered on our home region of Ohio, Kentucky, and Indiana, but also ranging to New York, Tennessee, Colorado, and beyond. Our primary research focus has been revising the sequence stratigraphy of the Upper Ordovician (Katian) Cincinnatian Series, with particular emphasis on the upper Cincinnatian Richmondian Stage and the Ordovician-Silurian boundary interval. Additional fieldwork has focused on improving our understanding of slightly older (the lower Upper Ordovician Mohawkian Series) and younger (Silurian through Devonian) strata. Together we have collaborated with the amateur paleontologists of the Cincinnati Dry Dredgers, students and professors at the University of Cincinnati and other institutions, and various state geological surveys.

Our work involves sustained, region-spanning field excursions, visiting and revisiting numerous localities to measure sections to centimeter-resolution, document fauna, photograph outcrops, and collect samples for later analysis, including chemostratigraphy and

biostratigraphy. These data are then used to interpret the strata within a sequence stratigraphic model that can predict and explain fossil occurrences and lithostratigraphic motifs. We frequently consult century-old geological literature and hunt for long forgotten localities to replicate or repudiate previous correlations. We also seek out and evaluate freshly blasted roadcuts, most recently a series of new exposures of upper Lexington Limestone near Millersburg, Kentucky and a string of cuts south of Mount Washington, Kentucky that provide a critical regional reference section for much of the Richmondian Stage. Additional recent effort has focused on poorly studied outcrops in south-central Kentucky and along the fringes of the Ordovician outcrop belt in Ohio. This research has contributed to stratigraphic publications both in print and in preparation, as well as many student projects. Furthermore, we have co-led field trips sponsored by the FOSSIL Project, IGCP 653, and the Geological Society of America to showcase our interpretations of classic Cincinnatian strata to amateurs and professionals alike.

GETTING BY WITH A SKELETON CREW IN THE VOLUNTEER STATE

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The East Tennessee Museum of Natural History (ETMNH) and Gray Fossil Site (GFS) is a relatively young organization with only 9 full-time staff and student workers. Limited funding allows for a part-time crew to be hired for only 8 weeks during the summer, but the ETMNH is able to excavate, collect, prepare, and curate an impressive number of fossils all year round through the help of an extensive and highly dedicated volunteer workforce. Many of the volunteers have worked at GFS for over a decade and contributed to 11,981 hours in 2017 alone. Throughout the year, there are generally 40-50 volunteers active at a time and this number usually swells to over 100 volunteers during the height of the field season. Each year, a volunteer drive is held at the ETMNH, attracting 70 or more potential volunteers in order to grow the GFS workforce and prepare for the start of the field season. Volunteers are then evaluated, receive specialized training, and are placed into different workforce divisions. Excavation volunteers allow us to extend our dig season from 8 weeks to 7-8 months of the year. In turn, this allows us to meticulously excavate over 20 tons of material on an annual basis. All excavated matrix is processed in a wet-screening operation which produces 1,000 bags of fossiliferous sediment concentrate annually. Volunteers are responsible for 64% of wet-screening production. In 2018, micro-fossils were collected from almost 1,200 sediment concentrate bags by volunteers yielding an estimated 10,000 specimens and providing an amazing resource for researchers. Excavations at GFS typically generate 1,000 or more surveyed specimens per season with volunteers playing a critical role in the preparation of these fossils prior to the next season. Volunteers also contribute within the collections range by rehousing, organizing, and labeling research specimens.

GFS volunteers work side by side with professionals at multiple levels providing a mutually beneficial relationship allowing them to participate in major breakthroughs and scientific discoveries. Often, the volunteers are aware of research findings before publication and are encouraged to attend, and sometimes present, at conferences. Having direct access to paleontologists and their research techniques, volunteers are given an insight into the science and the various processes involved that simply cannot be gained elsewhere. In the interest of bridging the gap between amateur and professional paleontologists, the junior volunteer program seeks to recruit interested high school students, providing them with training and career guidance to prepare them for enrolling at East Tennessee State University. Before graduation, many of these high school seniors have accrued more lab, field, and research experience than many incoming Master's students.

NEW INSIGHTS INTO THE EDIACARAN TAXA BEOTHUKIS & CULMOFRONS—A COMBINED MORPHOMETRIC AND STATISTICAL ANALYSIS APPROACH

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The Avalonian Ediacaran assemblage of Newfoundland, Canada contains an abundance of soft-bodied fossil specimens, many with remarkable preservation. One of the numerically dominant groups of organisms in the assemblages are the Rangeomorpha, a frondose

clade characterized by self-similar and repeating branching architecture. Minor variations in branching characters and gross morphology have historically been used to divide this group, resulting in conflicting opinions and some overlapping taxonomic diagnoses.

Here we investigate one such taxonomic dispute, the *Beothukis/Culmofrons* problem. These fossils were originally described as two separate taxa, *Beothukis mistakensis* (Brasier & Antcliffe 2009) and *Culmofrons plumosa* (Laflamme *et al.* 2012), but were later synonymized in Liu *et al.* 2016. Subsequent debate has focused on which taxonomic characters should be used for genus and species level subdivision of rangeomorph taxa. To test the validity of this taxonomic reassignment, we use a combination of morphometrics and statistical tests to identify natural clusters within our specimen dataset. The morphometric data combined with results of the cluster assignment appear to validate the original genus-level differentiation of *Beothukis* and *Culmofrons*. This study also suggests that more morphotypes may exist within the Rangeomorpha than originally thought.

BREAKING DOWN THE LITHIFICATION BIAS THROUGH TIME: DID VULNERABILITY TO LITHIFICATION STATE RELATED METHODOLOGICAL BIAS CHANGE THROUGH THE PHANEROZOIC?

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Fossil collections from lithified sediments are consistently less species rich and less even than their counterparts from poorly lithified or unlithified sediments, and these differences remain even after correcting for differences in sample size. The causes of these differences remain poorly constrained. Recent modeling work has shown that differences in collection methods used to sample lithified versus non-lithified fossiliferous strata can contribute to the observed bias, although they cannot explain it fully. This work has also demonstrated that the magnitude of this methodological bias is dependent on properties of the fossil assemblage in question, specifically the distribution of species among size and abundance classes. This link between the magnitude of the bias and the abundance and size distributions of the assemblage is significant because fossil assemblages of marine invertebrates from different parts of the Phanerozoic vary in terms of both. This raises the question of whether marine invertebrate fossil assemblages of different ages differ in their vulnerability to the methodological lithification bias. Additionally, changes in properties of shell beds through time, such as increased shell bed thickness and changes in the internal complexity of shell beds, may have also affected their vulnerability to this bias. Using the previously developed modeling approach, we examined how changes in both the character of fossil assemblages (evenness, the species abundance and size distributions, and differences in shell dimensions of taxa) and in the properties of shell beds (shell bed thickness, packing density, and whether shells could be nested) impact the methodological lithification bias. The model, which mimics the act of splitting a sedimentary rock to expose its fossil contents, is implemented in Matlab and consists of a cubic volume populated by "shells" created using Raup's coiling model. A volume is split by one or more horizontal planes, representing the fracturing of the rock, and specimens intersected by planes are counted. This analysis differs from previous work in that it examines a broader range of species size distributions, shell dimension data sets, bed thicknesses, and shell packing densities. Specifically, this work incorporates assemblage size and dimension data from Paleozoic brachiopod assemblages and Mesozoic mollusk-dominated assemblages, whereas previous modeling work was parameterized using data derived solely from Cenozoic mollusk assemblages. Preliminary results support previous suggestions that vulnerability to the methodological lithification bias increased over the Phanerozoic. The results suggest that the increase was primarily due to the increased potential for bias in more species-rich and higher evenness assemblages, although changes in the size distributions of assemblages through time also contributed to these effects.

SPIRALING CONSEQUENCES: CHARACTERIZING HYDRODYNAMIC IMPACT OF SINGLE PARAMETER SHAPE CHANGE IN AMMONOIDS

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The 300-million year history of ammonoid cephalopods includes recurrent cycles of diversity boom and bust, and repeated evolution of distinct coiled shell shapes. Paleoecological research aims to determine ammonoids' likely trophic levels, swimming habits, and consequent roles in broader marine systems. Influential factors may include shell integrity, material efficiency, or streamlining. Analogue experiments in water flow tanks demonstrated a wide range of

hydrodynamic drag induced by different planispiral shell shapes. Our recent digital simulations refine these results and support some basic overall trends: inflated shells are more costly to propel at higher speeds (or larger sizes) due to stable pressure drag. Compressed shells generally produce less pressure drag, but exposed central coils along a shell's umbilicus induce added drag at higher speeds (or larger sizes). The trade-offs between inflation, whorl expansion, and umbilical exposure remain unclear.

We advance this work with digital simulations that examine single parameter variation in shell shape. We apply today's versatile 3D modelling tools, coupled with Computational Fluid Dynamics(CFD) software. We created two morphological series of ammonoids, each varying only a single geometric parameter: whorl expansion or umbilical exposure. We incorporate these shell models into the CFD software ANSYS Fluent to determine the impact each step of change has on the hydrodynamic performance of the shell. Results demonstrate gradients in drag response that are highly scale-dependent. The variation in drag around a set of shells at low Reynolds numbers (low-turbulence flow around small and/or slow shells) differs dramatically from the trends at high Reynolds numbers (greater turbulence generated by large and/or fast shells). These results highlight the importance of size and speed in ammonoid motility and relative efficiency, and establish primary boundary conditions suitable for large-scale ecological modeling.

RESPIRATORY AND CIRCULATORY ANATOMY SUPERSEDE ECOLOGICAL ESCALATION IN DRIVING SIZE INCREASE IN MARINE ANIMALS

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The mean size of marine animal genera in the fossil record has increased in biovolume by two orders of magnitude since the beginning of Cambrian time. Statistically, this trend is best explained by active evolutionary forces driving animals toward larger sizes rather than neutral drift away from a lower bound. Here we explain this dramatic increase in mean size in terms of the anatomical and physiological features of more than 18,000 marine animal genera spanning the Phanerozoic fossil record. We coded the respiratory anatomy of each genus along two binary axes: respiratory medium (i.e., air versus water) and open versus closed circulatory system. We also coded each genus as a predator or non-predator in order to compare the relative influence of feeding style versus respiratory/circulatory anatomy on body size. Feeding mode may account for some of the initial increase in mean body size, but most of the increase across Phanerozoic time is accounted for by size increase in taxa that accomplish oxygen delivery through closed circulatory systems. Closed circulatory water breathers were initially smaller than water breathers with open circulatory systems, but the taxa with closed circulatory systems experienced nearly continuous increases in mean size over the Phanerozoic and overtook the open circulatory water breathers during Early Ordovician time. The mean size in this anatomical grouping increased by nearly five orders of magnitude over the Phanerozoic. The mean size of air breathers with closed circulatory systems today are about 1.5 orders of magnitude larger than water-breathing counterparts. However, the air-breathers show very little change in mean size over time, particularly in the Cenozoic. Though air-breathers do contribute to the overall increase in mean size, their diversity is so low compared to other groupings that their contribution is small. Respiratory and circulatory anatomy have influenced body size across geological time and explain more of the long-term trend toward larger size than does feeding mode. These data suggest that the trend of increasing marine animal body size across Phanerozoic time has been much more strongly related to uptake and transport of oxygen rather than to the capture and digestion of food.

UNIDENTIFIED FOSSILS IN THE ENIGMATIC PHOSPHATIC STEINKERN LAYERS OF THE CINCINNATI ARCH REGION (ORDOVICIAN, KATIAN) LEAD AN AMATEUR PALEONTOLOGIST INTO MULTIPLE COLLABORATIONS

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Phosphatic micro-steinkerns (internal molds) known generally as "Cyclora fossil hash" in the Cincinnatian Series have been largely unstudied until this century – an excellent opportunity for amateur paleontologists to engage in professional collaboration. One amateur paleontologist, William Heimbrock of the Dry Dredgers, has spent years sorting and identifying these tiny bits of phosphatic infills and meticulously

recording site details in a quest to identify a mystery fossil and understand these strange yellowish layers.

An unidentified fossil in the hands of an amateur can provide a gateway into scientific inquiry which may engage collaboration. The collaborative fossil club, the Cincinnati Dry Dredgers gave Heimbrock access to a network of professional paleontologists to help him identify his mystery fossil and learn a great deal about Cincinnati paleontology .

Amateur paleontology and outreach have been greatly enhanced in this century by websites and social networks. Heimbrock started Xfossils.com in the year 2000 in hopes of offering fossils for collaboration. The website was useful to Michael Vendrasco of Pasadena City College when he found evidence of early nacre on the surfaces of Heimbrock's late Ordovician mollusk steinkerns. Heimbrock mailed specimens from 30 sites to Dr. Vendrasco. This resulted in two professional papers in which Heimbrock was a co-author (Geosciences 2013 and Journal of Paleontology 2019).

Benjamin Dattilo of Purdue University Fort Wayne also used Heimbrock's phosphatic steinkern samples, site information and insights to help show that these tiny "micromorphs" represent normal-sized fauna selectively preserved and not a dwarfed assemblage in a stressed environment as was previously thought (Palaios 2016). Heimbrock's co-authorship in this paper was another success in his efforts to understand the abundant and overlooked phosphatic fauna of the Cincinnatian.

NEOICHNOLOGICAL EVIDENCE OF PREDATORY BEHAVIOR RECORDED BY SOIL ARTHROPOD TRACE FOSSILS

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Soils were one of the earliest terrestrial environments to be colonized. Modern soils host diverse ecosystems that include micro-, meso-, and macrofauna at all trophic levels. Predatory arthropods are known from terrestrial environments since the Silurian. Since their first occurrence, many of these animals have acquired specialized behavioral adaptations suited for soil environments, including various burrowing styles and even permanently fossorial habits. Our knowledge of arthropod predators in Paleozoic soil ecosystems, however, is limited. Ichnofossils are abundant in Paleozoic paleosols, yet most are of uncertain origin and may record a hidden diversity of predatory arthropods.

In order to better understand the use and morphology of predatory soil arthropod burrows, laboratory experiments were conducted with various species of scorpions, whip scorpions, spiders, and centipedes. The animals studied included those that were active surface hunters and passive ambush hunters. Multiple specimens of each species were placed in sediment-filled terrariums and observed for 10–30 days. Open burrows were cast and ichnofabric was observed through serial sections. The morphology of the traces was described qualitatively and quantitatively and compared using nonparametric statistical methods.

The animals burrowed with a variety of techniques including intrusion, excavation, and backfilling. The burrows were generally produced over short periods of time (1–3 days). The longevity of individual burrows varied depending on the species and even the individual. Some burrows were occupied for short intervals (2–5 days), others were permanently occupied and maintained, and in some species a single burrow was continuously expanded and modified. Burrow morphology ranged from simple vertical shafts to complex boxworks. The burrows served as temporary to permanent dwellings. But in addition to providing protection, some burrows also served a role in hunting prey and were used as sites for concealment for ambush or as prey traps. While the overall complexity of the burrows was not related to their use, distinct morphologies could be linked to different predatory behaviors. In addition, burrow morphology could be correlated to tracemaker morphology and burrowing techniques.

Predatory arthropods produce unique three-dimensional biogenic structures that can be distinguished from other soil organisms and can be linked to specific behaviors. Data collected from these and similar experiments can be applied to ichnofossil assemblages found in Paleozoic paleosols in order to increase our understanding of the evolution of predatory arthropods, their geographic distribution through time, and their response to changes in soil environments, as well as improve interpretations of the paleoecology of ancient soil ecosystems. This knowledge is especially important given the relatively poor preservation potential of predatory soil arthropods in the environments they inhabit.

VIRTUAL TEACHING COLLECTIONS IN PALEONTOLOGY

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Many college-level paleontology and historical geology courses include a survey of major fossil groups. Students are often introduced to these groups through study and comparison of physical hand samples. Such specimens have always had great pedagogical value and this will continue to be the case long into the future. Physical hand samples, however, present several practical limitations. First, they are often not available for students to study outside of the classroom or laboratory. Second, teaching collections do not always provide representative samplings of the diversity o certain taxonomic groups, nor demonstrate adequat preservation of key morphological features. Finally many courses have no laboratory component or are taught entirely online, limiting the potential for students to learn directly from physical specimens.

Virtual teaching collections (VTCs) consisting of interactive 3D digital models of real fossil specimens overcome the limitations described above and provide a supplemental resource to help students learn about ancient life, including outside of traditional classroom settings. As part of the National Science Foundation-supported Digital Atlas of Ancient Life project (www.digitalatlasofancientlife.org), the Paleontological Research Institution (PRI) has begun to develop 3D models of specimens from its collections using a process called photogrammetry. Once captured, these models are loaded on the Sketchfab model-sharing platform and key features are annotated. To date, 240 models—representing a broad survey of taxonomic groups—have been developed from specimens in PRI's collection. These may be accessed at sketchfab.com/DigitalAtlasOfAncientLife. Further, these models, which have Creative Commons licensing, may be freely downloaded and 3D printed. Many additional fossil specimens from other museum collections are also available for viewing on Sketchfab.

While fun to interact with, the 3D models have limited educational value without supporting context. Because of this, VTCs are being developed that include curated collections of models that are grouped by theme (e.g., fossil cephalopods, types of fossil preservation, Devonian fossils from New York, etc.). In this way, each VTC is akin to the drawers of physical specimens that an instructor might place on a table during a laboratory that covers a certain topic. Existing VTCs may be accessed at www.digitalatlasofancientlife.org/vtc/. The 3D models are also being embedded into relevant chapters of the online, open access Digital Encyclopedia of Ancient Life (DEAL) textbook (www.digitalatlasofancientlife.org/learn/), which allows students to explore and interact with virtual fossils as they read and learn about corresponding groups.

EVOLVING BIODIVERSITY AND PALEOECOLOGY OF MARINE COMMUNITIES ACROSS THE END-CRETACEOUS MASS EXTINCTION IN CALIFORNIA

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One of the greatest mass extinctions in Earth's history occurred at the end of the Cretaceous. While faunal response to this event was global, taxonomic and ecological responses varied regionally. Recent museum digitization efforts provide new opportunities to explore regional and local-scale patterns of taxonomic diversity, paleoecology, and biogeography during this transition. Until now, large-scale analyses of the extinction event in the fossil record of California were not possible due to a lack of digitally aggregated, high-quality paleontological data. Here we analyze museum samples of marine invertebrates across the Cretaceous-Paleogene (K-Pg) boundary in California to identify patterns and processes of community reconstruction after the mass extinction. This includes more than 93,000 newly available specimens of Late Cretaceous age, and an additional 37,000 specimens from the Paleocene.

Of 122 genera occurring in the Cretaceous dataset, 67 (60%) went globally extinct at the K-Pg boundary, 11 had valid post-Cretaceous fossil records outside of the eastern Pacific (locally extinct), and 34 (28%) ranged beyond the K-Pg boundary in the northeastern Pacific. Pre- and post-extinction comparison of numerical abundance indicates that relatively few of the most common Cretaceous genera (e.g., *Glycymerita*, *Turritella*, *Cucullaea*) surviving the K-Pg event remained similarly abundant in Paleocene assemblages. *Turritella* was, by far, the most abundant taxon in post-extinction assemblages, represented by more than five times the number of specimens than the next most abundant genus. Abundant Cretaceous genera such as *Biplica*, *Calva,* and *Cymbophora* did not survive the event, while the venerids *Pitar* and *Macrocallista* first appeared in abundance in Paleocene assemblages. Local extinction rates were elevated across many well-sampled ecological groupings, including motile

infaunal suspension feeders (89%) and slow-moving surficial predators (84%), although both groups diversified rapidly during the Paleocene, in particular predatory gastropods with more than 33 genera (87%) first appearing post-extinction. Multivariate analyses of taxonomic composition indicate a clear divide between pre- and post-extinction assemblages. This distinction is less pronounced when considering ecological traits, rather than taxonomic identification, although Danian-age assemblages were often unique in their overwhelming abundance of suspension-feeding gastropods (turritellids).

This dataset permits the first comprehensive analysis of the impact of the K–Pg extinction on marine macroinvertebrate communities of the eastern Pacific. Importantly, such analyses are now possible due to the digital mobilization of the vast "dark data" in museum collections. The datasets included herein were made possible two NSF grants, the "Cretaceous Seas of California" project (NSF #1561429) and the "Eastern Pacific Marine Invertebrates of the Cenozoic" Thematic Collections Network (NSF #1503065).

WINNERS AND LOSERS: REVISITING THE QUALITY OF CALIFORNIA'S FOSSIL RECORD

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Valentine's (1989) classic study "How good was the fossil record? Clues from the Californian Pleistocene" demonstrated that the marine fossil record does have the potential to capture a very high percentage of once living species, and those that are not represented have somewhat predictable traits such as rarity, small body size, or preference for deeper habitats. An important implication was that major deficiencies in the fossil record are likely to have been imposed through tectonic destruction, burial, erosion, or diagenesis.

Digitization of major Cenozoic marine invertebrate collections through the "Eastern Pacific Marine Invertebrates of the Cenozoic" Thematic Collections Network (NSF #1503065) lays the groundwork for much finer resolution assessment of the qualities of the Pleistocene fossil record in the Californian province. Additionally, the digitization of invertebrate zoological collections provides additional resources upon which to assess the traits of species that either succeed or fail to leave a fossil record. Here we reproduce Valentine's study using a dataset of more than 1.7 million specimens (46,000 lots) digitized from the Natural History Museum of Los Angeles County's (NHM) Invertebrate Paleontology collection, paired with rich data from NHM's Malacology collection, and an exhaustive literature search on reported Quaternary occurrences. This reassessment also builds on considerable new taxonomic, biogeographic, and environmental data published over the last decade.

A review of recently published monographs and unpublished reviews on the Mollusca of the eastern Pacific, indicate the presence of more than 1590 named species living in the Californian province. Our literature review of the Quaternary (incorporating the Gelasian) discovered 898 species bearing a fossil record from this region, of which 192 are now extinct. Adding data from the NHM Invertebrate Paleontology collections reveals an additional 171 named species for which a fossil record had not previously been reported, in addition to many as yet unnamed species. A difference of 524 represents the number of living species for which a fossil record cannot be established. Many of these occur in depths greater than 50 m (23%), are rare among living faunas (22%), are known only from their type locality (22%), and are less than 5 mm in maximum diameter (21%).

The digital revolution unfolding in the paleontological collections of natural history museums is mobilizing a vast quantity of historically inaccessible knowledge. Critical examination of these new data not only informs us about the quality of the fossil record, but can enable more precise estimates of geographic and stratigraphic ranges, the magnitude and selectivity of extinctions, and improved knowledge of the distribution of taxa across environmental gradients, among many other paleobiological themes. The fossil record of the Californian Pleistocene is indeed quite good and the data is now available!

FOSSIL RESOURCES OF SHELLABARGER PASS, DENALI NATIONAL PARK AND PRESERVE, ALASKA

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The Paleozoic through Mesozoic fossils of Shellabarger Pass in Denali National Park and Preserve have an integral and unique story to tell of the history of life and the geology of North America. This remote region in southcentral Alaska has not been well-explored or documented. As part of our national and historical heritage it is pertinent to record and analyze the

paleontological and geological history of Shellabarger Pass. This is the first year of a two-year project to characterize the Paleozoic and Mesozoic fossils of Shellabarger Pass in order to explain the geological evolution of the region. Shellabarger Pass is a remote area of the preserve, far from the road system and accessible only by helicopter and backcountry fieldwork. By targeting sites also of interest to thearchaeological researchers, coordination allows the maximum use of available backcountry equipment and creates a diverse field experience covering theOrdovicianto the time of North America's early human populations. The paleontological project has two approaches. The first is a review and accumulation of all prior research on the paleontology of Shellabarger Pass and the location status and updated documentation of any collected specimens. The second approach is visiting known and new potential sites to survey, compile geological data, take field observations, and document paleontological samples. Fossils recovered to date from Shellabarger Pass are primarily of Ordovician, Silurian, Devonian, and Lower Jurassic age. The Devonian fauna are highly diverse and include a number of non-Laurentian (non-North American) genera. Their abundant presence suggests that the Farewell terrane rocks of Shellabarger Pass are of Eurasian origin, most likely representing a rifted portion of the Siberian paleocontinent, or a tectonic entity nearby. Our planned future efforts include making better known the distinctive Devonian and Early Jurassic fauna of this region. Upper Silurian cyanobacterial reefs are well developed in Shellabarger Pass, and contain an unusual Uralian megafauna, including aphrosalpingid calcareous sponges and brachiopods. The Early Jurassic(Sinemurian) fauna will be emphasized in our future study and includes ammonites, bivalves (including the distinctive genus*Weyla*), brachiopods, and possibly the earliest record of belemnites in North America. The results of this project will be used to develop models of the sections, integrate research with previous literature, and prepare reports and publications that are pertinent to our understanding of North America's tectonic history through fossil heritage. Furthermore the project promotes a better understanding for the public in the importance of protecting Denali National Park and Preserve's fossil resources.

IRVINGTONIAN AND RANCHOLABREAN SMALL MAMMALS FROM THE HARVESTON LOCALITY, SOUTHWESTERN RIVERSIDE COUNTY, CALIFORNIA

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A mitigation project conducted in 2003 during construction of the Harveston subdivision in Temecula, southwestern Riverside County, California, recovered numerous fossil vertebrates. Material was recovered from two units: the Irvingtonian Pauba Formation and an overlying unnamed Rancholabrean unit (based on the presence of *Bison antiquus*). Preliminary examination of the microvertebrate sample from the Pauba Fm. has resulted in the identification of the genera *Microtus* (43% of identified small mammal fauna), *Thomomys* (30%), *Neotoma* (11%), *Dipodomys* (6%), *Peromyscus* (6%), *Onychomys* (2%), and *Sylvilagus* (2%). The overlying Rancholabrean unit has produced *Thomomys* (75%) and *Neotoma* (25%), but is based on only four identified specimens. While the sample size is small, the Rancholabrean fauna is similar to the *Thomomys*- and *Neotoma*-dominated microvertebrate fauna from Diamond Valley Lake, located only 10 km away. *Thomomys* and *Neotoma* are generally associated with more arid and open habitats. This is consistent with the large mammal fauna recovered from the Rancholabrean unit at Harveston, which includes *Equus*, *Bison*, *Mammuthus*, *Hemiauchenia*, and cf. *Antilocapra*. The shift from a *Microtus*-dominated fauna in the Irvingtonian to a *Thomomys*-dominated fauna in the Rancholabrean suggests a shift toward more arid conditions during the Pleistocene.

QUANTIFYING THE EFFECTS OF CHANGING DEPOSITION RATES AND HIATUSES ON THE STRATIGRAPHIC DISTRIBUTION OF FOSSIL OCCURRENCES

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Stratigraphic paleobiology has shown that the fossil record is not a direct reflection of biological processes, but is strongly controlled by the sequence stratigraphic architecture. This control includes the effects of facies changes, breaks in deposition, and changing deposition rates.

To infer genuine biological patterns in the fossil record, statistical methods incorporating knowledge about these controls are necessary.

I present a method that, based on any model of deposition or erosion rates, allows to reconstruct the

time of deposition of a point in the section and determine the point in the section that is formed at a given time. This allows to transform observations such as fossil abundances and last fossil occurrences from the section into time and vice versa.

This transformation can be used to correct paleontological observations for the effects of changing deposition rates. Most importantly, it can be used to study and quantify the robustness of interpretations of the fossil record under a scenario of conflicting deposition models.

The proposed method is backwards compatible with all previously published methods, allowing them do derive results in time instead of stratigraphic height. The method can also be applied to geochemical proxies, ecological parameters, and evolutionary relationships.

PREDICTIONS FOR THE STRATIGRAPHIC PALEOBIOLOGY OF CONTINENTAL SYSTEMS

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The stratigraphic record of continental systems is governed by two aspects that exert an overriding control on the occurrence and taphonomy of continenta' fossils. First, continental systems alternate betweeı low-accommodation and high-accommodation sys tems tracts, in addition to a net long-term shift towards lower-accommodation conditions; these control the relative abundance of facies, each bearing a characteristic suite of fossils, taphonomic mode, and preservation potential. Second, the most important ecological gradients in continental systems are correlated with elevation and distance from the coast. Elevation in basins will vary in response to cycles of accommodation, and it will increase over the long-term history of the basin, as rates of accommodation decline, and it fills with sediment.

These changes in accommodation and elevation lead to six main predictions for the continental fossil record. (1) Continental biotas will preserve an overall trend from low-elevation to high-elevation communities over the history of a basin. (2) Communities will cyclically vary in composition, owing to cyclic changes in elevation caused by changes in the rate of accommodation. (3) Biotas will change abruptly across sequence boundaries, owing to the hiatus and the net change in elevation. (4) Biotas in coastal continental settings will change abruptly across the updip expression of marine flooding surfaces. (5) The taphonomic mode and types of preserved biota will change progressively over the history of a basin, owing to the net shift to a low-accommodation system. (6) Taphonomic mode and type of preserved biota will also change systematically in response to cyclic changes in the rate of accommodation.

Other abiotic controls (i.e., climate change) and biotic responses (e.g., extinctions, and evolutionary trends), will be recorded against this backdrop of changing accommodation and elevation. Because paleontological studies often focus on relatively small geographic areas, owing to limitations of time, money, and outcrop exposure, it becomes critical to recognize stratigraphic patterns in the fossil record that are a record of changing accommodation and elevation, rather than climate change, extinction, evolution, etc.

STEWARDING OVER 100 YEARS OF USGS PALEONTOLOGICAL RESEARCH INTO THE 21ST CENTURY

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The U.S. Geological Survey (USGS) fossil collection is the authoritative reference collection for 116 years of USGS paleontological and stratigraphic research. The fossils continue to be examined by non-USGS researchers to inform studies on landscape change, paleoecology, climate change, and extinction events. The collection contains some of the first fossils collected by the U.S. Government's geologists and paleontologists during their surveys of the West in the late 19th and early 20th centuries, much of what is public land today. The collection is supplemented by large quantities of documentation, including field books, annotated maps, and preliminary reports. Drawing on the fossils and their associated data, the USGS Paleontology and Stratigraphy (P&S) Branch published more than 5,000 scientific papers on geology and paleoecology. They published thousands of geological maps that were dependent on examining these fossils, along with nearly a hundred years of sequence stratigraphy research that has been essential in locating and understanding natural resource deposits, including oil, minerals, and natural gas. Scientists at the Smithsonian's U.S. National Museum, also known as the National Museum

of Natural History (NMNH), have been close research collaborators with the USGS since the inception of both organizations. Since 1879, USGS collections, when no longer needed for active investigations, have been deposited at NMNH as required by the Civil Sundries Act of 1879. NMNH and the USGS continue to collaborate by integrating and digitally sharing the collections' specimen inventory data, all associated research data, and publications. Digital discovery for the entire collection requires the use of archival data standards for associating records and datasets (such as field books and annotated maps) and utilizing natural history informatics best practices to mobilize the specimen data online. The last major subset of the USGS fossil collection to be physically transferred to NMNH are the specimens currently retained by the USGS Denver Core Research Center. The specimens stored in Denver are no longer used for active USGS mission-based research. Transferring them to NMNH will provide for their long-term care and accessibility. Beginning in 2018 and projected to end in 2020, all collections (nearly 1,000 museum cases) and their associated material will be moved to the Smithsonian Museum Support Center in Suitland, MD. NMNH is working with the USGS to curate the Denver specimens and archival material. Efforts are currently underway to manage all USGS collection data digitally, so the collections are accessible for new research and are discoverable through a variety of contextual links to USGS research.

ONTOGENIES AND ATTACHMENT STRATEGIES OF EARLY PALAEOZOIC BRACHIOPODS

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Our knowledge of the ontogenies and attachment strategies of early Palaeozoic brachiopods has improved considerably during the last decade, mainly thanks to the increasing number of exceptionally preserved faunas both from Burgess shale-type Lagerstätten, as well as from other examples of unique preservations. The new early Palaeozoic records of brachiopod ontogenies show that most include a first formed organic bivalved shell with two to three pairs of larval setal sacks and a pedicle lobe, secreted at some time during the pelagic stage. This ontogeny is best known from early Cambrian Paterinida, which had a prolonged pelagic stage and settled on the posterior part of the body, where metamorphosis most likely proceeded without mantle reversion. The paterinide type of larva is found in most known Paterinida, but it has recently also been documented in the earliest Acrotretida and Lingulida, as well as in some Orthida and stem group brachiopods (e.g. *Mickwitzia*). Other early brachiopods have a modified planktotrophic paterinide larva, where the secretion of the ventral valve was delayed until settlement and the end of metamorphosis. The larva settled on the posterior part of the body and attached itself to the substrate soon after settlement, while the larval pedicle lobe was significantly reduced. The modified paterinide larva is probably present already in some tommotiids and also in some early problematic brachiopods (e.g. *Salanygolina*), and it has also recently been found in of siphonotretides, orthotetides (e.g. *Coolinia*) and probably also in chileides. All these groups are characterized by the presence of a variably developed but distinctive attachment-structure called the 'colleplax' with and umbonal opening in the ventral valve. The'colleplax'pedicle would have been secreted from a specialized modified region of the ventral mantle (as in *Kutorgina* from Chengjiang), and it would not be homologous with the type of pedicle that emerge posteriorly from between the valves in most living and fossil brachiopods. Further evolution of the modified paterinide larva resulted in the origin of pedicle sheath (='colleplax'pedicle) in derived Billingsellida (*Antigonambonites*) and the Strophomenida. The larva of living rhynchonelliforms probably developed directly from the paterinide larva through acquisition of lecithotrophy and mantle reversal. It is most likely that the lecithotrophic larva of recent craniiforms also evolved directly from some type of modified paterinide larva that developed lecithotrophy. Further evidence supporting this interpretation comes from recent studies of Hox gene expression, indicating a conserved nature of patterning between the Craniiformea and the Rhynchonelliformea, indicating that the posterior tip of the craniiform larvae corresponds to the pedicle of Rhynchonelliformea.

GLENDONITE OCCURRENCES IN THE TREMADOCIAN OF BALTICA: FIRST EARLY PALAEOZOIC EVIDENCE OF MASSIVE IKAITE PRECIPITATION IN TEMPERATE LATITUDES

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The Tremadocian (Early Ordovician) is currently considered a time span of greenhouse conditions with tropical water surface temperature estimates, interpolated from oxygen isotopes, approaching 40°C. In the high-latitude Baltoscandian Basin, these data are in contrast with the discovery of glendonite a pseudomorph of ikaite ($CaCO_3 \cdot 6H_2O$) and valuable indicator of near-freezing bottom-water conditions. Previous records of glendonites display an apparent gap from Neoproterozoic to Permian times. However, similar calcareous nodular aggregates embedded in Tremadocian black shales of the East Baltica (so-called "antraconites") have been known for more than 150 years. These aggregates are documented from numerous localities in the Türisalu and Koporiye formations (*Cordylodus angulatus* - *Paltodus deltifer pristinus* zones) exposed along 600 km of the Baltic-Ladoga Glint and sporadically in the Orasoja Member (Kallavere Formation). All these units accumulated in the Baltoscandian Basin, an epeiric sea with a central flat-floored depocentre rimmed to the south (recent coordinates) by a chain of low islands and associated shoal complexes. During Tremadocian times, the basinal depocentre recorded black shale deposition episodically punctuated by wave and storm-induced processes, pointing to a sediment-starved, distal offshore-dominant clayey substrate, in which organic matter and trace metals became highly concentrated due to extremely low deposition rates and an exceptionally low influx of siliciclastic material. In contrast, nearshore environments comprised uncemented, well-washed, cross-laminated quartzose sands, which included high concentrations of allochthonous obolid coquinas that were continuously reworked along the shorelines. Perhaps the most suprising aspect of this new record is that the precipitation of glendonite is contemporaneous with the record of conodonts displaying low $\delta^{18}O$ values, which would suggest high temperatures (>40°C) in the water column. Therefore, the early Tremadocian sediments of Baltoscandia contain both "greenhouse" pelagic signals and near-freezing substrate indicators. This apparent paradox suggests both the influence of isotopically depleted freshwater yielded by fluvial systems, and the onset of sharp thermal stratification patterns in a semi-closed basin, which should have played an important role in moderating subpolar climates and reducing latitudinal gradients.

Ontogeny of the trilobite Estaingia bilobata from the Cambrian Series 2 (Stage 4) Emu Bay Shale, South Australia

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The ellipsocephaloid trilobite *Estaingia bilobata* Pocock, 1964 is by far the most abundant element of the Emu Bay Shale biota from the Big Gully locality, situated on the north coast of Kangaroo Island, South Australia. Certain surfaces within the *Konservat-Lagerstätte* interval in the lower part of the formation exhibit densities of more than 600 individuals per square metre, with the majority of specimens being articulated and often well-preserved. A brief and incomplete description of the ontogeny of *E. bilobata*, based on a small number of specimens from the coastal outcrops of the Emu Bay Shale, was provided in the 1990s. However, more recent excavations at Buck and Daily Quarries further inland have produced hundreds of meraspid specimens, as well as several thousand holaspides.

Here we provide a description of the largely complete (post-embryonic) ontogenetic series for *E. bilobata*, as well as some preliminary morphometric analyses examining variation and size-related shape change across this series. As with many trilobites, the meraspid pygidium of *E. bilobata* had an extended equilibrium period, where subterminal segment production was matched by anterior release into the thorax. For the majority of the meraspid phase, there were probably six segments in the pygidium, which was subsequently reduced to a stable number of three in the holaspid phase, by the sequential release of the anterior three segments. Thus, growth in *E. bilobata* appears to conform to the protomeric mode of trunk development, with the epimorphic phase being

attained prior to the holaspid phase. Considerable allometric growth occurred not only across the meraspid period in *E. bilobata*, but also during holaspid growth.

SCALES, FUZZ, OR BOTH? REMAINING DIFFICULTIES IN DETERMINING THE ANCESTRAL INTEGUMENTARY STATE IN DINOSAURIA

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The discovery of feathers and simpler filaments ("fuzz") on the bodies of both primitive carnivorous dinosaurs and various bird-hipped dinosaurs suggests the possibility that the ancestor of all dinosaurs wasn't simply covered with scales. Was the first dinosaur fuzzy? How can we tell? Several factors provide impediments to effectively determining the ancestral integumentary state in Dinosauria and in various nodes within this clade.

One common approach is to use phylogenetic comparative methods (PCM) to estimate the relative support for fuzzy or non-fuzzy first dinosaurs. However, in order to properly use this method, we have to make certain initial assumptions. Of significant importance is whether the pycnofibers of pterosaurs are homologous with the filaments of dinosaurs.The situation is further complicated in that we are not certain whether all the scaly body impressions we see in dinosaurs represent the retention of the ancestral reptilian scales, or if they are fuzz or feathers transformed into scales (as modern birds have on their legs), or if they are simply fractured heavily keratinized skin (as in the face of modern crocodilians).Additionally, only *Lagerstätten* are even capable of preserving the remains of filamentous and filament-derived integument, whereas typical fine-grained detrital sediments can preserve squamous impressions. Absence of fuzz in scaled dinosaur skin impressions does not actual demonstrate absence of fuzz on those dinosaurs. Indeed, a newly-described specimen of a Mesozoic enantiornithine bird pes in amber shows fuzz in between more typical squamation.

A new series of PCM analyses are conducted, using alternative phylogenetic frameworks (the "Saurischia", "Ornithoscelida", and "Phytodinosauria" hypotheses) and alternative scoring methods (assuming pycnofibers are non-homologous with dinosaurian fuzz; assuming that they are; and using only observations from *Lagerstätten* sites.)It is found that the phylogenetic alternatives do not greatly affect the likelihood predictions for the base of Dinosauria nor for most of the nodes within the tree, while the alternative interpretations of the homology of pycnofibers and dinosaurian filaments is the greatest determinant.

Finally, although operationally we would prefer that phylogenetic position to be the sole—or at least primary—control over what form of body covering an animal manifests, observation of modern animals shows that close relatives can have radically different integuments. There is no good "general theory of integument", and firm definitive statements about the absence or presence of filaments within non-coelurosaurian dinosaur clades are problematic at present.

DIGITIZATION OF THREE-DIMENSIONAL SURFACE MORPHOLOGY OF MILLIMETER-SCALE FOSSIL SPECIMENS THROUGH FOCUS STACKING AND PHOTOGRAMMETRY TECHNIQUES

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Photogrammetry is an effective technique for extracting three-dimensional (3D) surface morphology of fossil specimens. Recently, this technique has been experimented on millimeter-scale specimens by resolving the shallow depth of field issue of camera lenses at higher magnification through combination of focus stacking method with photogrammetry. However, the effect of composite images on the accuracy of photogrammetry has not been tested. This study plans to compare 3D surface model of millimeter-scale trilobite specimen reconstructed by photogrammetry and focus stacking process with surface data collected through laser scanning and tomography in order to estimate theinfluence of focus-stacked images on photogrammetry. Future studies include utilizing the shape data acquired from photogrammetry to identify ontogenetic shape trajectory of scrobiculae on the rugae of trilobite *Glyptagnostus stolidotus*.

COMPARISON OF GROWTH RATES IN THE TRILOBITES ELRATHIA KINGII (MEEK, 1890) AND AULACOPLEURA KONINCKII (BARRANDE, 1846)

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One of the most common and well-recognized trilobites in scientific, educational, and private collections is *Elrathia kingii* (Meek, 1870). Despite the potential availability of large sample sizes of articulated specimens, *E. kingii* has been the subject of relatively little evolutionary biology research. For example, only one

paper (Bright 1959) has been previously published on growth rates in *E. kingii*, and though the sample studied was large, it consisted almost entirely of holaspids. Here I use newly collected material to estimate growth rates and describe shape change over the entire ontogeny of *E. kingii*. Trilobites were hemianamorphic, meaning their ontogeny was characterized by a period of post-embryonic growth when new segments were added to the thorax (the meraspid period) followed by a period of continued molting with no new thoracic segment addition (the holaspid period). The addition of new segments during meraspis provides a size-free measure of relative age that may be extrapolated to holaspid specimens when the growth rate of the cephalon is constant. Over 300 well-preserved, articulated specimens were collected from a 1.5 meter interval of the upper Wheeler Formation in western Utah, and multiple specimens representing each post-embryonic stage were recovered. 140 specimens have thus far been prepped and photographed, and the photographs used to collect size and landmark-based shape data for each specimen. As in many (but not all) trilobite species, the rate of cranidial shape change in *E. kingii* decreased at the transition from the meraspid period to the holapsid period. Growth rates, including characterization of growth gradients along the trunk, were estimated following previous work by Hughes, Fusco, and colleagues, on *Aulacopleura koninckii* (Barrande, 1846). Results for this preliminary dataset indicate that, like *A. koninckii*, cephalic growth rate in *E. kingii* was constant and of similar magnitude to the minimum growth rate along the trunk during meraspis, and that growth rates in the trunk were lower during the holaspid period than during the meraspid period. However, initial body sizes were smaller, the growth gradient along the trunk during meraspis was shallower, and the number of terminal thoracic segments were fewer in *E. kingii* than in *A. koninckii.* Despite these differences, these two species were similar in size at the transition to holaspis and achieved similar maximum body sizes, primarily because higher overall growth rates in *E. kingii* compensated for other differences.

MATHEMATIC MODELING TO RECONSTRUCT THE TAPHONOMIC HISTORY OF THE BURGESS SHALE-TYPE FOSSILS

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Burgess Shale-type preservation provides an important resource for studying the evolution of early life because exquisitely preserved soft-bodied fossils bear limbs and internal organs that can be compared with those of modern animals. Resolving the process behind the preservation of soft-tissues has become a central research issue in paleontology. Taphonomic studies including decay experiments based on modern animals are all devoted to reveal how this extraordinary preservation was mitigated. Many factors (e.g. chemical sealing, burial matrix and anoxic environments) have been suggested to be involved in exceptional preservation, but physical principles affecting soft-bodied preservation are relatively rarely considered. The role of physical controls related to specimen orientation within the sediment gives an independent perspective from which to view the taphonomic history of the soft tissues. Here I use the middle Cambrian trilobite *Olenoides serratus* from the Burgess Shale fauna as an example to reveal the physical process of compaction acts as a taphonomic control on the shapes of soft structures. In this study, mathematic principles are applied to reconstruct the original state of a particular structure during or at the beginning of the preservation. The establishment of the modeling based on mathematic principles applies not only Burgess Shale-type preservation but also other important fossil deposits. Reconstruction based on these reveals how compaction controlled the final preserved phenotype of ancient life and permits visualization of organisms in a three-dimensional space obtained from a two-dimensionally preserved fossil.

BRIGHT AND EARLY – TRENDS IN COGNITION AMONG PHANEROZOIC MARINE ECOSYSTEMS

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Cognition is the ability to acquire, process and utilize information. Though cognition itself is not directly preserved in fossil organisms, correlates of it can be. Sense organs reflect information acquisition abilities, while nervous systems indicate information processing abilities. Behavior, as shown by both body and trace fossils, reflect responses and actions taken by organisms upon utilizing information. Plotnick et al. (2010) introduced the concept of the Cambrian information revolution, whereby biotically-driven increases in signals, behavioral interactions, and landscape spatial complexity, concurrent with the Cambrian explosion, drove a rapid increase in animal cognition. A continued rise in cognitive abilities

throughout the Phanerozoic might also be expected, as increases in biotic and ecological complexity continue onto the present. These trends should be expressed in the number and variety of sense organs and the complexity of nervous systems.

I tested the idea that cognition increased over time in Phanerozoic marine ecosystems by tallying the share of metazoan species in various marine Lagerstätten possessing two forms of sense organ – macroscopic eyes, and anterior antennae/feelers. I also recorded the distribution of nervous system types among them as decentralized network, ganglia, or centralized brain. There is notable variability among Cambrian Lagerstätten in the presence of sense organs and nervous system complexity, some with levels as high as those in younger ecosystems. Some of this variation may be due to habitat. These high levels in the Cambrian suggest that sophisticated information processing was already present among metazoans early in Phanerozoic ecosystems. This is broadly comparable with the trace fossil record. Arthropods were the bulk of the taxa capable of complex information processing in Cambrian ecosystems, while mollusks and vertebrates would make up larger shares afterward.

HOW DID MAMMOTHS AND MASTODONTS GROW AND BECOME DWARFED? ONTOGENETIC LONG BONE GROWTH COMPARED TO ISLAND DWARFING IN PLEISTOCENE PROBOSCIDEA

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Large mammals on islands, especially proboscideans, hippos, and rhinos, often show a trend towards dwarfing during their isolation. This may be due to limited resources, lack of competition, or lack of predators. How do these animals change their proportions as they become dwarfed, and how does it compare to the allometric slope of growth of those same mammals? We looked at a large sample of the extinct Pleistocene pygmy mammoths *Mammuthus exilis* from the Channel Islands, and compared the slope of their limb growth from young juveniles to the slopes of size reduction of their limbs from their ancestor, *M. columbi* (Columbian mammoths). The first surprise is that neither the pygmy mammoths nor the living African elephants show growth slopes that are as robust as expected for a huge graviportal mammal. Instead, the humerus, femur, and tibia change isometrically as they grow, and only the ulna tends to grow more robust as the mass increases rapidly. Previous studies have shown that dwarfed hippos and rhinos tended to develop more robust limbs as they became dwarfed. However, the pygmy mammoths only showed more robustness in the shrinking proportions of the humerus and ulna, but the femur and tibia became reduced in size isometrically. Thus, these expectations of much greater robustness as proboscideans grow huge, or as they reduce in size, is not matched by most of the limbs we examined.

COPROLITES IN CAMBRIAN STAGE 4 GUANSHAN BIOTA AND THEIR ECOLOGICAL IMPLICATIONS

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The Guanshan biota, occurring in the lower Wulongqing formation (Cambrian Stage 4) of eastern Yunnan, has been the subject of a great deal of research in the last decade. Much of the focus of this previous work has been investigations of either the morphological diversity and/or phylogenetic relationships of the animal taxa present. Few studies have investigated the trace fossils or explored how trace fossils from the Guanshan biota may elucidate understanding of the development of ecological strategies during the Cambrian.

Recent excavations of the Guanshan biota at the Shijiangjun section of eastern Yunnan Province have recovered a large collection of well-defined coprolites. These coprolites can be assigned to three distinct morpho-types based on their morphological characteristics. Type A only occur on bedding planes and never penetrate through multiple beds. They are generally straight or slightly curved, filled with fecal pellets, and are up to 17cm in length, 2mm in diameter. The fecal pellets are parallel or sub-parallel to the orientation of the trace fossil. Type B has an irregular morphology, that sometimes cuts across layers, and lack any ornamentation; Due to their irregular morphology, the length of this type is highly variable, but it is consistently shorter and wider than Type A. In general, the fecal pellets in Type B are tightly compacted. Type C is similar in morphology to Type B, except that they also contain a pyritized tube. The length of this slightly curved tube is variable, up to a maximum of 8cm, and its width is about 1.5mm. All three types of coprolite consists of discrete spheroids that can be assigned to the ichnogenus *Tomaculum*

Groom, 1902. According to previous work the formation of *Tomaculum problematicum*, and presumably other forms of *Tomaculum*, is attributed to the feeding behavior of deposit feeders. Kulkarni and Panchang (2015) identified that the formation of *Tomaculum*, based upon neoichnological observations, is likely due to the activity of polychaete worms. These previous results, combined the morphological characteristics of these coprolites, lead us to conclude that Type A are the result of deposit feeding epifaunal polychaetes, while Types B and C can be attributed to deposit feeding infaunal polychaetes. In addition, the existence of the pyritized tube in Type C may due to bioturbatior by scavengers after formation.

These coprolites represent the first reported occur rence of *Tomaculum* from the Guanshan Biota. Previously reported, from the Chengjiang Biota, diminutive trace fossils in body fossils that were locally filled with tiny pellets, but these were not identified as *Tomaculum*. Compared with these similar trace fossils found in the Chengjiang Biota, those found in the Guanshan Biota are greater in both size and complexity . These results indicate that by Cambrian Stage 4, polychaetes may have already developed mature deposit feeding behaviors comparable to those found in modern polychaete worms.

THE RELATIONSHIP BETWEEN TECTONICS AND OSTRACODS: OSTRACODS FAUNAL CHANGES UNDER A SUBDUCTION INITIATION SYSTEM IN THE TASMAN SEA

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Middle Eocene to Pleistocene ostracod faunal assemblages were reconstructed from marine sediment cores obtained in International Ocean Discovery Program (IODP) Expedition 371 Sites U1506, U1508, and U1510 in the Tasman Sea. The Tasman sediment cores are characterized by a regional Eocene-Oligocene unconformity. Recent geological surveys have suggested that the unconformity was possibly tectonic-driven. We discovered abundant neritic ostracods in Eocene and Oligocene sequences whereas the present water depths of all sites are deeper than 1000 meters. Preliminary results show that the signals of uplifting and subsidence varied across time and space, and that the scale of vertical movements is over 500 meters. Beta diversity assessment indicates high heterogeneity of neritic ostracod diversity under the uneven topographic fluctuations in the Paleogene. The later colonization pattern of deep-sea ostracods suggests that the modern deep oceanic setting in the Tasman Sea was probably established around 25 Ma. Future studies will focus on the influence of the paleogeographic changes, especially the subsidence and subsequent development of deep ocean communication, to evolutionary processes of the deep-sea organisms.

MACROEVOLUTION OF BODY SIZE AND DIETARY PREFERENCE IN NEOGENE LARGE MAMMALS

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Body size is often used as a proxy for how a species (or a higher taxon) interacts with its environment, because it co-varies with a wide range of physiological and ecological traits. Therefore, understanding of the broad-scale patterns of body size, especially in relation to spatial and temporal variation in environmental conditions, can shed light onto the underlying processes that shape the biodiversity patterns of the world. One key ecological trait that links animals intimately to their environment, and thus potentially underlies the association between body size evolution and environmental changes, is the animals' dietary preference.

In our study, we evaluate the connections between body size distribution and dietary preference in a biogeographic framework, using the Neogene (~23–3 Ma) large mammals (orders Artiodactyla, Carnivora, Perissodactyla, Primates and Proboscidea) as a model system. We considered two separate environmental templates: Europe and North America, as the different biogeographic setups on the two continents might have impacted the ecology and evolution of mammals differently. Specifically, we compared temporal patterns of taxonomic diversity and body size variation in mammals with similar dietary preference to illuminate the underlying processes that shape regional faunas. For example, accumulation of diversity can be achieved through tighter packing of niches within a dietary group (constant variance in body size) and/or expansion of the niche space (i.e. increasing range and variance of body size through gaining more taxa of extreme body sizes). In contrast, diversity might be lost through a reverse process of tighter niche packing or shrinking niche space (reduced range and variance as taxa with extreme body size preferentially lost without replacement of similar sizes).

Our study shows that in general, the temporal

patterns of taxonomic diversity (number of genera) are different between Europe and North America, but similar among dietary groups within continents. However, the variance of genus body size shows a variety of patterns among the different dietary groups even on the same continent, suggesting that different processes underlie the accumulation and loss of taxa in different groups. Collectively, our results suggest that taxonomic diversity and ecological diversity (e.g. variation in body size, and thus in many other biological traits correlated with body size) can be linked through different mechanisms in different biogeographic systems.

CONTRASTING COMMUNITY DYNAMICS OF TERRESTRIAL ECOSYSTEMS IN THREE MASS EXTINCTIONS THROUGH THE PALEOZOIC–MESOZOIC TRANSITION

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The Earth has been beset by many crises during its history, and yet comparing the ecologic impacts of these mass extinctions has been difficult. Here, by application of paleocommunity dynamics modeling, we explore three mass extinctions through the 100-million-year interval from Middle Permian to Early Jurassic (280–180 Ma). Although all three events may have been driven by similar environmental crises (massive volcanic eruption triggering global warming, acid rain, ocean acidification and stagnation), there are substantial differences in the scales of species losses. We restrict the study to a unique succession of terrestrial rocks and communities in the northern Xinjiang region in China, so we have comparable paleolatitudes and ecologies throughout. Paleocommunity dynamics modeling of 14 terrestrial communities shows that the largest of the three events, the Permian–Triassic (P–Tr) mass extinction differed from the other two, the Permian Guadalupian–Lopingian (G–L) and Triassic–Jurassic (T–J) mass extinctions, in two ways: (1) recovery from the P–Tr crisis was prolonged, and the three post-extinction communities of the Early Triassic show low stability and highly variable and unpredictable responses to perturbation primarily because of the loss of key herbivore species; and (2) the G–L and T–J mass extinctions were each preceded by communities with low stability, but recovery after each crisis was rapid. Our results confirm the uniqueness of the P–Tr mass extinction, but also shed light on the durations of the three events, and how complex communities respond to stress and how species can evolve to fill ecologic gaps after the crisis is over.

FOSSIL COMMUNITY CONNECTIONS: STRENGTHENING PROFESSIONAL-AVOCATIONAL PARTNERSHIPS FOR THE FUTURE OF PALEONTOLOGY

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Part 2 of the FOSSIL Project symposium centers around developing meaningful relationships within the community of professional and avocational paleontologists, educators, enthusiasts, and more.

The science of paleontology has a long legacy of avocational involvement and advancement. Many paleontologists started their careers as “amateurs” but went on to prominent positions within the paleontological community. One such example, E. O. Ulrich, started out as a surveyor and then became the “janitor” for the building of the Cincinnati Society of Natural History, eventually becoming the head of the stratigraphic division of the U.S.G.S. All such avocational paleontologists were and continue to be avid collectors and researchers, contributing large quantities of fossils to museum collections across the country and publishing many foundational papers in paleontology.

Scholarly research and publication are now mostly left up to the professionals with advanced degrees, but this overlooks the wealth of knowledge, experience, and resources avocational paleontologists have and continue to contribute to the science of paleontology. Through interactions with museums, academic institutions, commercial enterprises, media, and paleontological organizations the amateur and non-professional community are involved in scholarly research and publication, educational programming, community engagement, and collections-based initiatives.

The majority of avocational paleontology groups have the same mission as professionals: to contribute

to scientific research and increase the public's awareness and understanding of paleontology and its relevance. Indeed, more and more paleontological organizations are recognizing that avocational paleontologists are critical to the future of paleontology. Avocational groups and educators can also forge connections to benefit new generations of paleontologists. However, questions still remain as to how best develop these relationships. Often cited obstacles include a poor or complete lack of communication between professionals and avocationals, competing missions and motivations between museums and avocationals, private collections and their potential role as repositories of scientific data, and commercial collecting.

The FOSSIL platform provides a unique method of connecting avocational paleontologists, educators, students, and enthusiasts of all backgrounds to one another, and to create the much-needed communication across groups that strengthens the science of paleontology. This panel will provide an opportunity to highlight successful relationships between formal educators and professional and avocational paleontologists/groups. We offer a space to discuss questions regarding the current and future role of these collaborations in paleontology, and the paths forward for improving understanding, cooperation and achievement of common goals between groups for the future health of our science.

A NEW SOMASTEROID FROM THE FEZOUATA LAGERSTÄTTE IN MOROCCO AND THE EARLY ORDOVICIAN ORIGIN OF ASTEROZOA

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The somasteroids are Lower Palaeozoic star-shaped animals widely regarded as ancestors of Asterozoa, the group of echinoderms that includes brittle stars and starfish. However, the origin of asterozoans, the assembly of their distinctive body organization, and their relationships with other Cambrian and Ordovician echinoderms remain problematic due to the difficulties of comparing the endoskeleton between disparate groups. Here we describe the new somasteroid from the Early Ordovician Fezouata Lagerstätte in Morocco. It shares with other somasteroids the presence of rod-like virgal ossicles that articulate with the ambulacrals, but differs from all other known asterozoans in the absence of adambulacral ossicles defining the arm margins. Developmentally informed Bayesian and parsimony phylogenetic analyses, which reflect the homology of the biserial ambulacral ossicles in Palaeozoic echinoderms according to the Extraxial-Axial Theory, recover our taxa as the earliest divergent stem-group asterozoan. Our results illuminate the ancestral morphology of Asterozoa, and clarify the affinities of problematic Ordovician forms. Somasteroids represent a paraphyletic grade within stem and crown-group Asterozoa, whereas stenuroids are paraphyletic within stem-group Ophiuroidea. Our results also offer potential insights on the evolutionary relationships between Ordovician crown-group Echinodermata (e.g. asterozoans, crinoids) and its Cambrian stem-group representatives (e.g. edrioasteroids, blastozoans), and suggest that blastozoans are a paraphyletic grade relative to crown-group echinoderms.

EXCEPTIONALLY PRESERVED LATE ORDOVICIAN 'STARFISH BEDS' FROM THE TAFILALT AREA, MOROCCO: IMPLICATIONS FOR THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT

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The Upper Ordovician series of the Tafilalt area (eastern Anti-Atlas, Morocco) have yielded several echinoderm *Lagerstätten*, providing a relatively continuous record of successive, nearshore, cool water, echinoderm-dominated assemblages from the early Sandbian to the Hirnantian. During this time interval, the diversity of the majority of the Tafilalt echinoderm assemblages shows relatively little change, with the persistence of the same dominating groups such as crinoids, coronates, diploporitans, edrioasteroids, eocrinoids, glyptocystitid rhombiferans, solutans and stylophorans. However, these assemblages represent one of the earliest episodes where ophiuroids and asteroids also become a significant, and in some cases dominant, part of the some of the assemblages. This includes some of the earliest preserved examples of dense aggregations of brittle stars, the echinoderm meadows often observed today in deep water/cool water habits. Unlike assemblages of comparable age such as Lady Burn Starfish Beds, Scotland, these examples are likely to be *in-situ*. Closer examination of the generic and specific content of the three main asterozoan assemblages reveal that distinct assemblages first dominated by protasterid ophiuroids appeared in the early Ordovician, while other assemblages contain entirely new taxa of both ophiuroids and asteroids and

represent the rapid diversification of the these groups during the Great Ordovician Biodiversification Event.

ESCALATING PARASITISM OF BIVALVE MOLLUSKS IN THE MESOZOIC

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The influence of parasitism on ecosystems has historically been assumed to be negative or inconsequential due to their deleterious impacts on human health and typically diminutive body size, however a growing body of literature suggests that parasites play vital and underappreciated roles in healthy ecosystems. Parasitism is probably the single most successful life mode, as judged by biodiversity. The inclusion of parasites in food web analyses has demonstrated that parasites can actually increase ecosystem stability by increasing connectance, the percentage of realized possible links within trophic webs. More directly, parasites can influence community structure by reducing the efficacy of their hosts in other predator-prey or competitive interactions. Parasites are indeed important consumers in modern ecosystems and likely were in deep time. Modern bivalves serve as hosts to a diverse group of parasites including viruses, prokaryotes, protistans, fungi, parazoans, and metazoans, but only a subset of these interactions have been identified in the fossil record. A meta-analysis of the peer-reviewed literature reveals a remarkable post-Paleozoic escalation of parasite-bivalve host interactions. Paleozoic parasites include sponges, annelids, and unknown taxa that infested an average of 3.6 unique host genera per period with a mean prevalence value of 0.3%. The Mesozoic Era witnessed the addition of mollusks and platyhelminthes to the list of parasite phyla. The number of unique host genera per period increased from three during both the Triassic and Jurassic to 17 in the Cretaceous. Likewise, mean prevalence increased from 18.2% to 30.9% between the Jurassic and Cretaceous, with an overall average of 28.1% prevalence for the Mesozoic. The number of parasite phyla increased again in the Cenozoic to include phoronids and foraminifera. The number of unique host genera per Period increased from 21 to 59 in the Paleogene and Neogene, respectively, with an Era-wide mean prevalence of 28.4%. The Phanerozoic history of parasitism of bivalves broadly mimics previously documented temporal trends in predation intensity and identifies the Mesozoic as both an important time of escalation between parasites and hosts and a transitional period between Paleozoic and post-Paleozoic style antagonistic interactions. Though likely influenced by sample availability and taphonomic biases, our results are consistent with an increasingly dangerous ocean during the Mesozoic marine revolution. Future work will explore the patterns and processes relating parasitic interactions with biodiversity of bivalves and other host groups.

AN ADULT SPECIMEN OF SCALOPOSAURUS (THERAPSIDA: THERIODONTIA: THEROCEPHALIA) FROM SOUTH AFRICA AND SIZE-AGE STRUCTURE IN LILLIPUTIAN ASSEMBLAGES OF THE TRIASSIC RECOVERY

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'Scaloposaur' therocephalians (or 'shrew-lizards') represent a wastebasket taxon once regarded as central to the origin of mammals. This group is now thought to be made up of mostly paedomorphic or juvenile specimens representing other known Triassic therocephalian taxa. First known from Richard Owen's 1876 descriptions of Karoo nonmammalian therapsids, 'scaloposaur' species have traditionally been characterized by their relatively small size and gracile appearance. Here, a new large therocephalian is described from the Early Triassic *Lystrosaurus* assemblage zone (AZ) on the farm Donald 207, Bethulie district, Free State, South Africa. Other Triassic theriodonts from this locality have included the therocephalians *Moschorhinus*, *Scaloposaurus* and *Tetracynodon*, and the cynodonts *Galesaurus* and *Thrinaxodon*. The new skull is mostly articulated, but with a slightly crushed antorbital region, requiring high-resolution x-ray computed tomography (HRXCT) to virtually restore the diagnostic palate morphology. Apomorphic features—including a bony maxillovomerine bridge forming a secondary palate and six upper incisors, two small precanines and at least nine or ten postcanines—are consistent with the

genus *Scaloposaurus*, a well-represented Early Triassic therocephalian known previously to occur at Donald 207. However, linear dimensions of the present specimen (basal skull length 117 mm) dwarf others, being 175% larger than the previous largest specimen from Thaba 'Nchu (basal skull length 67 mm). Our discovery of the largest *Scaloposaurus* reveals distinctive adult morphology in the genus and underscores previously documented plasticity in growth rates of Permo-Triassic therapsids (gleaned from histologic analysis by our research team). Nevertheless, mixed-age theriodont assemblages are occasionally documented in the *Lystrosaurus* AZ, and fully-grown specimens continue to be remarkably rare. These findings are consistent with our recent hypothesis that, unlike in preceding intervals, juvenile excess mortality was high during Early Triassic *Lystrosaurus* AZ times.

SIZE MATTERS? A NEW RELICT MEGATEUTHIDID BELEMNITE FROM THE OXFORDIAN OF WYOMING (USA)

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Herein, we present the results of a study of peculiarly large (diameter ~6 cm) and stout belemnite rostra, collected from the lower-middle Oxfordian of Wyoming (upper part of the Sundance Formation) and belonging to a new taxon. There are only two such finds per thousands of 'normal' belemnites of the family Cylindroteuthididae that are common in the same strata. Our investigation, based on the analysis of several yet poorly understood belemnite characters, allows us to justify the affinity of these large rostra with genus *Brevibelus* (family Megateuthididae) — a cosmopolite genus common in the Toarican–Bajocian interval. The last record of this lineage is from the early Bathonian of West Pacific (New Caledonia), while the family Megateuthididae is a typical Early – early Middle Jurassic group with a single post-Bathonian report from the upper Kimmeridgian of Central Russia. Thus, the new belemnite from Wyoming represents a relict member of the *Brevibelus* group and is the first record of the megateuthidid belemnites for the North American Late Jurassic. In contrast, several records of morphologically similar rostra from the same region and strata, turned out to be typical cylindroteuthidids of pathological nature, resulting from injuries during life.

At first glance, the new belemnite from Wyoming was a real giant — no other known belemnite species attain 6–7 cm in rostrum width. But the comparative study of body proportions among several related taxa, known from various exceptionally preserved fossils from Lagerstätten, indicates that this impression is false. The mantle length of our new taxon was estimated as not exceeding 40–50 cm, comparable to co-occurring cylindroteuthidids. The extreme rarity of finds indicates some narrow specialization, which was reflected either in adaptation to a certain type of prey, or to a highly specific biotope.

To conclude, our data show the existence of previously unknown megateuthidid refugium in the Northwestern Pacific area. Contrary to the widespread perception, this family crosses the Middle/Late Jurassic boundary by several lineages in different parts of the world.

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THE IMPORTANCE OF GEOCHRONOLOGY FOR INTERPRETING NON-MARINE RECOVERY FROM THE END-PERMIAN MASS EXTINCTION

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Over the past two decades, a critical question has been the nature and timing of ecological recovery from the end-Permian mass extinction. With the advent of accurate and precise CA-ID-TIMS U-Pb dating of interbedded volcanic zircons, key Early-Middle Triassic sedimentary archives of marine fossil assemblages are now well-constrained by radioisotopic ages. These data demonstrate that the Early Triassic was relatively short (~4.7 Ma), and that ultimate recovery of most marine ecosystems did not occur until the beginning of the Middle Triassic, some five million years after the extinction event. Recent work with non-marine fossil assemblages suggests that recovery in these ecosystems was also delayed until the Middle Triassic,

with elevated endemicity in these early Middle Triassic recovery assemblages. However, proper interpretation of these non-marine fossil patterns is severely limited by the fact that most key fossiliferous strata have been dated in a relative sense using long-distance vertebrate biostratigraphy, and remain largely unconstrained by precise and accurate radioisotopic ages. Thus, it is largely unknown whether 'Early Triassic' and 'Middle Triassic' non-marine strata are actually assignable to these chronostratigraphic units (whose boundaries are defined in marine sections), and the timing of extinction recovery is unclear. New U-Pb ages from multiple basins in Argentina suggest several iconic "Middle Triassic" assemblages are actually Late Triassic (Carnian) in age. Preliminary age data from the supposedly Anisian upper Moenkopi Formation of the western United States suggest these strata could be as young as upper Ladinian. The iconic and intensely studied fossil records of southern and eastern Africa remain unconstrained by radioisotopic ages, so any age model applied to these data is largely heuristic. The unknown or Late Triassic ages of many "Middle Triassic" assemblages means they cannot speak to ecological recovery from the end-Permian mass extinction. Suggestions of Middle Triassic endemicity among non-marine ecosystems may instead reflect differing ages among the different assemblages sampled. As such, these new radioisotopic ages demonstrate that we know relatively little about the non-marine recovery from this mass extinction, and more broadly, the importance of accurate and precise biostratigraphically-independent age constraints when interrogating the fossil record with macroevolutionary and paleoecological questions.

THE EDIACARA FOSSIL SITE AT NILPENA, SOUTH AUSTRALIA: FINDING NEW WAYS TO MANAGE A NEW NATIONAL PARK

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The Ediacaran Hills in South Australia's Flinders Ranges are the original location after which the Ediacaran biota was named. Immediately south is the globally significant Nilpena Ediacara Fossil Site, which over the last 20 years has been managed by the private owners of the Nilpena Station as an *in situ* research site.

In recognition of the significance of Nilpena, and to secure its long term protection, a new national park is being created but with all of the challenges of ensuring it is well managed and secure, and made accessible for researchers and visitors.

To meet these challenges, a new approach to managing a national park is being pursued through the creation of the philanthropic Flinders Ranges Ediacara Foundation. A sustainable, long-term partnership between the foundation and the government will establish a new way for managing a fossil site in the context of a large national parks system where palaeontology competes with many other demands.

This talk will present this unfolding initiative for conserving and managing Nilpena's fossils against the backdrop of World Heritage Listing that is being pursued for the Flinders Ranges.

A COMPARISON OF MIS5E AND MODERN CORAL REEFS IN THE RED SEA

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Our oceans are rapidly warming as a consequence of an increase in atmospheric CO_2 concentrations. Corals are suffering from the heat stress and often react with bleaching, which can result in a decreased live coral cover and diversity. While it is crucial for conservation efforts to predict the adaptation and acclimatization potential of corals as well as future biogeographic shifts, it can be difficult to make projections based on experimental data alone. Using the recent geological past to study in situ behavior of coral reefs under higher temperatures is a crucial tool to improve projections derived from modelling.

In the substage MIS5e of the last interglacial period, ~125,000 years ago, oceanic temperatures and sea level were higher than today, while coral species were largely identical to the modern ones. Therefore, the distribution and diversity of the fossil coral reefs are a valuable analogue for the near future. A global comparison of MIS5e and modern coral reefs indicated species range expansion towards higher latitudes and contractions from the equator, especially in the northern hemisphere.

By studying the fossil and modern reefs along the coast of Egypt and Sudan, we will be able to gain insights about ecosystem stability under higher temperature conditions and along latitudinal gradients within the Red Sea. Data are collected with line intersect transects (LIT) and photo-quadrates. A comparison of the datasets will reveal community differences between MIS5e and recent reefs, including potential northward shifts during warmer climates. First results

from Egyptian fossil reefs will be presented. The acquired data will result in more accurate projections of coral diversity hotspots in the Red Sea under higher temperatures in the near future. To maintain the high coral diversity in the Red Sea, it will be essential to protect those future hotspots from additional human disturbances, such as increased sedimentation rate and pollution.

A CLADOCERAN-LIKE ARTHROPOD FROM THE BURGESS SHALE; BENTHIC NICHES IN CAMBRIAN BIVALVED ARTHROPODS

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The arthropod carapace, a sclerotized element originating from the dorsal part of the head and extending posteriorly and even encapsulating the whole body, is a common trait in extant crustacean groups. A number of Cambrian arthropods, informally termed "bivalved" arthropods, exhibit a division of the carapace into two individual valves. At the Burgess Shale (Wuliuan Stage) these are represented by basal euarthropods (*Isoxys*, *Surusicaris*), early mandibulates (*Tokummia)*, bradoriids (*Liangshanella*) and species of uncertain affinity (*Nereocaris*,*Perspicaris, Plenocaris, Tuzoia, Carnarvonia*), representing an unassessed high disparity of carapace morphologies. Such disparity could relate to different functional adaptations (protection, gas exchange, brood care, buoyancy) as well as differentiated ecological niches. Bivalved arthropods have been interpreted as nektonic (e.g. *Tuzoia*), benthic (e.g. *Canadaspis*) or nekto-benthic (e.g. *Waptia*). Their mode of feeding is well-known for only a few species (e.g. *Waptia*), and poorly known for taxa with homonomous segments and without differentiated limbs (e.g. *Nereocaris*, *Loricicaris*). Here we present a new bivalved arthropod from the localities of Marble Canyon and Tokumm Creek (Burgess Shale) which offers evidence for a deposit feeding habit. This species (ca. 10-20 mm in length) possesses a pair of semicircular carapaces which are frontally and dorsally fused. These originate from a posteriorly facing head and enclose most of the body, but leave a large dorsal cavity, a shape reminiscent of cladocerans. Most strikingly, the carapace extends anteroventrally into a long and straight bifid spine, directed sub-parallel and close to the carapace. The body is multisegmented and homonomous, and bears a series of unspecialized appendages up to the telson. Two posteriorly-directed, peduncular compound eyes project from the ventrally positioned head, just behind the base of the spine. The gut is U-shaped, as the mouth is pointing posteriorly. Observed tridimensionally preserved guts with brittle fractures suggest solidification of the gut contents prior to burial. The overall shape of the carapace, the homonomous segmentation and morphology of the appendages is somewhat similar to the much larger *Nereocaris* from the Burgess Shale, although in this species the carapace only covers ca. a third of the body, opens at the front and has much smaller spines along the anteroventral margin of the carapace. The limbs of *Nereocaris* also do not extend to the telson. The sediment filled gut suggests a deposit feeding habit, a strategy inferred in other Burgess Shale arthropods (eg. *Burgessia*), including bivalved species (e.g. *Plenocaris*). However, the absence of walking-type appendages suggests a different approach to deposit feeding, in which the ventral spine could have a potential functional role as stabilizer. Our discovery further emphasizes the role of detrital and meiofaunal food sources in structuring Cambrian communities.

CAN WE ESCAPE OUR HISTORY AND UPDATE OUR FOCUS ON FOSSIL CEPHALOPOD SHELL FUNCTION(S)

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Function of chambered cephalopod shells, both fossil and modern, has long intrigued researchers. In particular, the mechanical rational for sutural complexity has received considerable attention. This complexity varies between taxonomic groups of fossil cephalopods and relative to shape within specimens. However, no currently accepted overarching explanation accounts for these multiple facets of variation. Here, I revisit the convoluted history regarding the buoyancy function of chambered shells, and how this impacted 19thand 20thcentury interpretation of fossil cephalopod shell function. And argue that recent functional, morphospace, and complexity studies lack commonality of measurements and thus poorly serve a community interested cross taxon functional interpretation

Hooke at the end of the 17thCentury provided the first functional explanation of cephalopod shell buoyancy - pressurized gas displaced water like the swim bladders of fish or a modern submarine. Such a mechanism nearly balances forces of the gas inside and water

pressure outside the shell, suggesting that hydrostatic force does not "shape" the shell. In contrast, Owen in the 19th century noted the absence of a mechanism to generate gas; the Rev. Buckland then recognized the implicit pressure difference across the shell and argued that complex sutures supported the shell against this pressure difference. These competing buoyancy mechanisms variably influenced researchers for 140 years without resolution until the 1960s -1980s, when an osmotic, non-gas mechanism of shell emptying was demonstrated[1, 2]. Despite seeming acceptance of the Owen/Buckland "school", this convoluted history continued to haunt aspects of functional interpretation[3]. Nevertheless, it led to a renaissance in interest in cephalopod shell function both modern and ancient.

In this context, multiple workers came to study the overall form and/or sutural morphology, from "modern" perspectives, including morphospaces, metrics of complexity, and narrower functional analyses. However, these efforts rarely assemble sufficient measures (e.g. of shape and local sutural complexity) from the same specimen such that competing functional explanations can be adjudicated much less across major fossil groups such that competing functional explanations could be adjudicated or such that function between groups could be compared. Perhaps it is now time for an interested community to define and begin to populate a more comprehensive shared database supporting comparative analyses of fossil cephalopod groups.

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COLD CRADLES AND WARM GRAVES - TOWARDS A SYNTHETIC VIEW OF TEMPERATURE, OXYGEN AND DIVERSITY

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We tend to compartmentalize Earth history such that we do not see the most general patterns. For example, Neoproterozoic snowball Earth events seemingly anticipate the evolution of animals, while warm events in the Phanerozoic associate with episodes of extinction implying a cold "cradle" for animal diversity, followed by episodic warm "graves," and this pattern appears to be a function of temperature on oxygen. Here we assess the multiple impacts of temperature on the "effective oxygen" available for complex active multicellular organisms and place these in a single overarching scheme so that events in earth history can be compared to each other. Factors limiting effective oxygen with increasing temperature include reduced thermohaline circulation, reduced solubility of gases in water, increased microbial oxygen uptake, and increased metabolic demand for oxygen by the organisms themselves. These operate in parallel to reduce available oxygen for large complex organisms. In the simplest conception, water-rich worlds have states along a continuum with Snowballs at one end, Polar ice worlds in the middle, and Green/Hot houses at the other extreme. This continuum feeds back on the factors controlling effective oxygen. For example, both snowball and greenhouse earths are expected to have stratified oceans suggesting that partially glaciated worlds should have advantages in effective oxygenation and the evolution of complex multicellular life. This is consistent with an inter-snowball, or post-snowball "Gaskiers" initiation and radiation of Metazoa. Plausibly, emergence of large complex eukaryotes during transitions from global cold to polar glacial conditions may be a general property of earthlike planets. On earth it appears that eukaryotic life first became large, and secondarily developed epithelial form to take advantage of transitioning marine benthic boundary layer processes - rangeomorphs evolved elongate form to avoid diffusion limited conditions near the bottom- while the benthic flat-lying form of later Ediacara such as *Dickinsonia* likely function to focus the benthic redox gradient at the organismal surface - a phenomenon also typical of modern metazoan gut epithelia. These, perspectives suggest how transitions to a polar world initiated the local conditions necessary to evolve animal diversity. However, we are now engaged in a grand experiment to force the earth from a polar world to a greenhouse-towards the other side of the continuum. And new attention is directed towards greenhouse gas related Phanerozoic thermal events and associated mass extinctions as model predictions for our experiment. This continuum from icehouse to polar and then greenhouse worlds provide an overarching model for planetary diversity past, present and elsewhere in the universe. Amount, rate and position of change on the continuum are all potentially informative providing potential common assessment, of events at disparate times in Earth history.

AUGMENTING TRADITIONAL METHODS OF TEACHING CARBONATE SEDIMENTOLOGY WITH MICRO-CT AND 3D SEGMENTATION

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Carbonate sediments are host to a bewildering diversity of grain types, skeletal elements, and calcifying framework builders and binders. In carbonate sedimentology and petrography courses, historically the "golden standard" has been to use carbonate thin sections to illustrate these individual constituents. However, this inherently presents a two-dimensional view of the constituents, and does little to inform on overall complexity of the biotic constituent and how they contribute to the rock fabric. Moreover, mastery in the identification of these individual components is a fundamental skill which requires an understanding of biomineralized structures. This presents a major challenge for students with minimal background in organismal biology. Advances in technology provide educators with access to new teaching tools, including virtual dissection and 3D modeling, offering a different perspective of traditional 2D views on sedimentology.

Herein, we utilize X-ray tomographic microscopy to produce 3D datasets of modern sediments to supplement traditional methods and augment student learning in sedimentology courses. These advanced visualization methods can enhance student comprehension of concepts such as skeletal construction and orientation, bioerosion and encrustation, and porosity. Through these techniques students will not only develop a skillset in recognizing sedimentary features, but also to develop an understanding for these advanced visualization methods and their applicability to other fields (academic or industry). These case-studies will be developed into individual laboratory exercises for submission to the Science Education Resource Center (SERC) for widespread educational applications.

THE HISTORY OF MOTILITY IN COMATULID CRINOID EVOLUTION

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Modern crinoids are dominated in species richness by the comatulids, those crinoids which as adults are both stalkless and free-living. Comatulids are motile and some are notable for their elegant swimming, which is believed to allow escape from predators. The modern diversity pattern is in contrast to crinoids in the fossil record, which are usually stalked, and have traditionally been thought to be largely sessile. These observations have led to the conclusion that the success of comatulids is due to their greater motility. Recently, rapid crawling has been observed in stalked crinoids, an ability which seems to allow escape from benthic predators. Crawling is likely plesiomorphic for comatulids, and the same may be true about swimming. Based on a previously developed biomechanical model and observations from functional morphology we determined traits that may allow comatulids to swim. These observations allow us to infer if a fossil comatulid was likely a swimmer, or if it likely could only crawl. We apply these observations to fossil comatulids and suggest that swimming may have been present in the earliest comatulids. Fossil comatulids may have had shifting relative diversities of swimming and crawling species, but for most of comatulid history, including today, swimming species have dominated comatulid diversity. Combined with the phylogenetically widespread presence of swimming in extant comatulid species, at present the most parsimonious evolutionary scenario is non-swimming species descend from lineages in which the ability to swim was lost. The origin of comatulids was during the early phase of the Mesozoic marine revolution, and may have been in response to benthic predation pressure. The evolutionary dynamics of subsequent crawling and swimming comatulid lineages may have been affected by expansion and contraction of reefs, or other effects of the Mesozoic marine revolution.

TESTING FOR THE EFFECTS OF DEPOSITIONAL RATES IN MULTIPROXY MODELS OF ENVIRONMENTAL AND FAUNAL CHANGE: THE SILURIAN LAU $\Delta^{13}C$ EXCURSION

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The Silurian Period is characterized by several extinction events, among them the late Ludfordian Lau event, which mainly affected conodont and graptolite communities. This event was followed by the strongest global positive $\delta^{13}C$ excursion of the Phanerozoic. This event has been first recognized in the classical succession in Gotland, Sweden, where a continuous increase in $\delta^{13}C$ values of up to nearly 9‰from the upper När Formation to the Eke Formation is observed. It has been attributed to large scale carbon cycle

perturbations. This time period is also characterized by a regression and associated changes in sedimentation and deposition rates. This raises the question to what extent these factors contribute to the observed changes in faunal diversity and geochemical proxies.

A mechanism linking changes in seawater chemistry and faunal turnover has been proposed based on a high abundance of malformed acritarchs observed during the onset phase of some Phanerozoic isotope excursions including the Lau isotope excursion. Malformations during the late Silurian Pridoli event coincide with a significant increase in trace metal content measured in fossils and host rock, which suggests the teratology to be caused by metal pollution. However, also in the case of an increase in the trace metal content the contribution of changing depositional rates has not been quantified.

Models developed in the field of stratigraphic paleobiology have demonstrated that changing deposition rates have a substantial influence on the stratigraphic distribution of fossils. In the same sense, element concentrations can be altered by changing deposition rates, which may dilute or condense the primary element signal. For this study, concentrations of different trace elements were measured across a profile in an outcrop (Bodudd, Gotland), which exposes the Lau isotope excursion from the upper När to the Eke Formation. Using a newly developed statistical method, the effects of changing deposition rates were quantified and the measured element signal corrected for these effects. This method uses a deposition model to transform the measured element signal, which is a function of the stratigraphic height in the outcrop, back into a temporal rate. The temporal rate reflects the primary element signal and is defined as a function of time instead of stratigraphic height. Thus, the effect of changing deposition rates is accounted for. Approximate deposition models were created based on Th concentrations measured across the profile, which act as a proxy for the rate of terrestrial input. Pre- and post-transformation element patterns were compared for different deposition models and evaluated with respect to their ability to preserve element peaks.

TREPTICHNID TRACE FOSSILS AS EXAMPLES OF GEON 5 BEHAVIORAL INNOVATIONS

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From about 550 to 535 Ma the rock record documents a wide range of metazoan behavioral innovations in the form of trace fossils. Critically, this involved deeper excursions into the sediment and more intensive sediment mixing, with implications for global biogeochemical cycles. Among the earliest examples of morphologically complex trace fossils are serial repetitions of curved burrow elements. Trace fossils of this type have been described under various ichnogeneric designations, including *Phycodes*, *Treptichnus* and *Streptichnus*. Specifically, *Treptichnus pedum* forms part of the definition of the base of the Cambrian System. Although the ethology of this type of trace fossil remains open to question, it is reasonable to consider them representatives of some complex behavior, and as such they are among the earliest known. Scalidophorans are likely producers of at least some Cambrian treptichnids. This is somewhat surprising considering that published information on the burrowing of modern priapulids, although admittedly scant, indicates significantly less ordered trajectories in the sediment. Although they are relatively common and widely distributed trace fossils in Cambrian strata their three-dimensional structure generally is incompletely preserved and often has to be interpreted from what are essentially two-dimensional sections. Consequently, two morphologically distinctive trace fossils may yield identical or near-identical appearances on bedding-plane preservation, a fact particularly important to take into account when dealing with late Ediacaran material. This has indeed lead to the erroneous identification as treptichnids of trace fossils that were formed by vertically oriented sinusoidal movements. As it cannot be expected that complex morphologies of this type originate as fully developed specimens, their Ediacaran roots are of interest but still somewhat uncertain. In this connection, the relationship between treptichnids and horizontally coiled spiral trace fossils warrants attention.

CLOUDINA-MICROBIAL REEFS IN AN UNSTABLE CADOMIAN RETRO-ARC BASIN OF THE IBERIAN PENINSULA

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The ability of Ediacaran shelly-microbial consortia

to survive, and recover from, environmental disturbances is vital to recognize adaptations that led to the long-term persistence of Phanerozoic metazoan reef ecosystems after stressful events. The Navalpino anticline of the Central Iberian Zone, Spain, provides a unique case study of well-exposed late Ediacaran reefs (Ibor Group) developed on a perturbed platform that comprised a mosaic of differentially subsiding, fault-bounded crustal blocks located in a Cadomian foreland (retro-arc) basin fringing West Gondwana. Drone images allow identification of the spatial arrangement of reefs, which consists of tens of cloudinid-microbial, patch, biohermal and reef complexes encased in a dominantly shaly succession. Reefs display the traditional core/flank/inter-reef distinction and developed in generally low-energy, clear-water substrates, between fair-weather and storm wave base. Texturally, the reef-core facies consists of *Cloudina*-thromboid boundstone and floatstone with local development of peloidal and intraclastic pockets, in places interrupted by laminoid (stromatolitic) fabrics. Where flank beds are developed, their margins commonly intercalate with inter-reef sediments. Locally, these individual geometries are arranged into stacked patches becoming both vertically and laterally aggregated into reef complexes. Shells vary in abundance and some patch reefs apparently lack them. The predominant skeletal components are *Cloudina* and *Sinotubulites.* Due to intense neomorphism, the calcified microbial communities are not well preserved, but their clotted textures occur directly encrusting both microsparitic substrates and shelly walls. Larger bioherms and reef complexes display Neptunian dykes, which were filled with angular shale and intraformational carbonate clasts, up to 5 cm long. The spotty distribution of the reefs, in conjunction with their sharp modifications in thickness. and evidence of synsedimentary fissuring related to hydrothermal influence, suggests that their nucleation and growth was primarily controlled by synsedimentary tectonism, which dictated local bathymetric and hydrodynamic conditions. The frequency of catastrophic events within a particular segment of the retro-arc Cadomian basin determined whether adjacent carbonate factories (including reef buildups) could recover from tectonically induced disturbances.

NEW ANISIAN (MIDDLE TRIASSIC) AMMONOIDS FROM BRITISH COLUMBIA (CANADA): BIOCHRONOLOLGICAL AND PALAEOBIOGEOGRAPHICAL IMPLICATIONS

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British Columbia (BC) of Canada and Nevada of U.S., which are renown for well-preserved Triassic mid and low paleolatitude marine deposits, provide excellent materials for studying Triassic latitudinal gradients, biochronology and paleogeography of marine invertebrates. Abundant ammonoids have been described since the early 20th century, contributing greatly to the biostratigraphic correlation between the two localities. However, for the Middle Triassic, the correlation of ammonoid zonation was insufficient, therefore suggests little biogeographic exchange along the Paleopacific margin of North America. Here we describe new Anisian (Middle Triassic) ammonoids from BC (Canada) based on an old collection (gathered during 1990s). Eight species of ammonoids are reported from BC for the first time, including one new genus and two new species. New ammonoid subzones are recognized, leading to an improved correlation between BC and Nevada: 1) the *Hollandites minor* Zone is correlated with the interval intercalated between the *Unionvillites hadleyi* Subzone and the *Pseudodanubites nicholsi* Subzone; 2) an *Eogymnotoceras thompsoni - Anagymnotoceras spivaki* Zone is recognized in BC and correlated with the interval intercalated between the *Augustaceras escheri* and *Anagymnotoceras spivaki* subzones; 3) *Gymnotoceras weitschati* is found in BC for the first time and co-occurs with *Eogymnotoceras deleeni*, suggesting either a rough correlation with the sum of *G. weitschati*, *G. mimetus* and *G. rotelliformis* zones of Nevada or a strong diachronism of *G. weitschati* and *G. rotelliformis* along the Paleopacific margin of North America. The rare occurrences of low-paleolatitude restricted species in the mid-paleolatitude record indicate that biogeographic exchanges were more frequent than previously documented during the Anisian. Despite a preservation bias in north-eastern BC due to the lower carbonate content, it clearly emerges that the enhanced sampling effort leads to maximal association zones with duration of the same order of magnitude as those of Nevada, indicating that evolutionary turnover rates of ammonoids did not decrease toward higher latitude. Therefore, the common view that geographically differentiated evolutionary rates originates from the latitudinal gradient of taxonomic richness does not hold for Anisian ammonoid faunas along the Paleopacific margin of North America.

ZHANGOXYLON GEN. NOV., A NEW CONIFEROUS WOOD GENUS OF SCIADOPITYACEAE FROM THE JURIASSIC OF WESTERN LIAONING, NE CHINA

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The Sciadopityaceae are today a monotypic family of conifers, restricted to Japanese endemic *Sciadopitys verticillata*. Megafossil remains assigned to the Sciadopityaceae have been reported from various part of the boreal hemisphere, including leaves, seed cones, conescales and woods. In this study, we present the oldest anatomically preserved fossil wood of Sciadopityaceae, which bears pith and primary xylem. A new genus *Zhangoxylon* is proposed for the new wood, which is anatomically characterized by a heterogeneous pith, endarch primary xylem and secondary xylem of the *Protosciadopityoxylon* type. The anatomical structures of the new genus are similar to those of the living *Sciadopitys* except for the type of radial wall pitting. The present specimen has araucarian pitting on the radial walls of its tracheids, while the living *Sciadopitys* is abietinean in this respect. This new fossil sheds new light on the early evolutionary history of the coniferous family Sciadopityaceae and contributes to a better understanding of the paleoecological environment of the Jurassic Yanliao Biota.

The new genus has distinct growth rings with very wide early wood and narrow late wood, which reveal a humid climate suitable for evergreen plant. Growth ring pattern analysis of the fossil conifer wood demonstrates a distinct seasonal climate during this period. Nowadays, the living *Sciadopitys verticillata* is now geographically restricted in Kyushu, Honshu of Japan, and orientates in rocky regions (at altitudes of 600-1200-m) with cool, and ample summer rainfalls, and a mean annual precipitation between 1300 and 2600 mm/ year. In the Eocene palaeoecosystem, the importance of the habitat humidity for *Sciadopitys* is highlighted; indicating humid source forests, or even raised bogs to swamp habitats. Therefore, it is inferred that *Zhangoxylon* may have same or similar environment requirements to the living *Sciadopitys*.

THE EARLY OLIGOCENE INIYOO LOCAL FAUNA OF NORTHWESTERN OAXACA, SOUTHERN MEXICO

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Paleogene Mexican local faunas (LFs) include the northern early Eocene (Wasatchian) Lomas Las Tetas de Cabra LF of central Baja California, the early to late middle Eocene (Bridgerian–Uintan) Marfil LF of central Guanajuato in central Mexico, and the late middle Eocene (early late Duchesnean) Rancho Gaitán LF of northeastern Chihuahua in northern Mexico. Recent $^{87}Sr/^{86}Sr$ isotopic analysis of a shell of the gastropod *Turbinella maya* from Los Pocitos locality in Simojovel, north-central Chiapas, southern Mexico, gave an age of 23 Ma (early late Arikareean), and the presence of *Melongena* (gastropod with early Miocene first appearance datum) in the same bed where the tayassuid *Simojovelhyus* was collected, indicate an early Miocene age for Los Pocitos, not late Oligocene as previously thought.

Recently, a new Paleogene mammalian assemblage, the Iniyoo LF, was reported from the municipality of Yolomécatl in northwestern Oaxaca, southern Mexico. After 10 years of continuous study, much better indications of its taxonomic composition and age, and of the stratigraphic relations of the fossiliferous beds have emerged. The Iniyoo LF was originally regarded as late Eocene (Chadronian) in age, but records of Arikareean index taxa (canid *Cormocyon*, oreodontid *Oreodontoides oregonensis*) and typical early Arikareean taxa (geomyid *Gregorymys*, Jimomyidae, leporid *Archaeolagus*, amphicyonid *Mammacyon*, tayassuid *Perchoerus probus,* "nothokematine" camelid, hypertragulid *Nanotragulus*, rhinocerotid *Subhyracodon*) now indicate an age no greater than 30 Ma. The absolute age of the Iniyoo LF (ca. 28–29 Ma) is constrained by the *Mammacyon* first appearance datum and the *P. probus* last appearance datum. A detrital zircon U-Pb

maximum depositional age of 30.6 Ma for a sandstone bed that overlies the fossiliferous strata supports an early Arikareean age (Ar1) for the LF. Highest taxonomic similarity of the Iniyoo LF is with mammalian assemblages from the Turtle Cove Member of the John Day Formation (Fm) in Oregon and, to a lesser extent, the Upper Sharps Fm of South Dakota.

The fossiliferous beds consist of reddish silty clay with some volcanic lithic fragments and pedogenetic alteration. The beds are part of a stratigraphic sequence that, in its lower part, comprises alternating layers of red mudstone with some volcanic lithic fragments, greenish to gray volcanic sandstone, and volcarenitic matrix-supported conglomerate, greenish and whitish siltstone, and medium- to thickly bedded, partially silicified limestone beds. That sequence changes upward into one comprising layers of thinly to thickly bedded, reddish mudstone with several interbedded paleosols and layers of silicified calcrete and volcanic conglomerate. Textural, mineralogical, and infrared analyses, as well as their stratigraphic relations, indicate the fossiliferous beds are part of the Chilapa Fm, an Oligocene sequence of lacustrine origin, as previously reported in a regional geological study of northwestern Oaxaca.

THE LATE PLEISTOCENE EQUIDS FROM SOUTHERN MEXICO

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Equids are among the most common mammals in the Late Pleistocene Mexican faunal assemblages. Currently, there are four recognized Pleistocene species in Mexico, which were erected based on specimens from central and northern Mexico: *Equus conversidens, E. mexicanus, E. francisci,* and *E. cedralensis.* Much of what is known about the *Equus* species derives from their study from central and northern Mexico; much less is known about the species from low Mexican latitudes. At present there are 23 main Pleistocene *Equus* localities; of them, just five (21.73%) were formally reported from southern Mexico. In most of these reports, the equid taxa are only mentioned or briefly described.

Here we describe the three species that inhabited Oaxaca and Chiapas states. The fossil localities are in northwestern and central Oaxaca; the localities of Chiapas are in the central part of the state. In Oaxaca, the largest species, *Equus mexicanus,* and the medium-sized *Equus conversidens* are represented by mandibles, skulls, diverse isolated teeth and some postcranial bones, and the smallest species, *Equus francisci* (=*Haringtonhippus francisci*) is represented by a skull fragment and few isolated teeth. In Chiapas, *E. mexicanus* is represented by a mandible and several isolated teeth, *E. conversidens* by several mandibles and diverse isolated teeth and *E. francisci* by isolated teeth and two mandibles. AMS radiocarbon and uranium series dating of some of the *Equus* localities in Oaxaca and Chiapas indicate that they were at least present since around 44,000 Cal BP years, they were common around 30,000 Cal BP years and that were still present at the end of the Pleistocene, around 12,000 years ago. The record of *E. francisci* from Chiapas is the youngest in North America.

An extended mesowear analysis showed that the species from Oaxaca cluster with each other and then with the extant grazing-dominated *Equus ferus*, *E. grevyi, E. hemionus, E. kiang, E. hartmannae* and *E. quagga*. *Equus francisci* from Chiapas clusters with these extant grazing-dominated *Equus* species, whereas *E. conversidens* from Chiapas clusters with the obligate grazer *Ceratotherium sinum. Equus mexicanus* from Chiapas clusters with the variable grazers *E. africanus* and *E. khur* and the extinct *E. capensis.* These mesowear patterns differ from those of the same species from central Mexico, which mainly cluster with obligate grazers, having a more abrassive signal than those here studied.

Geographic distribution of localities in southern Mexico indicates that during the Pleistocene the *Equus* species moved across the Transvolcanic Belt-Sierra Madre del Sur temperate biogeographic corridor and the Tamaulipas-Central America Gulf Lowlands tropical corridor.

CAN TURBID-WATER HABITATS SERVE AS REEF REFUGIA IN THE CORAL TRIANGLE? INSIGHTS FROM THE FOSSIL RECORD

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There is an urgent need to identify habitats that might provide ecological refugia as coral reef systems rapidly decline throughout the tropics. New attention is being devoted to so-called "marginal reef" systems such as those acclimatized to high sea surface temperatures or the deeper zones of clear-water reefs or shallow turbid settings because there is emerging evidence that reefs in these habitats have been more resistant to mass bleaching events in the past few decades. What can we learn from the fossil record to test this idea? Analysis of large scale new collections of fossil biota from the Coral Triangle region of Southeast Asia suggests that extinction rates have been relatively low in this region since the Late Oligocene. This result explains in part why this is the global marine biodiversity hotspot, but also raises the question of which ecological mechanisms are providing long term persistence of taxa while other tropical regions have suffered high rates of extinction over the same time interval. One potential answer is that there is a long history of reef development in shallow turbid habitats that provide refugia from the impact of environmental change. Here we will present data from East Kalimantan (Indonesia) and Sabah (Malaysia) supporting this hypothesis. Shallow turbid habitats in the Coral Triangle hosted a high coral diversity with 100 species from 55 genera in the Oligocene and 234 species of 79 genera in the Miocene. We found no significant faunal turnover at generic level within the studied time interval as 85% of extant genera were already present by the early Miocene. As for many tropical marine systems, we know have more data from the fossil record of the region than for the modern ecosystems, and we are working to fill this gap by documenting the biodiversity and reef structure on relatively unexplored modern turbid-water reefs in eastern Sabah. These new data will be key to understand both the distribution of taxa among habitat types and potential flexibility in habitat preference that would be required for turbid water reefs to function as effective refugia. Carbonate production is an important ecosystem function coral reefs, and in part will define the ecological "success" of potential refugia. To begin the development of reef budget models, we analyzed of coral growth, calcification, and bioerosion rates using micro X-Ray computed tomography of fossil and modern specimens and compared them with previously published data. The resutls suggest that growth rates and intensity of bioerosion are not significantly different between turbid and clear-water settings. Thus, reefs developing in turbid waters may have similar functioning to their clear-water counterparts and further support the hypothesis that turbid reefs may have played an important role as refugia habitats in the Coral Triangle for the past thirty-million years and provide hope that they will continue to provide this service in the future.

FOSSILS AND THE FUTURE: THE ROLE OF PALEONTOLOGY IN THE 21ST CENTURY

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Fortunately for us, the Earth has surface processes that bury and exhume its dead. The resulting fossils form the record of past worlds whose differences from the present state carry useful information that is relevant to our understanding of how the World works. As we apply the techniques and insights of the Human Genome Project to the genomics of biodiversity, it is clear that we will soon have a resolved tree of life for all extant organisms. But rather than making paleontology obsolete, this global phylogeny will endlessly benefit from the age-calibration of nodes, the exposition of extinct phenotypes, and the explication of extinct ecosystems and biomes. Paleontology's relevance to biology will only grow. Despite the diligent efforts of the last few century's paleontologists, the vast majority of fossiliferous sedimentary rock on the Earth's surface has barely been touched. It is blindingly clear that the best fossils remain to be discovered and that the greatest age of paleontology is still in front of us.

The argument for fossils is also an argument for museums, those antique entities that remain relevant despite the digital revolution that has disrupted most other aspects of modern life. In a digital world, museums are the last bastion of the real thing. The rare fossils that find themselves reassembled in these urban temples to nature are genuine messages from earlier Worlds. For children who are naturally curious and for adults that retain this useful attribute, museums are easy-access portals to the deep narrative of the planet. This is genuine time travel but only recently have we realized that we can also go forward in time as we go backwards. Ancient ice-free worlds of the Paleogene Hothouse provide ready examples of what is to come as humanity accelerates the carbon cycle by burning fossil fuels. A child born in 2019 into a world of 410 ppm CO2 will, in 81 short years, become a resident of the 22nd century and likely experience an Eocene atmosphere. That same child will have likely experienced an inexplicable prepubescent love of dinosaurs.

For some children, dinosaurs will be a gateway drug to science itself.

It was an awareness of our challenging future combined with the intoxicating narrative punch of fossil worlds that inspired the Smithsonian National Museum of Natural History to completely rethink the National Fossil Hall and to refit it for this century. Housing the vast fossil collections of both the Smithsonian Institution and the U.S. Geological Survey, the National Museum is a particularly fulsome telescope to the past. The recently opened new National Fossil Hall, entitled "Deep Time," tells the story of the history of life on Earth, but unlike other similar exhibitions, its storyline extends into the future rather than ending in the past. We hope that this exhibition will become a useful tool in society's toolkit for negotiating the future.

PALEOECOLOGY OF THE MID-MIOCENE TONOPAH LOCAL FAUNA OF SOUTHWESTERN NEVADA

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The Tonopah Local Fauna (TLF) is a Barstovian fauna from the western slope of the San Antonio Mountains, a few miles north of Tonopah, Nevada. Formation terminology is unsettled; the fauna has been variously referred to the Siebert Formation, the Tonopah Formation, and the Esmeralda Formation. A very diverse assemblage of herbivores and carnivores is present within this fauna, including canids, felids, rhinocerotids, camelids, equids, antilocaprids, insectivores, rodents, and lagomorphs. The fauna is curiously rich in carnivores, with four canid taxa, one felid, and one mustelid.

We are engaged in a study of the sedimentology and paleoecology of this assemblage, which lived just prior to the Mid-Miocene Climate Optimum (MMCO), a 3-4 million year-long interval of anomalously high temperatures. Comparison of the TLF with other Great Basin Miocene communities, such as the Coal Valley, Stewart Springs, and Barstow Formation faunas, will improve our understanding of how mammal communities responded to long-term climate change in the Miocene. The Coal Valley assemblage, for example, also of southwestern Nevada, was deposited just after the MMCO, providing an opportunity to examine how the MMCO impacted Great Basin mammal communities. Paleoecological aspects to be compared include community structure, diversity, and food web complexity.

DELAYED CALCAREOUS NANNOPLANKTON BOOM-BUST SUCCESSIONS IN THE EARLIEST PALEOCENE CHICXULUB IMPACT CRATER

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The mass extinction event at the Cretaceous-Paleogene boundary (K-Pg; 66 Ma) was caused by a bolide impact on the Yucatán Peninsula, Mexico which eradicated ~75% of species on Earth. Among the most affected organisms were calcareous nannoplankton: a dominant group of unicellular phytoplankton which supply an important food source to primary consumers and contribute greatly to the marine biological pump. For this reason, the near complete extinction of these organisms at the end Cretaceous would have greatly perturbed the functioning of the marine ecosystem, including trophic interactions and biogeochemical cycling. The recovery of calcareous nannoplankton following the K-Pg boundary was globally heterogenous. In the Northern Hemisphere, earliest Paleocene nannoplankton assemblages are characterized by a short-lived series of high-dominance, low-diversity acmes ("boom-bust" successions) which are thought to represent adaptation to an unstable post-impact environment. However, the causal mechanisms that drove the taxonomic switchovers between different acmes are uncertain, and it is unknown whether these processes would have operated in the harshest environment on Earth at that time: "ground zero". Here, we present detailed analyses of calcareous nannoplankton and planktic foraminifer assemblages from the peak ring of the Chicxulub impact crater. Significantly, we show that nannoplankton boom-bust successions and changes in the dominance of different planktic foraminifer trophic groups were synchronized. This suggests that the recovery of both groups was linked to a gradual, long-term trend towards oligotrophy driven by the restoration of biological pump efficiency. Because switchovers between nannoplankton acmes are delayed by at least 500 kyr at Chicxulub, we hypothesize that boom-bust successions were globally diachronous due to differential timing in biological pump restoration between oceanic basins and settings.

LATE QUATERNARY EXTINCTIONS IN INDIA

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The megafaunal extinction was one of the most significant faunal events of the Quaternary. The causes of this extinction are unclear. Both humans and climate change have been implicated. While much research on this event has been conducted on other continents, South Asia has rarely been studied in this context. Here, using the largest compilation of Indian mammal occurrences from the last 100,000 years, we investigate the dynamics of extinction in this region. We compiled a dataset of 56 late Pleistocene and Holocene faunal localities and associated dates from the published literature, and used it to estimate the number of extinct taxa, the temporal duration, magnitude, rate and body size bias of the extinction. We report on four extinct mammals (*Palaeoloxodon namadicus*, *Stegodon namadicus*, *Hexaprotodon* sp., and *Equus namadicus*), a mammal that undergoes a pseudoextinction (*Bos namadicus*) and one extirpated bird (*Struthio camelus*) in our dataset. Using the temporal occurrences of extinct taxa, we analytically estimated the probable time of extinction for each species. *Stegodon* is the first to go extinct at the end of marine isotope stage (MIS) 3, *Palaeoloxodon* and *Equus* appear to go extinct within MIS 2, and *Hexaprotodon* and *Struthio* persist into the earliest Holocene. *Bos namadicus* is survived today by the domestic zebu cattle, *Bos indicus*. The mammalian extinctions occur in a 22,000 year window, at least 30,000 years after the arrival of *Homo sapiens* in the Indian Subcontinent. These extinctions represent only 3.39% of the terrestrial non-volant mammalian fauna from peninsular India. We estimated the per-capita rate of extinction over 100,000 years, and compared it to similar rates from continents such as North and South America, and Australia, and subcontinental regions like eastern and southern Africa, Europe, and Japan. The rate of extinction in peninsular India is same as that experienced in eastern and southern Africa, but half of what is seen in Japan, and a third to a fourth lower than those experienced in the Americas, Europe, and a fifth less than the extinction rate in Australia. Much like the rest of the world, the extinctions in India are large-size biased, hinting at a substantial role played by humans, but in magnitude and rate, are similar to those seen in both regions of Africa. Additionally, like Africa, several species of megafauna are still present in the Subcontinent. India also appears to have the longest time lag between the arrival of humans and the extinctions anywhere outside of Africa, suggesting that humans may have acted in concert with prolonged environmental change to drive these taxa to extinction.

ANATOMICAL REDESCRIPTION AND PHYLOGENETIC ANALYSIS OF THE MATERIALS ASSIGNED TO THE TAXON *"CAPTORHINIKOS" CHOZAENSIS*

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The Late Paleozoic family Captorhinidae is generally considered the basal-most clade of the Eureptilia. Although Late Pennsylvanian and Early Permian members are exclusively North American, the group achieved a global distribution by the Middle Permian. Captorhinids are well known for the development of multiple rows of maxillary and dentary teeth in some, though not all, members. Traditionally Captorhinidae have been characterized as generalized reptiles with a fairly conservative morphology, suggesting they are a useful model as a basal amniote. Recent phylogenetic analyses have suggested multiple tooth rows likely developed more than once and a greater diversity of dental structure than previously realized. "*Captorhinikos" chozaensis*is a multiple-tooth-rowed captorhinid reptile from the Lower Permian Clear Fork Group, undivided formation. Upon re-examination of the several specimens associated with the taxon from the Chicago Field Museum of Natural History and the Smithsonian National Museum of Natural History, we reaffirm their affinity and collective identity as a valid taxon. Our study recovers a hypothesis of relationships of the Captorhinidae wherein *"Captorhinikos" chozaensis*does not belong with either of the two members of its assigned genus, *C. valensisor"C." parvus*. Instead it occupies its own branch within the Captorhinidae: *[Protorothyris[Paleothyris[Thuringothyris[Concordia [[Romeria prima, Romeria texana] [Reiszorhinus[Protocaptorhinus[Rhiodenticulatus[Saurorictus astralis, [[Captorhinus laticeps [Captorhinus aguti, Captorhinus magnus], ["Captorhinikos" parvus["Captorhinikos" chozaensis [Labidosaurus,* Moradisaurinae]. This conclusion is based on strong results from a phylogenetic parsimony analysis combined with an analytical apomorphy analysis.

BUILDING BIG DATA WITH AUTOMORPH: A HIGH-THROUGHPUT IMAGING, MORPHOMETRICS, AND MACHINE LEARNING PIPELINE ACCELERATES MACRO- AND MICROFOSSIL PALEOECOLOGICAL RESEARCH

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The acceleration of global environmental change has highlighted the gaps in our understanding of its effects on ecosystem health and structure on long timescales. As the fields of macro- and paleoecology have worked to fill these gaps, it has become apparent that there is an increased need for truly big datasets that capture detailed ecological information across space and through time. Because traditional methods of data collection are time- and labor-intensive, datasets are often taxonomically or geographically limited, thus limiting the questions that can be asked of them. Advances in automation can remove these barriers, accelerating the rate at which big datasets are aggregated and expanding the realized scope of paleoecological research. Here we present the software suite *AutoMorph*, which processes specimens digitized using high-throughput imaging methods to produce high-resolution images and 2D and semi-3D measurements of size and shape. Thus far, the software has been used to digitize and measure over 100,000 microfossils (of which 61,000 are foraminifera), 50,000 fish teeth, and 12,000 limpets, demonstrating its utility for rapid generation of micro- and macrofossil data. These datasets have been used to address a variety of problems. The limpet dataset was used to assess drivers of molluscan body size variation along a latitudinal gradient, while the fish teeth were used to characterize a previously unknown pulse of fish diversification following the K-Pg event. Critically, the foraminiferal images have been used to train convolutional neural networks that identify fossil taxa with success rates equal to or greater than those of taxonomic experts. Future expansion of these machine learning algorithms, including their incorporation into the broader *AutoMorph* pipeline, will remove one of the largest remaining barriers to community paleoecological data collection by vastly accelerating whole-assemblage image identification. Automation thus allows for the rapid generation of big paleoecological data with temporal and spatial resolutions captured neither by modern ecology nor traditional paleontology alone. Such data are urgently needed to understand how individual species and whole ecosystems will respond to the coming centuries of change.

AMATEUR/PROFESSIONAL COLLABORATION – A PERSONAL JOURNEY

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When I joined the Dry Dredgers my goal was to learn everything I could about the fossil fauna of the Cincinnatian but also to understand the paleoenvironments and how the fauna interacted. My mentor was another amateur who taught me the value of reading professional level books and papers. We collected together for many years. He taught me how to collect and document my finds. Learning at club meetings was easy with up to six local active paleontologists in the area who regularly attended Dry Dredgers meetings. Graduate students from the University of Cincinnati were also regular attendees and program speakers. The opportunity for learning was everywhere.

My first foray into publishing and real research was quite by accident. I had contributed specimens as a gesture of kindness to Professor Stephen Donovan who came back to me with an offer to be a coauthor. I hadn't realized there was anything special about what I had sent him. Besides the specimens, I contributed a paragraph to the actual paper that resulted. This was the hook that made me passionate about research and publishing. As an amateur, I had hopes that one day I would find something new to science and be able to publish on it. Eventually, that did happen.

I involved Stephen Donovan again when I believed I had a discovered a unique specimen. This time I asked him to be coauthor. His contribution was about a paragraph or so (not counting his expertise in editing). This involved a new species and I undertook all of the literature and collections research to be able to put the paper together.

A significant find of rare echinoderms resulted in papers based upon them. On these I was coauthor but my contribution was less involved. These works were in coordination with David Meyer of the University of Cincinnati and Ben Dattilo of Indiana University Purdue University Fort Wayne. I had done a significant amount of research, data collection and analysis on

these echinoderms and still have a potential paper waiting for my attention.

My most recent project involved a suite of self-collected specimens. I approached Bill Ausich of The Ohio State University to confirm my analysis of a potential new species. My initial thoughts were confirmed. On this paper my contribution was significant: literature research, collections research and field work such that Bill honored me with first author status.

None of this would have been possible without connections made through the Dry Dredgers. Everyone with whom I have worked has been a primary or secondary connection made through that organization. Making connections and getting to know professionals is only a part of a successful collaboration. As an amateur one must be able to communicate an interest and knowledge of whatever area of paleontology you wish to work with. Most amateurs that I know are self-taught in this field so reading text books, both old and new, reading the professional literature and asking questions to gain understanding is paramount.

CONVERGENT, GEOGRAPHICALLY-REGIONALIZED OCCUPATION OF HERBIVORE NICHES BY EUTHERIODONT THERAPSIDS FOLLOWING THE PERMO-TRIASSIC MASS EXTINCTION

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In the late Permian, dicynodont therapsids were the dominant herbivorous terrestrial vertebrates: global in range, highly species-rich, and typically the most abundant tetrapod components of their ecosystems. However, dicynodonts were devastated by the Permo-Triassic Mass Extinction (PTME), and although the clade survived into the Late Triassic, post-extinction dicynodonts were fairly homogeneous and never re-evolved the broad ecological and morphological diversity of their Permian forebears. Herbivorous niches formerly occupied by dicynodonts were instead occupied by an array of new Triassic taxa, including procolophonoids and various archosauromorph subclades. Among synapsids, the most important group of Triassic herbivores was the Gomphodontia, a cynodont subclade characterized by complex, molariform postcanine teeth. Gomphodonts are best known from a series of Middle–Late Triassic assemblages in southern Africa and South America, but have been recorded in Triassic deposits worldwide. As part of ongoing revisionary work on synapsid systematics, I re-examined all supposed Northern Hemisphere cynodont records and determined that many of these fossils do not represent cynodonts (and in some cases, not even tetrapods). The only definitive Northern Hemisphere gomphodonts are the 'boreogomphodont' traversodontids from the Ladinian–Norian of Europe and eastern North America. The majority of supposed Northern Hemisphere gomphodonts are instead bauriamorph therocephalians, a distantly related clade of eutheriodont synapsids that convergently evolved molariform dentition and a complete secondary palate. The supposed Chinese gomphodonts*Sinognathus*and*Beishanodon*are definite cynodonts, but may represent probainognathian or non-eucynodont taxa rather than gomphodonts. This research indicates that three groups of eutheriodont therapsids converged on the 'gomphodont' morphology simultaneously in the wake of the PTME: true gomphodont cynodonts in Gondwana, one subclade of which had dispersed into Europe and eastern North America by the Middle Triassic; bauriamorph therocephalians in east Asia and Russia, with representatives in Africa by the Middle Triassic; and sinognathine cynodonts in east Asia in the Early-Middle Triassic. This degree of regionalization is a novelty to the post-extinction recovery fauna—late Permian synapsids were generally cosmopolitan at least at the clade level and the earliest Triassic synapsids (e.g., the disaster taxon*Lystrosaurus*) had transcontinental distributions even at the species level. The wholesale exclusion of cynodonts from certain regions (e.g., southwestern North America) is also a remarkable feature of Triassic tetrapod distribution, which previous work has related to climatic intolerance. Increased regionalization of Triassic synapsid groups can likely be attributed to greater intensity and land area of arid belts, with limited routes for dispersal (such as along rift lake systems) compared to in the Permian.

CONNECTING NON-MUSEUM GOERS TO PALEONTOLOGY USING ART AND ROCK N' ROLL

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A challenge for museums that seek to grow their audiences is to connect to members of the public who do not typically consider themselves "museum-goers". A novel, independently-created traveling exhibition being prototyped in Chicago deconstructs the misconception that museums are not for everyone by using narrative frameworks, surrealist art and rock n' roll.

This exhibition depicts significant moments from the life story of a major rock star, who is a lifelong dinosaur enthusiast, and is set in a series of nine thematic vignettes, which feature anatomically-accurate dinosaur sculptures and a soundscape of the musician's iconic music. An accompanying section introduces the science behind the storytelling, where the dinosaurs from the vignettes are revealed as actual paleontological specimens.At these science stations, touchable fossil casts and information provided by experts on each species are paired with examples of how the paleoartist referenced the best available science to create accurate dinosaurs within the narrative structure and visually evocative landscapes. The famous musician still attracts millions of fans and followers, particularly millennials, many of whom may not typically choose a museum as an entertainment destination. This type of exhibit has the potential to bring new audiences into the museum and prompt return visits due to relevant and engaging interaction with the content.The mashup approach to this exhibition concept can provide a winning model for museum engagement and can be an appealing exhibit for a broad potential suite of venues: from natural history museums, art museums, and science centers, to pop culture museums, or even the Rock N' Roll Hall of Fame.At any given hosting institution, the core member audience has the potential to be engaged while attracting a diverse new audience.

ENCRUSTERS ON THE FOSSIL OYSTER HYOTISSA HYOTIS: EXAMINING THE BIODIVERSITY OF SCLEROBIONTS ON A HARD SUBSTRATE COMMUNITY FROM THE CALIFORNIA MIOCENE

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A powerful tool for understanding ecological relationships, trace fossils provide the opportunity to study organisms that may not otherwise be preserved in the fossil record. In this study, we report evidence of sclerobionts on *Hyotissa hyotis* oysters from the Latrania Formation in the Southeast Coyote Mountains near Ocotillo, California. The upper Miocene Latrania Formation represents an ancient shoreline of the Proto-Gulf of California. We examined target-collected specimens of the large, free-living oyster *H. hyotis* from this locality. The specimens included in this study were disarticulated oyster valves with the hinges intact. The abundance of bioerosion and trace fossils on the *H. hyotis* suggests that these oysters provided a hard, biogenic substrate for a diverse community of encrusting and boring sclerobionts.

To gain insight into the paleoecology of this community, we analyzed occurrences of borings from clionid sponges, spionid polychaete worms, and bivalves. None of the borings completely penetrated the shells; thus, bioerosion of the internal surface of the shell is an indicator of postmortem encrustation. Of the collected oysters, 100% showed clionid sponge bioerosion (*Entobia* isp.*)* on the external surface of the shell and 95% of these oysters showed sponge borings on the internal surface. Spionid burrows were found on 68% of the oysters, occurring on external and internal surfaces. It is possible that some sponge and worm borings may have occurred *in vivo* and postmortem on shells lying on the seafloor.

Bivalve borings (*Gastrochaenolites* isp.) occurred on 73% of shells and these borings primarily originated on the external surface of the oysters suggesting that boring bivalves generally inhabited living oysters. Clionid sponge borings inside of the bivalve borings were uncommon. Rare incidences of serpulid polychaete worm tubes (2.4%) and spirorbid worm tubes (1.2%) were identified and also found on the exterior and interior surfaces of the shells.

PERCHING ON A PRECARIOUS FUTURE: A CONSERVATION PALEOBIOLOGY PERSPECTIVE ON UNDERSTANDING AND SUSTAINING LIZARD DIVERSITY IN THE ANTHROPOCENE

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The Caribbean is one of the most well-studied biodiversity hotspots, regions that in total cover less than 3% of the Earth's surface yet host the majority of the planet's endemic species. But the diversity of today's Caribbean is only a fraction of what once existed there, as climate, sea-level fluctuations, and multiple human colonization events have restricted the ranges of many species, or worse, contributed to their extinction. Given this past history of environmental perturbations, paleobiology is well-suited to inform ongoing conservation needs in this system. Such perspective from the past is essential now more than ever before, as continued habitat degradation, non-native species introductions, and ongoing range contraction, extirpation, and extinction threaten to erode the remaining

biodiversity. My research explores how one seemingly successful group of Caribbean vertebrates, the lizards, have been impacted by environmental perturbations throughout the Pleistocene, Holocene, and into the Anthropocene. By utilizing historic museum specimens and fossils from paleontological sites, as well as the entire breadth of modern Caribbean lizard diversity, I unveil extinction biases within the Caribbean. These observations have transformed how we understand lizard extinctions globally and have the potential to shape conservation policy for this dynamic group of vertebrates. I also report on the excavation of a new paleontological site in Puerto Rico. The assemblage encompasses the past 20,000 years and data gathered from the site are concordant with overarching trends in the Caribbean fossil record: most notably, large-scale extinction of terrestrial non-volant mammals and fewer losses in other taxonomic groups, such as lizards. However, detailed stratigraphic records at the site reveal an instance of turnover in the widespread *Anolis* fauna that has ramifications for understanding historic and ongoing range shifts for this genus in light of human-facilitated habitat modification, climate change, and intensifying hurricane activity on the island. This newly described paleontological data, historic extinctions in other genera, and data gathered from reforested areas of Puerto Rico can be utilized to form conservation management plans with broad regional applicability.

CONSTRAINING MORPHOLOGICAL DISPARITY IN RANGEOMORPHS

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Avalonian Ediacaran successions (those from Newfoundland, Canada, and Charnwood Forest, UK; c. 575-560 Ma) host the oldest known communities of complex multicellular organisms, including some of the best candidate early animals. Rangeomorphs dominate these communities, and are the most geographically and environmentally widespread of the Ediacaran clades. Although the gross morphology of rangeomorph taxa is broadly similar, some species bear morphological structures that are unique among these groups. For example, the recently discovered "brushes" from Charnwood Forest bear a unique external sheath-like structure, while some multifoliate taxa, including *Hylaecullulus fordi*, demonstrate novel eccentric growth architecture.

Diversity and species richness are critical parameters in studies of modern and fossil ecology. However, where these measures are influenced by changing opinions on classification, morphological disparity is not. Here we present an analysis of the disparity of rangeomorph taxa, across 20 communities, using metric and non-metric dimensional scaling and multivariate analysis. Our analyses are coded to include intraspecific variation, which has recently been recognised to be considerable in some rangeomorphs taxa. Our disparity framework provides a tool with which we then test how species with unique features (e.g. the "brushes") fit within the rest of the known rangeomorph taxa. Finally, quantifying morphological disparity in rangeomorphs allows their levels of disparity to be compared to that of extant groups, and provides a quantitative assessment of the biotic composition of different communities.

DIVERSE AND DENSE TRACE FOSSIL ASSEMBLAGES FROM THE EDIACARAN OF NAMIBIA

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The Ediacaran—Cambrian boundary records one of the most iconic and fundamental transitions in the history of life. It encompasses the change from the microbially-dominated world of the Proterozoic to the animal-dominated one of the Phanerozoic. Although research has traditionally focused on the Ediacaran macrofauna, it is the trace fossil record that constrains the evolution of early animal bodyplans, diversity, and behaviours.

The latest Ediacaran strata of southern Namibia host a moderate diversity of trace fossil taxa, the majority of which record simple, horizontal locomotion traces. We report here the first association of the macrofossil *Vendotaenia* in association with treptichnid–like trace fossils, recording direct co-occurrence between metazoan bioturbation structures and a classic Ediacaran taxon. Where bioturbation has been recorded in Ediacaran beds, it is typically not intense, and of low ichnodiversity. In contrast, a thin sandstone

interbed near the base of the Spitskop Member (c. 543 Ma) is densely bioturbated and hosts an assemblage of three distinct and disparate ichnogenera, including sediment bulldozing trace fossils, U-shaped burrows, and simple horizontal structures. The diversity and density of bioturbation in this bed is unprecedented for rocks of this age, and likely records colonisation in fully marine settings on the Spitskop carbonate ramp.

A UNIQUE ARTICULATED FOSSIL SHEDS LIGHT ON THE TAXONOMY OF TWO PLEISTOCENE SPECIES OF GIANT KANGAROO FROM THE GENUS PROTEMNODON

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Prior to the extinction of the genus around 40 000 years ago, kangaroos of the genus *Protemnodon* Owen, 1873 (Marsupialia: Macropodidae) were common members of mammalian herbivore assemblages across Australia and New Guinea. Of these, the mixed-feeding and grazing species *Protemnodon brehus* and *P. roechus*, found in open woodland and forest deposits from the Australian Pleistocene, were some of the largest kangaroos ever at between ~120 kg and ~170 kg. These two taxa are poorly delimited, with morphological descriptions relying heavily on variable dental characteristics, leaving significant grey-areas and lacking postcranial descriptions despite a wealth of postcranial material. Although *P. brehus* is described as smaller than *P. roechus* and differing in certain features of the cheek teeth, preliminary data from this study have suggested that these taxa may represent a single spatiotemporally widespread species. This study will utilise visualisation of craniodental and postcranial measurement data, morphological descriptions and geometric morphometric analyses of taxonomically significant areas, taken from a large sample of *P. roechus* and *P. brehus*, to test the taxonomic definitions of these taxa. An articulated fossil specimen in this study, that of a mother *Protemnodon brehus* with a joey preserved while still held within the pouch, presents the rare opportunity to be certain of the sex of a fossil marsupial. With this unique fossil it will be possible to visualise the degree of sexual dimorphism in size in *Protemnodon brehus*. It is possible that, given the significant size sexual dimorphism among medium- to large-sized extant kangaroo species, the perceived difference in size between *P. brehus* and *P. roechus* is an artefact of sexual dimorphism within a single species.

PROBOSCIDEANS (MAMMALIA) FROM MIO-PLIOCENE OF NORTHERN PAKISTAN

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The research work provides a comprehensive new collection of the Siwalik Mio-Pliocene proboscideans from Northern Pakistan. The collected specimens are more than 60 in number including tusks, deciduous and permanent premolars, and molars. Some of the specimens are reported for the first time from the Siwaliks and new to the Siwalik palaeontology in the subcontinent. The complete hemimandibles of *Deinotheriumpentapotamiae,*lower tusk of *Protanancuschinjiensis*, juvenile and adult lower tusks of *Konobelodon*sp., the deciduous premolars of *Gomphotherium browni*have been reported for the first time from the Siwalik Group. The specimens belong to ten species, eight genera and five families viz. Deinotheriidae, Amebelodontidae, Gomphotheriidae, and Stegodontiidae. The stratigraphic range of *Protanancuschinjiensis*has been extended from the Chinji Formation to the Dhok Pathan Formation of the Siwalik Group. *Konobelodon*sp. has been reported for the first time from the Chinji Formation of the Lower Siwalik Subgroup. The status of *Stegolophodon latidens* has been validated.

The new proboscidean material comes from the Siwalik localities namely Chabbar Syedan, Padhri, Hasnot, Dhok Gojriand Lehri of district Jhelum; Chinji, Lawa, Bhilomar, Kundal Nala northern, Sethi-Nagri, Dhok Pathan and Naraghiof district Chakwal; Dhok Mila of district Attock and Kanhatti of district Khushab, northern Pakistan. The localities date 18 – 3.5 Ma. The Siwalik Mio-Pliocene proboscideans exhibit diversity in the habitats, ranging from damply andswampy places to open grasslands and have mixed diet, ranging from grazers to browsers or even diggers.

IF WE BUILT IT, WOULD THEY COME? NEW INSIGHTS INTO NATURAL BASELINES FOR SOUTHERN CALIFORNIA SHELF MACROBENTHOS AND THE ROLE OF LAND USE IN THEIR DECLINE

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Analysis of benthic samples collected by public agencies on the muddy southern California open continental shelf revealed abundant empty shells of

diverse epifaunal suspension feeders -- such as scallops (*Chlamys, 'Euvola'*), terebratulid brachiopods (especially*Laqueus*), barnacles, erect bryozoans, and calcifying polychaetes -- that have rarely or never been found alive at the same sites despite ~50 years of intense biomonitoring, occurring only on rare rocky outcrops and canyon walls. Our extensive age-dating showed that*Laqueus*populations thrived on the mainland shelf for thousands of years, only to decline in the early 1800s and become functionally extinct by the early 1900s (Tomasovych and Kidwell 2017 Proc Roy Soc B). This timing, and the embedding of these skeletal remains in mud, implicate increased solid-sediment runoff from the adjacent coastal plain, where unmanaged livestock grew exponentially from 1769 to the 1840s, followed by conversion of all 1 million acres to cultivation by 1900; Los Angeles was the top US agricultural producing county until 1950, by which time the filter-feeding communities had been extirpated, replaced by today's detritus-based system. This ecological collapse within historic time, completely unsuspected despite this being one of the best-studied shelves in the world, has given all of us pause – the baseline is very different than assumed. Moreover, how confident are we that solid-sediment runoff alone could cause such a change on the open shelf, with implications for this stressor in other regions? Siltation has formerly been imputed as a driver of ecosystem change only in lakes and coastal traps such as estuaries and back-reef lagoons. Here, we (1) analyze organic nitrogen runoff (manure) as a possible contributing factor and (2) consider the nearby Channel Islands as a second test-case, where terebratulid populations continue to thrive on a still-sandy shelf despite a similarly prolonged and arguably even more intense history of unmanaged livestock. We also present new data on (3) the original spatial heterogeneity of macrobenthic communities on the pre-livestock mainland shelf and (4) living and death assemblages from island shelves as guides for at least partial recovery on the mainland shelf. For example, the mainland shelf supported at least 3 shell gravel communities, patches of trophically diverse and stable muds, and a now ~extinct inner-shelf community of byssate modiolid mussels. On island shelves, surveys consistently detect higher per-sample diversity of macrobenthos and taxa known alive only on these shelves, USGS videos reveal thriving*Laqueus*beds, and dead bivalve shells are associated with a rich fouling community, including bryozoans that locally dominate shell gravels. Rare encounters of 'Channel Island' species on the mainland shelf – living on sandy dredge-spoil heaps and wrecks that provide mud-free oases – indicate that larvae are still in the species pool.

PALEONTOLOGY AND THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE: A CALL FOR ACTION

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As impacts of current climate change are becoming increasingly apparent, there is a pressing need for paleontology to provide knowledge that can be used in the IPCC's assessment reports on climate change. Our discipline has important insights to contribute, particularly to Working Group II, which assesses the vulnerability of socio-economic and natural systems to climate change and adaptation options. Paleontology has already provided invaluable results on the effects of long-term and acute climate change on taxa and ecosystems. However, the potential of paleontology is currently underexploited and results not much absorbed by the IPCC, for which I identify three main reasons:

(1) Limited acknowledgment of issues with temporal resolution

(2) Insufficient attribution of detected patterns to climate-related stressors

(3) Parsimony with numbers

Limited temporal resolution continues to be the main note of caution when the paleo literature is screened for relevant messages by neontologists. There is little we can do to improve temporal resolution – time-averaging in bioturbated sediments will always be the ultimate limit. However, paleontology could target more specifically in how far our insights transcend time scales.

The attribution of fossil patterns to particular climate-related stressors and their interaction has improved in the last few years, but it is still underdeveloped. It is not enough to check how specific traits are linked to extinction risk through time or even across mass extinctions. We need to specifically target ancient hyperthermal events and then check sensitivities of organisms across taxa, traits, systems, and geographic regions to make useful contributions. Combining paleontological data with biogeochemical modeling is way to go in this regard.

Finally, paleobiology is too parsimonious with

numbers. We are trained to use non-parametric statistics for hypothesis testing, which is good. But the IPCC is hungry for numbers. A typical statement for policy makers looks like this: "Coral reefs are projected to decline by a further 70–90% at 1.5°C (high confidence)". Providing numbers and quantifying uncertainties is of pivotal importance to be heard. Modern machine-learning algorithms offer a way to deal with non-normally distributed data in this regard.

With currently two paleontologists as lead authors in IPCC's WGII there is a unique opportunity for paleontology to be heard. An improved contribution to policy-relevant processes will not only enhance the visibility of our discipline, but also help predict the impact of current climate change with greater accuracy.

POTENTIAL NITRATE AEROSOL FERTILIZATION IN RED SEA GIANT CLAMS RECORDED IN $\Delta^{15}N$ OF SHELL ORGANIC MATERIAL

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The giant clams are globally distributed reef-dwelling bivalves which use the same photosymbiotic partnership characteristic of reef-building corals. But while the declining health of corals in the face of climate change and human pollution are the topic of intensive research, comparatively little work has been dedicated to understanding trends in the health of giant clams in relation to environmental change. We have collected fossil and modern specimens of three species of *Tridacna* from reefs fringing the Gulf of Aqaba in the Northern Red Sea. After calibrating the daily/twice-daily growth bands from the outer layer of their shells, we have determined that all three species are growing more quickly in the modern day compared to fossil specimens from Holocene and Pleistocene reefs.Comparing fossil and modern growth of giant clams using dimensionless growth indices k and Φ formulated from shell daily growth measurements, all three species show acceleration in the modern.

We found that giant clam shell organic $\delta^{15}N$ of modern specimens show a 4.5‰ lower average value compared to fossil specimens (Figure 2), an offset which we propose is most likely attributable to increased deposition of isotopically light nitrate aerosols in the modern era. As nitrate is a known accelerant of giant clam growth, it may play a role in the faster growth seen in modern populations. We found that that growth is positively correlated to temperature as measured by oxygen isotope paleothermometry of their shell carbonate, and discuss how lower winter cold temperatures in the past may have depressed giant clam growth compared to the relatively small seasonal availability seen today. We are currently investigating the order and width of aragonite needles in fossil and modern specimens to determine whether accelerated growth has led to more shell porosity and fragility in modern shells, which will help to determine whether accelerated growth helps or harms the fitness of giant clams. Giant clams can serve as isotopic and physiological sentinels of reef environmental change, both to determine their own comparative health and that of the coral reefs they inhabit.

THE MIDDLE CAMBRIAN SPENCE SHALE (MIAOLINGIAN: WULIUAN) LAGERSTÄTTE: IMPROVING OUR UNDERSTANDING OF A KEY CAMBRIAN ECOSYSTEM

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The middle Cambrian (Miaolingian: Wuliuan) Spence Shale Member of the Langston Formation in northern Utah and southern Idaho (U.S.A.) is a relatively well-known Burgess Shale-type (BST) deposit preserving a diverse soft-bodied fauna including various arthropods, priapulids, hyoliths, and lobopodians, as well as abundant trilobites, brachiopods, and echinoderms. Information from this deposit has provided important insights into middle Cambrian paleoecology, biodiversity, and phylogeny. Diversity in the Spence is well documented, although new taxa continue to be discovered. However, until recently, patterns of species co-occurrence and their environmental preferences were poorly known due to lack of locality information and stratigraphic context for many previously collected specimens. Recent donations to the University of Kansas Invertebrate Paleontology collections by private collectors, as well as collections by the authors in 2017 and 2019, significantly improved the understanding of species occurrence within the Spence Shale. This information enhances our knowledge of this BST deposit and helps with making comparisons between the Spence and other BST deposits. Notably, the Spence Shale differs in several

key aspects from other Lagerstätten in the Great Basin, including preserving large number of echinoderms, extremely rare sponges, and a low agnostoid diversity.

In addition to furthering our knowledge of the biota, new lithological, geochemical and ichnological data is improving our understanding of the depositional environment, and the taphonomic and diagenetic pathways of the soft-bodied fossils within outcrops and between localities. The data also highlight some of the differences between the Spence and other BST deposits in Utah, especially as the mudstones preserving the specimens are closer in composition to those of the Burgess Shale and the Rockslide Formation of Canada. Analyzed samples have yielded an abundance of information suggesting that the preferred habitats of certain taxa can be characterized. For instance, the majority of the arthropod fauna occurs in the deeper water mudstones of the Wellsville Mountains. However, some species (e.g., *Dioxycaris argenta, Gogia guntheri* and *Haplophrentis reesei*) also occur in varied environments across different occurrences in the Spence. Additionally, the diverse benthic fauna, trace fossils and the differences in faunal composition suggest well oxygenated bottom waters for at least the Wellsville Mountains sections. For subsequent field seasons, we will sample several outcrops to gain a better understanding of the distal and proximal communities. Ultimately, better characterization of the Spence will assist in deciphering the multifarious nature of BST deposits in the Cambrian of western Laurentia.

CONSTRAINING THE JURASSIC – CRETACEOUS TERRESTRIAL BIOTIC CRISIS IN NORTH AMERICA: NEW DATA FROM UTAH HELPS CLOSE THE GAP

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Along the western Cordillera of North America, there is an extensive temporal gap between the Jurassic and the base of the Cretaceous (JK gap) spanning some 25–30 million years. Intensive field research on the terrestrial faunas of the central Colorado Plateau in Utah has succeeded in significantly closing this gap. Much of these data have been derived from research on the Lower Cretaceous Cedar Mountain Formation (CMF) in Grand County. Terrestrial vertebrate fossils have only been recovered from the basal Yellow Cat Member in that area, where the member is divided into a lower and upper Yellow Cat by a massive multitiered paleosol. The calcrete separates two distinctive dinosaur faunas having strong biogeographic ties with Europe. Ferruginous paleosol facies (wet JK boundary interval) similar to those in the lower Yellow Cat are recognized elsewhere in Utah beneath the cliff-forming conglomerates previously used to mark the base of the Cretaceous, but only in the northern Paradox Basin of Grand County are these strata thick and richly fossiliferous. Research shows that renewed salt tectonics during the Early Cretaceous caused local subsidence on either side of the Paleozoic Salt Valley anticline, which is responsible for the spectacular geological features of Arches National Park. Radiometric dating and microfossils have revised the age range of these strata to Berriasian-Valanginian to early Hauterivian (~140–133 Ma, based on detrital zircons), thus making these the two oldest Cretaceous terrestrial faunas in North America. The overlying Poison Strip Member has a similar Wealden "style" fauna but seems to correlate with the Lakota Formation in the Black Hills region of South Dakota. The Aptian faunal extinction markedly separates these three Wealden "style" faunas from the more endemic Aptian-Albian Cloverly "style" faunas. Given a current minimum age of ~149.0 Ma ("middle" Tithonian) for the top of the Morrison Formation and ~139.7 Ma for the base of the CMF, the JK gap in Utah has been closed to 9–10 million years.

A significant North American JK faunal turnover remains between the last occurrence in the Morrison Formation of ceratosaurs, diplodocid and camarasaurid sauropods, and stegosaurids, and the first occurrences in the lower Yellow Cat Member of the CMF of haramiyid mammaliforms, therizinosaurs, ornithomimiforms, dromaeosaurids, turiasaur sauropods, and basal styracosternan iguanodontians. Groups that remain through this time interval include eileenontid sphenodonts, allosauroids, troodonts, brachiosaurid sauropods, and polacanthid ankylosaurs. Although new fossil taxa are still being discovered, the scale of this faunal turnover seems comparable to that in the Aptian, when slender-toothed titanosauriform sauropods replaced broad-toothed turiasaur and brachiosaurid sauropods, more primitive endemic tennontosaurid iguanodontids replaced basal styracosternan iguanodontians, and nodosaurid ankylosaurs replaced polacanthid ankylosaurs.

MIKE MURPHY'S IMPACT

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Paleontology and biostratigraphy in the last half of the 20th century into the 21st have been dominated by specialists who characteristically focused on one fossil group and only one, or part of one period of the time scale. Michael A. Murphy is one of the major exceptions to this generalization. In a long career Mike has accomplished groundbreaking research on the evolutionary patterns and resulting biostratigraphic value of Cretaceous ammonites, Silurian and Devonian conodonts, as well as graptolites. His diverse fields have included biostratigraphy and taxonomy (including significant publications on the morphometrics of conodonts), lithostratigraphy, sedimentology and geologic mapping. After B.A. and Ph.D. degrees at UCLA, he spent most of his teaching and research career at the University of California, Riverside, where he continues as an Emeritus Professor. Mike trained a consequential number of research students, three of whom are the organizers of this symposium in his honor.

In teaching the UCLA field course in central Nevada in the late 1950s, he came in contact with J.G. "Jess" Johnson then beginning his Ph.D. field work there on Lower Devonian stratigraphy and brachiopods. After Jess contracted polio, Mike was responsible for many of the collections used in the dissertation and Jess' subsequent GSA Memoir on Lower Devonian brachiopods. His prolific publications made him one of the, if not *the* leading Devonian researcher(s). Furthermore, during Jess' long teaching and research career at Oregon State University, Mike field checked many of Jess' 27 M.S. and four Ph.D. students' stratigraphic and mapping research in Nevada.

In summary, Mike Murphy continues to be an inspiration and mentor to many, including the greatly appreciative author of this abstract.

THE END OF THE TRAIL; A LOBOPODIAN MORTICHNIA

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Lobopods are extinct marine organisms that superficially resemble 'worms with legs'. Given their softbodies and the need for exceptional preservation to fossilize, most lobopodians have been recovered from Paleozoic Lagerstätten. To date, over thirty lobopodian species have been described ranging from the Lower Cambrian to the Upper Pennsylvanian. Despite the growing catalogue of taxa and subsequent knowledge of their anatomy, the ecology and behavior of lobopods remains somewhat elusive. Workers on trace fossils from the Middle Cambrian (*Bicavichnites martini)* and the Late Ediacaran (unnamed trails) have suggested lobopods as possible tracemakers but some debate has remained. Here we present the first documented lobopodian mortichnia. This series of trackways, *Nereites isp.* x *Bicavichnites*-like tracks, followed by the body impression of its tracemaker, provides the first direct and conclusive evidence of ancestral lobopodian behavior and ecology. This fossil also confirms the possible identity of a lobopodian tracemaker for *Bicavichnites* and for the first time indicates a lobopod as a producer of the grazing trail *Nereites.*

THE R PACKAGE DIVDYN FOR QUANTIFYING DIVERSITY DYNAMICS USING FOSSIL SAMPLING DATA

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Methods used to calculate accurate estimates of diversity dynamics are in constant development. These include metrics of global taxonomic richness, extinction, and origination rates, as well as sampling standardization protocols. With the increasing size of this toolkit, it becomes more difficult to keep track of the available methods, and to compare their performance and accuracy. To date, paleontologists have implemented calculations based on occurrence data on their own, using stand-alone software. As reconstructed trajectories of biodiversity dynamics are often the basis of hypothesis testing, the community would benefit from an easily deployable toolkit that helps to calculate such variables in a quickly reproducible way.

Here we present the R package 'divDyn,' which allows the rapid calculation of a large array of raw and sampling-standardized metrics. The package can draw from any sort of time-binned occurrence database, such as the Paleobiology Database, the Neotoma Paleoecology Database, Neptune, or Ammon. The package also offers functions to infer the environmental affinities of taxa, compute significance tests of extinction selectivity, and generate publication-quality visualization options of raw fossil data and the output time series. A wrapper function allows the application of popular sampling standardization processes such as classical rarefaction, occurrence-weighted by-list

subsampling, and shareholder quorum subsampling. We hope this user-friendly implementation will facilitate the distribution and wider application of such approaches.

To exemplify application, we illustrate patterns of Phanerozoic-scale diversity dynamics of marine invertebrates resulting from different methods. With the help of the core function and standard subsampling options, we revisit patterns such as the decline of taxonomic rates over time, the magnitude of mass extinctions, and equilibrial diversity dynamics and assess their methodological dependency. Our results suggest that rates declined only over the early Phanerozoic, only three mass extinctions stand out clearly, and evidence of equilibrial dynamics is dependent on the methods that are used. This last point highlights the importance of comparing the results of different calculation protocols, which is greatly facilitated if code is organized into a comprehensive library.

QUALITY OVER QUANTITY: BIVALVES AS TAXONOMIC SURROGATES OF ENTIRE BENTHIC COMMUNITY IN COASTAL POLLUTION ASSESSMENT

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Long-term biomonitoring programs are often limited by the cost and taxonomic expertise required for whole-fauna analyses at the species level. Taxonomic surrogates, in the form of coarser taxonomic units and/or selected clades, are nonetheless rarely utilized in ecological studies, despite their frequent use in paleontology (e.g., coarsening to genus level or use of shelled taxa only). Here, we use a large, 45-year long macrobenthic dataset to evaluate the ability of bivalves alone to detect spatial and temporal patterns across a wastewater outfall gradient on the southern California continental shelf. Species-level numerical abundance data were collected from 1972 to 2017 on the Palos Verdes shelf by the Sanitation Districts of Los Angeles County to monitor benthic condition associated with treated wastewater effluent from their White Point outfall system. We focus on 11 sampling sites in 60 m (middle shelf) water depth arrayed with increasing distance from the outfall. Sites were classified as either proximal or distal to the outfall based on sediment chemistry, and annually-sampled replicates were analytically pooled into five temporal bins (varying in duration between 2-19 years) based on the level of wastewater treatment. Compositional differences (abundance-based Bray-Curtis) between proximal and distal sites were assessed with PERMANOVA for three taxonomic sets (whole fauna, bivalves only, polychaetes only) at four taxonomic levels (species, genus, family, order) for each temporal bin. Results for all groupings suggest spatial homogenization of the benthic community in response to improved wastewater treatment. During early treatment phases when the pollution gradient was strongest, bivalves did better than other groups in distinguishing proximal and distal sites, particularly at coarser taxonomic units, based on correlation coefficients between compositional dissimilarities and outfall distances. However, variation in polychaete composition paralleled that of the whole fauna more closely than did bivalves, as expected given that polychaetes comprise the largest proportion of species richness and abundance. Per-site taxonomic richness, abundance, and evenness (PIE) also differed more strongly between proximal and distal sites for bivalves than for the whole-fauna or polychaetes. Bivalves are thus an effective surrogate for variation in whole-fauna response to pollution over space and time in this especially well-documented study area, and in fact reveal gradients that more inclusive taxonomic assessment obscures. These findings encourage both (1) prioritizing bivalves in areas with fewer resources for conducting whole-fauna assessment and (2) using bivalve dead-shell assemblages to reconstruct benthic conditions for periods before the onset of monitoring efforts, given strong live-dead correspondence in other tests.

TALES FROM A HARBOR DOWNUNDER: HOW THE MODERN MOLLUSCAN COMMUNITY DIFFERS FROM THE PRE-COLONIAL COMMUNITY

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Sydney Harbour is a subtropical marine estuary with a diverse biotia, but little is known about its ecological history or the impact of western colonisation and industrialisation on its biotia. I will discuss my efforts to understand changes in the harbor's molluscan community using shell material from a subtidal excavation. Total molluscan productivity (measured as shell carbonate [g / m2 / yr]) hasremained consistent through the last 6ka to the present day whereas the composition of the community has

changed dramatically. Historically *Fulvia* dominated the molluscan community while the modern molluscan community is dominated by *Notocallista*. The decline in *Fulvia* abundance appears to pre-date western colonisation and it appears to be associated with a regional warming event. Due to its scarcity in the death assemblage, the rise of *Notocallista* appears to have occurred in the past couple decades, perhaps associated with recent improvements in water quality. The proportion of drilled valves for individual taxa are largely consistent throughout the past 6ka, suggesting stable predator-prey interactions through the present day. Preliminary analyses of microgastropod diversity suggest a consistently diverse fauna of ~120 species throughout the core.

While the identity of the dominant mollusc has changed, this change is most likely associated with a regional climate event rather than colonisation or industrialisation. Most indices of community productivity and diversity have remained relatively stable over the last 6ka. Despite these rather comforting paleoecological conclusions, most molluscs thought to live in the harbour are known only from dead shell material and our knowledge of the living molluscan community remains poor.

MULTI-MILLENNIAL STABILITY OF BENTHIC COMMUNITIES RECORDED IN SURFICIAL MOLLUSK SHELL ACCUMULATIONS

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Surficial shell accumulations represent archives potentially suitable for assessing histories of local ecosystems over multi-millennial time scales. We assessed the value of this approach using three case studies in radically different settings: (1) San Salvador Island (a small oceanic island surrounded by a tropical carbonate platform with seagrass and patch reefs), (2) Florida's Gulf Coast (a subtropical continental shelf with terrigenous sediments and seagrass), and (3) North Carolina Atlantic Coast (a temperate coastal habitat).

On San Salvador Island, we sampled surface sediments along 12 transects (60 samples, 20301 specimens, 180 species). Radiocarbon dating of individual shells indicated that surficial shell accumulations represented a multi-millennial record of local communities. Multivariate ordinations separated samples of mollusks by transect, habitat, and regional context (leeward vs. windward setting), with the faunal composition of samples from seagrass being less variable than the composition of samples from sand. Along Florida's Gulf Coast, we sampled shallow coastal seagrass meadows and sandy bottoms. Again, radiocarbon dating indicated that surficial shell accumulations represented a multi-millennial archive of local communities. The results also indicated that life assemblages from seagrass sites were characterized by elevated alpha diversity and depressed beta diversity, death assemblages differed significantly between the two habitats, and live-dead faunal agreement was significantly greater for seagrass habitats. In North Carolina, we compared macrobenthic communities and sympatric death assemblages at 52 localities in Onslow Bay. Live and dead datasets were greater than 80% congruent in pairwise comparisons to the literature estimates of beta diversity in other marine ecosystems, yielded concordant bathymetric gradients, and produced nearly identical ordinations that consistently delineated habitats. Therefore, despite prolonged exposure to anthropogenic activities, the spatial structuring of local macrobenthic communities has not changed dramatically and the regional ecosystem structure has not shifted notably from its historical state.

Despite major differences between the three systems, multiple commonalities emerge. In all cases, surficial shell accumulations represented multi-millennial archives of local ecosystems. In all systems, time-averaged shell assemblages have retained an interpretable spatial pattern. The retention of spatial gradients suggest that regional ecosystems have remained stable over multi-centennial time scales. The three case studies also suggest that non-invasive sampling strategies targeting dead mollusks can be an effective approach for assessing the spatial distribution of faunal associations and elucidating processes that drive spatial structuring of communities over centennial-to-millennial timescales.

FOSSIL: BUILDING A COMMUNITY OF PRACTICE VIA SOCIAL PALEONTOLOGY

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Since its inception in 2013, the FOSSIL (Fostering Opportunities for Synergistic STEM with Informal Learners) project has been building a national network of amateur and professional paleontologists, mostly in the United States, using the theoretical and conceptual framework of a "Community of Practice" (CoP). To achieve this goal, our focus has been on supporting the practice of social paleontology, which emphasizes collaborative and open participation in the science of paleontology. We have come to recognize that the CoP exists across diverse social technologies, each with a different segment of the community. The FOSSIL project supports and engages with the CoP through the myFOSSIL website and mobile app, strategic face-to-face events, and with a presence on numerous social media platforms. The evolution of the FOSSIL CoP has largely mirrored advances in digital platforms during this time.

Seven years ago we planned for the FOSSIL CoP to be built using our web site, listserv, and e-newsletter. As we added social media, however, the demand among community participants changed dramatically. The growth of social media, including Facebook, Twitter, and Instagram, have eclipsed all of our originally envisioned means of e-communications. We currently are approaching 10,000 CoP participants. While there are more than 1,200 members on the myFOSSIL web site, the majority are interacting via social media, i.e., Facebook (5,177), Twitter (2,612), and a rapidly expanding Instagram presence (1,300), the latter of which has only been active for ~1.5 years, but has shown the greatest relative rate of increase in participation. Our myFOSSIL app has only recently gone public and is likewise increasing the FOSSIL CoP.

Key findings of our learning research include:

(1) A 21st century CoP is built by participants joining from a variety of platforms (i.e., niches in a digital ecosystem), including the web, social media, and e-newsletter, as well as face-to-face events.

(2) Trying to drive traffic from social media to the web is ineffective and CoPs are best developed as a diverse set of entry and participation platforms, each with a different segment of the community, but all of which have value for the network.

(3) Different strategies attract and resonate with different demographics in ways that are related to the communication platform. Thus, in order to further engage younger learners, strategies will be different than those for older lifelong learners.

(4) Very few (< 5 %) of the CoP members participate via multiple platforms.

(5) Strategies that create synergy between digital niches and face-to-face experiences is an area in need of further exploration.

This spark will be followed by panelists (Eleanor Gardner, Sadie Mills, and Lisa Lundgren) who will respond to, and further elaborate upon the FOSSIL Project.

THE CONSTRUCTIVE GROWTH OF PHANEROZOIC MARINE BIODIVERSITY

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It is indisputable that total global biodiversity has increased since the beginning of the Phanerozoic eon around 540 million years ago. The question is why this is the case. Previous work often focused on novelty as a driver of the Phanerozoic biodiversity increase and global diversity as a balance between origination and extinction. According to this, new species and higher taxa appear in ecosystems when they successfully occupy new niches and go extinct when the lost the advantage. Taxa with early burst, rapid diversification pattern have key adaptations that allow them to expand.

Alternatively, long-term accommodation and persistence of taxa can build biodiversity. We understand ecological accommodation as a process by which taxa can coexist successfully for some time at low diversities, imposing a lag time before the taxa expand. These processes are well studied at ecosystem level. We applied the concept to the geological time scale at global level and suggest that biodiversity accumulates through evolutionary novelty and the persistence of taxa. Our question was, which of these factors was a more important driver of the Phanerozoic biodiversity increase.

We used data from the Paleobiology Database, covering hundreds of thousands of occurrences from the Phanerozoic marine fossil record and applied capture-recapture modeling for diversity estimation. This resulted in a marine Phanerozoic genus level diversity curve which is very similar to iconic curves published previously. This result encouraged us to make a detailed comparison of the diversity curves of two cohorts of genera; one with an early burst family diversification pattern, the other with family diversification delayed by millions of years. The resulting curves show a steady but randomly fluctuating influx

of novel taxa showing an early burst pattern over the course of the Phanerozoic. Only the cohort with long macroevolutionary lag-time between origination and diversification tracks the characteristic Phanerozoic diversity curve, with its net increase since the early Paleozoic. We conclude that the Phanerozoic biodiversity increase is primarily driven by long term lineage accommodation and persistence, rather than the appearance of evolutionary novelty.

THE TALE OF TWO RIVERS: FOSSIL MOLLUSK ASSEMBLAGES OF THE WAKULLA RIVER DOCUMENT ECOLOGICAL CONSEQUENCES OF CLIMATE CHANGE, INVASIVE SPECIES, AND HURRICANE MICHAEL

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Anthropogenic impacts, both direct and indirect, have had drastic effects on the health and diversity of Florida's freshwater spring and river ecosystems. These include the introduction of invasive species, upstream migration of brackish/marine species into previously freshwater areas, and the upstream retreat of freshwater species. These shifts are driven by rising sea levels amplified by surges from hurricanes and storms. As sea level rises, storm and tidal surge events can increase salinity further upriver, causing the freshwater vegetation and freshwater invertebrate communities to shift in response.

Hurricane Michael made landfall in Florida on 10 October 2018, bringing more than 3 meters of storm surge and other effects. In the specific case of the Wakulla River, the hurricane forced brackish water upriver as far as the headspring. Using fossil (Holocene) mollusk records as well as live mollusk samples collected before and after Hurricane Michael, we documented the response of Wakulla's molluscan communities to the hurricane's storm surge. We also compared these communities with freshwater fossil assemblages previously collected from the Wakulla River, representing Holocene conditions. These samples were collected from eleven sites along the upper eleven kilometers of the river, beginning in the headspring. A total of sixty-one live and thirty-one fossil samples were collected over three sampling excursions in 2017 and 2018.

Seventeen species (all native) were identified from fossil deposits present along the river's length. Before the storm, modern species richness had dropped to seven, including two invasive species (*Corbicula fluminea* and *Melanoides tuberculata*) and one brackish gastropod (*Vitta usnea*). This likely reflects increased competition from invasive species, a decrease in water flow, increased nutrient input, and others harmful, recent impacts on spring ecosystems. Following the hurricane, richness remained the same, but the relative abundances of many species shifted. Specimens of the brackish gastropod were found further upriver than before the hurricane. Additionally, the proportion of native taxa relative to invasive species dropped at every sampled location.

The lack of brackish species in the fossil record suggests this upriver encroachment of salinity-tolerant species is a recent development, likely reflecting rising sea levels and resulting upstream surges of marine waters. Additionally, compared to native species, invasive taxa seem more resilient to surge events: they either recover faster from, or are less affected by, rapid changes in salinity. These trends suggest native taxa are at an elevated risk as sea level continues to rise, and the frequency and severity of hurricane events increase.

THE LONG-PROBOSCID INSECT POLLINATION MODE OF THE MID-MESOZOIC: ITS DISCOVERY, BIOLOGY AND IMPLICATIONS FOR UNDERSTANDING GYMNOSPERM REPRODUCTIVE BIOLOGY

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A decade ago, paleobiologists from the National Museum of Natural History in Washington, DC and Capital Normal University in Beijing described the head and mouthpart structure of a clade of scorpionflies (Mecoptera) that bore unusually long proboscises structured similar to a modern butterfly. The proboscis bore two extended elements, the galeae, from the maxillary segment of the head that were prolonged into a tubular siphon in which each galea half-tube was sutured above and below as a siphon for imbibing fluids. The scorpionfly siphon varied significantly among its five families, as well as in three other insect orders, lacewings (Neuroptera), flies (Diptera) and moths (Lepidoptera), preserved in earlier compression and in later amber deposits of the mid Mesozoic. At one end of this morphological spectrum, one family

of mosquito-sized, two-winged scorpionflies (Dualulidae) housed short, hairless, 2.5 mm long, straw-like proboscises with regularly arranged, encircling, sclerotic bands on their outer surfaces. At the other end were lacewings (Neuroptera: Kalligrammatidae) that bore, large 25 mm long, flexible, proboscises clothed on their outer surfaces with random arranged setae and tipped with paired pseudolabellae for capillary adsorption of surface fluids. Other long-proboscid insects from all four insect orders ranged from forms with ridged proboscises, with or without terminal sponging structures, to smooth surfaced forms, and densely pilose forms, all of which have parallels in modern long-proboscid insects. Suction power for incoming fluids was powered by an expansive cibarial (food) pump with compressor muscles mounted on the frontal part of the head. Recent amber evidence also indicates that long-proboscid insects bore a second, much smaller, pharyngeal (salivary) pump for providing fluids through a hypopharyngeal duct of considerably less diameter than the siphon food tube, for fluidizing and mobilizing surface food for uptake. The food source of long-proboscid insects initially was enigmatic, as the mouthpart ensembles of the long-proboscid insects lacked stylets that would have been involved in blood feeding. The only reasonable hypothesis was feeding on angiosperm nectar, through analogy to all modern long-proboscid insects that also would include additional, rampant convergent evolution by long-proboscid beetles (Coleoptera) and caddisflies (Trichoptera). However, a fundamental problem ensued in that angiosperms in general, and deep-throated forms in particular that would have been consistent with a long-proboscid pollination mode, were absent during the relevant mid-Mesozoic interval. (An exception is earliest Cenomanian Myanmar amber, which has bowl-shaped angiosperm flowers possibly pollinated by small long-proboscid forms but lacking deep-throated flowers of the later Cretaceous.) The evidence now strongly suggests that tubular structures –funnels, micropyles, channels and pappus tubes – in a variety of extinct gymnosperms provided nectar-like pollination drops for long-proboscid insects. This pollination mode was extinguished by the appearance of angiosperms during the Aptian and Albian, reflecting a major type of pollination that no longer exists.

POST-EMBRYONIC DEVELOPMENT OF FRITZOLENELLUS REVEAL ANCESTRAL MORPHOLOGY OF EARLY DEVELOPMENTAL STAGES IN TRILOBITA

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Trilobite development has been intensively investigated during the past decades, but information about ancestral characters and character combinations in the early developmental stages of trilobites remains virtually unknown. Trilobites of the suborder Olenellina are one of the earliest diverging trilobite groups, and therefore can provide crucial information about development.

Herein, we describe numerous well-preserved specimens of the olenelloid trilobite *Fritzolenellus lapworthi* from the Forteau Formation of western Newfoundland. The material comprises specimens ranging from very early stages (cephalic length less than one mm) up to the adults (more than 20 mm in cephalic length) and provides the first detailed insight into the early morphological development of *Fritzolenellus*.

The morphology of the early developmental stages of *Fritzolenellus* differs in many aspects from the morphology of equivalent stages of some of the other members of Olenelloidea, such as in *Olenellus*, *Nephrolenellus* or *Bristolia*. In contrast, early stages of *Elliptocephala*, *Holmia*, *Daguinaspis*, *Choubertella* and *Eoredlichia* strongly resemble contemporaneous stages observed in *Fritzolenellus*. Consequently, two basic morphotypes can be recognized during the early development of basal trilobites. Mapping these morphotypes into known phylogenies of basal trilobites shows that the morphotype represented by the early stages of *Fritzolenellus* has a character combination that is probably ancestral for Trilobita as a whole. The developmental modifications of olenelloid taxa showing the second morphotype might be related to predator deterrence or to stabilization of the animal on a muddy substrate.

POST-EMBRYONIC STAGES OF A MOROCCAN ARTHROPOD SUGGEST DIRECT DEVELOPMENT IN MARRELLOMORPHA

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Marrellomorphs are a group of marine arthropods known from Cambrian to Devonian strata of Argentina,

Australia, Canada, China, Czechia, Germany, Morocco and UK. The group comprises two orders – Marrellida and Acercostraca – and their representatives differ mainly in the morphology of the cephalic shield and the nature of their anteriormost appendages. The precise phylogenetic position of the group is problematic, as Marrellomorpha is variously resolved as stem Mandibulata, stem Chelicerata or even stem Euarthropoda. The post-embryonic development of the group is insufficiently known, as early stages of marrellomorphs are generally rare, but this information could help resolve their phylogenetic affinities. Here, we describe the early post-embryonic stages of a marrellomorph arthropod from the Fezouata Forma tion (Lower Ordovician) of Morocco.

The early developmental stages of this marrellomorph range from two to four mm in sagittal length, including the length of spines. The dorsal shield bears three pairs of needle-like spines; first pair projecting anteriorly, second pair laterally and the last pair posteriorly. All these spines are nearly straight, or just slightly curved, so they morphologically differ from strongly curved spines present in adult forms of this species. Synchrotron microtomography data, collected at the TOMCAT beamline of the Swiss Light Source, reveals detailed morphology of the appendages. Both the first and second antennae, and the biramous limbs of the early stages are morphologically similar to those of adults specimens.

The general similarity between the early developmental stages and the adults of this Moroccan marrellomorph imply direct development in this species (assuming there were no earlier pre-metamorphic stages). Therefore, we suggest no niche differentiation took place during development of this species. This conclusion is also supported by co-occurrence of early stages and adults in some of the localities. The smallest known stages of the closely related taxa *Marrella* from Miaolingian of the Burgess Shale (Canada) and *Mimetaster* from the Lower Devonian Hunsrück Slate (Germany) seem to also be morphologically similar to adults, suggesting that direct development might be a general pattern in the ontogeny of Marrellomorpha.

TWELVE TO TANGO: AVOCATIONAL AND PROFESSIONAL PARTNERSHIPS TO INCREASE PUBLIC UNDERSTANDING OF PALEONTOLOGY THROUGH INFORMATIONAL PAGES, BLOGS, AND SOCIAL MEDIA PLATFORMS

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Evolution remains a contentious topic in United States politics and education, where several states currently allow the teaching of alternative ideas to well-supported scientific theories (e.g., intelligent design) and various legislative initiatives seek to spread this practice more widely. Additionally, the Trump administration has recently weakened or removed federal protections for public lands that contain valuable and irreplaceable fossil resources (e.g., Bears Ears National Monument in Utah). In this contentious political environment, the public has a critical need to be presented with the basic facts of evolutionary theory, the implications of evolution and how it impacts their lives, and why the preservation of fossils and their surrounding strata is so crucial.Social media and other online platforms have vastly improved the speed and accessibility of information dissemination. However, these improvements also apply to the spread of misinformation and disinformation, particularly related to controversial topics such as evolution. This problem is compounded by the inherent complexity of the scientific subject matter, as rigorous, jargon-filled, and accurate descriptions have difficulty competing against simple but inaccurate content. To address these issues, we created Time Scavengers (timescavengers.blog), maintained by a group of twelve avocational scientists, academics, and graduate students. The site includes over 35 static pages about general geology, climate change, and evolution written for the public, with easy-to-understand content. To make the process of science and specifically paleontology more transparent, the site also includes six blogs to provide insight into data collection and interpretation, field work, and interactions with the public. The overarching goals of the site are to bridge the gap between scientists and the public through engaging, informational pages

and personal experiences in the field, lab, classroom, and community, and to increase paleontology literacy through fun, easy-to-digest content. Time Scavengers also participates in social media hashtags (on Twitter, Instagram, and Facebook), such as #FossilFriday, to further engage with our community. These posts highlight a new fossil or extinct group every week to encourage and foster a love of paleontology and understanding why preserving and studying ancient life is important. Google Analytics data kept on the site's visitors indicate this collaborative project has been successful in reaching over 33,000 people in 183 countries to date. The largest audience is among people ages 18 to 34 who find the site through organic internet searches (59.9%). This indicates that the site and its strong partnerships among avocational, academic, and graduate student geoscientists are reaching a population that will make decisions regarding the future of important fossil localities and evolutionary education

PALEOBIOGEOGRAPHY OF THE NEOGENE PLANKTIC FORAMINIFERAL GENUS GLOBOCONELLA TO INTERPRET LONG-DISTANCE DISPERSAL MECHANISMS

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Incredibly, modern planktic foraminiferal species with a bi-latitudinal distribution have a striking amount of genetic similarity. It remains largely unknown how modern species with such widely distributed populations and specific temperature, salinity, and nutrient tolerances can disperse across ocean basins. One hypothesis put forth is that species use coastal upwelling zones as 'stepping stones' from one high-latitude region to another, with ocean currents being the driving mechanisms behind such dispersal potential. An understudied region of the world's oceans that may also allow for such dispersal and connectivity among populations are western boundary currents (WBCs) of the subtropical gyre systems. These are areas in the oceans where subtropical and subpolar waters meet in the mid-latitudes, creating a biological mixing zone called an ecotone. These areas have been found to promote dispersal of species into adjacent areas in terrestrial systems, but marine ecotones remain poorly studied. It is unclear how WBCs contribute to speciation and dispersal dynamics in the marine realm. The best way to tackle hypotheses regarding species dispersal across oceans, and if or how WBCs contribute to speciation and dispersal dynamics can best be answered using the plankton fossil record. An ideal group to tackle such hypotheses are species of the Neogene planktic foraminiferal genus *Globoconella*. These taxa are transitional-water mass dwellers, often found in greatest abundances at mid-latitude sites characterized by ecotones. Species' documented occurrence data from deep sea sites were downloaded from the NEPTUNE database and from a primary literature search for a global-scale study. Over 45 sites are identified as containing globoconellid foraminifera. Species' first and last occurrences at each site were interpolated using published age models (based on orbitally tuned sediment records, magnetostratigraphy, tephrochronology, and calcareous nannofossil biostratigraphy) updated to the Geologic Time Scale 2012. Most sites containing globoconellids are located in the mid-latitudes, with sporadic occurrences in equatorial and subtropical upwelling regions. This observation alone provides tantalizing evidence that the use of equatorial upwelling regions as 'stepping stones' for long-distance dispersal may be valid. Preliminary range data indicate that the *Globoconella* lineage did evolve in the southwest Pacific Ocean, with few exceptions: *Globoconella praescitula* evolved in the western equatorial Pacific, and *G. conomiozea* evolved in the northwest Pacific. In the northwest Pacific, late Neogene species persist in this region long after going extinct from the southwest Pacific. Additional range data will shed light into the way in which transitional water mass species disperse across equatorial regions, and the drivers behind such long-distance dispersal.

WHAT'S THE DEAL WITH CHASMATASPIDIDS?

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Chelicerates were important components of Paleozoic aquatic ecosystems, with eurypterids occupying a wide variety of ecological roles and xiphosurids (horseshoe crabs) radiating in Carboniferous coal swamps. While both eurypterids and horseshoe crabs have been the subject of major studies into their phylogeny and paleoecology, there exists a third aquatic chelicerate group – Chasmataspidida – that has received relatively little attention. Studies into chasmataspidids tend to be restricted to descriptive works, due in part to their low taxonomic diversity but compounded by doubts as to the monophyly of the

group, with the Ordovician *Chasmataspis* exhibiting more xiphosurid-like characteristics while the Silurian-Devonian diploaspidids more closely resemble eurypterids.

Investigations into chasmataspidid relationships have been hampered by the generally diminutive size of diploaspidids, which renders study of their morphology difficult without exceptionally preserved individuals that, until recently, have been lacking. The discovery of multiple specimens of a large, exceptionally preserved diploaspidid from the Ordovician Big Hill Formation of Michigan, USA, has provided new information regarding the early evolution of diploaspidids and stronger links between the later diploaspidid species and *Chasmataspis*. The new species, named *Hoplitaspis*, also indicates that chasmataspidids occupied a broader range of ecological roles than previously thought. *Hoplitaspis* was a moderately-sized predator that coexisted in its environment with early eurypterids, but was a far more common component of the community. The detailed preservation of the morphology of *Hoplitaspis* also provides new clues to the identity of a variety of problematic arthropod fossils that may, in fact, have a chasmataspidid affinity.

These new discoveries allow preliminary analysis of biogeographic and paleoecological trends within chasmataspidid evolution, suggesting that the group originated in Laurentia and began to transition into non-marine environments during the Devonian at the same time as eurypterids and xiphosurids. Additionally, juvenile chasmataspidid specimens suggest a heterochronic component to the transition from a *Chasmataspis*-like to diploaspidid-like morphology. These preliminary analyses suggest that, rather than being little more than rare oddballs, chasmataspidids exhibit a complex and diverse evolutionary history equal to that of their more well-known relatives.

REVISED (EARLY LATE DUCHESNEAN) AGE OF LOWER RANCHO GAITAN LOCAL FAUNA, PRIETOS FORMATION, NORTHEASTERN CHIHUAHUA, MEXICO

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The Lower Rancho Gaitan Local Fauna (LF) (LRGLF) from the Upper Tuffaceous Mbr. of the Prietos Fm. in NE Chihuahua is considered earliest Chadronian in age and coeval with the Little Egypt LF (LELF) from the upper Chambers Tuff Fm. (CTFm) of the Vieja Grp. in SW Texas (TX), but older than the late early Chadronian Ahearn Fauna (AF) from the Ahearn Mbr. (AMbr) of the Chadron Fm. (CFm) in the Chadronian North American Land Mammal Age (NALMA) type area, SW South Dakota. There, the AMbr underlies the Peanut Peak Mbr., the lower unit of the CFm and the Chadronian NALMA stratotype/type area in NW Nebraska. Therefore, the Lower AF (LAF) from the lower AMbr is the oldest Chadronian LF from the type area and, thus, early earliest Chadronian in age. Accordingly, the LELF is of latest Duchesnean age. Notably, the LELF contains the dentally derived oreodontid *Prodesmatochoerus dunagani* (smallest record of genus) rather than its much larger, earliest Chadronian descendants beginning with large *P*. n. sp. B of the LAF. Critically, the LRGLF shares the dentally primitive oreodontid *Aclistomycter middletoni* (incl. two skulls previously referred to Merycoidodontidae gen. and sp. indet, cf. ?*Merycoidodon* sp., *M. dunagani*) with the Lower Porvenir LF (LPLF) from the basal CTFm underlying the lower marker bed (LMB) and the correlative Montgomery Bonebed LF (MBBLF) from the middle part of the Bandera Mesa Mbr. of the Devil's Graveyard Fm. of the Buck Hill Grp. in SW TX. The small equid *Mesohippus viejensis* (incl. *M. texanus*) and the small hyracodontid *Hyracodon medius* (incl. *H. primus*, *H.* cf. *H. nebraskensis*) are members of the LRGLF, the LPLF, the Upper Porvenir LF (UPLF) from the lower (but not basal) CTFm lying 0.0–26.8 m above the LMB, and the LELF. The LRGLF also shares the oreodontoid *Bathygenys reevesi*? with the Red Table LF (RTLF, new), which underlies the MBBLF. Based on shared taxonomic occurrences, the LRGLF is coeval with the LPLF, RTLF, and MBBLF and is earliest late Duchesnean in age, whereas the UPLF is late early late Duchesnean. Agriochoerids in the LRGLF include the medium-sized, dentally derived protoreodontine *Eomeryx* n. sp. B (incl. *Protoreodon* cf. *P. petersoni*) and the very large agriochoerine *Diplobunops* n. sp. (incl. "*Agriochoerus maximus*"), a member of the late early late (type) Duchesnean Lapoint Fauna of NE Utah. The ages of the LPLF, UPLF, LELF, and, by correlation, the LRGLF are constrained by corrected Ar/Ar dates for the Buckshot Ignimbrite (37.680–38.288 Ma) and Bracks Rhyolite (37.141–37.273 Ma), which bracket the CTFm. Correlatives of the LRGLF, LPLF, RTLF, and MBBLF probably include the Diamond O Ranch LF

from the Climbing Arrow Mbr. of the Renova Fm. in SW Montana, the "Lower" Titus Canyon Fauna from the Lower Red Beds of the Titus Canyon Fm. of SE California (CA), the Spring Canyon LF (new) from the Upper Mbr. of the Pomerado Conglomerate in coastal S CA, and unnamed LFs in the upper Palm Park and Rubio Peak Fms. of SW New Mexico.

CLIMATE AND LIFE IN EARTH HISTORY: CO_2 OR OTHER FACTORS?

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Different Earth climates impact life by changes in pCO_2, tectonic activity, sea level, and ice expanse. High temperature periods are typically termed "greenhouse intervals", defined as periods of high greenhouse gas (largely CO_2) levels. Other climate factors are generally not part of this temperature model, yet they may account for long warm periods. These two models influence interpretations of ecology and evolution of ancient biotas.

With "greenhouse" temperature control assumed, climate syntheses may be logically circular with ancient, precise del^{18}O temperatures compared to temperatures assigned to estimated pCO_2 values along the GEOCARB model. A GEOCARB pCO_2 value can then be assigned to ancient temperatures. Thus, a Cambrian temperature may be compared with a Cenozoic temperature and a pCO_2 assigned to the Cambrian temperature based on the estimated Cenozoic pCO_2. Newer proxy studies) question this model by showing average pCO_2 through the cooling Cenozoic not dissimilar to the present, by halving the GEOCARB estimates for the early Eocene, and unlinking the onsets of Antarctic pack ice and glaciation developments to pCO_2 change. GEOCARB model concerns include very high pCO_2 estimates (30+x and 15x pre-industrial atmospheric levels, PAL) in carbonate-rich intervals (the later Cambrian and middle Mesozoic, respectively). However, modern oceanic acidification and problems in plankton calcification now appear with pCO_2 at only 1.5x PAL. A ~25%+ recent increase in global warming rate with Arctic Ocean ice loss suggests additional factors must be incorporated into the GEOCARB model and climate syntheses.

Increasing anthropogenic pCO_2 drives climate with rising temperatures forcing changes in biotic habitats. The standard model that global temperatures are primarily driven by alternations in CO_2 sequestration and production need reevaluation. These include higher global insolation and temperature with eustatic sea level rise in the ancient past, a condition also countered by likely pCO_2 decrease with onlap of warming epeiric seas with low oxygen content (i.e., Late Ordovician, later Devonian) and high carbon sequestration rates that correspond to dominant calcite biomineral production. Similarly, global temperatures should increase with marine onlap of largely equatorial continents and without increased pCO_2. Increasing insolation with sea-level rise by glacier melting suggests a near-future of accelerating warming beyond the "greenhouse paradigm" of the recent climate predictions.

Warmer climates themselves do not cause extinctions; they allow diversification. But climate warming by sudden volcanic CO_2 releases does cause extinctions by eliminating habitats, redistributing biotas and disrupting ecologies. Latitudinal and altitudinal cooling compresses habitats restricting biogeographic ranges but does not cause major extinctions.

UPPERMOST TRIASSIC PHOSPHORITE DEPOSITS FROM WILLISON LAKE, CANADA: AN INDICATOR OF PERTURBED CONDITIONS PRECEDING THE END-TRIASSIC MASS EXTINCTION

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The triggering mechanism of the end-Triassic mass extinction (ETE) has mainly been attributed to rapid rates of CO2 input into the atmosphere as a result of Central Atlantic Magmatic Province (CAMP) emplacement during which the Modern Fauna was severely affected. Therefore, the ETE is a suitable analogue for studying the consequences of current rising CO_2levels. The existing knowledge base on the conditions leading up to the ETE is incomplete, as the main focus has remained on the timing associated with initial emplacement of CAMP. In this study we investigated the paleoenvironmental conditions leading up to the ETE using upper Rhaetian phosphorite deposits from three sections (Ne Parle Pas, Pardonet Creek and Black Bear Ridge) at Williston Lake, British Columbia (Canada). Black Bear Ridge is the more proximal section and has a major hiatus as a result of sea-level fall during

the Rhaetian; yet, it preserves a veneer of phosphatic clasts at the sequence boundary. The upper 13 m of the Ne Parle Pas and the upper 3.5 m of the Pardonet Creek Rhaetian sequences consist of interbedded calcareous siltstone beds with high-energy phosphatic grainstone beds varying in thickness from a few cm to 40 cm. These phosphatic sequences represent storm event beds that were deposited between fair-weather and storm-weather wave base. Phosphatic coated grains (PCG) are abundant within phosphatic deposits and have a fragmented nature due to winnowing and reworking. Models investigating the formation of PCG are in agreement that PCG require deposition near the sediment-water interface in organic-rich sediment under suboxic to euxinic or anoxic conditions where repeated reworking of phosphatic grains and fluctuation of redox conditions play a fundamental role. Therefore, phosphatic coated grains indicate shallow water conditions where grains could be reworked with episodic euxinia near the sediment-water interface. The presence of pyrite framboids within PCG and phosphatic crusts corroborate suboxic to anoxic conditions within the zone of phosphogenesis. Petrographic and scanning electron microscopic analyses of phosphorites reveal spherical and filamentous structures which are interpreted as microbial microfossils. Spectroscopic analysis shows high intensity D-G bands (1350 cm^{-1}-D1 band and 1600 cm^{-1} - G band) that are indicative of organic matter (kerogen) supporting the microbial origin of phosphorites. This study presents the first shallow marine episodic euxinia record associated with the genesis of phosphorites which preceded the emplacement of CAMP. We suggest that either CAMP volcanism was not a sole trigger for the ETE or CAMP eruptions began earlier than previously thought. Stressed environments in shallow marine settings were perhaps precursors for reduced environmental stability leading up to the ETE in the northeastern Panthalassic Ocean.

REVISITING ROMER: EURYPTERID INFLUENCE ON EARLY VERTEBRATE EVOLUTION

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For over sixty million years during the early Paleozoic, eurypterid (Arthropoda: Chelicerata) and early vertebrate (Chordata: Vertebrata: Agnatha) populations thrived in nearshore environments of extensive but shallow seas. Eurypterids, with their scorpion-like features, developed increasingly raptorial appendages. Early vertebrates biomineralized calcium-phosphate into progressively more complex exoskeletons of bony scales and fused plates of armor. From this, Alfred S. Romer (1933) hypothesized that vertebrate armor was an adaptation for defense against predators like the coeval eurypterids. An interspecies relationship, including competition for resources or a predator-prey interaction between coexisting, but extinct, organisms is difficult to establish given the paucity of articulated fossils and almost no proof of direct interaction. However, extant taxa provide a testable means to infer the function of mouth parts and appendages in trophic function. From published experiments on the biomaterial strength of the telson and cuticle of *Limulus*, a horse-shoe crab, the pincers of the eurypterid *Acutiramus*, generate a puncture force against conspecifics or prey with 2-8 newtons (N) force. Ganoid scales of the armored *Polypterus* resist puncture forces of 0.5 to 1 N. Predation damage on two specimens of armored Pteraspidomorphi is attributed to eurypterids. Analogs from the Chelicerata, the subphylum that contains Eurypterida, and other aquatic arthropods from the subphylum Crustacea provide the basis to infer the other feeding capabilities of eurypterids as a second order consumer. Analogs of extant, aquatic vertebrates compared to known traits of euvertebrates support their trophic level as a first order consumer. The lack of a comprehensive phylogeny of the jawless euvertebrates hampers further consideration of how the lineages interacted and influenced the other over time. Nonetheless, there is still sufficient evidence in extant chelicerates, crustaceans and aquatic vertebrates to support Romer's original hypothesis, with some modification, that eurypterids influenced vertebrate history as being an available, capable predator in the coeval habitats of euvertebrates.

DIVERSITY DYNAMICS AND CLIMATE CHANGE IN CENOZOIC MARINE SILICEOUS PLANKTON

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The siliceous tests of the photosynthetic diatoms and the holoplanktonic, often mixotrophic radiolarians comprise a large fraction of the available Cenozoic plankton fossil record. Their diversity (several thousand and several hundred living species, respectively) and biogeographic complexity (poles to tropics, surface to abyssal) substantially exceed the that of the other major deep-sea fossil plankton groups,

particularly coccolithophores and planktonic foraminifera, and both siliceous groups play a large role in the ocean carbon pump. Their taxonomy and species-level ecology is however still relatively poorly understood, as most research has targeted carbonate secreting plankton for geochemical paleoceanography and/or the search for oil.

Diatoms originated as benthos in the early Mesozoic but became common in open ocean plankton only in the early Cenozoic, and their diversification is very closely tied to Cenozoic climate cooling. Diatoms may have played a key role in the draw-down of atmospheric CO2 and the initiation of Antarctic glaciation at the Eocene-Oligocene climate transition. The close link between diatom diversity and cooling in the Cenozoic suggests that living cold water species, many of which are important carbon exporters, may be at risk of extinction due to anthropogenic global warming. Radiolarians have been common plankton components since the basal Phanerozoic. They show major changes in taxonomic composition over the Cenozoic, also linked to paleoceanographic change, and a major reduction in test silica use, due to an inferred major decrease in dissolved silica concentration over the Cenozoic caused by increases in diatam silica use and sequestration in deep waters by increased ocean stratification.

Recently our group has begun a new 4 year project ('Paleogene Polar Plankton and Productivity' aka P4, funded by the MOPGA-GRE program) to better understand the two-way links between siliceous plankton evolution and Cenozoic climate change, concentrating on the 40-30 Ma time interval that marks the major cooling and initiation of Cenozoic glaciation. Bidiversity dynamics analyses using the NSB (Neptune) database plus new comprehensive biodiversity surveys of both diatoms and radiolarians in globally distributed sections will be combined with new paleoceanographic productivity and ocean temperature proxy data and interpreted in the context of ocean productivity-circulation models.

Initial results of the new NSB-based diversity analyses and their relation to climate change will be presented together with details of the P4 project plan. Lastly the current status and prospects will be reviewed for obtaining a first comprehensive dataset of Cenozoic siliceous plankton diversity which would better illuminate the links between siliceous plankton evolution and global climate change.

NSB AND MIKROTAX: DATABASES AND SOFTWARE TOOLS FOR FOSSIL AND LIVING PLANKTON RESEARCH

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The fossil record of marine plankton, mostly from deep-sea sediment sections, is without question the most completely preserved record of species-level evolution available to science. Further it is closely linked in the same sections to equivalently detailed records of environmental change. Long used primarily to provide geologic ages for paleoceanographic studies, or to find oil, it is increasingly being used to understand interactions between large scale patterns of biologic evolution and planetary change. Thousands of specialist studies have been published alone on fossil plankton species taxonomy, and their stratigraphic and geographic distribution over time. Very little of this information has been made available in general paleontologic databases like PBDB. Instead, parallel databases have evolved from initiatives in the marine micropaleontologic community, particularly NSB (Neptune) and Mikrotax. The most recent trend has been the development of links between these databases, which support a much larger range of information retrieval and new types of data synthesys tools.

NSB is the current instance of the Neptune database of deep-sea microfossil occurrences (currently ca 780K records), together with taxonomy name lists (ca 9K species names) and geologic age models for hundreds of globally distributed sections. The website (nsb-mfn-berlin.de) provides downloads of taxonomically resolved occurrence datasets by age, paleolocation and other parameters; individual section age model, biostratigraphic and event calibration data; and simple taxonomic name lists.

NSB is supported by open-source end-user applications for creating age models (Age Depth Plot or ADP) and Raritas, a counting program with a rare-taxa mode, to generate quantitative occurrence data from samples.

Mikrotax is the main community marine microfossil taxonomy database, accessible at www.mikrotax.org. It contains full taxonomic catalog information for several thousand species and higher level taxa of living, Cenozoic nad Mesozoic calcareous nannofossils and planktonic foraminifera, plus literature citations,

geologic range charts and many advanced search and data synthesis functions. Parallel catalogs can be made for original descriptions and current taxa concepts. Mikrotax provides taxonomic name list updates to NSB and dynamically generates age and paleobiographic distributions for taxa from NSB. Catalogs for Cenozoic radiolarians and Paleozoic acritarchs are currently in development.

Mikrotax is widely used for routine taxonomic queries by the global micropaleontology community. NSB and its prior incarnation as Neptune has mostly been used for paleobiologic and evolutionary ecology studies, although it also has a growing user base of the geologic age models for paleoceanographic studies.

FORAMS OF COASTAL UTAH: A RECORD OF OCEANIC ANOXIC EVENT 2 (~94-93 MA) ALONG THE WESTERN EDGE OF THE US WESTERN INTERIOR SEA

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The Upper Cretaceous of southern Utah contains thick deposits of dark mudrock and shale that capture critical oceanographic changes at the onset of Oceanic Anoxic Event 2 (OAE2) and record rapid environmental perturbations during the transgression of the Greenhorn Sea. We investigated the response of planktic and benthic foraminifera in a shallow (~50 m) marine environment, at the interface of Boreal and Tethyan water mass influences, stressed by the onset of OAE2 during the Cenomanian-Turonian boundary interval (CTB=93.9 Ma). Our research is based on quantitative foram population counts from a composite 30-m outcrop and 10-m core section of the Tropic Shale near Big Water, Utah. The OAE2 interva is identified by a distinctive $\delta^{13}C_{org}$signature and cor relation of bentonites and carbonate-rich units across the seaway. A total of 291 samples were analyzed, with average resolution of ~1.5–2.0 ka below bentonite B and ~3.5–5.0 ka above.

The basal 6 m of the Tropic Shale are sandy and contain sparse assemblages of agglutinated benthics and very rare specimens of planktic foraminifera as the seaway advanced westwards. The onset of OAE2 coincides with rapid transgression; surface waters were abruptly dominated by species of triserial *Guembelitra*with minor portions of biserial *Planoheterohelix*. Benthic abundances increase at the same time and were initially dominated by infaunal *Neobulimina albertensis*. Importantly, this transgressive interval contrasts with the correlative well oxygenated and diverse "Benthonic Zone" of the central and eastern portions of the seaway. There is no evidence for ocean acidification in the foraminifera at the onset of OAE2. Epifaunal *Gavelinella dakotaensis*briefly proliferated during the early plateau phase of OAE2, closely coinciding with the widespread planktic "*Heterohelix*shift" at 12 m. The peak of OAE2 at ~17 m is marked by a rapid shift in benthic assemblages to infaunal *Neobulimina*dominance. We suspect incursion of warm, oxygen-poor Tethyan waters with continued transgression, coupled with high productivity resulted in the rapid depletion of benthic oxygen. This interpretation is consistent with biomarker data indicative of enhanced water column stratification and reducing conditions. A sharp decrease in *Guembelitria*and concomitant increase in trochospiral planktic taxa mark a major flooding event at 22 m in the outcrop section, prior to the decline of OAE2. These correlations result from an intricate relationship among rising sea level, shifting water masses (Boreal and Tethyan?), flux of organic matter, reduced benthic oxygenation, and consequent biotic turnover. Periodic oxygenation(?) events on the seafloor coincide with pulses of planktics after OAE2 in the early Turonian. The foraminiferal record reveals strong cyclicity in planktic/benthic ratio and in species dominance resembling eccentricity-paced parasequences of Utah that can be correlated to the limestone-marlstone couplets in central Colorado.

MARINE OXYGENATION AND THE EARLY DEVELOPMENT OF PALEOZOIC REEFS

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Microbial carbonates were major components of early Paleozoic reefs until coral-stromatoporoid-bryozoan reefs appeared in the mid-Ordovician. We recognize six Cambrian-Ordovician reef intervals: I, Late Ediacaran (~550–541 Ma) microbial reefs with *Cloudina*, *Namacalathus*, and *Namapoikia*; II, Earliest Cambrian (Fortunian–mid-Age 2) microbial reefs with rare "*Ladatheca*"; III, Microbial-archaeocyath sponge reefs with radiocyaths, coralomorphs, etc. from mid-Age 2 to Age 4; IV, Microbial-lithistid sponge reefs in

the mid-late Cambrian; V, Microbial-lithistid sponge reefs augmented by *Calathium*, pulchrilaminids, bryozoans, *Lichenaria*, *Amsassia*, and *Cystostroma* in the Early and early Middle Ordovician; VI, Skeletal-dominant reefs mainly constructed by stromatoporoids, corals, and bryozoans together with microbial carbonates in the late Darriwilian and Late Ordovician.

This pattern indicates initial increase in skeletal reefs (Intervals I–III) followed by mid-late Cambrian decline (Interval IV) and then Ordovician recovery (Intervals V–VI). We suggest that this largely reflects changes in marine oxygenation mediated by global temperature fluctuations. During Intervals I–III, oxygen increase contributed to diversification of marine animal life. This was followed during Interval IV by a prolonged period of 'greenhouse' conditions. As sea-level rose and CO_2 increased, the mid–late Cambrian was unusually warm. These elevated temperatures lowered oxygen solubility, promoting widespread thermal stratification that resulted in a tendency to marine dysoxia and hypoxia. Greenhouse conditions also stimulated carbonate platform development, locally further limiting shallow-water circulation. Reduced oxygenation has been linked to episodic extinctions of phytoplankton, trilobites and other metazoans during the mid–late Cambrian. We propose that this tendency to dysoxia-hypoxia in shallow marine environments also limited many metazoan reef-builders, resulting in the rise of a distinctive microbial-lithistid sponge consortium well-adapted to low oxygen conditions that globally dominates mid-late Cambrian reefs. These conditions ameliorated during the Ordovician as CO_2 decline lowered temperatures and promoted ocean ventilation. Thus, the prolonged time gap occupied by low diversity reefs between the 'Cambrian Explosion' and the 'Great Ordovician Biodiversification Event (GOBE)' reflects elevated temperatures and reduced marine oxygenation that limited metazoan diversification in shallow marine environments. This reef perspective could be broadly applicable to marine biotas in general, providing an overarching explanation for the prolonged mid-late Cambrian pause between the Cambrian Explosion and the GOBE.

LEAVING A MARK: HORSESHOE CRAB TRACE FOSSILS OF THE PONY CREEK SHALE LAGERSTÄTTE, UPPERMOST PENNSYLVANIAN, KANSAS

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The uppermost Pennsylvanian Pony Creek Shale Member of the Wood Siding Formation in Wabaunsee County, Kansas, contains exceptionally preserved horseshoe crab (Xiphosura) fossils. Associated with these fossils is an ichnofauna that includes horseshoe crab traces, as well as burrows and bromalites.

The deposit has been interpreted as a marginal marine deposit. More specifically the Pennsylvanian Pony Creek Shale Member has been interpreted as a transition between multiple depositional environments (from non-marine to marginal marine & higher intertidal to non-marine).

Of the trace fossils recovered from the Pony Creek Shale Member, 15 represent Xiphosuran moving traces of varying morphology and clarity, the other traces represent the ichnogenus *Rhizocorallium*, several unidentified burrows, and a number of bromalites, some preserving animal remains.

The Xiphosuran moving traces from the Pony Creek Shale Member are primarily crawling trails. These traces are distinguished by back and forth scratch marks, as opposed to the typical Xiphosuran tracks that show independent foot marks in the sediment. However, some of the specimens from the Pony Creek Shale Member still show the groove made by the telson. There is also one Xiphosuran moving trace that indicates ploughing into the sediment.

The low diversity and types of trace fossils present indicate a tidal flat depositional environment, as traces from Xiphosurans have been associated with marginal marine and non-marine environments, *Rhizocorallium* is often associated with a variety of marine (and some lacustrine) environments, and the presence of mud cracks indicates reoccurring sub-aerial exposure.

PALEOENVIRONMENT AND FOSSIL DISTRIBUTION ON AN EDIACARAN-CAMBRIAN MIXED CARBONATE RAMP (TAMENGO FORMATION, BRAZIL)

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Mixed carbonate-siliciclastic exposures of the Tamengo Formation (Upper Corumbá Group – Terminal Ediacaran), record the rise of metazoans and the origin of calcareous biomineralization in animals. To explore the relationships between environmental settings and the first appearance of calcified metazoans and their ecology, we present sedimentological and stratigraphic detailed data across transects that capture the final stages of the Ediacaran (550 to 543 Ma). This study combines stratigraphic characterization with detailed facies descriptions and makes an evaluation of lateral heterogeneity and overall ramp sedimentation integrated with fossil distributions, strongly controlled by sedimentary facies. The Tamengo Formation represents a mixed storm-dominated ramp developed on a low-gradient ranging from outer to inner settings. Outer to mid-ramp are composed of very fine siliciclastic rocks containing *Corumbella* body fossils and thin-bedded mudstone/wackestones containing *Cloudina*. Mid to inner ramp are dominated by wackestones/packstone with abundant *Cloudina* fragments as skeletal debris and oolitic packstones/grainstone shoal deposits. Locally, fragments of *Corumbella* and *Cloudina* are found at the same layer, which is distinguished by a high accumulation of small fragments of both kinds of carapaces, likely resulting from the reworking and mixing of the epifaunal organisms. The general distribution of *Corumbella* and *Cloudina* suggest these organisms have habitat preferences. When compared to other occurrences worldwide, the dataset indicates an already complex ecosystem in the Ediacaran, where these early animals were capable of migrating and adapting to specific environmental niches.

THE ROLE OF FIELD PALEONTOLOGY HIGH SCHOOL EXPERIENCES IN SHAPING SCIENCE STEWARDSHIP ON PUBLIC LANDS

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Many paleontologists can remember their first formative field experiences, and can acknowledge the role these experiences play in shaping their understanding of the natural world. Field paleontology educators of all stripes can attest to how these experiences infuse a sheer joy of discovery in the learner. In addition, field experiences on public lands have the potential to shape the ways in which learners perceive their place in the natural world, and their sense of responsibility and motivation to conserve it. The idea of such 'science stewardship' is not a new one in the twin fields of outdoor and experiential education, yet research on paleontological science stewardship on public lands remains a relatively untapped area of study. Studying the relationship between human beings and the natural areas with which they interact - human dimensions research – builds a growing and much needed conceptual framework of this interaction, especially in the context of paleontology on public lands.

This study analyzed separate groups of female-identifying (n=49) and male-identifying (n=51) 9th grade high school students on their first field paleontology experience at Rainbow Basin Natural Area, California, managed by the Bureau of Land Management. Likert-style surveys and instructions for written self-reflections were given pre-treatment, providing quantitative and qualitative data respectively. Post-treatment surveys and written self-reflections were given within a four month span of the field experience to reduce short-term effect. To triangulate data effectively, select students and faculty were interviewed post-treatment. A comparison group of students who chose not to select a 10th grade honors paleontology class as a continuation of the field experience was also analyzed via survey to gain further perspective on student motivation to study paleontology in a formal setting.

Likert-style responses were grouped thematically by question, by total individual responses to each question, and student-by-student across each question. Written responses were also grouped using thematic analysis. A comparison of female-identifying and male-identifying response trends also allowed insight into a secondary question on increasing female motivation to pursue paleontology as a career. Survey data indicate relative consistency in pre- and post-treatment responses student-to-student, through when paired with qualitative responses, the power of science stewardship and a personal sense of connection to public lands becomes markedly apparent. In a climate of aggressive public land boundary and policy changes, assessing the impact of public lands paleontology on the sense of stewardship in younger learners is timely. Future work to study science stewardship motivation on public lands will continue to lay the foundation for our understanding of how we interact with, and learn from, irreplaceable paleontological

resources and the lands that house them.

NEW NON-TRILOBITE ARTHROPODS FROM THE DRUMIAN 'DEEP WHEELER' LAGERSTÄTTE OF THE HOUSE RANGE (UTAH, USA)

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The Drumian (Miaolingian) strata of the Wheeler Formation in the House Range of Utah have yielded one of the most diverse Cambrian Burgess Shale-type biotas of the USA. Yet, only a handful of its c. 40 non-biomineralizing taxa are known from more than a couple, often incomplete specimens. In this contribution, we describe new remarkable fossils belonging to nine arthropod species, which contribute in various ways to a better understanding of the deep Wheeler biota.

We report the first occurrences of some taxa in the Wheeler strata of the House Range, such as the radiodonts *Amplectobelua* (*A. stephenensis*) and *Hurdia* (a new species), and megacheirans (one, possibly two species). Other findings provide new insights on taxa previously reported from these deposits: two isolated valves of *Perspicaris*? *dilatus* show that this 'bivalved arthropod' occurs outside the type locality of the Wheeler Formation, and reached a larger size than previously reported; a complete dorsal exoskeleton of *Naraoia compacta* dispels doubts surrounding the presence of this species in the deep Wheeler; a new specimen of *Messorocaris magna* – the second known to date – displays a bifurcated telson, a character excluding this arthropod from the Sanctacarididae; and a specimen of *Itagnostus interstrictus* demonstrates that fossils of this particularly abundant agnostine species may preserve appendicular remains.

Although the Wheeler Formation in the House Range is not as prolific as the Burgess Shale or Chengjiang Lagerstätten, the continuous collecting effort and systematic description of remarkable fossils from these strata allows this biota to shine its own complementary light on the early evolution of modern-style marine ecosystems.

EVOLUTION OF THE DIGESTIVE SYSTEM IN CAMBRIAN TRILOBITES

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Trilobites were the most prominent members of the Cambrian Evolutionary Fauna, which has dominated taxonomically and ecologically marine ecosystems for most of the Early Paleozoic. The spectacular diversification of these euarthropods during Cambrian Epoch 2-Miaolingian times was accompanied with a dramatic increase of their morphological disparity, which can be challenging to translate into a coherent phylogeny and to interpret in terms of ecological changes. Similarly, the evolution of trilobite internal anatomy during that critical period remains essentially unknown, as organ systems are rarely fossilized (if ever) and their organization is usually not reflected by the dorsal exoskeleton. The digestive system represents an exception to these limitations, and a rare opportunity to explore the evolution of trilobite internal anatomy during the early radiation of the group.

In this contribution, the architecture of trilobite gut and its variations in Cambrian representatives is reviewed using direct (i.e. digestive structures) and indirect (e.g. muscle scars, glabellar morphology, phylogenetic inferences) evidence, including the first examples of fossilized guts in seven species. The different preservation modes and the way they may influence gut reconstructions are briefly presented. Known variations in gut architecture are also mapped on a recently published phylogeny of Cambrian trilobites, in an attempt to reveal aspects of gut evolution in these organisms. We conclude that the ancestor of all trilobites likely possessed a simple digestive tract flanked with numerous, simple digestive glands, as inferred from glabellar morphology and conditions observed in trilobite closest relatives. A pouch-like differentiation of the foregut or crop likely evolved in various independent clades as early as the Cambrian Age 3, and repeatedly thereafter. In the most spectacular cases, this evolution was associated with a complete loss of the digestive glands, as illustrated by new examples of phosphatized guts in the Olenellina. Some variations, such as the ventral expansion or complexification of digestive glands, are presented but their scarcity prevents discussing their evolution within the clade.

Lastly, interpreting the variations of gut architecture in trilobites in terms of feeding strategies is difficult, but we present the case of the evolution of predatory habits in the Olenellina.

THE EVOLUTION OF PHENOTYPIC PLASTICITY IN STYLOPOMA

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Bryozoans colonies grow by asexual propagation of members ("zooids") within a colony. Previous studies of the cheilostome bryozoan *Stylopoma* have shown that there is a wide range of morphological variation of zooids within in a colony. This pattern limits the amount of evolution that occurs within a colony, since phenotypic changes don't accumulate. But different *Stylopoma* species are morphometrically distinct, showing that even though these same attributes cannot evolve within colonies, they can and have evolved across different species. Therefore, the pattern of evolution within colonies must be screened off from the pattern of evolution between species. To study this evolutionary process, I test the idea that the degree of plasticity of morphology within a colony is evolving rather than individual phenotypes of zooids within in a colony. Using *Stylopoma* colonies bred in a common garden breeding experiment, I measure the heritability of phenotypic plasticity between colonies.

THE EARLY ORDOVICIAN LITHISTID SPONGE-MICROBIAL REEFS, TARUTAO ISLANDS, THAILAND: A PRELUDE TO THE RECOVERY OF METAZOAN REEFS

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The late Cambrian and Early Ordovician are characterized by a resurgence of microbialites and a nexus of metazoans and microbial mat communities in reef ecosystems. The latest progress suggests there was a critical change in reef composition on the Tremadocian-Floian boundary globally, but there were significant regional variations in the patterns of this biotic transition. Shallow-marine shelf sediments of the Ordovician are widely distributed in the Tarutao Archipelago, off the coast of Satun Province of southern Thailand. Well-preserved Early Ordovician reefs are exposed along the shoreline of the Pa Nan Island. The lithistid sponge-microbial reefs occur in the late Tremadocian Pa Nan Formation, Thungsong Group. There are at least three reef horizons in the outcrop. Individual reef bodies are domical or lenticular in shape with a thickness of 2.8–11.5 m, surrounded by bioclastic limestones. The microbial reefs mainly composed of columnar stromatolites and domal thrombolites. Horned lithistid sponges (anthaspidellids) occur exclusively in the thrombolites. Except for lack of *Calathium* (hypercalcified sponge), the microbial reefs we studied here exhibit a striking similarity to the early Floian microbialites of Perlis, western Malaysia. Both cases of the reefs from Turatao and Perlis represent remnants of the microbial-dominated ecosystems during this transitional period, providing invaluable clues to the stepwise recovery of metazoan reefs after the late-Early Cambrian archaeocyaths reef crisis.

UNTANGLING LOWER MIOCENE REEF FRAMEWORKS: A CASE STUDY FROM THE XISHA ISLANDS, SOUTH CHINA SEA

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With more than 200 carbonate platforms of Oligocene to Recent age, South China Sea provides a natural laboratory to explore isolated platform systems. Especially in the Xisha Islands, a rich and well-preserved Miocene fossil record of small patch reefs has been reported since the 1980s. However, the framework structures of these reefs and the paleoecology of reef builders have not been investigated in detail. Based on the drill core materials of the Well XK-1 from the Shi Island (a small island in the northeastern Xisha Islands), a particular description of the frameworks of patch reef in the lower Sanya Formation (Lower Miocene) is presented. Four facies types are distinguished within the reef limestones (about 10 m thick): (1) coral-algal framestone, (2) chaetetid-algal bafflestone, (3) bryozoan-algal bindstone and (4) alga-foraminiferal bindstone. Due to their relatively broad ecological tolerance, larger benthic foraminifera are common in all facies. As a dominant type, the coral-algal framestone shows a three-dimensional skeletal framework

that is mainly constructed by corals and stabilized by coralline algae. Most corals are densely packed in growth position and *Porites* is the leading reef builder. The reef is formed by a complicated mosaic of these four types of lithofacies, and no vertical zonation was recognized. The massive reef limestone is overlain by thick-bedded bioclastic rudstone. Reef of the lower Sanya Formation were terminated by shallowing, indicated by a short-term regression above the reef.

BIOTIC INTERACTIONS BETWEEN CORALS AND STROMATOPOROIDS FROM THE UPPER-UPPERMOST FAMENNIAN (DEVONIAN) ETOUCUN FORMATION, HUILONG, SOUTH CHINA: IMPLICATIONS FOR THE RECOVERY OF REEFAL ENVIRONMENTS AFTER THE F-F CRISIS

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Biotic interactions between corals and stromatoporoids are important to understand the Paleozoic reef structure and evolution through time. Extensive reef complexes occurred globally in the Givetian and Frasnian, characterized by various forms of coral-stromatoporoid associations. However, the reef community suffered greatly in the global Frasnian/Famennian biotic crisis and little is known about the coral-stromatoporoid relationships in the Famennian. In this study we document biotic interactions between corals and stromatoporoids from the upper-uppermost Famennian (Devonian) Etoucun Formation, Huilong, South China, indicating the recovery of reefal environments for metazoan during latest Famennian, approximately 13 Ma after the F-F crisis.

The upper-uppermost Famennian Etoucun Formation at Huilong, which is the stratotype section for the regional Shaodongian stage of South China, is characterized by thick-bedded to massive peloidal limestone containing abundant stromatoporoids, syringoporoid tabulate, rugose corals, gastropods, and oncolites, indicating open to restricted carbonate platform environments. Two foraminifer biozones, corresponding to DFZ4-DFZ6 and DFZ7, respectively, are recognized in the formation, and contain different stromatoporoids and syringoporoid tabulate corals. In the former foraminifer zone, biotic interactions are relatively rare and include: stromatoporoid *Labechia* and *Gerronostroma* encrusting *Cystophrentis* rugose corals; endobionts auloporids embedded in the skeleton of stromatoporoid *Gerronostroma*, indicating a syn-vivo interaction; syringoporoid tabulate coral *Chia* settling on the growth surface of stromatoporoid *Platiferostroma*. In the latter foraminifer zone, biotic interactions are much more frequent and include: syringoporoid *Fuchungopora* settling on the growth surface of stromatoporoid *Gerronostroma* and conversely, fouled by the latter genus; stromatoporoid *Labechia* encrusting syringoporoids; overgrowth between stromatoporoids *Gerronostroma* and *Stylostroma*. These associations, combining with the development of stromatoporoid biostromes in the DFZ7, indicate an obvious recovery of metazoan reefs in the uppermost Famennian, although the scale and complexity is much less than those of the Givetian and Frasnian reefs.

SHELL STRUCTURE AND AFFINITY OF THE PROBLEMATIC EARLY CAMBRIAN BRACHIOPOD HELIOMEDUSA ORIENTA SUN AND HOU, 1987

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The origin of the Brachiopoda has long been a hotly debated topic of discussions, and various models have been proposed, both based on molecular studies of their living representatives as well as on morphoanatomical investigations of fossils with exceptional preservation of soft parts. The lower Cambrian (Stage 3) *Heliomedusa orienta* from the Chengjiang Lagerstätte eastern Yunnan of South China is an important example of such an exceptionally preserved, but problematic fossil brachiopod that have been important in the various proposed models for early brachiopod evolution. The proposed affinities of *Heliomedusa* have varied widely but lately it has been suggested to belong within the mickwitziids; these problematic brachiopods are widely distributed components of the lower Cambrian "small shelly fossil" assemblage, and have been suggested to form a paraphyletic stem group within the Brachiopoda. Detailed studies of exceptionally preserved *Heliomedusa* have increased our knowledge of the soft-part anatomy of this important early brachiopod, notably the unique architecture of the lophophore, but in contrast almost nothing is known about the shell structure. Here we describe the shell

structure of new exceptionally preserved specimens from Chengjiang localities imaged using Scanning Electron Microscopy, micro-XRF and high resolution optical z-stacked analysis better revealed both the external and internal structure and morphology of the shell. The radial costellae radiating from the apex of ventro-biconvex shell valves are remarkably reminiscent of those seen in other mickwitziid brachiopods. Moreover, at the anterior margin of valves, there are tiny openings filled with pyritized matter, potentially representing preserved setae. These setae, 50um in diameter and 4mm in length at most, are preserved in pyrite with a distinct framboidal texture; they are oriented in a radial fashion originating from the centroid but with a posterior-facing tendency along the posterolateral margins. In addition, in some well recrystallized specimens, 4-5 broad concentric growth bands can be seen from the shell surface. Compared with the Swedish *Mickwitzia monilifera*, they share many similarities in shell structure supporting the view that *H. orienta* is probably closely related to *Mickwitzia*.

EXPLORATION OF CAMBRIAN FOSSILS BY MICRO X-RAY FLUORESCENCE SPECTROMETER

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With the increasing emphasis on basic research in China, great achievements have been made in paleontology, especially in the study of early life and the Cambrian explosion. Research facilities have been improved, such as Scanning Electron Microscopy (SEM) and X-ray micro-tomography Scanner (Micro-CT) have been used extensively in researches. Micro X-ray Fluorescence (μ-XRF) is a non-destructive technique used to study those exceptionally preserved brachiopod fossils from the lower Cambrian lagerstätten in South China. Here we present the first μ-XRF mapping of exquisite fossils with soft-part preservation recovered from the Wulongqing Formation of two important localities, the Jianshan section and the Gaoloufang section in eastern Yunnan. Due to the Penetrative capabilities of this technique, some fine details, such as lophophore, which is invisible under optical microscope, can be observed. Semi-quantitative analysis of chemical elements (Na-U) and compounds in the matrix also reveals subtle differences in sedimentary mineral characteristics between the Chengjiang and the Guanshan deposits. μ-XRF does not require any sample preparation before testing and scanning, which is a useful and non-destructive technique for surface scanning of specimens, and micro-area analysis at different scales. μ-XRF is providing critical new information for comparative studies of the preservation and sedimentary environment of fauna in critical deposits such as the Chengjiang and the Guanshan deposits.

REGIONAL PATTERNS OF LATE-QUATERNARY EXTINCTIONS IN SOUTH AMERICA: TOWARDS A MORE REALISTIC MODEL OF EXTINCTION DYNAMICS

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The late-Quaternary megafaunal extinction event (LQE) represented the greatest faunal change that terrestrial ecosystems had experienced during the Cenozoic, but the causes and dynamics of this event remain intensely debated. One obstacle to consensus, and to applying the lessons of this past ecological collapse to our current biodiversity crisis, is that most studies of the LQE seek a single cause for the extinctions, and consider only either very broad or very local geographic scales. Here we present the first study to investigate the LQE from a regional perspective, integrating multiple regions across a continent. We focus the study on South America, where the LQE was latest and most severe, and coincided closely with both human migrations and end-Pleistocene climate changes.

Improvedradiocarbon chronologies, detailed population and biogeographic models, and quantitative comparisons between paleontological, paleoclimatological, and archaeological datasets indicate that the LQE in South America was protracted and geographically heterogenous, involving different pressures acting independently and in concert on distinct taxa across several thousands of years. Key results include: (1) Human colonization of the South American continent was extremely rapid, whereas extirpations of megafauna occurred patchily in different regions; (2)

High-altitude and high-latitude regions more sensitive to climate warming appear to have lost megafauna earlier, and coincident with late-Quaternary climate changes; (3) Individual taxa responded differently to different end-Quaternary phenomena, with equids disappearing during vegetational shifts in multiple regions, notoungulates and large carnivores frequently disappearing shortly after human arrival, and Xenarthrans often coexisting with humans for thousands of years; and (4) In at least one region, climate change and anthropogenic impacts combined synergistically to hasten megafauna collapse. Taken together, these results paint a complex picture of extinction much more comparable to our understanding of modern ecological patterns and processes, and point a way forward for applying the lessons of the past to investigating, and hopefully averting, the sixth mass extinction.

THE SIGNOR-LIPPS EFFECT IN PALEOBIOLOGY, PALEOECOLOGY AND EVOLUTION

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In 1982, Signor and Lipps noted that all mass extinctions were preceded by gradual extinction patterns; Raup later named this the Signor-Lipps Effect. The Signor-Lipps publication became a "landmark paper" in the mass extinction debates, a topic of debate itself, an item of classroom instruction, and included in textbooks. The gradual Signor-Lipps Effect occurs when plots of taxa ranges approach an extinction event. This is a general pattern in the fossil record and is found at many places, at many times. Better and more intensive sampling in the field and laboratory did not reveal a sudden pattern, which assumes that the species occur in every sample over their biogeographic and evolutionary lifetimes. To test this, ranges of various organisms occurring up to every sampling site in several stratigraphic successions showed a gradual range truncation at every sample, even though all species occurred in older and younger samples. Thus, inadequate outcrop sampling or sample processing and examination do not explain the Signor-Lipps Effect. Instead other geological, biological and methodological processes create such patterns, including taphonomic changes, diagenesis, missing strata, solution or breakage, removal of specimens by predation or competition during life, population declines, or emigration of populations during life from the sampling site to another area, and failure to collect or find all taxa in samples. Numerical processing of biostratigraphic data assumes that the fossils occur in all samples but this is clearly not true. Since the absence of taxa in samples are caused by other factors, statistical methods will produce incorrect results. In paleoecology and evolution, the Signor-Lipps Effect is thus important for the evaluation of the complete biodiversity and macroecology of an evolving sequence of organisms. The Signor-Lipps Effect must be considered in phylogenetic analyses of taxa because some or all nodes cannot be detected. Mass extinctions themselves can best be detected by examination of biotas that occur before and after the event and that are significantly different.

BIOLAMINATION STRUCTURES FROM GUOJIABA FORMATION (CAMBRIAN STAGE 3) IN HANZHONG AREA, SOUTH CHINA

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Microbially induced sedimentary structures (MISS) are microbial traces in sandy deposits. They are formed by various modes of microbial behaviour in response to the prevailing physical dynamics in shallow marine environments since the early Archean. In Hanzhong area, the Guojiaba Formation is characterized by laminated sandstones, siltstones and mudstones, over 300m in thickness, which disconformably over lies the Dengying Formation and conformably underlies the Xiannüdong archaeocyathan limestone. The upper part of the Guojiaba Formation is composed of silty shales and mudstones with limestone nodules, which bears diverse shelly faunas. While as, the lower sandstone unit is unfossiliferous. Petrological analysis shows that the mineral composition is mainly quartz and feldspar, with a small amount of muscovite. A typical structure of MISS, the biolamination, is flourishing in this unit. Biolamination is typical for epibenthic microbial mats in supratidal zones and distributed in dynamically quiet areas. The structures arise from the microbial growth followed by the rapid *in situ* lithification. In cross-section, the laterally continuous mat laminae are visible. The laminae are wavy-crinkled in mm scale. While, seen from above, a planar mat surface covers the original depositional surface, and the prior sedimentary surface structures such as ripples are not visible anymore. Poorly preserved fossils, sponge spicules, are found in the mat surfaces here.

LOTAGNOSTUS SPECIES FROM THE CAMBRIAN (FURONGIAN) WINDFALL FORMATION, NEVADA, AND THEIR SIGNIFICANCE REGARDING ON THE GSSP FOR CAMBRIAN STAGE 10

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Peng, et al. (2015) advocate the FAD of *Lotagnostus americanus* (Billings, 1860) in the Wa'ergang section, China, for as the GSSP of Cambrian Stage 10, utilizing a broad species concept (Peng and Babcock, 2005) that encompasses from both strongly scrobiculate and weakly scrobiculate forms.

Large collections of agnostoid arthropods and olenid trilobites were recovered from several horizons in the Windfall Formation at Ninemile Canyon, Nevada. The sclerites are well preserved, displaying minimal taphonomic sheering or compaction. Scrutiny of >1100 *Lotagnostus* sclerites fromthe stratigraphically lowest horizon revealed the presence of two, non-intergrading morphologies: a strongly scrobiculate form with obvious trisection of the posteroaxis and a second form on which the scrobiculae and trisection are weakly developed or absent. Both morphs would fall within the range of variation outlined by Peng and Babcock for *L. americanus*. However, comparison of specimens of equivalent size confirms that the 2 morphs are not not an ontogenetic variants; intermediate forms are lacking in all size ranges. A stratigraphically younger, *Lotagnostus*-dominated USGS collection (D3381-CO; with co-occurring euconodonts of the *Proconodontus* or *Eoconodontus* Zone) from the same locality also contains non-intergrading morphs: a strongly scrobiculate form conspecific with that of the older collection and a weakly scrobiculate morph that differs in several respects from that in the lower collection and represents a third species. This disparity in stratigraphic distribution, along with the morphologically distinct forms in both collections, suggests that these morphs represent separate species and that, unlike earlier agnostoids, *Lotagnostus* may have species that are more morphologically restricted, as suggested by Westrop, et al. (2011). The broad concept proposed for *L. americanus*by Peng and Babcock, is not supported and the status of the synonymized species should be reevaluated.

The paleogeographic distribution of *Lotagnostus* in the deposits of northern Laurentia also argues against its suitability as a taxon for defining a GSSP.The lower collection from the Windfall, dominated by *Lotagnostus*, represents a grainflow deposit delivered to a dysoxic, deeper-water setting. The rarity of *Lotagnostus* incoeval faunas from more proximal slope facies in of the Hillard Limestone in Alaskaand the Rabbitkettle Formation in the Yukon,Canada, and its absence from shelf break faunas of the Jones Ridge Formation in Alaska, indicate that the genus is was restricted to deep, dysoxic settings. Such environmental restriction severely compromises that utility of *Lotagnostus* for use in correlation into shallow platform successions of Laurentia and other tropical paleocontinents.

BAY OF THE LIVING DEAD: A PALEONTOLOGICAL PERSPECTIVE ON CHESAPEAKE OYSTERS

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The eastern oyster (*Crassostrea virginica*) plays a vital role in Chesapeake Bay habitats, acting as an ecosystem engineer and improving water quality via filtration. Populations of bay oysters have declined precipitously in recent decades, primarily due to human harvesting and disease. By the time oyster monitoring was established in the 1940s, reefs were already decimated, suggesting that scientists have never actually observed a healthy reef in the Chesapeake Bay. The fossil record, which preserves 500,000 years of once-thriving reefs, provides a unique opportunity to study pristine reefs and a possible baseline for oyster mitigation.

For this study, over 4000 fossil oysters were examined from 11 Pleistocene localities in the mid-Atlantic U.S. Data on oyster shell lengths, lifespans, growth rates, and population density were assessed relative to data from modern oyster monitoring surveys, in addition to archeological and historical sources. Comparisons to modern *C. virginica*, sampled from similar environmental conditions, reveal that fossil oysters were significantly larger, longer-lived, and an order of magnitude more abundant than modern oysters. This pattern results from preferential harvesting and disease-related die-off of larger, reproductively more active females from the modern population.

These fossil data, when combined with modern estimates of age-based fecundity and mortality, make it possible to estimate ecosystem services in these long-dead reefs, including filtering capacity and carbon burial. Conservation paleobiology can provide us

with a picture of what the Chesapeake Bay looked like, but also how it functioned before humans.

ALGAL STRUCTURE FROM THE UPPER MEMBER OF THE MIDDLE MIOCENE BARSTOW FORMATION, CALIFORNIA

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The middle Miocene Barstow Formation crops out extensively in the Mud Hills region of the Mojave Desert (San Bernardino County, California) and is composed of about 1,000 meters of nonmarine deposits that span about 6 million years (approximately 13–19 mya). The formation is subdivided into three members (Owl Conglomerate, middle, and upper) and the middle and upper members have yielded fossils of vertebrates, invertebrates, plants, pollen, phytoliths, and algae. In the lower part of the middle member, laterally persistent tufa deposits are present and have been referred to as the Massive Stromatolitic Limestone (MSL). The MSL on the south limb of the Barstow syncline is thinner and more thrombolitic than the massive development of stromatolitic phytoherms (which can exceed three meters in thickness) on the north limb of the syncline about 1.7 km distant. Marl beds from the upper member exhibit evidence of tufa development, but nothing as extensive as the MSL. In 2016, a large algal structure, with a hummocky thrombolitic surface texture, was found as float in a dry wash lying on strata of the lower part of the upper member. The specimen, as preserved, is nearly a meter long, 35 cm wide, and 22 cm thick. It is broadly curved in cross section relative to its long axis. Four smaller pieces that appear to be from the same structure were found 5 to 40 meters upstream and downstream from the very large specimen. The curvature of the algal structure suggests that it might have grown on a submerged log in a subaqueous environment. The presence of this large algal structure, along with the abundance of the aquatic gastropods *Lymnaea* and *Planorbula* and beaver teeth in the lower part of the upper member, indicate that there was significant development of persistent aquatic environments during the time these strata of the Barstow Formation were deposited.

MOLECULAR VS. MORPHOLOGIC PHYLOGENIES IN NEOGENE AND QUATERNARY LUCINIDAE (BIVALVIA) OF THE WESTERN ATLANTIC

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The Pliocene and Pleistocene was a time of change in the Caribbean and Western Atlantic, with large-scale biological exchange, global climate change (cooling during glacial intervals), and alterations in oceanographic and atmospheric circulation. During this time of environmental transition, bivalves and gastropods in this region experienced a taxonomic turnover event, the 'Plio-Pleistocene Regional Extinction.' Among taxa potentially affected are the Lucinidae, the most speciose family of living chemosymbiotic bivalves. To fully understand the potential effects of the Plio-Pleistocene regional turnover on lucinid evolution, a phylogenetic hypothesis for lucinids that includes fossil taxa is needed. However, the most recent lucinid phylogenies use molecular characters, therefore limiting them to extant taxa. Here, we develop a matrix of morphologic characters and reanalyze published molecular data to test the congruence of these datasets and the potential use of morphology to reconstruct evolutionary history. The incorporation of fossil taxa in molecular phylogenies often results in recognition of morphological synapomorphies. In fact, published lucinid molecular phylogenetic studies note shell characters with a potential phylogenetic signal that could be applicable to the fossil record.

Congruence between published molecular data and a new suite of morphologic characters were tested by producing molecular, morphological, and combined phylogenies that included fossil and extant taxa. In these species-level analyses, 52 Neogene and Quaternary lucinid taxa from the Western Atlantic were selected to represent lucinids across the Pliocene and Pleistocene regional turnover event. A morphologic matrix of 58 characters was developed to describe interior and exterior shell features including ornamentation, the hinge and teeth, muscle scars, pallial line, and the inhalant channel (a region assumed to be associated with chemosymbiosis). Published molecular data for two nuclear ribosomal genes (18S and 28S rRNA) and the mitochondrial gene cytochrome *b*(cyt*b*) were used for 21 extant species. We conducted both parsimony and Bayesian analyses on all character matrices. Both parsimony and Bayesian analyses of morphology produced poorly resolved phylogenies that show considerable non-congruence with molecular phylogenies. Further, in the combined dataset of morphologic and molecular characters, cladograms

contain many polytomies and were not congruent with molecular phylogenies. Therefore, this study indicates that morphologic characters seem to have a low phylogenetic signal and may be highly homoplastic. As a result, morphology may instead be a more reliable proxy for environmental factors.

THE PTERIDOLOGICAL COLLECTIONS CONSORTIUM: AN INTEGRATIVE APPROACH TO PTERIDOPHYTE DIVERSITY OVER THE LAST 420 MILLION YEARS

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Pteridophytes have an excellent and extremely long fossil record that can be linked to extant diversity, and are therefore an ideal system for studying evolutionary and ecological processes through time. The only comprehensive records documenting pteridophyte lineages and their changes in diversity over time and space are specimens in herbaria and natural history museums. These neo- and paleobotanical collections are typically housed in separate facilities and curated and studied by separate communities of researchers. The Pteridophyte Collections Consortium (PCC), funded in August of 2018, aims to fill a major gap in our knowledge by uniting these communities and facilitating the study of pteridophyte distribution and evolution from their origins roughly 420 million years ago to the present. The goal of our consortium is to image over 1.6 million herbarium and fossil pteridophyte specimens held in 36 U.S. institutions, and digitize their associated metadata. This neo-paleo integrative approach within a PCC Symbiota framework (http://pteridoportal.org) will allow unprecedented synthesis of neontological and paleobotanical approaches. These integrated open-access data will be critical tools for understanding deep evolutionary history of these major land plant lineages, charting the origin and change of terrestrial ecosystems over time, and for developing models to predict how plants respond to environmental change. Progress during the first year will be summarized.

PLANT MASS EXTINCTION AND RECOVERY? INFERRING THE NATURE OF ECOLOGICAL UPHEAVALS AT THE BASE OF THE TERRESTRIAL FOOD WEB

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Discoveries about the global history of life on our planet, and its most dramatic episodes—mass extinction and recovery—capture the imagination of the scientific community and the general public alike. Our thinking about this history in terms of fluctuations in global diversity is firmly rooted in the advent of quantitative marine invertebrate paleontology, exploring changes in diversity and assessing underlying rates of extinction and origination. The very definition and connotation of the term mass extinction is based on the marine invertebrate record, and first and foremost makes sense in that context. Compared to the marine invertebrate record the plant macrofossil record is hugely incomplete, both temporally and spatially, as well as with respect to which plant organs are preserved. Also problematic is that the floras are skewed towards plant communities that occupied the basinal lowlands where sediment deposition takes place, and are thus taxonomically and environmentally biased. The palynological record, on the other hand, has a much higher temporal resolution and spatial coverage, but represents a more regional signal, is biased towards mass producers, and the botanical affinity of palynomorphs is often unknown or not very specific. Paleobotanical global diversity dynamics studies do show us rates of extinction and origination in in major taxonomic groups, but they fail to inform us about what may have been happening at the biological organizational level. It is here where disturbance may have cascading effects causing system collapse during biotic crises, or the subsequent rebuilding of system complexity during the recovery phase. In order to better understand what happened in the terrestrial realm across the Permian-Triassic transition and its aftermath, we choose to treat the plant fossil record as a global collection of community to ecosystem-scale case studies. Here we will present a number of such cases.

TESTING SPECIES DESIGNATIONS IN EXTANT

AND FOSSIL LAQUEUS (BRACHIOPODA, TEREBRATULIDA) THROUGH THE QUANTITATIVE ANALYSIS OF SHELL OUTLINES AND MACHINE LEARNING

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Since morphology plays a critical role in species recognition in the fossil record, analyzing morphological characters in a quantitative manner in fossils and comparing ranges of variability with living close relatives is essential. The aim of our research is to determine if shell shape, specifically valve outline, can be used to accurately distinguish among extant brachiopod species, and if outline shape parameters in extant specimens can be applied as a guideline to test and differentiate fossil species. Furthermore, given the assumption that external morphology offers little resolution for classification of terebratulide brachiopods, we aim to test if outlines are good proxies for more taxonomically informative characters such as long loops—the calcareous structures supporting the lophophore. Given how complex and fragile these structures are, long loops are rarely preserved in the fossil record. Therefore, finding good proxies for these internal features is a fundamental goal.

To approach our research questions, we focused on the genus *Laqueus* Dall, 1870. *Laqueus*, compared to other terebratulide brachiopods, displays low levels of shell variability; its planar commissure makes it an ideal candidate for 2D outline analysis: and long loop morphology has been shown to reliably discriminate species within the genus. We analyzed and compared two datasets: 1) outlines and long loop landmarks and semilandmarks from extant specimens imaged using CT and 2) outlines of photographed extant and fossil specimens. Outline analysis was performed for both datasets using elliptical Fourier analysis (EFA). To quantify variation in shell shape, the resulting elliptical Fourier coefficients were then used as variables for a Principal Component Analysis (PCA) and a Canonical Variate Analysis (CVA) with leave-one-out cross-validation to test classification accuracy. To examine morphological integration between long loops and outlines, we used our CT dataset and performed a partial least squares analysis (PLS) on Procrustes-fitted coordinates of two blocks: 3D landmark and semilandmarks for long loops, and outline coordinates for the same set of specimens. Finally, to test fossil species assignations, we trained a model using the outline of extant specimens, described by elliptical Fourier coefficients, under the Random Forests algorithm. Our results demonstrate that, even though outlines are not considered to be the most diagnostic characters, they provide enough morphological information to distinguish among extant named *Laqueus* species, validating current taxonomic assignments. Furthermore, there is a high correlation (r=0.77) between long loop shape and shell outlines, proving that, in the absence of taxonomically informative internal features, outlines offer sufficient resolution to classify *Laqueus* specimens. Our prediction model, based on extant shell shape variables, accurately categorized 81% of the fossil specimens to their previously assigned species.

TAPHONOMY OF THE PHACOPID TRILOBITES CERAUSUS PLEUREXANTHEMUS AND FLEXICALYMENE SENARIA FROM THE WALCOTT-RUST QUARRY (UPPER ORDOVICIAN)

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Trilobites are a dominant group of euarthropods throughout the Paleozoic, and are known primarily from their biomineralized dorsal exoskeleton. Despite their impressive diversity estimated to reach some 20,000 described species, the appendicular ventral anatomy of trilobites is only known from 31 taxa. In 1879 Charles Doolittle Walcott reported the preservation of trilobite appendages from the Rust Formation of the Trenton Group in Herkimer County, New York. Although trilobites are common throughout this group, appendages are only known from the partially enrolled individuals in Layer 3 of the Spillway Member. Shortly after deposition, calcite crystals formed inside these specimens, consisting mainly of the phacopids *Cerausus pleurexanthemus* and *Flexicalymene senaria*, preserving aspects of the ventral anatomy in three dimensions with little compaction and a spectacular degree of fidelity. Despite the preservation quality, the taphonomic pathway leading to calcification of soft tissue in the Rust Formation trilobites remains poorly understood. Brett *et al*. (1999) suggested that the partially enrolled individuals created a microenvironment conducive to the precipitation of calcite thanks to anaerobic conditions where sulfate-reducing bacteria created a high concentration of bicarbonate and sulfide as waste leading to localized precipitation of calcite. Examination of hundreds of prepared thin sections of Walcott-Rust trilobites demonstrate

that the ventral anatomy is typified by a uniform rim of crystals perpendicular to the exoskeleton and occasionally around mud infills. In particular, sparry calcite crystals replicate the soft tissues in exceptional detail, including delicate structures such as exopod lamellae and endopod endites. We employ diverse modern techniques, including petrographic microscopy, scanning electron microscopy backscatter and cathodoluminescence to understand the process of soft tissue calcification in these unique exceptionally preserved fossils.

REGIONAL PATTERNS OF MAMMAL DIVERSITY THROUGH BASIN AND RANGE EXTENSIONAL HISTORY, 36 MA TO PRESENT

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Tectonic history exerts important influences on the fossil record at local and regional scales. At the local scale, tectonic activity can determine rates of accommodation and sedimentation that affect the preservation of fossils during the depositional history of individual basins. At regional scales, tectonic regime governs the types of basins that form and the timing of basin development, which in turn may influence regional patterns of diversity in the fossil record. Widespread extension in western North America since the Oligocene created the numerous basins of the Basin and Range physiographic province. The fossil record from many of these basins shows high mammal diversity over an interval of elevated areal extension, including a peak in mammal diversity at ~16 Ma. A possible scenario contributing to high diversity is that high rates of extension led to increased sediment accumulation, thick stratigraphic sequences, and increased fossil burial. Thus, the observed patterns of mammal diversity may be the result of increased sediment and fossil accumulation over broad areas of high accommodation due to regional extension.

In order to test whether mammal diversity is linked to the timing of basin development, we compiled records of 630 lithostratigraphic units representing 60 basins in the Basin and Range from the Macrostrat database and literature sources. For these lithostratigraphic units, we determined stratigraphic thickness and sediment accumulation rate and their timing of deposition in relation to extensional deformation rates over 36 Myr. For 120 fossiliferous units within this timeframe, I calculated mammal species richness per 0.5 Myr in four subregions: the California Coast, Northern Great Basin, Southern Great Basin, and Columbia Plateau. The results show that deformation rate and deposition of the fossil record are decoupled. Average deformation rates in the four subregions increase substantially after 30 Ma but decline prior to the mid-Miocene peak in mammal diversity. The number and thickness of fossiliferous lithostratigraphic units increase after deformation rates decline; mammal diversity is correlated with unit number and thickness. The ~10 Myr offset between intervals of high deformation and diversity may relate to the type of sedimentary environments forming in extensional basins: synextensional deposits typically do not preserve mammal remains, whereas postextensional deposits have higher preservation potential. This regional pattern is similar to the pattern of fossil occurrence documented for individual extensional basins. Regional patterns of Neogene mammal diversity in the Basin and Range are linked to its tectonic history and may stem from the history of deposition and fossil preservation occurring in individual basins.

PHYLOGENETICS OF TRUE CRABS, AND THE EARLY ORIGINS OF CRAB-LIKE FORMS

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True crabs or Brachyura are among the most ecologically dominant, economically significant, and popularly recognized group of arthropods that have conquered marine, freshwater, and terrestrial habitats worldwide. Although there are over 7,000 extant and 3,000 fossil species of true crabs ranging from the Early Jurassic to the Holocene, the evolutionary history and phylogenetic relationships among—and within—the main brachyuran groups remain unresolved. This is in part because few early splitting branches have left living descendants, molecular data are currently unavailable for many key extant taxa, and useful fossils are rare, incomplete, or even missing from key time intervals such as the 'mid' Cretaceous. Some recent works have expanded considerably our understanding of the evolution of true crabs through time. Yet, there is presently a lack of well-supported phylogenetic frameworks that combine molecular and morphological data for all crablike groups, and include reliable fossils for time calibrations. Construction of

comprehensive datasets, including fossil and extant species of most, if not all, major ranks, is crucial to identifying the key characters that define what a crab is, resolving the multiple origins and losses of 'crab' body forms through time and identifying the timing of origin of key evolutionary novelties and body plans.

We examine hypotheses about the early evolution of true crabs in light of new molecular, morphological, and fossil data, and investigate the phylogenetic relationships among extinct and extant brachyuran higher taxa. In our phylogenetic analyses, the earliest brachyuran stocks known as 'podotreme' crabs are recovered as paraphyletic with respect to the more inclusive eubrachyurans, or 'higher' true crabs. In contrast, Eubrachyura are consistently recovered as monophyletic, but with conflicting internal topologies and unclear relationships. We also present several new Early and mid-Cretaceous body plans, whose exceptional preservation challenge conventional views of crab evolution. Although several true crab lineages have Jurassic origins, it is during the Cretaceous that brachyurans underwent a major adaptive radiation and morphological experimentation in what could be deemed as the 'Cretaceous Crab Revolution'. Disentangling the phylogenetic relationships across extinct and extant crab groups is central to understanding the origins of body plans and key novelties linked with the evolution of crablike forms (carcinization), and even the multiple losses of these forms (decarcinization), through geological time.

A NEW HORSESHOE CRAB FROM THE EARLY ORDOVICIAN FEZOUATA BIOTA AND ITS RELATIONSHIP WITH HEREFORDSHIRE SYNZIPHOSURINES

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The Fezouata Formation in southeastern Morocco is an Early Ordovician Lagerstätte that preserves a wide variety of non-biomineralized taxa and anatomical features. At least two different undescribed Xiphosurans are known from this locality, which would make them the oldest occurrence of horseshoe crabs in the fossil record. An in-depth study of the Fezouata shale horseshoe crabs is required to clarify evolution and phylogeny of early xiphosurids and synziphosurines, and the relationship between these Xiphosura suborders.

Here we described a new synziphosurin taxon from the Fezouata shale. More than 200 samples have been examined . We focused our research on the appendages and their insertion in the prosoma, the morphology of the first pair of appendages, the dorsal prosoma, the opisthosomal segment, abdomen and telson. A diagnosis character list for the taxon has been constructed based on the plesiomorphy characters but also on the synapomorphy shared with other Ordovician and Silurian synziphosurines.

The new synziphosurin taxon shows similarities with *Offacolus kingi* and *Dibasterium durgae* from the Silurian Herefordshire Lagerstätte. We undertook a phylogenetic analysis to evaluate if these three synziphosurine taxa could form a family level taxon of stem Xiphosurans. This analysis contributes to the understanding of early euchelicerate divergences.

SCHRÖDINGER'S MAMMOTH – ECOLOGICAL ASSEMBLY IN THE AGE OF HUMANS

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Ecologists have long been interested in how species assemble into communities. In particular, they are interested in how species traits, environmental factors, and biotic interactions affect species distributions, and membership and persistence in ecological communities. Determining whether assembly rules exist and what they are is particularly important in the face of ongoing climate change. However, despite decades of study, no clear consensus has emerged. In part because modern studies are limited by the short time scales over which they are able to collect data and by the fact that humans are incredibly successful ecosystem engineers who have affected almost every part of the planet. This puts modern ecologists into a situation, as in the paradox of Schrodinger's Cat, where observing the system affects the outcome. Or rather our ability to study the system comes from the same traits that have caused us to greatly alter the system. In contrast, paleontologists have been interested in the interplay between species traits and the environment, and how these relationships change over time in response to global forcing factors such as climate change. Increased knowledge of taphonomic processes has led to an understanding that fossil assemblages often preserve reliable information about ecological communities and species interactions. By comparing the structure of these fossil assemblages with modern assemblages, we can begin to identify aspects of community structure that are similar across many taxonomic groups over different scales of geological time. The fossil record thus provides a powerful baseline for understanding how these patterns have

changed with the increasing dominance of humans on the globe. Using a macroecological lens, I examine mammalian community structure over long and short time scales including metrics such as co-occurrence structure, body size distributions, and functional traits. I evaluate how these patterns change over time and how they correspond to shifts in global climate. Finally, I examine how some traits associated with extinction risk have changed through time and the consequences of such changes for ecological communities. I find that in paleoecological communities, there are consistent patterns in terms of co-occurrence structure, body size distributions, and extinction risk, but many of these patterns change as human impacts increase, including the role that functional traits play in mediating co-occurrence structure. This suggests that humans are fundamentally altering ecological communities and resetting ecological assembly rules. Paleontology has a key role to play in identifying how humans are disrupting long-established, "natural" community assembly rules and what that means for predicting how species are likely to respond to future climate change, habitat fragmentation and the loss of biotic interactions because of extinctions.

WHY IS THE CHENGJIANG BIOTA EXCEPTIONALLY WELL PRESERVED?

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Elected as a World Natural Heritage site in 2012, the Chengjiang Biota is renowned for its exceptional soft-tissue preservation, which provides crucial evidence for early metazoan evolution. However, it is not yet clear why the Chengjiang Biota is exceptionally well preserved. In recent years, this question has received greater scrutiny with the reporting of exceptionally preserved decay-prone tissues, namely neural, cardiovascular and visual structures. It has often been assumed that these labile tissues do not withstand fossilization and would decay away shortly after the animal's death. Yet mounting evidence supports the interpretation of these exceptionally preserved labile structures as true anatomical characters, further highlighting the gap in our understanding of exceptional preservation in Cambrian fossils. In this presentation, I will show how the latest developments in geochemical research shed new light on our understanding of the taphonomy and preservation of the Chengjiang fossils. The contrasting redox conditions in the event and background beds indicate that the Chengjiang Biota was flourishing in persistently oxic shallow marine environments, while the animals were buried and transported to an adjacent dysoxic deep-water depositional environment, which allows internal tissues to be organically preserved with fidelity. Polymerisation appears to be central to the long-term survival of normally decay-prone tissues.

MESOZOIC ACARODOMATIA REVEAL THE ANTIQUITY OF PLANT-MITE MUTUALISMS

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Mutualisms—cooperative associations between species—have been critical in the ecological rise of flowering plants (angiosperms) during the Cretaceous Period (145–66 Ma). Pollination and seed dispersal are commonly studied in modern and deep time communities, but mutualisms between angiosperms and mites are less well known despite the importance of these interactions today. Acarodomatia, or mite domiciles, are located on the underside of leaves and often positioned in the vein axils. Acarodomatia morphology includes pouches, pits, and tufts of trichomes, which protect the mite and its eggs from desiccation and provide protection from other predators. These structures in turn facilitate tri-trophic interactions between the host plant, the fungus or herbivore adversary, and the fungivorous or predaceous mites inhabiting the acarodomatia. Today, acarodomatia are widespread and have been found on over 2,000 species of angiosperms, with the vast majority occurring on eudicots with woody growth habits. However, evidence for the evolutionary history of plant-mite mutualism is rare in the fossil record despite the abundance of mite domiciles found on leaves in modern ecosystems.

Tracing the evolutionary trajectory for this plant-mite mutualism is particularly challenging because angiosperms have convergently evolved acarodomatia numerous times and this association is geographically widespread. Furthermore, the associations between the host plant and mites are not as constricted as some plant-pollinator relationships; the acarodomatia of an individual host plant may harbor multiple species of mites, and a single species of mite may occupy

acarodomatia on different host plants. This situation makes detection of early acarodomatia on fossil leaves especially important. Nevertheless, the fossil record of these foliar structures is poorly known. Previously, the oldest documented acarodomatia were described from the Cenozoic Era, in two Eocene Epoch deposits dating to 49 and 42 Ma, and in younger Miocene Epoch deposits dating to 20 Ma. Here, we report the first occurrence of Mesozoic Era acarodomatia in the fossil record from Upper Cretaceous fossil leaves found in the Kaiparowits Formation (76.6–74.5 Ma) in southern Utah of North America. This extends the evolutionary origin of acarodomatia by >25 million years. The antiquity of this plant-mite mutualism provides important constraints on the evolutionary history of acarodomatia on woody angiosperms.

SCIENTIST-TEACHER PARTNERSHIPS IN PALEONTOLOGY

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Scientists interested in outreach frequently go into K-12 schools as part of their professional activities. In some instances these can develop into sustained collaborations. This study describes such a partnership between a scientist (MacFadden) and high-school biology teacher (Broo Sunderman). This partnership began during a teacher professional development (PD) summer institute held at the University of Florida in 2014 and has continued since that time. Our partnerships have principally focused on science content, i.e., fossils and paleontology, and evidence for evolution, climate change, and museums. This content has been delivered in the K-12 classrooms via lesson plans aligned with NGSS standards. It has included participation of the scientist and his graduate students in classroom content and role model visits, at which time we also have discussed STEM careers and college preparation. The teacher has been involved in numerous paleontology-related field and museum activities in Florida, Nebraska, and Panama (including the GABI RET "Great American Biotic Interchange—Research Experience for Teachers). She has also co-presented at national conferences, and participated as a coauthor in peer-reviewed publications (e.g., *The American Biology Teacher*). As part of the FOSSIL project, we have also co-presented our work on fossil horses and evolution to the Dry Dredgers Club in Ohio. The teacher has also revised her curriculum to use fossils and paleontology to introduce evolution at the beginning of the semester.

A clear message from our partnership is that for these to be most effective, they should be viewed as an ongoing collaborations and not a "one-off" event. They also should not just involve the scientist and teachers, but also their students. Graduate students in K-12 classrooms are particularly effective because they serve as near-peers; conversely the graduate students benefit from improved science communications skills. Many studies have demonstrated the benefits of scientist-teacher partnerships, particularly from the point of view of benefits accrued to the teacher. Results of our summative evaluation of the GABI RET project, however, also demonstrates that the scientists derive meaningful benefit from these partnerships.

WHALES N' SNAILS: A POTENTIAL MIOCENE SHALLOW MARINE WHALE FALL COMMUNITY

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Whale fossils are common in marine sediments of the Peninsular Ranges of Southern California, although the majority of whale sites consist of isolated vertebrae or fragments that have little scientific value. A noteworthy whale locality has recently been discovered in the lower Vaqueros Formation at the Frank R. Bowerman Landfill in Irvine, California. The sequence consists of two whale beds, separated by an approximately 20-centimeter-thick, unfossiliferous sand bed. The lower bed contains an articulated 3-meter midsection of a small whale, with few diagnostic elements, on a bed of crystalline *Turritella inezana* shells. The upper bed contains a jumble of disarticulated skull, ribs, vertebrae, and limb elements surrounded by *Macoma sp.* and *Arca sp.* casts, decapod chelae, and shark teeth. The finds in this locality have the potential to add to the scientific knowledge of shallow water whale falls during the early Miocene.

Whale falls are a common occurrence in deep marine environments but are less studied in shallow shelf and coastal environments. To determine whether the Bowerman whale beds exhibit the characteristics necessary to be considered a whale fall, the associated fauna, taphonomic characteristics, and depositional environments were compared to documented whale falls, as well as other fossil localities within the Vaqueros Formation. The preservation and fauna of the lower bed of the Bowerman whale site is consistent with only the earliest mobile scavenger and enrichment-opportunist stages associated with typical whale

falls and was likely disrupted by the deposition of the unfossiliferous sand bed. The upper whale bed is more characteristic of a typical whale fall but is missing key chemosynthetic characteristics, although it is possible that the whale carcass was too shallow for this stage to occur. The site has sediments characteristic of a shallow interdistributary bay, where currents may be too strong for chemosynthetic communities to form on a submerged whale carcass. Preparation of the upper bed of the Bowerman whale site is ongoing and may reveal additional evidence of chemosynthesis.

Although the chemosynthetic stage is considered a key element in the definition of a whale fall, the absence of this stage does not necessarily exclude a submerged whale carcass from being a whale fall. The presence of scavengers, opportunists, and reef-building organisms at the Bowerman whale site are a unique find that will add to a better understanding of whale fall ecosystems.

FOSSILS AT THE LANDFILL: INTERACTIVE TOOLS FOR PUBLIC EDUCATION

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Recent fossil discoveries at the Frank R. Bowerman Landfill in Irvine, California, are being used to create an interactive website to highlight the geological and paleontological history of Orange County. The premise of the website is simple and entertaining. It teaches visitors about tectonics, biostratigraphy, and geologic principles such as superposition and original horizontality. The website will focus on the late Paleogene – early Neogene marine transgression and subsequent regression, uplift of the Peninsular Range, and movement along the San Andreas Fault. Website visitors can travel through geologic time using the fossils found at localities found throughout excavation of the landfill. Images of terrestrial mammals, plants, and insects will be used to represent the fluvial system present during deposition of the Sespe Formation. A wide variety of marine vertebrate and invertebrate fossils will be used to represent the marine transgression in the Vaqueros, Topanga, and Puente Formations. Pleistocene megafauna will be used to represent more recent environments after the uplift of the Peninsular Range. Pages for each of the localities will include information on the fossils found, their significance, and an interpretation of the depositional environment based on the geology and fossil evidence.

The website release is planned to coincide with the annual Earth Day celebration and outreach event and is a collaborative effort between paleontologists who have worked at the landfill and the Orange County Waste and Recycling Public Communications Department. The website will be combined with traditional, hands-on learning and informative brochures available at the Earth Day event. This website, with the help of social media outreach, has the ability to reach a much wider audience, and serves as an augment to traditional outreach in our goal to educate and inform the public of the paleontology and geology of their surrounding area.

STABLE CARBON AND OXYGEN ISOTOPES PROVIDE NEW INSIGHTS ON CLIMATE AND PALEOECOLOGY DURING THE MIOCENE OF NORTHERN NEW MEXICO

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The integration of stable isotope geochemistry and paleontology is crucial to understand ancient ecosystems. Previous studies on carbon and oxygen isotope ratios in the marine record offer an extensive view of changing climatic conditions and shifting paleoecology throughout the Cenozoic. In contrast, however, notably less evidence has been presented for the terrestrial record of carbon and oxygen isotope data that might be used to compare to the marine record, and of relevance here, the Mid Miocene Climatic Optimum (MMCO) and the onset of C_4 grasses in southwestern North America.

Stable carbon and oxygen isotope ratios from 61 terrestrial fossil mammal teeth of the Miocene Tesuque and Chamita formations of the Santa Fe Group in northern New Mexico provide new insights into herbivore paleodiets, ecology, and past climatic conditions. Temporally, the Santa Fe Group is significant because the age range of deposition (~18–6 Ma) occurs during two major climate-driven events. One would expect terrestrial mammals feeding on vegetation during this period to incorporate carbon and oxygen isotopes into their tooth enamel that reflect these events. Preliminary results however do not wholly replicate this pattern. With regard to grasses, stable carbon isotopes from the older Tesuque Formation (~18–13 Ma) show $\delta^{13}C$ values (mean=-8.01 ‰) likely indicating some mixing of C_3 and C_4 grasses or plants. In contrast, $\delta^{13}C$

values (mean=-8.29 ‰) from the younger Chamita Formation (~7–6 Ma) likely indicate a C_3 plant dominated environment, possibly due to water stress. The latter results are in contrast to other evidence demonstrating a global shift to C_4-dominated ecosystems during the late Miocene. Regional uplift and climatic conditions in southwestern North America potentially serve as contributing factors to a C_3 plant dominated environment. The stable oxygen data from the Tesuque (mean=-5.66‰) and Chamita (mean=-6.66‰) formations allow for analysis of the magnitude of these influences, however, their interpretation is more complex. In summary, stable isotope data from the Santa Fe Group provide an opportunity to interpret distinct climatic and ecological conditions during the Miocene of southwestern North America. Spatially these data coincide with important events including the MMCO and onset of late Miocene grassland evolution.

INDIA'S LOST FLORA: DISTINCTIVE FRUITS AND SEEDS OF THE DECCAN INTERTRAPPEAN BEDS LACKING CLOSE LIVING RELATIVES

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The chert floras of the Deccan Intertrappean beds are distributed across an area spanning more than 300 km north to south and ca. 400 km west to east in central India. Containing excellently preserved fossil fruits and seeds, the chert beds are intercalated among basalt flows considered to belong to Chron 29r, which extends from late Maastrichtian to Paleocene. We focused on the floristic composition of eight sites that have been considered to be late Maastrichtian, including Ambagholi, Bara Bheralya, Mahurzari, Mohgaonkalan, Murai Patan, Pudiyal Mohda, Shibla, and Singpur. Only a few species could be identified with high confidence to modern families, including Arecaceae (*Palmocarpon*, *Hyphaeneocarpon*), Lythraceae (*Enigmocarpon*), Malvaceae (*Harrisocarpon*), Phyllanthaceae (*Phyllanthocarpon*),Vitaceae (*Indovitis*), and Zingiberaceae ("*Musa*" *cardiospermum*). Despite excellent preservation and distinctive morphology and anatomy revealed by physical sectioning, peels, and micro-CT scanning, a large proportion of the angiosperms remain difficult to place systematically. Most of them exhibit distinctive character sets that do not seem to conform to extant families. Angiosperm genera whose familial affinities remain uncertain include: *Achenocarpon*, *Baccatocarpon*, *Centrospermocarpon, Chitaleycarpon, Cremocarpon, Deccanocarpon, Drupaceocarpon, Graminocarpon, Indocarpa, Pantocarpon (=Verbenaceocarpon), Portulaceocarpon, Sahniocarpon*, *Sahnipushpam, Scaevolacarpon, Spinusocarpon, Surangea, Surangeocarpon, Tricoccites, Unispermospinocarpon, and Viracarpon.* Some can be placed in broader clades, e.g. monocots (*Sahnipushpam*, *Tricoccites*, *Viracarpon*) but cannot be placed into modern families as they are currently understood. The difficulty in identifying the familial relationships in relation to extant taxa might be in part due to extinction, not only of these genera, but of entire clades to which they belonged, making their affinities with related modern taxa more remote. More extensive comparisons need to be made with Eocene floras, both of India and in Eurasia, to determine if some of these genera survived the climate change and floristic interchange accompanying the northward movement and collision of the Indian tectonic plate with Eurasia. These genera might represent the "not out-of-India" taxa that perished due to environmental change and/or competition from influx of Eurasian taxa as the continents merged.

BEHAVIORAL INNOVATIONS IN SPACE AND TIME: INSIGHTS FROM THE TRACE-FOSSIL RECORD

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As records of behavior, trace fossils are powerful tools to reconstruct the evolution of bioturbating and bioeroding organisms. In addition, the intimate link between trace fossils and substrates allows for valuable insights into the response of the infauna to environmental factors, prompting a finely tuned integration with information derived from conventional facies analysis. A systematic review of the trace-fossil record emphasizes the notion that matgrounds were instrumental as substrates for interactions with early bilaterians during the Ediacaran and earliest Cambrian, but that sediment bulldozing is first manifested close to the Ediacaran-Cambrian transition, resulting in increased disturbance of the sea bottom. Application of tools derived from stratigraphic paleobiology are instrumental to understand the nuances involved in detecting spatio-temporal patterns of some of these innovations. The Fortunian is rather unique in its dual

nature, as revealed by the appearance of a new cast of Phanerozoic evolutionary actors but a persistence of an Ediacaran-style matground-dominated ecology. The three main marine evolutionary radiations (Cambrian Explosion, Great Ordovician Biodiversification Event and Mesozoic Marine Revolution) detected in the body-fossil record are also expressed in the trace-fossil record, as indicated by increases in ichnodiversity. The Cambrian Explosion displays the most marked of such increases, but is restricted to bioturbation structures, whereas the one signalled by the Great Ordovician Biodiversification Event, albeit more modest, is represented by bioerosion structures as well. The Mesozoic Marine Revolution is a more protracted event with ichnodiversity increases in the Early Jurassic and Late Cretaceous. Overall increases in the degree of bioturbation and ichnodiversity did not occur in all marine settings at the same time, but in a diachronic fashion, progressing from settings between fair-weather and storm wave bases along the depositional profile both seawards towards deeper-marine settings and landwards towards brackish-water marginal marine settings. Analysis of the trace-fossil record within a paleoenvironmental and sequence-stratigraphic framework significantly helps to reconstruct and evaluate paleobiologic megatrends.

DALLAS PALEONTOLOGICAL SOCIETY: AN EXAMPLE OF AMATEUR – PROFESSIONAL COOPERATION IN PALEONTOLOGY

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The Dallas Paleontological Society (DPS) was founded in 1984 for the purpose of promoting interest in and knowledge of the science of paleontology. It was intended by the founding members that the Society would be a network for the exchange of data between professionals and serious amateurs in this field.

The DPS was founded as an outgrowth of an amateur - professional project to assemble a mammoth for display at the then Dallas Museum of Natural History. Overlapping that project the Heath mosasaur was excavated and assembled by an amateur - professional team and put on display. Chief curator Charles Finsley led these projects which led to the formation of the DPS.

Through the following years numerous excavations were assisted or completed entirely by amateurs. DPS members and other amateurs were involved with the excavation of several mammoths, a mastodon jaw, several mosasaurs, an Alamosaur leg bone, a plesiosaur, a nodosaur, Tyrannosaurid leg bones, a Xiphactinus and the Arlington Archosaur Site.

In 1997, The Fossil Bureau of Investigation (FBI) was formed as a subgroup of the DPS that specializes in excavations. All material excavated must be donated to a museum or university. The FBI fields contacts from the public and answers identification questions, determines the importance of fossil finds and assists or leads excavations in cooperation with local museums and universities.

Several DPS members prepare fossils in the Southern Methodist University (SMU), Perot Museum of Nature and Science, Whiteside Museum of Natural History and Heard Natural Science Museum Fossil Labs. The Heard Museum Fossil Lab was created as the result of a DPS excavation of the Duck Creek mosasaur and is still run by amateur DPS members.

The Mineral Wells Fossil Park was created through a cooperative effort between amateurs from the DPS, the city of Mineral Wells, TX and local paleontological professionals.

The DPS coordinates a Collect It Yourself exhibit at the Heard Museum. Fossils found by members are put on display for six months in cooperation with the Heard exhibits department.

Major speakers are brought in for the Charles Finsley Lecture Series to present on paleontological subjects of interest to the general public. Speakers typically visit local university and museum staff to exchange research information or hold technical sessions for students. Professional Advisors are typically involved with the visit and make speaker introductions.

DPS members assisted SMU in the preparation of a major exhibit at the Smithsonian Institution: *Sea Monsters Unearthed: Life in Angola's Ancient Seas.* Preparation included fossil preparation, molding and casting, 3D scanning, metalwork, painting and more.

DIY GO EXTINCT!: GAME DESIGN INSPIRES STUDENT ADVOCACY OF BIODIVERSITY

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Evolutionary trees are one of the most important representations of biological knowledge. Scientists frequently use them to succinctly convey information and to present new taxa in context with well-known relatives. Students approaching evolutionary trees for the first time, however, often find them difficult to

understand because the information is not presented linearly. I designed *Go Extinct!* to capitalize on the sets-within-sets structure of evolutionary trees in order to create a strategically-engaging twist on Go Fish that overcomes the initial hurdle for students learning evolutionary trees. The game includes a deck of 54 animal cards and a simplified, yet accurate, evolutionary tree board used for reference during play. Instead of collecting sets of numbers as in Go Fish, players collect groups of closely related animals by asking for clades of varying inclusivity. For example, students could get the Human card by asking for the Human specifically or by asking for one of the more inclusive clades humans belong to, such as mammals or tetrapods. Winning requires players to understand the hierarchical structure of evolutionary trees and to identify common ancestors. The game's vocabulary emphasizes traits or lines of evidence that scientists use to classify vertebrates in the tree. Over 1000 students, from 1st graders to undergraduates, have played the game with the most successful implementations occurring in middle school and up. Afterwards, students can define a clade and make evolutionary observations such as: "chickens are dinosaurs and we've been eating them!"

DIY Go Extinct! is a new free online platform that allows students to create their own versions of the game around the evolutionary trees of Australian flora, fauna, and fossils.DIY Go Extinct! further engages students by putting them in the designer's seat: choosing their favorite evolutionary tree, species for the cards, animal photos, game colours, and board layout. By the end of the workshops, students get their own custom game to share and explain to friends and family. My goal is to empower students to become science advocates who are excited to share their new knowledge and nature appreciation beyond the workshop. The 2018 launch event for DIY Go Extinct! received survey comments like, "The content is amazing, I feel like I learned way more than I would from a 'traditional' book. Also appreciated how intuitive the interface is." And, "There are a lot more creatures in the Great Barrier Reef than I ever imagined!" DIY Go Extinct is live at:https://www.steamgalaxy.com/design-your-own-game/ The interface is highly adaptable and the evolutionary trees available for students to customize could be expanded to feature local flora, fauna, and fossils anywhere on the globe.

MISSING THE BIG (BEDDING PLANE) PICTURE: SMALL SAMPLES DO NOT ALWAYS CAPTURE THE LATERAL HETEROGENEITY OF BIOTURBATION

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Temporal variations in the character and intensity of bioturbation in marine environments have long been employed to interpret changes in water depth (e.g., Seilacher, 1967), oxygenation (e.g., Savrda et al., 1984), and evolutionary adaptations to burrowing infaunally (e.g., Ausich and Bottjer, 1982; Droser and Bottjer, 1988; Bottjer et al., 2000). Assembling a temporal series of marine ichnologic data requires assessing the degree to which numerous stratigraphic intervals, each representing a past zone of benthic biological reworking, were disrupted by bioturbating organisms. Depending on the setting and scope of an ichnologic study, assessment of each time-limited stratigraphic interval could be based on the width of a piston or box core, or on tens of meters of laterally-continuous outcrop. When the study focus is bioturbation preserved on bedding planes, the likelihood of obtaining sample areas larger than 1-2 square meters is uniformly low due to the general rarity of broad field exposures of such surfaces. For studies that rely on small sample areas, heterogeneity in the lateral distribution of bioturbation across stratigraphic horizons could reduce the accuracy of ichnologic interpretations made from both vertical and bedding-parallel outcrops. For example, a bed could be interpreted as undisturbed if the width of the available exposure matches the width of a gap between adjacent patches of bioturbation.

We conducted a pilot study of lateral bioturbation heterogeneity in which we mapped the size variation and distribution of bedding-parallel trace fossils across three exceptionally large (>5 m^2) Cambrian bedding planes that had been exposed through commercial quarry operations in central Wisconsin (Marenco and Hagadorn, 2019). The wave-dominated intertidal sand-flat facies represented in these bedding planes (MacNaughton et al., 2019) is characterized by a low-diversity ichnofauna dominated by bedding-parallel ichnogenera, including (among others) *Climactichnites*, *Diplichnites*, *Protichnites*, and *Gordia* (Getty and Hagadorn, 2008, 2009; Collette and Hagadorn, 2010; Collette et al., 2010; Seilacher and Hagadorn, 2010). Across the bedding planes that we mapped,

trace fossils tend to occur in meter-scale patches that are separated by unbioturbated zones varying in size from <0.5 m^2 to >3 m^2. In addition, each bioturbated patch is internally heterogeneous with respect to the degree of biogenic disruption. These field observations support our hypothesis that bioturbation can exhibit lateral heterogeneity at scales of centimeters, meters, and decameters. Patchy biogenic sediment disruption has also been observed in modern environments, including intertidal settings (e.g., Moore and Scruton, 1957) and the deep sea (e.g., Heezen and Hollister, 1971). Therefore, any comprehensive assessment of the character and intensity of bioturbation within a time-limited stratigraphic interval is best served by maximizing the width of the sample area under study.

NEW SPECIMENS OF ACAENASUCHUS GEOFFREYI (ARCHOSAURIA) FROM PETRIFIED FOREST NATIONAL PARK (ARIZONA) SUPPORT EVIDENCE FOR A NEW TRIASSIC CLADE OF ARMORED PSEUDOSUCHIANS IN NORTH AMERICA

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Upper Triassic non-marine strata of North America have produced an incredible diversity of morphologically disparate tetrapod taxa that were adorned with a variable amount of postcranial dermal bones. These ossifications range from dorsal rows of osteoderms in taxa such as phytosaurs, rauisuchids, and crocodylomorphs, to partial or full carapaces, such as those found in *Vancleavea*, *Revueltosaurus*, *Euscolosuchus*, and aetosaurs. One such taxon, *Acaenasuchus geoffreyi*, was originally named a new aetosaur genus based on just a few small (~2-4 cm mediolateral width) paramedian and lateral osteoderms from the Norian-aged lower Chinle Formation near St. Johns, Arizona. *Acaenasuchus* has subsequently been considered a juvenile *Desmatosuchus*, the sister taxon of *Desmatosuchus*, or a non-aetosaur pseudosuchian. We introduce new specimens of *Acaenasuchus* from Petrified Forest National Park and the holotype locality near St. Johns, including ornamented skull bones, novel osteoderm morphotypes, trunk vertebrae and ribs, and appendicular bones such as the humerus, ilium, pubis, ischium, femur, and tibia. Differences in the shape and articular surfaces of the osteoderms of *Acaenasuchus* indicate positional variation in osteoderm morphology depending on placement over the body. The paramedian osteoderms are serially coossified to one another in the cervical region but not over the trunk, and coossified osteoderms form rings around the tail, much like those of Pleistocene glypodonts and meiolaniid turtles. A phylogenetic analysis performed using these new specimens supports the hypothesis that *Acaenasuchus geoffreyi* is closely related to *Euscolosuchus olseni* from the Carnian-aged Vinita Formation of Virginia; both taxa share features on the osteoderms such as the presence of a large lateral spine on trunk lateral osteoderms and dorsal ornamentation consisting of narrow, anastomosing ridges. *Acaenasuchus* therefore represents a clade of stem-aetosaurs, and histological data indicate that the diminutive osteoderms from the type locality of *Acaenasuchus geoffreyi* are skeletally mature, further supporting the argument against it being a juvenile aetosaur. Our results emphasize the importance of osteohistology as an independent line of evidence for estimating skeletal maturity and suggest that even fragmentary fossils can shed light on previously unknown diversity in the Late Triassic vertebrate assemblages in North America. This study also reflects the importance of fossils on public lands, partnerships with research institutions, and in-park science programs in the National Park Service.

TRACKING THE EVOLUTION OF THE SILURIAN MARINE BIOSPHERE USING LIPID BIOMARKERS AND STABLE ISOTOPE GEOCHEMISTRY

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The Silurian (443–416Ma) marine biosphere apparently experienced at least four major positive carbonate $\delta^{13}C$ excursions each associated with faunal turnover in the benthic and pelagic realm[1]. Lithographic evidence of facies change from globally correlated sections suggest that these events are also contemporaneous with changes in climate and sea level[2,3]. The most susceptible fauna to these changes are the realm of calcareous plankton and benthos, most notably, algae and reefs. In the paleotropics, early Silurian reefs began to form on the southern shelf of Baltica. Starting in the Wenlock, (lagoonal facies) reefs emerge, reaching their largest extent in the Ludlow (reef facies), and a decline in the Pridoli (open shelf facies)[2]. It is likely that nutrient cycling and the amount and mode of primary productivity were important factors as a food source for the communities sustained

in these Silurian reef habitats. Lipid biomarkers offer a unique opportunity to study these relationships although molecular records are currently sparse for the Silurian Period, especially for Middle and Late Silurian rocks and oils.

We are investigating the biomarker assemblages in strata from a well-preserved drill core from Podolia, Ukraine (Baltica) that captures the breadth of Silurian time from a succession of carbonate-rich sedimentary rocks from the marine shelf settings. The thermal maturity of the host rocks is highly suitable for biomarker work (early to middle oil window maturity) as verified by Rock-Eval pyrolysis parameters. We have observed systematic changes in polycyclic alkane maturity parameters with increasing core depth, over 400m of depth, verifying the synergy of the biomarker signals in the host rocks. Our initial biomarker results generally indicate microbial communities rich in bacteria in mainly low productivity and oxic settings, which likely reflect nutrient limitation favoring bacteria over algae as the major primary producers in these shelf settings. Some notable characteristic biomarker features observed previously for Ordovician biomarker assemblages are also sustained through the Late Silurian in Podolia.

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THE EVOLUTION UNDERGROUND: HOW BURROWS CHANGED THE WORLD

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Burrows serve many purposes for animals, including protection against environmental stresses, predator evasion, feeding, reproduction, and raising young. The number of animal clades with burrowing ancestors and/or descendants in their evolutionary lineages is astounding, including (but not restricted to) cnidarians, nematodes, annelids, trilobites, xiphosurids, crustaceans, myriapods, arachnids, insects, echinoderms, crossoptyerigians, batrachopmorphs ("amphibians"), sauropsids, and synapsids. Yet the Earth did not always have burrowing animals. Indeed, the onset and proliferation of infauna radically altered oceanic and continental environments, while also offering distinct advantages to burrowers during mass extinctions. Burrowing began toward the end of the Ediacaran Period (560-550 *mya*), and initially was shallow and limited to horizontal bedding planes. However, this planar constraint was succeeded by the deeper vertical burrows of suspension-feeders in the lastest Ediacaran and Early Cambrian, followed by the pervasive bioturbation of deposit feeders throughout the early Paleozoic. The earliest of these burrowers punched through seafloor biomats and irrigated previously low-oxygen sediments, permanently altered geochemical cycles in the world's oceans. With the advent and proliferation of predators early in the Phanerozoic, burrowing also became a means of concealment, or conversely was used by predators to acquire prey. Colonization by animals of brackish, freshwater, and terrestrial ecosystems later in the Paleozoic was likely facilitated by burrowing, which buffered against environmental stresses in those ecosystems. The fossil record of mass extinctions likewise attests to burrowing as a means for surviving the worst environmental crises in Earth history. For example, *Lystrosaurus* in the Early Triassic and oligochaetes in the earliest Paleogene represent burrowers as essential elements in the ecological rebounds following the end-Permian and end-Cretaceous extinctions, respectively. For modern examples, pocket gophers around Mount St. Helens in the 1980s were key drivers of post-eruption ecological recovery there, and gopher tortoises host more than 300 species of burrow commensals in fire-dominated ecosystems of the southeastern U.S. In short, burrows mattered in the geologic past, and will provide us with valuable lessons to consider as we ponder an uncertain future posed by anthropogenic climate change.

"TAPHONOMY: DEAD AND FOSSILIZED": A NEW BOARD GAME DESIGNED TO TEACH PLAYERS ABOUT THE PROCESS OF FOSSILIZATION

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Fossils are an easy "hook" for classrooms and outreach activities; however, it can often be difficult to explain to new paleontology enthusiasts the processes that made the fossils they see in a classroom, lab, or museum. Accurately distilling the intricacies and timescales associated with fossilization and taphonomy (i.e., processes that affect an organism as it fossilizes, moving from the biological to the geological record) can be challenging, but these factors are a cornerstone in understanding the geological history of life on Earth.

Incorporating games into a classroom or outreach program can demystify the fossilization process and help people conceptualize paleontological concepts

through experiential learning. Classroom games have been shown to help students retain material and become innovative problem solvers. 'Serious Games' facilitate learning and offer advantages over lectures in terms of availability, rapidity of feedback, cooperative learning, as well as interaction, engagement, and enjoyment.

Here we describe a new serious game, "Taphonomy: Dead and Fossilized", based on a Jurassic fossil deposit in Canada. This physical board game is an active learning tool that can be used in a classroom or lab, or as an outreach activity at a museum or summer camp. The educational objective of "Taphonomy: Dead and Fossilized" is to teach the player about taphonomy, while the gameplay objective is to preserve and recover the best fossil collection. Through competitive and collaborative play, students learn how biology, environment, physical and chemical changes during exposure, burial, and decomposition, as well as discovery biases, influence whether or not an organism is collected. Players "time travel" to the Jurassic to protect their specimens from taphonomic factors (either from random environmental events or other players) and learn what processes enhance or diminish preservation. Players then return to the present to recover their specimens and learn that collection also biases sample recovery.

"Taphonomy: Dead and Fossilized" was incorporated into undergraduate classroom activities in 21 colleges and universities across the United States (2018 and 2019) and the students and teachers surveyed to assess the efficacy of the game as a teaching tool. Our survey results show that the students enjoyed playing the game and found it to be well balanced in terms of enjoyment and scientific learning. The majority of students reported that the game helped them understand fossilization and taphonomy and that they would rather play the game than attend a regular class or lab.

DETERMINING THE ROLE OF SELECTIVE OVER-EXTRACTION IN THE BODY SIZE AND COLORATION OF ENDEMIC MOLLUSCS FROM RAPA NUI (EASTER ISLAND)

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Molluscs have been a staple food resource with high cultural significance for people inhabiting Pacific oceanic islands for millennia, but how molluscs responded to the sequential colonizations of remote Pacific islands is not well understood. Rapa Nui (Easter Island) is the most isolated island on Earth and 40% of its molluscan fauna is endemic. The island has been populated for ~1200 years, during which time the human population increased to twice present-day numbers, only to decline and increase again more recently. Today the island receives a relatively high number of tourists which further intensifies harvesting pressure on marine molluscs for food and jewelry. In this study we explore the impact of harvesting on the body sizes and coloration of marine gastropods using modern survey data, colorimetric data, local knowledge and historical museum collections (National Museum of Natural History, USA and the Museo Nacional de Historia Natural, Chile). Data suggests that unrelated gastropod species have declined significantly in size over time. We postulate that human-induced declines in body size may manifest themselves more quickly in isolated populations like Rapa Nui. Preliminary observations on the coloration of the gastropod *Planaxis akuana*, which is utilized heavily to make decorative necklaces, suggest that the continuousphenotypic variation in shell coloration present in historical material has now changed by selective harvesting of more desirablecolor phenotypes. We present a set of tools to rigorously explore these questions and discuss how this information can provide local islanders and policy makers with crucial information on how best to conserve this highly isolated and endemic fauna that currently lacks protection.

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INTERMIXED MESSAGES: INTEGRATED GEOCHEMICAL AND PALEONTOLOGICAL ANALYSIS OF END-DEVONIAN MARINE COMMUNITIES IN THE APPALACHIAN BASIN, USA

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The end-Devonian Hangenberg Crisis (~359 Ma) is unique as a major biocrisis following closely on an extensive faunal restructuring resulting from the previous late Devonian extinctions. However, as

extinction events are traditionally defined through use of the fossil record, less is known about the overall impact the Hangenberg Crisis had on phytoplankton and other microorganisms that sustained food webs and controlled Paleozoic biogeochemical cycles. To determine the distribution of primary producers and test the stability of microbial communities before and throughout the expression of the Hangenberg Crisis we have combined geochemical (organic and inorganic) and paleontological examination (ichnofabric indices) of the Cleveland Shale, which records this global event in the Appalachian Basin, USA.

We find that the Hangenberg Crisis interval of the Cleveland Shale preserves both positive carbon ($\delta^{13}C_{org}$) and nitrogen ($\delta^{15}N_{total}$) isotopic excursions that appear linked to eustatic rise. Trace metal analysis (Mo, U) and the ubiquitous abundance of the green sulfur bacteria carotenoid biomarker, isorenieratane, indicate that deposition of the black shale sequence occurred locally under primarily euxinic waters. The presence of small but discernible trace fossil fabrics in several black shale horizons suggest, however, that some bioturbation and associated seafloor oxygenation occurred episodically throughout the succession. This highlights the idea that geochemical proxies used in isolation may fail to capture more rapid and sporadic redox fluctuations that take place during the deposition of ancient black shale systems. Eukaryotic primary producers (in this case, green algae) were relatively abundant throughout the expression of the biocrisis and other biomarkers commonly of interest during extinction events, such as the 2α-, and 3β-methylhopanes, are nearly indistinguishable from Phanerozoic averages. Our combined results suggest that the Hangenberg Crisis was not an immediate cause of marine microbial community restructuring in the Appalachian Basin. Rather, the overall expression of the Hangenberg Crisis in the Cleveland Shale maintains that a stable, algal-rich primary producer community thrived in a locally redox-stratified paleoenvironment.

FIRST RECORD OF SILESUNIONINA (ORDER UNIOIDA) BIVALVES IN SOUTH AMERICA: APTIAN CRATO FORMATION, NORTH EASTERN BRAZIL

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Cropping out in the southern, northern, and eastern borders of the Araripe Plateau, a large and isolated flat-topped geomorphic structure in northeastern Brazil, the Aptian Crato Formation (Santana Group) is known worldwide for its exceptionally preserved biota, which is mainly recorded in the laminated limestones of the basal part of the formation. This is the main Cretaceous fossil *Konservat-Lagerstätte* of the Gondwana and, therefore, the search for fossils in this unit were focused on these fossil-rich limestones. Consequently, the record of macrofossils in the Crato Formation in beds other than the *Konservat-Lagerstätte* is meager. The possible presence of unionid bivalves in mudstones, is one of the rare accounts of benthic macrofossils from levels of the Crato Formation that do not belong to the laminated limestone facies. However, despite the relevance of this information, no data (i.e., descriptions, illustrations, repositories) has ever been published about these "unionid bivalves", leading some authors to consider such references as probably erroneous. Herein, bivalves of the Suborder Silesunionina, Order Unionida are reported from South America for the first time and compared to known taxa from Africa, Australia and Europe. The studied material was collected at the Três Irmãos quarry, Nova Olinda county, State of Ceará, northeastern Brazil, and comprises 39 specimens, consisting of well-preserved molds (external, internal and composite) of elliptical bivalves. These are constrained in a 0.3- to 1-m-thick grey to yellow mudstone bed located 30 cm above the main laminated limestone unit of the lower part of the Crato Formation. The fossils preserved key anatomical information, including the distinct muscle scars, hinge teeth and ornamentation. Analyses of these characters indicate that those bivalves constitute a new genus and species. Notably, the presence of a series of small pedal elevator scars linearly arranged on the external wall of the umbonal cavity indicates that the bivalves closely resembles other Mesozoic Silesunionina bivalves. This is the youngest known occurrence of this group of Unionida bivalves, since

closely related forms (Silesunionidae and Unionellidae) were previously reported from Triassic deposits of Australia, Africa, Europe and possibly India. Detailed stratigraphic, sedimentological and taphonomic observations indicate that the Silesunionina within the Crato Formation are confined to tidal flat deposits and not associated with true fluvial or lacustrine sedimentary facies. They possibly lived on a muddy tidal bank some way up in an estuary under brackish-water conditions, subject to occasional freshening events. Financial support was provided by FAPESP (grants 16/13214-7, 17/22036-8 and 17/20803-1), CNPq (grants 401039/2014-5 and 304800/2017-1), and PETROBRAS Sigitec (2014/00519-9).

TRACKING BENTHIC FAUNAL CHANGES IN A MONOTONOUS OXYGEN-DEFICIENT LITHOFACIES: A STUDY CASE IN THE EARLY CRETACEOUS ROMUALDO SHALES, ARARIPE BASIN, NORTHEASTERN BRAZIL

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Herein, data on benthic faunal changes in a 1 to 11-m-thick monotonous succession of concretion-bearing black shales of the Lower Cretaceous Romualdo Formation, Araripe Basin, are presented. The formation is a siliciclastic-dominated unit recording a short-lived late Aptian marine ingression in the northeastern Brazil, during the opening of the South Atlantic Ocean. Data was gathered from four high-detail columnar sections, sampled cm-by-cm, and oriented in an east-west profile. The Romualdo Formation corresponds to a depositional sequence composed of two transgressive-regressive cycles. The investigated strata are well constrained in the transgressive part of the lower cycle, which can be tracked laterally for over 170 kilometers. In the eastern margin of the basin (Sobradinho and Mãozinha sections, Ceará State), the shales contain *Corbulomima* assemblages associated with lucinids and/or *Calva* (*Corbulomima* – lucinid association) recording dysoxic and low energy conditions, below storm wave base. Toward north (Estiva section, Ceará State), the concretion-bearing shales contain monospecific pavements of articulated sergestid shrimps (*Paleomattea deliciosa* association), small complete fishes, plus plant fragments, suggesting largely anoxic with brief spells of dysoxic conditions, below storm wave base. Bivalves and gastropods are absent. To the westernmost margin (Curralinho section, Piauí State), the concretion-bearing mudstones are less fossiliferous, resting directly over the crystalline basement. As usually, fishes are common inside concretions, but macrofaunal benthic invertebrates are lacking in the shales. Stratigraphic data suggests that during this time the margins of the Araripe Basin were flooded, and anoxic conditions prevailed, probably hampering the profuse colonization of mud-rich bottoms by benthic macroinvertebrates. Our data indicate that despite the absence of lithofacies change in the concretion-bearing shales throughout the basin, small-scale local environmental variations are mirrored in benthic faunal composition. These may reflect changes in bottom oxygenation, organic matter content, and water depth. As expected, samples with lower diversity (or even no benthic macrofossils) show a strong relationship with intervals when water conditions were deepest in the study area. Yet, data reinforces the notion that despite the limited to no apparent changes in lithofacies, benthic taxa are sensitive indicators of local environmental changes, and extremely useful as a tool in paleoenvironmental reconstructions of monotonous successions. This research was financially supported by FAPESP (16/13214-7, 17/20803-1, 18/01750-7), CNPq (401039/2014-5, 152385/2016-9, 304800/2017-1, 300107/2015-3), and Petrobras (2014/00519-9).

JUVENILE SPECIMEN REVEALS UNEXPECTED DENTAL MORPHOLOGY OF EARLY DESMOSTYLIANS

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Desmostylians are one extinct clade of marine mammals. There are various hypotheses of mammalian clades that they could belong to, including the Perissodactyla, Afrotheria, or Paenungulatamorpha.

Their fossils are known from Oligocene to Miocene strata of the North Pacific Rim coasts. They had pillar like unique teeth that are not seen in other taxa and they seem to be a hippo-like herbivore. Most of their fossils were found from middle Miocene strata, but several well-preserved Oligocene fossil records are known from Oregon state (United States) and British Columbia (Canada).

In this study, we report on a Paleoparadoxiidae skull (USNM 23895) from the lower Yaquina Formation (latest Oligocene) at the Yaquina Bay State Recreation Site (Newport, Oregon). This skull is missing most of its tooth crowns but had two unerupted brachydont molars with an enlarged protocone resembling *Paleoparadoxia* and *Archaeoparadoxia*. Therefore, we scanned USNM 23895 with X-ray Computed Tomography (CT) and got an image stack. Next, we reconstructed the 3D models of the teeth and skull from the CT scans using Amira software. By using this 3D model, we compared the dental formula and morphology among USNM 23895 and other desmostylians, Perissodactyla, Afrotheria, and Paenungulatamorpha.

USNM 23895 is a very small skull and did not finish its cranial suture closure, but only has two unerupted molars. These unerupted molars have no dental roots, but their crowns are almost completely developed. Therefore, USNM 23895 seems to be a juvenile individual of a lesser ontogenetic stage than the holotype *Paleoparadoxia tabatai* that has an erupted but unworn M3 (body length: about 2 m). USNM 23895 is at a more advanced ontogenetic stage than *Neoparadoxia cecilialina* that has an unerupted and incompletely developed M3 (body length: 2.44 m). The width across the antorbital processes of the frontals of USNM 23895 is about 1/4 times as large as *N. cecilialina*. From these facts, USNM 23895 was about the size of a large dog. This is presently the smallest known desmostylian. In addition to this, the dental formula of USNM 23895 is ?/1/4/3 based on 3D rendering data of its teeth. Four premolars is a primitive character of placental mammals and this characteristic is identified for the first time in Desmostylia. Furthermore, this characteristic is not seen in other Afrotherian members and can see in Paenungulatamorpha (e.g. Hyracoidea) and Perissodactyla (e.g. Equidae). This characteristic, therefore, supports the possibility that Desmostylia is not a member of Afrotheria. From the above, USNM 23895 is an extremely important specimen for understanding Desmostylia.

INFERENCES ON AQUATIC ADAPTATION OF FOSSIL MAMMALS BASED ON CRANIAL CHARACTERISTICS WITH AN EXAMPLE OF THE ENIGMATIC FOSSIL CLADE DESMOSTYLIA (?AFROTHERIA: MAMMALIA)

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Desmostylia is the only fully extinct clade of marine mammals. This clade is currently considered belonging to either Afrotheria, Paenungulatomorpha or Perissodactyla. In the currently-accepted taxonomic scheme, Desmostylia includes two families, Desmostylidae and Paleoparadoxiidae. Numerous desmostylian fossils have been reported from Oligocene to Miocene marine strata along the North Pacific coastline. Nonetheless, their paleoecology is still debated mainly because they are characterized by unique, highly-specialized postcranial skeletal morphology. In particular, inferences on an aquatic adaptation of desmostylians greatly vary, with their inferred habitats ranging from mostly terrestrial to fully-aquatic in the pelagic area. Most such inferences have been based on postcranial skeletal characters. In this study, we instead focused on the cranial morphology, especially characteristics related to sensory organs for olfaction and vision, to infer the degree of their aquatic adaptation. There have been few studies analyzing the correlations between such characters and the degrees of aquatic adaptation quantitatively in extant mammals, a prerequisite for inferring aquatic adaptation in fossil taxa.

Therefore, we firstly analyzed characters related to the skull and brain endocast quantitatively in 97 species of extant mammals covering all major clades based on digital 3D reconstructions using CT scan data, with a particular focus on the sizes of the olfactory bulb and orbit and optic canals, all of which past qualitative observations indicated as having been modified through aquatic adaptation. The result showed that the sizes of the olfactory bulb and optic canal are significantly different among mammals of different degrees of aquatic adaptation and tend to become smaller in more extensively aquatic taxa, thus establishing these characters as quantitative indices for making an inference on the paleoecology of fossil taxa. The orbital size, however, did not show a clear difference corresponding to different degrees of aquatic adaptation.

Based on these results on extant taxa, an inference was made on the paleoecology of *Paleoparadoxia* sp. (Paleoparadoxiidae) from the middle Miocene in the Fukushima Prefecture in Japan based on a CT data set of the entire skull. The relative size of the olfactory bulb of this specimen was intermediate between the median values of extant aquatic and semiaquatic mammals whereas its optic canal size was close to the median of aquatic and full-aquatic species. These data thus suggest that *Paleoparadoxia* was likely a semiaquatic species, with its habitat limited to shallow marine realms. In addition, *Desmostylus* sp. (Desmostylidae) from the Nye Formation, of which age is around the Oligocene/Miocene boundary, was also analyzed similarly, and its results are discussed with an emphasis on the difference and potential evolutionary changes in aquatic adaptation within Desmostylia.

THE PHYSIOLOGICAL LANDSCAPE OF THE CARBONIFEROUS: FINDING THE FRONTIER OF FROST TOLERANCE

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Global vegetation has affected the Earth System by modulating mass and energy exchange at Earth's surface. In deep time, however, vegetation biogeography and its limiting factors are not well understood. We used meteorological data derived from GENESIS 3 Earth System simulations of the Late Carboniferous, and measurements of C:N, maximum stomatal conductance and leaf specific conductivity derived from fossil plant groups (Lycopsids, Sphenophytes, Pteridosperms, Tree Fern, and Conifers), we produced a 2 degree global grid of ecosystem process simulations using *p*BGC, a modified version of the ecosystem model BIOME-BGC. These simulations indicated that a large proportion of Pangea was physiologically available for vegetation: 29% during glaciation and 69% during interglacial periods. If plants could not survive frost those proportions decreased to 9% and 11%, respectively. This suggests that the evolution and advantage of freeze-tolerance in plant lineages may be a key factor in determining the global biogeography of vegetative cover, and therefore Earth System parameters such as erosion and albedo in the Late Carboniferous. Incorporating these indirect feedbacks from vegetation to climate into Earth System Models may improve their ability to explain complex Earth System disturbances like the Late Paleozoic Ice Age and the Permian Triassic Mass Extinction, as well as current Earth System projections.

THE IMPERIAL FORMATION IN SAN GORGONIO PASS, SOUTHERN CALIFORNIA: IMPLICATIONS FOR PALEOGEOGRAPHY AT THE NORTHWEST HEAD OF THE LATE MIOCENE GULF OF CALIFORNIA

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The Imperial Formation in the Salton Trough of southern California records latest Miocene marine deposition in the evolving transtensional Gulf of California. Current thinking envisions late Cenozoic sedimentary fills in the Salton Trough region—including the Imperial Formation—as syntectonic deposits that accumulated on the hangingwall of the West Salton Detachment (WSD), a regionally extensive, down-to-the east, low-angle normal-fault complex that evolved in concert with the San Andreas Fault system beginning at ~8 Ma.

Three stratigraphic successions of the Imperial Formation occur in the San Gorgonio Pass (SGP) region, ostensibly at what then was the NW head of the late Miocene Salton Trough: (1) the Whitewater Imperial sequence rests nonconformably on crystalline rock of Transverse Ranges-type (TR), and consists of a basal-conglomerate unit overlain by mudrock and fine sandstone. The Imperial in turn is overlain transitionally by the Painted Hill Formation that in part may be marine in origin. Clasts in the two formations exclusively are of TR-type; (2) The Cabazon Imperial sequence rests on the nonmarine Hathaway Formation, a Miocene unit containing clasts of Peninsular Ranges-type (PR) and TR-type; contact relations are ambiguous. The Imperial is overlain by the Painted Hill Formation containing clasts of TR-type and subordinate PR-type. The basal contact of the sedimentary sequence is not exposed, but geophysical data indicate that PR basement of the San Jacinto Mts extends N beneath the sedimentary rocks; (3) The Garnet Hill Imperial sequence consists

mainly of sandstone and pebbly sandstone interbedded with conglomeratic rocks that probably are long-runout rock-avalanche deposits; clasts are exclusively of PR-type. The Imperial is overlain transitionally by conglomeratic rock of the Canebrake Fm. The basal contact of the sedimentary sequence is not exposed, but most likely is crystalline rock of PR-type.

The three Imperial successions are different from one another, and these differences confound efforts to integrate them within a coherent stratigraphic and paleogeographic framework. Differences include paleobathymetry, stratigraphic succession, sediment provenance, and—especially—underlying basement on which the Whitewater succession was deposited in contrast to the Cabazon and Garnet Hill successions. We use these differences to reconstruct late Miocene paleogeography and structure at the NW head of the Gulf of California: (1) the Whitewater Imperial succession accumulated on parautochthonous TR-type basement, (2) the Cabazon and Garnet Hill Imperial sequences accumulated on the hangingwall of the WSD, and (3) the late Miocene Banning Fault traversed this landscape in an unknown way. This proposal requires that a late Miocene strand of the WSD projects westward through SGP and beyond, and the San Jacinto Mts massif was a rising WSD footwall block that shed debris into the Miocene-Pliocene Cabazon and Garnet Hill hangingwall sequences.

EARLY JURASSIC SPICULITES: GLASS RAMP DEPOSITS OF PERU IN THE MICRO AND MACRO SCALE

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In the wake of the End-Triassic mass extinction several shallow-marine ecosystems of both the Panthalassa ocean and Tethys sea became dominated by siliceous sponges. These spiculitic "glass ramps" replaced carbonate regimes and persisted for millions of years. However, our knowledge of the controls of this paleoecological expansion, as well as the architecture of these "glass ramps", remains nebulous. Here we combine previously published stratigraphic sections of the Central Peruvian Andes with microfacies analyses of sponge spiculites and concomitant sediments, in order to develop models for sponge distribution, deposition, and preservation. We analyze bioclasts, trace fossils, terrigenous grains, and early diagenetic fabrics to tie microenvironments to their broader basinal context. This work will be combined with geochemical analyses that seek to add a temporal dimension to this spatial examination and will provide a detailed understanding of these peculiar chert formations that can bolster research on other similar paleoenvironments.

COLLABORATIONS BETWEEN AMATEURS, PROFESSIONALS AND YES, EVEN FOSSIL DEALERS…A PERSONAL PERSPECTIVE

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Collaborations between professional and non-professional paleontologists come in many forms and are wide ranging, ongoing and productive. Fossil clubs/societies frequently donate fossils and money to the professional community. They donate their time as well, sometimes to help curate professional collections, similar to the inventory project currently being done at the University of Texas in collaboration with the Paleontological Society of Austin – though this is but one of many forms such donations of time can take.

Members of the general public, amateur/avocationals and even fossil dealers frequently find and donate rare taxa to professionals. Many amateur/avocationals collaborate with their professional counterparts in peer reviewed and published literature including several members of the North Carolina Fossil Club, Dry Dredgers, Dallas Paleontological Society and myself, to name only a few.

Fossil dealers also provide a venue for professionals to obtain research specimens, as is the case with Donna Russell of Geological Enterprises. There are also "Pay to dig" fossil sites like U-Dig Fossils and PaleoAdventures that use the general public to excavate and allow the diggers to keep common specimens while retaining rare and unusual ones for scientific study.

These are all collaborative efforts that I have either been directly involved with or have firsthand knowledge of. The results of these collaborations continue to move paleontology forward in ways that would otherwise not be possible.

We will examine specific case studies of each of these types of interactions, for their methodology and best practices. There are sometimes barriers to such

collaborations, strong barriers, but if we can reach past these and arrive at a place of mutual understanding and cooperation, we will realize both communities benefit immensely from such synergy. Especially in a time where science is being assaulted as a whole, it behooves us to stand together as one united force. The study of paleontology will be forever changed for the better for it.

THE IMPACTS OF CLIMATE WARMING AND OCEAN ACIDIFICATION ON THE MARINE ECOLOGY OF THE ANTARCTIC PENINSULA

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The western Antarctic Peninsula is the most rapidly warming region of our planet. Eighty-seven percent of the glaciers are in retreat, major coastal ice sheets are disintegrating, and over the past thirty years the annual sea ice has receded forty percent both in its duration and extent offshore. Marine ecosystems are being dramatically restructured. Populations of key species including krill and Adélie penguins are being negatively impacted, and in some instances, disappearing. Warmer weather species including gentoo penguins, chinstrap penguins, and elephant and fur seals, are exhibiting southern range extensions as air temperatures warm. And with ocean warming, deep-water king crabs are for the first time moving up the Antarctic slope toward the continental shelf where they may decimate weakly-calcified prey that have been isolated from crushing predators for millions of years. Ocean acidification, exacerbated by the increased absorption of carbon dioxide at low temperature is dissolving the delicate aragonite shells of sea butterflies, and threatens select marine invertebrate species in benthic coastal ecosystems. Collectively, these unprecedented impacts on Antarctic Peninsular marine species, and the ecosystems they comprise, speaks to the urgency of addressing global climate change. Fortuitously, the story of the discovery and mitigation of the hole in the ozone over Antarctica offers a poignant model of hope for a societal transition away from the combustion of fossil fuels.

***BOREALOSUCHUS* (CROCODYLIA) FROM THE EARLY CAMPANIAN MOOREVILLE CHALK REVEALS NEW INSIGHTS INTO THE LATE CRETACEOUS FAUNA OF ALABAMA AND THE ORIGIN OF CROCODYLIAN LINEAGES**

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Borealosuchus is a significant genus as it is either a basal crocodylian or close outgroup. A new species has been identified from the early Campanian Mooreville Chalk of Alabama. This is one of the oldest known crocodylians, and extends the stratigraphic range of *Borealosuchus* from the Maastrichtian minimally into the Campanian. It co-occurs with the giant alligatoroid *Deinosuchus* in deposits formed in a marginal marine setting with fluvial input. Its age, along with the phylogenetic position of *Borealosuchus*, renders this material critical for understanding the morphological conditions and relationships at the root of Crocodylia. The most complete specimen consists of partial cranial, mandibular, and post-cranial remains. This form preserves a unique combination of characters including a short dentary symphysis, splenial participation in the symphysis, the lack of a discrete concavity on the angular dorsal margin for an external mandibular fenestra, and bipartite ventral osteoderms. The external mandibular fenestra was either absent or very small, raising questions about the ancestral condition for this structure in Crocodylia. The new species is, surprisingly, closer phylogenetically to more derived species of *Borealosuchus,* including *B. wilsoni*, *B. threeensis*, and *B. acutidentatus*, than to *B. sternbergii* and *B. formidabilis*. This creates many range extensions and ghost lineages in the clade and suggests substantial unsampled diversity in *Borealosuchus*. There is additional mandibular material from the Santonian Eutaw Formation that can may be referable to this new species, further increasing its stratigraphic range. An additional specimen consists of a partial post-cranial skeleton from the Mooreville Chalk that is significantly larger than the holotype of the new species, and is referable to *Borealosuchus* sp., but is too incomplete to be referred more precisely. These newly described specimens provide additional information about the faunal make up of Alabama during the Late Cretaceous, as well as have broader implications because they are some of the earliest crocodylian material known. Indeed, the Eutaw material appears to be the oldest known occurrence of Crocodylia.

NEW UPPER CRETACEOUS VERTEBRATES FROM THE MENEFEE FORMATION IN NEW MEXICO: BLENDING FIELD WORK, RESEARCH, AND OUTREACH TO PROMOTE PALEONTOLOGY ON BLM LAND

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During the Late Cretaceous, the interior of North America was flooded by a saltwater seaway, forming two separate landmasses—Appalachia in the east and Laramidia in the west. The fossil record of dinosaurs and other terrestrial vertebrates from Laramidia is among the best in the world. However, all the most productive dinosaur-bearing Upper Cretaceous units in Laramidia date to between 77 and 66 Ma. The earlier evolution of many predominant groups, such as the giant tyrannosaurs and hadrosaurs, remains enigmatic.

A joint project by the Western Science Center and Zuni Dinosaur Institute for Geosciences, with volunteers from the Southwest Paleontological Society, is exploring the Allison Member of the Menefee Formation, dating to between 80 and 79 Ma. Since 2011, we have collected material of dinosaurs, crocodyliforms, turtles, fish, freshwater invertebrates, and plants on land administered by the U.S. Bureau of Land Management in San Juan County, New Mexico. Field work will continue in 2019 and for many years to come.

In 2018, we published the first results of this project: two new dinosaurs, the nodosaurid *Invictarx zephyri* and the tyrannosaurid *Dynamoterror dynastes*. Although a partial ceratopsid skeleton was reported from the Allison Member by Thomas Williamson (New Mexico Museum of Natural History & Science) in 1997, these are the first named dinosaurs from the unit.

We are now describing a rich collection of more recent discoveries curated at the Western Science Center. A new genus and species of hadrosaurid is known from a partial skull and right forelimb. Features of the nasal crest and skull roof identify it as a member of Brachylophosaurini, a clade of solid-crested hadrosaurs known from Alberta, Montana, Colorado, and Utah. Our new specimen is the southernmost occurrence of the clade and the first crested brachylophosaurin south of Montana. Another significant hadrosaur specimen is an isolated maxilla from a very young juvenile.

Crocodyliform specimens include osteoderms similar to *Denazinosuchus* from the younger Kirtland Formation, a small partial skull similar to *Brachychampsa sealeyi* (named by Williamson in 1996 based on a more complete skull from the Allison Member), and an incomplete skeleton of the giant *Deinosuchus*, including vertebrae and characteristic inflated osteoderms. This is the first *Deinosuchus* from the Menefee Formation and among the earliest from Laramidia.

At least four turtle taxa are present, including a trionychid and a large baenid similar to *Neurankylus baueri* from the Kirtland Formation.

The Western Science Center is laser-scanning the fossils and 3D-printing copies, which allows both institutions to share our discoveries with the public in a hands-on way that would be hazardous for the fossils. The 3D models are uploaded to Sketchfab and MorphoSource. Publications are accompanied by social media posts, lectures, and paleoart; Kara A. Kelley and Brian Engh created life restorations of *Invictarx* and *Dynamoterror*.

THANKS MIKE!

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This is an anecdotal paper and it is tough to write. How can I appropriately give proper thanks to an educational and life mentor without making it about me? The fact is I am the person that I am today largely because of great life mentors like Michael A. Murphy, Ph.D. So, THANKS Mike … I appreciate what you did for me!

I arrived at UCR in the fall of 1970 largely unprepared. I wanted an education in Geology to better prepare myself for what I really wanted to do in life … become an architect. As I timidly explained to my professors why I was studying geology I was pleasantly surprised at their almost universal level of support.

Mike repeatedly went out of his way to find parallels and abstract connections between geology and architecture for me. I can remember him pulling me aside pointing to a particular topographic shape or sequence of rocks and/or soils and asking me what was I seeing from an architect's perspective. More often than not, his questions stumped me. In the field, Mike was simply amazing. When I didn't or couldn't answer, he asked the question in a slightly different way. He would sometimes point to a detail in the question leading me to the answer. What Mike was teaching me was that I needed to understand the difference between looking at something and seeing something. Seeing is understanding … Mike taught me that. But not right away. I was a pretty slow learner.

Years later in 1986, as an architect I had a school client that was really excited about a site a developer wanted to donate to the school district for their new elementary. I met the client on a Saturday to look at their beautiful new "free" site. The site was about ten miles north of Yucca Valley just off of Highway 246. As my client walked me up onto a rise on the western side of the site just past a small existing house, he said "just look at that view".

At that moment, Mike finally took over my mind … I said "yeah Jack it is a pretty view but what are we standing on?" "Looks like decomposed granite" he said. "Correct but it isn't quite that simple … anything else you think has something to do with designing a school here" I asked? "DG makes for good playground material … we won't have to import the DG" he responded. "While that is true, it isn't the issue" I told him. "What do you think makes decomposed granite like this when the granitic rocks nearby are nice and solid" I asked? I had finally realized that Mike had taught me to look first and then see clearly with understanding. Now, the problem was how will I convince my client not to accept this free dangerous site and to convince his school board that they need to find and purchase a suitable site since he really hasn't seen the issue yet.

A PALEONTOLOGICAL PERSPECTIVE TO CONSERVING FOR CHANGE

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Landscape conservation practices are pivoting from a restoration framework to one that emphasizes the need to conserve for change. This shift recognizes that populations and species will need to track their climatic niches on the landscape and adapt to impending environmental change. For practical purposes, conserving for change prioritizes the preservation of resilient landscapes, characterized by diverse habitats, high landscape connectivity, and microrefugia for a diversity of species. This assumes that species will dynamically shift across the landscape as they adapt to changing climates. However, we do not yet understand the conditions that promote resilience in the face of environmental change nor do we know the extent to which species and ecosystems move rather than adapting in place.

To inform landscape conservation policy, we must understand the ecological dynamics of the systems we are trying to preserve. Conservation paleontology has the tools to understand resilient landscapes and the dynamic responses that species have exhibited in the face of change. Here, I demonstrate how we can use the paleontological record to inform the conserve for change framework by exploring ecosystem dynamics and resilience in the face of historical change. I discuss projects that address two questions and their implications for the conserve-for-change framework: 1) Should we expect dynamic range shifts in response to climate change? 2) What are the impacts of fragmentation and human impacts on mammalian niches?

We find that plant biomes exhibit relatively short residence times, dynamically shifting when climate changes. Using 20,000-years of pollen records from North America, we have been able to calculate that plant biomes transition approximately every 300 years. These trends imply that we should resist the urge to restore to the norm following disasters and rather allow for the progression of transitioning biomes. We also demonstrate that human impacts on the landscape are preventing mammals from tracking their preferred niches. Species living in 25% of natural land areas in North America are unable to achieve climate connectivity today. The impacts of humans on the landscape has led to dramatic contractions in mammalian niches. These findings emphasize the need to increase connectivity to facilitate the maintenance of biodiversity during periods of rapid change.

Although we sometimes worry that spatial and temporal scales may preclude paleontological research from having impacts on conservation decisions, at the landscape scale a deep time perspective can be crucial. The realization that biomes shift rapidly and that human impacts directly affect realized niches bolsters the approaches and strategies of advocates of the conserve-for-change framework. These findings have the potential to shift large-scale policies, emphasizing the integration of management units on the ground to allow for the establishment of well-connected climate refugia.

ASSESSING RECORDS OF ENVIRONMENTAL STRESS AND MASS EXTINCTIONS DURING THE EARLY PALEOZOIC

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The early Paleozoic encompassed a complex time of coupled biological and environmental change. Notably, an extensive interval of environmental stress spanning the Cambrian through Early Ordovician included numerous mass extinction events—mostly evidenced in Laurentian trilobites—and markedly high levels of atmospheric CO_2. Declining atmospheric CO_2 and global cooling during the Middle Ordovician coincided with the Great Ordovician Biodiversification Event. In this contribution we will discuss the global scope of upper Cambrian trilobite mass extinctions in context of new biostratigraphic and geochemical data from North China and South Korea. We will further assess how broad scale changes in global plate tectonic processes associated with long-term carbon cycle, particularly the waxing and waning of volcanic arcs, correspond with major changes in early Paleozoic climate. These data illustrate how variability in tectonic-sourced carbon fluxes can lead to environmental instabilities.

HAWK RIM; AN OREGON ECOSYSTEM ON THE-CUSP OF THE MID MIOCENE CLIMATIC OPTIMUM

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The Mascall Formation of Oregon is a classic Mid Miocene fossil assemblage. In addition to the vertebrate fauna, considerable historic attention was paid to the prolific flora, especially as a snapshot of ecosystems at, or near, the Mid Miocene Climatic Optimum. Work on the paleosol sequence further suggests a marked interval of environmental change recorded in the Mascall Formation, an interpretation supported by recent isotopic studies. The cumulative evidence thus far points out that this cooling and drying likely occurred in a cyclic nature, rather than a steady decline, but reconciling these interpretations is important for reconstructions of life responding to climatic change. Hawk Rim, a recently discovered Mascall locality from the latest Hemingfordian NALMA, and therefore the very base of the Mascall and Mascall equivalent sediment packages, offers a rare chance to integrate floral, faunal, paleopedological, geochemical, and isotopic data across a narrow temporal range for a single geographically isolated site.

My new data on paleosols indicate the presence of large woody plant systems periodically inundated by rivers and lakes. Consistent with a closed to semi-closed habitat, the mammalian fauna is composed of diverse ungulates, with the most common taxa skewed towards smaller-bodied animals, like a palaeomerycid and small horse, as opposed to the larger-bodied relatives more common in the higher Mascall type locality. Carnivores in particular were diverse, with a beardog, felid, three canids, and two mustelids, implying a rich ecosystem capable of supporting a high degree of productivity and niche partitioning. We also now include the non-mammalian vertebrates, namely a testudine fauna with pond, mud, and snapping turtles all indicative of a wetter ecology, as well as an avifauna from a similar environment, such as a cormorant and an owl. This ecosystem reconstruction, of forested river and lake banks, fits well with the novel flora from Hawk Rim. Unlike many sites producing both a flora and a fauna, vertebrates and flora are being produced in the same strata, implying coexistence. Wetland taxa like *Equisetum* and *Potemogeton* coincided with warm humid forest tree taxa like *Taxodioxylon* and *Metaseqoia* preserved as both leaf impressions and permineralized wood, as well as more abundant deciduous hardwoods.

In summary, the coupled geologic setting, flora, and fauna of Hawk Rim imply a diverse ecosystem heading into the MMCO. While many characteristic elements of both the flora and fauna remain into the Barstovian NALMA, abundance of larger-bodied grazers increases and the equally larger inferred pursuit predators, while some of the flora most comparably with subtropical humid regions is phased out. As the lithology throughout the Mascall is similar, the depositional environment likely shifted slowly from the wetter and more closed habitats at Hawk Rim, to the presumably semi-open ecosystems of the Mascall proper.

HIGH-LATITUDE BENTHIC BIVALVE BIOMASS AND RECENT CLIMATE CHANGE: TESTING THE POWER OF LIVE-DEAD DISCORDANCE IN THE PACIFIC ARCTIC

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Time-averaged molluscan death assemblages sampled from tropical to temperate open continental shelves commonly disagree in species composition

with local living communities only in areas that have changed in response to anthropogenic eutrophication and other locally intense human stresses, providing a means of recognizing shifted baselines. In contrast, the ability of live-dead discordance to resolve the spatially heterogeneous effects of human-induced climate change has not been tested in high-latitudes, where climate change entails substantial changes in nutrient cycling with consequences for benthic biomass and where cold waters are antagonistic to carbonate shell preservation. North Pacific Arctic and Sub-Arctic seabeds offer ideal conditions for testing the resolving power of molluscan live-dead discordance, using well-documented ecologic changes in nutrient cycling and benthic biomass in response to reduced sea ice. Ecosystem monitoring since 1980 has established that the boundary between the Arctic and the Sub-Arctic on the Bering Sea continental shelf, maintained by ice-influenced bottom water, shifted northward between 1998 and 2001. The benthic community in the transitioned area now experiences new pelagic predators, more variable quantity and quality of deposited food, and altered sediment grain size, and macrofaunal dominance has shifted from diverse communities of specialized suspension or deposit feeders to facultative deposit feeding guilds. We find that in habitats where either Sub-Arctic or Arctic conditions have persisted bivalve death assemblages agree closely with counterpart living communities in taxon and guild composition and are not subject to significant post-mortem bias. Significant live-dead discordance occurs only in areas with documented changes in carbon delivery, sediment grain size, and community composition over the last several decades and that death assemblages are mixtures of shells from pre- and post-transition communities, as confirmed by monitoring data. This spatial pattern is robust to both numerical abundance- and biomass-based measures of community composition. In fact, biomass is especially powerful in revealing fine, station-level discordance that is strongly tied to known sites within habitats where new carbon deposition levels, grain size, or benthos have occurred since 1980. Live-dead discordance can thus reliably differentiate between stable and rapidly changing habitats in cold, high-latitude settings, relevant to evaluating climate change, and that biomass-based currencies of community composition are as robust as numerical abundance data, and in fact, improve spatial resolution.

THE DRY DREDGERS OF CINCINNATI: A HISTORY OF OUTREACH AND COLLABORATION

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Professor Kenneth E. Caster founded the Dry Dredgers in 1942 in Cincinnati at the request of participants in a lecture-discussion series for the public at the University of Cincinnati. Caster presented lectures on the local geology, paleontology, and anthropology, accompanied by field trips. The group became an association of amateur geologists and paleontologists that flourishes to this day. Even earlier, Cincinnati had a tradition of "amateur" participation in paleontology and geology through the so-called "Cincinnati School" of publishing amateurs in the late 19th and early 20th Century. Prominent among these were S.A. Miller, E.O. Ulrich, A.F. Foerste, Charles Schuchert, and others from various walks of life who became scientific leaders in the early history of North American paleontology and stratigraphy. To this day Dry Dredgers meetings feature lectures by faculty or paleontology graduate students. Many donated specimens became types for new species and material for student dissertations. Members gained knowledge of the scientific importance of their fossils and satisfaction of contributing to growth of the science. A reciprocal, mutually rewarding association developed. Over the years Dry Dredgers have been primary discoverers of fossil-rich beds of echinoderms, trilobites, trace fossils, brachiopods, bryozoans, and mollusks that are the underpinnings for advances in Ordovician paleontology with global significance. Dry Dredgers have grown from being collectors and suppliers of unique fossil specimens to become citizen scientists who themselves describe new fossils, assemble fossil datasets and publish original research either with professionals or on their own. Professional organizations such as the Paleontological Research Institution and the Paleontological Society have taken notice of the achievements of Dry Dredgers in presenting major awards to members in recognition of their contributions to paleontology. Dry Dredgers have two programs, sale of fossil kits and co-sponsorship of GeoFair by which they generate funds used for a grant program open to the paleontological research community. GeoFair is a public exposition where fossil collections, demonstrations, and lectures provide major avenues for public communication about science. Dry Dredgers have also been active participants at NAPC meetings and at conferences and field trips sponsored by the FOSSIL Project. The

Dredgers website, DryDredgers.org, is a rich source of information about meetings, field trips, new books, and paleontology as an avocation through guides to fossil identification, and best practices for fossil collecting and curation. Throughout their 77-year history, the Dry Dredgers have demonstrated how mutually beneficial collaboration between amateurs and the scientific profession can be developed to enhance informal science education and to encourage the growth of paleontological citizen science.

UNDERSTANDING EXCEPTIONAL PRESERVATION THROUGH COMPARATIVE MICRO-ANALYSIS OF FOSSILS FROM THE CAMBRIAN KINZERS FORMATION (~514–509 MYA) OF CENTRAL PENNSYLVANIA, USA

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Exceptionally preserved fossil material, such as eyes, digestive tracts, and skin, offer the only opportunity to study certain aspects of paleobiology (e.g., nervous systems, organ structure, or cellular development) in the fossil record. Exceptionally preserved fossils, especially in the Cambrian Period, are usually represented by soft-bodied organisms. Despite the importance of exceptional preservation to our understanding of past life, there are important gaps in the study of exceptional preservation: the poor understanding of the diversity, mechanisms, and processes of exceptional preservation. These gaps make it difficult to predict the physical-chemical conditions under which exceptional preservation occurs. This work looks into the timing and role of clay minerals in exceptional preservation through traditional petrographic investigations, micro-analytical techniques, and in-situ three-dimensional visualization and reconstructions of fossils from the Kinzers Formation of south-central Pennsylvania. It finds that the Kinzers fossils are more clay-rich and have a broader range of 'exceptional preservation' than previously reported.

REGIONAL VARIABILITY OF THE RECOVERY OF SHALLOW MARINE INVERTEBRATES DURING THE EARLY TRIASSIC

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The Permian Period ended with the taxonomically and ecologically most destructive extinction event in the Phanerozoic. The return to pre-extinction levels of diversity and the recovery of complex ecosystems after the catastrophic event span the first 8 to 10 million years of the Triassic. Repeated global environmental perturbations paired with regional environmental variability result in differences in the pace and pattern of recovery, so that there is no discrete answer to when the recovery is "complete". This study focuses on the intra-formational variability of recovery within the Sinbad Limestone of eastern-central Nevada which records a Smithian-age shallow marine environment. Previous work on the Sinbad Limestone have described the taxonomic diversity, ecological complexity, and average size of mollusks, especially microgastropod deposits. This study used taxonomic diversity, functional ecology, and size metrics to build on previous studies of the Sinbad Limestone to examine the intra-formational variability in recovery by analyzing samples collected along a proximal-distal gradient.

Bulk samples (approx 3L) were collected from three stratigraphic sections of the Sinbad Limestone. Samples were disaggregated, we identified the specimens to the genus level, and measured them across their greatest dimension using calipers. We omit specimens that were smaller than two millimeters. We then used the Paleobiology Database to assign the specimens to ecological life modes; feeding, motility, and position relative to the sediment-water interface.

Of the Early Triassic bivalves, brachiopods, and gastropods in our samples, a large quantity of the existing species appear to have been suspension feeders. The second most common feeding mode was chemosymbiosis, represented by abundant Sinbadiella pygmaea in more offshore sections. Stationary bivalves were common, including an abundance of Eumorphotis and Leptochondria followed by facultatively mobile bivalves. The majority of individuals were epifaunal bivalves, with infaunal and deep infaunal comprising the second and third most abundant life modes. The average size of bivalves and gastropods is consistently below 10mm for all 3 sections.

THE RELATIONSHIP BETWEEN AMATEUR COLLECTORS AND PROFESSIONAL PALEONTOLOGISTS IN COLLECTING FOSSIL LAGERSTÄTTEN

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Gerald O. Gunderson and Ronald C. Meyer

Between the early 1980s and the present we have been involved in the collecting, and two cases the

discovery, of significant Lagerstätten.

In each instance the relationship between us and the professional paleontologist was quite different in terms of the fossils collected and the resulting possible scientific studies that followed

Two Silurian Lagerstätten, the Brandon Bridge and the Scotch Grove formations suffered the same fate. In each case we were able to collect and prep substantial collections of an extraordinary softbodied fauna. However, eventually our continued collecting was prevented by the professional paleontologists involved. In addition, either because of lack of ability or interest by these paleontologists few if no scientific papers resulted.

Our collecting of the famous ruin wash lower Cambrian Lagerstätten resulted in the discovery of many softbodied specimens with many species predating the Burgess Shale. The result was scientific papers largelyin collaboration with Dr. Bruce Lieberman of the University Kansas.

Our discovery of an extraordinary site in the Eocene green river of Colorado resulted in the finest collection of insects, arachnids and plants found so far in this formation. Many of the specimens ended up, through good graces of Dr. Kirk Johnson, in the collections and on displays at Denver Museum of nature and science. Eventually the site fell into the hands of fossil dealers.

Our most recent discovery of the big Hill upper Ordovician Lagerstätten has produced our best experience with regard to collaboration with professional paleontologists. We have been able to control the collecting of the site. In addition the collaboration between the professional paleontologist, Dr. Derek Briggs, Dr. James Lamsdell and Dr. Steve LoDuca has resulted in three major papers and more on the way.

Much can be learned from the success of the collaboration between us and the professionals from the big Hill experience.

GUIDED DISSECTION OF PRIMARY PALEONTOLOGY RESEARCH AS A TOOL TO BUILD SCIENCE LITERACY IN HIGH SCHOOL STUDENTS

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Comprehending primary research literature is an essential skill needed for students wanting to conduct their own research projects. However, teaching novice students how to breakdown complex science topics in a way that is engaging and effective can be challenging. The purpose of this exercise was to engage high school students, all interested in paleontology, with primary scientific literature to develop their research comprehension skills. The Sternberg Museum of Natural History Field Paleontology: Kansas Camp offered a unique opportunity to provide students from diverse socioeconomic backgrounds with an outlet to express their interests and concerns regarding research. Students attending the field camp were given a paleontology-focused peer reviewed journal article and a detailed article synopsis that included an in-depth dissection of the article's sections and figures. Students were given access to these documents months before they arrived at camp. During the lab portion of the program, students were divided into two groups based on their age. Discussions about the article, the synopsis, and finding reliable research online were led by the authors. The campers were encouraged to discuss their interpretations, ask questions, and think critically about the provided article's content, and the purpose of its respective components. After the camps, the students were provided an opportunity to give feedback on the exercise and to offer suggestions for future uses of this lesson. Students expressed willingness to do the activity again at future camps and have stated that they have gained useful skills and knowledge that they have since applied to their schoolwork. High school students with limited access to educational resources may further benefit from the implementation of research literature dissection activities by gaining an understanding of science methods and paleontology that they may not have previously considered.

ALLOMETRIC VARIATION IN THE GENUS STEINMANELLA (TRIGONIOIDA, BIVALVIA) FROM THE LOWER CRETACEOUS OF THE NEUQUÉN BASIN (WEST-CENTRAL ARGENTINA)

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Because of the outstanding diversity and disparity they reached during the Mesozoic, the paleobiology of trigoniid bivalves has attracted considerable interest. In this work, we assessed the patterns of allometric variation within the genus *Steinmanella*Crickmay (Myophorellinae, Trigonioida) as it occurs in the lower Valanginian – upper Hauterivian (Lower Cretaceous) of the Neuquén Basin (west-central Argentina). The shells of 236 specimens belonging to 7 species of *Steinmanella* (namely, *S. quintucoensis, S. subquadrata, S. curacoensis, S. caicayensis, S. pehuenmapuensis, S. transitoria* and *S. vacaensis*) were digitized in three dimensions, and variation in two prominent external morphological characters, general valve geometry and sculpture, was subsequently analyzed. Shell surface shape and size were measured by means of geometric morphometrics, whereas sculpture was quantified using counts of ribs and nodes. The trajectories of the studied species through different size categories (intended to represent meaningful ontogenetic stages) were compared using phenotypic trajectory analysis. Our results show that early and late growth changes differ in nature between species. The former seems to be far more plastic, being characterized by changes in the direction and magnitude of the allometric trajectory through the shell surface and sculpture morphospaces respectively. On the other hand, late growth seems to be more conserved and channeled, showing more infrequent changes which mainly involve the magnitude of the trajectory across the shell surface morphospace. Therefore, the distinctive features of each species would had been acquired early in life, with later changes involving a general trend towards shell elongation, thus challenging the view that early development is more conserved in evolution. These findings can have important implications for the evolution of *Steinmanella*, as heterochronic processes acting upon ontogenetic variation is thought to be a major driver of bivalve evolution.

ANTLERS OF THE ARCTIC NATIONAL WILDLIFE REFUGE: BASELINES OF BIOLOGICAL VARIABILITY FROM BONES ON THE TUNDRA

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Quantifying natural variability in geographic range (including seasonal landscape use and migration) is a primary concern for evaluating animal populations and establishing management and conservation goals. Unfortunately, this variability is often modeled using datasets with limited temporal perspectives. This predicament is exacerbated in arctic settings, where logistical complexities frequently interfere with biological surveys; including on economically and culturally keystone species, such as caribou (*Rangifer tarandus*). Unique aspects of caribou biology and ecology enable surface bone accumulations to significantly extend the observational window with which we study seasonal landscape use, particularly calving ground geographies (birthing grounds). Caribou females, like males, annually grow and shed antlers. While male caribou (and non-pregnant females) shed their antlers after the breeding season, pregnant females maintain their antlers until casting them within days of calving. Thus, the geographic distributions of male and female antlers offer data on historical migration and calving grounds. Because antlers can survive on arctic surfaces for centuries or longer, antler surveys not only offer insight into recent calving activity that is complimentary to traditional monitoring data, but they provide a unique source of historical baseline data on calving ground geography across timescales not available from ecological datasets. Here, we take advantage of naturally occurring accumulations of shed female caribou antlers to acquire data on calving ground landscape use and migratory fidelity across $10^2$to 10^3years. Further, we pair these data with hemispheric climate records (Arctic Oscillation) and other environmental and geographic parameters to test the drivers of calving ground geography and evaluate the impacts of current climate trajectories and recent changes in federal management policies. Antler surveys were conducted on foot across the Coastal Plain of the Arctic National Wildlife Refuge (ANWR), Alaska. Surveys focused on*Dryas*Terrace habitats, which are dry, have low vegetation cover, and appear to be a focal habitat during the calving period. On the ANWR calving grounds, accumulations of shed female caribou antlers can be large (> 1,000 antlers/km^2). Relative to expectations from aerial surveys, many surveyed regions have higher-than-expected antler concentrations. Additionally, the rank-order correlation between modern and pre-1980 antler records is low, indicating a lack of congruence between modern and historical calving geography. Changes in the geographic distribution of antlers through time also indicate links between calving geography and climate (Arctic Oscillation) on decadal time-scales. Surficial bone records

offer valuable resources for recording variability in season-specific landscape use that extend far beyond current temporal limitations in wildlife monitoring.

NASHVILLE DISCOVERS PALEOZOIC FOSSILS: PROGRAMS AND FIELD TRIPS AT AN URBAN HISTORICAL PARK

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Fort Negley Park (FNP) is the site of a Civil War fort built into underlying Ordovician limestone in downtown Nashville. FNP celebrates the history of this Union fort, built by African Americans - some freed-slave volunteers, others forcibly conscripted by Union forces. Their contributions under terrible conditions were pivotal in determining the war's outcome, as Fort Negley helped to secure Nashville's critical river and railroad hubs for the Union. The cultural legacy of the African Americans who built the Fort is inextricably tied with Nashville's history and its moniker as the "Music City," as their spiritual music brought musical recognition to the city during European tours in the late 1800s. Outcrops at FNP contain well-exposed fossils of *in situ* tabulate corals and stromatophorids, as well as disarticulated brachiopods, crinoids, trilobites, and bryozoans that were deposited in a high-energy shallow marine setting. FNP offers an excellent opportunity to connect earth science with American history and culture and to engage a unique audience that might not otherwise be introduced to paleontology.

The Friends of Fort Negley (FoFN), the volunteer group supporting FNP, has forged collaborations with multiple community partners to draw Middle Tennesseans to the park to discover the area's ancient life and deep-time history. Programs include: "Fossils at the Fort," an annual outreach event led by Vanderbilt Earth and Environmental Science students as a service-learning component of the paleontology course; and "Fossil Finders," a monthly series that features guided fossil collecting from a pile of fossil-rich rock donated by Vulcan Materials Company. With support from the Predators Foundation (Nashville's professional hockey team), FoFN began supporting field trips to FNP for K-5 schools in Nashville in 2017. The educational programs offered by FoFN meet Tennessee Academic Standards for Science, focus on hands-on active learning activities, and provide quality educational experiences for subjects best taught in the field (e.g., geology, paleontology, ecology). Targeted Nashville schools include those categorized as 2018 Priority Schools for improvement and those most in need of financial support for transportation.

About 1000 students participated in the field trips during Spring 2019, representing a diversity of socioeconomic, ethnic, and cultural backgrounds. FoFN is committed to expanding these opportunities in the 2019–2020 school year by seeking additional funding and forging new community partnerships in the private and public sector. The suite of programs offered to the public introduce Nashville students and parents to key components of their community history: its geology, ancient life, and role in the Civil War.

DEPOSITION, CLIMATE, AND DIVERSITY: ALLIGATORINES AS A CASE STUDY OF THE COMMON CAUSE HYPOTHESIS

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Alligatorines are climate sensitive reptiles with a high chance of fossilization, leading to their use as paleothermometers. Previous analyses of Cenozoic crocodylian diversity returned a bimodal curve peaking over global thermal maxima in the early Paleogene and mid-Miocene. However, these analyses did not incorporate up-to-date taxonomies, phylogenetic data, or variation in the extent of rock exposure across time. Do these observed patterns reflect climate-driven extinction and diversification? Changes in rates of preservation? Is there a different signal when phylogeny is accounted for?

I performed an extensive literature search and compiled the most recent age estimates of all beds the oldest and youngest specimens identifiable to each currently valid alligatorine species have been found in, including some undescribed new species. This dataset is more precise and up-to-date than recently published studies using only raw Fossilworks data without digging deeper. Then, I plotted my phylogenetic hypothesis against time, resolving the single polytomy to minimize stratigraphic debt.

I tabulated species richness, originations, and extinctions in four million year time bins with and

without phylogenetic data. I pulled outcrop area of fluviolacustrine and swamp rocks from regions alligatorines have been found in from Macrostrat. Swamp rocks are rare after the warm early Eocene. Lacustrine rocks from the Paleocene are common, mostly absent until the mid-Miocene, then increase in the Pliocene. A "pull of the recent" of fluvial rocks is present starting 10 Ma. For climate, I pulled $\delta^{18}O$ values for mean annual temperature (MAT) from a NOAA dataset. Data failed tests for normality so I compared diversity, rocks, and climate to each other by calculating Spearman's rho correlation coefficients.

Alligatorine diversity tracks climate change well. Climate correlates with rock record to a lesser degree and variably; fluviolacustrine rocks decrease with increasing MAT, while swamp rocks show the opposite pattern. The highest MATs of the Cenozoic also coincide with the wettest part of the era. Diversity has little correlation with rock exposure, with swamps vs. originations and presence incorporating phylogeny being exceptions. There is weak to no correlation when only taxonomic ranges preserved in the fossil record are compared. No correlation exists between rocks and extinction.

In contrast to published analyses based on less accurate taxonomic data, this pattern of correlations and lack thereof show that alligatorine diversity through time is not a reflection of rock record bias. Rather, any similar patterns are a secondary effect largely based on the co-occurrence of a warmer, wetter climate both with more swamps and higher alligatorine diversity. This supports the common-cause hypothesis—all three metrics are tied together rather than rock record bias being the end-all-be-all of apparent co-occurring changes of diversity and outcrop area.

FOSSIL ACCOMPLISHMENTS AND OUTCOMES: HARNESSING DIGITAL PLATFORMS AND IN-PERSON EVENTS TO FOSTER COMMUNITY RELATIONSHIPS

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Part 3 of the FOSSIL symposium describes the products, accomplishments, outcomes, and summative evaluation of the FOSSIL Project.

Throughout its tenure, the FOSSIL Project has built a multiplatform community of practice where professional and amateur paleontologists, educators, and more can take part in the practice of paleontology. Participation in the community has been facilitated via online interactions, through dissemination of scientific research and community news, and by hosting virtual and in-person events and training opportunities. FOSSIL's digital presence has expanded to six platforms, including myFOSSIL.org, the myFOSSIL mobile app, Facebook, Instagram, Twitter, and YouTube. Combined, these platforms engage almost 10,000 individuals worldwide. Research on the FOSSIL community has produced five peer-reviewed papers in five different academic journals and more than 45 conference presentations and posters. Community news has been disseminated via the publication of 20 newsletter issues, including over 181 articles written by FOSSIL community members. FOSSIL's virtual and in-person events have been collaborative efforts between team members, clubs, and professionals, and have included webinars, mini-conferences, workshops, and citizen science experiences.

The outcomes of these accomplishments were assessed in a summative evaluation conducted in 2018. This evaluation consisted of an online, quantitative survey of more than 300 participants, followed by a subset of qualitative, semi-structured telephone interviews. Key questions investigated by the summative evaluation included: 1) Who benefitted from the FOSSIL Project?, 2) What factors contributed to a greater impact?, and 3) How does the FOSSIL Project serve as a community? Quantitative results revealed that 75% of survey respondents felt they benefited to some degree from the FOSSIL project, with nearly one quarter noting they benefited greatly. Individual connections between FOSSIL team members and participants helped forge a greater sense of impact. Finally, most respondents felt they were part of a greater paleontology community, though sometimes only on the periphery. These results help chart the path forward for expanding and supporting diverse contributors to the field of paleontology.

The panel discussion will highlight several of the FOSSIL products and accomplishments from the perspectives of a graduate student, amateur paleontologist, K–12 teacher, and museum professional. The multiple viewpoints will explore outcomes including those unexpected, such as the utility of the myFOSSIL

platform as a tool for engaging students in collection management procedures.

USING INTRA-SPECIFIC VARIATIONS TO DETECT SEXUAL REPRODUCTION IN EDIACARAN ORGANISMS

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Ediacaran macrofossils are the among the oldest (~566 Ma) known examples of macroscopic eukaryotic organisms. Ediacaran bedding planes from Newfoundland, Canada preserve thousands of specimens of*Fractofusus*, a "fractally-branching" rangeomorph of unresolved phylogenetic affinity. The preservation of this sessile organism in large in-situ bedding planes allows original spatial distributions to be analysed. Previous analyses determined that*Fractofusus*has a complex life history of multigenerational stolon-like asexual reproduction, punctuated by dispersal via waterborne propagules. However, whether these propagules were sexually-produced gametes or asexually-produced fragments or buds has not previously been resolved. Fractofusus populations from three surfaces in Newfoundland, Canada were recorded using a laser-line probe to produce high-resolution (50μm) 3D community maps. Colonies were identified using spatial analyses, with a colony defined as the dispersal-generated aggregation around large/founding specimens. There were significant differences in intra-specific variation (length to width ratios and number of primary branches) between colonies, with no significant differences between founding specimens and the next generation. This result is consistent with the hypothesis that founding members were sexually produced via waterborne gametes while the subsequent generations were asexually produced. Thus, this study provides evidence of the oldest instance of sexual reproduction of macroscopic organisms in the fossil record.

RESOLVING EDIACARAN DISCOIDAL FOSSILS

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Abundant circular impressions found on the surfaces of siltstones of the late Ediacaran (~560 Ma) Fermeuse Formation in Newfoundland, Canada, are amongst the most common Ediacaran macrofossils. Those historically assigned to the genus Aspidella have been considered to represent discrete organisms, component parts of frondose organisms, or inorganic or microbial structures. To distinguish between these hypotheses we characterize the morphology and spatial distribution of Aspidella specimens, and compare these to bona fide frond holdfasts, tubular body fossil holdfasts, and inorganic structures also found on late Ediacaran bedding planes. Our findings are further informed by thin section analysis to assess taphonomy and morphological variation across Aspidella-bearing bedding planes. Fossils uncovered on recent fieldwork reveal true frondose holdfasts and taxa preserved by volcanic ash in the Fermeuse Formation at Ferryland, suggesting that larger Aspidella may indeed be frond holdfast structures. However, some of the larger discs cannot be interpreted as any holdfast structure currently found in Ediacaran assemblages. Spatial statistics comparing the distributions of millimetre-scale Aspidella on particularly high density bedding planes with known juvenile frond distributions reveal significant differences between these groups. Together, our findings suggest that Aspidella specimens in the Fermeuse Formation reflect a variety of original organisms.

GNATALIE QUARRY, A WINDOW TO UNDERSTAND THE DINOSAURIAN PALEODIVERSITY OF THE LATE JURASSIC OF SOUTHEASTERN UTAH (MORRISON FM., USA)

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A new Morrison Fm. bone-bed (Brushy Basin Member) from San Juan County (Utah) has been reported. The 'Gnatalie quarry' (locality LACM 7683; all specimens are housed at the Dinosaur Institute of the Natural History Museum of Los Angeles County) is one of the most important bone accumulations from the Upper Jurassic of Utah yielding multiple partial skeletons in anatomical connection or with a low dispersion of their skeletal elements in a moderate to low degree of articulation. More than 400 bones were found belonging to crocodylomorphs and dinosaurs including theropods (*Allosaurus* sp.), sauropods, ornithopods and thyreophorans (Ankylosauria indet. and Stegosauria indet.). Sauropods are represented by two taxa, one diplodocine and one camarasaurid. This fossil-site has produced several partially complete

diplodocine individuals (at least five individuals), and the performed phylogenetic analyses place all these sets within the clade *Barosaurus*+*Diplodocus*, sharing the presence of a double posterior centroparapophyseal lamina on posterior dorsal vertebrae, straight ventral surface with projected chevrons facets in mid-caudal vertebrae, or high twisted humeral shaft (>40º). The presence of pneumatic foramina until the 16th caudal vertebra (and perhaps beyond), deep ventral hollow in anterior- and middle-caudal vertebrae, or hook-like ambiens process, all support the inclusion of these specimens within *Diplodocus*. The recovered phylogenetic hypothesis and the detailed comparative analyses support a close relationship of the Gnatalie diplodocines with *Diplodocus hallorum*. In addition, the camarasaurid specimen found in Gnatalie comprises skull remains, dorsal, sacral and caudal vertebrae, dorsal ribs, chevrons and some partial appendicular elements. The detailed study of several specimens attributed to *Camarasaurus* reveals a possibly closer relationship with the type specimen of *Camarasaurus lewisi*. Both specimens share the presence of (i) posterior centroparapophyseal lamina (that can be double in some vertebrae) in the middle-posterior dorsal vertebrae; (ii) sacral neural spines with transversely concave anterior and posterior face; (iii) bridged chevrons; (iv) dorsoventrally short neural canal; and (v) and anterior tuberosities on the ventral face of the middle caudal vertebrae. However, the Gnatalie camarasaurid is also characterized by an exclusive set of features, which might justify the establishment of a new taxon, and includes the presence of a dorsoventrally short quadrate fossa; markedly robust anterior chevrons with an anteroposteriorly compressed distal end and a very short haemal canal; and a robust fourth trochanter displaced to the midline of the femoral posterior face. For the moment, the Gnatalie assemblage appears to comprise only one diplodocine and one camarasaurid form, corresponding to the most southwestern occurrence of *Diplodocus hallorum* and Camarasauridae in the Morrison Formation, west to the paleo-Lake T'oo'dichi'.

TESTING THE ROLE OF ENVIRONMENTAL CONDITIONS ON PROMOTING ECOLOGICAL ESCALATION: MIDDLE JURASSIC CARMEL FORMATION, CENTRAL UTAH, USA

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Ecological escalation is thought to have played a primary role in structuring Mesozoic marine ecosystems and driving invertebrate macroevolutionary patterns. For escalation to be sustained, specific environmental conditions are required (i.e., warm, productive, well-oxygenated waters). A recent test of the escalation hypothesis during the Jurassic demonstrates that evidence of escalation is strongest where environmental conditions conducive to escalatory interactions occur, in the western Tethyan realm. However, it is uncertain whether evidence of escalatory interactions can be found in areas with environmental conditions are thought be not conducive for escalation. Here, the absence of escalation is tested during the Middle Jurassic in the southern Sundance Seaway of the western United States, where the environmental conditions were not conducive to escalation (i.e., sluggish circulation, prone to low-oxygen and hypersaline conditions), to determine the extent of the role that environmental conditions played on escalatory interactions. Using occurrence and abundance proportional data of ecological groups with escalation-sensitive traits, field data from the Bajocian and Bathonian Carmel Formation in Utah are compared temporally and spatially with European data from the Paleobiology Database that have previously yielded evidence of escalation. Changes in proportions are tracked to determine if the mean proportion of taxa from ecological groups change in the direction predicted by escalation. To control for the effects of water depth on ecological composition of assemblages, proportional data were compared within facies. The results reveal that overall evidence of escalation is lacking as predicted in Utah, with evidence of escalation observed in Europe, which was expected. Evidence of escalation in Europe is supported by decreases in non-cementing epifauna, and increases in facultatively mobile, shallow infaunal, and cementing fauna. The results of this study support the environmental aspect of the escalation hypothesis, which posits that specific environmental conditions are required to promote escalation. Furthermore, this study underlines the fact that while biotic factors may drive some macroevolutionary patterns, the development of these factors may depend on particular physical environmental conditions.

THE PHYLOGENETIC AND MACROEVOLUTIONARY HISTORY OF SEA URCHINS: A COMBINED GENOMIC, PHENOMIC AND PALEONTOLOGICAL APPROACH

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Echinoidea, one of the five living groups of echinoderms, constitutes one of the most iconic clades of marine animals. A little over 1,000 species of echinoids live today in the oceans, including species commonly known as sea urchins, heart urchins and sand dollars. One of the most characteristic features of crown echinoids, whose roots extend back at least into the Permian, is their globose test composed of tightly interlocking plates. This structure not only provides a wealth of morphological information useful for phylogenetic inference, but also contributes to their high preservation potential. The combination of a rich extant diversity, an extraordinary fossil record that can be placed in a phylogenetic framework, and a wealth of information on their developmental biology, makes echinoids a unique clade with which to address evolutionary questions in deep time. Nonetheless, research on echinoid macroevolutionary dynamics has been halted by the phylogenetic uncertainty and conflict arising from molecular and morphological data.

Here, we attempt to remedy this situation through a combined use of genomic, morphological and paleontological information. We first use an expanded transcriptomic dataset composed of more than 2,350 loci to confirm previous molecular resolutions of the echinoid tree. We also gather a novel dataset of stratigraphic ranges for representatives of more than 90% of crown echinoid families, and employ it for tip-dated phylogenetic reconstruction. We show that a significant fraction of the supposed conflict between morphological and molecular datasets is alleviated by employing a Bayesian inference approach, especially once a morphological clock is enforced. Our analyses also suggest that multiple lineages of early cidaroids (the sister clade to all other crown echinoids), might in fact fall along the echinoid stem. Finally, we combine all data in a total-evidence tip-dated analysis, providing the most comprehensive estimate of crown echinoid relationships and divergence times.

Our efforts represent a significant step forward towards the development of echinoids as a model clade for macroevolutionary research. As a proof of concept, we employ this topology to study the evolution of body size, exploring the patterns and processes driving its dynamics through more than 250 Ma of evolutionary history.

EARLY ONTOGENY OF THE CAMBRIAN HYOLITH *PARKULA ESMERALDINA* AND ITS PALEOBIOLOGICAL IMPLICATIONS

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Hyoliths are a group of problematic Paleozoic spiralians that had an aragonitic skeleton consisting of a long conical shell or conch, an operculum, and (in some) two spines extending from the conch aperture. Their phylogenetic affinities have long been controversial; many have regarded them as a group of molluscs, while others have interpreted them as an independent group that convergently evolved shells. Recent work on hyoliths with preserved soft parts from the Burgess Shale, Spence Shale, and Chengjiang has suggested a stem-group brachiopod placement due to structures interpreted as homologous with the lophophore and pedicle of brachiopods. We report on material of the hyolith *Parkula esmeraldina* from the latest Dyeran (Cambrian Stage 4) Combined Metals Member of the Pioche Formation from the Pioche–Caliente region of southeastern Nevada, USA. Several specimens have a delicate phosphatic layer preserving the outer surface of the shell, including details of ornamentation and growth lines. Commarginal growth increments show that aperture of the conch is initially straight and gradually develops a broad ventral shelf (ligula) and a mid-dorsal sinus. At the apex of the conch is a conical region without growth lines that is 200–250 μm tall; we interpret this as a protoconch formed during embryonic or larval development and recording the shape of the shell at the beginning of the juvenile stage. At the very apex of this protoconch is a tube or spine about 10 μm in diameter; a mold of this structure is preserved as a tall spike on the apex of steinkerns. This apical structure was therefore a tubular extension of the conch interior, although it is difficult to tell from available specimens whether or not it was open at its distal end. The interpretation of this apical structure is consequently somewhat equivocal, but we explore the possibility that it may have housed a pedicle-like structure similar to that described from the Chengjiang hyolith *Pedunculotheca diania*. If this hypothesis were correct, the pedicle would have been present at the conch apex of newly settled juveniles, which may have been sessile filter-feeders; its narrow diameter would suggest that its use was soon abandoned as the animal

grew larger and likely became mobile. We compare this structure with brachiopod pedicles to test proposed phylogenetic hypotheses. Another potentially informative character is offered by opercula; the first growth line delimits a subcircular proto-operculum about 90 µm in diameter, considerably narrower than the aperture of the protoconch. Assuming that conchs and opercula come from the same species, this would indicate either that the operculum began mineralizing earlier in ontogeny than did the conch, or else that the proto-operculum did not fully occlude the aperture of the protoconch.

REACHING A DIVERSE AUDIENCE FOR PALEONTOLOGY ON YOUTUBE

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The staff of one of YouTube's most-watched channels about paleontology, PBS Eons, will discuss the many ways in which it endeavors to pursue, depict, and encourage diversity within the field. Initiatives discussed will include representation, particularly of women in paleontology; accessibility, specifically through the use of a narrative structure to engage the broadest possible audience; and the emphasis placed on general scientific literacy, in how the show presents competing hypotheses and unanswered questions, in order to demonstrate how we know what we know (or what we think), and why.

The team will also present metrics about the age, gender, and geographic breakdown of its viewership and share the findings of an online survey that sheds light on how teachers, students, and home-learners use our channel to learn about paleontology.

The session will conclude with a look at the future of PBS Eons, theobstacles we face in reaching a wider audience, and our plans to overcome them in order to reach an even broader and more diverse audience.

THE ANCIENT EVOLUTION OF CYANOBACTERIA AND PLASTIDS

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The evolutionary history of Cyanobacteria and plastids is central to our understanding of the early biosphere, primary production, and the oxygenation of the Earth. Some stromatolites and fossils from the Archean and Proterozoic are hypothesized to have a cyanobacterial origin, and these organisms are often invoked to explain the rise of oxygen in the atmosphere, or the Great Oxidation Event (GOE). However, the timing of these evolutionary events remains highly uncertain, and two major questions remain: 1) When did Cyanobacteria and oxygenic photosynthesis evolve relative to the GOE, and 2) Can various stromatolites and fossils that predate the rise of oxygen be attributed to Cyanobacteria, given the evolutionary timeline of the phylum? We address these questions by attempting to constrain the diversification of crown group Cyanobacteria. This is done by combining genomic sequences of cyanobacteria and plastids and the most diagnostic cyanobacterial fossils in molecular clock models.

We identify an informative set of well-dated fossils with morphologically distinct modern cyanobacterial analogs. This includes the 1.5 Ga *Obruchevella* from the Gaoyuzhuang Formation, the 2.0 Ga *Eoentophysalis* from the Belcher Island Supergroup, and the 800 Ma endolithic cyanobacteria from the Eleanore Bay Group. These fossils are well accepted as cyanobacterial, but have not been used previously to calibrate molecular clock models due to a lack of sequence data for their modern analogs. Our phylogenetic analyses include plastid sequences and add newly sequenced cyanobacterial groups like *Entophysalis*, *Spirulina*, and *Chroococcidiopsis* that are the modern analogs to *Eoentophysalis*, *Obruchevella* and endolithic cyanobacteria. Using this expanded phylogeny, we careful constrain the age of divergence of the plastid clade and test the addition of these diagnostic fossils as calibrations. All models produce chronograms that place the diversification of crown group Cyanobacteria between ~2.6 Ga and ~3.3 Ga, indicating an evolution of Cyanobacteria before the GOE. These results suggest that cyanobacteria may have contributed to shaped various Archean stromatolites and geochemical signals much earlier than the GOE.

SILICEOUS VSM TESTS AND THE ORIGIN OF PROTIST BIOMINERALIZATION IN NEOPROTEROZOIC OCEANS

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The metabolic pathways by which organisms began to precipitate minerals to form protective hard parts were shaped by natural selection late in Earth history when "armored" eukaryotes putatively arose in response to predation and environmental change. Vase-shaped microfossils (VSMs) date back to about 740 Ma, and possibly as early as c. 810 Ma, but until recently, very little evidence for VSM wall compositions was available, despite excellent three-dimensional preservation of VSMs as authigenic mineral-filled molds and casts within shales, limestones, and phosphatic and siliceous nodules. Biomineralization of siliceous tests, although suspected in Arcellinida analogs among the VSMs has been suggested but not fully demonstrated. Contrary to this, kerogenous and/or siliceous vestiges of original walls are characteristic of practically all VSMs found in dolostone clasts within the Neoproterozoic Urucum Formation (Jacadigo Group), southwest Brazil. This exceptional preservation is attributed to successive very early cementation events in microbially influenced settings that effectively encapsulated the tests within "Matryoshka-like" (after the nested Russian dolls) concentric carbonate cement rims. High-resolution imaging techniques provided strong evidence of silica biomineralization in some of these tests. Dissolved silica was readily available in Neoproterozoic seas, as evidenced by abundant early diagenetic cherts in peritidal microbialites and by the chert hosting the casts and molds of the classic VSM assemblages of the Kwagunt and Callison Lake formations. Silica biomineralization of protists may have been triggered by a combination of widespread appearance of predation, crown group Arcellinida diversification, and changing redox conditions in mid-Neoproterozoic seas. Whatever the cause, VSMs dramatically disappeared from marine rocks shortly before the onset of near-global Sturtian glaciation around 720-700 Ma, perhaps partly due to gradual loss of silica derived from continental weathering. The ensuing ecological bottleneck may then have driven the group closer to continental environments, the habitat of modern Arcellinida.

EXPLORING THE PALAEOBIOLOGY OF TWO CLOSELY RELATED SPECIES OF THE AMMONITE MAORITES (MARSHALL, 1926) FROM THE LÓPEZ DE BERTODANO FORMATION, (JAMES ROSS BASIN, ANTARCTICA) WITH THE AID OF A MEDICAL CT SCAN

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Using medical CT-scanning techniques ontogeny variation in shell morphology of two species of *Maorites*, *M. densicostatus* and *M. seymourianus* is documented, based on the measurement of shell several parameters from 20 specimens in 30° steps, up to a minimum diameter of 10 mm. The Results show that posterior to dm=10 there are morphological changes that affect both species, the aperture height, whorl height, whorl width and umbilical width are shell parameters that show low intraspecific variation, correlate with themselves and can be considered continuous characters that are easily modeled, and are useful for further phylogenetic analysis using statistical models. In contrast shell parameters related with indexes and rates such as the conch width index, whorl width index, umbilical width index and whorl expansion rate posses a high intraspecific variation, and can be categorized on independent stages, with ontogenetic trajectories that tend to follow a rapid change stage known as Perlatum Stage, followed by a constant stage known as Gibbosum stage (following the terminology of Alberch *et al.* 1979). A third stage associated with the adulthood can also be proposed based on the ornamentation modifications and a slight change in morphology for both species. Results also show that *M. seymourianus* and *M. densicostatus* share similar ontogenetic trajectories up to dm=26 mm approximately, point where *M. seymourianus* gets to the end of its Perlatum stage. Such stage seems to continue up to around dm=35 mm for *M densicostatus*, and adults of this species also tend to be similar to juveniles and sub-adults of *M. seymourianus*, suggesting an heterocronic shift, and possible paedomorphosis as evolutionary mechanism.

PODCASTING PALEONTOLOGY WITH THE "COMMON DESCENT PODCAST"

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Podcasting is an extremely popular and useful tool for science communication, allowing an interested audience to access information as much as they want, on their own schedule, and in whatever way is most convenient. We launched the "Common Descent Podcast" in January 2017 with the goal of presenting informative and engaging discussions about topics in paleontology, evolution, and earth history. Since then, we've regularly released episodes every two weeks. Our format is conversational; we want listeners to hear informal scientific discussion, complete with our own natural expressions of curiosity and critical thought. Each podcast episode includes a brief "news" segment highlighting recent research, and a longer "main discussion" segment that presents an overview of a selected topic from a paleontological perspective. Topics have included living groups (sloths, sharks, etc.), events of the past (mass extinctions, Cambrian explosion, etc.), geographic locations (Madagascar, Antarctica, etc.), and more.

The Common Descent Podcast is hosted on the website PodBean, which provides statistics on the podcast's reach. Our podcast has been downloaded by listeners on six continents, and our download numbers continue to increase steadily across all episodes. Our social media platforms (Facebook and Twitter) provide further information on our listener demographics. Audience engagement is very important to us. Though the podcast includes only the voices of the two hosts and occasional guests, we encourage listeners to contact us via email or social media with questions and comments. Our most successful audience engagement comes in the form of listener requests. Almost every episode of the podcast has centered on a topic suggested by the audience, and we have over 200 requests still on our "to do" list. This practice 1) ensures that we're discussing topics of interest to our audience, 2) provides us with a broad range of topic ideas, and 3) allows listeners to hear the results of their own input. So far, feedback has been overwhelmingly positive, which leads us to suspect we're doing something right.

Compared to other media, podcasting is fairly simple, inexpensive, and intuitive. We have been learning as we go, making use of free editing software and cheap recording equipment, and producing content in our spare time. We also receive donations through the crowd-funding website Patreon, which currently cover all podcast maintenance costs. Podcasting is appealingly versatile; we regularly deviate from our standard format to try new things: scientist interviews, movie science analysis, speculative evolution discussions, and more. Finally, the podcast provides an excellent platform for collaboration. We have been able to introduce our growing audience to several other scientists and science communicators, and we look forward to more collaboration in the future.

CHARACTERIZING MIDDLE TRIASSIC SPONGE-MICROBIALITE MID-RAMP DEPOSITS DURING THE RECOVERY FROM THE END-PERMIAN MASS EXTINCTION

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The recovery of marine ecosystems after the end-Permian mass extinction took place throughout the Early and Middle Triassic. Relatively low data resolution for the Middle Triassic shallow marine environments makes it difficult to discern the timing or constrain the geographic heterogeneity of recovery. Recent work on Anisian shallow marine environments from the Tethys Ocean has found evidence for a return to pre-extinction levels of community ecology and taxonomic diversity in Hungary and high diversity and functional richness of shallow marine system but lack of evenness of functional guilds from a section in China. Previous work from eastern Panthalassa finds that some shallow marine ecosystems are in the colonization stage of reef development. We find preliminary evidence for sponge-microbalite reefs that were deposited in eastern Panthalassa.

The samples were collected in the Humboldt Range in the Unionville Quadrangle in northwest Nevada; an area previously mapped by Wallace et al. (1969). Sedimentary structures and grain sizes observed in the field were used to develop stratigraphic sections. We combined field and petrographic observations to determine the depositional energy, rock microfacies, fossil content, and diagenetic history of the sections. The primary depositional environment was determined to be the mid to deep ramp. Preliminary petrographic observations include clotted textures which may represent the presence of microbial mats which may have developed during periodic anoxic events sourced from pulses of deep anoxic waters as has been previously suggested for Early Triassic deposits. The presence of metazoan sponge reef structures observed in outcrop as chert nodules is similar to studies in

nearby sections of the Augusta Mountains and in other late Early Triassic localities throughout the Southwest United States. These metazoan-microbialite accumulations have previously been interpreted as representing increased ecological complexity and therefore more advanced recovery in the Early Triassic. That these metazoan-microbialite reefs persist into the Middle Triassic Anisian interval raises the question of what regions and depositional settings of eastern Panthalassa were subject to environmental conditions that either promoted or dampened recovery.

PALEOBIOLOGY MEETS SCLEROCHRONOLOGY (AGAIN): USING GROWTH INCREMENTS IN FOSSIL BIVALVES TO ANSWER EVOLUTIONARY QUESTIONS

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The field of sclerochronology - the study of periodic features in the accretionary skeletons of marine organisms - has long been known to paleontologists. Nevertheless, despite the central role of growth rate, age, and body size in many questions related to macroevolution and ecology, these types of studies and the data they produce have received only episodic attention since the field's inception in the 1960s. We feel it is time to reconsider their potential. Not only can the data of sclerochronology help to address long-standing questions in paleobiology, but they can also bring to light new and interesting questions that would otherwise have been altogether impossible to address. Several recent studies illustrate this. First, renewed efforts to recover archives of Holocene conditions for the purpose of understanding climate change have shown that bivalves include some of the longest-lived organisms on the planet, with several species capable of living more than 100 years and one, *Arctica islandica*, over 500 years. Is extreme longevity a result of selection, phylogeny, or simply a side consequence of environment? What are the deep-time implications of each? Second, this recent proliferation of data allowed for a meta-analysis that documented a latitudinal life history gradient (LLHG) in modern bivalves, whereby tropical bivalves tend to be faster growing and shorter lived than those at high latitudes. While data on modern bivalve lifespans and growth rates are now plentiful and sufficient to reveal these latitudinal patterns, fossil data are within reach but extremely scarce. Does this geographic pattern persist into the past? Is it sensitive to global climate change? What are its implications for macroevolution? Third, because bivalves have indeterminate growth, age at size relationships can be determined throughout ontogeny. Not only are these the fundamental data needed to decipher heterochronic trends, but they can tell us about body size evolution as well. Are trends toward increasing body size over the Phanerozoic due to faster growth, as might be implied from hypotheses of increasing nutrient availability and organism energetics through time, or due to longer lifespans? Though sclerochronologic work is time consuming and dependent upon quality of preservation, the potential for significant intellectual advance is great. The field of paleobiology stands to benefit greatly from techniques developed and long used by sclerochronologists. We will review a brief history of the interactions between the two fields, discuss recent findings, and posit what the future might hold if the two are reunited.

HURDIID RADIODONTANS AND THE EXPLOITATION OF CAMBRIAN INFAUNAL FOOD SOURCES

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Radiodontans are large soft-bodied extinct animals which are most abundant in Cambrian Burgess Shale-type deposits. They putatively represent key morphological intermediates between vermiform lobopodian taxa and the euarthropods, and as such offer an important window into the earliest evolution of Earth's most diverse animal phylum. Radiodontans have traditionally been regarded as nektonic apex predators, however, many aspects of radiodontan morphology, evolution and ecology have remained unclear because of the typically fragmentary nature of fossil material. Here we describe a new radiodontan from exceptionally complete and abundant remains uncovered at the middle Cambrian (Wuliuan Stage) Marble Canyon and Tokumm Creek localities of the Burgess Shale, British Columbia. Estimated to measure up to ca. 30 cm in length, the new taxon possesses a blend of morphologies seen in *Peytoia*, *Hurdia*, and *Aegirocassis*, strongly supporting a hurdiid affinity. It is characterized by an enlarged dorsal sclerite (H-element) that is rounded anteriorly and bears a pair of posterolateral spinous processes which are separated from rounded posteromedial processes by deeply incised eye notches. The lateral (P) elements are teardrop-shaped, narrowing

to a triangular posterior tip. The carapaces cover the extremely enlarged head and the anterior portion of the body. The entire body is shorter than the head and bears eight main pairs of flaps and probably a four-bladed tail fan. The stout and highly distinctive frontal appendages possess five imbricated curving, rake-like endites with 20-25 elongate hooked auxiliary spines. Endite morphology is reminiscent of the pectinate appendages of some decapods and eurypterids and suggests a micro to macrophagous sediment sifting ecology. The oral cone is *Hurdia*-like, composed of toothed plates with a tetraradially arranged outer ring and at least four inner rows. The inner plates in these taxa may have served roles in filtration and food manipulation, likely associated with their particulate-rich diet. Overall, the new taxon emphasizes the high ecological diversity that had been achieved by radiodontans by the middle Cambrian and illuminates the exploitation of the diversifying infauna by these large animals as a food source in the immediate aftermath of the Cambrian explosion.

COAL BALL META-ANALYSIS OF PALEOWILDFIRE IN PENNSYLVANIAN COAL SWAMPS

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The paleobotanical record of the Pennsylvanian equatorial tropics is known for its rich fossil assemblages, many of which provide *in situ* snapshots of paleolandscapes. These assemblages often also capture the history of wildfire in the form of fusain—fossilized charcoalified materials. The Pennsylvanian subperiod is known for having increased wildfire activity, potentially related to "hyperoxic" conditions, i.e. atmospheric oxygen levels above the Present Atmospheric Level of ~21%. Hyperoxic wildfire likely acted as one of the agents shaping wetland and seasonally dry ecosystems of Pennsylvanian Euramerica. However, as of now, the behavior of wildfire under hyperoxic conditions in general, and the characteristics of fires in Pennsylvanian landscapes in particular, are at best partially understood.

Our methodology for studying Pennsylvanian wildfire uses a multi-faceted approach involving coal ball analysis, experimental combustion, and wildfire simulation. The focus here is on multivariate meta-analysis of coal ball studies. We utilized a dataset of over 85,000 microscopically analyzed square centimeters of coal ball peels collected from five Pennsylvanian localities in the US Midcontinent and the Southern Appalachian Basin. This dataset includes information on the plant genus, broader taxonomic group, tissue type, plant organ, aerial/subterranean condition, and critically, preservational features such as evidence of fusinization, for each square centimeter. We found correlations between specific plant tissues or organs and fusain abundance, but also patterns in fusain abundance related to the mean plant size of taxa. Interestingly, the paleowildfires seemed to lack a strong taxonomic "discrimination", but there is a positive correlation between fusain abundance and assemblage dissimilarity (beta diversity).

IMMIGRANT TAXA, SPECIATION EVENTS AND NICHE STABILITY: THE JURASSIC BRACHIOPOD DIVERSITY OF WESTERN INDIA

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The Kachchh and Jaisalmer basins of India formed due to rifting from South Africa in the Triassic during Gondwana fragmentation. The newly opened foreland basin provided nutrient rich ecospace creating a rich fossil record. By Bathonian, an endemic marine invertebrate fauna developed, brachiopod as an important constituent. The first brachiopods to enter the basin were immigrants from the Ethiopian province. They produced the local diversity in the beginning, then biodiversity increased by rapid speciation. Kachchh and Jaisalmer, being part of the Indus foreland basin in the Jurassic, document coeval sedimentation and show faunal similarity especially ammonites. Comparison of brachiopod bio-diversity in both area reveal negative correlation between endemic and immigrant taxa. In the upper Bathonian-Callovian of Kachchh, colonization of the endemic fauna, rapid speciation events that increased clade diversity and stasis in a few species, characterise the brachiopod community but the Jaisalmer brachiopod fauna reveal colonisation by immigrant taxa in particular levels.

The earliest rhynchonellid *Daghanirhynchia* appeared in the Bathonian in both areas,*D. susanae* and an endemic species *D. indica*. In the Late Bathonian-*Cryptorhynchia*appear in Kachchh and rapid speciation gave rise to four species, a result of paedomorphic heterochrony. *Daghanirhynchia* and *Cryptorhynchia* has stratigraphic overlap in Kachchh and are sister groups. In the middle-upper Bathonian *Daghanirhynchia*

flourished in Jaisalmer,with two endemic species, together with another immigrant *Plectoidothyris* from Boreal realm. *Kutchithyris*, an endemic genus appear in the Middle Bathonian in Kachchh and continue till Oxfordian, with 12 species. The *Kutchithyris* clade is an example of punctuational model of evolution and cladogenesis. Rapid speciation and high species turnover rates characterise Kachchh brachiopod diversity. Bathonian of Jaisalmer is colonised by a single species of*Plectoidothyris,Kutchithyris* is absent. In the lower – middle Callovian, four *Kutchithyris* species of Kachchh are present but in the late Callovian, *Bihenithyris* is the sole terebratulid taxa in Jaisalmer. *Plectoidothyris* and *Bihenithyris* migrated from the Boreal and Ethiopian regions to Jaisalmer in the middle-upper Bathonian and late Callovian respectively but they are absent in Kachchh. The typical brachiopod assemblage of Kachchh and Jaisalmer basin are absent after the Oxfordian - Kimmeridgian boundary, in the Tithonian two immigrant taxa *Acanthorhynchia* and *Somalithyris* enter the basin for a brief interval.

The α diversity is low in the Bathonian of Jaisalmer Basin but high in Kachchh. In the Callovian, though α diversity increases in Jaisalmer but still it never matches with Kachchh. Rapid speciation events compatible with punctuational model and allometry induced heterochrony played a major role in creating the Bathonian brachiopod diversity in Kachchh but interestingly it never operated in Jaisalmer.

STRONG MECHANICAL RELATIONSHIPS BIAS THE TEMPO AND MODE OF MORPHOLOGICAL EVOLUTION

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The influence of biomechanics on the tempo and mode of morphological evolution is unresolved, yet is fundamental to organismal diversification. Across multiple four-bar linkage systems in animals, we discovered that rapid morphological evolution (tempo) is associated with mechanical sensitivity (strong correlation between a mechanical system's output and one or more of its components). Mechanical sensitivity is explained by size: the smallest link(s) are disproportionately affected by length changes and most strongly influence mechanical output. Rate of evolutionary change (tempo) is greatest in the smallest links and trait shifts across phylogeny (mode) occur exclusively via the influential, small links. Our findings illuminate the paradigms of many-to-one mapping, mechanical sensitivity, and constraints: tempo and mode are dominated by strong correlations that exemplify mechanical sensitivity, even in linkage systems known for exhibiting many-to-one mapping. Amidst myriad influences, mechanical sensitivity imparts distinct, predictable footprints on morphological diversity.

THE FIRST VERTEBRATE SKELETAL TISSUES AND THE 'BIOMINERALIZATION TOOLKIT'

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Conodonts are the earliest vertebrates with a mineralized skeleton. Otherwise entirely soft-bodied, conodonts possessed a set of phosphatic tooth-like elements. First known from the Guzhangian, paraconodonts (with a dentin-like skeleton) gave rise to euconodonts in the Jiangshanian, after the evolution of 'crown' tissue, an enamel-like euconodont apomorphy.

Between the latest Neoproterozoic and the end of the Cambrian, biomineralization also evolved independently in virtually every other group of animals with hard parts, contributing to a dramatic ecological turnover through this period. Observations from developmental and molecular biology, suggest that all animals inherited a common 'toolkit' of genes, independently co-opted to similar tasks, including building skeletons. This initially imprecise 'toolkit' was subsequently honed by the acquisition of more and more complex gene regulatory networks. This predicts a pattern of initial mineralization of a pre-existing organic skeleton with loose control followed by increased control via the accumulation of lineage specific secretory mechanisms, and skeletal fabrics. Here I use the fossil record of the conodont skeleton to compare the histological disparity close to the origin of each component tissue, with observations of equivalent assemblages from later in conodont evolutionary history, thus providing evidence to test the predictions of the 'biomineralization toolkit' hypothesis.

***BELODELLA* VERSUS CAVIDONTS AND CONODONTS, TAXONOMY AND BIOSTRATIGRAPHY**

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The *Belodella* are group of organisms based on

distinctive kinds of small (in the approximate size range of conodonts, 0.3–3.0 mm), phosphatic, elongate pyramidal fossils (here referred to as elements), some of which bear a fringe of hair-like projections along one edge of the element. These fossils have been referred to as elements of a skeletal apparatus comparable to that found in conodonts. However, there is no evidence of their function or position in the belodellid animal. The best evidence available for interpretation is found in fused clusters that have been described as fecal pellets, but these do not show the total range of morphologies present in large samples. Because of our ignorance as to function and position, we do not refer to them as parts of skeletons or a "skeletal apparatus". *Belodella* could be entirely skin, mouth, fin or other parts, parts that have different functions and positions in the animal but do not function as an integrated support structure.

Belodella have been considered as conodonts in the Class Cavidonta, Phylum Conodonti, but it has long been recognized that they are different from other conodonts and have therefore been accorded ordinal rank. They differ from conodonts as follows: the walls do not show peripheral layering, no basal filling has been observed, organic matter is not retained in the element because they don't change color like conodonts when heated, and some very well preserved forms show closely spaced, transverse darker bands around the element. If the bands represent growth lamallae, then the genus, *Belodella*, is certainly not a member of the Conodonti and their presence supports placing *Belodella* in the a separate taxon, which has been done. If these transverse bands are growth related, which seems to be the logical conclusion, then a reclassification of the Belodellida Sweet as a taxon equal in rank to the Conodonti is necessary. It is not clear if any of the other cavidont genera would accompany the Belodellida as a cursory search of these taxa has not revealed the banding.

What has been determined is that three basic kinds of elements make up the plethora of things we call *Belodella* and that each of the basic kinds has two to over a dozen variants. Also, there are morphological features that seem to be present only during some time intervals although the sample size is small. The examples are: relatively short basal cavities are only found in the middle Lochkovian; discrete denticulation only in the Emsian; and longitudinal costation only in the Middle Devonian. All of these are generally larger than the earlier members of the group, Silurian and basal Devonian, so they are potentially a powerful additional tool for biostratigraphy.

HOLOCENE ARRIVAL AND HISTORIC LOSS OF THE CALIFORNIA GRIZZLY BEAR: BRIDGING TIMESCALES OF DECLINE IN THE 6TH MASS EXTINCTION

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Conservation biologists today often monitor isolated populations to prevent extinction on the scale of decades. Conversely, paleontologists often focus on extinction on the scale of thousands of species over millions of years. These differences in scale contribute to the perception that extinction in the past and in the present represent two disconnected processes, creating an artificial divide between conservation biology and paleontology. However, historic extinctions are where "the rubber hits the road" regarding these two parallel approaches to extinction, as they cross the boundary between historical narratives and geologic timescales.

We employed a transdisciplinary research approach to document the full span of Holocene arrival, decline, and historic loss of a culturally iconic mammal, the California grizzly bear (*Ursus arctos californicus*), in light of recent reintroduction proposals. Our interdisciplinary team – representing paleontology, conservation biology, and history – applied paleontological techniques to historic specimens to assess consilience and disagreement between approaches at this critical timescale. We located 60 individual bears from fossil, archaeology, and zoology museum collections, and radiocarbon dated putatively historic specimens of unknown or suspect ages. At 25 dates, our dataset represents the largest regional radiocarbon dataset for the brown bear worldwide, ranging from 8000 years before present to 1899 AD. Of these dates, 10 represent the Spanish and American period of California (post 1600 AD).

We applied standard paleontological approaches to inferring extinction timing, including the Gaussian-Resampled Inverse-Weighted McInerny (GRIWM) method. We compared these results to confirmed historic sightings using BearMap: A Historical Atlas of California Grizzlies produced by the California Grizzly

Research Network. In comparing radiocarbon vs. traditional detection approaches, we find that paleontological estimates yield a plausible median extinction time but are easily biased to overestimate the persistence of grizzlies by 100-200 years – insignificant geologically, but significant to human perception.

The last California grizzly was spotted in 1924 AD near Yosemite National Park; thus, current proposals suggest inland forests were its most suitable habitat. We built species distribution models that test the effect of only incorporating historic – not Holocene – occurrences. We found that historic datasets overestimate the suitability of inland habitat, whereas Holocene grizzlies were more likely found on coastlines and pushed inland with European arrival. This work provides key insight into the process of extinction as it crosses temporal and disciplinary boundaries, and directly shows how fossils can be brought to bear on modern conservation dilemmas.

DEPOSITIONAL DYNAMICS IN THE INNER DETRITAL BELT OF NORTH AMERICA AND IMPLICATIONS FOR BIOMERE EXTINCTIONS

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Cambrian–Ordovician boundary sections are exposed along the length of the Rocky Mountain region from Montana to southwest Texas. Our integrated high-resolution sedimentological, biostratigraphic, and chemostratigraphic data set from these strata indicate that the inner detrital belt of western Laurentia was a dynamic setting in which depositional and evolutionary dynamics were influenced by changes in relative sea level and the interplay between siliciclastic and carbonate sedimentation. Regional stratigraphic patterns are linked to carbon isotopic trends, and trilobite, brachiopod, and condont extinctions and radiations. Our data indicate diachronous flooding of the Rocky Mountain region, with early flooding in the northern U.S. Rockies. Initial shoreline quartz arenite facies were spatially heterogeneous, in part reflecting the deposition of these strata over a topographically complex surface dominantly underlain by Precambrian basement rock. Continued transgression resulted in deposition of iron-rich lithofacies, including glauconite-rich, large-scale, tidally generated, subaqueous dunes and locally the deposition of iron oolite facies. Subsequent deposition of deeper inner detrital belt facies produced well-developed meter-scale deepening-upward cycles associated with terminal Sunwaptan trilobite extinctions. Such inner detrital belt facies disappear nearly isochronously with landward progradation of carbonate belt facies low in the *Rossodus manitouensis* conodont Zone. Widespread deposition of grainstone-rich deposits at this time considerably altered the hypsometry of the western Laurentian seaway and set the stage for subsequent development of widespread microbialite buildups shortly after the trilobite extinctions at the base of the Stairsian Stage. The disappearance of the mixed siliciclastic-carbonate facies that characterize the inner detrital belt at about this time suggests the possibility that the changes in hypsometry included elimination of the route followed by cooler waters that decimated the platform faunas across the entire Laurentian shelf at Cambrian biomere boundaries. Uppermost Stairsian strata in New Mexico and western Texas record inhibition of reef development during deposition of a widespread oolite unit that spans the boundary between the Stairsian and Tulean Stages. Carbon isotopic data with supportive biostratigraphic control allow for recognition of cryptic unconformities in the section and illustrate the relationship of isotopic changes to extinction events.

UNDERSTANDING BIOGEOGRAPHY DURING THE CAMBRIAN THROUGH ECO-EVOLUTIONARY PROCESS

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With the most important diversification events of marine organisms, the Cambrian period is characterized by major changes in within and between community diversity. Lacking rigorous quantitative approaches, it remains enigmatic how these changes scale up to first-order biogeographic patterns. Here we outline time-traceable bioregions for marine invertebrates across the Cambrian using a compositional network based on species-level fossil occurrence data from the Paleobiology Database. We find high by-cell biogeographic turnover through the whole period without major rises and falls. The time series of

by-bioregion turnover (emergence and disintegration) in the Cambrian suggest that dramatic biogeographic changes occurred in Stage 5 and in the Guzhangian, with highest disintegration and highest emergence values, respectively. We suggest that the disappearance of archaeocyath sponge reefs in Stage 4 could be responsible for the severe disintegration of bioregions in Stage 5. Excluding trilobites, the emergence peak in the Guzhangian disappeared, and both disintegration and emergence become lowest in the Paibian. To test if biogeographic patterns in the post-archaeocyath Cambrian was governed by dispersal among trilobites, we calculated the maximum geographic range of newly-emerged trilobite species within stages based on their paleo-coordinates in the database. We find that the median maximum geographic range increased from Cambrian Stage 3 to the Drumian and dropped in the Paibian. The widest median ranges in the Drumian and the Guzhangian indicate an increased number of cosmopolitan species, likely due to stronger dispersal ability, which is also suggested by the contemporaneous increase in the proportion of occurrences of the pelagic fauna. Our findings imply that ecological changes (i.e., reef system destruction) could lead to a more homogeneous world in the post-archaeocyath Cambrian, with dispersal and species redistribution playing pivotal roles in shaping global biogeographic patterns.

DIVERSITY AND STRUCTURE OF THE BURGESS SHALE PALAEOCOMMUNITY WITH NEW INSIGHTS FROM MARBLE CANYON, BRITISH COLUMBIA

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The middle (Wuliuan Stage) Cambrian Burgess Shale is famous for the exceptional preservation of diverse and abundant soft-bodied animals. Previous quantitative studies of the Walcott Quarry and the Tulip Beds, both in Yoho National Park, have suggested that the Burgess Shale palaeocommunity was locally dynamic at ecological and sub-evolutionary time scales. Here we perform additional quantitative analyses, integrating the previous two sites with the Raymond Quarry in Yoho National Park and the recently discovered Marble Canyon locality in Kootenay National Park. The established stratigraphic relationship of these sites, with the Marble Canyon being the youngest fossil assemblage of the 'thick' Stephen Formation and the Tulip Beds being the oldest, allows us to assess wider geographic and temporal variations of the Burgess Shale community than previously possible. All sites, except the Tulip Beds which was collected as an induced time average assemblage, show significant temporal changes in both taxonomic and ecological groups, suggesting that periods of stasis followed by rapid turnover patterns characterized the ecological dynamics of the Burgess Shale community at both local and regional scales and across the entire thick Stephen Formation. Correspondence analyses based on a combined dataset of 77,179 specimens with 234 taxa suggest that Marble Canyon, Raymond Quarry, Walcott Quarry and Tulip Beds occupy distinct areas in multivariate space with limited overlap. These results highlight that despite some commonalities between localities, significant differences exist in taxonomic composition, relative abundances and ecological modes across the Burgess Shale. In addition, our study emphasizes the overall predominance of suspension feeding and predatory/scavenging trophic strategies, although the dominant trophic mode observed in each locality changes over relatively short timescales. Taken together, short-term stochastic environmental or biotic changes may have played a key role in structuring the Burgess Shale paleocommunity at an ecological scale, while stratigraphically or spatially disjunct localities may have been structured by changes in biotic or abiotic conditions at evolutionary or sub-evolutionary time scales. Overall, this study suggests that the Burgess Shale palaeocommunity is far more complex and dynamic than previously thought at both local and regional scales, and highlights the importance of new discoveries of soft-bodied fauna for reconstructing a more accurate view of ecological networks in early animal ecosystems.

ENVIRONMENTAL AND TAPHONOMIC CONTROLS OF DIVERSITY PATTERNS ACROSS A DEPOSITIONAL SEQUENCE: HOLOCENE BENTHIC MOLLUSKS OF THE PO PLAIN, ITALY

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Sequence stratigraphic control on fossil diversity patterns has been supported by theoretical models, numerical simulations and empirical studies, but the relative importance of eco-environmental versus taphonomic processes in driving this relationship remains poorly understood. We address this question using mollusk assemblages from a series of cores drilled throughout the Holocene transgressive-regressive succession of the Po coastal plain. We analyze changes in rarefied sample-level diversity, species turnover and regional diversity within and across systems tracts, and link these patterns to lateral and stratigraphic variation in depositional environments and magnitude of time averaging estimated based on geochronological dating on individual mollusk shells.

For data pooled across the cores, sample-level diversity and evenness are considerably higher in the late transgressive systems tract (TST) and maximum flooding zone (MFZ) compared to the early highstand systems tract (HST), and decrease even further in the late HST. However, between-sample turnover at the regional scale do not vary significantly between systems tracts. This result contrasts with the higher turnover in the HST previously documented in the Po basin based on the analysis of distal cores. What is more, within individuals cores the relationship between the stratigraphic position and sample-level diversity depends on the location along the depositional profile: strong up-section decrease in diversity typical for the distal cores, is missing from the proximal, back-barrier settings.

The results suggest that highly uneven representation of different depositional environments across systems tracts combined with 1) onshore-offshore gradient in the diversity of benthic communities, and 2) downdip increase in the scale of time averaging in transgressive deposits and MFZ, are the primary drivers of the observed stratigraphic patterns in diversity. The limited turnover within TST and MFZ observed along single cores is compensated on the regional scale by a greater lateral variation in facies and thus stronger faunal turnover along the depositional dip. Moreover, the two most species-rich facies associations – transgressive sand sheet and offshore transition – recording millennial-scale condensation and maximum water depths in the studied succession, are unique to the TST and MFZ and spatially restricted to the distal part of the study area. Their exclusion from the analyses eliminates most of the differences in sample-level diversity between the TST, MFZ and early HST.

Our study underscores the importance of collecting and interpreting fossil data within a well-defined time-environmental framework. However, in spite of exceptional sampling efforts, most of the environments could not be traced continuously thought the depositional sequence. The nature of the stratigraphic record thus severely limits the resolution of paleoecological studies addressing within-habitat diversity trends.

ANIMAL-PLANT INTERACTIONS IN THE MARINE REALM: ECHINOID-CORALLINE ALGAL DOMINATED ECOSYSTEMS IN THE MIOCENE OF SARDINIA

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Well preserved echinoids and coralline algae from the Miocene of Sardinia allow not only for assessing paleoecology, but also for analyzing complex, trophic interactions. Grazing on coralline algae by echinoids has been discussed with respect to key developments in both tooth morphologies among regular sea urchins as well as biotic interactions with potential algal prey. Both echinoids and coralline algae are especially appropriate for paleoenvironmental reconstruction due to functional morphological aspects and actualistic comparisons of their close association in modern shelf environments.

In Miocene sublittoral sedimentary successions of Sardinia (Proto Torres and Santa Caterina di Pittinuri), two substrates types containing exceptionally preserved biotic components are often juxtaposed: 1) highly bioturbated, echinoid-rich, fine grained sediments, within which 2) rhodolith pavements, containing non-geniculate coralline algae, various regular echinoid associations as well as spatangoids and clypeasteroids. This study concentrates on the later which are found in different localities with varying faunal and floral associations allowing for the relationship of sea urchins and algae to be analyzed.

Preliminary results show a wide range or rhodolith sizes, generally spheroidal to subspheroidal in shape. Various components are present in the core including

corals, encrusting acervulinid foraminifera as well as bryozoans and barnacles also contribute. Different coralline algal taxa are present, growth forms range from densely encrusting thalli to highly protuberant. Rhodolith associated echinoids from Porto Torres (northern Sardinia) consist of spines and test fragments of the cidaroids *Prionocidaris* and *Eucidaris*; along with the remains of *Schizechinus* and trigonocidarids, while those from Santa Caterina di Pittinuri (central-western Sardinia) include co-occurrence of the diadematid (*Diadema*) and toxopneustid (*Tripneustes* and *Schizechinus*) echinoids. The size and complexity of the rhodoliths including extensive encrustation sequences and intense bioturbation indicated long surface residence times within the photic zone. The sea urchins found among the beds represent epibenthic grazing regular echinoids and it is discussed to what extent the rhodoliths or other epiphytic organisms served as a source of food.

THE ECHINOID SKELETON. AN EXEMPLARY SOURCE OF ADAPTATIONS AND THEIR POTENTIAL USEFULNESS IN TECHNICAL APPLICATIONS

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The multi-plated echinoid skeleton is a welcome object for studying adaptations and their evolution. Structures of the echinoid skeleton have been interpreted with respect to self-support structures; modular, thin-shelled vaults emulating monolithic shells, multi-plated amalgamates and so on. This is especially relevant for the clypeasteroid test which has evolved complex plate boundaries and internal support systems enabling these animals to colonize high energy shallow water environments in both siliciclastic and carbonate settings.

This presentation will review the state of the art and present new research with respect to the stability of clypeasteroid echinoid skeletons, and showcase some models derived from cooperation with civil engineers and architects. Methods have included high-resolution X-ray micro-computed tomography, finite-element analysis and physical crushing experiments. Various internal support systems are present among different clades with plate boundaries and internal support systems showing high material accumulations. The importance of skeletal stability for preservation and taphonomic filters is discussed. These analyses also consider tracking of traits among evolutionary pathways.

When shells are regarded, biologist and paleontologist can profit not only from direct studies concerning the morphology of skeletal elements and their functional interpretations with respect to ambient environmental factors, but also from the methodology and insights applied by engineering including modelling and visualization techniques. This is especially the case for the planning and construction of double-curved, shell constructions. Finally, the potential for biomimetic research as a whole based on fossil and recent shells will be reviewed.

PHYLOGENY OF AN ENIGMATIC AND DISTINCT CLADE OF CAMBRO-ORDOVICIAN TRILOBITES FROM LAURENTIA WITH NEW AND REVISED SPECIES OF *CLELANDIA*

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Clelandia Cossman, 1902, is a poorly understood group of 12 currently named species of trilobites. These species range from the late Cambrian (Furongian; Jiangshanian; Sunwaptan) to the Early Ordovician (Tremadocian; Skullrockian) of Laurentia. No phylogenetic work has previously been carried out and the family affinity of the group is uncertain. Species of *Clelandia* have reduced morphology and effaced sclerites which limit the morphological data available for analysis. Compounding this is the quality of published images, which are frequently of poor resolution and few in number.

Field-based study of Skullrockian faunas from the Great Basin of the western United States has produced material representing four new species of *Clelandia*. Detailed study of trilobite sclerites is possible in three dimensions due to preservation through secondary silicification. Species are represented by material free of matrix with multiple representative sclerites and growth stages. These new species are diagnosed by several cranidial features. None exhibit glabellar furrows or the extended glabellar-occipital spine structure seen in other members of the genus. Two of these species have greatly reduced furrow definition and lack an occipital spine, traits rarely seen in other members of the genus.

With fresh, high-quality images of the new and previously described taxa, morphological data are sufficient to propose a species-level phylogeny. The Marjuman *Brachyaspidion* was used as an outgroup.

Phylogenetic analysis of the genus recovers a hypothesis of evolutionary relationship largely congruent with stratigraphic record and notable morphological features. One subclade is characterized by species with long genal spines, an arcuate preglabellar furrow, and the glabellar-occipital spine structure. The two Sunwaptan species are consistently recovered in a basal position, sister to the remaining Skullrockian taxa.

Previous studies have claimed that species of *Clelandia* to represent plesiomorphic shumardiids. These arguments have been based exclusively on study of the cephalon. The first described articulated specimens of the genus do not support this conclusion. Multiple putative synapomorphies of the thorax and pygidium indicate a distinct, low-diversity clade of Laurentian trilobites which persisted through the Cambro-Ordovician boundary into the upper Skullrockian.

Desmetia annectans Walcott, 1925, is reassigned to *Clelandia* on the basis of distinct cranidial morphology. *Desmetia* is considered a junior synonym.

CAMBRIAN SEA LEVEL CHANGES: A SCANDINAVIAN PERSPECTIVE

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Most published Cambrian sea level curves are rather crude. This is regrettable, as reliable sea level reconstructions (both global and local) are very useful for correlation of strata, unravelling depositional patterns, identifying local depth anomalies relating to tectonic overprint and, not least, analyzing evolutionary patterns, for instance whether sea level changes influenced the various phases of the 'Cambrian Explosion'.

We present ongoing work aimed at establishing a detailed Cambrian sea level curve (3rd order) based on analyses of the sedimentary record in the epicontinental basin that covered Scandinavia from the 'early' Cambrian to the Silurian. The craton was tectonically quiescent, being surrounded by passive margins, the sea floor was exceptionally flat and the sedimentary supply was extremely limited, hence eustasy played a dominant role controlling the facies distribution and depth changes in the epicontinental sea. Assessing the scale of the sea level changes is, however, a notorious problem; an alternative approach based on accommodation space calculations is outlined, but is workable only for the 'lower' Cambrian succession. In the overlying, monotonous Miaolingian-Furongian Alum Shale, deposited very slowly on the outer shelf under low oxygen conditions, sea level changes are inferred via combining biofacies analyses with identification of regional hiati, reworking, and distribution of conglomerates – all phenomena linked to sea level lowstands – along with shifts in location of the depocentre.

On a 1st order scale, the sea level rose significantly during the 'early' Cambrian and the Miaolingian to reach a Cambrian high in the latest Miaolingian. The Furongian sea level was slightly lower. Five 2nd order Cambrian sea level cycles are recognized. The analysis of 3rd order fluctuations is only completed up to the middle Miaolingian and the total number of Furongian cycles is as yet undetermined. The number of 3rd order cycles, broadly speaking, matches the sea level curve published by Haq & Schutter (2008), but not all details correspond and detailed correlation is difficult.

SELECTIVE TRANSFORMATION AND ONTOGENETIC BIASES OF PHOSPHATISED SOFT TISSUES IN THE SIRIUS PASSET LAGERSTÄTTE, NORTH GREENLAND

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Mineralised soft tissues give an extraordinary opportunity to study the anatomy of extinct animals. At the Lower Cambrian Sirius Passet Lagerstätte, North Greenland, fossils frequently preserve internal tissues such as nerves, guts, and muscles. Guts and muscles are preserved three-dimensionally in a black-grey mineral but their composition varies; muscles are typically preserved as silica and guts as calcium phosphate (apatite). This selective mineralisation suggests that it either reflects a differential timing of apatite mineralisation in guts and silica mineralisation of muscles during localised changes in chemical conditions implying a very complex taphonomy (Strang *et al.* 2016, *R. Soc. Open. sci.* 3:160420), or that a secondary silica mineral phase have replaced a primary apatite phase in the muscles implying a common phosphatisation taphonomy but complex metamorphic overprint. Either way,

it is important to understand the taphonomy in order to correctly interpret the biology and depositional environment of the Sirius Passet Lagerstätte. Here, we have scrutinised a collection with ~2830 specimens for authigenic mineralisation and used SEM-EDS and silicon isotope analysis to assess the original phase of the black-grey mineral and the source of silica. In total, 718 cases of authigenic mineralisation occur in the collection. We show that both guts and muscles were originally preserved in apatite and that muscles were subsequently replaced by silica from an abiotic likely high-temperature source. The phosphatisation exhibits strong taxonomic and ontogenetic biases as the potential for phosphatisation varies between and within taxa. This suggests that the phosphatisation process was intrinsic and dependent on the relative mass and structure of tissues within the organism. This study also highlights the importance of disentangling metamorphic overprint from diagenetic processes, especially in Lagerstätten deposits.

INSIGHTS FROM NEW RECORDS OF LATE TRIASSIC ICHTHYOSAURS, MINERAL COUNTY, NEVADA

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The Upper Triassic Luning Formation of central Nevada hosts one of the world's most significant concentrations of ichthyosaur fossils. The richest and best studied locality within this unit occurs at Berlin-Ichthyosaur State Park (BISP), Shoshone Mountains, Nye County, NV, where Charles Camp excavated multiple articulated adult specimens of the giant ichthyosaur *Shonisaurus popularis* from lagerstätte in the *Klamathites macrolobatus* zone of late Carnian age. An unusual feature of the BISP assemblage is that, despite the abundance of material, it appears to be monotaxic, in contrast with most other Triassic marine reptile assemblages in western North America. In addition to the famous BISP localities, ichthyosaur fossils are abundant in Luning Formation outcrops in the Pilot and Cedar mountains of Mineral County, NV, but are poorly studied despite decades of sporadic collecting.

We report specimens from several new localities in the Pilot Mountains within the lower Luning member, *Stikinoceras kerri* zone (early Norian). Three surface concentrations of skeletal elements were documented - two in Dunlap Canyon, and one in Cinnabar Canyon. Most of the material is likely referable to *S. popularis* and consists largely of vertebrae and rib fragments, with one partial femur, coracoid, and distal paddle element. Several elements were found in place, and show evidence of post-depositional transport and post-mortem encrustation by invertebrates. All *in situ* elements were disarticulated and fragmented, and encased within a calcareous mudstone matrix or associated with bioclastic beds intercalated within the mudstone. The specimen of greatest interest is an ichthyosaur dorsal vertebra from Cinnabar Canyon that is considerably smaller than any previously associated with adult specimens of *S. popularis*. The maximum centrum diameter is 6 cm, and the height/length ratio is 2. Two facets are present on the dorsal surface for neural arch articulation, and lateral surfaces show double rib articulation processes that are large and knob-shaped. Although this specimen might be a juvenile specimen of *S. popularis*, the height/length ratio compares more favorably to specimens of *Toretocnemus*, known from the Late Triassic of California and Sonora, Mexico. However, the diameter of this specimen is 2 or 3 times larger than other vertebrae assigned to *Toretocnemus*. The Pilot Mountains material is significant because it represents the largest concentration of *Shonisaurus* material outside of BISP and is from early Norian age strata, slightly younger than BISP's late Carnian-aged concentrations, and slightly older than *Shonisaurus* from British Columbia. If the *Toretocnemus*-like vertebra is not a juvenile *Shonisaurus*, it may represent the first evidence of another marine reptile taxon besides *Shonisaurus* in the Luning Formation.

IMPROVING TEMPORAL CONSTRAINTS ON THE SHURAM CARBON ISOTOPE EXCURSION VIA ENHANCED STRATIGRAPHIC CORRELATION OF MERCURY CONTENT, $\Delta^{13}C_{ORG}$ AND $\Delta^{15}N_{ORG}$ WITHIN THE EDIACARAN DOUSHANTUO FORMATION OF SOUTH CHINA

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Exceptionally preserved geochemical data and fossils from the Ediacaran Doushantuo Formation of South China provide the basis for regional and global climate and ecology reconstructions preceding the Cambrian Explosion. Although the Doushantuo records

a major negative $\delta^{13}C_{carb}$ excursion, dubbed the Shuram Excursion, the timing and duration of this event is poorly constrained, both within the Doushantuo and in other Shuram recording localities. This event likely accompanied a major disruption to the carbon cycle. The Shuram Excursion occurs in the Members III and IV of the Doushantuo. There are no reported datable ash beds near the base of the Shuram in the Member III, making it difficult to date its beginning. In some sections, the Member IV is a continuous black shale believed to correlate with a tripartite sequence found in other sections: a Lower Black Shale, an Upper Dolostone, and the Miaohe Member black shale. This correlation is useful for interpreting the Shuram, as its end is defined from carbonate concretions in continuous shale sections and there is an ash bed dated to 551.1 ± 0.7 Ma at the top of a Miaohe Member unit, giving a tentative end date. However, if the continuous Member IV is solely correlatable to the Lower Black Shale (and thus the Upper Dolostone and Miaohe Member with the Hamajing and Shibantan Members of the overlying Dengying Formation), as suggested by biostratigraphic workers, then the Shuram Excursion ends much earlier than 551 Ma, suggesting an overall briefer duration, one potentially easier to explain with existing models of C cycle. To resolve these conflicting correlations, we are building on current lithologic and stable isotopic correlations through organic carbon isotopes ($\delta^{13}C_{org}$) and organic nitrogen isotopes ($\delta^{15}N_{org}$) and additionally employing the unutilized chemostratigraphic tool of mercury [Hg] content and comparison of mass-dependent and mass-independent Hg isotopes of these black shale units. Mercury preferentially accumulates in organic material and is influenced by global volcanic input and local redox conditions, making these black shales ideal for [Hg] analysis. The $\delta^{13}C_{org}$ will also be used to compare the Miaohe Member shales and their equivalents with the upper portion of the continuous Black Shale Member IV units. Together, these geochemical data will help us to resolve both regional redox conditions and global Hg flux, the latter of which could facilitate stratigraphic correlation between sections and thereby resolve sectional correlation of the Member IV, and better constrain the duration of the Shuram. Preliminary [Hg] data suggest two correlatable mercury excursions: in the uppermost Member IV and Miaohe Member; and in the basal Member IV and the Lower Black Shale supporting the conventional correlation and the longer duration Shuram. With a refined chronostratigraphic framework, we can better constrain the major evolutionary and environmental events in the Ediacaran Period.

RISE OF OXYGEN IN THE PHANEROZOIC WORLD: FROM GREY SEDIMENTS TO WHITE IN THE EARLY MESOZOIC

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An analysis of the color spectra of carbonate rocks records an abrupt change from nearly exclusively reduced carbonates (shades of grey) to the first widespread appearance of oxidized colors (white, yellow and tan) ~200 million years ago. This color transition occurs across all sedimentary environments between intertidal mudflats to the deep sea. We suggest that the appearance of oxidized colors in the early Mesozoic is due to rising oxygen concentrations ~200 million years ago that were capable of fully oxidizing organic detritus and limiting the formation of pyrite by bacterial sulfate reduction. Sediment color evidence for rising environmental O2 is supported by trends toward increasing body size of marine fauna, bioturbation rates and community energetics in the Phanerozoic. Data presented here suggests that canonical models of high Carboniferous oxygen concentrations should be revisited in favor of models coherent with geochemical proxy data and paleobiological evidence. Our data support recent reconstructions of atmospheric O2 from I/Ca measurements, Mo isotopes and the minimum O2 needed to promote biomass burning. Our results also explain the long-standing observation made by Derek Ager in The Nature of the Stratigraphical Record, that the geologic eras of the Phanerozoic could be identified by secular changes in the color of carbonate sediments in outcrop. The early Mesozoic was a watershed moment when environmental O2 levels rose high enough to engender ecosystems and animal energetics approaching those of the modern world.

FOSSIL FISHES OF DEATH VALLEY NATIONAL PARK, CALIFORNIA: RECONSTRUCTING THE ORIGINS AND HISTORICAL BIOGEOGRAPHY OF WESTERN NORTH AMERICAN FRESHWATER FISHES

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Miller (1945) described three species of cyprinodont fossil fishes from Death Valley National Park

(DVNP), southeastern California. Included was the only known record of the extinct pupfish *Cyprinodon breviradius*. The exact location, stratigraphic horizon, and geographic extent of the respective fossil locality and, thus, the geologic age of these specimens have always been uncertain. Recent discoveries of fossil fishes most likely from the same locality represent a taxonomically diverse ichthyofauna. Pending verification, it comprises additional specimens of *Cyprinodon* (pupfish) and other cyprinodont genera and families, including the genera *Profundulus* (Middle American killifishes) and *Fundulus* (topminnows); the family Goodeidae including both subfamilies Empetrichthyinae (spring and poolfishes); a perch-like fish of the Percidae family, possibly of the genus *Etheostoma* (darters). Continued collecting and analysis will likely increase the taxonomic list. Fish are preserved in calcareous mudstones associated with spring mounds, algal mats, and fresh water mollusks resembling *Pyrgulopsis* (springsnails). The exact age of the fossil-fish bearing mudstones is still unknown however they are stratigraphically above the Titus Canyon Formation (late Eocene to early Oligocene) and in an interval containing at least five intercalated ash-fall tuff beds. The lowest tuff bed correlates to a tuff bed dated to about 17Ma and the uppermost tuff bed most likely represents the Crater Flat Tuff, which has been dated at 13.5MA. Many of these fossil fishes represent the oldest and first known occurrences in the fossil record. The extent of the fossil-bearing deposits covers a wide outcrop exposure of at least 20 miles. Fishes are associated with spring fed lakes within a fluvial system of the ancient Armagosa Valley. Timing of origin and subsequent geographical distribution of Cyprinodont fishes has been the subject of many theoretical models. The discovery of this fauna will be critical in reconstructing the origins of the native fish fauna of DVNP and subsequent geographical distribution.

FOSSIL VERTEBRATE TRACKS OF DEATH VALLEY NATIONAL PARK: INDICATION OF A LARGE MAMMAL AND BIRD POPULATION IN DEATH VALLEY DURING THE PLIOCENE

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Extremely well preserved fossil tracks and trackways of birds, camels, horses, cats, proboscideans and other vertebrate ichnotaxa are preserved in Pliocene lacustrine deposits of Death Valley National Park. Four localities within Death Valley are known however only one locality within the Copper Canyon Formation is well documented. The other three localities are within unnamed and unmapped deposits. The Copper Canyon Formation represents approximately 1800 m of conglomerates, basalt flows, and fluvial-lacustrine sediments exposed within Copper and Coffin Canyons on the west side of the Black Mountains in southern Death Valley National Park, California. Twenty-six ichnospecies of cat, camel, horse, mastodon, and bird tracks have been identified from 60+ localities spanning over 1200 meters of lacustrine deposits. These deposits have been dated between 5-3Ma. The other localities within Death Valley contain similar tracks as those found within the Copper Canyon Formation and therefore are assumed to be of similar age. Tracks are preserved within mudstone beds interpreted as playa-mudflats that also preserve numerous shoreline features including mud cracks, ripples, and raindrop impressions. In comparison fossil vertebrate bones are rare within these deposits. The abundance and diversity of mammal and bird tracks within Death Valley suggests a large animal population existed in Death Valley at this time and conditions favored fossil preservation of these trace fossils. On-going research looking at the mammal and bird track diversity will enable a better understanding of the animal population in Death Valley at this time.

FOSSILS3D AND PALEOAPP: NEW INTERACTIVE AND USER-FRIENDLY LEARNING TOOLS IN PALEONTOLOGY

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A strong background in systematic paleontology is essential for understanding more specialized and practical paleontological applications (e.g., vertebrate and invertebrate paleontology, micropaleontology, paleobotany, etc.). However, one of the main obstacles faced by students enrolled in introductory paleontology courses at the few tertiary institutions that still offer them either as core courses or elective courses is the excessive memorization that renders their course contents tedious and overwhelming. At Missouri University of Science and technology, we are developing new interactive and student-centered approaches to improve how paleontological concepts are taught and assessed. We recently digitized the teaching fossil collection for systematic paleontology to transition the course from a classroom/laboratory

teaching format to a blended format with a distance learning (synchronous/asynchronous) section. This process enabled us to identify the need to develop an online database (Fossils3D) and a web app interface for desktop and IOS/Android devices (PaleoApp) to stimulate students' interest in paleontology. These new eLearning tools are intended to facilitate their understanding of fundamental paleontological concepts through engaging educational materials that provide access to online experience with 3D fossil specimens, especially where introductory paleontology courses are not formally taught. Therefore, this eLearning project complements ongoing efforts by other entities, such as the Paleontological Research Institution, to make paleontology more accessible, especially to students all over the world who do not have the opportunity for face-to-face instruction.

FOSSILS DEFINE NATURAL VARIATION IN A CARIBBEAN CORAL REEF ECOSYSTEM AND REVEAL AN UNEXPECTED BRIGHT SPOT

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Coral reefs are one of the most threatened marine ecosystems in the world. Fortuitously, reefs tend to leave excellent fossils records that can be exploited to define change and variation in coral communities over time and space to provide context to the current declines in reef health. In this study we quantify the Historical Range of Variation (HRV) in coral community structure in a mid-Holocene (7.2–5.6 ka) fringing reef system in western Panama and compare it to variation in adjacent modern communities. Our results, somewhat unsurprisingly, show that most of the modern reefs exist in completely novel states, driven principally by the loss of the staghorn coral *Acropora cervicornis,* but also changes in other coral components. In sharp contrast to this expected region-wide shift, we discover one modern reef whose coral assemblages are contained within the fossil-defined HRV, identifying it as a potential vestigial reef community, or coral reef "bright spot". Reef matrix cores reveals this isolated reef has remained in this state for at least the last 800 years. Curiously, the reef has never been considered outstanding despite being the focus of much research, presumably because it fails to satisfy assumptions about what a "pristine" coral reef should look like in this area. This finding demonstrates how quantifying the gamut of past variation of an ecosystem can better define pre-human baselines, help reveal what is natural and what is novel, and uncover unexpected bright spots.

THE END-TRIASSIC MASS EXTINCTION (ETE) ON LAND AND THE ROLE OF HIGH-LATITUDES IN DINOSAUR DOMINANCE

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Late Triassic continental tetrapod communities show a bi-polar provinciality in which all herbivorous dinosaurs and several temnospondyl amphibian groups are restricted to higher latitudes whereas diverse pseudosuchians with uncommon carnivorous dinosaurs and a very low diversity of temnospondyls characterize the tropics. A similar provinciality is apparent in pollen and spores, most notably in the distribution of the voltizialian conifer vesicate pollen forms (e.g. *Patinasporites*) that were dominants in the tropics becoming rare then absent towards the high latitudes. This provinciality collapsed by the earliest Jurassic, part of the distinctive biotic pattern of the ETE. Notable is the differential survival of archosauromorph forms dominant in higher latitudes, sorted by clade-level physiologically-related traits and size. All large (> 1 m) continental, presumably uninsulated, bradymetabolic pseudosuchians and other archosauromorphs became extinct prior to the earliest Jurassic, while not only were the insulated (protofeathers), tachymetabolic dinosaurs (and pterosaurs) minimally effected, large herbivorous dinosaurs expanded their ranges though the tropics and the earliest known ornithischians (also primitively insulated) appear and become common. During the Early Mesozoic, the higher latitudes (> 40° N or S) were forested with no evidence of polar glaciers presumably because of high CO_2, (800-4000 ppm) although there is evidence of seasonal freezing. There are almost no tetrapods known from these forested areas, whereas slightly lower latitudes in both hemispheres are some of the richest Late Triassic and earliest Jurassic continental

assemblages, a pattern which we assert is a due to a collection and/or preservational bias. We additionally propose, that the abundance of large, insulated herbivores in the higher latitudes reflects their dependence on reliable food sources and a preference for cooler climates, while they could not compete with generally bradymetabolic pseudosuchians in the violently variable tropics under high atmospheric CO_2 levels.

Seemingly paradoxically, during the CO_2 doubling events (~2000 to 4000 ppm) generated by emplacement of the Central Atlantic Magmatic Province (CAMP) ~201 Ma and the ETE, the continental low latitude biomes were wiped out and replaced by members of higher latitudinal communities, rather than a poleward shift that might be expected from global warming. We resolve this paradox by noting that among continental amniotes only small forms that could take advantage of burrows or insulated clades, including both large and small forms, survived the ETE, which would seem to be accidental pre-adaptations for survival through brief but intense freezing episodes as would be expected of the super-volcanic winters of the CAMP. Thus, despite the 150 year prejudice of casting the Age of Dinosaurs as tropical, the dominant life forms on land became so by being fundamentally cold-adapted.

REVIEW OF THE MIDDLE CAMBRIAN TRILOBITES OF THE BATHYURISCUS-ELRATHINA BIOZONE OF MONTANA: TAPHONOMY AND TAXONOMIC INFORMATION

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Although Cambrian outcrops are extensively exposed in western Montana, relative few studies have been conducted on the trilobites from these strata. The last thorough description of the trilobites of Montana was published by Charles F. Deiss in 1939. Since that publication, many taxa have been synonymized or reclassified. Here, I present new information on the trilobite fauna present in the Middle Cambrian shale units near Manhattan, Montana. The composition of 171 samples in the paleontology collection at the Museum of the Rockies, Montana State University includes three orders (Corynexochida, Agnostida, Ptychopariida) and four families of trilobites. These trilobites, though typically found as shed elements, are well preserved, facilitating identification. The dataset includes species indicative of the Bathyuriscus-Elrathina biozone and are comparable to those of the Wheeler Shale in Utah and the Burgess Shale in British Columbia. In addition to trilobites, brachiopods and one sponge are also represented. The Middle Cambrian faunas of Utah, Nevada, British Columbia, and Alberta have been well explored. As Montana is situated between these areas, these trilobites are critical to the understanding of the faunal and biogeographical transitions between these regions.

LATE QUATERNARY ENVIRONMENTAL CHANGES IN THE VALLEY OF MEXICO INFERRED FROM SMALL MAMMAL ASSEMBLAGES

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Tlapacoya Hill is an eroded andesite volcano located on the shore of the former Chalco Lake, in the southern Valley of Mexico. Between 1965 and 1973, several excavations were carried out in Tlapacoya, including two rock shelters Tlapacoya II and V located on the west and east slopes of the hill. Thousands of small bones were collected through sieving and housed in the Paleontological Collection (INAH). In this work, we present the results of the preliminary study of the small mammals remains, analyzing the shifts in their taxonomic abundances based on genus level identification to infer the environmental changes during the Late Quaternary on the region.

In the interior of Tlapacoya II, nearly eight-thousand identified specimens of small mammals, were recovered from a 3-meters stratified deposit encompassing from the end of the Pleistocene to the middle of the Holocene. Identified mammals include chiropterans of the genera *Mormoops*, *Myotis*, and *Desmodus*, three lagomorph genera (*Lepus*, *Sylvilagus* and *Romerolagus*),two soricids (*Cryptotis* and *Sorex*), and 18 rodent genera from four families (Sciuridae, Cricetidae, Geomyidae, and Heteromyidae). The rodent community represents distinct temperate and xeric environments. The presence of the volcano mouse *Neotomodon* and rabbit *Romerolagus,* indicate lower altitudinal displacement of the temperate forests. Extralimital rodent *Onychomys* suggests an

expansion of the northern xeric shrublands during the early Holocene into the region. The relative abundance decreasing of the vole *Microtus* against the kangaroo rat *Dipodomys* is indicative of increasing aridity toward the middle Holocene.

In the Tlapacoya V cave more than 17-thousand of mammal remains were excavated from an eight-layer sequence spanning the Late Holocene, including large mammals as deer (*Odocoileus*) and armadillo (*Dasypus*). The small mammal fauna includes one opossum genus (*Didelphis*), five bats genera (*Choeronycteris*, *Glossophaga*, *Leptonycteris*, *Mormoops, and Tadarida*), two leporids (*Lepus* and *Sylvilagus*), two shrews (*Cryptotis* and *Sorex)*, and a total of 16 rodent genera, with their taxonomic abundances suggesting a more open vegetation. The increasing relative abundance of the hispid rat *Sigmodon* suggest an expansion of grasslands probably related to the establishment of pre-Columbian societies and agriculture activities. The presence of the grasshopper mouse *Onychomys* in the deposit revealed a recent extirpation of the genus for central Mexico. Introduced taxa in the uppermost layer (*Mus*, *Rattus*) is correlated with the Spanish colonization and the urban development of the region.

A NEW TERMINAL EDIACARAN VERMIFORM BODY AND TRACE FOSSIL ASSEMBLAGE FROM ANCIENT BRISTLECONE PINE FOREST, INYO COUNTY, CA

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The Deep Spring Formation of the western United States contains a variety of rare, terminal Ediacaran and early Cambrian fossils. The Deep Spring has become known for the occurrence of a soft-bodied tubicolous vermiform fauna that proliferated during the final 10 million years of the Precambrian and bridged the transition from the sessile, peculiar classic Ediacarans to the modernesque Cambrian fauna. The widespread presence of the vermiform fauna just prior to the Cambrian Explosion indicates that they may have played a vital role in the restructuring of the seafloor and contributed to the escalation of marine ecological interactions. Along with the tubicolous body fossils, the Ancient Bristlecone section of the Deep Spring contains remnants of Ediacaran fauna–dominated by holdfasts and traces of early bioturbators–and early Cambrian fossils. Although the preservation of the vermiforms is poor in comparison with other known localities, the presence of the fossils expands the geographic range of these organisms and may provide important information about the preserved transition across the Precambrian-Cambrian boundary. Through morphological comparisons to vermiforms from the Mount Dunfee section of the Deep Spring, the Johnnie section of the nearby Wood Canyon Formation, and the Gaojiashan Lagerstätte from South China, we have determined that the Ediacaran strata contain cloudinomorph specimens that co-occur with evidence of early destructive bioturbation. The presence of both fossil groups indicates the possibility of future isotopic work to support bioturbation as a major driving mechanism for geochemical changes across the Precambrian–Cambrian boundary and paleontological changes among the sessile fauna.

STATISTICAL APPROACHES TO IDENTIFYING THE ORIGIN OF UNDOCUMENTED PALEONTOLOGICAL COLLECTIONS: A MAZON CREEK EXAMPLE

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As the implementation of digitizing collections becomes commonplace, it is likely that the existence of undocumented specimens will lead to major delays in collection organization and impede future research on such specimens. A recent investigation into the taxonomic diversity of the "Mazon Creek" collection housed at North Dakota State University has led to a dilemma in regards to dealing with undocumented, donated collections. An attempt to locate the original source of a collection of approximately 600 (part/counterpart) fossils labelled originally as Mazon Creek siderite concretions resulted in the discovery that the collection is a combination of at least two donated collections from two distinct formations. The first batch was donated to the collection prior to 1978, with no indication of the original donor. This collection has been identified as Mazon Creek in origin. The second batch, comprised entirely of Pennsylvanian-age plants, was donated by a North Dakota State faculty researcher and was collected from the Brazil Formation of Greene County, Indiana. The fossils from this area, dubbed the Stanley Cemetery flora, are slightly older than the Mazon Creek (with some overlap) and dominantly terrestrial. Although the two collections have distinct labelling schemes, approximately one-half of the specimens are lacking in any label whatsoever. Using faunal and floral identifications, it became apparent

that this third group is a combination of the two collections, containing both plants and animals that could be Mazon Creek or Stanley Cemetery in origin, leading to the difficult task of identifying the origin of temporally similar and preservationally identical fossils. Through the application of varying statistical analyses, and the utilization of known fossil occurrences from the Mazon Creek and Stanley Cemetery localities (sourced from the Paleobiology Database, Mazon Creek identification guides, and the original description of the Stanley Cemetery flora (Wood, 1963)), we are aiming to identify (to the highest certainty possible) the origin of the unlabelled specimens. We have tentative provenance determinations, with the unlabelled flora specimens showing similarity to the Stanley Cemetery and the unlabelled fauna specimens showing high similarity to the Mazon Creek. This research represents an approach to dealing with uncertain provenance that may be useful for other collections managers.

FAUNAL TURNOVER AND CHANGES IN ECOLOGICAL COMPLEXITY ACROSS THE END-CRETACEOUS MASS EXTINCTION IN CALIFORNIA

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Marine ecosystems often experience complex transformations following major mass extinction events. How these events affect the functional structure of marine ecosystems is not always well understood, and the data required to investigate these responses are not often digitally accessible and thoroughly vetted. Until recently, this has been true for the fossil record of California. Museum digitization efforts at the Natural History Museum of Los Angeles County and collaborating institutions are now providing opportunities to explore regional and local-scale patterns in paleoecology during major Earth-Life transitions. Here we analyze museum samples of molluscs and brachiopods from across the Cretaceous-Paleogene (K-Pg) boundary in California to identify how the functional structure of marine ecosystems changed during the late Cretaceous, weathered the extinction event, and recovered during its aftermath. The dataset includes more than 93,000 newly digitized specimens of Late Cretaceous age and an additional 37,000 specimens from the Paleocene.

Preliminary results indicate a total of 25 modes of life represented by 390 genera are present in the complete K-Pg dataset. Six of these modes are absent from post-extinction Danian assemblages, most notably fast pelagic predators (ammonites). Additionally, there was a 21% decrease in the diversity of epifaunal molluscs and brachiopods, and a 6% decrease in infaunal taxa. In contrast, a two-fold increase in predatory gastropod diversity followed the extinction. With respect to motility, burrowing bivalves and gastropods increased in diversity by about 10%, while non-motile and attached forms decreased in richness by nearly 70%. Functional richness (the area of functional space occupied by ecological modes of life in each interval) decreased by 31%. Functional dispersion (the distance of those modes of life from the center of gravity) decreased by more than 25%. Functional evenness (distribution of the abundance of each mode of life) was highly uneven during the Maastrichtian, but increased throughout the early Paleogene. Lastly, functional redundancy (number of genera occupying each mode of life) decreased by more than 30%, indicating that ecological packing decreased significantly in the Danian.

These data permit the first large-scale quantitative analysis of ecosystem structure before, during, and immediately after the K-Pg extinction in the northeastern Pacific. We acknowledge that these analyses are only possible due to the digital mobilization of "dark data" in museum collections through two NSF grants, the "Cretaceous Seas of California" project (NSF #1561429) and the "Eastern Pacific Marine Invertebrates of the Cenozoic" Thematic Collections Network (NSF #1503065).

KUMTUKS ILLAHIE AND THE ROLE OF PALEONTOLOGY IN PLACE-BASED OUTREACH

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Place-based education is a pedagogical technique that provides a relatable context for a wide range of natural sciences and that encourages involvement of underrepresented groups in science. Place-based teaching is widely used in classroom settings and can also be an extremely effective means of engaging the general public, promoting scientific literacy, and encouraging stewardship. Paleontology has a long and proud history of place-based outreach, with museums and parks across the world using sites or regions to

illustrate aspects of Earth and life history. Coordinating place-based outreach across broader areas allows natural processes to be interpreted at a grander scale and provides opportunities for demystifying science, inspiring public engagement and involvement, and encouraging environmental citizenship. The transnational Cascadia Bioregion (loosely, Washington, Oregon, Idaho, and British Columbia) lends itself particularly well to such efforts due to its rich biological and geological heritage, the importance of nature to local society, economy, and culture, and the presence of both a large permanent population and a robust tourist industry. Kumtuks Illahie (Chinook Jargon for "Understanding the Land") is a project aimed at using the Northwestern landscape as a foundation for teaching about complex topics in the natural sciences. At its most basic level, it will provide a guide to regional sites, parks, and museums. The main goal of the project, though, is to provide a narrative framework connecting these disparate locations. These narratives will illustrate concepts ranging from climate change to plate tectonics to ecosystem recovery. Just as importantly, scientific storytelling can break down the perceived boundaries between researchers and the public to promote understanding of scientific inquiry and critical thinking. By emphasizing the interrelationship between human society and nature in the region, these stories will demonstrate not just how research is carried out in the natural sciences, but why that research has implications beyond the lab or classroom. The narratives at the core of Kumtuks Illahie will focus on particular localities (*e.g.,* John Day Fossil Beds, Okanagan *lagerstätten*), events (*e.g.*, Missoula floods, Columbia River Basalt eruptions), or taxa (*e.g.*, salmonids, cetaceans) and will be told in a variety of media (including podcasts, blog posts, and museum and site audio guides). Due to its position at the confluence of geology and biology (as well as to its charismatic nature), paleontology will play an especially important role in this effort. It is hoped that Kumtuks Illahie, and in particular its paleontological component, can provide a model for other large-scale outreach efforts focusing on particular regions or fields of study.

THE XIAOSHIBA KONSERVAT-LAGERSTÄTTE: OVERVIEW, SIGNIFICANCE AND FUTURE DIRECTIONS

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The Xiaoshiba section from the Hongjingshao Formation (Qiongzhusian to Canglangpuan; *Yunnanocephalus-Chengjianaspis-Hongshiyanaspis* biozone to *Zhangshania* biozone) in Yunnan Province, represents one of the major early Cambrian (Stage 3) sites of exceptional preservation known from South China. Although most work on the Xiaoshiba Konservat-Lagerstätte has taken place within the last decade, this site offers a unique perspective on the preservation and evolution of early Cambrian soft-bodied fossils, and critically fills the gap between the stratigraphically older Chengjiang biota (Series 2, Stage 3; Yu'anshan Member of Chiungchussu Formation; *Eoredlichia-Wutingaspis* biozone), and the younger Guanshan biota (Series 2, Stage 4; Wulongqing Formation; *Palaeolenus* to *Megapalaeolenus* biozones). The preservation and diversity of the Xiaoshiba biota evokes parallels with that of the Chengjiang, albeit with some significant distinctions, such as peculiar modes of disarticulation among the preserved euarthropods that reveal insights about their morphology and evolution. Similar to other Cambrian Konservat-Lagerstätten, panarthropods dominate in term of diversity and abundance, and include unique taxa from major groups such as fuxianhuiids, artiopodans, bivalved euarthropods and lobopodians. Ongoing efforts are starting to piece together a better view of the diversity preserved in the Xiaoshiba biota, as well as its particular ecology and depositional environment within the Hongjingshao Formation.

THERMAL NICHE TRACKING OVER THE LAST 120,000 YEARS: COMPARING MODERN AND LATE PLEISTOCENE COASTAL MARINE ENVIRONMENTS AND MOLLUSCAN COMMUNITIES IN SOUTHERN CALIFORNIA

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Whether Earth enters its sixth mass extinction will depend, in part, on whether species can keep pace with climate change by tracking their thermal niches across wide distances and biogeographic barriers — and those that cannot track will need to adapt or face extinction. Here, we examine the extent to which coastal marine molluscs tracked their thermal niches in response to Quaternary climate change. We focus on understanding the responses of molluscan

communities to climate change in southern California, where extensive marine terraces of Pleistocene sea level highstands preserve a sequence of environmental conditions and molluscan communities at key climate states. Utilizing stable and clumped isotope analyses of well-preserved gastropods (*Callianax biplicata*) from these terraces, we reconstruct temperatures during Earth history's three most recent sea level highstands: 120,000 years ago, 80,000 years ago, and the present. We use these temperature reconstructions, paired with molluscan community compositions from several locations in Los Angeles County and San Nicolas Island, to determine the extent to which coastal marine molluscs have tracked their thermal niches over the last 120,000 years.

TAPHONOMY OF FISH CONCENTRATIONS FROM THE UPPER JURASSIC SOLNHOFEN PLATTENKALK OF SOUTHERN GERMANY

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The density of vertebrate fossils on bedding planes is generally very low in the Upper Jurassic plattenkalks forming the Solnhofen fossil lagerstätte. There are, however, a few bedding planes where large concentrations of the small fish *Leptolepides sprattiformis* (Blainville, 1818) occur. We analyse and interpret these fish concentrations from a taphonomic point of view. The taphonomic features of *L. sprattiformis* concentrations on three large slabs were semi-quantitatively analysed. The concentrations of individuals on bedding planes are explained as recording local mass mortality events caused by tropical storms that, for short intervals, disrupted the pycnocline which separated hypersaline, oxygen-poor to anoxic bottom waters from normal marine surface waters in the plattenkalk basins. Mass mortality is supported by tetany features such as gaping jaws, hyperextended branchiostegal rays, and splayed fins, which occur in the majority of the specimens. The generally excellent preservation of the fish resulted from lack of post-mortem floatation, rapid burial and/or overgrowth by microbial films, and quick re-establishment of the pycnocline with inhospitable conditions on the basin floor. The post-mortem concave-arching of the backbones and various displacements of the vertebral column were most likely caused by varying decay resistance of soft tissues and the pressure of decay gases in the body cavities, respectively. The taphonomic analysis of fish concentrations can provide very detailed palaeoenvironmental information and serves as an independent line of evidence for palaeoenvironmental reconstructions that complements geochemical and sedimentary data.

THE RISE AND FALL OF NOVEL ECOLOGICAL COMMUNITIES

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Local and global environmental change is transforming living ecological communities into new configurations, resulting in ecosystems with 'novel communities'. Key factors for the emergence of novel communities include the rapid pace of global climate change, breakdown of biogeographic barriers, habitat degradation and species invasions, resulting in novel environments, new species combinations, and altered ecosystem functions. We develop a robust methodology for the identification of novel communities, determine their natural long-term frequency, and quantify the probability of local extinction, emigration, local origination and immigration in transitioning to and away from novel communities. Our approach to analyzing novelty in ecological communities provides a quantitative tool to measure the frequency and drivers of novel ecosystems that can be applied at any temporal scale for any taxonomic group, provided sample sizes are large enough for meaningful time-series analysis. Using the Neptune Sandbox global dataset of Cenozoic marine plankton communities, we find that the mean probability for a community to shift to a novel state is low, 1.7% to 2.8% per time interval. Shifting to a novel community substantially increased the per-taxon probability of local extinction, origination and emigration up to eight times that of background shifts with the probability of species loss about equal to that of species gain. Once a novel community state emerged, the chance of shifting into another novel community state was greater than expected by chance. Thus, novel communities are particularly sensitive to further extinctions and community shift. Our results suggest that efforts to reduce extinction risk are

consistent with the active management and conservation of novelty in modern ecological communities. Under the influence of human impacts, not improving the conditions which brought about the transition to novelty may well facilitate further novelty accompanied by additional species extinction. Our results contravene any notion that the original pristine state of a community can or should be the conservation goal; rather, ecosystem management should focus on how to facilitate the natural propensity for newly developed novel communities to persist and prevent transitions to additional previously unseen ecosystem states that are linked with heightened extinction risk.

BROADENING THE TAXONOMIC SCOPE OF CORAL REEF PALEOECOLOGICAL STUDIES USING ANCIENT DNA

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Marine environments face acute pressures from human impacts, often resulting in substantial changes in community structure. On the inshore Great Barrier Reef (GBR), paleoecological studies show the collapse of the previously dominant coral *Acropora* from the impacts of degraded water quality associated with European colonization, starting around 1850. Evei more dramatic impacts can result in the replacemen of corals by fleshy macroalgae on modern reefs, bu their past distribution is unknown because they leave no fossil record. Here we apply DNA metabarcoding and High-Throughput Sequencing of the 18S rDNA gene on paleoenvironmental DNA (aeDNA) derived from sediment cores at two sites on Pandora Reef (GBR), to enhance paleoecological studies by incorporating key soft-bodied taxa, including macroalgae. We compared temporal trends in this aeDNA record with those of coral genera derived from macrofossils. Multivariate analysis of 12 eukaryotic groups from the aeDNA community showed wide variability over the past 750 years. The occurrence of brown macroalgae was negatively correlated only with the dominant coral at both sites. The occurrence of coralline and green macroalgae was positively correlated with only the dominant coral at one of the sites, where we also observed a significant association between the whole coral community and the occurrence of each of the 3 macroalgae groups. Our results demonstrate that reef sediments can provide a valuable archive for understanding the past distribution and occurrence of important soft-bodied reef dwellers. Combining information from fossils and aeDNA provides an enhanced understanding of temporal changes of reef ecosystems at decadal to millennial time-scales. Given the success of this study over a geographically limited scale, we now have confidence to embark on further studies over broader scales of the GBR to: 1) Reconstruct the marine eukaryotic diversity from tropical coral reefs during the last 1000 years (including European colonization) using two universal genetic markers; 2) Compare the aeDNA signature of foraminifera and corals to their macro-fossil record from multiple GBR sites to quantify the fidelity of this new proxy; and 3) Reconstruct the taxonomic composition of past benthic algae communities, by determining past presence/absence of common algal taxa, along a GBR latitudinal gradient over the last 1000 years. These reconstructions will target significant changes in the soft-bodied reef fauna in response to local anthropogenic and natural environmental change, as well as more recent human-induced climate change.

HOW A FAMILY OF AMATEUR PALEONTOLOGISTS IS FINDING FOSSILS ONLINE AND HELPING SCIENTISTS DISCOVER NEW SPECIES

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We are a family of amateur paleontologists who are working with professional scientists around the world to discover new species of prehistoric life. We search for fossils online to find interesting specimens for sale and then contact paleontologists about them. If they are interested in studying them, we buy the fossils and donate them to museums and university collections.

So far, our family has donated more than 200 fossils to such institutions as the National Museum of Natural History, the American Museum of Natural History and the Natural History Museum of Los Angeles County. Paleontologists have described more than 20 new species, including fish, beetles, mites, thrips, a fairyfly, a booklouse, a crab and a crinoid. More papers are on the way.

We've been fortunate to work with many incredible paleontologists who have kindly answered our emails about specimens we've found. As our efforts have evolved, we've begun working with scientists to find particular specimens that they are most interested in studying. We also have started to co-author papers describing some of the new species we've found. We

hope to broaden our efforts and work with more paleontologists in the months and years ahead. There are more fossils to be found, and we want to make sure they're in collections where scientists can study them.

AN OVERVIEW OF MARINE TURTLE EVOLUTION WITH AN EMPHASIS ON NEW DATA FROM EASTERN PACIFIC FOSSILS

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Marine turtles are well known by the general public and are flagship species for conservation efforts around the world. The seven extant species have their own scientific societies and conferences. Until recently, thebroad appeal of extant species has not translated into intense research on the evolution of marine turtles. Today, more researchers than ever are tackling some of the enduring questions about marine turtle evolution such as: Do marine turtles have a single origin or multiple origins? When did the modern lineages evolve? How and why did leatherback sea turtles evolve such an unusual shell? In this presentation, I review the fossil record and evolution of marine turtles with a special emphasis on new (unpublished) data from the Eastern Pacific. A comparison of the global record with that of the Eastern Pacific shows that, since the Cretaceous, pelagic-specialized forms are cosmopolitan whereas more littoral forms show patterns of regional endemicity. In combination with data from other parts of North America, this pattern helps us evaluate competing hypotheses of marine turtle origins (i.e., are *Archelon* and other protostegids an independent marine invasion?) from a biogeographic perspective. In the Cenozoic, the persistence of *Pacifichelys* (a littoral, durophagous, stem cheloniid) into the late Miocene of Orange County, California, shows that previous hypotheses about ecological replacement among marine turtles might need to be revised to account for regional endemicity. The replacement of durophagous stem cheloniids by durophagous crown cheloniids (carettines) may have occurred at different times around the world, but more descriptions of Miocene pan-cheloniids are sorely needed. Finally, a time-calibrated record of fossil dermochelyids from Southern California provides the first framework for understanding the timing of major evolutionary changes to their bony mosaic. This new record of well-dated, associated, ossicles documents the transition from thick-shelled Paleogene and early Neogene forms to the extremely thin-shelled modern leatherback (*Dermochelys coriacea*). In summary, the fossil record of marine turtles in the Eastern Pacific helps test patterns from other more well-studied regions, but also provide unique insights into the evolution of marine turtles.

USING THE ARCHAEOLOGICAL RECORD TO ASSESS RESOURCE OVEREXPLOITATION IN THE CANARY ISLANDS, SPAIN

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Marine resource overexploitation can adversely impact the sustainability of marine ecosystems and shellfisheries that provide critical protein sources for coastal human communities worldwide. However, detection of the degree of overexploitation, and its potential negative effect on marine resources, can be difficult to identify without a geohistorical perspective. The present research integrates shellfish body size data with oxygen isotope ($\delta^{18}O$) profiles derived from human-harvested archaeological and modern shells from the Canary Islands to assess resource exploitation patters and attempt to identify signs of overexploitation. The studied taxon is the black limpet (*Patella candei* d'Orbigny, 1840), a rocky intertidal gastropod that has been an integral part of the economy and gastronomy of these islands for over two millennia. We test the hypothesis that present harvesting practices are more intense and have caused a human-induced diminution of the modern black limpet when compared to prehistoric shell records, as has been documented in several other regions in the world for other coastal resources.

The size (shell length, width, and height) of adult *P. candei* was measured from ten radiocarbon-dated shell middens and compared to live-collected specimens. Shell margin $\delta^{18}O$ values were used to establish the sea surface temperatures (SSTs) at the time of shellfish harvest. The results indicate that relative limpet shell sizes both increased and decreased throughout the last 2,000 years; however, all archaeological limpets

from all time-periods and islands investigated were significantly larger than living specimens. Moreover, the SST estimates indicate that aboriginal shellfish harvesting was conducted predominately during the warmer-half of the year (SST > 20°C), which contrasts with modern, year-round harvesting. The results indicate that adult shell sizes have diminished by ~31% ($n_{archaeological}$ = 100, mean = 52.07 ± 7.59 mm; n_{modern} = 80, mean = 37.87 ± 7.43 mm) from aboriginal times to the present, likely due to a transition from prehistoric seasonal to current year-round exploitation to feed a significantly larger human population. This study reinforces the usefulness of geohistorical records to inform the health status of coastal resources difficult to assess otherwise.

EXAMINING LATE TRIASSIC (NORIAN-RHAETIAN) TERRESTRIAL FAUNAL ASSEMBLAGE COMPOSITIONS IN THE CHINLE FORMATION OF NORTHEASTERN ARIZONA

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The Triassic Period is the only geological period in Earth history bracketed by two major extinction events, the end-Permian and end-Triassic events. The Triassic is also punctuated by other smaller-scale extinction events that mainly pertain to epoch and/or stage boundaries. The Chinle Formation of western North America potentially preserves a mid-Norian extinction event represented by the boundary between two terrestrial biozones, the Adamanian and Revueltian. This turnover affects primarily aetosaurian and phytosaurian archosauriform reptiles, but also local palynology. This event has been preliminarily dated to between 214-216 Ma and roughly coincides with the Manicouagan impact event in Quebec. Ongoing work at Petrified Forest National Park in Arizona, where the Chinle Formation is exposed extensively, seeks to enhance our understanding of the Adamanian and Revueltian vertebrate assemblages to document other taxa potentially affected by this turnover. Recent new finds include a variety of vertebrate taxa, punctuated by an emphasis on the microvertebrate record. These include new records of actinopterygians, amphibians, diapsid reptiles, and a variety of archosauromorph reptiles. These records show a potential step-wise reduction in species richness as certain clades go extinct in the last 25 million years prior to the end-Triassic mass extinction. The Late Triassic dinosaur record of western North America shows an extinction of non-dinosaurian dinosauromorphs, leading to the introduction of sauropodomorphs and ornithischians, radiation of coelophysoid theropods, and dramatic increases in body size in the Early Jurassic.

MESO- TO NEOPROTEROZOIC LAKHANDA LAMICROBIAL INFESTATION OF SHELL CARBONATE: THE MICRITE ENVELOPE AS AN ENVIRONMENTAL INDICATOR

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Collect any shell on the beach and it will most likely have a white, dusty-looking surface if it has spent time as a member of the marine death assemblage. One's first impulse is to assume the shell has lost luster because of dissolution, or possibly abrasion. However, on close inspection, the loss of luster for shell carbonate is most often caused by infestation by microbial borers. This is true for shells from both siliciclastic and carbonate environments. The character of the microbes and their environment (the boring taxa, their access to light and food sources) changes rates of infestation, density of borings, as well as patterns of borings. These features together create a signature that changes with depositional environment. The signatures have been documented for a number of modern marine environments and has been applied to ancient shells in at least one setting (Ordovician; Vogel and Brett, 2009). Most often the goal of microboring studies is to characterize the various boring organisms based on the shapes and patterns of their traces. That is a laudable endeavor requiring excellent preservation of open micron-scale borings in the shells. As one attempts to translate that work to fossil shell, it becomes more difficult as borings become infilled with sediment or mineralization, and given that techniques used to study the borings involve epoxy impregnation of the empty borings, useful results are elusive. The goal of this study is to use the same impregnation techniques on modern shell, but instead of dissolving the shell and looking at the burrows in plan view, we use a cross-sectional view. The shell is sectioned perpendicular to the outer shell surface and etched to a consistent depth. This brings out the borings in cross section. We quantify the density and depth of borings, instead of identifying the boring taxa. Our rationale is that in order to apply this to fossil shell, it will be more useful to work in thin-section where the microbially bored surface is better known as the micrite envelope. The density and

thickness of the micrite envelope, then, can be matched to water depth and other environmental factors based on our data from modern shells.

Our results show that the microbored surface (envelope) begins to develop within four weeks of exposure at the sediment-water interface. Near 100% shell loss to borings in the outer 15 microns of shell occurs by six months in shallow, well-lit carbonate settings. With time, borings extend deeper into the shell with a somewhat consistent depth limit of about 50 microns after twelve years of exposure in carbonate environments. Density and depth of borings develops quickly below 100m water depth, and more slowly from 100m to 300m and in siliciclastic settings. Using depth of penetration and density of borings, two factors that are easily distinguished in thin sections, we hope to contribute to better environmental interpretation of fossiliferous rocks at least from the Ordovician forward.

TRILOBITES IN CRUISE CONTROL: CLOCKING THEIR EVOLUTIONARY RATES AND THE END OF THE CAMBRIAN EXPLOSION

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Trilobites are arguably the most abundant, diverse and morphologically complex group of animals that spanned most of Cambrian time. The oldest trilobite body fossils around the world, at or near the Terreneuvian–Series 2 boundary (~521 Ma), already show established phylogenetic disparity and biogeographic provincialism. This has been used as evidence to suggest that trilobites had a protracted but cryptic evolutionary history that extends back into the Precambrian. We evaluate evolutionary rates across the Cambrian by applying Bayesian tip-dating methods to a comprehensive dataset of Cambrian trilobites. Our results show that the initial standing diversity of trilobites can be reconciled with a Cambrian origin and, surprisingly, that trilobites have constant morphological evolutionary rates throughout their entire Cambrian record. This demonstrates that the Cambrian explosion had concluded by Series 2 and was a truly rapid and abrupt evolutionary event, perhaps spanning less than 20 million years. Morphological clock results show that trilobites may have originated as early as the Fortunian, but this raises the issue of missing body fossils in Terreneuvian rocks. One possibility is that the trilobite fossil record is a relatively accurate representation of the group's evolutionary history, with rapid dispersal and subsequent provincialism occurring in a short geologic timeframe. An alternative explanation is that trilobites have not been preserved or yet discovered in Terreneuvian strata. The absence of body fossils could relate to a number of factors, including the possibility of the earliest forms being non-biomineralized, thus having low preservation potential. Such a scenario would have required multiple lineages to simultaneously converge upon a calcite exoskeleton around 521 Ma, unless initial evolutionary rates were much faster. Notably, this time roughly coincides with the first appearance of other calcitic bilaterians (e.g. echinoderms and rhynchonelliform brachiopods) and a change in seawater chemistry to a 'calcite sea'. Thus, environmental influences, as well as biological factors (such as predation), were driving this major episode of biomineralization and diversification during the final stages of the Cambrian explosion.

CLIMATE CHANGE AND SPECIES RESPONSE: AN UNFULFILLED PROMISE OF STRATIGRAPHIC PALEOBIOLOGY

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How climate change affects species patterns of abundance and distribution is one of the main challenges we face in a warming world. The fossil record is essential to meet this challenge because it offers unique perspectives of worlds far warmer than today. Stratigraphic paleobiology should play a key role because of its emphasis on analyzing and interpreting abundance and distribution of extinct species based on the stratigraphic context of fossil occurrences.

Multivariate analyses of collections of fossils containing taxon counts have revealed that a primary control on the distribution and abundance of marine organisms is a complex gradient of environmental variables related to water depth. Based on the multivariate analyses, taxon response curves can be estimated with a few simple ecological parameters (e.g., preferred habitat, peak abundance, environmental tolerance). These ecological parameters can then be compared across space and through time to determine how changing climate affects species distributions. Analysis of Upper Ordovician assemblages in North America illustrates the promise of this approach.

Ecological parameters of marine benthic invertebrate genera persisted relatively unchanged for millions of years, even across a major warming interval that is marked by a biotic invasion. In contrast, during the invasion interval, ecological parameters of noninvading, shared genera were not conserved across a gradient from a warm-water carbonate platform to a mixed carbonate-siliciclastic ramp, although warm-water carbonate genera that successfully invaded the mixed carbonate-siliciclastic ramp (invading shared genera) conserved their environmental parameters. A few studies have extended this approach to include multiple geochemical proxies of environmental variables and have attempted to determine the importance of each variable in driving assemblage change over intervals of warming. Characterizing niche dimensions across multiple environmental variables is within our grasp, but will require targeted field studies designed to measure environmental proxies and fossil abundance within the same stratigraphic section.

Although publicly available databases have played an important role, they often have limited environmental and temporal information that are required to answer many critical questions. High-resolution field data on richness, abundance, and environmental information are needed to determine the range and variety of responses of ecosystems to climate change.

BODY SIZE AND EXTINCTION RISK IN THE FOSSIL RECORD AND THE MODERN WORLD

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Larger body size is strongly associated with extinction in many groups of marine and terrestrial animals in the present and in the Pleistocene fossil record. This pattern has been assumed by many ecologists and evolutionary biologists to reflect a general phenomenon produced by the scaling of properties such as fecundity, generation time, and home range size with body mass, but lack of comprehensive size data for fossil taxa has prevented systematic tests. Here we use a database comprising the body sizes, stratigraphic ranges, and occurrence patterns of 9,408 genera of fossil marine animals across the past 485 million years to test for consistency in the association between body size and extinction across time and taxa. Contrary to expectation, smaller-bodied animal genera have been consistently and preferentially lost to extinction across the fossil record of marine animals, even after accounting for the consistently poorer sampling of smaller genera in the fossil record. An association between larger body size and wider geographic range, after accounting for effects of Linnaean class, genus age, and stage-based differences in sampling completeness, accounts for much of the association between size and extinction. The preferential loss of larger-bodied animals during the current biodiversity crisis therefore represents a reversal of the typical evolutionary trajectory rather than an acceleration of background trends.

EVOLUTION OF EUMALACOSTRACAN GRASPING APPENDAGES FROM AN EXTRAORDINARILY PRESERVED CRUSTACEAN FROM THE TITHONIAN OF GERMANY

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Eumalacostracans are a highly diverse and successful group of crustaceans that were able to colonize practically all aquatic environments, and even terrestrial ones. The specialization of a large number of appendages has a lot to do with the great success of the group. From very early on in the eumalacostracan evolutionary history we find different types of grasping appendages, for example, among representatives of Peracarida (including opossum shrimps and woodlice), Hoplocarida (mantis shrimps) and Decapoda (shrimps, lobsters and crabs).

Grasping appendages are mostly formed by a terminal element that occludes against the penultimate element, forming a mechanism used for grabbing food, to facilitate copulation or to attach to a host. In extant representatives we can find at least four types of grasping structures: 1) true chela, formed by the elongation (fixed finger) of one side of the penultimate element, and the terminal element acting as a movable finger, 2) pseudo-chela, resembling the chela, but the fixed finger is significantly shorter than the movable one, resulting in a different type of occlusion, 3) subchela, with a simple penultimate element, and a curved terminal element which folds back in the direction to the penultimate element ("jack-knifing"), and 4) carpochela, a rare configuration in which the antepenultimate element additionally has a fixed finger acting together with a more distal subchela; this is in fact a special type of multichela known in other representatives of Euarthropoda.

We present new fossil crustaceans from the

Tithonian (Upper Jurassic) of Franconia, Germany, that show remarkable subchelate appendages. Specimens were documented with modern imaging techniques and revealed extraordinary details of the morphology of the subchela. The penultimate element is heavily armed with long spines, and the enclosing distal element bears smaller spines pointing at the opposite direction from the one in the penultimate element. While at a first glance the arrangement is reminiscent of the raptorial appendages of mantis shrimps, the appendages bearing these sub-chelae are not compatible with an interpretation of the fossils as mantis shrimps. Instead, comparable appendages in a comparable position are known on specialized representatives of Peracarida. We provide a detailed comparison of the grasping appendages of the fossils to those of extant forms.

EXPERIMENTAL BIOMECHANICS OF TRINUCLEID FRINGE PITS (TRILOBITA)

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The asaphid trilobite family Trinucleidae were common Ordovician benthic dwellers best recognized by a wide, perforated cephalic fringe dotted with perforated fringe pits (Campbell, 1975). The specific function of this "lace collar" construction has been the subject of much speculation for well over a century. We address the most commonly accepted morphological hypothesis, that the fringe served as a filter feeding mechanism, by means of subjecting a 3D-printed fossil to a series of experiments inside a custom-built flume. Our findings suggest the fringe does not allow for the easy passage of fluid through its pits, and thus would have failed as a reliable feeding mechanism. Our analyses instead suggest that the distinctive shape of the pits might instead serve as a structural fingerprint of the Trinucleid growth strategy. We conclude by contributing an updated model for fringe function, paying close attention to pit shape and the structural integrity it offers.

LATE EDIACARAN MARINE SHELF ENVIRONMENTS: EVIDENCE FOR NUTRIENT CONTROL ON LOCAL COMMUNITY STRUCTURE AND PRODUCTIVITY

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While there has been much discussion on the relationship between low oxygen and nutrient availability during the early Neoproterozoic there has been less focus on nutrient cycle dynamics in the late Ediacaran, particularly in oxygenated basins. Here, we report a lipid biomarker and stable isotope ($\delta^{15}N_{total}$ and $\delta^{13}C_{TOC}$) investigation of exceptionally immature, late Ediacaran strata (560-540 Ma) from multiple locations across Baltica (modern Ukraine and western Russia), including locations which host Ediacaran Biota.

We report very distinctive biomarker assemblages, including anomalously high hopane/sterane ratios (a broad measure of bacterial/eukaryotic source organism inputs), from our Baltica sedimentary rocks. The highest hopane/sterane ratios (22–119) occur during the peak in diversity and abundance of the Ediacara Biota. By the Ediacaran, eukaryotic algae were established as major producers in many marine ecosystems. The discrepancy between the globally important contribution of eukaryotic algae in the late Neoproterozoic and yet the low levels of sterane biomarkers in our samples indicates that there must be some local determinant on eukaryotic abundance. The most parsimonious explanation for the extremely elevated hopane/sterane ratios alongside low total organic carbon (TOC) contents and low hydrogen indices (HI) found for our samples is that these strata were deposited in oligotrophic (i.e., strongly nutrient-limited) settings, in which bacteria outcompeted algae.

Prior to the Ediacaran Period, low nutrient abundances are often explained as a consequence of low oxygen. However, in the modern, well oxygenated ocean system, supply of essential nutrients including nitrogen, phosphorus, silicon, and iron primarily control the global marine productivity patterns. The late Ediacaran may mark a transition to an ocean system where nutrient balance primarily controls the local mode of bacterial versus algal primary productivity and strongly influences the marine community

structure. Thus, the nutrient cycle, rather than redox, could be the main driver of chemical and ecological heterogeneity during the late Ediacaran in marine shelf settings. Notably, Ediacaran Biota faunal occurrences have been reported from rocks from both the Redkino and Kotlin stratigraphic horizons across Baltica, but are not found in corresponding South Oman strata, where biomarker data[1] indicates highly productive, algal-rich settings. This difference in environmental conditions suggests niche competition might have been prevalent amongst emerging multicellular organisms and other consumers.

[1]Love, G.D. et al., Fossil steroids record the appearance of Demospongiae during the Cryogenian period. Nature, v. 457, no. 7230, p. 718–721. 2009.

DISCOVERY OF A NEW EXCEPTIONAL PRESERVED CAMBRIAN BIOTA FROM THE LONGHA FORMATION IN SOUTHEASTERN YUNNAN

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A new exceptional preserved Cambrian biota, with fossil groups belonging to multiple phyla, was recently found from the middle part of the Longha Formation, near Fulu Village, Funing County, southeastern Yunnan. All specimens are collected from a 3-m-thick interval of dark grey mudstone within the second member of the Longha Formation. So far as known, the fossil groups include polymerid trilobites, agnostoids, worms, eocrinoids, hyolithids, brachiopods, bradoriids, large bivalve arthropods, macroscopic algae, and trace fossils. The trilobites are abundant and usually articulated, preserved commonly as completed exoskeletons. For a number of genera or species, the complete exoskeleton is recorded for the first time. Eocrinoids are diverse whereas hyolithids and bivalves are relatively rare. The age of the new biota is well constrained by the presence of cosmopolitan agnostoid species, such as *Proagnostus bulbus* and *Agnostus modestus*. There agnostoid species are know from the *P. bulbus* Zone and the former is eponymous species of the zone, suggesting the biota a late Guzhangian Age (late Miaolingian Epoch). This age indicates that the biota occurs between the Kaili Biota in age of early Miaolingian and the Guole Biota in age of middle Furongian Epoch. It is a new biota recorded for the first time in China, and is more or less equivalent in age to the biota from Weeks Formation in Great Basin, western United States.

MEASURING ECOSYSTEM ENGINEERING IN CAMBRIAN AND ORDOVICIAN REEFS

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Habitat complexity is widely regarded as a driver of biodiversity in modern and ancient ecosystems, and theory predicts that heterogeneous environments should provide a wider variety of ecological niches. The rise of complex reef environments through ecosystem engineering has been suggested as a global biodiversity driver in the Palaeozoic, but attempts to measure the complexity or heterogeneity of reef environments over time are few. This hampers a mechanistic understanding of the long-term role of reef building in generating and sustaining biodiversity over the Phanerozoic. Studies of modern reefs vary widely in approaches to measuring environmental heterogeneity, complexity and ecosystem engineering, encompassing surface roughness, substrate heterogeneity, and the abundance, diversity, size and spatial arrangement of structural elements, some of which should be measurable in fossil reefs.

We attempted to address the environmental evolution of reefs through a regional study of the Cambrian – Ordovician of Newfoundland and Labrador. Shelf deposits in this area have numerous well-described microbial and metazoan reefs of ages ranging from early Cambrian to late Ordovician. This time window encompasses the last of the archaeocyath reefs, the resurgence of large microbial reef complexes and examples of the low, biohermal mounds constructed by lithistid sponges and other metazoan communities, providing selection of reef types for comparison. We used existing descriptions of the sedimentology and palaeoecology of reef localities as the basis for detailed mapping, combined with point count and cluster analyses of their sedimentological composition. This data collection effort, combined with regional fossil occurrence records, allows comparison of the time-averaged diversity, heterogeneity, evenness and contribution of calcareous ecosystem engineers to reef environments in this area during the Cambrian and Ordovician.

Initial results suggest that formation genus-level diversity estimates from the Paleobiology Database do not correlate significantly with substrate heterogeneity, habitat evenness, or facies diversity in the studied

reefs. This may suggest that alternative measures of habitat complexity, or alternative scales of measurement, are required. The results also underline the high diversity and habitat complexity of early Cambrian archaeocyath reefs, and the lasting regional impact of their disappearance on reef environments. We suggest that inferences on the role of ancient reefs in diversification events should be tested against the preserved features of the sedimentary record, in order to understand underlying mechanisms.

UNGUAL UNDRESSED: COMPARING THE BONE AND KERATIN SHEATH OF CLAWS ACROSS EXTANT RAPTORS

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The behavior of extinct organisms can be better understood by using structure-function relationships in extant taxa to interpret fossilized structures in extinct taxa. This can be difficult in cases where the soft-tissue of the fossilized structure is not well preserved. Dromaeosaurids, a small theropod from the late cretaceous period, have a strikingly enlarged second pedal claw (C2) that despite being heavily studied, has had multiple conflicting behavioral interpretations. Many of these interpretations based on the pedal talons of extant birds of prey. Unfortunately, only the ungual bone of the dromaeosaurid claw is preserved, lacking the keratinous sheath- the structure which interacts with the environment. This makes the comparison between extinct ungual and extant claw less appropriate without a better understanding of how the ungual and sheath relate. To approach this issue, we analyzed the morphological relationship between ungual and sheath using high resolution microCT scans of the C2 from five extant birds of prey (the golden eagle, great horned owl, goshawk, osprey, and red-tailed hawk). Using longitudinal slices, we measured the inner and outer curvature of both sheath and ungual as well as how far the sheath extended from the tip of the ungual. We then took five cross-sectional slices at standard anatomical positions and compared ungual and sheath morphology along the length of the claw. Using these measurements, we found evidence suggesting that the curvature of the ungual does not match that of the sheath. The distance between ungual and sheath tip varies across species, as does the thickness of the sheath. Notably, the eagle differed largely from the two hawk species, even though previous studies have suggested that all of these species share a similar hunting strategy that was then proposed for dromaeosaurids based on similarities in curvature. Additionally, we discovered that some talons have a sharp, ridge-like structure on them, which does not appear to be previously described. These preliminary results reveal that it is important to look at the relationship between the ungual bone and the keratin sheath in order to properly interpret what the function of the dromaeosaurid claw may have been. Future work will explore morphological correlates between ungual and sheath to aid in reconstruction of extinct taxa with a focus on the function of the keratinous ridge and whether such a structure may have existed in dromaeosaurid claws.

A NEW DESMATOPHOCID (PINNIPEDIA) FROM THE EARLY MIOCENE OF OREGON SHEDS NEW LIGHT ON THE ORIGINS OF THE EXTINCT LINEAGE

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Desmatophocids (Pinnipedia) represent an early lineage of extinct pinnipeds represented by abundant and well-preserved fossils spanning the Miocene of the North Pacific. Recent studies have clarified desmatophocid taxonomy and phylogenetic relationships, with an emphasis on the geochronologically younger genus Allodesmus. These studies suggest that desmatophocids may be sister to Phocidae; however, the exact phylogenetic relationship between desmatophocids, Phocidae, and stem pinnipeds remains enigmatic. Here, we describe a new desmatophocid from the early Miocene of the Pacific Northwest (Astoria Formation, Oregon). This specimen is contemporaneous with the geochronogically oldest desmatophocids, Desmatophoca brachycephala and Desmatophoca oregonensis. Despite preserving several key synapomorphies of Desmatophocidae, this new specimen has strong affinities to stem pinnipeds. Our phylogenetic analysis recovers this specimen basal to all other desmatophocids. Accordingly, this specimen is temporally and phylogenetically ideal to elucidate the evolutionary origins of desmatophocids and their relationships relative to Phocidae and stem pinnipeds.

PUBLIC-PROFESSIONAL PARTNERSHIPS IN PALEONTOLOGY RESEARCH: SERENDIPITY VS. STRAT-

EGY

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Through the course of my research career, I have had the opportunity to work closely with members of the public that identify as amateur or avocational paleontologists. These individuals practice paleontology because of their love of fossils and are not driven by compensation, which is the only truly distinguishing characteristic between an amateur/avocational paleontologist and a professional paleontologist. Three case studies in which collaborations between myself and the public led to peer-reviewed publications are analyzed. From these case studies, two main factors are considered: connection and contribution. Connection refers to how these collaborations were initiated. Contribution refers to what each member of the collaboration added to the project. Within the three case studies analyzed, the connections were primarily the result of serendipitous interactions. However, with the development of the myFossil website and mobile app platforms, and the community built within them, there are opportunities to strategically initiate these connections. Within the website and mobile app, community members can start Groups and/or Forum Topics that can be used to target specific research questions. This allows for the development of strategic connections to community members that have relevant information or interest in a research project. Once a connection is made, the next consideration is what level of contribution should be expected. The level of contribution should be determined based on the interest and expertise of your collaborator. Some collaborators may only want to contribute specimens, while others may want to be involved in advanced analyses. As a researcher, public or professional, it is important to respect the interests of your collaborators and to work within these confines. This process of public-professional paleontology research can be initiated by either an amateur/avocational paleontologist or a professional paleontologist. In either case, the use of the myFossil platforms can provide a strategic vector for initiating a collaboration and from there the success of a project is simply contingent upon a clear understanding of each individual's expected contributions to that project.

PLEISTOCENE MAMMAL FAUNA MIGRATION AT LAGUNA DE LAS CRUCES, SAN LUIS POTOSÍ, MÉXICO

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A complicated topic to evaluate in Cenozoic paleoecology studies is the migration, home range, and distance that mammal herbivorous could move. However, in the last decades, the use of oxygen and strontium isotopic relationships have turned into an important tool to evaluate those paleoecological traits. In this study, the 87Sr/86Sr dental enamel relationships are utilized to evaluate the migration, if any, and distance that moved Late Pleistocene camelids, *Camelops hesternus*, horses, *Equus* sp., and mammoths, *Mammuthus columbi* from Laguna de las Cruces, San Luis Potosí, Mexico. For accomplishing that objective, plants and soil samples were collected from Laguna de las Cruces as well as from 9 Potosinan localities (Armadillo de los Infantes, Cedral, Cerritos, Charcas, Laguna de las Cruces, Paso del Águila, Presita Blanca and Tepetate) and 1 Zacatecan one, Los Pinos-Altamira; those samples were processed for obtaining their strontium isotopic values for comparison with the values from the fossil herbivorous, and separating resident from migrants individuals, as well as the possible site where those moved to. The 87Sr/86Sr values of some camelids, horses and three mammoths were similar to those showed by plants and soil of Laguna de las Cruces, while 1 camelid and 3 mammoths had different values than those from analyzed localities. Those results indicated that camelids and mammoths included mixed-origin individuals, both native and migrant, while horses were uniquely native to the study area. The presence of an ancient spring in Lagunas de las Cruces could have offered a site where these animals would feed and drink water, even though it is necessary assaying further strontium analyses of plants and soils from other localities to identify the possible site where those animals came from.

BIOMINERALIZATION IN EXTREME ENVIRONMENTS: THE CASE OF ANTARCTIC SCALLOP

SHELLS

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Shallow-water benthic communities in Antarctica have received significant attention because of their archaic composition and structure, resembling Paleozoic benthic faunas[1]. Within the Antarctic benthos, the scallop *Adamussium colbecki*is a key component and has been described as a sentinel organism for ecological and climatic change[2]. This scallop species is characterized by a very thin shell, usually less than 1 mm, that could be explained by the difficulty of precipitating $CaCO_3$in low seawater temperatures[1, 3]. In this talk, we will describe the major findings about the microstructure and chemical composition of these shells, and how these organisms have adopted unique biomineralization strategies to thwart predation. In addition, we will discuss an alternative hypothesis for the presence of thin shells and its connection with the absence of durophagous crustaceans related to the cooling initiated in the late Eocene.

[1]Aronson, R.B. *et al.*2007. Climate change and invisibility of the Antarctic benthos. A*nnual Review of Ecology, Evolution and Systematics* 38, 129-154.

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[3]Vermeij, G.J. 1978. *Biogeography and Adaptation: Patterns of Marine Life*. Harvard University Press (Cambridge, MA), 332 pp.

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MORPHOLOGY AND EVOLUTION OF BASAL CHEIRURINA (TRILOBITA) FROM THE FEZOUATA BIOTA (LOWER ORDOVICIAN, MOROCCO)

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Cheirurina is one of the major group of Phacopid trilobites and first appears in the fossil record in the latest Cambrian or early Ordovician and goes extinct during the Devonian. The group is currently subdivided into several families: Cheiruridae, Pliomeridae, Encrinuriadae and possibly also Pilekiidae (but the taxonomic rank of Pilekiidae is uncertain). Even though Cheirurids have been extensively studied by numerous authors, their internal phylogeny as well as their relationships with other groups is largely unknown. Some authors have even proposed than Cheirurina is not a monophyletic group, since some of the taxa show more affinity with other phacopids. The Tremadocian cheirurids are crucial for understanding the early evolution and morphological diversification of the group.

Numerous species of basal cheirurids have been described from the Lower Ordovician of Morocco. Owing to taphonomical and morphological variability, it is possible that the group has been split into too many species. In this contribution, numerous specimen have been studied in order to clarify the taxonomy and to re-describe the morphology of the cheirurids from the Lower Ordovician of Morocco. Morphological and biostratigraphic data suggest that most of the species belong to the genus *Anacheirurus,* instead of *Lehua* to which they were assigned previously. In addition, a few specimens show preservation of the post-antennal appendages. The exopods bear long lamellar setae and the endopods have small spines along their ventral margin and distally ends with a terminal claw.

Different characters in the exoskeleton of basal cheirurids are relevant to understanding of the early evolution of the group. Comparison with other basal cheirurids from Bohemia, North America, United Kingdom and Norway suggest that the Moroccan taxa show numerous plesiomorphic characters, such as the morphology of the pleural furrows and the glabella. The Moroccan cheirurids described here are important taxa for resolving the relationships within the group and to the other phacopids.

NEW NEKTASPID ARTHROPOD FROM LOWER ORDOVICIAN OF MOROCCO

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Nektaspida are a group of exclusively Paleozoic trilobitomorph arthropods. Their record extends from the Lower Cambrian in to the Silurian, and has a nearly global distribution. They include naraoids, liwiids and probably also emucaridids. Some recent studies have also included the petalopleurids as well as some other genera in the Nektaspida. However, the relationships of these groups within the Nektaspida are still far from resolved.

Here we describe a new nektaspid arthropod from the Lower Ordovician (Tremadocian) Fezouata

lagerstätte of Morocco. The three specimens of this new taxon share an oval cephalic shield with rounded anterior and straight posterior. The trunk is composed of four articulated thoracic tergites. The two furthest anterior of these tergites are overlapped by the posterior edge of the cephalic shield. The posterior shield is elongated and has a medial longitudinal crest. These characters suggest a close relationship of this new taxon with *Tariccoia arrusensis*, a liwiid from the Ordovician of Sardinia. While morphological similarities between the new taxon and *Tariccoia* are sufficient to demonstrate a close relationship, significant differences in the shapes of the cephalic and posterior shields, as well as the length of the medial crest are enough to warrant a new species.

This new species provides insights about the biology and the palaeogeographic distribution of liwiids. Exceptional soft tissue preservation of gut diverticulae in the anterior part of the cephalon shows a similar form to those of *Misszhouia*, potentially suggesting comparable feeding strategy –a more regular feeding than in Naraoia. Moreover, most of the liwiids seem to be restricted to high latitudes of Gondwana and Baltica, which contrasts with mostly equatorial distribution of naraoids. This new information helps to understand and infer the lifestyle and the habitat preferences of liwiids.

SEXUAL DIMORPHISM IN SCAPHITID AMMONOIDS: DIFFERENCES IN HYDROSTATIC PROPERTIES REVEALED BY VIRTUAL 3D MODELING

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Scaphitid ammonoids exhibit a considerable amount of sexual dimorphism in shell morphology between micro- and macroconchs (interpreted as males and females, respectively). These dimorphic pairs are particularly different for *Hoploscaphites crassus*. At maturity, both micro- and macroconchs of this species consist of a planispiral and somewhat involute phragmocone that is followed by an uncoiled body chamber resembling a U-shaped hook. Macroconchs of *H. crassus* are very inflated and subglobose, while their microconch counterparts are less inflated and significantly smaller. Additionally, the body chambers of mature microconchs are further separated from the phragmocone than macroconchs. These differences in shell morphology influence the organismal mass distribution and hydrostatic properties during life, including the conditions for neutral buoyancy, *syn vivo* orientation, and hydrostatic stability (resistance to rotation from the equilibrium position).

Well-preserved specimens of *H. crassus* were collected from concretions in the Pierre Shale from the Cedar Creek Anticline, Montana. Virtual 3D models of micro- and macroconchs were created using a combination of photogrammetry and the replication of shell segments and septa with array generation algorithms. Three-dimensional volumes of each material of unique density (soft body, shell, cameral liquid, and cameral gas) were created to understand the total mass distribution relative to the buoyant properties. Both the micro- and macroconch are nearly neutrally buoyant and require all of their cameral volumes to be emptied at maturity. These models suggest that without active locomotion, they would very slowly sink due to a nonzero value of effective mass (similar to the adult *Nautilus*). Locomotion could have been facilitated by the hyponome if it was large enough to point in the opposite direction of the upturned apertures. Alternatively, the soft body density and/or volume could have been lower than previously thought. The macroconch has a very similar hydrostatic stability to the extant *Nautilus*, while the microconch is slightly more stable. This difference is largely due to the microconch further separating its mass distribution from the center of buoyancy. This stability-increasing tactic may also have been utilized in the similarly-shaped ancylocone morphotype. An additional model of the *H. crassus* macroconch was constructed to investigate the hydrostatic influences of the jaws (including the aptychi) and the mantle cavity. The difference between these components of variable densities and an averaged bulk density negligibly influenced the mass distribution and hydrostatic properties.

DOES THE EARTH HAVE A KILL SWITCH? MACROSTRATIGRAPHIC PREDICTIONS FOR ATMOSPHERIC OXYGEN CONCENTRATION OVER THE PAST 3 BILLION YEARS

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Covariation between the sedimentary rock and fossil records occurs at multiple spatial and temporal scales. Traditional views of the sedimentary cycle, combined with the more recent insights of

stratigraphic paleobiology, highlight the ability of geological mechanisms to impose non-biological patterns on paleobiological data. Although outcrop-scale shifts in the balance between accommodation and sediment supply will always overprint outcrop- to basin-scale fossil data, recent work has shown that traditional views of global sediment cycling apply only to deep-sea and to a lesser extent non-marine sediments. The majority of the mass of the sedimentary record is from marine environments on continental crust that show little signature of cycling.

Partitioning the net sedimentary reservoir into fast (half-life 30Myr), intermediate (~100Myr), and slow (~1000 Myr) cycling components, combined with temporal shifts in the primary locus of gross sediment flux, has important implications for our reading of the fossil record and for the state of Earth's surface environment. Notably, the amount of atmospheric molecular oxygen (O2) depends on the balance between sources and sinks that intersect in the Earth's crust. In the oft-presumed steady-state, the burial of photosynthetic organic carbon (+ pyrite) is balanced by the weathering of organic carbon (+ pyrite) and there is no net input of O2. In this case, O2 falls because it is lost to geological sinks (e.g., oxidative weathering of Fe-bearing minerals in volcanic rocks), albeit at rates that are slowed by complex negative feedbacks. When the burial of organic carbon exceeds the oxidative weathering of organic carbon-containing sediments, O2 is free to rise, also at rates that are slowed by complex negative feedbacks.

Here we show that the slowest-cycling component of Earth's sedimentary reservoir covaries on short (~5 Myr) and long (≥100 Myr) timescales with major features in the fossil record of all living things and with independent proxies for atmospheric O2. The most notable feature in the mass-age relationship of the slow-cycling sedimentary reservoir is an abrupt increase during the Ediacaran-Cambrian. A simple forward model for atmospheric O2 calibrated on observed sediment mass-age and estimates for oxidative weathering suggests that this growth phase in sedimentary mass drove a rise in O2 to near modern levels by the Devonian. The data also suggest a similar Paleoproterozoic growth phase that could have driven an increase in O2 to near modern levels at ~2Ga. A subsequent shift to steady-state sediment cycling at ~1.5Ga may have depleted O2 and maintained it at low levels during the Proterozoic "boring billion." The possibility that an O2-rich atmosphere is a long-lived but also transient state that depends on the ability of continental crust to increase its sediment storage capacity ultimately means that complex multicellular life may be hard to maintain over planetary timescales.

ESCALATION OF ECHINOID-ASSOCIATED PREDATORY AND PARASITIC DRILLING DURING THE MESOZOIC MARINE REVOLUTION

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Escalation of antagonistic biotic interactions, one of the hallmarks of the Mesozoic Marine Revolution, may have been related to the post-Paleozoic increase in diversity and complexity of marine ecosystems. The fossil record has provided substantial evidence for increased frequency of biotic interactions, as primarily documented by traces of drilling and durophagous predation on mollusk prey. Less attention has been paid to trace-producing antagonistic behaviors associated with echinoids, which, like mollusks, are known to be targeted by specific trace-producing predators in modern ecosystems. Predatory cassid and parasitic eulimid gastropods can produce diagnostic drill holes on the tests of living echinoids, which potentially allows for studying predation and parasitism archived in fossil echinoid tests. The newly established Echinoid-Associated Traces (EAT) Database aims to elucidate macroevolutionary and macroecological trends in biotic interactions involving echinoids. The assembled data, which include frequency, morphology, size, location, selectivity, and ecology of drill hole and other trace occurrences on echinoid tests, are being acquired by direct fieldwork, museum collection surveys, and harvesting of primary literature.

Here, we provide a preliminary report on frequency of drill holes in Jurassic to Holocene fossil echinoid populations from the EAT Database, for the purpose of tracking the timing of the post-Paleozoic escalation in drilling behavior targeting echinoid prey or hosts. We observe a near absence of drill holes in the Early Cretaceous and a gradual increase in drill hole frequencies through the Late Cretaceous and Paleogene, following the appearance of cassids and eulimids in

the fossil record. The oldest occurrences of echinoids with notable frequencies of drill holes date back to the Eocene, coincident with a well-documented diversification of cassids and eulimids. The Eocene onset of more frequent drilling on echinoids stands in contrast with the fossil record of drilling on mollusks, for which notable drilling frequencies are reported already by the Late Cretaceous. Additionally, the Eocene intensification of drilling attacks on echinoids took place long after the Cretaceous radiation of infaunal echinoids. These preliminary results imply that the increase in drilling predation and parasitism on echinoids notably postdated the infaunalization of echinoids suggesting that evolutionary pressures other than predation by drilling organisms may have driven major evolutionary trends in echinoids. Moreover, differential timing of the rise of drilling predation on mollusks and echinoids suggest a complex history of the post-Paleozoic increase in predator-prey and parasite-host interactions, with asynchronous rise in the intensity of biotic interactions across different groups of marine benthic invertebrates.

TESTING CONVERGENCE AND FUNCTION OF EXTREME PARIETAL CALLUS IN MARINE GASTROPODS

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This study investigated the homoplastic evolution of "extreme parietal callus." EPC is a callus that covers more than 50% of the ventral shell surface and is often grown throughout ontogeny. EPC has been identified in some species within at least 8 gastropod families. We examined lateral cross sections of individuals drawn from four marine gastropod families: Olividae, Pseudolividae, and Volutidae (which make a monophyletic clade) and Strombidae (as an outgroup). At least two species from each family were compared; one species that develops EPC and another (usually a congener) with normal callus development as a control. We used an SEM to examine the gastropod shell, callus, and spines (if present) to characterize the layers used to build the shell of the adult and which of those layers contribute to the development of normal callus and EPC.

We observe evidence of parallel evolution in Olividae where two genera *Olivancillaria* and *Amalda,* each construct shell and EPC using crossed-lamellar aragonite with a prismatic horizon separating shell and EPC. Crossed-lamellar microstructure is interpreted as a well-constrained, energy-intensive depositional process. There is also evidence for convergent evolution in Olividae, where different shell layers are co-opted to construct EPC in the confamilial *Ancillopsis altilis.* In the olivid *Ancillopsis altilis*, as well as the fossil pseudolivid *Sulcobuccinum santander,* and the volutid *Athleta tuomeyi* the EPC is poorly-ordered and massively constructed from a combination of weakly-ordered fibrous, irregularly-ordered prismatic, and homogenous microstructures. The microstructure of EPC in these taxa is convergent as it does not derive from the shell or spine microstructure of their closest congeners or con-familials. We interpret this poorly-ordered microstructure to be a low-energy alternative to highly-ordered and energetically-expensive construction of crossed lamellar microstructure. Miocene strombids have also converged on the cross-lamellar structure used by olivids to develop EPC.

We also conducted a wave tank and pool drop study on *Athleta tuomeyi* (with EPC) and *A. symmetricus* (without EPC) to test two functional hypotheses for EPC. First, that it might function as ballast helping to right the gastropod in high energy environments. Second, that it might orient the shell as it falls through the water column. With the shells plugged with wax, we varied the initial orientation (aperture up, aperture down) and observed how fast the shells with EPC ceased rolling in a wave tank or fell to the bottom of a deep pool and noted the final orientation of the shell. We find evidence that EPC might function as ballast in turbulent water. Specimens with EPC cease rolling more rapidly compared to the control. However when dropped through the water column, EPC does not have a significant effect on the free-fall time or the final shell orientation, so we do not support EPC as an anchor to reorient falling shells.

HUMAN LANDSCAPE IMPACTS HAVE SHAPED NORTH AMERICAN MAMMAL NICHES

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Human population has increased substantially since the last glaciation, especially across temperate areas with easy access to water sources. Human mediated landscape transformation can exclude mammal species from their former habitats. Thus, we anticipate a change in the realized niches of mammal species as increased human population forces them to shift within their fundamental niches. In our study, we collected species occurrences from 20,000 ybp to the present for 37 North American mammal species covering six taxonomic Orders (Artiodactyla, Carnivora, Chiroptera, Insectivora, Lagomorpha and Rodentia). We inferred temperature and precipitation for each location using paleoclimate simulations (CCSM3). We used these data to calculate niche overlap between multiple past time bins and the present to identify whether the realized niches of these mammals do indeed shift through time. Time bins include late Pleistocene (20,000 to 11,650 ybp), Holocene (11,650 ybp to 500 ybp), Modern (500 to 150 ybp) and Present (150 ybp to the present). We also calculated the environmental niches of modern habitat types and calculated their niche overlap with mammal species' niches at each time bin. Habitat types included human altered habitats such as urban areas or croplands and less disturbed habitats like alpine areas or wetlands.

We find that mammals now live in areas that are warmer and dryer, on average, as mean annual temperatures rise and precipitation decreases. Further, the environmental niches of most mammal species have significantly contracted and/or changed across these 4 time periods, suggesting subsequent extirpations. We find that 24% of these mammals are now overlapping more with human-impacted environments than they did in the past.

Among less disturbed habitats, only deserts, marshlands and swamps show increased overlap with some of the studied species (10, 32 and 21% respectively). None of the species show an increased overlap with forests or shrublands. However, 46% of the mammals in the study show widespread extirpations from most land cover types, suggesting that geographic and anthropogenic dispersal limitations together with a low niche plasticity might prevent animals from migrating to new localities as human population increases and climate changes. Geographic models that integrate fossil and modern niche preferences will help elucidate the reasons behind the observed patterns. Moreover, understanding these patterns will help us formulate better conservation plans for the species we wish to protect.

EXPLORING THE MICROFOSSIL RECORD OF THE LATE DEVONIAN HANGENBERG EVENT IN THE CLEVELAND SHALE, OHIO

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The Hangenberg event is one of the major pulses of extinction associated with the late Devonian mass extinction. This global crisis devastated entire ecosystems and represents a major turning point in the evolution of many faunal groups. Multiple triggers of the event have been proposed, but no dominant theory has emerged.

The palynological record of the Hangenberg crisis has been used by researchers in Poland's Holy Cross Mountains to decipher local causes of extinction, but little palynological study of the Hangenberg event has been done outside of Europe. Here, we analyze the microfossil record in a section of the Cleveland Shale in northeastern Ohio that captures the Hangenberg event. We present acritarch and miospore abundance and diversity throughout the end of the Hangenberg event, as well as geochemical analysis of Hg records in this section. Both Hg and fossil abundance are normalized to total organic carbon (TOC) to account for preservation biases.

The presence of miospore index species *Retispora lepidophyta* and *Verrucosisporites nitidus*, as well as the overall assemblage composition, correlate our section of the Cleveland Shale with the Hangenberg Black Shale and the Western European miospore zone LN. In particular, *R. lepidophyta* is uncommon but present in upper Cleveland shale layers and the Hangenberg Black Shale (Marynowski and Filipiak, 2007), but rises to dominance in samples taken from just above the black shale in both Poland and Ohio. This correlation of palynological records in the Cleveland Shale with the Hangenberg Black Shale shows consistency of miospore response to the cause or causes of the Hangenberg event.

Microfossil abundance varies throughout the studied section, culminating in a complete lack of microfossils at the top of the Cleveland Shale. Acritarch and miospore abundances generally parallel one another, though miospores are more abundant than acritarchs in our youngest samples, possibly due to regression

and decreased water depth. We see no clear association between Hg and fossil abundance in the Cleveland Shale. Additionally, there are no Hg/TOC spikes that might represent volcanism during the Hangenberg event, a trend that continues at sites in nearby Western New York. We instead suggest that changes in oxygen and redox cycling, or local conditions like water depth and sea level change, are more likely causes of the Hangenberg event.

MONTBROOK FOSSIL SITE DISCOVERIES: AN IMPOSSIBILITY WITHOUT VOLUNTEERS

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The Montbrook Fossil Site (MFS) is one of the most important fossil localities of the late Miocene (~5 MA; Hemphillian North American Land Mammal Age) in the Southeast United States, producing over 100 fossil taxa. The site was discovered by the landowner's five-year old granddaughter on a mission to find dinosaur fossils. Little did she know that the bones she found are scientifically more valuable. MFS is powered through the efforts of over 700 volunteers since digging began in November 2015 and has produced more than 30,000 identifiable vertebrate fossils. Nearly 50% of the specimens found are thanks to the involvement of the volunteer paleontological community. Notable finds include fossil elements of some of the earliest swans and white-tailed deer in North America, skull of a saber-toothed cat, and jaws of a bone-crushing hyena-like dog and a lynx. Transporting large fossils from the site to the lab is a monumental endeavor, requiring a massive human effort which includes creating and moving 30 proboscidean (elephant-relative) skull and mandible jackets, all greater than 300lbs. This endeavor would be impossible without the help of volunteers. Involvement of volunteers does not end at the field site. They also work in the Florida Museum of Natural History (FLMNH) Division of Vertebrate Paleontology collection and preparation lab to screen wash, prepare, identify and curate the fossils found at MFS. In three years, over 20,000 fossils have been curated, and made available for research and display. Contributions of volunteer paleontologists at MFS are highlighted in the extension of the permanent public exhibit, the 'Florida Fossil Hall', at the FLMNH. More than 300 K-12 students have participated in the MFS discoveries through classroom activities such as screen washing matrix. Important microfossil finds can be attributed to these students. By bringing the site back to the classroom, it becomes accessible to community members who would not normally be able to go out into the field (due to age restrictions). This broadens participant opportunities and creates interest of the natural history in their backyards.

ILLUMINATING THE EVOLUTION OF BIRDS USING LASER-STIMULATED FLUORESCENCE IMAGING

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Laser-Stimulated Fluorescence (LSF) is a geochemical imaging technique that instantly shows parts per million differences in mineral chemistry across fossil specimens. In revealing unknown anatomical and chemical information, LSF shows that fossils offer higher degrees of preservation than previously appreciated. In many cases, LSF fills important detection gaps showing data missed by more popular imaging techniques like synchrotron and UV. These strengths have allowed LSF to investigate important issues related to the evolution of birds. LSF has directly confirmed the expected form and function of the tail and legs of the early-diverging paravian *Anchiornis* and added data to its enigmatic volant capabilities by showing its narrow propatagia and unordered leading edge wing feathering. LSF has even detected feathering in perinate enantiornithines supporting their precociality and rediscovered the quill of the first described fossil feather, demonstrating that it is a new species. The preserved lateral body outline of the Early Cretaceous bird *Sapeornis* was revealed with LSF. For the first time, these soft tissue data were used to quantitatively improve the accuracy and reconstruction of its flight performance and style. The latter were further refined for the early-diverging pygostylian *Confuciusornis*, using its LSF lateral and ventral body outlines. In addition, LSF revealed a muscle-like propatagial ligament, unusually thick shoulders and a shallow chest profile in *Confuciusornis* that underscores the characteristics to fully consider when analyzing the early avian flight stroke and reconstructing flight performance. As a rapid, portable and low-cost technique, LSF promises to become a tool-of-choice in the study of avian evolution.

IMMERSIVE AND ENGAGING E-LEARNING EXPERIENCES: INSIGHTS FROM AN E-COURSE ON DINOSAURS

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The paleosciences continue to inspire generations of science learners by bringing Earth's incredible past to life. E-learning is emerging as an important part of these efforts. I am going to present a case-study on *Dinosaur Ecosystems,* a Massive Open Online Course (MOOC) offered by the University of Hong Kong which I produced and teach. My talk will focus on the strategies employed to address the opportunities and challenges of delivering our goal to create an immersive and engaging dinosaur e-course. We leveraged the e-learning format to make heavy use of field-based learning so students could see palaeontological work in action. This involved visits to world-renowned field sites and institutions in more than 6 countries, including the Gobi Desert of Northern China and the American Museum of Natural History in New York. The online format also allowed us to give learners a unique perspective of cutting-edge developments in the field through direct connections with myself, co-instructor Prof. Xing Xu and 20+ international experts. As non-compulsory courses, student engagement is a paramount consideration for MOOCs. We addressed this through a relaxed learning experience using bite-sized, content-rich videos with clear and concise learning objectives. Grassroots community activities were employed to encourage peer-to-peer learning and two mobile apps were developed to further involve younger people. The course has so far reached 16,000+ learners from 120+ countries and in 2018 was nominated for the edX Prize for Exceptional Contributions in Online Teaching and Learning. As a testament to e-learning's vast untapped potential, I will conclude by sharing current efforts to introduce newer production technologies to enrich future editions of the e-course.

THE TAPHONOMY OF BEHAVIOR

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Ichnologists are beginning to recognize the rel evance of behavioral biology to their discipline, which has long been dominated by the use of traces for environmental interpretation. This is despite the long tradition of behavioral interpretations of ichnofossils, including the development of an independently derived classification of behavior.This classification, and in fact nearly all ichnological research, remains overlooked by behavioral biologists. Studies of trace fossil behavior have been dominated by two approaches. The first of these, as exemplified by the work of Seilacher, focuses on close study of particularichnofossils and attempts to infer the patterns of activity and perhaps the organism that produced them. For example, graphoglyptids, such as*Paleodictyon*,have been interpreted as bacterial farmers, akin to leaf cutter ants, although there is no independent evidence of such behavior. A secondtacticis to focus on modern organisms known to form traces and examine the processes by which the traces are formed. This approach encompasses both field and laboratory neoichnological studies. What neither approach does, however, is consider the entire range of behaviors carried out by organisms and assess which of these potentially produce a trace. In direct parallel to studies of body fossils, we need to assess the preservational potential of the complete suite of behaviors and determine the fidelity of preserved traces to the original biological signal.Similar to body fossil taphonomy, preservational potential can vary among the behaviors exhibited by a specific organism, such as mating or feeding, across different environments, or among taxonomic groups. In order to integrate ichnology with behavioral biology, these behaviors need to be described using the language and concepts of the latter discipline. This common language will allow the analysis of the evolution of behavior in deep time, such as the origin of cognition.It would be useful to adopttheframework ofBock and vonWahlert(1965), that distinguishesthe form and function of a structure from its biological role.We will discuss these conceptsin context of the known farming behavior of social insects and the range of activities, such as agonistic interactions, displayed by crayfish.

ASSESSING FORM-FUNCTION-ENVIRONMENT INTERACTIONS USING ECOMETRIC ANALYSIS OF FUNCTIONAL TRAITS

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The interactions between organisms and their environments are mediated by functional traits, whether those be the metabolic pathways needed to process oxygen or the tooth structures needed to process newly evolved seed types. Some traits have a functional relationship with the physical environment,

such as traits that provide insulation against cold temperatures, whereas others relate to the biotic environment, such as traits that provide protection from predators. A particular trait state will perform better in some contexts than in others, conferring a fitness advantage when the trait-environment match is good. The form-function-environment interaction can, therefore, influence both the evolution of traits within species lineages and the assembly of species into ecological communities. Quantitative analysis of functional trait distributions within and between ecological communities – or ecometrics –provides a useful framework for studying the response of morphological evolution to environmental change because it allows functional morphology, community ecology, and phylogenetic comparative methodology to be combined seamlessly.

In this talk I will present an example of how ecometrics can be applied by looking at turnover in locomotor traits in North American mammalian carnivores through the last half of the Cenozoic. This interval of Earth's history witnessed a massive decline in global temperatures, transformations of the terrestrial landscape by tectonic processes and the origins of new biomes, including open grasslands, tundra, and boreal forests. I will show that the distribution of locomotor traits in living carnivores is sorted by landscape-level features of topography and vegetation, that the sorting has a strong phylogenetic component, and that modern trait-environment distributions arose through a massive upheaval of trait evolution and clade sorting associated with the onset of Quaternary environments.

PALEONTOLOGY AND US NATIONAL MONUMENTS: WHY DOWNSIZING GRAND STAIRCASE ESCALANTE AND BEARS EARS IS BAD FOR SCIENCE

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In 2017, US President Trump shrank Grand Staircase-Escalante GSENM) and Bears Ears (BENM) national monuments, both in Utah, by 47% and 85% respectively. These monuments were established under the Antiquities Act to protect paleontological resources, but the Trump administration asserted that the same protection could be provided with smaller boundaries. The Society of Vertebrate Paleontology and other plaintiffs filed suit arguing that presidents lack constitutional authority to rescind protection and (2) that downsizing substantially weakened protection for paleontological sites. National monuments exist to protect specific historic, archaeological, or scientific objects. GSENM was established in 1996 to protect paleontological and geological resources, motivated by discoveries of unique Late Cretaceous mammals. Its original boundaries enclosed units from Permian through Cretaceous, all with "medium" to "high" potential for paleontological resources. Trump's reductions systematically excluded all of the Permian (including the type section of the Kaibab Fm.) and most of the Triassic and Jurassic sections. More than 700 scientifically important localities were excised, including many of the original Cretaceous mammal sites. BENM was established in 2016 to protect archaeological and Pennsylvanian through Cretaceous paleontological sites. The reduction systematically excluded the Paleozoic units, including important early tetrapod sites, and most of the Triassic sections, some of which were pilfered prior to monument protection. Verifiability is a key feature of the scientific process, and monument status ensured that sites were protected in perpetuity for reinvestigation by new generations of scientists. Despite the Paleontological Resources Preservation Act, sites in the excluded areas have considerably less protection, especially against mineral, oil, and gas extraction, than they did within the original monuments.

HAGERMAN'S PET DOG: CURRENT RESEARCH BY THE HAGERMAN PALEONTOLOGY, ENVIRONMENTS, AND TEPHROCHRONOLOGY PROJECT

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Hagerman Fossil Beds National Monument preserves a diverse fauna (~200 species) with several holotypes and perennial discoveries of scientific importance. A mosaic of lake, wetland, woodland, and grassland habitats can be inferred based on the composition of the Hagerman fauna. However, this faunal community dates from 4.2 to 3.17 Ma, spans 17.6 km^2 of deeply-incised gullies, and should not be considered synchronous or sympatric. Stratigraphic facies correlation and refined relative dating of fossil localities are needed if we are to separate out and recognize spatial-temporal variations in Hagerman's ancient communities and landscapes.

The Hagerman Paleontology, Environments, and

Tephrochronology (PET) Project is an interagency collaboration (National Park Service and United States Geological Survey) formed in 2017 to address these needs. The PET Project has increased chronostratigraphic control by identifying and tracing several otherwise discontinuous silicic and basaltic tephra across the monument using electron microprobe (EMP) and inductively coupled plasma-mass spectrometry (ICP-MS). This has also helped expand the lateral extent of previously dated ash beds, providing upper and lower date ranges for several important fossil specimens.

Our current focus is to date and reconstruct the environmental contexts of five fossil-rich areas, colloquially-named Otter, Peccary, Bear, Horse, and Dog. The Dog Area (DA) consists of a series of fossil-rich localities running across the eastern ridge and down the southern flank of a large bluff. Four discrete ash beds (one inferred, three mapped) intersect the slope at its base, midline (2), and upper ridge, providing potential for a well-resolved series of dates for the DA. Medially-located Bed G (932 m a.s.l.) is confirmed at 3.79 Ma and dates for other ashes are forthcoming. The DA is of interest because of the definitive presence of *Canis lepophagus*, a coyote-sized canid which joins the smaller *Canis ferox,and a* borophagine dog, *Borophagus hilli*, as the third canid and the 19th confirmed carnivoran known from Hagerman. The canid was recovered from a sandy blowout near the base of the slope (918 m a.s.l.) with an estimated approximate age of 4 Ma. This locality has produced in-situ fossils but also abuts a wash that may have transported specimens, including the canid, from above. Our current evidence implies that the canid originated above Bed G (and < 3.79 Ma) from a locality rich with other carnivoran taxa and with mat-forming diatoms and other fauna indicative of a shallow water wetland.

REDOX STATE OF THE MARINE NITROGEN CYCLE AND EVOLUTION OF EUKARYOTES DURING LATE NEOPROTEROZOIC

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The oxidation state of fixed nitrogen (N), a major limiting nutrient for marine primary production, is dictated by the ambient environmental redox conditions: in an anoxic ocean, inorganic N would be stable as ammonium, while in the presence of dissolved O_2 nitrate is stable. We have developed a method of determining nitrate content in carbonates, Carbonate Associated Nitrate (CAN), as a proxy for the oceanic nitrate content. To investigate changes in the global O_2 and marine nitrogen cycles through time, concentrations of CAN have been evaluated in both limestones and dolostones from multiple localities around the world, spanning the ages from ~3 Ga through modern. The highest CAN values were found as several distinct peaks in the late Neoproterozoic carbonates from two locations: Caborca in Sonora, Mexico, within a stratigraphic sequence deposited during the Ediacaran, and within the Rainstorm Member of the Johnnie Formation in the Death Valley, California, likely deposited at the onset of the Ediacaran Shuram $d^{13}C$ excursion. The $d^{15}N$ of nitrate in these rocks is consistent with oxidation of the pre-existing oceanic ammonium pool, perhaps driven by increasing pO_2 during this time. Transformation of fixed N from the reduced to the oxidized form (from ammonium to nitrate) may have caused a major restructuring of the global ocean N cycle, potentially contributing to the diversification of the eukaryotic phytoplankton, which were forced to adapt to nitrate instead of ammonium as the major nitrogen source.

HOW DO BIRDS EVOLVE IN RESPONSE TO CLIMATE CHANGE? DATA FROM THE LONG-TERM RECORD AT LA BREA TAR PITS

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Biology textbooks describe the small changes in the Galápagos finches as exemplars of how birds evolve and change in response to environmental changes. Yet recent studies of all the common birds (golden eagles, bald eagles, turkeys, teratorns, caracaras, condors, black vultures, Great Horned owls, barn owls) at La Brea tar pits finds no evidence of evolutionary responses to the dramatic climate changes of the last 35,000 years, including the last glacial-interglacial cycle. All of these birds showed complete stasis in body size and limb proportions, even during the peak glacial period about 18,000-20,000 years ago, when the chaparral vegetation now found at La Brea was replaced

by snowy coniferous forests. But these are all large birds with broad habitat preferences, capable of living in many different environments. Perhaps the smaller birds at La Brea, which have smaller home ranges and narrower habitats, might respond to climate more like Galapagos finches. The only three common small birds at La Brea are the Western Meadowlark, the Yellow-Billed Magpie, and the Raven, plus the robin-sized burrowing owl and the raven-sized long-eared owl. These birds also show complete stasis over the last glacial-interglacial cycle, with no statistically significant changes from one dated pit to another. Recent research suggests that the small-scale changes over short time scales seen in the Galápagos finches are merely fluctuations around a stable morphology, and rarely lead to long-term accumulation of changes or speciation. Instead, the prevalence of stasis strongly argues that speciation and lasting morphological change occurs only rarely in short time scales, and is only visible in long-term records of hundreds of thousands to millions of years.

CAN WE USE THE PAST TO SAVE THE FUTURE? TESTING THE PROJECTIVE POWER OF ECOLOGICAL NICHE MODELS USING THE PALEONTOLOGICAL RECORD

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Global warming has already had a profound effect on the distribution of modern species. Predicting how species will respond to a projected rise in global temperatures has become an integral part of conservation. Ecological niche models (ENMs) are the most common method for predicting a species' ecological distribution based on how a species' fundamental niche shifts due to climate change. The accuracy of these predictions can only be tested empirically with the passage of time. However, waiting for the passage of time puts at risk the very species that the predictions are trying to protect. The paleontological record permits testing of ENMs empirically in diverse ecosystems and over multiple time spans. Databases, such as the PBDB and Panama Paleontology Project, provides researchers with thousands of georeferenced presence data points which are corrected geographically for their age. Furthermore, recent advances in paleoclimatic reconstructions provide gridded paleoclimate data that are suitable inputs for ENMs. The mid-Pliocene (3.6 – 2.6 Ma), presents an excellent time period for testing the projecting power of ENMs for modern conservation purposes as the Pliocene experienced a warming event like that projected for the end of the 21st century. We tested the predictive quality of four commonly used presence-only ENMs (BioClim, GARP, Mahalanobis Distance, Maxent) by (A) projecting modern marine invertebrate niche spaces into the Pliocene and comparing the results to the known fossil occurrences; (B) projecting Pliocene niches into the present day and comparing the results to the modern occurrences; (C) comparing the spatial extent and suitability values of the predicted niches (those built using the occurrences within their respective periods) with the projected niches (those built in the opposite time period and then projected through time). We found that models which are based purely on the environmental conditions of the occurrences, BioClim and MD, had the lowest overall performance and that Maxent, a heuristic algorithm, outperformed all other models, both in predicting the taxon's occurrences within their own time periods, and when projecting through time. However, all models had low niche-similarity values indicating the projected niches were unable to mirror the spatial extent and distribution of the predicted niches, which is particularly problematic as it means projections through long-term climate change may be unable to predict the spatial distribution of a species or its niche correctly. Our results exhibit the applicability of the paleontological record for testing the projective accuracy of niche models. Given the models currently accessible, we advise modern conservationists to utilize machine learning algorithms when projecting the response of modern species to current climate change, and that more studies should test the accuracy of ENMs in predicting the spatial distribution of a species niche through long-term climate change.

REFINING ARTHROPOD EVOLUTIONARY HISTORY: INVESTIGATION OF AN UNDESCRIBED CRUSTACEAN-LIKE FOSSIL FROM THE WAUKESHA LAGERSTÄTTE, WISCONSIN

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The Brandon Bridge Formation of Waukesha, Wisconsin, USA, hosts a Konservat-Lagerstätte of distinctive Silurian soft-bodied organisms. This fossil assemblage lacks most of the shelly fauna typical of other Silurian biotas, thereby providing a unique record of

life not observed elsewhere. Although several unique specimens have already been documented, much of the Waukesha biota remains relatively unstudied.

Included in this assemblage are numerous specimens of a previously undescribed crustacean-like arthropod of unknown taxonomic affinity. Cursory analysis of these specimens suggests an affinity with either the Crustacean class Thylacocephala or Remipedia. Thylacocephalans, previously documented in the Brandon Bridge Fm., are known from the Lower Silurian to the Upper Cretaceous, though their range may extend into the Cambrian. Remipedes, on the other hand, have a poor fossil record extending only into the Carboniferous. Both thylacocephalans and remipedes, interpreted by some to have a sister-group relationship, are characterized by long, segmented trunks, three pairs of anterior raptorial appendages, and a suite of small posterior swimming appendages. Importantly, thylacocephalans are almost entirely enclosed in a bivalved carapace. Remipedes have no carapace, and, unlike other extant crustaceans, have only one trunk tagma.

Initial observations of the crustacean-like arthropods reveal two or three potentially raptorial head limbs, a carapace covering the head, and the presence of 2 tagmata, thereby rendering assignment to either Remipedia or Thylacocephala problematic. They may be thylacocephalans without a whole-body carapace, carapace-bearing remipedes, or a unique class of arthropods plausibly related to one or both groups. Further study using high resolution techniques is necessary to critically evaluate the taxonomy of these fossils, and better understand their relationship, if any, to thylacocephalans and remipedes. Here, we show mosaic electron microscopic images of entire specimens that allow for precise correlation of secondary and backscatter electron images to better identify morphological characteristics that may be difficult to see in either image alone. Detailed characterization of these likely unique presumed crustacean fossils adds to our understanding of the taphonomically and taxonomically unique Silurian Brandon Bridge Lagerstätte. Furthermore, this work has the potential to provide a better understanding of arthropod phylogeny, and, specifically, may elucidate the relationship between Thylacocephala and Remipedia.

IMPROVING THE TAXONOMIC ACCURACY AND PRECISION OF FOSSIL POLLEN IDENTIFICATIONS

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Taxonomic resolution is the greatest limitation of the fossil pollen and spore record – a data source of terrestrial vegetation that is otherwise unequaled in its geographic extent and abundance in the geologic record. The limited precision and accuracy of most fossil pollen identifications constrain the ecological and evolutionary inferences that can be made using palynological data.

We demonstrate that the low taxonomic resolution of fossil pollen data is a result of a reliance on (1) identification methods that are largely visual and qualitative and (2) microscopy techniques that do not capture the full range of morphological differences among pollen species. We demonstrate that by employing microscopes with higher optical resolution (optical superresolution) and machine learning tools such as convolutional neural networks (CNNs), we are able to substantially improve expert identifications.

We briefly present two examples. First, in the case of *Picea critchfieldii*, we use Apotome fluorescence microscopy and a patch-based matching machine learning methodology to distinguish the pollen of this extinct spruce from its extant congenerics. By doing so, we are able to reconstruct the Late Quaternary expansion and decline of populations of the extinct species for the first time. Second, in the case of *Striatopollis catatumbus*, we use optical superresolution microscopy and deep CNNs (ResNet) to create three classification models to determine the biological affinity of individual specimens of this pantropical morphospecies. By doing so, we are able to reconstruct the biogeographic expansion and Cenozoic diversification history of the Amherstieae legumes in both the Paleo- and Neotropics – again for the first time using fossil pollen.

Our results demonstrate the tremendous potential of these methods to broaden the ecological and evolutionary hypotheses that can be addressed with fossil pollen data in both Quaternary and deep-time palynological research. With *P. critchfieldii*, we demonstrate how improved taxonomic resolution allows us to identify cryptic extinction events. With *S. catatumbus*, we demonstrate the ecological and evolutionary diversity that had largely been ignored within a single pollen morphospecies. These two examples demonstrate the ecological and evolutionary turnover that is

largely missed in traditional analyses. By employing more sophisticated microscopy and analytical tools to fossil pollen analysis, we would be able to reconstruct a more complete history of past vegetation dynamics.

PRESERVATION AND MICROSTRUCTURES OF SMALL SHELLY FOSSILS FROM THE CAMBRIAN TERRENEUVIAN YANJIAHE FORMATION

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The small shelly fossils (SSFs) provide important evidence for the evolution of marine invertebrates and environments during the Ediacaran-Cambrian transition in particular biomineralization and skeletonization of early animals during the Cambrian explosion. However, most previous studies mainly focused on the morphological identification of fossils extracted from the host rock with weak acid. Such pretreatment, very common in micropaleontological research, resulted in the loss of important information in terms of the original biomineralization and/or the fossilization of the animals.

To understand the preservation and mcirosctructures of SSFs within host rocks, we performed a systematic study on the structural and chemical features of SSFs from millimeter scale to atomic level with various microscopic and microspectroscopic approaches. The nodule sample used in this study was collected from the Gunzi'ao section of the Yanjiahe Formation, which is located at the Sandouping Town, Yichang city, Hubei province, China. X-ray diffraction (XRD) analysis revealed that the host rock is composed of dominant phosphorite (~55%) and silica (~39%) and a small amount of carbonates. Micro-CT analyses revealed that the SSFs are stratified along the concentric layers of the phosphorite nodule. Optical microscopy observations on the thin and polished section samples showed that the SSFs are predominantly constructed by carbonate and phosphate minerals. Scanning electron microscopy (SEM) observations and energy dispersive X-ray spectroscopy (EDXS) analyses on the diamond-polished section samples demonstrated at least two different preservation patterns for SSFs: either preserved as phosphorite or dolomite (sometimes mixed with a small amount of calcite or phosphorite) in the shell wall, despite that both the inside and outside of the SSFs were filled with phosphorite and patched with calcite, dolomite, silica, and even barite. The structural, mineralogical and chemical features of SSFs were further investigated by the combination of Raman microscopy on the polished section samples, and transmission electron microscopy (TEM) and synchrotron-based scanning transmission X-ray microscopy (STXM) on FIB foils cut from the shell wall of the SSFs. The experimental results clearly showed the spatial relationship of different minerals within the shell wall and at the interface between the shell wall and the host rock, as well as the distribution and maturation of organic carbon associated with each mineral component. Together, this study provide a line of evidence for the fossilization and preservation of SSFs, i.e., dolomite might be the first mineral which replaced the original carbonate shell or precipitated within the shell wall, subsequently, some SSFs preserved by dolomite were further replaced by phosphorite during the formation of nodule. Calcite vein might invade the shell wall of SSFs at the later stage of nodule formation or slight late after that.

A PHYLOGENOMIC APPROACH ELUCIDATES THE DIVERSIFICATION OF SKELETAL TYPES IN THE CLASS ANTHOZOA (CNIDARIA)

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The anthozoan cnidarians (e.g., corals, sea anemones) are an ecologically important and diverse group of marine metazoans that occur from shallow to deep waters worldwide, and include some of the ocean's most important ecosystem engineers. Our understanding of the evolutionary relationships among the ~7500 species within this class is, however, deeply flawed. Molecular phylogenetic studies have revealed widespread homoplasy in morphological characters and widespread polyphyly at the ordinal, family, and genus levels. Resolution of both deep and shallow nodes in the anthozoan phylogeny has been hindered by a lack of phylogenetically informative markers that can be sequenced reliably across taxa whose divergence may pre-date the Cambrian. Therefore, we used available anthozoan genomes and transcriptomes to design a set of 16,306 target-capture baits for enriching both ultraconserved elements (720 loci) and exons (1071

loci). Target enrichment was conducted on 230 anthozoan species, representing all orders and a majority of families. Illumina sequencing of enriched genomes recovered 1,774 loci, with a mean of 889 ± 253 loci per species. Maximum likelihood analyses of a 917-locus dataset with 50% taxon occupancy yielded highly resolved trees. Divergence dating using 10 fossil calibrations indicated that major radiations of aragonite and calcite producing corals arose during times (~225 and 175 MYA) when seas favored those chemical conditions. Furthermore, the ancestral character type was absence of skeletal elements and multiple gains and losses of different skeletal types subsequently occurred throughout the clade. This study highlights the utility of a target-capture genomic approach to resolve evolutionary relationships of corals and their relatives while elucidating trait diversification throughout the clade.

RELAXED SELECTION ON TOOTH GENES SUGGESTS A TWO-STEP MODEL FOR TOOTH LOSS IN BALEEN WHALES

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The loss of teeth and evolution of baleen racks in Mysticeti were profound transformations that permitted baleen whales to radiate and diversify into a previously underutilized ecological niche of bulk filter-feeding on zooplankton and small fish. Ancestral reconstructions suggest that teeth were lost in the common ancestor of Mysticeti. Genomic studies provide some support for this hypothesis and suggest that the genetic toolkit for enamel production was inactivated in the common ancestor of living baleen whales. However, molecular studies to date have not provided direct evidence for dentin loss on the stem mysticete branch. Given these results, several questions remain unanswered: (1) Were teeth lost in a single step or did enamel loss precede dentin loss? (2) Was enamel lost early or late on the stem mysticete branch? (3) If enamel and dentin loss were decoupled in the ancestry of baleen whales, did dentin loss occur on the stem mysticete branch or independently in different crown mysticete lineages? To address these questions, we compiled and analyzed complete protein-coding sequences for eight tooth-specific genes from cetaceans with available genome data. Seven of these genes are enamel-specific (*ACP4*, *AMBN*, *AMEL*, *AMTN, ENAM*, *KLK4*, and *MMP20),* and one is related to dentin formation (*DSPP*). Our results indicate that all seven enamel genes have inactivating mutations that are scattered throughout Mysticeti. Two enamel genes (*ACP4* and *MMP20*) have inactivating mutations that are shared by all mysticetes. Dentin (*DSPP*) does not have any inactivating mutations that are shared by all mysticetes, but there are shared mutations in Balaenidae as well as Balaenopteroidea + Neobalaenidae. These shared mutations suggest that dentin was lost at most two times. Estimates of selection intensity on loci (via dN/dS analyses) and divergence times were used to reconstruct inactivation times of genes and, by proxy, phenotypes. These inactivation times suggest that enamel was lost early on the stem Mysticeti branch, whereas dentin was lost closer to the common ancestor of crown Mysticeti. Overall, these results are most compatible with a two-step model for loss of teeth in the ancestry of living baleen whales. These results further suggest that some stem mysticetes, or even crown mysticetes, may have vestigial teeth comprised of dentin with no enamel, an inference that can be tested with the discovery of additional stem mysticete fossils.

SPINAL NERVES, THE IMMUNE SYSTEM, AND EVOLUTION OF THE AVIAN TAIL

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The shortening and distal fusion of the tail were crucial morphological changes in avian evolution. The earliest birds with these changes were the founding members of the Pygostylia group; this group originated in the Early to Mid- Cretaceous and continues to this day. To better understand the biological events that led to modern avian tail morphology, we have followed tail development in different bird groups. Several interesting phenomena have emerged from these studies. During spinal nerve development, for example, we observe that emus form the initial dorsal and ventral roots to the very distal end of the tail, which differs from every other bird and reptile we have examined, including chicken, pigeon, quail, alligator, and lizard. Paleognath pygostyles tend to have potential exit foramina for spinal nerves, which appears to be a paleognath-specific feature. These findings lead to additional questions regarding the evolutionary

origins of paleognathous and neognathous birds. We have also observed nucleus pulposus structures in avian tails. This result is contrary to current literature that concluded nucleus pulposi only form in mammals. As in mammals, these avian structures are derived from the notochord, and upon notochord fragmentation, partition into the intervertebral disc spaces and become surrounded by layers of fibrocartilage. We are gathering evidence that nucleus pulposi are integral to the mechanism that causes distal vertebral fusion, and hence to the formation of the pygostyle. We hypothesize that heterophil-mediated removal of nucleus pulposus cells in the pygostyle sets off a chain of events that leads to ankylosis. The immune system, therefore, may be responsible for generation of an evolutionarily important morphological feature in birds.

THE MIDDLE ORDOVICIAN SHIFT IN THE STATE OF THE EARTH

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Ecosystem structures change rapidly on a planetary scale during major, climate induced transitions in the state of the Earth[1]. The Ordovician Period marks a particularly spectacular interval in Earth history where ecosystems were significantly altered. The Great Ordovician Biodiversification (GOBE) represents the largest and most sustained increase in marine biodiversity levels of the entire Phanerozoic and following this event was the Late Ordovician mass extinctions (LOME) – the second largest of the 'Big Five' with respect to taxonomical loss. Both events appear intimately linked to a cooling climate[2,5], but accepting this causal mechanism also implies that both of these major speciation and extinction phases should be controlled basically by the same determinant: cooling climate – something that seems counter-intuitive. However, several lines of evidence now indicate that the early Middle Ordovician (Darriwilian) experienced significant changes in several environmental conditions and that this paved the way for the main pulse of the GOBE[4]. The Darriwilian, therefore, may represent an Earth State change that allowed the carrying capacity of ecosystems to rise to a new level relative to the Cambrian–Early Ordovician world[3]. A main driver behind this may well have been cooling of the oceans to present-day levels, but what is important is that temperatures perhaps were too high for life to flourish and radiate prior to the Darriwilian. Late in the Ordovician increased dispersal and geographical expansion of species ranges caused biodiversity accumulation to fall through most of the Katian Age. Thus, onset of the Hirnantian icehouse during the final stages of the LOME caused temperatures to be too low to support the already stressed faunas.

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NEW INFORMATION ON THE MADAGASCAN MIDDLE JURASSIC SAUROPOD LAPPARENTOSAURUS MADAGASCARIENSIS: TOWARDS TO THE CETIOSAURIDAE CONFIRMATION

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The systematic position of the Middle Jurassic sauropod *Lapparentosaurus madagascariensis* is not fully understood due to a lack of useful anatomical detail. Despite many new bone fragments relating to the axial skeleton, post-cranial skeleton and hind limb having been unearthed, its systematic position has not yet been satisfactorily established. The lack of a complete skeleton, or even a skull with dentary, prevents a full systematic study. Although this Malagasy taxon is only recognised by two autapomorphies located in scapula and coracoid, the fragmented femur and neural spine, which are reported here, provide additional details on the common autapomorphies shared with the British genus *Cetiosaurus*. A full description of the femur and neural spine helps to determine some aspects of its relationship to other similar taxa. Remains of *Lapparentosaurus madagascariensis* has been recovered from mixed facies that may have been deposited in a in a shallow water lagoon during a transgressive period in the Isallo IIIb subunit in the Majunga Basin.

Keywords: Sauropod; autapomorphy; Cetiosauridae; Brachiosauridae; Bathonian; Isalo; Majunga

EVOLUTIONARY RATES AT HIGH LATITUDES AND THE EQUATOR DURING THE LATE PALEOZOIC ICE AGE

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Because biostratigraphic zonations reflect evolutionary rates, the average duration of biozones enables comparison of evolutionary rates across intervals of climate change. With the onset of the Late Paleozoic Ice Age (LPIA) at the Mississippian/Pennsylvanian boundary, high-latitude climate became colder as equatorial climate became wetter, and possibly warmer. Global regression at the Mississippian/Pennsylvanian boundary marks the appearance of significant Southern Hemisphere glaciation. Evidence of Northern Hemisphere glaciation during the LPIA remains equivocal. However, brachiopod migrations away from the North Pole at the Mississippian/Pennsylvanian boundary indicate that the high latitudes of the Northern Hemisphere became cooler during the LPIA.

A comparison of the average duration of paleoequatorial biozones across the Mississippian/Pennsylvanian boundary suggests that equatorial evolutionary rates were faster during the LPIA. The number of marine and terrestrial plant biozones increased from the Mississippian to the Pennsylvanian, and their average duration decreased. For example, the number of conodont biozones increased from 17, with an average duration 2.1 my per zone, in the Mississppian to 21, with an average duration 1.2 my, in the Pennsylvanian. Land plant biozones increased from 4, with an average duration of 8.9 my per zone, in the Mississippian to 10, with an average duration of 2.4 my per zone, in the Pennsylvanian. Foraminifera, ammonites and spore-pollen biozonations for the Mississippian and Pennsylvanian show a similar pattern. Evolutionary rates, as reflected by biozone duration, were much faster in the Pennsylvanian than in the Mississippian. The average duration of Permian equatorial biozones remained short, although glaciation may have ended by the middle Permian. However, the average duration of equatorial biozones varied markedly during the Permian. For conodonts, early and late Permian biozones had very short average durations (0.62 my/zone); however, mid-Permian conodont biozones had long average durations (2.8 my/zone).

Comparisons of the average duration of LPIA biozones in high (Siberia and Mongolia, Australia) and equatorial (North American midcontinent, Europe, South China) latitudes suggest a steep latitudinal gradient in evolutionary rates. The number of Pennsylvanian spore-pollen biozones dropped from 10 at the paleoequator (av. duration 2.4 my) respectively to, 3 on the Siberian Platform at ~60°N paleolatitude, and 2 in Australia, which lay at ~ 60°S paleolatitude. These high-latitude biozones had average durations of 8 - 12 my. High-latitude assemblages from Siberia and Australia are well studied: the observed latitudinal gradient in biozone length does not result from lack of knowledge. Changes in sea-level and climate, driven by glacial-eustacy, or warmth could contribute to rapid evolutionary rates at the equator relative to high latitudes during the LPIA.

COMMUNITY CHANGES DURING TIMES OF OROGENY; EXAMPLES FROM THE UPPER DEVONIAN OF PENNSYLVANIA

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The Devonian period (416–358 mya) is a time of major diversification, especially in brachiopods, mollusks, and bryozoans. This diversification is thought to have been driven by numerous, often inter-related processes surrounding mountain building events and global cooling. In order to understand how taxa developed during this time, museum specimens collected from the Upper Devonian strata (382.7–358.9 mya) of Pennsylvania were analyzed. The fossils used come from the Harrell, Trimmers Rock, Brallier, Lock Haven, Catskill, Foreknobs, Chadakoin, Venango, Oswayo, Knapp, and Riceville Formations. Specimens analyzed consisted of brachiopods, mollusks, bryozoans, and cnidarians. Museum specimens were augmented with data from the Paleobiology Database to create simple network diagrams using 'Big Data' analytics (network analysis). This work aims to facilitate a better understanding of the relationship between community scale changes in paleoecology and Earth systems.

OREGON HAS TWO DINOSAURS

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Before October 2018, there were no confirmed dinosaurs from the state of Oregon, but by the end of that month there were two, both on public lands. One of these is a toe bone of a large (5.1 m long and 678 kg live weight) ornithopod from BLM land near

Mitchell, Oregon, found by Greg Retallack. Associated ammonites give a very precise age of about 103 Ma (early Albian, Early Cretaceous), and also indicate that it was from a disintegrating carcass that drifted out into the ocean. The Mitchell ornithopod is a pedal phalanx lacking collateral pits and girdling sulcus of most dinosaur toe bones, but has lateral lappet basins like large ornithopod dinosaurs. The age of the Oregon toe bone is between that of well-known *Tenontosaurus* and *Eolambia* from Utah and Wyoming. Associated fossil plants in the same marine shales are evidence of a coastal redwood forest like that of modern Redwoods National Park. A further similarity with Northern California today, are the gravelly sediments of shingle beaches and alluvial fans from nearby sea cliffs.

A second report published in October was a sacrum of an equally large ornithopod from marine sandstone of Cape Sebastian State Park, found along with ammonites and inoceramids dated to about 74 Ma (late Campanian, Late Cretaceous). This specimen was first discovered in 1969 by Don Savage of Berkeley, and collected in 1994 by David Taylor, but preparation from its very hard matrix was completed recently. It has eight co-ossified vertebrae, an undulose iliac bar, and tall strut-like sacral ribs fused centrally to the centra. The most similar known sacra are those of hadrosaurine duckbills of the genus *Kritosaurus*. Associated fossil leaves are evidence of broadleaf forest flanking shallow marine or shore-face sandstones of a low gradient coastal plain. Both fossils were rare finds, unlikely to be repeated and required no special management plan, but were facilitated by welcome flexibility from governing agencies.

OSTEOHISTOLOGICAL GROWTH CURVE RECONSTRUCTION IN *SMILODON FATALIS*

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Osteohistology is increasingly being used to infer the life history of fossil vertebrates by reconstructing growth curves using lines of arrested growth (LAGs) deposited in the cortices of long bones. While osteohistological studies on archosaurs are common, similar studies on fossil mammals are relatively rare, and there has never been a growth curve computed for any extinct carnivoran species. A comprehensive osteohistological analysis of life history in a species requires a large sample that includes multiple ontogenetic stages, which is rarely available for large mammalian carnivores. Such a sample does, however, exist at the Rancho La Brea (RLB) asphalt seeps in Los Angeles, California, which is dominated by large mammalian carnivores including the dire wolf (*Canis dirus*) and the saber-toothed cat (*Smilodon fatalis*). Thus, the specimens collected from RLB provide an incredible opportunity to study the life history of large extinct carnivorous mammals. In this study, we use thin sections taken from the femora of *S. fatalis* to reconstruct a growth curve for the species and compare this growth curve with those for extant big cats including the lion (*Panthera leo*) and tiger (*P. tigris*).

Primary bone tissue throughout the cortex in juveniles (specimens with no epiphyseal fusion) and in the inner- to mid-cortex of adults (specimens with epiphyseal fusion), where visible, is composed of woven-fibered bone with primary osteons. In adults, the outer cortex is composed of lamellar bone. Vascular canals are typically longitudinally oriented. Bone remodelling appears to begin early in ontogeny and secondary osteons are found in all individuals, with the density of Haversian systems increasing with age. Femora classified as juvenile do not have more than two LAGs preserved and adults have a variable number of growth marks; any specimen with three or more preserved LAGs is included in a growth curve reconstruction using a mixed-effects process-error Richards growth model. The inflection point for the resultant growth curve occurs between 0.5 - 1.5 years of age and the asymptotic body mass ranges from 160 – 255 kg. Growth was rapid until the animal was about three years old and asymptotic body mass was reached by six years of age, which is similar to the age at which male *P. leo*reach that asymptote. Comparatively, asymptotic body mass in*P. tigris* is reached shortly after two years of age. This delayed maturation may be a sign of gregarious social behavior in the saber-toothed cat. Overall, this study has produced the first growth curve for any fossil carnivoran, and the methods used provide a framework within which the evolution of life history strategies in felids can be examined.

LAYING THE GROUNDWORK FOR UTILIZING ISOTOPES TO UNDERSTAND REPTILIAN RESPONSE TO CLIMATE CHANGE

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Climate change, habitat loss, and the introduction of invasive species are imperiling Earth's ecosystems. In

response to these and other pressures, many herpetofauna are facing global population declines, although the responses of different species are not equal. The fossil record can provide a deeper historical context to better understand species responses to current and future environmental change. Stable isotope analysis, in particular, can be used to understand the habitat use, diet, movement and life-history of extinct animals. Unfortunately, stable isotopic studies on squamate reptiles are rare for both modern and fossil taxa, with one contributing factor being the lack of foundational research measuring the fractionation of isotopes between tissues.

The few studies addressing fractionation of carbon and nitrogen isotopes in lizards examine blood, skin, muscle, and scat, but do not include bone collagen or combination tissues, which are necessary or desirable for paleontological and ecological studies. Here we report $\delta^{13}C$ and $\delta^{15}N$ values of muscle, bone collagen, and tail and toe clippings of 10 captive *Uta stansburiana* specimens. The $\delta^{13}C$ values differ significantly among the four tissue types (ANOVA, $F(3,36)=12.59$, $p < 0.001$). A post-hoc Tukey test indicates that mean $\delta^{13}C$ of toe clippings (-20.2‰), collagen (-19.3‰), and muscle (-21.3‰) all differ significantly, while values of tail (-20.1‰) and toe clippings do not. Tail clippings and collagen were also not significantly different. There is no significant difference in $\delta^{15}N$ values among any of these tissues. (ANOVA, $F(3,36)= 0.535$, $p>0.05$). Continuing work will add specimens of wild *Podarcis siculus* and diet samples, to allow estimation of critical diet-tissue fractionations.

CLADE-WIDE POPULATION DYNAMICS OF MODERN PLANKTONIC FORAMINIFERA SHOW NO EVIDENCE OF COMPETITION AMONG SPECIES

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Many clades display the macroevolutionary patterı of a negative relationship between standing levels o diversity and diversification rates. Competition among species has been proposed as the main mechanism that explains this pattern. However, we currently lack empirical insight into how the effects of individual-level ecological interactions scale up to affect clade dynamics. Here we investigate the planktonic Foraminifera clade, which has shown evidence for negative diversity-dependent diversification in their Cenozoic fossil record, and test whether the clade's modern communities are regulated by interspecific competition. We explore two community-level patterns expected under interspecific competition: (i) local competitive exclusion (spatial pattern) and (ii) compensatory dynamics (temporal pattern). By combining species relative abundances in seafloor sediments and a community phylogenetics approach, we test for signs of local competitive exclusion among ecologically similar species (defined as closely related or of similar shell sizes). Using sediment-trap time series spanning from one to 12 years, we analyse whether population abundances of co-occurring species co-vary negatively through time. The great majority of our seafloor assemblages show no significant co-occurrence patterns regarding phylogeny or shell size, and are indistinguishable from randomly assembled communities (spatial pattern). Regarding the temporal dynamics, most species pairs correlated positively through time, indicating synchronous population dynamics instead of compensatory dynamics. We found no evidence for interspecific competition structuring extant planktonic Foraminifera communities. Neutral processes seem to dominate how these communities are assembled, and population dynamics are likely regulated by the abiotic environment and phytoplankton dynamics, rather than intra-clade density dependent processes. Our findings indicate that the mechanisms underlying community dynamics of extant planktonic Foraminifera are not consistent with the mechanisms proposed to explain the patterns observed in their fossil record. To bring community ecology and macroevolution closer together, we need to consider defining the species pool of macroevolutionary dynamics ecologically rather than only phylogenetically.

SQUID OR FALCON? EVALUATING CONVERGENT EVOLUTION IN BEAKS OF CEPHALOPODS AND BIRDS

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The beak of a Giant Squid (*Architeuthis dux*) is strikingly similar to the bill of a Peregrine Falcon (*Falco peregrinus*), despite their half-billion years of evolutionary separation. It is tempting to apply

conclusions from biomechanics research on bird bills, and interpretations of long-term selective pressures on bill shape, to beak evolution in cephalopods. First, however, it is necessary to determine if cephalopod beak evolution compliments the overarching patterns observed in bird bills. I here present a first-order analysis of geometric morphometrics on extant species.

Emerging research on bird bills presents three hypotheses applicable to cephalopods. 1) Beak shape spans between pointy and blunt; accordingly, multivariate analyses will reiterate analyses of linear measures. 2) Beak shape will covary with supporting structural elements. 3) Size will explain the majority of beak shape variation within cephalopods (or sub clades). To produce the geometric data, I captured RGB images from specimens in published diagnostic monographs and 3D scan repositories, then applied landmarks in FIJI. The cephalopod beaks (65 species) are predominantly from Southern Ocean fauna (54 squid species, 8 pelagic octopus species). For birds, I considered only the upper rostra of whole prepared skulls (25 species). I formatted the data in R and produced principal components analyses (PCA) using packages *shapes* and *geomorph*.

Results support the first two hypothesis and reject the third. Distinct shapespace is occupied by bird rostra, squid beaks, and octopus beaks. When only the bite surface is examined, bird bills are indistinguishable from squid beaks, but octopus beaks remain distinct from both groups. Of cephalopods, octopus beaks resemble bird bill aspect ratio, while squid beaks resemble the bill bite surface. Of the bird clades, falcon rostra are more similar to squid beaks, and parrot rostra more similar to octopus beaks. In all analyses, *Nautilus*, *Vampyroteuthis*, and *Architeuthis* occur near the center of generated morphospace. Squid beaks extend into distal morphospace via overlap of specimens from 22 different families. Beak size does not predict morphospace consistently across cephalopods, or subclades (via orders, families, or published genetic phylogenies), even when analyses target specifically ontogenetic trajectories (10 species), or are limited to only cephalopods, squid, or single beak elements (upper or lower).

Overall, the results demonstrate profound convergent evolution in the shape of cephalopod beaks and bird bills. Initial results reject the hypothesis that cephalopod beaks paralleled evolutionary pathways interpreted for bird bills (paedomorphism; size-selection in feeding mode). These results highlight the need for greater scrutiny of the biomechanical properties of cephalopod beaks; of associations between cephalopod beak shape and diet; and of change in cephalopod beak shape over their extensive fossil history.

DENTAL MICROWEAR OF NORTH AMERICAN TAENIOLABIDOID MULTITUBERCULATES INDICATES NICHE EXPANSION AFTER THE END-CRETACEOUS MASS EXTINCTION

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Multituberculates, an order of non-therian mammals, were among the most taxonomically diverse mammals of the Mesozoic and early Cenozoic and comprise the longest-lived mammalian clade. One clade of multituberculates, the Taeniolabidoidea, are notable for their early Paleogene radiation following the end-Cretaceous mass extinction and for being the large largest-bodied multituberculates currently known. Although most multituberculates are considered to have been omnivorous or insectivorous, the taeniolabidoids are characterized by a suite of dental adaptations that suggests a primarily herbivorous diet. Furthermore, recent work employing orientation patch count analysis (OPC), a measure of dental complexity, has confirmed that at least some of the larger taeniolabidoids may have been herbivorous. While dental complexity measures such as OPC are useful, they require three-dimensional dental reconstructions that can be difficult to obtain. An alternative approach is the study of dental microwear, which has been frequently used as a proxy for the diets of extinct animals. Dental microwear is microscopic damage done to teeth. Microwear analyses examine the patterns of pits and scratches on the surface of a tooth to infer the physical properties of food items. We examined the dentitions of taeniolabidoids to determine whether microwear could be used to detect herbivory in multituberculates. Most North American taeniolabidoids (*Taeniolabis taoensis*, *Catopsalis calgariensis, Catopsalis fissidens, Catopsalis alexanderi, Valenopsalis joyneri, Catopsalis kakwa*) were included in the analysis, and some North American non-taeniolabidoids (*Meniscoessus major, Meniscoessus robustus, Mesodma* sp., *Ptilodus* sp., *Cimolomys* sp., and an undescribed large cimolomyid) were included for outgroup comparisons. Microwear was collected from molar cusps.

All cusps with microwear were included, regardless of their position in the cusp row. Because of the small size of the teeth, scanning electron microscopy (SEM) was used to capture high-resolution images of the microwear. Two 0.1 x 0.1 mm regions of interest were circumscribed on each image, and microwear was categorized based on coarse and fine scratches, large and small pits, and gouges. A preliminary analysis indicates that the taeniolabidoid molars have relatively larger microwear features and a relatively low ratio of scratches to pits, suggesting that the taeniolabidoids and non-taeniolabidoids had different diets. The prevalence of pits and large features on the taeniolabidoid molars is an indication that the taeniolabidoids were consuming more resistant food items. These results demonstrate that microwear analysis may be able to lend new insights into how multituberculates responded to environmental changes following the end-Cretaceous mass extinction, adding to our understanding of niche expansion and the evolution of herbivory in non-therian mammals.

THE ROLE OF LIBERATION LAGERSTÄTTEN AS WINDOWS INTO PAST BIODIVERSITY

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Many conservation lagerstätten feature excellent fossil preservation, but the environmental conditions responsible for the preservation, such as anoxia or hypersalinity, are often not favorable for highly diverse communities. Concentration lagerstätten contain abundant fossils that are commonly not well preserved, which inhibits taxon identification. There are fossil occurrences that feature both very good preservation and are not necessarily characterized by an impoverished ecosystem. These neither qualify as conservation nor as concentration lagerstätten. We assign these to a new type of fossil lagerstätten, *liberation lagerstätten*. Liberation lagerstätten are defined by fossiliferous sediments, from which three-dimensionally preserved macrofossils can be easily extracted. Many feature a low grade of lithification and good preservation of fossils. Silicified faunas in limestones are a special case of liberation lagerstätten. Fossils can be liberated using weak acids, and preservation is excellent.

Examples of liberation lagerstätten are the Carboniferous Finis Shale, the Permian Word Formation, the Late Triassic Cassian Formation, and the Cretaceous White Chalk of Rügen and Ripley, Owl Creek, and Coffee Sand Formations. The Cassian Formation (Dolomites, Northern Italy) stands out among the most diverse formations and well-known lagerstätten. It features the highest species richness of any spatially constrained pre-Quaternary formation reported until now. Using data from the literature and own samples, we report a total of 1429 species of animals (1421 invertebrate species). Molluscs comprise 67 % of all invertebrates, with gastropods being most diverse (39 %) and bivalves (21 %) in second place. The Cassian proportion of gastropods is unusually high for the Mesozoic and nearly on par with recent tropical environments.

Liberation lagerstätten from poorly lithified sedimentary rocks typify a Cenozoic-style preservation, which is especially supportive for mollusc preservation, including that of small gastropods. Many liberation lagerstätten yield highly diverse fossil assemblages with a large proportion of gastropods. This sheds light on the role of gastropods in past ecosystems. We suggest that the increase in the proportion of gastropods among faunal assemblages through time is partly due to preservational effects and that liberation lagerstätten like the Cassian Formation provide a glimpse into biologically meaningful clade proportions among the skeletal fauna.

THE "BAKEVELLIIDAE SEA" OF THE ROMUALDO FORMATION: A SHORT-LIVED APTIAN MARINE INGRESSION IN THE NORTHEASTERN BRAZIL

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The Araripe Basin is an interior rift basin in the northeastern Brazil, generated in response to the late Jurassic-early Cretaceous Gondwana break-up. The basin is filled with a ~1400-m-thick succession of mainly siliciclastic Mesozoic (Jurassic–Cretaceous) rocks, encompassing the pre-rift (Late Jurassic), syn-rift (Early Cretaceous), and post-rift (Early to Late Cretaceous) megasequences. The basal part of the post-rift megasequence includes the deposits of the Santana Group (i.e., Barbalha, Crato, Ipubi, and Romualdo formations), recording marine pulses in the Araripe Basin. The youngest short-lived marine episode is in the uppermost part of the Romualdo Formation. However, interpretation of this event is largely based on the occurrence of some marine benthic invertebrates (e.g., irregular echinoids and certain gastropods taxa). Herein, we mapped shell-rich concentrations at the top of the Romualdo Formation and those can be dominated by bakevelliid bivalves, another important fully marine faunal element in this interval.Bakevelliids are an extinct group of epi- or endobyssate pteriomorphians with an extensive biogeographical distribution in Mesozoic marine successions. Preliminary morphological analysis of nearly 440 specimens indicate that at least three species of bakevelliid could be present, one of them securely belonging to the genus *Bakevellia* King, 1848. Taphonomic and autoecologic data suggest that both epibyssate, on hard (shelly) substrates, and endobyssate, semi-infaunal modes of life are probably present. In at least two localities (Sobradinho, Ceará State and Caldeirão Grande, Piauí State), cm-thick transgressive carbonates preserved bakevelliids *in situ*, suggesting the episodic burial of living populations by high energy events, below storm wave base. Contrary of echinoid-bearing limestones, which are mainly recorded in the western margin of the Araripe Basin, the bakevelliid-rich carbonates were found in all basin margins. This indicates that fully oxygenated, marine waters flooded the whole Araripe Basin (= the bakevelliid sea) at that time. In the northeastern Brazil, bakevelliids are also known in the Aptian-Albian strata of the Riachuelo Formation, Sergipe-Alagoas Basin, been another convincing paleontological evidence for an interior marine seaway entering the Araripe Basin from the south through the Recôncavo, Tucano, and Jatobá basins, as supported by stratigraphic evidences. Finally, in the Sobradinho section, which occupies the deeper and more offshore position among all studied geological sections, the bakevelliid-bearing limestones are recovered by regressive siltstones with carbonized plant debris marking the end of the bakevelliid sea in the Araripe Basin.

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SEDIMENTARY DYNAMICS OF AN INTERNALLY COMPLEX BAKEVELLIID-DOMINATED SHELL BED: EVENT CONDENSATION AND TAPHONOMIC FEEDBACK IN MUDDY BOTTOMS

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Dense, shell-rich concentrations are among the most difficult subjects in paleoecological-oriented studies, owing to their complex sedimentological, taphonomic and biological histories. Herein, the taphonomic history of a 90-cm-thick, complex bakevelliid-bearing shell concentration from the Aptian Romualdo Formation, Araripe Basin, Brazil, is disentangled. The studied concentration occurs at the Sobradinho section, Ceará State, southeastern margin of the basin, in the upper part of the Romualdo Formation. This bakevelliid-rich concentration offers a good opportunity to study small-scale, bed-by-bed processes of sedimentation, which can influence benthic colonization and faunal changes in muddy bottoms. The internal complexity is expressed in the: (1) subdivision of single cm-thick, shell-rich layers by discontinuity surfaces, (2) mixture of shells with different taphonomic signatures/pathways, and (3) mixture of mollusk species from different sub-environments. Based on sedimentologic/

petrographic, taphonomic and paleoecologic attributes, at least five microstratigraphic units (MUs) were recognized, each one separated by thin layers of silty shale with irregular boundaries. Each individual MU records increasing energy levels upwards. Development of the bakevelliid shell concentration started (MU-1) with interbedded wackestones, packstones, and grainstones with fragmented and chaotically-oriented shells (few bakevelliids, cassiopids, epitoniids, and undetermined remains). These are overlain by lime mudstones and gastropod-bearing wackestones with chaotically arranged and highly fragmented shells (MU-2). This is succeeded by fine interbeds of packstones, mudstones and shell concentrations with highly fragmented undetermined bivalve shells and few large-size gastropods (cassiopids and undetermined ones) (MU-3). Up in the succession, packstones occur with wackestones, mudstones and grainstones, characterized by abundant terrigenous material and by highly fragmented bivalve shells (MU-4). At the top of MU-4, bivalves with closed articulated valves are also recorded. At the very top of the concentration, a 15-cm-thick succession of shell concentrations interbedded with bivalve-rich packstones is present (MU-5). Thisunit is dominated by predominantly disarticulated, non-fragmented bakevelliid shells, oriented parallel to bedding (shell pavement). Immediately above, closed articulated bakevelliids are preserved in growth position, recording a mainly physically-driven in situ taphonomic feedback. The in situ shells are covered by sandstones with hummocky cross-stratification, indicating that living bakevelliids were abruptly buried by rapidly deposited sand, probably by storm-induced processes.

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EVALUATION OF THE ECOSYSTEMS OF THE WESTERN MEDITERRANEAN THROUGH PALEOECOLOGICAL STUDIES

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Over time, the plant landscape has changed as a result of the numerous events on a global and local scale that have happened. This is the case of the Mediterranean ecosystems (one of the most complex and rich in endemisms on the planet), subjected to anthropic pressures from the beginning of civilizations. The intervention in these systems together with climate changes, has led to changes in diversity, tree cover, shrub, and ultimately in the structure and functioning of these ecosystems.

Paleopalinology is used as a tool for analyzing pollen and non-pollen microfossils preserved in the flooded grasslands of the Middle Atlas (Morocco). This allows reconstructing the evolution of vegetation and climate, as well as providing data and reasoning to different ecological, cultural and historical processes. Although climatic and anthropic events are well documented in Europe, they are not so well documented in North Africa, which gives added value to the study area.

The results obtained serve to predict the behavior and evolution of Mediterranean mountain ecosystems during the Holocene, their response to future changes, resilience and recovery from climatic and anthropic disturbances. In the stratigraphic series analyzed, nine major events were detected, eight of which appeared to be of climatic and anthropic origin, and one unexpected, related to volcanic activity.

THE EMERGENCE AND ECOLOGICAL STABILITY OF GEOLOGICALLY PERSISTENT PALEOCOMMUNITIES

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The emergence of an ecological community in evolutionary time is the result of species evolution and coevolution. In species rich and functionally diverse communities, there are a multitude of alternative pathways along which emergence could proceed. Nevertheless, analysis of alternative pathways for paleocommunities spanning more than 13 million years of the Permian-Triassic of the Karoo Basin of South Africa, suggests that pathways actually taken represent a small subset of the total available. This leads to a narrow representation of the total number of communities possible given a specific number of species and level of functional diversity. Furthermore, the paleocommunities were always superior to structural alternatives of equal complexity, in terms of community global stability (the number of species that can coexist stably and indefinitely). Such optimization could indicate a selective process during the formation of types of communities, or simply be emergent from the

coevolutionary framework. Here we present ongoing work to support an emergent process by which many alternative types of communities may form constantly on ecological timescales, but where few are stable and persistent on longer timescales. This leads to the compositional stability of paleoecological units often noted in the fossil record, and the apparent incumbency of long-lasting lineages. The aftermath of mass extinctions present opportunities to test this hypothesis, because previously persistent communities are replaced by newly emergent ones, and the emergence process itself can be extended to geological timescales because of ongoing environmental instability, and the time required for the reformation of coevolutionary relationships and functional structures. Such is the case in the aftermath of the Permian-Triassic mass extinction, when Early Triassic paleocommunities in the Karoo Basin were sub-optimal compared to alternative, hypothetical histories.

Understanding long-term ecological persistence is crucial to our understanding of the modern anthropogenically-driven environmental crisis. Modern ecosystems are the documented products of geological and evolutionary history. Species acclimatization and adaptation to ongoing changes are not necessarily guarantees of the future persistence of the resulting reorganized systems. It will become critical to determine if the biosphere has already turned down new ecological and evolutionary pathways, or is still operating in the capacity of the pre-Anthropocene system.

MORPHOLOGICAL ANALYSIS OF ENIGMATIC ARTHROPODS OF THE SILURIAN WAUKESHA LAGERSTÄTTE, WI

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The Waukesha Lagerstätte is an early Silurian fossil deposit found in the Brandon Bridge Formation, which may be found in Wisconsin and Illinois, although exceptional fossils are known only from Waukesha and Milwaukee, WI. Samples come from a finely laminated mudstone and dolomite in the lower portion of the formation. Fossiliferous bedding planes are thought to be large accumulations of arthropod molts within sediment traps. Despite the abundance and quality of the fossils of the Waukesha biota, there is still much worked needed to classify the array of taxa. Among these are a group of enigmatic arthropods that resemble Marrellamorpha—at least superficially. Marrellamorpha, named after its original member *Marrella splendens* Walcott, 1912, from the Cambrian-age Burgess Shale Lagerstätte, is a small class of Paleozoic arthropods including *Furca bohemica* Fritsch, 1908 (Ordovician), *Mimetaster hexagonalis* Gürich, 1931 (Devonian), *Vachonisia rogeri* Lehmann, 1955 (Devonian), and *Xylokorys chledophilia* Siveter et al., 2007 (Silurian). To better determine the taxonomic placement of these Waukesha arthropods, samples were photographed using varying light angles and features were traced using Affinity Photo and Affinity Designer. The defining characters of Marrellamorpha from Rak et al. (2013) were used to evaluate if these sample are marrellamorphs. These characters include longer cephalic exopods, the possession of rounded endopod endites, multisegmented trunk exopods, a truck with more than 25 segments, and medially-directed, filamentous exopod setae on each podomere. Our investigations have revealed an organism with one pair of short, stout antennae, and a 9-11 segmented trunk, with most trunk somites bearing short pleurites and a short pair of legs with setae. Thus, the taxon likely does not belong to the Marellamorpha, and alternate taxonomic placements are considered.

VIRTUAL FIELDWORK EXPERIENCES FOR ONLINE EXPLORATION OF CENOZOIC PACIFIC COAST FOSSIL LOCALITIES FOR THE EPICC PROJECT

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Virtual fieldwork experiences (VFEs) are being created for four important paleontological sites along the western coast of the US as part of the educational outreach associated with EPICC (Eastern Pacific Invertebrate Communities of the Cenozoic) project. Virtual fieldwork experiences allow visual exploration of sites for those who cannot visit physically, engaging audiences in the physical features of an area through the eyes of a geoscientist. They can also be of scientific and educational value for those documenting sites. VFEs generally offer some combination of gigapixel-resolution images, panoramas, 3D imagery, and video taken at the site, and may also integrate research collections and microscope images, together with other data. They integrate imagery and data at the sites with other data such as maps and models.

Example imagery in a typical EPICC VFE includes identifying large structural features at continental,

regional, and local scales and zooming in on representative fossils and sedimentary structures at the outcrop scale. EPICC VFEs also highlight the importance of paleontology and research collections in contributing solutions to 21st century societal issues.

The EPICC VFE sites include: 1) the Kettleman Hills near Coalinga in central California (completed); 2) outcrops of the Purisima Formation along the California coast (completed); 3) Pleistocene terraces in southern California (in draft form); and 4) the Astoria Formation of Oregon (forthcoming). Some of these sites are difficult to access or being lost to development.

Each EPICC VFE is divided into modules, such as "Explore Landscapes", "Explore Sediments", "Explore Fossils", "Field to Museum", and "What is a Fossil?" Learners of any background could use the VFE imagery to explore the sites, but the text and supporting guides are designed particularly for secondary school teachers and students. Driving questions within the modules helps to make NGSS connections and better illustrate NGSS Crosscutting Concepts. A glossary helps to provide geological and paleontological definitions. The "For Educators" part of the EPICC VFE website also contains "Conceptual tools" and "Technical tools" on the pedagogy and technology of making VFEs. The EPICC VFEs can be visited at https://epiccvfe.berkeley.edu.

THE EXAMINATION AND PLACEMENT OF A NEW SPECIMEN IN ALLIGATORINE EVOLUTIONARY HISTORY

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Extant *Alligator* comprises two species – the American (*A. mississippiensis*) and Chinese (*A. sinensis*) alligators, but it has a fossil record extending back to the late Eocene. Nevertheless, a gap separates *Alligator* from its closest published relative in the late Paleocene *(Wannaganosuchus brachymanus)*, which like other early Paleogene alligatorines was very small (≤ 2 m), short snouted, and with adaptations for durophagy, such as a robust palate and enlarged distal maxillary and dentary teeth. Here, we describe a new species from the middle Eocene (Uintan NALMA) Uinta Formation of Utah that fills the stratigraphic gap and represents an intermediate form between earlier durophagous alligatorines and more generalized modern species. It resembles earlier alligatorines in many ways – its snout was comparatively short, its suborbital fenestrae were relatively small, its narial chamber was not inflated, and its orbital margins were not upturned – but it lacks the enlarged cheek teeth that characterized earlier alligatorines. The nasals project into the narial space, but do not completely subdivide the naris. A phylogenetic analysis recovers the new Uintan form as the sister lineage to *Alligator*. The living American alligator is an ecological generalist, but it arose from more specialized ancestors; the transition from specialist to generalist largely occurred after generalized crocodyloids disappeared from North America, suggesting that it was in response to niche availability, but the new form co-occurred with some of these crocodyloids, suggesting that the transition was already underway before the sharp contraction of crocodylian diversity in the northern continents after the middle Eocene.

PREHISTORIC BODY THEATER: BRINGING PALEONTOLOGY NARRATIVES TO GLOBAL CONTEMPORARY PERFORMANCE AUDIENCES

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Sixty-six million years ago, a massive asteroid struck the Earth with the force of a billion atomic bombs. The ensuing apocalyptic extinction, which ended the 150+ million year reign of the dinosaurs, is captured by the fossils of Montana's Hell Creek State Park. Here, we find a miracle: the bones of humanity's earliest primate ancestor, *Purgatorius unio*, who rose from the ashes, and thrived on the earliest fruits as the world was born anew.

What is the boundary between human and animal? How do the stories we tell about our body's origins connect and divide us from nature and each other? Can paleontology and biology offer a universal deep-time identity based on our evolutionary ancestry? How do we contend with this proposition from our diverse cultural identities and traditions?

Prehistoric Body Theater (PBT) is an emerging interdisciplinary performing arts company dedicated to staging evolutionary narratives as revealed by the paleontological sciences with world-class artistry, and grappling with global questions of ancestry, embodiment, and empathy.

PBT was conceived by American artistic director Ari Rudenko in Indonesia, in dialog with Indonesian artistic traditions of animal representation in dance, and is currently developing an international touring performance with an Indonesian dance ensemble titled

GHOSTS of HELL CREEK. GHOSTS of HELL CREEK (GoHC) is an hour-long performance for proscenium theaters, staging a vast tale spanning 500+ million years, articulated around the Hell Creek ecosystem. The work is presented in four acts, each act featuring a specific vertebrate animal species. Staged like an immersive diorama, the work features multilayered clay body makeup and clay set installation evocative of the Hell Creek Formation's stratigraphy, embellished with complex atmospheric lighting and bass-heavy sound design with Indonesian musical stylings.

PBT won University of Washington's 2017 Bergstrom Award for Art-Science Interface in collaboration with paleontologists Dr. Greg Wilson (Burke Museum curator, Hell Creek Project Director) and Dr. Dave Evans (dinosaur curator, Royal Ontario Museum), to develop the performance's structure and choreographic methodology based on comparative anatomy and locomotion. A.R. engaged in hands-on research as the artist-in-residence at the 2017 Hell Creek Project.

PBT is planning a North American tour of GoHC with an Indonesian ensemble, including a residency at Hell Creek Project for the Indonesian team. The live performance will show on North American stages, and will be accompanied by a suite of companion programming including Round-table Dialogs on Deep-time Identity with the Indonesian ensemble, mentor scientists, and audiences, allowing for a rich and equitable conversation exploring diverse perspectives on human ancestry and origins, giving voice to the Indonesian ensemble's process in relationship to their rich cultural traditions.

NEITHER A RODENT NOR A LAGOMORPH: GOMPHOS AS THE MOST SUCCESSFUL BASAL GLIRES (CLASS:MAMMALIA) IN THE EARLY EOCENE OF CHINA

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The "Mixodontia", a paraphyletic group of early Glires partitioned between Eurymylidae and Mimotonidae, is known from the Paleocene to the earliest Oligocene of China, Kazakhstan, and Kyrgyzstan. This array of ca. 20 species is morphologically closer to lagomorphs than rodents, but overall presents a mosaic of dental and skeletal characters found in both groups.

Most of the taxa are extremely scarce in the fossil record, with the exception of *Gomphos*. It was a large mimotonid (weight ca. 2 kg) and the most successful representative of early Glires, known from the earliest Eocene "red beds" (the Bumbanian ALMA), otherwise called the "*Gomphos* beds".

We studied the fossil remains of *Gomphos* (maxillary and mandibular fragments, teeth, and postcranial elements) from 11 localities of Bumbanian through early Irdinmanhan age in the Erlian Basin (Nei Mongol, China), with the focus on the tarsal elements (mostly, the calcaneus and astragalus). We analyzed 14 calcaneal measurements of *Gomphos elkema*, the most abundant species stratigraphically restricted to Bumbanian, using the Analysis of Variance (ANOVA) and Principle Component analysis (PCA). Samples from the Nuhetingboerhe, Shaerhaolei and Ulanboerhe localities yielded most of the material (over 400 specimens), allowing us for some statistical comparisons within *Gomphos elkema* paleopopulations.

The ANOVA test result of the calcaneus measurements showed great uniformity across the Bumbanian samples from all Nei Mongol localities (including also younger, Arshantan material). The most variable part of the calcaneus appeared to be the calcaneal eminence, which hosts the posterior articular surface for the astragalus and therefore constitutes the main point of the shank support. The dimensions of this structural element showed some differences at a slight ($p<0.1$) to moderate ($p<0.05$) level of significance between the samples. Our quantitative results coincide with some qualitative observations on the calcaneus morphology. *Gomphos* displays a rodent type of the calcaneus, with only one (not two, as in lagomorphs) facet on the eminence, the facet for the astragalus. Medially to this facet, there is an area serving as a partial support for the fibula and the attachment for the calcaneofibular tendon. This surface is variable in size and structure; in some specimens it forms a nascent fibular facet, which could be a functional adaptation possibly paralleling the lagomorphs. The results of PCA show that the calcanei of *Gomphos* lie in the morphospace closest to that of a marmot and musk rat, which tentatively indicates adaptations to burrowing and a relatively poor running ability.

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PRESERVATION BIAS IN THE FEZOUATA SHALE

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Exceptionally preserved biotas have been providing crucial paleontological data on the earliest major pulses of animal evolution – the Cambrian Explosion and the Ordovician radiation – for over 100 years. The Fezouata Shale is the only Ordovician formation to yield a diverse exceptionally preserved biota, yet the mechanism behind the preservation of soft parts in this formation and the potential of the Fezouata Shale depositsto revealaccurate snapshots of early animal life remain poorly understood. Here, based on two recently drilled cores, we constrain facies controls over the exceptional preservation of the Fezouata Biota. We find that the mechanisms leading to soft part preservation in some distal facies of this formation are strikingly different from those at play in Cambrian deposits. In addition to that, based on an original database, we compare the preservation potential of this new mechanism to the processes operating for Cambrian soft tissue preservation in the Burgess Shale and the Chengjiang Biota. Using a statistical approach,we show that the spatial distribution and type of soft tissues preserved are significantly different betweenCambrian biotas and theFezouata Shale, which is distorting to a variable extent our knowledge on the original diversity in ancient paleoenvironments. Constraining this bias is essential to correctly recon struct paleoecological and evolutionary scenarios.

THE RISE AND FALL OF THE 'AGE OF FISHES': VERTEBRATE RESPONSES TO PALEOZOIC EXTINCTIONS

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While vertebrates are both diverse (65000+ species) and ecologically important in modern oceans, they were noticeably marginal during classic early Paleozoic radiations, including the Cambrian Explosion or the Great Ordovician Biodiversification Event. It was unclear whether this absence was due to preservational issues or lack of effort. Newer quantitative analyses have revealed that jawed fishes and their relatives exhibited stepwise diversification centered on two Paleozoic mass extinctions: the end-Ordovician (443 Ma) and the end-Devonian (359 Ma). In this talk, I will show how mass extinction drove significant vertebrate turnover while also opening opportunities and altering selective regimes. While stem-vertebrates first appeared at classic Cambrian sites such as Chengjiang and Burgess, they were scarce at or absent from equally famous and productive Ordovician Lagerstatten, with the exception of ubiquitous conodonts (currently relatives of jawless lamprey and hagfish). The so-called 'Age of Fishes' only started in second half of the Silurian, following a post-extinction faunal hiatus and long-term losses among conodonts. Hard tissue fossils of jawed fishes and relatives became abundant, and these lineages gained a high level of ecological diversity through the Devonian. However, the familiar modern fauna of sharks, ray-finned fishes, and tetrapods only became dominant during the Carboniferous, once prior incumbents were eliminated by the Hangenberg event. Paleozoic recovery intervals, the Silurian-early Devonian and Mississippian, were marked by dramatic shifts and innovations in vertebrate ecology; their influence on vertebrate evolution was as significant as the turnover events themselves. Thus, Paleozoic mass extinctions and their recoveries had a profound impact on vertebrate biodiversity, which can be observed to this day.

CAPTURING CONVERGENCE AND INNOVATION IN FISH ECOMORPHOLOGY ACROSS TIME AND SPACE

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Biomechanical studies routinely link fish form with functional and ecological demands, including hydrodynamics and feeding mechanics. The reality of this phenomenon is also shown by the numerous cases of convergence in body form among fishes and other vertebrates (e.g. whales, ichthyosaurs), and even invertebrates (e.g. sea slugs), past and present. Anomalous, single-origin forms like seahorses are the exception that proves the rule. However, body form has never been quantified across the 500-million-year fish record and/or their 34000+ living species, let alone the extent and correlates (ecological and structural) of convergence across time and space. Construction of the requisite 'morphospace for all fishes' was limited by a lack of homologous structures for geometric morphometrics, and the apparent complexity of their traits. Here, we show results from a new reductionist approach using discrete coding to captures the form of

functionally-relevant, analogous features, such as "median hydrofoils," regardless of their construction. This has permitted the creation of a single morphospace encompassing Paleozoic jawed and jawless fishes as well as modern tropical fishes from the Great Barrier Reef. Akin to 'Raup Space' for mollusks, this new fish space allows explicit testing of the scope and stability of links between specific forms for functional traits, relationships between form, or form diversity, and other ecological variables (e.g. benthic assemblage zone, tooth form, salinity, or known/inferred diet), and changes in ecotype occupation and clustering across time and space, allowing us to address long-standing hypotheses of ecological diversity.

THE GRAY FOSSIL SITE OF TENNESSEE: A UNIQUE RECORD OF MAMMALIAN LIFE IN THE EARLY PLIOCENE OF EASTERN NORTH AMERICA

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The Early Pliocene age (4.9 to 4.5 Ma) Gray Fossil Site (GFS) of northeastern Tennessee has well-preserved and diverse flora and fauna, representing one of only a few late Neogene fossil sites in eastern North America. The fauna unearthed so far includes fish, amphibians, non-avian reptiles, birds, and mammals, and is unlike others of similar age. Tapir (*Tapirus polkensis*), rhino (*Teleoceras*), *Alligator*, and turtles are common, while an ailurid (*Pristinailurus bristoli*) and tremarctine bear (*Plionarctos*) are present. Both macro- and microfossils of plants from the site indicate a forested environment, which was dominated by oak, hickory, and pine.

Ongoing excavations and extensive screen-washing efforts in recent years have yielded thousands of specimens, including remains of many new mammals. Rodents include two castorids, six cricetids, a dipodid, and five sciurid. There are also two leporids, four talpids, and a dromomerycid now recognized. Additional carnivorans include a new species of wolverine (*Gulo*), a mephitid, and a procyonid. Multiple skeletons of an unusual large, longirostine mammutid are also currently being excavated.A number of these new taxa support previous environmental interpretations based on fauna, flora, and isotope records. Tree squirrels, flying squirrels, and a ringtail at the site support the forested interpretation, as does the absence of burrowing rodents. The presence of two beaver species and a desman support the presence of year-round water.

Comparison to the mammal faunas from five well-known late Miocene (Hemphillian) and early Pliocene (Blancan) sites from across North America highlight the uniqueness of GFS. Taxa from each site were coded into crown height and locomotor categories, revealing clear differences between the faunas at GFS and elsewhere. In particular, GFS has abundant low-crowned herbivores (55% brachydont), nearly double the proportion found at any other site, and relatively few hypsodont or hypselodont taxa. It also has many climbing-adapted taxa (23% scansorial, arboreal, and gliding), greatly exceeding that of other sites, along with very few cursorial mammals. These finding support the results of other studies, which suggest the site was a relatively closed, forested habitat. Overall, this highlights the uniqueness of the site, not only in terms of age and location, but also in the environment preserved. In sum, the combination of flora and fauna at GFS are unique among North American biotas, and have potential to greatly improve our understanding of the origin of modern ecosystems in the Appalachian region of eastern North America.

A NEW LARGE KANGAROO RAT-LIKE RODENT FROM THE EARLY MIOCENE OF OREGON AND THE PHYLOGENY OF EARLY HETEROMYIDS

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Several living families of rodents include ricochetal species, which have highly specialized cranial and postcranial morphology. A new latest Arikareean age record of a heteromyid from the Johnson Canyon Member of the John Day Formation in Oregon represents a new taxon, consisting of a nearly complete skull, dentary, and hind foot. The specimen is characterized by a mosaic of ancestral heteromyid features and highly derived cranial structure. Dental morphology

and some cranial characteristics are similar to early heteromyids and *Schizodontomys*, but other aspects of morphology are more similar to living and fossil dipodomyines (kangaroo rats and kangaroo mice). Like dipodomyines, the Johnson Canyon heteromyid has exceptionally inflated auditory bullae, though the inflated portions of the skull and convergence of the bullae are quite distinct from living taxa. The new heteromyid is also rather large, comparable in size to some of the largest living species of *Dipodomys*. We compiled data and coded characters for a wide range of geomorph rodents to build a new morphological phylogeny for the group. Preliminary analysis places the Johnson Canyon heteromyid within the Heteromyidae, but outside of a clade that includes all living heteromyid subfamilies (Heteromyinae, Perognathinae, Dipodomyinae). Overall, the morphology of the new heteromyid suggests independent acquisition of characteristics associated with a ricochetal lifestyle. This is interpreted as convergent evolution of a kangaroo rat-like form, prior to the appearance of dipodomyines later in the early Miocene. We hypothesize cooling and drying conditions in the late Oligocene and early Miocene presented selective pressures that favored adaptations for life in more open habitats, resulting in the specializations seen in both groups of heteromyids.

LATEST CRETACEOUS VERTEBRATE DIVERSITY FROM MICROVERTEBRATE SITES PRIOR TO THE CRETACEOUS/PALEOGENE (K/P) BOUNDARY, HELL CREEK FORMATION, NORTH DAKOTA

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Latest Cretaceous terrestrial vertebrate paleocommunities from prior to the Cretaceous/Paleogene (K/P) mass extinction have been well documented from the Hell Creek and Lance formations of Montana, Wyoming, and North and South Dakota. An important study from the Hell Creek of North Dakota recorded numerous vertebrate fossils from many sites leading up to the K/P boundary. However, this work was based on surface collection and excavation, and not from screen-washing microvertebrate sites, potentially missing or under-sampling small specimens such as shark teeth. Does screen-washing microvertebrate sites and recovering these smaller specimens change the pre-K/P diversity patterns and the paleoenvironmental interpretations for these deposits? To address these questions a selection of the microvertebrate sites previously reported on were surface collected and screen-washed. We used fine-mesh screens, and sorted the resulting matrix with microscopes. This yielded thousands of small specimens (teeth and bones) from numerous vertebrates, some of which had been missed or under-sampled by surface collecting. Fish are abundant, especially gar (*Lepisosteus*) and ray (*Myledaphus*), among other fish and sharks. There are amphibians, lizards, and snakes. Turtles are numerous and include cf. *Compsemys*, baenids, cf. *Adocus*, Trionychids, and chelydrids. Crocodylians and champsosaurs (204 specimens) include cf. *Borealosuchus*, *Brachychampsa*, *Leidyosuchus*, and *Champsosaurus*. Dinosaurs (139 specimens) include hadrosaurs and ceratopsians, probably from hatchlings. Theropod dinosaurs (45 specimens) include tyrannosaurids, cf. *Saurornitholestes*, *Richardoestesia*, "*Paronychodon*", and bird. Mammals (58 specimens) include multituberculates (*Mesodma*, *Meniscoessus, Cimolodon*); marsupials (pediomyid and alphadontid); and eutherians (cf. *Gypsonictops*). How do the screen-washed samples differ from the surface collected samples? From screen-washing, numerous small specimens were recovered that were missed or under sampled during surface collection. For example, sharks, rays, and other fish are the most abundant specimens recovered from screen-washing, yet they were missed or under-sampled during surface collection. Their abundance indicates the proximity a seaway in this area. Small teeth from the fish-eating theropod, *Richardoestesia isosceles* and from the fish-eating bird (cf. Hesperornithoformes) support this interpretation. Other abundant specimens from screen-washing include numerous teeth from small (hatchling) hadrosaur and ceratopsian dinosaurs, indicating dinosaur nesting sites were nearby. Our screen-washing efforts have yielded new and important discoveries and new paleoenvironmental interpretations about the latest Cretaceous paleocommunities leading up to the K/P mass extinction.

THE ALF MUSEUM AND THE INSTITUTE FOR THE STUDY OF MONGOLIAN DINOSAURS: AN INTERNATIONAL COLLABORATION FOR PALEONTOLOGY EDUCATION

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Collaborations are a means by which institutions can supplement resources and development, especially for small and developing institutions. The Raymond M. Alf Museum of Paleontology and the Institute for the Study of Mongolian Dinosaurs (ISMD) have recently begun such a collaboration to provide educational training and resources to educators and students in Mongolia while also providing paleontologists and students in America a unique opportunity to engage an underrepresented community in paleontology. Both institutions are paleontological research institutions dedicated to providing first hand educational experiences in paleontology for students, particularly for high school students. The ISMD was founded in 2007 as a means to provide educational resources to the Mongolian people through education and research programs. The Alf Museum has had an established program for high school students for over 50 years, with a rigorous student research program having been in place for the last decade. By combining efforts and expertise, both the Alf Museum and ISMD look to expand educational resources and development opportunities for students and staff through a series of exchanges and projects. Exchanges include museum personnel traveling to the each other's institutions for training and student exchanges to provide first-hand learning experiences in paleontological research. Projects include the development of educator workshops in Mongolia and the implementation of augmented reality technology for translation and accessibility for Mongolian audiences. Through this international collaboration, the Alf Museum and ISMD look to foster cultural exchange between personnel and students, and also develop diversity within the international paleontological community.

CELEBRATING THE PALEONTOLOGICAL HERITAGE OF GRAND CANYON NATIONAL PARK DURING THE PARK'S CENTENNIAL

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On February 26, 1919, the U.S. Congress designated a portion of the Grand Canyon in Arizona as a national park. During 2019, the National Park Service will host a year-long centennial celebration recognizing the 100th birthday for Grand Canyon National Park. The geology and paleontology of the Grand Canyon are world-renowned, representing one of the most recognizable geologic features on Earth. The park and designated World Heritage Site draw between five and six million visitors from around the world each year to experience a geologic landscape extending nearly 2,000 square miles and a record of deep time spanning 1.8 billion years.

As part of the Grand Canyon National Park Centennial, the National Park Service is undertaking a comprehensive paleontological resource inventory for the park. The rich and diverse fossil record of Grand Canyon preserves primitive life forms from the Precambrian; Paleozoic plant, invertebrate, and vertebrate body and trace fossils; and Pleistocene / Holocene fossil remains associated with park caves. Teams of paleontology specialists will help compile the paleontological resource information to present in a publication that will highlight the scope, significance, distribution, history and management issues of the fossil resources of Grand Canyon National Park.

The first documented occurrence of fossils from the Grand Canyon appears in J.S. Newberry's 1861 geology report published in Lt. Joseph Ives's *Exploration of the Colorado River during 1857 and 1858*. Over the following 160 years, extensive paleontological field work, fossil collecting and research in the Grand Canyon has been undertaken by paleontologists from the Smithsonian (Charles Walcott, Remington Kellogg, Charles Gilmore), the U.S. Geological Survey (John Wesley Powell, Edwin McKee, George Billingsley) and other academic institutions .

As part of the Grand Canyon National Park Centennial Paleontological Resource Inventory, the park will be hosting a "PaleoBlitz." The Grand Canyon "PaleoBlitz" will consist of field-based activities involving multi-disciplinary teams of paleontology specialists to survey potentially fossiliferous locations. The teams will consist of professional paleontologists, students, volunteers and park staff to undertake field evaluations and documentation. All geologic, paleontological, and geospatial data obtained at each fossil locality will be incorporated into the park's data management system. Discoveries made during the "PaleoBlitz" will be on display for the public and media during a National Fossil Day event hosted by the National Park Service on the last day of the "PaleoBlitz." A number of National Fossil Day partners, including the American Geoscience Institute, U.S. Geological Survey, Arizona

Geological Survey, and the Museum of Northern Arizona plan to participate in the public outreach event at Grand Canyon National Park.

SHIPWORM BIOEROSION OF LITHIC SUBSTRATES IN A FRESHWATER SETTING, ABATAN RIVER, PHILIPPINES: ICHNOLOGIC, PALEOENVIRONMENTAL AND BIOGEOMORPHICAL IMPLICATIONS

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Teredinid bivalves, commonly known as shipworms, are known for their propensity to inhabit, bioerode, and digest woody substrates across a range of brackish and fully marine settings. Shipworm body fossils and/or their borings, which are most allied with the ichnotaxon *Teredolites longissimus*, are found in wood preserved in sedimentary sequences ranging in age from Early Cretaceous to Recent and traditionally they have been regarded as evidence of marginal marine or marine depositional environments. Recent studies associated with the Philippine Mollusk Symbiont International Collaboration Biodiversity Group (PMS-ICBG) expedition on the island of Bohol, Philippines, have identified a new shipworm taxon (*Lithoredo abatanica*) that is responsible for macrobioerosion of a moderately indurated Neogene foraminiferal packstone cropping out along a freshwater reach of the Abatan River. In the process of drilling into and ingesting the limestone, these shipworms produce elongate borings that expand in diameter very gradually toward distal termini, exhibit sinuous or highly contorted axes and circular transverse outlines, and are lined along most of their length by a calcite tube. Given their strong resemblance to *T. longissimus* produced in wood but their unusual occurrence in a lithic substrate, these shipworm borings can be regarded as incipient *Gastrochaenolites* or, alternatively, as *Apectoichnus longissimus*. The alternate names reflect that the borings provided a testbed for ideas of the appropriateness of substrate as an ichnotaxobasis. The discovery of previously unrecognized shipworm borings in lithic substrates and the co-occurrence of another shipworm (*Nausitora*) in submerged logs in the same freshwater setting have implications for interpreting depositional conditions based on fossil teredinids or their ichnofossils. Of equal significance, the Abatan River study demonstrates that macrobioerosion in freshwater systems may be just as important as it is in marine systems with regard to habitat creation and landscape development. *L. abatanica* serve as ecosystems engineers in the sense that networks of their abandoned borings provide habitats for a variety of nestling invertebrates, and associated bioerosion undoubtedly enhances rates of mechanical and chemical degradation, thus influencing the Abatan River profile.

USING REGIONAL STRATIGRAPHIC CONTEXT OF THE PO-ADRIATIC SYSTEM (ITALY) TO INFER BIOTIC RESPONSE OF CHAMELEA GALLINA TO HOLOCENE ENVIRONMENTAL CHANGE

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Understanding how marine taxa will respond to climate and environmental change is one of the main challenges for management of coastal ecosystem services. Ecological studies on factors controlling shell proprieties and morphology of commercially important mollusk species are commonly restricted to latitudinal gradients or small-scale laboratory experiments. Few studies, however, have investigated how shell growth and microstructure varies in relation to climate dynamics and facies tracts in the recent fossil record. This preliminary research investigates skeletal properties and growth of *Chamelea gallina* from the Holocene shoreface deposits of the Adriatic Basin (Italy). Four horizons rich in *C. gallina*: one from the Early Holocene, when the area was an estuarine system; two from the Late Holocene, when the area transitioned from a wave-dominated to fluvial-dominated delta, and one from the present-day shallow subtidal (ca. 6m depth), 40 km south of the modern Po delta.

Here, we investigated shell skeletal parameters (bulk density, micro-density and porosity) in relation to shell length, used as a rough proxy of the animal age. Across all horizons, juveniles are more porous than adults, suggesting that *C. gallina* promoted an accelerated shell accretion, at the expense of possessing a mechanically weaker shell, in order to quickly attain the size required for sexual maturity. No variation was

observed in shell $CaCO_3$ polymorphism (100% aragonite) or in compositional parameters among the four analyzed horizons.

Spearman's rank correlation analyses between alkenone derived sea-surface-temperatures (SSTs), age (a proxy for different depositional settings) and clam microskeleton parameters were also performed. Micro-density and bulk density correlated positively with SSTs, whereas porosity correlated negatively. Age is correlated (positively) only to micro-density. Trace elements analysis show higher presence of metals like chromium (Cr) and nickel (Ni) in valves of modern clams, suggesting that shell trace element ratios can provide useful archive of environmental pollution.

The stratigraphic context in which *C. gallina* assemblages were embedded, aid understanding the biotic response of this important shellfish species to anthropogenic activities and climate-driven changes in depositional settings (estuarine *vs* deltaic).

SOFT-TISSUE PRESERVATION IN CLOUDINOMORPHS FROM THE TERMINAL EDIACARAN OF NEVADA MAY PROVIDE CLUES ONTO PHYLOGENETIC POSITION

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The terminal interval of the Ediacaran Period (~551–539 Ma) represents a turning point in the evolution of complex multicellular eukaryotes. Uniquely positioned between the peak diversity of the Ediacara biota and the subsequent rise of true metazoans during the Cambrian explosion, the fossil record of the terminal Ediacaran exhibits communities comprised of multiple taxa with broadly tubular morphologies, including the iconic index fossil *Cloudina*. These generally small, tubular organisms bore witness to several significant ecological and environmental events, including the origins of macro-scale biomineralization and predation. Given their pivotal role in the advent of biomineralization, these tubes, although phylogenetically uncertain at present, may serve as an evolutionary bridge across the Ediacaran–Cambrian transition. Here, we investigate terminal Ediacaran tubular taxa from the Deep Spring and Wood Canyon formations, Esmeralda and Nye counties (respectively), Nevada, USA. From our analyses, we have characterized these tubular fossils both taxonomically and taphonomically, offering new assignments within the 'cloudinomorph' morphoclade.

Using a combination of optical microscopy, scanning electron microscopy, energy dispersive x-ray spectrometry, and x-ray microscopy, we confirm preservation through pyritization—comparable to similar tubular taxa of the Gaojiashan lagerstätte, South China—and report the presence of potential soft tissues within their extracorporeal tube walls. The soft tissues reported manifest as internal tubular structures, mm-scale in diameter and hollow-to-pyrite-infilled, that extend through the majority of the outer structural tube. We here investigate several possibilities for the nature of this internal soft tissue, including stalks of rhabdopleurid hemichordates, gastrovascular cavities of tube anemones, and digestive tracts of tube-dwelling polychaetes.

A LOOK INTO THE EYES OF TRILOBITES

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From the very beginning of their appearance trilobites were equipped with compound eyes, which during the Cambrian explosion evolved into highly differentiated systems. Some of these compound eyes developed more than 10,000 lenses, and sophisticated backgrounds of adaptations. In the fossil record, however, hardly soft parts, such as neural tissues or even receptor cells are preserved. Only under special conditions of preservation and by application of modern techniques, such as x-ray tomography or synchrotron radiation, it became possible in rare cases to trace up relics of sublensar structure.

Trilobites show up two main types of compound eyes. The so-called holochroal eye is the first type to appear and the most common. These look very similar to the eyes of modern bees or dragonflies. Often numerous lenses lie densly packed in hexagonal arrays. The schizochroal eye is restricted to the subfamily Phacopina. Here the lenses lie separated from each other, and are much larger compared to those of holochroal eyes. Some of them reach a diameter of more than a millimeter in size.

Nothing had been known hitherto, however, about the internal, functional structure of trilobite eyes. Anything could lie below the lenses – it could be an ocellus, an array of receptor cells forming a retina,

it could be an ommatidium as known from modern forms, or some other structure.

Recently, the eyes of a very early trilobite was described from the Lower Cambrian of Estonia; this species *Schmidtiellus reetae* (Bergström, 1973) is amongst the oldest trilobites of all. First represented only by trace fossilsat the stratigraphical level from where it comes, trilobite fragments then were found, and finally an almost complete, well preserved specimen was discovered. In phosphatised preservation it excellently shows ommatidia. In some ways this is simpler than the eyes of modern apposition type, yet the structures are clearly ommatidia.

Wolfgang Stürmer was head of the Siemens x-ray department, and was a pioneer of x-ray analyses in fossils. He described elongated linear bands, packed bundles, within the eye of Devonian phacopid trilobites. He interpreted these as light guides, but this was not well received by other palaeontologists; some indeed were very sceptical, considering them to be gill filaments. Reconsideration of his material and re-study of his x-radiographs gas shown that these linear bands indeed had formed integrated components of the eye. At the distal end of each of the bands clearly can recognise sets of individual ommatidia with spherical lenses, sharing the large aperture of their covering big lens. This discovery reveals the enigmatic phacopid system as consisting of small compound eyes below each of the big lenses. The now small ommatidia may have invaded from the sides, explaining the big interspaces between the lenses. So this 400 million year old eye reveals as a highly sophisticated system, probably well adapted to dark and muddy water conditions.

UNDERWATER CAVES OF THE YUCATÁN SHED LIGHT ON LATE CENOZOIC BIODIVERSITY AND FAUNAL INTERCHANGE IN MIDDLE AMERICA

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Tropical regions are typically associated with poor fossil preservation, leading to gaps in the fossil record, and therefore in our understanding of paleobiology, evolution, and temporal biodiversity over vast areas. In the Americas, these tropical environments extend from southern North America, through Central America, and into northern South America. Caves in tropical Middle America provide important windows into this otherwise depauperate record, but preservation is often poor. Recent exploration of submerged cave systems by technical divers in the Yucatan Peninsula of Mexico is now revealing a diverse record of well-preserved late Pleistocene and early Holocene mammals.

This presentation focuses on the Sac Actun cave system, near Tulum, Mexico. While skeletal remains have been found throughout this cave, most attention has centered on Hoyo Negro (HN), a collapse feature that served as a natural trap preserving fossils. Mammals entered the cave through horizontal passages when sea level was lower during the late Pleistocene, and many fell to their deaths in HN. Expeditions to the site require innovative technology to document and retrieve specimens now preserved under 40 m of water. Underwater photogrammetry is used to record fossils *in situ* prior to removal. The fauna includes opossum, bat, rodent, tapir, peccary, an elephant-like gomphothere, at least three types of giant ground sloth, sabertooth cat, puma, ocelot, white-nosed coati, short-faced bear, canid, and a human. The human is currently the oldest and most complete of the earliest *Homo sapiens* skeletons in the Americas.

Recovery and analysis of sloth, bear, and canid remains provided biogeographic and evolutionary surprises. A megalonychid sloth is a new genus and species that may be endemic to the region. The bear, *Arctotherium* ("South American" short-faced bear), is the first record of the genus outside South America, and represents the late Pleistocene species *A. wingei*. The relative abundance of *Arctotherium* individuals in the deposit (at least seven), and pristine condition of their remains, makes this the most complete and abundant short-faced bear material from any locality. A terminal Pleistocene radiocarbon date indicates the bear co-occurred with early humans in the Yucatán. A canid represents another “South American” genus

and species, *Protocyon troglodytes*, previously unknown outside that continent. While the sloths may be part of earlier stages of the Great American Biotic Interchange, we hypothesize that the bear and canid expanded their distributions out of South America during or since the last full glacial, between ~35,000-12,000 years ago. At this time, sea-level lowering, widening of the isthmus, and more-open habitats may have created greater opportunities for dispersal of these carnivorans.

NEW PALEONTOLOGICAL PERMITS AND PERCEPTIONS ON FOREST SERVICE LANDS

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Administration of paleontological research and collection permits on National Grasslands and Forests (Department of Agriculture) embraces the position that permitting is the most important paleontological service we provide to the public. Non-federal mitigation and research paleontologists (permittees) provide the workforce for fundamental stewardship efforts across National Forest System lands (NFS), as called for in the Paleontological Resources Preservation Act (PRPA). Good customer service resulting in timely issuance of permits is the key element for effective paleontological resources management on federal lands.

Permittees are actively and ethically engaged in the inventory, monitoring, recordation, and conservation of paleontological resources on federal lands. Paleontological resources managed in this way are made available for scientific and educational uses by present and future generations, and foster collaboration between federal entities, non-federal partners, the scientific community, and the general public. Moreover, federally approved partner repositories agree to onboard as benefactors for collection permits, serving to stabilize and house paleontological resources in perpetuity at no cost to government. In this regard, both permittees and repositories should be viewed as partners who provide valued stewardship services for federal lands.

Forest Service (FS) paleontological permitting has progressed remarkably in recent years, due to the creation of a resource specific permit and application forms package (made possible by authority of PRPA). Prior to PRPA, FS was constrained to issuing paleontological permits under Special Uses authority, which unintentionally characterized paleontological resource management as a "use", rather than stewardship. The new authority allows for wording of applications and permits well suited toward paleontological principles, and obligate paleontology staff can now initiate and guide the permitting process. Paleontological administrators must still shepherd and track permit applications through internal process to signature by decision makers, ensuring that applications are reviewed and processed effectively and consistently.

The FS paleontological program continues to outreach internally and externally, encouraging applications and support for paleontological work on NFS lands. Paleontological permits do not always involve fossil collection. Permits also authorize special access for inventory and discovery of new fossil specimens, stratigraphic work, or monitoring and recording of in situ resources. Avocational paleontologist and students can qualify for particular permitted activities. Permitted activities and casual collection opportunities can (and do) occur concurrently.

MORPHOLOGY IN TIME AND SPACE: HOW DOES SHAPE CHANGE WITH SEQUENCE STRATIGRAPHIC ARCHITECTURE?

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In their seminal work on stratigraphic paleobiology, Patzkowsky and Holland highlighted the need for more morphological data that are placed within a stratigraphic context. This will lead to more robust study of the impact of environmental change on morphological disparity. The ability to collect morphological data within sequence stratigraphic architecture has been limited by technique; most morphological data is collected from museum specimens or in the laboratory. We used the photogrammetry technique, Structure-from-Motion, to collect brachiopod morphological data from outcrops in the Late Ordovician Cincinnati Arch (Indiana, Ohio, Kentucky; USA) and quantified morphological change within the already established sequence stratigraphic architecture.

SfM uses 2D photographs taken from different angles to reconstruct a 3D shape. We photographed

external valves of brachiopods in the field in 360 degrees (approximately 24 photos per specimen) and used the SfM software 'Agisoft Photoscan' to make 3D models of those specimens. We exported these models into R and used the package 'geomorph' to generate a set of semi-landmarks. We used these to create a morphospace to explore the effects of environment and time on 3D shape.

Results indicate that brachiopod shells separate in morphospace according to their degree of inflation and roundness. These differences are likely controlled by environmental conditions at each position along a water depth gradient. Additionally, when comparing stratigraphic sequences, the separation in morphospace is weaker in the C2 than the in the C5. This is consistent with the previously observed breakdown of the environmental gradient in response to the Richmondian invasion. Ultimately, our study demonstrates that SfM makes gathering 3D morphological data from the field possible, highlighting an avenue for research in answer to Patzkowsky and Holland's call for more data. Because this is a low-cost and easily accessible method, possibilities of applying it more broadly within paleobiology abound. Further development of this technique will not only provide a better understanding of the distribution of morphological form within stratigraphic architecture, but also increase the quantity of morphological data from key intervals throughout the Phanerozoic. These data can be stored as a digital archive that could facilitate large-scale meta-analyses as well as education and outreach activities.

THE ARLINGTON ARCHOSAUR SITE: AN AMATEUR DISCOVERY LEAD TO AN AMATEUR-PROFESSIONAL COLLABORATION IN PALEONTOLOGY

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The Arlington Archosaur Site (AAS) began in an undeveloped pocket within the metroplex of Dallas-Fort Worth, Texas. The AAS is situated in the Woodbine Formation, a coastal delta plain ecosystem. Dinosaur and other bones were discovered in 2003 by two sets of amateurs. Since discovery, the site has provided insight into the understanding of the mid-Cretaceous, 96-98 ma, on the eastern side of the Western Interior Seaway. Materials from the site include dinosaur, mammal, lungfish, crocodyliform, turtle, and other animals.

For five years following discovery, the site was of limits to official exploration. The landowner wanted to sell the land without conflict or devaluation due to the associated fossils. The property was sold around 2008. Coincidentally, Derek J. Main began his doctoral studies at the University of Texas at Arlington (UTA) under Dr. Christopher Scotese. Part of the uniqueness of the site was a sense of urgency. Mr. Main had to collect as much material as possible before development. Mr. Main gathered amateurs (sometimes over 100 at a time), many from the Dallas Paleontological Society (DPS), college and high school educators and students, and others from around the globe. Mr. Main and other volunteers gave walking educational tours of areas nicknamed the Dinosaur Quarry, the Turtle Buffet, and the Nursery.

Volunteers have given countless talks to various local groups. Amateurs presented to professionals at the Geological Society of America (GSA) 2010, Society of Vertebrate Paleontologist (SVP) 2011, 2012, 2013, 2015, and 2016, DPS Occasional Papers 2009 and 2011, and the Hadrosaur Symposium Alberta 2011, Science Teacher Association of Texas, and the National Park Service (NPS) Grand Canyon Teacher Workshop.

Just after graduation Dr. Main passed away unexpectedly. By then, Dr. Main had established the AAS as a major (possibly world-class) paleontological resource. The Perot Museum of Nature and Science (Perot) in Dallas, Texas agreed to curate the collection after UTA. Dr. Chris Noto, University of Wisconsin–Parkside, and other professional paleontologists have collaborated with Mr. Main and several of the amateurs on projects stemming from the AAS.

To date, 12 scientists representing seven institutions have studied the AAS material. These scientists have named new species of lungfish, turtle, and crocodyliform. Professional paleontologists and scientists will certainly name new species collected and sometimes prepared by amateurs.

FOSSILS OF LATE PLEISTOCENE BISON FROM PUBLIC LANDS IN THE COLORADO AND MOJAVE DESERTS: IMPLICATIONS FOR THE DIVERSITY AND BIOGEOGRAPHY OF BISON IN SOUTHWESTERN NORTH AMERICA

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The genus *Bison* was a common and abundant component of many megafaunal communities in the late Pleistocene of North America. Recent genomic

investigations have proposed that *Bison* migrated into North America in two waves, the first between ~195 and ~135 ka, and a second between ~45 and 21 ka. The initial immigration was followed by relatively rapid dispersal and concomitant phenotypic diversification, particularly in horn core size, shape, and orientation. Complementary fossil evidence from the American southwest sheds light on the timing and character of this dispersal.

The chronology of fossils of *Bison* recovered from public lands in the Colorado and Mojave Deserts of the southwestern United States conforms well to this genomically inferred dispersal pattern. For example, outcrops of the Las Vegas Formation in Tule Springs Fossil Beds National Monument, southern Nevada, have produced the Tule Springs local fauna, the largest open-site vertebrate fossil assemblage dating to the late Pleistocene in the Mojave Desert/southern Great Basin. *Bison* is well represented in this fauna in multiple units ranging in age from ~100 to 14 ka.

A long-horned morphotype of *Bison* in the Tule Springs local fauna is represented by a partial skull recovered from bed B_2 of the Las Vegas Formation, which dates to between ~55 and 45 ka. The size and morphology of the preserved horn core suggests affinity with the long-horned species *Bison latifrons*; however, the horn core is shorter and more strongly curved than classic examples of that species. Consequently, this skull has previously been assigned to a variety of other species of debatable validity, or alternatively has been interpreted to represent a hybrid form. It is more likely that the skull represents a regional variant of *B. latifrons*, and that observed differences in horn core length and curvature reflect geographic plasticity consistent within a rapidly diversifying evolutionary lineage. Similar horn cores of *Bison* from other southwestern localities (Rancho La Brea, Diamond Valley Lake) support this interpretation.

The smaller, shorter-horned species *Bison antiquus* co-occurs with *B. latifrons* in bed B_2, but is also present in beds D_1, E_0, and E_{1b} of the Las Vegas Formation, which collectively span 37.4 – 14.5 ka; *B. antiquus* is the sole bison species represented in these younger members of the formation. Fossils resembling *B. antiquus* have also recently been documented from Death Valley and Joshua Tree National Parks; the former is likely between ~31 and 24 ka, while the latter dates to ~18.4 ka. The reduced body size, smaller horn cores, and increased abundance and distribution of *B. antiquus* relative to *B. latifrons* and other megafauna likely correspond with the second immigration pulse deduced from genomic data. The dominance of *B. antiquus* in midcontinent North America at the end of the Pleistocene suggests a shift from smaller groups towards large herds.

A MACROSTRAT APPROACH TO THE EDIACARAN OF NORTH AMERICA

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The Ediacaran Period (635-541 Ma) witnessed the end of 'snowball Earth' global glaciations, the appearance of the earliest known metazoan life, and the earliest stages of a step-wise increase in the marine inundation of the continents that peaked during the early Paleozoic. The latter transition is expressed over most of North America as a stratigraphic unconformity, known as the "Great Unconformity." In most regions of North America, this surface is a non-conformity that juxtaposes Cambrian marine sediments over underlying and much older crystalline igneous and metamorphic rocks. Recently, it has been suggested that snowball Earth continental glaciers (including the Ediacaran Gaskiers) were responsible for generating the Great Unconformity by eroding kilometers of Precambrian continental rock and generating the accommodation space necessary to rebury the erosional surface beneath marine sedimentary deposits. This "top-down" origin for the Great Unconformity is broadly consistent with the observed Phanerozoic increase in sediment storage on the continents and with the pressure-temperature gap that is evidenced by the underlying Precambrian rock. However, the onset of sedimentation following putative glacial erosion is temporally lagged with respect to the timing of deglaciation and isostatic model predictions. In order to test the Cryogenian "bulldozer" hypothesis and to characterize the nature of the Great Unconformity within the critical Ediacaran interval, a higher-resolution quantitative stratigraphic framework is necessary. Here, we present a new intermediate-resolution macrostratigraphic analysis of the North American Ediacaran succession. This analysis is based on a compilation of all known Ediacaran successions, their underlying and overlying rock units, and their general geological properties, including lithology, geochemical properties, and geochronological constraints. Preliminary results indicate that 'lower' Ediacaran strata are typically absent and that most Ediacaran successions

in North America are younger than the Gaskiers glaciation. The Ediacaran and Cambrian in North America are only rarely continuous, and many of these successions are non-Laurentian (e.g., Avalonia). Many of the Ediacaran successions in North America are composed of marine sediments and volcanics associated with island arcs that rifted from Gondwana during the early Cambrian and that were accreted onto the margin of Laurentia during the late Silurian to early Devonian. Although it is possible that global expansion of an intermediate resolution macrostratigraphic dataset for the Ediacaran will reveal an early-onset of marine sediment accumulation that is predicted by the snowball Earth 'bulldozer' model, the temporal lag between Neoproterozoic glaciation and reburial of the Great Unconformity will remain a prominent feature of the North American rock record.

DETERMINING THE IMPACTS OF THE ANTHROPOCENE THROUGH TIME-CALIBRATED TAPHONOMIC GRADING

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Global biodiversity loss threatens ecosystem integrity and related services for humans, but most communities lack baseline data to assess the magnitude of change. In marine conservation, molluscan death assemblages are increasingly being used as a proxy for baseline communities, and divergence between the live and the dead is assumed to reflect human impact. A drawback to partitioning an assemblage into live and dead is that inclusion of recently dead specimens in the baseline assemblage artificially reduces differences between before and after. In this study, we address this problem by using a radiocarbon- and amino acid-calibrated taphonomic grading scale to partition recently (post-1950) and long-dead shells from shallow shelf communities of the southwest Florida.

This calibrated taphonomic grading scale prevents recently dead (post-1950) specimens from being grouped with baseline assemblages, thus reducing temporal biases in live-dead comparisons. Preliminary data suggest that ecologically important species may have already experienced truncated ranges.

SURVIVAL OF THE SHARPEST: COMMUNITY TRENDS IN ORNAMENTATION AS A PROXY FOR PREDATION IN DEVONIAN STROPHOMENATE BRACHIOPODS

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Studies of predator-prey systems have shown prey animals have evolved antipredatory strategies to match the abilities of their predators through time. Due to a higher diversity of stronger predators in the tropics, predation pressure is greater in the tropics and so it may be expected that prey species near the equator would possess better antipredatory strategies than their temperate relatives. This hypothesis has been corroborated on a global level through several time intervals in the fossil record, but not on a finer scale. A common antipredatory strategy used by shelled prey is ornamentation of the shell, which increases the strength and effective size of the shell. We examined antipredatory ornament in Middle to Late Devonian brachiopod species of the Class Strophomenata across 30 degrees of paleolatitude in North America. We chose strophomenates as they are known to have been preferred prey for rapidly evolving fish and large arthropods, and would have benefitted more from antipredatory strategies than would have rhynchonellate or lingulate brachiopods. Taxa within Strophomenata display varying levels of ornamentation which may be organized into the categories: 1) none, 2) costae or lamellae, 3) plicae or rugae, and 4) spines. Abundance data on brachiopod communities at the species level were used and cross-referenced with the ornamentation level provided by species descriptions and visual examination of specimens to calculate the Weighted Mean Ornament (WMO). WMO is calculated by multiplying the abundance of each species in a sample by its respective ornamentation level, summing these values for all species, and dividing the result by the abundance of all species in the sample.. The WMO provides a value between 1 and 4 for each sample, and represents the relative degree of ornamentation, from the perspective of a predator, for the sample as a whole. Presence-absence data were also used to determine the proportion of spinose species within samples, as spinose ornament is thought to be much more effective in deterring predators than lesser degrees of ornament. Comparisons of samples across latitude showed that the WMO and proportion of spinose species increased across three trends: decreasing latitude, time, and decreasing water depth. The first result demonstrates that strophomenate ornament was used as an antipredatory strategy, and the degree of ornament between communities varied depending on the abilities and diversity of their respective

predators. The second result shows that prey did in fact improve their antipredatory strategies through time as their predators became stronger, even on relatively short time scales. The final result demonstrates that ornamentation can vary even on environmental levels between geographically proximal communities. Overall, ornament developed to suit the antipredatory requirements of the environment inhabited by strophomenates, which was influenced by local, regional and global factors.

ESTABLISHING A NEW PROTOCOL FOR DECAY EXPERIMENTATION USING X-RAY TOMOGRAPHIC MICROSCOPY

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Decay experiments are crucial to our understanding of the mechanisms that promote preservation, as well as the inherent biases involved in the interpretation of soft-bodied fossils. Previous studies have run the gamut on the influence of various factors, including but not limited to rate of decay, sequence of character loss and retention, bioturbation, chemistry of hosting sediments, and effect of microbes. Regardless of the experimental protocol, data collection and subsequent analyses in these studies have generally relied upon visual assessments and qualitative decay indices. Ultimately, although decay experiments have provided a wealth of information, variability between experimental protocols and inconsistencies in establishing qualitative scoring systems render comparison between studies unreliable. Establishment of new protocols should focus on providing directly quantifiable data, thus permitting better comparison between studies and experimental designs. With increasing availability of x-ray tomographic microscopy (μCT), and its increased use in paleobiological studies, it is perhaps surprising to note that very few experimental decay studies have employed this technology for observing the sequence of decay. This study utilizes μCT methods to scan decay experiment products, using peppermint shrimp *Lysmata wurdemanni* as target organisms, in order to systematically track decomposition through quantitative volumetric assessment, which has potential to improve the evaluation of decay through the nondestructive observation of organic materials both externally and internally over time. These methods allow for the examination of never before captured throughout-decay details through three-dimensional analyses. Refinement of this methodology would allow for future work to systematically track organismal decay under varying conditions, correlate taphonomic histories, and provide important information to help identify the taxonomy of fossil materials.

FOSSIL VERTEBRATES OF INDIA; MAJOR PLAYERS AND MINOR ABSENTEES

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Vertebrate records of India start from the Permian. Peninsular India has no geological records of Early Palaeozoic. The Indian Permian vertebrates are mainly noted from the Pranhita-Godavari Valley of Central India and from the Kashmir region. Non marine Fishes, temnospondyls and the endothiodons are the dominating fauna there. While the fishes and temnospondyls are Pangaean in nature, the endothiodons are similar to South African fauna. The Late Permian in India is also marked by the absence of pelycosaurs. Early Triassic terrestrial vertebrates of India are known through the various temnospondyl amphibians, lystrosaurids and monospecific *Chasamatosaurus*. Early Triassic of India is devoid of any procolophons barring some doubtful occurrences. The Middle Triassic mainly has dipnoan fishes, temnospodyls, rauisuchids and prolacertids . The first sign of moderately large land predator, has, thus been noted from Middle Triassic of India. A unique short-faced temnospondyl with parabolic skull having a deep cheek emargination and the first horned allocotosaurian, *Shringasaurus*, is the hallmark of Middle Triassic of India. Late Triassic non marine vertebrates of India are highly diverse and cosmopolitan with both Laurasian and Pangaean fauna. Metoposaurs reached India during this time from Laurasia and so are the different phytosaurs. Other southern elements like the dicynodonts, chigutisaurids, as well as pangaean aetosaurs, rhynchosaurus are also present. Any large land predator, is not common in this fauna except *Tikisuchus*. Metoposaurids and chigutisaurids occurred together in same Litho-Formation in India. The continental Jurassic in India is rare and the Pranhita-Godavari valley is the only area having large sauropods (*Barapasaurus* and *Kotasaurus*), several prosauropods, sphenosuchians and the complete absence of the temnospondyls, mammal like reptiles, rhynchosaurs etcetera. The early mammals are noted from India from Late Triassic through the Jurassic. Cretaceous fauna is noted by titanosaurids and abelisaurids. The Deccan basalt flow has started

erupting during this time and India was on its isolated journey separated from the Pangaea. Before the abutment with the Chinese plate, mainly in the Eocene, the dominance of Whales, dugongs indicate a marine backdrop. Whales are thought to be originated at the Indian Subcontinent. Recently a complete skeleton of an ichthyosaur has been noted from Western India. The Cambay shales, Vastan lignite mine, some areas of Surat have yielded diverse snakes, mammals, amphibians and most notably early birds. There is a paradigm shift in the Jurassic onwards fauna of India. These fauna are either mixed marine or only marine. It is the Siwaliks from where the terrestrial faunal boom had started again. The Siwalik fauna has diverse ungulates, carnivores, proboscidians, rodents and the camelids and marks the beginning of the modern vertebrate fauna of India.

EVOLUTION OF POWERED FLIGHT IN MESOZOIC STEM BIRDS

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While our knowledge about the origin of flight across the dinosaur-avian transition has grown substantially in the last few decades, the early stages of flight evolution in early Mesozoic birds are poorly understood. Here, we reconstruct the flight strategies of a large number of stem avians, spread throughout a comprehensive phylogenetic tree. Through the identification of ancestral strategies and their related morphological attributes, we trace the earliest stages in the evolution of flight in birds. Our results document a transition from limited flapping capabilities (estimated for *Archaeopteryx* and confuciusornithids) to flap-assisted gliding flight (estimated in *Jeholornis* and non-confuciusornithid stem pygostylians), a transition that preceded the rise of ornithothoracine (Enantiornithes + Ornithuromorpha) birds. This transition appears to have been mainly correlated to wing elongation, which entailed more efficient gliding phases, in turn allowing flap-gliding pre-ornithothoracines to perform prolonged flights. We also identify a subsequent transition from flap-assisted gliding to sustained flapping capabilities among Ornithothoraces. The increase in flapping efficiency was correlated to reduction in mass and wing length abbreviation—and the associated decrease in aerodynamic drags—as well as to an expansion of the olecranon and the improvement of the lever arm of the triceps for flapping. This improvement in flapping capabilities shown by our results is consistent with several morphologies first known for Ornithothoraces: a supracoracoideus pulley in the shoulder and the new arrangement of the trailing edge in flight feathers. We argue that a significant component of gliding characterized the transition from early short-distance flappers to sustained-flapping flyers, a transition that appears to have occurred between the Late Jurassic and the Early Cretaceous. Our results also highlight mechanical constraints acting on the long evolution of birds and limiting the basic modes of flight to just a few.

THE SPATIAL DIVERSIFICATION OF EVOLUTIONARY FAUNAS

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Recent research confirms the utility of the concept of Evolutionary Faunas first outlined by Sepkoski in 1981, but the rate, magnitude, and nature of the turnover between them remain incompletely understood. We used network analysis to examine Phanerozoic marine paleo-communities and quantify the spatial and temporal patterns of Evolutionary Fauna diversification. Specifically, we asked: Where do new Evolutionary Fauna's diversify? How long does it take them to spread from where they originate and to achieve global dominance? What permits the proliferation of the succeeding Fauna relative to the preceding Fauna?

We identified five genus-level groupings of taxa ("Cambrian", "Early Paleozoic", "Late Paleozoic", "Mesozoic", and "Cenozoic" Faunas), similar in taxonomic range to Sepkoski's Evolutionary Faunas. These groupings variably dominate diversity through time and show unique responses to critical transitions, such as mass extinctions and biodiversification events. Evolutionary Fauna turnover—when one Fauna rises to dominate global richness alongside the concomitant decrease in richness of another Fauna—occurs geologically rapidly in some instances and across multiple geologic stages in others. We used data on fossil assemblages representing these groupings to consider the geographic loci of Evolutionary Fauna turnover and compared the patterns to previously documented hypotheses of spatial diversification including the "onshore-offshore" hypothesis and the "tropics as a cradle/museum" hypothesis.

Quantifying the geography and timing of dispersal of new Evolutionary Faunas allowed us to map the changing regional pool of taxa through time–a critical first step for understanding how communities assembled through the Phanerozoic.

ADVANCES IN ECHINODERM PALEOBIOLOGY: COLLABORATIONS WITH AVOCATIONAL PALEONTOLOGISTS

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For many years, paleontological research has been improved by collaborations with avocational paleontologists. These avocational paleontologists often have the expert knowledge of local geology and extensive experience in collecting fossils from local outcrops that professional paleontologists may be lacking. In particular, avocational paleontologists have been instrumental in a number of paleontological discoveries concerning the knowledge of the evolutionary history of Silurian echinoderms from the midcontinent of the United States.

For quite some time, avocational paleontologists, largely from the well-known avocational group, Dry Dredgers, based in Cincinnati, Ohio, have been collaborating with professional paleontologists in collecting specimens of unusual blastozoan echinoderms from multiple localities. In recent years, avocational workers have uncovered rare and scientifically valuable specimens of these blastozoan echinoderms. Many of these specimens have well preserved features that are not commonly preserved (e.g., delicate oral and anal cover plates and brachiole feeding plates that have only been found on a few specimens out of thousands). avocational paleontologists have even uncovered new species of these echinoderms that provided new data points in a previously unidentified spaces. The discovery of some of these new species have fundamentally shifted previous understandings of biogeographical and temporal ranges within Diploporita (Echinodermata).

Further, many studies involving these Silurian echinoderm specimens require large sample sizes (e.g., ontogenetic or taphonomic studies) that exceed what can be collected in a single field season by professional paleontologists. In a recent study, avocational paleontologists from the Dry Dredgers amassed a collection of over 1,000 specimens of a single species through diligent collecting. These specimens will be used in future analyses to quantify growth trajectories of these organisms, as well as to quantify the role that environmental factors might play on overall body morphology.

Examples such as these discoveries illustrated above show the undeniable value of collaborations with avocational paleontologists in advancing paleontological research. These relationships benefit both avocational and professional scientists alike and facilitate broader participation in peer-reviewed publications, conference presentations, and more.

A HIGH-RESOLUTION MARINE INVERTEBRATE BIODIVERSITY TRAJECTORY FROM CAMBRIAN TO EARLY TRIASSIC

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One of the great challenges in understanding the history of life is resolving the role of environmental changes in controlling past biodiversity, which requires high temporal resolution of both fossil occurrences and environmental proxies. Previous analyses of long-term paleobiodiversity were largely resolved to ~10 Myr, which are too coarse to reveal fine details. Using quality-controlled stratigraphic occurrence data of Paleozoic marine invertebrates from across China, high-resolution biostratigraphic zonation, quantitative stratigraphic methods, and unbinned biodiversity calculation removed a major obstacle to resolving power in reconstruction of biodiversity trajectories and enabled us to reconstruct generic and species levels diversity patterns at a mean ~26 kyr-resolution. In contrast to previous analyses, the results show very different diversification and extinction rates for the entire Paleozoic and also for both the end-Ordovician and end-Permian mass extinctions. There was a long-term diversity decline from the early Middle Devonian until slightly above the Frasnian/Famennian (F/F) boundary. Biodiversification events include the Cambrian Radiation, the Great Ordovician Biodiversification Event, the Early Silurian Radiation and the late Carboniferous to early Permian biodiversification event associated with the Late Paleozoic Ice Age. To evaluate the influence of temporal resolution on apparent paleobiodiversity patterns, we smoothed the data to different resolutions. An average resolution of 0.5 Myr

produces optimal diversity estimates.

A COMPARATIVE STUDY OF ARMOURED PALAEOSCOLECIDS FROM THE CHENGJIANG BIOTA

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The palaeoscolecids are a group of extinct worms with an elongate, cylindrical, annulated body, an armoured proboscis and two posterior hooks. Ranging from Cambrian to Silurian, this group of animals are particularly abundant in Cambrian marine communities and played an important role in the evolution of early ecdysozoans. Several exceptionally preserved palaeoscolecid macrofossils were reported from the Chengjiang Biota, including *Mafangscolex sinensis*, *Cricocosmia jinningensis*, *Maotianshania cylindrica, Tabelliscolex hexagonus* and *Tabelliscolex maanshanensis sp. nov*. Different from all other palaeoscolecids, *Cricocosmia* and *Tabelliscolex* are armoured with segmentally arranged sclerites along the trunk. However, the morphological details of these sclerites are not clear, which hinders the understanding of their homology and evolutionary significance. This study is using newly collected fossil material at the Yunnan Key Laboratory for Palaeobiology, as well as applying the latest imaging and analytical techniques, to carry out detailed comparative studies on these armoured palaeoscolecids from the Chengjiang Biota.

SHEDDING SYNCHROTRON LIGHT ON THE ARCHITECTURE AND EVOLUTION OF CONODONT FEEDING APPARATUSES

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Conodonts are the first vertebrates to have developed mineralised tissues, forming microscopic teeth-like structures, known as elements. They are ubiquitous in marine rocks originating from the late Cambrian to Late Triassic. Due to the rarity of soft tissue preservation, the majority of specimens aredisarticulated and leave no insight into the structure of the original oral apparatus. The scarcity of information on 3D structures of the apparatus hinders reconstructions of the evolution of this hyperdiverse group and limits the understanding of its functional morphology. Architectural reconstructions of conodont apparatuses can be obtained from clusters - diagenetically fused elements that preserve the relative positions of elements.

We employ Synchrotron Radiation X-ray Tomographic Microscopy (SRXTM) to produce virtual models of the apparatus of the conodont clusters from the Kokomo Limestone of Indiana. These models help resolve homology among element positions, quantitatively test hypotheses on the feeding mechanisms of conodonts, and thus on their ecological role inmarine ecosystems. Furthermore, defining these positions provides the ability to establish character-based phylogenies. Constraining functional morphology by character-based phylogenies is essential to reconstruct the evolution of feeding ecology. This, in turn, allows testing hypotheses on the evolution of early marine ecosystems and their trophic structures.

PHOSPHORUS DRAWDOWN DROVE REDOX STABILISATION AND METAZOAN DIVERSIFICATION IN THE TERMINAL EDIACARAN NAMA GROUP, NAMIBIA

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The terminal Ediacaran witnessed a notable increase in metazoan diversity and ecological complexity marking the start of the Cambrian Explosion. In order to constrain the drivers of this diversification, we integrate high-resolution local redox (iron speciation) and nutrient (phosphorus speciation) data spanning full shelf to basin transects with a complete inventory of biotic diversity and distribution from the Nama Group, Namibia (~550 to ~538 Million years ago (Ma)). Unstable shallow marine redox conditions characterise all depths from ~550 to 547 Ma when the first skeletal metazoans appeared, but a marked deepening of the redoxcline and a reduced frequency of anoxic incursions onto the inner to mid ramp is recorded from ~547 Ma onwards. An increase in Mn/Fe further indicates progressive oxygenation of the inner ramp until ~542–540 Ma, with full ventilation

of the outer ramp being reached by ~542 Ma. This redox stabilisation coincided with the first appearance and marked diversification of sediment burrowers in shoreface and eventually mid ramp settings. P speciation data shows that basin-wide nutrient limitation was mediated by water column drawdown of reactive P under ferruginous conditions. We propose that the gradual ventilation and subsequent redox stabilisation of the Nama Group basins was linked to a long-term decrease in bioavailable phosphorus, shifting from dominantly anoxic, eutrophic to oxic, oligotrophic conditions, which in turn promoted the radiation of new mobile taxa.

PREDICTING PALEOENVIRONMENT FROM COMMUNITY MORPHOLOGY OF ARTIODACTYL LIMBS TO UNDERSTAND CHANGE THROUGH TIME

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Conservation paleobiology uses the fossil record to increase the long-term understanding of biotic responses to environmental change and to inform ongoing conservation efforts of extant taxa. Ecometric analyses quantify assemblage-level functional trait responses to environmental change and can be used to estimate paleoclimates from fossils preserved in a community or assemblage from a past location and time. We provide ecometric models of Artiodactyla that can be used to improve our understanding of the relationship between morphology and environment through time using gear ratios calculated from linear measurements of calcanea and radioulnae. The gear ratio is a measurement of the overall length of the element divided by the length of the in-lever. A low gear ratio indicates a long in-lever and a more plantigrade stance whereas a high gear ratio indicates a short in-lever and a more unguligrade stance. Artiodactyla has a nearly global distribution and taxa frequently overlap geographically to create a myriad of unique communities that are impacted by environmental change. Using community lists at 50km equidistant points, communities were sampled for mean and standard deviation of gear ratio as well as temperature, precipitation, and vegetation cover. A maximum likelihood approach was used to discern trait-environment relationships and to produce paleoenvironmental estimations. Finally, anomalies were calculated between the actual values and the estimated values. For precipitation, anomalies produced by the calcaneum ranged between -6.30 and 2.60 (mean=-0.26) whereas anomalies produced by the radioulna ranged between -6.77 and 3.24 (mean=-0.14). This suggests that community morphologies of calcanea and radioulnae can be used to estimate paleoprecipitation by applying these ecometric models to paleontological communities. An understanding of past community morphology and responses to environmental changes will enable better predictions of responses to expected future changes.

A MASS EXTINCTION OF OPEN-OCEAN SHARKS 20 MILLION YEARS AGO

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Sharks are an important group of top predators in most marine habitats, however their populations have been decimated in recent decades. Shark finning, overfishing, pollution, and other anthropogenic stressors have pushed the group to the brink of extinction. However, this is not the first time that shark populations have suddenly and dramatically declined in marine environments. Here, we investigate a rapid transition approximately 20 million years ago (Ma), when shark fossils, particularly isolated dermal scales (denticles), virtually disappeared from open-ocean sediments, reducing in absolute abundance by >90%, as well as relative abundance within a microfossil assemblage, from one shark fossil for every 5 fish fossils in samples older than 20 Ma to fewer than one shark fossil for every 100 fish fossils after the event. This disrupted the otherwise stable marine vertebrate community structure established following the Cretaceous-Paleogene Mass Extinction. We investigated this dramatic reduction of sharks in the open ocean by developing a morphological framework for description and classification of denticles, and then using the system to quantify morphological variation in over 1000 fossil denticles from DSDP Site 596, in the South Pacific gyre spanning 40 Ma to present and ODP Site 886, in the North Pacific gyre, spanning 34 Ma to 10 Ma. We also coded denticles from 130 species of extant elasmobranchs, to create a catalog of modern denticle diversity.

We find that there are two major types of denticles in open-ocean sediments: denticles with parallel or near-parallel ridges ('linear denticles') that aretypically associated with modern sharks, and denticles with complex, intersecting ridge-patterns ('geometric denticles'). Prior to 20 Ma, geometric denticles were

common in assemblages, with a diverse range of morphotypes present, however in sediments younger than 20 Ma, geometric denticles are extremely rare, both in absolute abundance, and when compared to the abundance of linear denticles, which also declined after 20 Ma. Further, only one major morphotype class of geometric denticle persists across the 20 Ma horizon, suggesting a near extinction of geometric-denticle-bearing sharks. Linear denticles also show a reduction in both morphological diversity across the event. Although there is no known significant geological event at 20 Ma, this transition is significant in the structure and function of marine vertebrate communities. Modern geometric denticles are associated with pygmy and cookie cutter sharks, tiny deep-sea sharks which do not swim long distances and have unusual trophic strategies. Linear denticles, in contrast, are associated with distance swimming sharks that actively hunt smaller prey. These results highlight 20 Ma as a potential tipping point for marine vertebrate communities and open ocean ecosystems, and demonstrate the utility of the marine vertebrate microfossil record in elucidating ecology and evolution in deep time.

TESTING THE ECOLOGICAL "RULES" THAT GOVERN TRAIT PLASTICITY USING BONY FISHES (OSTEICHTHYES)

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Early ichthyologists proposed broad ecogeographic correlations between fish characteristics and environmental variables such as habitat and temperature. However, most of these accepted "rules" have never been subject to quantitative assessment, limiting their utility for inferring ecology in the fossil record. One of these is 'Jordan's Rule,' which assumes the number of vertebrae in the skeleton of fishes varies with temperature, so that fishes inhabiting colder areas have higher counts of vertebrae than those in warmer climes. As originally stated, there is also strong phyletic or temporal signal: fish families with older divergence times tend to have higher numbers of vertebrae than those in clades with more recent common ancestry. Methodologically, vertebral counts are useful because they can be traced throughout the fish fossil record, offering an easy alternative metric from body size (though one which may not be entirely independent). The 'temporal depth' of the fish record, known homology, and plethora of intact axial columns could allow us to address the relevance of vertebral counts to ecological patterns at a variety of scales. Likewise, a specimen-based indicator of likely paleolatitude would be a boon to paleogeographical reconstruction. However, the observed latitudinal pattern in living fishes has yet to be corroborated fully, halting these promising research avenues in the fossil record. Most neontological work on Jordan's Rule has addressed trends on the scale of populations without looking at the patterns among higher-level taxa and has not tested for phylogenetic signal. Here, we combined fish vertebral count and environmental data from public compendia for living fishes such as Fishbase and GBIF and morphological surveys for more explicit tests of this accepted link. The high degree of convergence in fish body forms suggests that at some scale functional constraints of mobility in an aqueous environment could be paramount, driving adaptation, but that Jordan's Rule may still exist within these constraints. Thus, we also tested whether swimming mode and habitat are confounders in the signal of these data. Finally, we tested for phylogenetic signal – do older clades show greater counts or variation than younger fish families. Even if Jordan's Rule writ large fails to hold up under quantitative scrutiny, disproving a long-held assumption, explorations of vertebral counts should still help elucidate fish macroevolutionary and macroecological patterns. For instance, theory suggests that functional redundancy of serial homologous traits increases potential for differentiation and diversification. Alternatively, parts could accumulate in the absence of selective pressure. Our data should help clarify which is true in the case of fish spines, and when.

DOES DISPERSAL MECHANISM IMPACT THE ABILITY TO RESPOND TO RAPID, INTENSE CLIMATE CHANGE? A CASE STUDY IN TREES OF THE YOUNGER DRYAS

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Climate change has been implicated in all five of the great Phanerozoic mass extinction events, is thought to be responsible for a significant fraction of background extinctions, and is widely regarded as a dire threat to biodiversity in the coming centuries. Yet, despite differing extinction selectivity regimes of morphological and ecological species traits, we know relatively little about how species with different traits reacted to episodes of past climate change theorized to be causal to extinction events. This information will be invaluable in predicting how organisms will react

to future climate change.

In this study, I examine the movement of plant populations in North America and Europe during the Younger Dryas (13-11 Ka) as a function of their seed dispersal mechanism, using pollen data from the Neotoma database. A growing body of evidence implicates seed dispersal as influencing species geographic range size limits, which in turn affects their survival probabilities in all but the most intense extinction events. My recent work on seed dispersal in the Miocene of North America implies that extinction selectivity regimes on seed dispersal mechanism are different depending on the intensity of climate change experienced. The Younger Dryas provides an excellent model for studying the effects of climate change intensity on species traits, because the Younger Dryas was most intense in Europe and North America (2-6 degrees C), comparable to projected anthropogenic warming, in contrast to the much less severe climatic changes elsewhere in the world (1-2 degrees C).

Results so far indicate that ranges of plant taxa are strongly affected by relict populations that can persist for centuries in habitat rendered unfavorable by intense climate change before eventual extirpation. Animal-dispersed taxa expand their ranges more rapidly than taxa without animal dispersal, but coastal habitats and other forms of refugia complicate interpretations. That populations can persist for centuries in unfavorable habitat raises implications for conservation: first, the fact that a population exists does not mean that it is sustainable, and second, the presence of these persisting populations provides conservationists with a longer time window during which human-assisted colonization (i.e. animal dispersal) can allow endangered taxa to reach more favorable habitat.

THE ECOMORPHOLOGY AND MACROEVOLUTION OF THE SYNAPSIDA THROUGH THE PERMO-TRIASSIC

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The Synapsida enjoyed great taxonomic and ecological success through the Permian, and dominated terrestrial ecosystems. Their 'reign' as the dominant terrestrial tetrapods in the late Palaeozoic saw the evolution of relatively modern ecosystems, with the radiation of herbivory and the development of complex trophic networks. Synapsids were severely impacted by the Permo-Triassic mass extinction, but diversity studies show that surviving clades (Anomodontia and Eutheriodontia) recovered quickly. Nonetheless, synapsids ultimately ceded ecological dominance to diapsid archosaurs through the Triassic. This decline of non-mammalian synapsids was a key moment in evolutionary history, as archosaur prevalence would eventually foster the rise and terrestrial supremacy of the dinosaurs through the remainder of the Mesozoic Era. The nature of this faunal turnover remains uncertain, though modern analyses suggest it was a passive process, driven largely by environmental changes.

Our study provides an ecological perspective of synapsid macroevolution through this interval, from the Permian to the Early Jurassic. We apply geometric and functional morphometrics alongside phylogenetic comparative methods, using the ecomorphology of >200 synapsid genera to infer patterns of trophic ecology and evolution. Our results support extrinsic, environmental events as the primary drivers of synapsid macroevolution, but also find that intrinsic, ecological factors greatly influenced how some clades responded to environmental pressures. We find surprising and contrasting rates and patterns of morphological evolution through key events, such as the Permo-Triassic extinction and the Carnian Pluvial Event. Consequently, our findings highlight the complex interplay between extrinsic & intrinsic factors in shaping macroevolution, and the need to consider both when trying to understand the course of evolution through deep time.

COMPARISON OF EARLY PALEOCENE ICHTHYOFAUNAL DIVERSITY FROM CROC POT AND ROCHE PERCEE LOCALITIES, RAVENSCRAG FORMATION, SOUTHERN SASKATCHEWAN, CANADA

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The early Paleocene Ravenscrag Formation, representing a freshwater riverine environment, crops out in smaller localities near the towns of Eastend and Ravenscrag in southwestern Saskatchewan and Roche Percee in southeastern Saskatchewan. In particular, four fossil localities of Puercan age of the NALMA Paleogene period, namely Croc Pot, French Fry, RAV W1, and Pine Cree, are known from the southwest, while Roche Percee of Tiffanian age is known from the southeast. The Ravenscrag Formation is underlain by the Late Cretaceous Frenchman Formation and overlain by the Eocene-Oligocene Cypress Hills Formation. Since the discovery of the sites in the 1970s, diverse

vertebrate faunas have been reported, however, only the mammalian fauna have been extensively documented. The ichthyofaunas from Roche Percee and Croc Pot are here described. The ichthyofaunas are diverse and include the following fish taxa: *Lepisosteus*, *Esox*, Amiidae, Osteoglossidae, Percopsidae, Holostear A, Hiodontidae, and Gonorhynchiformes. Studies o the Paleocene faunas will help bridge the faunal ga between the faunas of the Late Cretaceous Frenchman Formation and the early Eocene to Oligocene Cypress Hills Formation. The abundance of fish fossils from both Paleocene sites are almost equal, whereas the diversity is greater in the Roche Percee locality. Varied environmental conditions are deciphered from the diverse fish taxa recovered.

THE CAMBRIAN EXPLOSION WITHOUT THE HARD-PARTS

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The most striking signal in the fossil record is the rapid rise in diversity of metazoan-derived skeletal hard-parts preserved in early Cambrian strata. Along with the expansion of trace fossil diversity at this time, such shelly fossils form the most obvious expression of the Cambrian radiation. Rare Konservat-*Lagerstätten* sites, however, reveal that fossils of organisms producing mineralized hard-parts represent only a small proportion of the total diversity, which largely comprised unmineralized forms. An alternate, but largely overlooked source of data on otherwise taphonomically invisible unmineralized taxa comes from the emerging record of 'small carbonaceous fossils' (SCFs). SCFs encompass a polyphyletic variety of fragmentary cuticular remains sourced from animals, algae and protists, and are beginning to reveal new aspects of Cambrian diversity from regions and time-windows where there are no known Burgess Shale-type *Lagerstätten*. A detailed new accounting of SCF records from Ediacaran–Cambrian successions on Baltica, Laurentia and elsewhere, reveals a clear temporal trend: early Cambrian (Stage 3–4) SCF assemblages are typically rich in metazoan diversity, including iconic taxa well known from Burgess Shale-type biotas elsewhere. Older 'pre-trilobitic' (Terreneuvian) assemblages are characterized by comparatively lower metazoan diversity and exhibit greater regional homogeneity of the fauna. Despite an entirely different taphonomic pathway, and though many of the taxa differ, this emerging signal broadly mirrors that recognized for the classical Cambrian radiation of 'shelly' fossils.

BASIN AND RANGE TECTONICS DRIVE DIVERSIFICATION DYNAMICS IN NORTH AMERICAN MAMMALS

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Mountains are biodiversity hotspots today for many different plant and animal groups. For example, rodent species richness in the high-relief Basin and Range Province of western North America is nearly double that of the low-relief Great Plains region. However, the underlying processes linking the formation of topographic complexity and the generation of biodiversity remain unresolved. To investigate how the landscape and climate history of the Basin and Range Province influenced macroevolutionary dynamics, I used a dense record of fossil rodent occurrences extracted from the MioMap database to evaluate past diversity patterns. Integrating information from geophysical models of tectonic activity in the region revealed a striking and significantly positive relationship between the rate of tectonic extension and species richness from 30 to 5 Ma. To further test if diversification rates are influenced by tectonic forces shaping topographic complexity in the region, I used the PyRate Bayesian modeling approach to jointly infer preservation, origination, and extinction rates from fossil occurrence data. In addition to tectonic extension, I tested alternate drivers of macroevolutionary dynamics, including diversity dependence and global temperature. I also assessed the area of the rock record as a driver of diversification patterns to evaluate whether preservation had a confounding effect on diversity. Implementing a multivariate birth-death model, I tested for correlations between these four time-continuous variables and origination and extinction rates through the Neogene. Under this model, I found a peak in origination rates from 20 to 15 Ma and lower variability in extinction rates through time. Origination rates were significantly correlated with rates of tectonic extension (positive correlation) and diversity dependence (negative correlation). In contrast, extinction rates were significantly correlated with temperature (negative correlation) and rock area (positive correlation). These results suggest that there were marked shifts in the dominant driver of macroevolutionary dynamics through time, with tectonics generating an origination pulse in the middle Miocene and cooling global temperatures following the warm Miocene Climatic

Optimum leading to increased extinction rates later in the record. In addition to these abiotic factors, origination rates depended on within-rodent diversity. The integration of dynamic landscape and climate histories with biological processes is key to understanding the formation of strong biodiversity gradients in relation to topographic complexity today and in the past. Tests from the fossil record strengthen the evidence that mountains were a species pump over geologic time; however, potentially only during periods of major tectonic activity and landscape change.

PHYLOGENETIC CONSERVATISM OF BIOTIC CRISES IN NORTH AMERICAN MAMMALS

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A priority research goal for paleoecology is to better understand the causes and consequences of past biotic crises, including mass extinctions. While the majority of the 'Big 5' mass extinction events have unique patterns and 'symptoms' of ecological change, less is known about the ecological consequences and drivers behind the major biotic crises of the Cenozoic Era. Phylogenetic signal may reflect these, as many intrinsic attributes in mammals (e.g., body size, gestation length, and trophic level) are phylogenetically conserved and would therefore be expected to render closely related species susceptible to extinction. Similarly, phylogenetic conservatism in a group of mammals that originate during the same interval might reflect environmental conditions that favored the emergence of intrinsic attributes shared by these mammals.

Here, we test for phylogenetic selectivity in mammal extinction and origination over the last 70 million years, an interval that encompasses numerous climatic and biogeographic changes as well as at least 5 noteworthy biotic crises. We quantify two indices of phylogenetic clustering and compare them with various diversity and turnover metrics throughout the Cenozoic. Our results suggest that the taxonomic and ecologic severity of mammalian extinction events throughout the Cenozoic were often decoupled. In particular, of the 4 extinction events with the highest taxonomic severity (the K-Pg extinction, PETM, EOT, and end-Pleistocene extinction), only 2 (the K-Pg and EOT) were highly clustered. The K-Pg bolide impact coincides with the loss of some stem mammal lineages (e.g., Metatherians and Multituberculates) and cleared the way for the adaptive radiation of multiple Eutherian lineages. The EOT saw the loss of many small mammal faunas (e.g., Rodentia and Lagomorpha). Both the PETM and the LPE were non-selective extinction events that eliminated lineages across the tree of life, perhaps due to new migrations, convergent evolution, and/or competitive exclusion. Our study yields promising results for examining the relationships between extinction trigger, extinction magnitude, and phylogenetic signal in mammalian faunas, and for assessing the degree to which anthropogenic impacts have structured the composition of the modern biosphere.

POLISHED SLABS OR THIN-SECTIONS? EXAMINING THE CONSISTENCY OF ALPHA DIVERSITY ESTIMATES ACROSS DIFFERENT MEDIUMS

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Both polished slabs and thin-sections are frequently used for equal area quadrat counts when quantifying the alpha diversity (taxa-richness) of a given fossil ecosystem. Although similar, the difference in resolution between each medium may lead to discrepancies in collected data. This study quantifies the differences in alpha diversity estimates produced using either polished slabs or thin-sections for equal area quadrat counts. In doing so, this study aims to provide a standard for alpha diversity comparisons across the two mediums. A set of six Norian reef carbonate samples were collected from Gosaukamm Mountain in Austria and processed to make polished slabs and thin-sections. The thin-sections were cut parallel to the polished surface. A 7.5 cm x 7.5 cm grid was overlain onto each of the twelve study samples, and an equal area count was conducted. Accumulation curves were used to determine the number of quadrats counted, and only macro-organisms were considered during the study. Bray-Curtis dissimilarity was used to compare the estimated composition of polished slabs with the corresponding thin-sections. The results of this study show the differences that exist in the accuracy, consistency, and reliability between these mediums.

RESTORING THE BIVALVE COMMUNITY IN THE COLORADO RIVER ESTUARY: JUST ADD WATER?

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Damming and diversions of the Colorado River during the last century have led to widespread ecological change in the downstream Colorado River estuary, including declines in the populations of many estuarine species (e.g., the clam *Mulinia modesta*). Restoration efforts in 2014 attempted to emulate a spring flood as occurred in the past to recreate estuarine conditions in the region. With the restoration flows, which amounted to approximately 1% of the Colorado River's annual historical discharge, targeted on the lowermost portion of the Colorado River, only 1% of the flows reached the most landward portion of the estuary. The restoration flows temporarily reduced salinity in the northernmost estuary and isotopic data from living foraminifera in the estuary suggest that, in recent years, agricultural runoff from the Hardy River has served to further reduce salinity.

Weeks prior to the restoration flows in 2014, live-dead samples were collected from two sites in the estuary to provide a baseline for the living bivalve community as compared to the past community represented in local accumulations of dead shells. At each site, approximately 50 samples were collected. All samples were sieved at 5-mm and all specimens were identified to species level, then counted. These baseline samples indicated a counterintuitive increase in the richness and evenness of the modern community; however, there was no discernible difference in taxonomic composition or rank-order abundance between dead and living samples.

Live-dead samples from the same sites were collected using the same protocol in February 2018—and will be collected in April 2019—to evaluate the effects of reduced salinity on the bivalve community. The samples collected in 2018 (n=217, with 6,839 specimens) contained only two living species, *Chionista fluctifraga* and *M. modesta*, indicating a potential return to a community with low richness and evenness, as occurred in the past. Notably, however, local *M. modesta* densities in the living community remained well below those estimated from the past. Although *M. modesta* densities remain lower than in the past, the relict population persisting in the estuary is primed for recovery, if habitat conditions and public support are favorable. If the runoff from the Hardy River was sufficient to reduce salinities in the estuary enough to induce spawning in *M. modesta*, restoration may be a matter of just adding water. Additional monitoring efforts focused on the living bivalve community are needed to further assess the effects of reduced salinity on community structure.

LIFE IN THE DEAD ZONE: A DIVERSE ICHNOFOSSIL ASSEMBLAGE PRESERVED IN VOLCANIC ASH, ASHFALL FOSSIL BEDS STATE HISTORICAL PARK, NEBRASKA, USA

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Ashfall Fossil Beds (AFB) preserves an extraordinary *Konservat-Lagerstätte* of Miocene vertebrate fossils; most of which are fully articulated and preserved in their original 3-dimensional death poses. The ash bed is stratigraphically within the Ash Hollow Formation of the Ogallala Group and interpreted as the fill of an ephemeral watering hole based on its lenticular geometry, sedimentary structures, and the taphonomy and paleoecology of the *Lagerstätte*. Colloquially, the ~3-m-thick ash bed is divided into three zones—the Skeleton Zone (lowest ~25 cm, containing mostly fossil ungulates), the Dead Zone (~2 m of pure ash in which body fossils are absent), and the Recovery Zone (ash and sand mix above ~225 cm, containing fluvially-transported vertebrate fossils). While AFB has been the site of nearly continuous paleontological research since its discovery, less attention has been paid to the diverse assemblage of vertebrate and invertebrate ichnofossils of the deposit. The Skeleton Zone and underlying sandstone contain such invertebrate ichnofossils as abundant fossil ant nests (*Daimoniobarax* isp.) and actively backfilled and passively filled invertebrate burrows (e.g., *Naktodemasis bowni* and cf. *Cylindricum*). There are also small (~6 cm) and large (~16 cm) diameter vertebrate burrow networks (cf. *Alezichnos*), in addition to large vertebrate tracks and trample zones. The Skeleton Zone is cross-cut by traces originating from the overlying Dead Zone; including branching $CaCO_3$-rhizoliths and large diameter (~70 cm x ~37 cm), subvertical (inclined ~70°) burrows associated with bone-fragments and likely produced by canids digging for ash-entombed carcasses. The Dead Zone also contains multiple $CaCO_3$-cemented algal mats of various morphologies, coprolites, canid trackways, and low numbers of *Daimoniobarax* and vertebrate burrow networks. Such invertebrate traces as *Daimoniobarax*, *Naktodemasis*, cf. *Cylindricum*, and cf. *Macanopsis* and small-diameter vertebrate burrow networks greatly increase in abundance just below and into the Recovery Zone. The ichnofossil assemblage

suggests that the Dead Zone was very much alive with multiple episodes of organisms colonizing and bioturbating the ash bed, likely during depositional hiatuses and subaerial exposure. The Ashfall Fossil Beds ichnofauna are in situ evidence of hidden biodiversity and organismal behavior not typically preserved or decipherable from the body fossil record alone.

TERTIARY CARIBBEAN MOLLUSKS AND THE ANCIENT GULF OF CALIFORNIA

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Before there was an ancient gulf the Baja California Peninsula lay against mainland west México, its tip near Puerto Vallarta, Jalisco. Crustal thinning, probably in connection with Middle Miocene Basin and Range extension, allowed western Sonora to sink below sea level. Seawater first reached the northeastern gulf and basins south of Yuma, AZ by 11.6 Ma. Marine sediments in some basins include in situ Middle Miocene dinoflagellates and nannofossils (Helenes et al., 2009, Marine Micropaleontology v. 72). Younger, Late Miocene megafossils date the arrival of seawater in the west central and northwestern gulf ca. 7.5–6 Ma in the Loreto, Boleo, Puertecitos and San Felipe basins, and in the southwestern Salton Trough from Coyote Mountain to Barrett Canyon and Fish Creek Basin. The same megafossil assemblage is found at southwestern Isla Tiburón in a marine section dated ~ 6.5 Ma, a correction by Bennett et al. (2015, Geosphere, v. 11) of an erroneous date published in Gastil et al. (1999, Revista Mexicana Ciencías Geológicas v. 16). These Late Miocene megafossils, best known from the Imperial Group Latrania Formation at Coyote Mountain, are also found in the Trinidad Formation in the San José del Cabo Trough along with older species that lived in western embayments of mainland México before the ancient gulf existed. Many taxa are Caribbean, found in Late Miocene formations in Trinidad, W.I., Venezuela, Colombia, Panamá, Ecuador and northern Perú. Paleontologic data from the ancient gulf support the model of Sutherland et al. (2012, Geosphere, v. 8) that uses multiseismic data from the southern gulf to date the onset of NW-SE extension at 14–12 Ma, well before a 6 Ma date favored by Oskin and Stock (2003, GSA Bulletin, v. 115) and Bennett et al. (2015, Geosphere, v.11) for earliest ocean water and the onset of oblique extension in the northern gulf. Caribbean mollusks occur in the Latrania Formation at San Gorgonio Pass and Painted Hill ("east of Whitewater River" auctt.) with Late Miocene 6–6.3 Ma microfossils and reworked Middle Miocene microfossils (McDougall, 2008, GSA Special Paper 439). I suspect that seawater did not extend that far north and that fossiliferous sediments were transported there before the Early Pliocene appearance of the San Andreas Fault system at 5–4 Ma (Mattie and Morton, 1993, GSA Mem. 178). Evidence of a Late Miocene shoreline includes Latrania Formation species in beach deposits southwest of Travertine Point and the Salton Sea. Taxonomic revisions make this an early report in the ancient gulf of many well-known Late Miocene Caribbean index species, including *Amusium mortoni, Anadara thauma* (=*A. carrizoensis* auctt.), *Dosinia grandis, Leopecten gatunensis, Spondylus* sp. cf. *S. falconensis, Conus bramkampi*, *Melongena consors, Murexiella (Subpterynotus) textilis*, *Strombus gatunensis*, *Turritella altilira* (=*T. imperialis*Hanna), and *Vasum haitensis*.

BRIDGING THE GAP: OUTREACH AND RESEARCH CONTRIBUTIONS OF THE NORTH AMERICA RESEARCH GROUP

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The North America Research Group (NARG) is a paleontology club founded in 2004 and based in Hillsboro, Oregon. Our mission is, "to encourage responsible stewardship of Earth's paleontological resources and to promote scientific research, communication and public education". NARG creates a space for individuals to develop their skills in collecting, preparation, display, general knowledge of paleontology and fossil conservation. In terms of public outreach, NARG hosts an annual FossilFest; participates in multiple FossilFests and rock, mineral, gem and fossil shows; prepares fossils at the Oregon Museum of Science and Industry's open prep lab and uses the most up-to-date teaching practices in the classroom. NARG is also a proud participant with FOSSIL. Discoveries by NARG members have led to around a dozen publications of new plant, invertebrate and vertebrate fossils, increasing our understanding of the diversity of life in the Pacific Northwest. As of such, paleontology clubs like NARG, that traverse the spectrum of paleontological expertise, are vital for outreach and research in maintaining the long-term sustainability of paleontology.

PLANT RESPONSE TO ENVIRONMENTAL CHANGE: A CASE STUDY OF MACROFOSSILS FROM THE

DECCAN INTERTRAPPEAN BEDS OF INDIA

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The Deccan Intertrappean Beds of India preserve a diverse biota that spanned the Cretaceous-Paleogene (K-Pg) boundary and was paleogeographically isolated, providing data on the response of a unique ecosystem to environmental changes and the role of India in the evolutionary and biogeographic history of many groups. Plants are primarily preserved in cherts, in three dimensions with anatomical structure and are represented by wood, leaves, stems, fruits, flowers, seeds, strobili, and pollen and spores. Paleobotanical localities are found predominantly in the Eastern Deccan Volcanic Province and Mandla subprovince. Data on species occurrences from 34 localities, representing a subset of the total number o known localities for which we have some confidenc of age, was compiled. Across all localities, the fractio of taxa represented by wood, non-wood megafossils, and palynological samples is about even. The most diverse locality is Mohgaonkalan, with >280 species described; the next highest is Mahurzari, with ~45 species, and most have <20 species. It is not clear to what extent these number are real vs. an artifact of incomplete sampling; Mohgaonkalan is the classic Deccan Chert locality and has received the most attention, while many of the others are more recently discovered. Fruit/seed taxa that are widespread in the Maastrichtian include *Enigmocarpon* (Lythraceae), *Indovitis* (Vitaceae), *Palmocarpon patanii* (Arecaceae?), and the incertae sedis taxa *Sahnipushpam, Baccatocarpon, Pantocarpon, Graminocarpon*, and dispersed seeds of *Harrisostrobus*. Sites considered to be Maastrichtian in age such as Mohgaonkalan and Mahurzari are more diverse and more different from each other than Paleocene sites such as Ghughua and Dhangaon, which occupy a subset of the Maastrichtian space in NMDS analysis. ~30 taxa, including many palms, as well as some pollen taxa of uncertain affinities, do not appear to be affected by the boundary event. Both ferns and gymnosperms show decreased species diversity in the Paleocene sites, with monocots seeming to form a greater fraction of the species diversity and non-monocot angiosperms remaining about the same at almost 50% of species composition. Numerous taxa are in need of reinvestigation to fully appreciate the extent of ecosystem disturbance at different taxonomic levels, as a large number of them remain incertae sedis, and new specimens and localities are still being collected. Geochemical data from paleosols show no significant change in temperature or precipitation across the K-Pg, and indicate a wet, temperate forest floral humidity province, consistent with palynological data. Further scrutiny to distinguish the effects of differential investigator bias from features of ecological, environmental, and/or stratigraphic significance is necessary. However, the general pattern of decline of ferns and gymnosperm—which form a small component of the flora—and replacement by the more diverse angiosperms is likely to hold.

HOW PREDICTABLE IS EXTINCTION? FORECASTING SPECIES SURVIVAL AT MILLION-YEAR TIMESCALES

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One of the great promises of paleobiology is that by studying the past we can better predict the future. This promise is particularly pertinent given as risk assessments for some modern species could potentially be improved by examining past extinction patterns and by using paleontological records to establish geographic range and abundance trajectories on geological timescales. Any effort to assess future risk based on past extinctions and range trajectories must address two key questions: (1) At a given timescale, are geographic range and extinction risk trajectories deterministic (past trends are likely to continue into the future) or Markovian (the future depends only on the present state)? (2) Given knowledge of past extinction/survival patterns and the present geographic ranges of extant taxa, how accurate are extinction risk predictions?

To address these questions we analyze the fossil record of Cenozoic planktonic microfossil taxa (foramanifera, radiolarians, diatoms, and calcareous nanoplankton). Using a model of species survival, we analyzed how survival probability changes over time as a function of species age, time of observation,

current geographic range, most recent change in geographic range, global temperature average, and the lag of global temperature. Our best supported model includes the historical covariates, change in geographic range and lag of global temperature, which indicates that the past improves our estimates of the present and future.

Our results show that our best performing model has an approximately 78% median probability of correctly ranking the relative extinction risk any two randomly selected species. Including the historical covariates and allowing their effects to vary over time yields marginally better predictions than not including them. However, the improvement in predictive power by including these historical covariates is modest at best, absent at worst, and ultimately reflects the extremely stochastic nature of species extinction. Using k-fold cross-validation, we found that in-sample model performance measures are approximately equal to out-of-sample performance, meaning that we can have confidence that our conclusions about our ability to predict species extinction risk in the future with similar accuracy to when we predict species extinction risk in the past. These results imply that at million-year timescales geographic range trajectories are nearly Markovian, perhaps because the processes driving geographic range changes vary on substantially shorter timescales. The effect of change in geographic range on survival most likely stands for many interacting and unobserved processes which in-turn produce that species' geographic range and its affect on survival. The results of this study reinforce the importance of the promise of paleontology and using the past to predict the future.

TESTING THE INFLUENCE OF HUMAN INTERFERENCE ON LAND SNAIL RICHNESS AND COMPOSITION FROM TEMPERATE FORESTS IN OHIO

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Anthropogenic disturbances are rapidly expanding through modification of urban through rural landscapes, significantly impacting species composition of animal and plant communities. Terrestrial snails, which exhibit reduced mobility and dispersal abilities, and high-habitat specialization, are thought to be highly sensitive to human interference and, it follows, therefore, that land-snail community composition should be greatly impacted by anthropogenic disturbance. To test this hypothesis, land snail diversity of macrosnails (>5mm) and microsnails (<5mm) was studied along an urban-to-wildland gradient in SW Ohio along which there was thought to be decreasing human influence, including: Mt. Airy Forest (within the city of Cincinnati), East Fork Wildlife Area (39 km east of Cincinnati), and Edge of Appalachia (124 km east of Cincinnati). We predict that old-growth (less human-impacted) forests exhibit greater abundances of woody debris and higher soil organic content, resulting in higher diversity of land snails. In contrast, second-growth (highly disturbed) forests should exhibit lower snail diversity.

A total of 27 species of macrosnails were collected using a standard visual search method. Only 5 species of microsnails were retrieved using the leaf-litter search method. Interestingly, all species encountered are considered native to the area. No introduced or invasive species were found. Multidimensional scaling ordination of species abundance reveals that snail communities from the investigated forests show significantly different species compositions. After sampling standardization, snail richness was observed to increase with increasing distance from Cincinnati, supporting the hypothesis that temperate forests closer to the urban center harbor lower snail diversity. Interestingly, tree species composition exhibit similar patterns along the gradient, suggesting that both snail and tree communities respond similarly to environmental differences among study sites, some of which may relate to anthropogenic disturbance. This investigation suggests that snail richness and composition appear to be sensitive to both changes in vegetation and distance to urban centers, and future research will attempt to tease these apart.

ENGAGING FAMILY GROUPS IN LEARNING ABOUT EVOLUTION WITH 3D DIGITIZED FOSSILS IN HANDS-ON ACTIVITIES AND VR

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Lineage is a collaborative educational media and outreach initiative that aims to engage individuals and families in learning about deep time, evolution, and how scientists know what they know. As part of this, at the Smithsonian National Museum of National History, we have developed hands-on facilitated learning

activities that will allow families to handle fossil evidence and participate in the scientific method to solve evolutionary puzzles. These activities make use of 3D scanned and printed fossil specimens, and will be made available online to make Smithsonian's rare collections universally accessible, as well as being deployed in the new Deep-Time Hall. They are designed around the concept of co-learning—where family members play interchangeable roles in a gamified collaborative effort. Twin Cities PBS, the Public Broadcasting System, Schell games, the Institute for Learning Innovation and Rockman et al are partners in the initiative, which also includes a VR experience, a film, and education research. Each of the platforms uses stories of the lineages of elephants, crocodiles, birds, and whales as the basis of the learning experiences. Research will be conducted in multiple locations to evaluate outcomes of the different learning platforms. Here we present successes and lessons learned in the iterative process of designing the hands-on activities and associated training material, and a comparison of design challenges for hands-on and VR, given the target learning outcomes.

REACHING NEW AUDIENCES THROUGH ESTABLISHED AND EXPERIMENTAL DIGITAL FORMATS

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Whether engaging the public with a new concept or helping dispel preconceptions surrounding a certain field or group of organisms, a considered and novel approach is often required in paleontological outreach.

In 2012, Palaeocast was set up to improve the taxonomic diversity of paleontological outreach and to do so, employed an under-utilized format: podcasting. Since then, Palaeocast has diversified its outputs to address a range of definable issues in the field of paleontological outreach, employing a bespoke digital solution for each.

Many of these projects are long-term, low budget, easily set up, and applicable to other topics and fields. Furthermore, these digital outputs provide the fewest barriers in terms of accessibility and have excellent longevity.

Here, we summarize several of our projects, explaining the concept, methodology and impact of each.

CONSIDERING ALL THE INGREDIENTS OF AN 'EXPLOSION'

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Animals originated and evolved during a unique time in Earth history—the Neoproterozoic Era. This talk aims to discuss the environmental context of early animal evolution, and how such factors may have affected ecosystems and body plans. Considering environmental conditions, geochemical data have long suggested that animals evolved in a relatively low oxygen ocean. Here, we present new analyses of sedimentary total organic carbon contents in shales suggesting that the Neoproterozoic ocean may also have had lower primary productivity—or at least lower quantities of organic carbon reaching the seafloor—compared with the Phanerozoic. Indeed, recent modeling efforts suggest that low primary productivity is an expected corollary of a low-O_2 world. Combined with an inability to inhabit productive regions in a low-O_2 ocean, earliest animal communities would likely have been more food limited than generally appreciated, impacting both ecosystem structure and organismal behavior. In light of this, we propose the "fire triangle" metaphor for environmental influences on early animal evolution. Moving toward consideration of all environmental aspects of the Cambrian radiation (fuel, heat, and oxidant) will ultimately lead to a more holistic view of the event. Finally, trait-based ecophysiological frameworks are explored as a pathway to understand the impact of multiple environmental parameters on early animal communities.

THE LAS VEGAS FORMATION AS THE LINCHPIN FOR UNDERSTANDING THE RESPONSE OF DESERT WETLANDS TO ABRUPT CLIMATE CHANGE

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The Las Vegas Formation is a distinctive sequence of light-colored, fine-grained, fossil-bearing, largely groundwater discharge deposits that represent a widespread desert wetland ecosystem that occupied the entirety of the Las Vegas Valley from at least the middle Pleistocene, ~500 ka, persisting on and off, into the early Holocene, at ~8.5 ka. Although the formation name was established more than half a century ago when the sediments were subdivided into informal stratigraphic units with a nascent chronologic framework, usage of the Las Vegas Formation name was hampered due to the lack of a robust definition and characterization of the entire lithostratigraphic sequence, its geographic distribution, and chronology. We recently redescribed and reevaluated the

stratigraphy of the deposits attributed to the Las Vegas Formation and both revised and expanded the geochronology based on a large suite of radiocarbon and luminescence ages. In all, we characterized 17 informa geologic units within the formation, including indi vidual members and their attendant beds, that each date to a unique period of geologic time. The Las Vegas Formation sequence represents a paleohydrologic system that registered dramatic hydrologic changes that are expressed in the record as repeated wetland expansion and contraction that occurred in response to abrupt changes in climate throughout the late Quaternary and in temporal correlation with Greenland/North Atlantic climate proxy data. Characterizing the nature of these important deposits and the recognition that they can be used as a high resolution paleohydrologic proxy record has facilitated studies of similar deposits associated with desert wetland ecosystems elsewhere in the Mojave, southern Great Basin, and Sonoran deserts. Utilizing the Las Vegas Formation as the linchpin sequence, we have established detailed stratigraphic and chronologic frameworks for multiple paleowetland sites in the American southwest. Our results show that these former desert wetland ecosystems document a long record of climatic and hydrologic conditions consisting of spring discharge events that are terminated by stable surfaces and/or erosion, followed by renewed spring activity. The timing of these wet-dry cycles indicate that wetland ecosystems regionally waxed and waned in unison in response to climate perturbations many times during last glacial period, including on submillennial-scale timescales during the Younger Dryas climate event. The timing and nature of ecosystem response recorded at these sites is strikingly similar to the hydrologic changes we documented in the Las Vegas Formation. The recognition that widespread desert wetland ecosystems closely track one another demonstrates that they are not simply reflecting local hydrologic conditions, but rather, they are responding to changes in synoptic-scale climate patterns that operated over a large geographic region in the southwestern U.S. during the middle to late Quaternary.

LINKING PALEOCLIMATE RESEARCH AND PLEISTOCENE VERTEBRATE FAUNAS IN DESERT WETLANDS ON PUBLIC LANDS IN THE AMERICAN SOUTHWEST

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Desert wetlands are keystone ecosystems in arid environments that are preserved in the geologic record as groundwater discharge (GWD) deposits. Because animals are drawn to these spring-fed water sources, GWD deposits commonly contain vertebrate fossils. In Tule Springs Fossil Beds National Monument (TUSK), we have investigated the stratigraphy, chronology and paleontology of the Las Vegas Formation, a middle Pleistocene to early Holocene sequence (~500– 8.5 ka) of GWD deposits that entomb the Tule Springs local fauna, the largest and most diverse late Pleistocene vertebrate fossil assemblage in the Mojave and southern Great Basin deserts. The resulting high-resolution stratigraphy and chronology revealed that these desert wetlands responded dynamically to abrupt climate change by expanding and contracting repeatedly during the last glacial period, in synchrony with warming and cooling events documented in the Greenland ice core record. This marks the first time that groundwater discharge deposits were used as a robust, high-resolution paleoclimate proxy record. In TUSK, vertebrate fossils occur in temporally constrained, discrete spring discharge intervals that were punctuated by sudden aridification leading to wetland collapse, only to be reinitiated by vigorous spring activity. This cycle occurred repeatedly throughout the late Pleistocene and into the Younger Dryas climate event, with each interval containing fossils. The stratigraphic and chronologic scaffolding we developed at TUSK provides a unique opportunity to discern if and when vertebrate faunas responded to abrupt warming events during the late Pleistocene within the monument and elsewhere. In the Rogers Beds in Death Valley National Park, for example, vertebrate fossils are present in discrete spring discharge intervals ranging in age from at least ~70 to 12 ka; each discharge cycle is terminated by stable surfaces and/or erosion, followed by renewed spring activity, as the wetlands waxed and waned in response to climate perturbations. We have established similar frameworks for other public lands in the Mojave, Great Basin, and Sonoran Deserts, as well as for a pluvial lake sequence in Joshua Tree National Park, all sites with documented vertebrate fossil remains. Overall, we find that sites throughout the region reveal wet and dry cycles that are strikingly similar in timing and character to the

GWD sequence in TUSK. The recognition that widespread desert wetland ecosystems closely track one another demonstrates that they are responding to changes in synoptic-scale climate patterns operating over a broad geographic region during the middle to late Quaternary. Consequently, understanding the temporal and depositional context of the inset late Pleistocene faunas has utility in determining how and when vertebrate animals responded to these climate stressors regionally in the American southwest, up to and including the terminal Pleistocene extinction event.

CONSTRAINTS AND ADAPTATIONS IN CROCODILIAN SKULL FORM AND FUNCTION

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Crocodilians, one of only two living groups of archosaurs, display a diverse range of skull morphologies. A classic hypothesis states that crocodilian skull shape is responsive to selective feeding strategy; yet extant crocodilians possess platyrostral (broad and flat) snouts, thought to be sub-optimal for feeding due to the conflicting demands of feeding optimization and hydrodynamic constraints. In contrast, numerous Mesozoic crocodilians possessed oreinirostral (dome-shaped) skulls. Some of these forms were terrestrial and hence free from the aforementioned constraints. This study aims to review the role of functional controls that determine skull shape in crocodilians and seeks to assess the differences in the feeding mechanics between the terrestrial extinct taxa and the semiaquatic extant taxa. This was carried out using beam analysis and finite element analysis (FEA) for evaluating resistance to feeding-induced loads in the Mesozoic taxa *Baurusuchus salgadoensis*, *Montealtosuchus arrudacamposi* and *Caipirasuchus paulistanus*, which have oreinirostral skulls, compared to the extant *Alligator mississippiensis, Crocodylus niloticus, Paleosuchus palpebrosus* and *Gavialis gangeticus,* with platyrostral skulls. Adductor muscles were digitally reconstructed in *Baurusuchus* and scaled in other taxa to assess myological variations, estimate bite forces and muscle efficiency. The results show that oreinirostral morphologies are comparatively better-suited for resisting force as lower stresses were observed under various biting scenarios. Conversely, bite forces are independent of rostral shape and instead scale positively with body size. The oreinirostral taxa, however, show increased mechanical advantages compared to their platyrostral counterparts, due to the differences in the musculoskeletal architecture. Overall, fossil taxa with oreinirostral morphologies show skull structures that are better optimized for feeding in the absence of hydrodynamic constraints. These observations are expected to serve as models to explore further the biomechanics of other tetrapods with homologous morphologies.

THE REPEATED EVOLUTION OF SKULL ELONGATION IN RAY-FINNED FISHES (ACTINOPTERYGII)

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Elongation of the skull is a common feature among vertebrates, but is especially prevalent and widespread amongst the ray-finned fishes (Actinopterygii). A diverse array of distantly-related actinopterygian taxa, ranging from the Late Devonian to the present, have been designated as bearing elongated skulls. The macroevolutionary patterns surrounding the repeated appearance of elongated skull morphologies are unclear: the degree of convergence of these forms has not been documented nor has their cohesiveness as types, and their structural diversity has not been examined. There is also no concrete basis for distinguishing taxa with lengthened skulls from taxa without lengthened skulls. We first defined elongated skulls as any derived anterior projection of the skull or jaw(s) beyond the nares or orbit. We then examined the literature on the cranial morphology of actinopterygians to elucidate the diversity of these structures. While the exact elements used to construct lengthened morphologies are highly variable throughout the record, we found that elongated skulls can be broken down into three groups of generally distantly related taxa based on overall structure. These include extensions of the skull roof anterior to the gape that superficially resemble lengthened snouts, elongations of the upper and/or lower jaws, which may include the bones associated with the mouth that do not bear teeth, and finally elongated bones of the mid-face region between the orbit and gape, which form tube-like snouts. This indicates that there are at least three distinct morphotypes being treated as a discrete, unified morphological category. We also employed geometric morphometric techniques to quantify skull shape in a preliminary

dataset containing species with and without elongated skulls. The principal variation in overall skull shape amongst our sample was in the height of the posterior-dorsal region of the skull, along with the length of the premaxilla and dentary. We also found that taxa with elongated skulls do not comprise unified clusters distinct from their relatives, and that fishes superficially belonging to our three groups vary considerably in their position in overall morphospace. While the appearance of similar phenotypes in distantly related taxa is often indicative of convergent evolution due to shared selective pressure resulting from a common niche, we found that fishes with elongated skulls vary considerably in ecology (as per the literature). This suggests that the gross similarities within each structural group are not due to common selective pressures associated with shared niches. Instead, the repeated evolution of elongated skull structures in ray-finned fishes might be caused by plasticity in development favoring such changes, and/or one-to-many-mapping of functions. We will further characterize the mode and pattern of convergence in this set of structures by comprehensively mapping their appearance amongst actinopterygians.

LEGAL AND POLITICAL MECHANISMS FOR PALEONTOLOGY ADVOCACY: THE BATTLE FOR GRAND STAIRCASE-ESCALANTE AND BEARS EARS NATIONAL MONUMENTS

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Public lands are vital to science, and paleontology especially, as a place for experimental and observational research across scales; as a source of specimens and associated data; and as a platform for engaging stakeholders, including the public, in research. The western US, in particular, has long been a vital region for paleontological research and exploration, producing new insights about the history of life on earth from the Precambrian through the present day. Grand Staircase-Escalante (GSENM) and Bears Ears (BENM) National Monuments, both in southern Utah, were designated by presidential executive order under the authority of the Antiquities Act in 1996 and 2016, respectively. Both were created, in part, explicitly to protect their unparalleled paleontological resources, and, by extension, to foster new science and publi education/outreach. GSENM preserves significan paleontological resources from geologic units span ning the Paleozoic through the Cretaceous, including an exceptional and continuous record of the late Cretaceous. Fossil-bearing units in BENM span Pennsylvanian through mid Cretaceous outcrop. Quaternary deposits are known from both monuments.

National Monument status confers a higher level of legal protection for fossils, mandates inventory and monitoring, opens new funding streams for research, creates staff paleontology positions, and provides a framework for science communication. The positive effects of this status are abundantly evident at GSENM and are nascent but developing at the much younger BENM. In 2017, however, a presidential executive order revoked this status for substantial portions of GSENM (~50%) and BENM (~85%). These reductions imperil known and unknown localities: already, new mining claims have been staked; oil and gas leases within sight of former monument boundaries are up for auction; and protections against collection of non-vertebrate fossils are no longer in place. Along with nonprofit organizations and partners in the recreation industry, the Society of Vertebrate Paleontology (SVP) has taken legal action against the reductions. Many paleontologists have been involved in efforts to maintain and, now, to re-establish protections for fossils at BENM and GSENM. Invaluable contributions from a diverse group of researchers include providing detailed comments on draft management documents, writing to public officials, giving interviews to the media, engaging in public outreach, and agitating broadly. On-going activism has helped prevent major new damage to fossils thus far, and recent political turnover has made possible an investigation by the House Committee on Natural Resources. The lawsuit is currently in the hands of the US District Court for the District of Columbia, and is expected to reach conclusion in the Spring of 2019. However, civic engagement of paleontologists will continue to be essential for resource protection and advancement of research.

IDENTIFYING CAUSES OF ABRUPT CHANGE AND RESILIENCE LOSS IN PALEOECOLOGICAL RECORDS OF GRASSLAND-WOODLAND SYSTEMS

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Many ecosystems have abruptly changed in the past, and these changes are likely to become more

frequent as anthropogenic global change progresses. However, prediction of change and inference of causal mechanisms remains challenging. Abrupt ecological change can result from rapid change in a driver, nonlinear driver-state relationships, or the interaction of multiple drivers and disturbances. Critical transitions are one mechanism of abrupt change where systems with alternative states cross a threshold. These shifts can be associated with a gradual loss of resilience, often signaled by increasing variance over time and space, and are of particular conservation concern because they are very difficult to reverse. Paleoecological time series have potential to reveal causes of abrupt change by linking driver and state variables to reveal underlying processes, and by documenting resilience loss associated with past critical transitions. However, sedimentological time-averaging and subsampling can transform these signals. Disentangling taphonomic and ecological signals is a key challenge for making inferences that can be applied to anticipating change in modern ecosystems.

We explore signals of regime shift and critical transition, and the effects of taphonomic transformation, in two empirical case studies. The first is the prairie-forest ecotone in midcontinental North America, which is likely an example of a system with alternative states, capable of critical transitions between prairie and forest when water availability declines below site-specific thresholds. Prior work has shown that the prairie-forest ecotone was highly mobile during the Holocene, shifting in response to changes in precipitation and fire frequency. Using high-resolution, well-dated pollen records from the Neotoma Paleoecology Database, we explore indicators of resilience loss, measured as spatial and temporal variance, in sites that remain prairie throughout the mid- to late Holocene, versus sites that transition from prairie to forest. We calculated variance by creating Generalized Additive Models for Location and Scale (GAMLS), which model both mean and variance through time for each site. We incorporated estimates of temporal uncertainly by creating Bayesian age models for each site, then resampling the model posteriors and creating a new GAMLS for each iteration. Preliminary results indicate no significant differences in variance between groups, suggesting that shifts in the prairie-forest ecotone were caused by climatic drivers that changed too quickly for resilience loss to occur, or that the system is not characterized by alternative states. In the second example, we investigate the effects of anthropogenic climate change on a California oak-woodland/grassland using a high-resolution sediment core from a 125-year-old reservoir. This system is also thought to be governed by moisture limitation and fire frequency. These analyses are currently underway.

THE LEGACY OF PAST CLIMATES IN CLIMATE-RELATED EXTINCTION RISK

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Climate change related extinction risk depends on the evolutionary history of the focal species. Throughout earth history, the reaction of species to climate changes likely depended on their adaptations to the previous long-term climate situation. Understanding the interactions between the effect of short-term temperature changes with previous long-term temperature trend is thus crucial when evaluating intrinsic extinction risk of species facing current warming.

Using fossil occurrence as available from deep-sea ocean drilling programs throughout the Cenozoic, we found extinction probabilities of different groups of microfossils to be influenced by the magnitude of temperature change interacting with past temperature trends. The effect strongly differs between groups and is influenced by data quality.

The identified legacy of past climates in climate-related extinction risk has crucial consequences for understanding the effect of current warming on extant biota. It also highlights the unique opportunity provided by the fossil record to study the interaction between climate change, past climate trends and the phylogenetic history of species on extinction risk. Approaching this crucial question only with extant data is impossible.

TIMING THE GOBE: COORDINATED BIOTIC AND GEOCHEMICAL CHANGES DURING THE DARRIWILIAN IN LAURENTIA

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The Ordovician Period records an extraordinary biodiversity increase known as the Great Ordovician Biodiversification Event (GOBE). A series of environmental changes to the Earth System is coincident with this diversity increase, notably a cooling global ocean, oxygenation, and increased nutrient supply from volcanism and continental weathering. The co-evolution

of Earth and its biota during this interval have been studied in various contexts and on multiple paleocontinents. Depending on the lens of investigation, different patterns emerge. Here we summarize the current state of understanding focused on the Laurentian fossil and sedimentary records.

Ordovician deposits crop out extensively within Laurentia. These units have a long history of scientific study, which provides a foundation for modern paleontological and geochemical analyses. Recent paleontological studies, mainly focused on rhynchonelliformean brachiopods, have documented details of diversification, body size increase, development of ecosystem complexity, and intensification of intercontinental dispersal from the Dapingian through Katian stages. Diversification rates increase statistically during the *Histiodellaholodentata* conodont Zone (mid Darriwilian Stage), which correlates with similar increases in Baltica and Gondwana.

Coincident with these biotic changes, Laurentian strata record significant change in the physical Earth system. Notably, oceanic temperatures decreased based on oxygen isotopic data measured from conodont apatite. Atmospheric oxygen levels increased to near modern levels coincident with the Middle Ordovician diversification of shelly fauna. Furthermore, a major drop in the strontium isotopic composition of the oceans occurred during the Middle–Late Ordovician, which is consistent with the weathering of juvenile volcanic rocks and delivery of nutrients to marine settings. This multi-proxy record is significant because it records near-simultaneous changes in fossil-rich shallow marine environments during exactly the interval of highest diversification rates.

By integrating biotic and geochemical data sets, a clear picture of the co-evolution of Earth and its biota during the GOBE emerges. Based on Laurentian records, the Darriwilian appears to be the critical interval of the GOBE. Future integration of the paleontological and geochemical records from other paleocontinents may elucidate whether this time interval is equally significant as it is in Laurentia.

MOVING FROM CORRELATION TO MECHANISM: TESTING THE ROLE OF OXYGEN AND TEMPERATURE CHANGE IN THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT

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The Great Ordovician Biodiversification Event, or GOBE, was one of the most rapid and dramatic diversity increases recorded in the Phanerozoic fossil record. Global cooling and atmospheric oxygenation have both been suggested to be important factors in driving the transition from the high-extinction regime of the Upper Cambrian-Lower Ordovician to the Middle-Upper Ordovician diversification, but there are a number of competing hypotheses. The research presented here proceeds from 1) geochemical analysis of global ocean redox change to 2) calibration of Earth system models with geochemical data, and finally to 3) testing evolutionary hypotheses with an ecophysiological framework. The uranium isotope proxy is proposed to track global marine redox conditions in geologic time, with predictable isotope fractionations from seawater recorded in shallow-water carbonates. We present $\delta^{238}U$ measurements of Upper Cambrian through Middle Ordovician carbonates from the Notch Peak Formation and Pogonip Group of the House and Confusion Ranges, Utah, to directly test whether there was a global marine oxygenation event coincident with the Ordovician radiation. We use a novel Monte Carlo uranium isotope mass balance model to provide error-bound, quantitative constraint from $\delta^{238}U$ measurements on the global extent of euxinic (anoxic, sulfide-dominated) bottom-waters through the Ordovician. These paleoredox estimates and a compilation of sea-surface temperature reconstructions are next used to calibrate a time-series of Ordovician ocean models from the cGENIE Earth system model. Finally, we use the Metabolic Index, a method developed to quantify the extent of viable aerobic habitat for marine ectotherms, to investigate the extent to which changes in habitat availability driven by temperature and oxygenation changes could have mechanistically driven the diversification observed in the fossil record. Specifically, we populate modeled oceans with a suite of 'ecophysiotypes', sampling from probability density functions summarizing the growing body of measured temperature-dependent hypoxia tolerances in modern marine ectotherms. The Metabolic Index approach thus allows us to model predicted changes in latitudinal diversification and migration gradients based solely on oxygen and temperature changes consistent with the geochemical record. For comparison, we use Shareholder Quorum Subsampling and Capture-Mark-Recapture analyses of data from the Paleobiology Database to dissect observed latitudinal biodiversity

dynamics in the fossil record. We compare modeled biodiversity dynamics to those identified in the fossil record to establish the extent to which observed diversification patterns could have been driven by marine temperature and oxygenation changes.

QUANTITATIVELY ASSESSING REEF MOUND COMMUNITIES WITHIN THE UPPER TRIASSIC CARBONATES ALON THE EASTERN PANTHALASSIC OCEAN

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Upper Triassic reefs along the edge of the Panthalassa Ocean receive much less attention than their counterparts within the Tethys region. Further investigation into this understudied area will lead to a greater understanding of global reef patterns during the Triassic. To help close this gap in knowledge, we present a quantitative study of microfacies analysis, within the Augusta Mountain Formation of Nevada, to characterize reef types. We use point counting to quantitatively access the relative abundance of reef components and multivariate statistics to quantitatively assess the taxonomic similarities between reef communities. Quantitatively characterizing reef community types will ultimately allow for better comparisons of other reef communities at different locations. Recrystallized sponges, microbialites, and microproblematica comprise the main reef components in the Augusta Mountain Formation limestones.Sponges, small corals, and*Tubiphytes*comprise the primary framebuilders while encrusting organisms and microbial crusts comprise the secondary framebuilders. All framebuilders correspond to low-growing communities and are thus considered reef mounds. Skeletal and non-skeleatal grains, microbialite, and cement fill the interstitial space between the reef framebuilders. Skeletal grains include fragments of echinoderms, brachiopods, bryozoans, and mollusks. And, non-skeletal grains include peloids, clotted micrite, and microbial crusts.These reef mounds parallel the Upper Triassic reef mounds reported from Japan: that is, low abundance of coral colonies that lack high-growing structures.

NEW REMAINS OF MIDDLE MIOCENE EQUIDS FROM THE CAJON VALLEY FORMATION, SAN BERNARDINO NATIONAL FOREST, SAN BERNARDINO COUNTY, CALIFORNIA

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The Cajon Valley Formation, located partially in the San Bernardino National Forest, spans the late Hemingfordian and early Barstovian NALMA. Previously considered part of the Punchbowl Formation, the Cajon Valley Formation has been excavated by various institutions since the 1970s, most notably by the University of California, Riverside (UCR) and San Bernardino County Museum (SBCM).

The majority of these fossil collections are now housed at University of California, Berkeley, SBCM, and Western Science Center (WSC), the last of which began work in 2018. Excavation of a quarry in the Cajon Valley Formation by WSC yielded new fossil material including remains of three equid taxa: *Archaeohippus mourningi*, *Scaphohippus intermontanus*, and the first record of "*Parahippus" brevidens* south of Oregon.

Archaeohippus mourningi has been previously identified from the Cajon Valley Formation and is the smallest of the three equids reported in the formation. Our new sample includes six upper teeth and a partial dentary with two complete teeth and a fragmented tooth.

Scaphohippus intermontanus is identified from three upper teeth, one isolated lower molar, and a partial dentary with four complete teeth. The best-preserved upper molar exhibits the simpler plications characteristic of *S. intermontanus* as opposed to *S. sumani*, and the occlusal surface has a smaller area than *Acritohippus stylodontus*, a similarly-aged equid species reported from the Barstow Formation.

"Parahippus" brevidens is identified from an upper molar that closely resembles the morphology of the holotype as well as referred specimens of *P. brevidens* from the Mascall Formation in Oregon. The presence of "*P." brevidens* in the Cajon Valley Formation represents a range extension for the taxon of over 1400 km.

Interesting ecological implications emerge for fossils from the Cajon Valley Formation when compared to those of the nearby Barstow Formation. The Barstow Formation lacks chalicotheres but does include fossils from *Hypohippus affinis* and *Megahippus matthewi*, neither of which occur in the Cajon Valley Formation.

The WSC is currently scanning and 3D-printing these fossils for use in research and outreach. The fossils have already enjoyed prominent visibility in

outreach efforts across Southern California, promoting paleontology on public lands in general and specifically the efforts of WSC in San Bernardino National Forest.

THE EARLY CRETACEOUS JEHOL BIOTA OF NORTHEAST CHINA AS A UNIQUE WINDOW ON THE DINOSAUR-BIRD TRANSITION

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The Early Cretaceous Jehol Biota of northeast China is more informative than any comparable assemblage with regard to the transition from non-avian dinosaurs to birds, even though the oldest elements of the Jehol Biota are about 20 Ma younger than the iconic *Archaeopteryx*. The Jehol Biota contains more than 20 non-avian theropod species and more than 50 avian ones, and includes relatively basal members of the three paravian lineages Dromaeosauridae, Troodontidae and Aves. Furthermore, the Jehol Biota is famous for its unusual quality of preservation, in that many Jehol specimens comprise near-complete skeletons of small vertebrates with accompanying soft tissues. Evidence from the Biota is crucial for understanding not only the diversity of early avians and their closest theropod relatives, but also the early evolution of characteristic avian modes of locomotion, respiration, digestion, reproduction, and even social behavior.

Nevertheless, interpreting the wealth of palaeontological data provided by the Jehol Biota is not always straightforward. The strata containing the Biota come from multiple basins spanning a considerable area in northeast China, and were deposited over some 11 Ma (131 – 120 Ma), implying that the Biota should be regarded not as a single ecological community but rather as a cluster of such communities that varied in their composition and potentially existed under quite different paleoenvironmental conditions. Furthermore, recognition of the exceptional preservational characteristics of the Jehol Biota should not obscure the Biota's taphonomic idiosyncracies. Large-bodied taxa may be underrepresented, for example, and preservation of soft tissue is selective in ways that are not fully understood. Keratinous structures such as hair, feathers and scales appear to have had a relatively high fossilization potential, and preserved ovaries and even lungs have been reported in Jehol birds, but other tissues including cartilage appear to have fossilized much less readily.

In general terms, the Jehol Biota seems to have flourished in a volcanically active landscape of gymnosperm-dominated forests dotted with lakes. Geochemical and paleobotanical evidence suggests the climate was at least intermittently cool, in contrast to the generally warm conditions during the Cretaceous as a whole. Many vertebrate fossils from the Jehol Biota may represent individuals that perished in mass mortality events resulting from volcanic eruptions, but the exact mechanisms of death, transport and burial remain unclear despite their potentially significant taphonomic implications. Nevertheless, the Jehol Biota represents a unique window on the dinosaur-bird transition and the faunal diversity of the middle Early Cretaceous, offering insights into entire taxonomic groups that may have been geographically widespread during this interval of Earth's history but which are well known only from the fossil record of northeast China.

PARTNERING VERTEBRATE PALEONTOLOGISTS WITH LOCAL NATIVE AMERICAN STUDENTS: LESSONS FROM THE PUEBLO OF JEMEZ, NORTHWEST NEW MEXICO, USA

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Because of the deep history of mistreatment of native groups, the rich paleontological resources of native American / First Nations lands are not typically accessible to non-native scientists. However, with the support of the David B. Jones Foundation, a new model of cooperation is has been tested on the reservation lands of Jemez Pueblo, New Mexico. The choice of Jemez is reflected in its rich paleontological potential and a unique outreach and training agreement. Jemez lands host a remarkable span of fossiliferous sediments ranging from the Early Permian Cutler Group to Late Cretaceous age Fruitland Formation. A collaboration between California State University San Bernardino and Jemez Pueblo was initiated in the summer of 2018. It demonstrated that the key to paleontological access was bringing youth of the Pueblo directly into the research program. The most important feature of the collaboration was that it was not a top down, academics to locals strategy. Rather, paleontologists and local native youth acted as equals. No one knows the Pueblo land better than the local residents. The reciprocal agreement of student training and

paleontological access is facilitated by utilizing Jemez's greatest resources: local geological expertise and local students with an understanding of their home - Jemez geography. Pragmatically, partnering visiting academics and local youth generated prospecting teams that could cover more territory than CSUSB or Jemez Geology staff could otherwise cover on their own. Initial success is promising. A taxonomic list generated by preliminary surface prospecting of Lower Permian sediments have demonstrated the presence of the sail-backed pelycosaurian synapsid *Dimetrodon* (cf. *D. occidentalis* Berman), the sail-backed dissorophoid amphibian *Platyhistrix*, the temnospondyl amphibian *Eryops*, as well as footprints and plants. Late Triassic taxa identified to date include large temnospondyl metoposaurs, aetosaur scutes, phytosaur teeth, wood and other plant remains. Teeth belonging to the extinct shark and index taxon *Ptychodus whipplei* were discovered in abundance in the Late Cretaceous age Mancos Shale (Juana Lopez Member). Initial prospecting has yielded fossil documentation from Late Paleozoic and a sampling of Mesozoic sediments, providing proof of concept for recruiting a larger number of future field teams to (1) expand survey of the extensive Mesozoic sediments in the Pueblo's lands; and (2) prospect in, and correlate with, equivalent age Paleozoic sediments of the Cutler Formation units in southeastern Utah in lands of the currently disputed Bears Ears National Monument. Bears Ears is a location to which Jemez Pueblo inhabitants trace their ancestral origins. The collaborative effort is forging dramatically a link between Jemez natives' deep cultural heritage in the area and its deep time paleontological assets.

THE POWER OF PALEONTOLOGY AND THE ARTS AS COLLABORATIVE FORCES

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In this age of ubiquitous visualization, most are not aware that the development of the animation industry itself can be traced to an animated dinosaur created over one hundred years ago. Paleontology and natural history played central roles informing and entertaining the Euro-American educated classes as far back as the Enlightenment. As the less privileged public was enabled by inexpensive printing and public museums, it enthusiastically consumed tales of colonial exploration and the fantastic creatures excavated, displayed, and brought to life. The public imagination continues to be stimulated by the charismatic megafauna characteristic of paleontology, the most popular examples of course include dinosaurs, which generate blockbusters based on digital reconstructions of widely-varying accuracy. This keeps them, if not the science, center stage in the public imagination.Many of the landmark events advances in animation coincide with a focus on paleontological topics. The technological child of animation—computer-generated visual effects—has also been driven by paleontology at lynch-pin moments during its key developmental windows. This highlights the natural relationship between paleontology and creative visual communication and serves as a lesson in the communication of science in general. Paleontologists are in a unique position to highlight the importance of exploration, inquiry and deep time to the public with inherently interesting and visually compelling stories. We present several examples of vertebrate function, morphology and ontogeny as taught to animators and digital effects artists in the film industry, and to students of all educational stages through image and animation. Science education occurs through the creatures paleontologists help bring to life. With paleontology's natural allies in the arts, we can turn STEM to STEAM, generating a powerful synergistic force for education, public awareness of the importance of science, and providing powerful practical and philosophical tools to the next generation. With the grave threats posed to the well-being of the planet now at the whim of a fickle electorate, educating the masses is more critical than ever before.

A TALE OF TUBE CITIES: THE ROLE OF *FUNISIA DOROTHEA* IN PRESERVING SHORT-TERM COMMUNITY SUCCESSION IN EDIACARA ASSEMBLAGES

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The Ediacara Member of South Australia (~550 Ma) hosts a diversity of White Sea-type Ediacaran fossils preserved on the soles of successive and unamalgamated bedding planes that represent the casting of *in situ* living communities by discrete mm- to cm-thick storm deposits. This mode of preservation, in conjunction with the ubiquity of dense organic mats and the absence of infaunal sediment mixing provides a

unique opportunity to reconstruct marine communities unaffected by geologic-scale time averaging. At the Nilpena National Heritage site in South Australia, the absence of sediment reworking resulted in an environment conducive to the preservation of an unusually complete record of community succession via the palimpsestic fossilization of multiple communities on individual bedding planes. Significantly, this record of ecological succession is primarily observed in association with dense assemblages of the tubular fossil *Funisia dorothea.*

F. dorothea is the most abundant fossil in the Ediacara Member and is most commonly preserved as densely packed and overlapped individuals covering entire bedding planes (> 5 m^2). We interpret *F. dorothea* to have had an elongate, hollow, and modular tubular body which extended upward from the seafloor into the water column, and to have lived in dense aggregations which prevented the colonization of other benthic organisms, as well as exercised a biostratinomic control on fossilization of these communities. At Nilpena, dense assemblages of *F. dorothea* occur in association with well-preserved *Aspidella* holdfast structures on multiple bedding planes otherwise characterized by low taxonomic diversity. This recurrent association indicates that, in life, *F. dorothea* aggregations may, by limiting local colonization of the seafloor by most other benthic organisms, have inhibited the establishment of diverse benthic communities. Moreover, *F. dorothea* aggregations may have significantly stabilized the seafloor, preventing the otherwise common current-mediated plucking and collapse of *Aspidella*. Upon death, hollow *F. dorothea* tubes collapsed and formed thick textured organic surfaces on the seafloor. Deceased and collapsed *F. dorothea* populations–which had, in life, prevented benthic colonization–provided the organic substrate necessary for the establishment of a new community. The development of a diverse benthic community on top of fallen *F. dorothea* populations is recorded on multiple Ediacara bedding planes that are characterized by poorly preserved *F. dorothea* populations overlain by well-preserved and diverse communities of both mobile and sessile organisms (e.g., *Dickinsonia, Tribrichidium,* and *Parvancorina*). This juxtaposition of taphonomically and ecologically distinct communities on single bedding planes provides unique evidence that time averaging in the Ediacara fossil record is of ecological rather than geological duration and offers insight into patterns of short-term succession in Ediacara communities.

HIGH-LATITUDE PREDATION PATTERNS DURING THE LATE TRIASSIC AND IMPLICATIONS FOR EVOLUTIONARY ESCALATION IN THE EARLY MESOZOIC

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Very few marine predators have been reported from the Late Triassic (235-200 Ma) in New Zealand, leading to a great deal of uncertainty in estimating regional or global predator diversity and abundance during this important interval. Sediment samples from the North Island (Kiritehere Beach) and South Island (Hokonui Hills, Taringatura Hills, Owaka) were disaggregated and examined for vertebrate microfossils from the Norian and Rhaetian stages. These samples yielded a consistent occurrence of likely Semionotiformes isolated teeth and rare dental palate fragments from the Early Norian to the Rhaetian, consistent with the known temporal range for this group but greatly extending their geographic range. Other Triassic vertebrate taxa were identified as well, including *Saurichthys*and other marine vertebrates. Overall the diversity of small demersal vertebrates appears to largely be lower than low-latitude marine deposits in Italy and Nevada for this interval, but with a greater proportion of specialized shell-crushing predators throughout the Late Triassic than low-latitude deposits. Data presented are the first reported occurrences of these taxa from New Zealand, and their presence suggests that latitudinal differences in predation intensity and mode existed during the Late Triassic.

THE HETANG BIOTA: A TAPHONOMIC WINDOW INTO THE CAMBRIAN EXPLOSION

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The Cambrian explosion marks the most fascinating biodiversification event in Earth history. Although recent systematic studies of Konservat-Lagerstätten from the early–middle Cambrian Period have significantly improved our understanding of the Cambrian explosion, the causes and consequences of this event remain controversial. The early Cambrian Hetang biota in South China, which comprises various metazoans and algal fossils, complements other Cambrian Lagerstätten in offering a distinct perspective on early Cambrian paleoenvironments, biodiversity, and taphonomy. The Hetang Formation was deposited in anoxic

deep-water environments and is well-known for its preservation of the earliest articulated sponge fossils. However, metazoan fossils other than sponges are poorly documented in the Hetang Formation, resulting in an incomplete picture of the Hetang biota and limiting its contribution to the understanding of early animal evolution. To address this knowledge gap, we present new data of the Hetang biota on the basis of intensive fossil excavations from the lower to middle Hetang Formation in South China. Our investigation, using various optical and electric microscopic tools and micro CT, revealed a diverse fossil assemblage from the Hetang Formation, including various sponges, bivalved arthropods, hyolithids, sphenothallids, possible trace fossils, algal fossils, and many undetermined fossil forms. Different types of preservation, including Burgess Shale type preservation, pyritization, cast and mold preservation, are represented in the Hetang Formation. In sum, our study indicates that the Hetang biota is more diverse than previously thought and provides important information about the paleoecology during the Cambrian explosion.

DO PERFORATIONS ON PROTEROZOIC ORGANIC-WALLED MICROFOSSILS REPRESENT PREDATION TRACES?

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Rounded perforations are ubiquitous in Proterozoic organic-walled microfossils (particularly spheroidal acritarchs) preserved in shales and mudstones. It has been proposed that perforations on late Mesoproterozoic and early Neoproterozoic acritarchs are holes produced by predatory protists. If true, they represent the earliest evidence for predator-prey interactions, which may have acted as an ecological driver to accelerate eukaryotic evolution and diversification. However, some acritarch specimens have a large number of these perforations, implying an unlikely scenario of surviving repeated predation events. In addition, thus far these perforations have been reported exclusively from organic-walled microfossils preserved in shales and mudstones; they have yet been identified on phosphatized and silicified acritarchs. Finally, similar perforations have been reported from small carbonaceous fossils that represent animal sclerites and cuticular fragments, which are unlikely to have been penetrated by predatory protists. These observations prompted us to reassess the interpretation of perforations on Proterozoic organic-walled microfossils. We investigated perforated organic-walled microfossils from the late Paleo- to early Mesoproterozoic Ruyang Group and early Neoproterozoic Liulaobei Formation in North China, using optical and electron microscopic tools such as secondary electron microscopy, backscattered electron microscopy, focused iron beam electron microscopy, energy dispersive X-ray spectroscopy, and elemental mapping. Our study revealed that rounded perforations on Ruyang and Liulaobei acritarchs are diagenetic in origin. They represent molds of digenetic minerals (e.g., pyrite and its weathering products such as gypsum) growing on and puncturing acritarch walls, often with the culprit crystals remaining in the perforations. Given that pyrite is typically formed in close association with organic matter degradation, we suggest that caution should be taken when interpreting irregularly shaped perforations on organic-walled microfossils as predation traces, although we acknowledge that perforations with regular morphologies (e.g., half-moon perforations and perfectly circular perforations with sloped margins from the Chuar Group; Porter, 2016, Proc. R. Soc. B 283: 20160221) cannot be accounted for by known diagenetic processes and thus may represent true predation traces.

THE EVOLUTION OF BIOTURBATION: TIMING AND GEOBIOLOGICAL CONSEQUENCES

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Bioturbation, the physical and chemical mixing of sediments by burrowing animals, is a critical engineering process in modern seafloor environments and exerts an important control on benthic ecology, sediment properties and ocean-wide biogeochemical cycling. Well-mixed sediments have long been assumed to appear at the Precambrian-Cambrian boundary with the first occurrence of the index fossil and three-dimensional burrow *Treptichnus pedum*. However, field-based analyses, synthesizing ichnological, stratigraphic, sedimentological and taphonomic data, collected from a range of lower Paleozoic siliciclastic successions spanning four paleocontinents, indicate that sediment mixing in marine shelfal environments remained limited until at least the late Silurian, 120 million years after the Precambrian-Cambrian transition. These field-based data are corroborated by a global compilation of Phanerozoic shallow marine erosive sole structures (e.g., tool and flute marks). The

frequency of sole mark preservation in shallow marine environments has dramatically declined through the Phanerozoic, indicating that seafloor rheology experienced major secular transformations over the past 541 million years, in conjunction with and likely directly due to the development of well-bioturbated sediments.

These stratigraphic data collectively indicate that the development of the sedimentary mixed layer was a protracted process. Evolutionary advances in sediment colonization (as recorded by the earliest three-dimensional burrows) appear to have significantly outpaced the ecological spread of intensive sediment mixing; the widespread establishment of modern-style mixgrounds postdates both the Cambrian Explosion and the Great Ordovician Biodiversification Event. This macroevolutionary lag may reflect the influence of a combination of ecological and environmental factors that served to limit both the extent and intensity of early Paleozoic sediment mixing. The protracted pace of mixed layer development also holds important implications for contemporaneous biogeochemical (e.g., C, P, O and S) cycling. For instance, stratigraphically derived mixed layer depths for the early Paleozoic are consistent with sulfur proxy data and supported by global sulfur model simulations which indicate that bioturbation exercised a first-order control upon Paleozoic sulfur cycling. The delayed development of intensive sediment mixing may additionally, via both biogeochemical and rheological feedbacks, be linked to the anomalous preponderance of exceptionally preserved soft-bodied Lagerstätten characteristic of the lower Paleozoic stratigraphic record.

BUILDING COLLABORATIONS WITH LOCAL COMMUNITY COLLEGES TO INCREASE DIVERSE STUDENTS' ACCESS TO PALEONTOLOGY

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The underrepresentation of certain groups in higher academia and STEM fields is directly contrasted by the overrepresentation of these same groups in U.S. community colleges. More than a third of all U.S. undergraduates are currently enrolled at community colleges, and nearly half of all students who graduate from a four-year institution have previously attended a community college. Relative to their peers at four-year institutions, community college students are much more likely to come from low-income households, identify as members of an underrepresented minority, or be the first in their family to attend college. However, only a small percentage of community colleges provide courses in paleontology, thus limiting the degree to which this diverse student base is introduced to the field at a pivotal early stage in their college career. This creates an opportunity whereby museums and four-year institutions may partner with local community colleges to both enrich students' educational experience and increase accessibility to the field of paleontology. At the University of California Museum of Paleontology at UC-Berkeley, we have developed a program that integrates hands-on, fossil-based laboratory class sessions into the course curricula of local community colleges. Each session is tailored to fit the learning objectives of the particular course at each partner college, and colleges spend their normal lecture and laboratory session times participating in these events on the UC-Berkeley campus in order to prevent disruption to students' class and work schedules. By enabling community college students to actively engage with the field of paleontology and interact with students, researchers, and faculty at UC-Berkeley who they may be able to identify with, we intend to foster an avenue by which community college students may gain both interest in paleontology and confidence in their ability to pursue higher academia.. Thus far, feedback from community college students and faculty has been extremely favorable, and we hope that we may help provide a blueprint by which other institutions can build avenues for local community college students to explore their interests and eventually bring their diverse backgrounds and perspectives into paleontology and related geoscience disciplines.

ISOTOPIC ANALYSIS OF FOSSIL CORONULID BARNACLES AS A MEANS OF UNDERSTANDING PREHISTORIC WHALE MIGRATION

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Migration is an integral feature of modern mysticete whale ecology, and the demands of migration may have played a key role in shaping mysticete evolutionary history. Constraining when migration became established and assessing how it has changed through time may yield valuable insight into the evolution of mysticete whales and the oceans in which they lived.

However, there are currently few data which directly assess prehistoric mysticete migrations. Here we show that calcite δ18O profiles of two species of modern whale barnacles (coronulids) accurately reflect the known migration routes of their host whales. We then show that δ18O profiles from well-preserved fossil coronulids exhibit trends and ranges similar to those of modern specimens, indicating that multiple Plio-Pleistocene whale populations of both the humpback and gray whale lineage were undertaking migrations of similar extent to those of the present day. We also find that Pleistocene whales congregating on the Pacific coast of Panama included individuals belonging to several different subpopulations, as the recovered δ18O profiles indicate very different migratory paths. Continued work on this project is aimed at integrating fossil coronulid δ18O profiles with paleoceanographic models and emerging proxies that can independently constrain seawater temperature and isotopic composition in order to more tightly constrain the migratory pathways of prehistoric mysticete whales.

A REAPPRAISAL OF HAPSIDOPHYLLAS FLEXIBILIS, A COMPLEX RANGEOMORPH ORGANISM FROM THE EDIACARAN BIOTA OF MISTAKEN POINT, NEWFOUNDLAND, CANADA

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The Rangeomorpha are a group of Ediacaran organisms characterized by the possession of multiple fractal-like, modular elements. They are a common component of the Late Neoproterozoic Avalon assemblage, which is found only in Newfoundland and England. These fossils are best exposed in Newfoundland at Mistaken Point, a 565 million year old locality found in the Mistaken Point Ecological Reserve on the south-eastern tip of the Avalon Peninsula. Owing to the international scientific importance of this fossil locality, the Mistaken Point Ecological Reserve was declared a UNESCO World Heritage Site in 2016.

One of the Ediacaran taxa unique to Mistaken Point is the complex rangeomorph organism *Hapsidophyllas flexibilis*. Although rare, specimens have been found on several bedding planes through the upper Mistaken Point Formation. They have been identified on the classic 'D' and 'E' Surfaces at Mistaken Point, as well as the notably smaller 'F' Surface. Specimens have also been found at Watern Cove, a site approximately 1 km north-east of the main Mistaken Point site, on a horizon correlated to the 'E' Surface as well as another horizon approximately 10 metres below the 'D' Surface at this locality.

Hapsidophyllas flexibilis was composed of a zig-zag shaped basal stalk (or stolon) and numerous elongate, frond-like branches which projected in an alternating fashion along both sides of the stolon. These fronds exhibited fractal branching: the large primary branches gave rise to smaller secondary branches, which emerged alternately along both sides of the primary branches. Small, tightly packed tertiary elements emerged from the leading edge of each of these secondary branches. It is generally accepted that the stolon of *Hapsidophyllas flexibilis* sat on the Ediacaran sea floor while the fronds extended upwards into the water column. The recent discovery of new material has prompted a reappraisal of this complicated organism. Careful study of key specimens suggests two distinctly different morphologies occur within *Hapsidophyllas flexibilis*: several specimens fit the original stolon plus elevated fronds model, while others appear to have grown along the sea floor surface (in a manner similar to *Fractofusus)*, lacking true fronds. The taxonomic status of *Hapsidophyllas flexibilis* may therefore need to be amended.

GAMIFYING VIRTUAL ENVIRONMENTS TO EXPLORE THE PAST 350 MILLION YEARS

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Traditional introductory STEM (science, technology, engineering and mathematics) courses often reinforce misconceptions because the large scale of many classes forces a lecture-centric model of teaching that emphasizes delivery of facts rather than exploration, inquiry, and scientific reasoning. This problem is especially acute in teaching about the co-evolution of Earth and life, where classroom learning and textbook teaching are far removed from the immersive and affective aspects of field-based science. Additionally, the challenges of taking large numbers of students into the field make it difficult to expose them to the context of the geologic record. Virtual explorations or Virtual Field Trips (VFTs), allow teachers to transport students to scientifically significant but inaccessible environments such as important localities associated

with the Cretaceous-Paleogene and Permian-Triassic mass extinction events. Grounded in the active learning of exploration, we are developing a game based experience where students non-linearly explore vertebrate evolution, ancient environments, and key adaptations that occurred along various evolutionary lineages over 350 million years. Created from research locations around the globe during actual expeditions and combined with scientifically accurate 360° simulated environments, students discover how animal traits evolved in response to environmental pressures, species interactions, and global mass extinctions. This interactive experience, developed in 360° VR (virtual reality), works in conjunction with an intelligent tutoring system that adapts to the individual learner as they interact within the program, making each experience unique to the student. Innovations in immersive interactive technologies are changing the way students explore the evolution of Earth, its environments, and its species, giving them a window into events such as the origin of mammals and the age of dinosaurs. The VFTs utilize state-of-the-art visual tools to capture high-resolution spherical content at field locations from major mass extinction boundaries. Through the use of advanced software, panoramic footage, gigapixel imagery of detailed fossil sites and unique views via drones are integrated into dynamic, game based virtual explorations that utilize adaptive feedback. As students explore these sites, the system gives teachers full pedagogical control over their students' learning. By designing an experience that merges rich paleontological content with intuitive learning courseware, teachers can cater to an individual student's needs and personalize their learning. These visual and scientifically rich experiences surpass conventional online exercises by allowing the student to engage in virtual environments that are more like games and less like lectures.

MORPHOLOGICAL DISPARITY OF CENOZOIC CASSIDS (MOLLUSCA: GASTROPODA)

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Cassid gastropods (Family Cassidae) are an underexplored mollusk group with poorly resolved taxonomy for multiple genera, time intervals, and regions. In addition to their phylogenetic significance as an important clade of gastropods, cassids are also of substantial paleoecological relevance: these echinoid predators drill distinct holes in the tests of their prey, recording predator-prey interactions. Cassid predation is well documented for present-day echinoids and drill holes are increasingly used to study predatory interactions between cassids and echinoids in the fossil record. The ongoing Echinoid Associated Traces (EAT) project explores traces of cassid predation on post-Paleozoic echinoids to better understand the evolutionary history of biotic interactions. This comprehensive study of the classification and distribution of cassids aims to supplement paleoecological efforts of the EAT project.

As part of this project we aim to resolve the taxonomy of the cassid gastropods from the upper Eocene Ocala Limestone, using specimens reposited in the Invertebrate Paleontology Division, Florida Museum. It is noteworthy that whereas fossil echinoids with traces resembling cassid drill holes are common in the Ocala Limestone, cassid specimens are rarely found in that rock unit. The cassid specimens displayed high morphological variation in shell ornamentation, and two morphotypes were identified; Morphotype 1 resembles *Phalium globosum* previously described from the Ocala Limestone (Dall, 1890), and morphotype 2 resembles modern *Semicassis* spp. There is high variability in specimens of morphotype 2, apparent in ordinations using Non-metric Multidimensional Scaling (NMDS), suggesting a gradient in ornamentation based on axial rib density and morphology. Thus, it appears that a minimum of two distinct morphotaxa of cassid gastropods are present in the upper Eocene Ocala Limestone of Florida.

To differentiate taxa, we carried out a morphometric analysis using 11 Cenozoic cassid morphotaxa. Nine linear measurements and six additional semi-qualitative character variables were collected from specimens representing 12 qualitatively defined morphotaxa. Principal Component Analysis (PCA) based only on the linear variables failed to distinguish distinctive morphotaxa. However, NMDS including both linear variables and additional variables delineated the qualitative morphotypes and also demonstrated temporal changes in morphological disparity and body size. This suggest that the combined use of continuous variables and semi-qualitative variables are better at distinguishing morphotaxa in the ordination space.

THE SMALL MAMMALS OF PAISLEY CAVES: DISENTANGLING CLIMATE-DRIVEN ENVIRONMENTAL CHANGE FROM PREHISTORIC HUMAN IMPACTS ON DIVERSITY DYNAMICS

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Quaternary paleoecology has greatly increased our understanding of community response to environmental change across the Pleistocene-Holocene transition during which modern ecosystems were first assembled. Small mammals have been central to this effort given their climate and habitat sensitivity and the myriad functional roles they play in ecosystems. Historical resurveys of small mammals spanning the last century, however, consistently reveal direct anthropogenic forces (e.g. habitat conversion) to be more important drivers of community dynamics than climate per se. This poses a seemingly strong limitation to the predictive use of paleoecological studies for the future. Little is known, however, about the strength of prehistoric human impacts and the role of climate-human interactions on small mammal communities, despite the fact that humans have shaped North American ecosystems since their arrival in the late Pleistocene.

Here we combine the paleontological and archaeological records of the Paisley Caves to evaluate late Pleistocene to late Holocene small mammal community dynamics in the Summer Lake Basin of central Oregon. The Paisley Caves complex is a world-famous site that includes the oldest directly-dated pre-Clovis human remains in the Americas (aDNA in coprolites) and a Rancholabrean megafauna assemblage. Focusing on Cave 5, we combine these cultural records with a faunal analysis of the small mammals (with ca. 1800 specimens of 32 species in 24 genera identified to date), using a new geochronologic framework built from 87 published AMS ^{14}C dates spanning ~16,000 to 1,000 cal years BP.

We find that small mammal richness and evenness remain high from the late Pleistocene through Younger Dryas, decline through the early and middle Holocene until ~4,000 years ago, then rebound into the late Holocene. These trends are consistent with previously-developed expectations from climate change, with richness tracking regional warming and drying through the middle Holocene, and amelioration of xeric conditions in the late Holocene, in an inverse manner. Based on the frequency of human artifacts, coprolites and megafaunal remains, human use of the site was also high in the late Pleistocene through Younger Dryas, rare between ~10,500 and 8,500 years ago, intermittent to ~5,500 years ago, low or absent to 3,000 years ago, then (paralleling the diversity of the small mammal community) rebounded to increasingly high levels over the late Holocene. Additional analyses of taxonomic composition and turnover of small mammals suggest a primary driving role of climate via the expansion of open habitats as the world warmed and dried, even for taxonomic groups known to have been directly exploited for resources (e.g., Lagomorphs). Future work will focus on quantitatively disentangling the direct and indirect effects of climate and human presence using regional paleoclimate records and composite indices of the human footprint through time.

AN *IOCRINUS* 'LOGJAM' FROM THE UPPER ORDOVICIAN KOPE FORMATION OF SOUTHWESTERN OHIO: PALEOECOLOGICAL AND TAPHONOMIC SIGNIFICANCE

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Crinoids are a common and well-studied faunal component of the Upper Ordovician (Katian; Edenian) Kope Formation in the greater Cincinnati Arch region, USA. However, a relatively fresh outcrop exposing the Southgate and McMicken members of the Kope Formation at Cleves, Hamilton County, southwestern Ohio, has yielded a crinoid specimen worthy of description and comment. The specimen is a "logjam" of numerous articulated columns of *Iocrinus subcrassus* displaying parallel alignment, reflecting the influence of storm-generated currents. *Iocrinus* is not typically found in such a state; the genera *Ectenocrinus* and *Cincinnaticrinus* are generally associated with "logjams" in the type Cincinnatian, making this an unusual occurrence. At least one of the columns has the coiled dististele of another, smaller *I. subcrassus* tightly wrapped around it. Although *I. subcrassus* is known to employ a coiled dististele as an attachment strategy, ramose bryozoans

are generally utilized as substrates and tight coiling around larger *I. subcrassus* columns has not previously been reported. Preservation of coiled dististeles, in general, is a feature not previously documented in Cincinnatian crinoid "logjams." This specimen illustrates that unusual, noteworthy and/or rare material representing relatively common organisms continue to be discovered even within extensively studied units in the type Cincinnatian.

PIRASOCRINID ANAL SAC SPINES WITH MULTIPLE PLANES OF REGENERATION IN THE UPPER PENNSYLVANIAN OF EASTERN OHIO

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Isolated crinoid ossicles showing evidence for regeneration following breakage, commonly generated by attempted predation, remain relatively under-studied in spite of their near ubiquity in upper Paleozoic crinoid-rich units in the North American midcontinent. Although there are numerous challenges to understanding and/or quantifying predator-prey relationships using exclusively disarticulated crinoid remains, exceptional specimens are nevertheless useful in recognizing paleoecological phenomena that were previously undescribed and capable of providing guiding questions for future studies. Very recently, the first isolated crinoid ossicles showing evidence for repeated breakage and regeneration—primibrachial spines of undetermined pirasocrinid cladids—were reported and described from the Upper Pennsylvanian Ames Limestone member of the Glenshaw Formation in eastern Ohio. These specimens most likely represent multiple predation attempts throughout the lifespan of single crinoid individuals; further, these repeatedly regenerated brachial spines occur within a crinoid fauna displaying the highest rate of regenerating spines of the entire Paleozoic. Herein we report specimens of pirasocrinid anal sac spines bearing multiple regeneration planes from the same stratigraphic interval as the previously described brachial spines. These specimens not only represent the first documentation of tegmen spines that were broken and began regeneration multiple times during the lifetime of an individual, but also corroborate the interpretation that pirasocrinid crinoids in eastern Ohio during deposition of the Ames Limestone were subjected to anomalously high (attempted) predation intensities. Additional examples of such specimens are needed to generate an explanatory model for the occurrence of such material, but relationships between the morphology of pirasocrinid crowns and interactions with associated non-predatory organisms may be the most important factor in explaining the high regeneration frequency of crinoid spines belonging to this group during the Pennsylvanian.

HOW DISTINCT IS DISTINCT? ATURIA (ATURIIDAE: CEPHALOPODA) FROM THE EARLY OLIGOCENE OF FLORIDA

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The fossil nautiloid genus *Aturia* is worldwide in its distribution. While many species of the genus are described, the extent to which these species differ is unclear, as many descriptions appear to be geographically specific. In 1947, Miller compiled a report of the named species of *Aturia* from the Tertiary of America - the most comprehensive report of the genus to date. With these data in mind, we attempt to place the *Aturia* species found in the Oligocene surficial deposits of Florida. This preliminary placement of the Florida Oligocene taxon is established using a combination of existing literature on the genus and features of these nautiloids, particularly, but not exclusively, the suture pattern.

Here, we take the approximately fifty specimens in our collection from the Oligocene of Florida and compare them against species described in the literature, specifically occurrences from the Gulf Coastal Plain and the West Coast of the United States, as cephalopods reported from these locations are similar in both age and appearance. In particular, we have looked at records of *Aturia curvilineata* (reported from other Cenozoic deposits in Florida) and *Aturia angustata* (recorded from multiple states along the West Coast of the United States). In addition to examining differences between species, we have also looked for any mention of unusual epizoans, as the only similar reports of epizoans that encrust many of the specimens from the Florida Oligocene occur in the Miocene of France. While epizoan encrustation is common in modern nautiloids and certain fossil taxa, it is variable in species of *Aturia*.

To add to our data on the Oligocene *Aturia* of Florida, we have used a micro-CT to scan additional silicified concretions posited to contain *Aturia*. Typically, preparatory methods used to expose the enclosed

cephalopods have been destructive and led to incomplete study. We hope that these scans will provide additional data for descriptive and morphologic work, as they both preserve detail and are non-destructive to the specimens inside. These scans have also proved to be useful in illustrating the preservation and parts of cephalopods in educational demonstrations.

MORPHOLOGICAL AND GENOMIC EVOLUTION OF THE ECHINODERM SKELETON

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The morphological evolution of the echinoderm skeleton is well-documented in the rich fossil record of the phylum. In addition to their well-sampled fossil record, the genomic underpinning of skeletogenesis in echinoderms is amongst the best known of any model animal group. The evolutionary history of the echinoderm skeleton is characterized by both expansion and reduction of mesodermal skeletal biomineral which is underlain by changed in the expression of biomineralization genes, transcription factors, and signaling molecules. One of the more drastic of these is the evolution of largely soft-bodied holothurians (sea cucumbers) from a heavily skeletonized echinozoan ancestor. This both parallels and contrasts with the putative reduction of the skeleton in larval echinoderms, both with respect to morphology and genetic regulatory changes. The evolution of the larval and adult skeletons of echinoderms provide insights into the larger and more general molecular mechanisms underlying morphological change in the fossil record.

THE FORMATION OF PERMANENT FOSSILS RECORDS: ESTIMATING POST-MORTEM DISINTEGRATION, BURIAL, AND MIXING FROM SHELL-AGE FREQUENCY DISTRIBUTIONS IN SEDIMENT CORES

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The completeness and temporal resolution of fossil records—what we collect and analyze as paleontologic time-series—is determined by the combination of skeletal disintegration, mixing, and burial, and each of these rates can vary with sediment depth. Slow sedimentation and/or deep bioturbational mixing decreases the temporal resolution of fossil assemblages in stratigraphic increments, which leads both to high time averaging and to temporal overlap in the ages of shells in adjacent sedimentary increments. In such cases, estimates of burial, disintegration, and mixing can be difficult to decouple. Here, we apply stochastic transition matrices to estimate these three parameters and their depth dependence using empirical data on downcore changes in the shape of bivalve shell age-frequency distributions from two sediment cores collected at 50 m water depth on the southern California shelf. The number of parameters in the matrix increases strongly with the number of sedimentary increments considered, and so we model parameters at only two scales: high resolution (4 cm-thick increments) and low stratigraphic resolution (10–20 cm-thick units; sediment-profile imagery shows that burrowing depth frequently reaches to 20 cm on our shelf). These models assume (1) time invariance in burial and mixing rates within each increment as well as (2) steady-state production of dead shells, but nonetheless successfully recover downcore shifts in the shape of age-frequency distributions observed in our cores, including (i) strongly right-skewed distributions in the uppermost core increments with rare but very old shells and (ii) normal-shaped distributions in deeper subsurface increments. The models (1) detect a relatively abrupt decline in disintegration rate, from very fast, yearly to decadal-scale disintegration in the upper 20–25 cm (i.e., taphonomic active zone) to very slow millennial-scale disintegration in deeper increments (including an 'incompletely mixed layer' penetrated by deep-burrowing callianassids, from which old shells can be exhumed), and (2) show that the upper 20–25 cm is a zone characterized by high mixing between adjacent 5 cm-thick increments ('complete mixing'). These results also support scenarios where shell disintegration slows significantly after subsurface (temporarily deeply buried) shells are exhumed back to the surficial taphonomic active zone —that is, shells both achieve a 'time out' from high loss rates during temporary deep burial and become 'less reactive', even when re-subjected by upward advection back into the rigors of the surficial taphonomic active zone. Sequestration processes can decouple per-individual and per-species preservation probability, and thus can allow for preservation of accurate information about species composition and diversity at centennial or millennial temporal resolution.

VALIDATION OF PSAMMICHNITES GIGAS ICHNOZONE (CAMBRIAN SERIES 2/ STAGE 4) IN TETHYAN HIMALAYA

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Trace fossils have become an important biostratigraphic tool in Early Cambrian non-fossiliferous deposits. The base of Cambrian system is also marked by *Treptichnus pedum* Ichnofossil Assemblage Zone (Narbonne, Myrow and Anderson, 1987; Landing et al., 2013; Laing et al., 2016; Buatois, 2018). Pre-trilobitic trace fossil zones have been established worldwide by Crimes (1987) and subsequently followed by several other workers (MacNaughton and Narbonne, 1999; Buatois and Mangano, 2011; Mangano et al., 2012; Jensen, 2003). In Tethyan Himalaya (India), previous literature marks a notable trend of two discrete pattern of trace fossil evolution (Raina et al., 1983; Kumar et al., 1984; De et al., 1994; Bhargava et al., 1986; Sudan et al., 2000; Sudan and Sharma, 2001; Parcha and Pandey 2011; Sudan and Sharma, 2000) which were latter abandoned by Hughes (2002; 2016). Hughes (2016) emphasised that in Cambrian of Himalaya there are few trace fossils that have short stratigraphic range and can be helpful as biostratigraphic marker. *Psammichnites gigas* is one of them that can be helpful in correlating the Cambrian Series 2 (Stage 4) strata across the length and width of the Cambrian of Himalaya (Hughes et al., 2013; Hughes 2016). *Psammichnites gigas ichno*zone (Hughes, 2016) in Himalaya is recognised to occur from *Drepanopyge gopeni* level to *Redlichia noetlingi* biozone of Cambrian Series 2, Stage 4 (Hughes, 2016). Present work in Chandra, Sumna and Parahio valleys of the Spiti region validate the existence of *Psammichnites gigas* ichnozone. In Tethyan Himalaya, this ichnotaxon have been reported from Spiti (Bhargava et al., 1986), Kashmir (Bhargava and Srikantia, 1982; Raina et al., 1983; Singh, 2011), and Zanskar (Hughes and Droser, 1992; Hughes et al., 2013). In Kashmir, *Psammichnites gigas* lies 1100 m above the base of the Lolab Formation that falls somewhere in the Cambrian Series 2/ Stage 4 as the uppermost part contains the *Redlichia takooensis*. We recorded *Psammichnites gigas* from two localities from Spiti region (1) from Parahio valley near the confluence of river Khemangar khad and Debsa khad towards Khemangar khad river and (2) from the Chandra valley. In Parahio valley, this record lies immediately below the *Haydenaspis parvatya* level (Cambrian Series 2/ Stage 4), therefore falls under Cambrian Series 2/ Stage 4. In Chandra Tal section, *Psammichnites gigas* is recorded from the Member D of Kunzam La Formation of Srikantia (1981) (Kaur et al., *in review*) and probably falls under the Cambrian Series 2, Stage 4. Although no age diagnostic fossils are known from Chandra valley so far. The distribution of *Psammichnites gigas* in the Cambrian of Tethyan Himalaya indicate its occurrence within the upper part of Cambrian Series 2/ Stage 4. Therefore, the present work validates the *Psammichnites gigas* ichnozone (Hughes 2016) in the Cambrian of Tethyan Himalaya which suggest Cambrian Series 2/ Stage 4 (516 Ma–509 Ma) age.

TROPICAL AND POLAR PLANKTON DEMONSTRATE CONTRASTING SENSITIVITIES TO CLIMATE CHANGE THROUGHOUT THE LATE NEOGENE

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Climate models have shown that modern global warming has a greater impact at the poles than at the equator, but the effect of this differential impact on plankton communities remains unknown. The early-mid Pliocene was a warm climate interval, and has been used as an analog for anthropogenic climate change. Following the mid Pliocene warm interval, progressive global cooling occurred throughout the late Pliocene and Pleistocene. A comprehensive radiolarian biodiversity history has been published for the Neogene Southern Ocean (Renaudie and Lazarus 2013), and shows a steep 50% decline in species richness over the last 6 million years. Until now, there has been no comparable investigation of tropical radiolarian populations. Here, the first reasonably-complete diversity curve for tropical radiolarians is presented for the last 6 million years of a deep-sea sediment core (IODP Site U1337) in the eastern equatorial Pacific (EEP). The dataset is compared to the methodologically similar Southern Ocean data to test whether tropical and polar radiolarians expressed similar responses to global climate change in the Late Neogene.

Radiolarians were identified and enumerated from samples spaced at 0.5 to 1 Ma intervals to calculate biodiversity, using cumulative frequency curves to

determine level of completeness (several thousand specimens counted per sample). With these data, range-through species diversity, Pielou equitability, and Shannon evenness indices were calculated, and compared to the Southern Ocean dataset. Preliminary analyses of these data indicate mean range-through biodiversity was 483 taxa (standard deviation=17) from 6–1.5 Ma. Remarkably, the average diversity observed at site U1337 was more than two fold greater than the maximum diversity observed in the Southern Ocean across all time bins. Despite discernible turnover in community composition over the last 6 million years, tropical radiolarians underwent very little change in community structure. For example, the Pielou equitability index averaged 0.84, with a standard deviation of only 0.02 across the study interval. Similarly, the mean Shannon evenness value was 4.99, with a standard deviation of 0.14. These results draw a stark contrast with Southern Ocean radiolarian assemblages, which display a sustained decrease in evenness circa 8 Ma, followed by a dramatic 50% decline in diversity from 6 Ma to present. Our comparison underscores a markedly different response between tropical and polar plankton communities to climate change with greater impact on the polar communities. If confirmed by further data and analyses, this result will help us predict how anthropogenic activity will impact plankton and their related marine geochemical cycles in the imminent future.

NEW CENSUS OF RADIOLARIAN COMMUNITIES IN THE EASTERN EQUATORIAL PACIFIC REVEALS UNPRECEDENTED BIODIVERSITY THROUGHOUT THE LATE NEOGENE

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Radiolarians are a particularly promising group of microfossils for evolutionary studies, owing to their high species diversity (~400 living taxa) and long, continuous long fossil record (500 Ma to present). Their Cenozoic occurrences are primarily recorded in DSDP/IODP studies, which are synthesized in the Neptune microfossil database that is regularly used in big-data analyses of plankton evolution. However, the majority of these studies focus on biostratigraphically-relevant taxa, which are important for age-determination of deep-sea sediments, but are not always representative of true evolutionary patterns. Previous work on Neogene radiolarian assemblages in the Southern Ocean showed that important aspects of the true biodiversity signal were only partially recoverable in Neptune (Renaudie and Lazarus 2013). So far, a full census of radiolarian taxa in other oceanographic regions has not been completed. Therefore, in order to lay the foundation for better understanding radiolarian diversity, evolution, and global distributions, this study presents the first reasonably complete catalog of radiolarian species occurrences and abundances from 6–1 Ma in the eastern equatorial Pacific (EEP).

Several thousand radiolarian specimens were identified largely to the species level and counted to uniform completeness for each of eight samples from Site U1337, dated: 1Ma, 1.5Ma, and 2 through 7Ma. Preliminary results indicate that range-through diversity (excluding bounding-edge samples) ranges from 460–500 taxa. Peak diversity occurred at 3Ma, but overall remained relatively stable throughout the study interval. Community composition, however, was not static. Preliminary analyses show approximately 30–40 first and last occurrences in each time bin spanning 5–2Ma (other samples omitted for edge effects). Considering previous documentation of Neogene EEP radiolarians, these high numbers of taxa are unprecedented. The Neptune database records only ~30 species (range-through diversity) per million-year time bin from 6-1Ma in tropical latitudes. The most recent publication on EEP biostratigraphy and turnover reported a total of 152 species over the last 17Ma, with first and last occurrence events averaging between 5–10 per million-year time bin (Kamikuri et al. 2009). Both of these sources agree with the general pattern of stable radiolarian biodiversity from 6–1Ma observed in this study; however, previous estimates do not come close to reflecting the true magnitude of diversity in these assemblages. Many of the new taxa are Plagiacanthidae, which tend to include smaller species than families typically used for biostratigraphy, likely contributing to their poor representation in past studies. These results underscore the need to continue documenting radiolarian diversity history in other oceanographic regions, unbiased by species' relevance to biostratigraphy, to maximize their potential for testing evolutionary questions in the fossil record.

PROGRESS AND CHALLENGES IN DECIPHERING COMPLEX STRUCTURE-FUNCTION MAPPING IN THE FOSSIL RECORD: EXAMPLES FROM THE

MAMMALIAN JAW MODEL SYSTEM

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The field of musculoskeletal functional morphology has made significant progress over the past decade in methodologies that quantify and clarify the mechanics and movements associated with different lifestyles of extant species. Such advances have had a catalytic effect on the study of the paleobiology of animals as a whole. In the area of functional morphology of the feeding apparatus, computational approaches such as finite element analysis and theoretical morphing represent some of the most powerful tools for quantitatively assessing hypothesized adaptations and structure-function relationships. In this presentation, I give an overview of the progress that has been made in our understanding of the biomechanical capabilities of extinct mammalian predators using those computational tools. Jaw structure-function studies have revealed unexpected size- and shape scaling relationships, novel interpretations of structural convergences for different predatory capabilities, and new lines of evidence linking macroevolutionary sensory innovations to modifications of jaw function. Even with these discoveries, great methodological challenges remain: (1) An actualistic framework for interpreting feeding functional morphology of extinct organisms is only beginning to mature through broad-scale studies and experimental validation of extant species datasets, (2) limitations in the ability to accurately capture morphological geometry for computational analyses grow with the geologic age of fossil specimens, and (3) incorporation of new computational methods and the broader use of currently available methods are hampered by steep learning curves and hardware resource requirements. I outline specific steps to address these challenges in order to further advance computational functional morphology in paleontology.

THE EARLIEST COMPLEX TRACE FOSSILS FROM THE TERMINAL NEOPROTEROZOIC OF NAMIBIA

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The Ediacaran Period is a critical interval in the history of life on Earth, as it records the first appearance of complex macroscopic metazoans in the fossil record. Ediacaran fossils herald not only major shifts in the sizes and complexities of benthic communities, but also fundamental behavioral innovations which lay the groundwork for the ever-growing suite of ecosystem engineering behaviors that characterizes the Phanerozoic. The Nasep Formation of the Nama Group, southern Namibia, preserves among the earliest 'complex' *Treptichnid*-like trace fossils known, recording the earliest evidence for systematic probing of the substrate. However, beyond an initial description of these fossils by Jensen et al. (2000), little about this ichnofauna is known. Using a large collection of slabs from two different localities we describe the ichnofauna of the uppermost Nasep Formation. We identify several different ichnotaxa, interpret them in context of diversity and complexity of bilaterian behaviors, and discuss their potential relevance to broader Ediacaran-Cambrian bioevents.

BODY SIZE CHANGE IN CHALK SEA ANIMALS DURING THE CENOMANIAN-TURONIAN WARMING EVENT

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The iconic Upper Cretaceous Chalk Group of southern England ranges in age from Cenomanian to Campanian and yields diverse fossil marine assemblages that have been collected for over 200 years. These fossils provide direct evidence of the ecological and evolutionary impacts of the Cenomanian-Turonian mass extinction event; a major biotic crisis in marine ecosystems associated with an interval of climate change, elevated temperatures, peak sealevel, and widespread oceanic anoxia. This study utilized specimens from museum collections to determine how the body sizes of a range of marine taxa changed through the Cenomanian-Turonian interval, and in particular to test the hypothesis that marine animals become smaller during episodes of global warming. Two major groups of organisms were selected for study, due to their ecological importance in Chalk Sea ecosystems: sharks and echinoids. The shark dataset comprised 14 genera of lamniforms, including apex predators, and in addition the enigmatic durophagous genus *Ptychodus*. Tooth-size was used as a proxy for body size, and the shark specimens mainly comprised disarticulated teeth, with a few articulated and associated dentitions. The echinoid dataset comprised six orders spanning

a range of niches, from infaunal spatangoids to epifaunal omnivores such as the cidaroids, with test size being used as a measure of body size. In all cases, the best-preserved and stratigraphically best-constrained available specimens were measured. Significant size reduction was recorded in a number of taxa, as predicted, but not all. In some cases, body sizes significantly increased across the Cenomanian/Turonian boundary. Echinoids that showed the predicted reduction in body sizes included representatives of the orders Salenioida, Holectypoida, Spatangoida and Holasteroida, whereas studied taxa of the Echinoneoida and Cidaroida increased in size. Taxon-specific responses may be due to differences in ecology and feeding, suggesting that body size was driven by a variety of factors, possibly including biotic factors such as availability of food and competition, not just temperature. Similarly, the sharks showed different responses, which also appear to correlate with feeding ecology. Lamniform shark teeth are much rarer in the Turonian, which means that in some cases it is not possible to determine whether recorded differences in size are significant, but some do become smaller. In contrast, the durophagous *Ptychodus* remained abundant and common during the Turonian, and did not decrease in size. Although museum collections suffer from various well-known biases, it seems unlikely that the different responses of body-size recorded in this study are solely driven by taxon-specific collection biases. Given their key ecological roles in Chalk Sea ecosystems, changes in the body sizes of sharks and echinoids recorded in this study have implications for how marine ecosystems functioned during this major climate change event.

BIOTURBATORS, GLOBAL WARMING AND SHRINKING SEAFOOD: IMPLICATIONS FOR ECOSYSTEM FUNCTIONING IN HOTHOUSE OCEANS

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Body size is a key trait with implications for many aspects of an animal's biology, ecology and behavior, and is correlated with many ecosystem functions such as productivity and nutrient cycling. This is especially true of the marine bioturbating 'ecosystem engineers', such as the infaunal crustaceans and echinoderms, which play a key role in sediment mixing and nutrient cycling in marine habitats. The body size of marine animals is known to be affected by a range of environmental conditions, such as temperature, salinity and hypoxia, and one key hypothesis of future change is that marine animals will become smaller in size due to current global warming with important consequences for food resources and ecosystem function at local, regional and global scales. This 'shrinking seafood' hypothesis is based on theoretical considerations and limited laboratory-based experimental studies. Body size is conserved during the fossilization process, and so the high-resolution marine fossil records of past global warming events are important archives of data that can be used to test the 'shrinking seafood' hypothesis. The sizes of lightly mineralized and unpreserved bioturbating infauna can be estimated from their fossilized burrows. Although a number of published studies have demonstrated a temporary reduction in body size in marine animals, at a variety of spatial, temporal and taxonomic scales, through intervals that are associated with evidence for past global warming, including for example the Permian-Triassic and Triassic-Jurassic intervals, consistent with the 'shrinking seafood' hypothesis, few of these studies incorporated paleoenvironmental proxy data or have investigated the implications of these changes for bioturbation and nutrient cycling. A correlation between the size of marine bioturbators and temperature change has not been satisfactorily tested in most cases. Thus, our knowledge can be improved by incorporation of associated paleoenvironmental data, from geochemical analyses of either the same horizons that yielded the fossils or from the fossils themselves, enabling a much more rigorous test of the 'shrinking seafood' hypothesis. Key strengths of the fossil record are that it provides long, multi-generational time series and whole-ecosystem data from natural settings, and enables temperature-related size change to be tested in relatives of extant organisms that cannot be, or have not been, studied *in vivo*. It also enables study of size change not only during the warming interval but also during the subsequent return to pre-warming size as conditions ameliorate. As demonstrated here, combining fossil data with experimental data from *in vivo* experiments on living relatives has the potential to generate novel insights into potential future change as well as a greater understanding of the impact of past global warming on the bioturbating 'ecosystem engineers' and nutrient cycling.

CHANGES IN PALEOCOMMUNITY STRUCTURE ASSOCIATED WITH THE MESOZOIC MARINE REVOLUTION IN THE WESTERN TETHYS

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Predators influence community structure and dynamics in many modern ecosystems, yet the importance of predation on macroevolutionary timescales remains controversial. Paleocommunity interactions such as increasing predation intensity, ecospace utilization, and disturbance may have led to the diversification and evolution of species. However, it is difficult to determine how changes in richness and ecospace utilization have altered community structure and functioning. Examining how ecosystems have responded to changes in predation intensity in the past could provide crucial insights into the potential range of responses and the severity of the current biodiversity crisis.

Here we compare the network topology of food web models of shallow marine paleocommunities from the Triassic (Anisian), Jurassic (Bathonian), and Cretaceous (Aptian) in the western Tethys, to identify differences in ecosystem structure and functioning associated with the Mesozoic Marine Revolution (MMR). Although richness increases from the Anisian to Aptian, functional diversity (i.e., the number of trophic guilds) did not, and was highest in the Bathonian (117 trophic guilds relative to 105 in the Anisian and Aptian). The appearance of new guilds was driven by increases in body size rather than new modes of life. The Bathonian network was also partitioned into fewer subcommunities, with the largest subcommunity dominated by suspension feeders, coinciding with radiations of phytoplankton during the Jurassic. In addition, the Bathonian network had longer trophic chains, possibly related to the increase in primary productivity and an increase of energy flux. These findings suggest that new evolutionary innovations and biotic expansions observed during the MMR may have triggered significant ecosystem restructuring and changes in energy transfer pathways, facilitated by the radiation of phytoplankton.

The examination of ancient food webs presents an opportunity to determine whether trophic organization has changed, and to understand the evolutionary mechanisms that have contributed to historical patterns of community structure. Given the current biodiversity crisis, understanding how and why ecological changes occur is vital for effective resource management.

FOSSIL CETACEANS OF THE EASTERN PACIFIC: A COMPARISON OF THE NORTHERN AND SOUTHERN HEMISPHERES

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Cetaceans (whales, dolphins and porpoises) are first found in the fossil record around 52.5 million years ago (Ma) during the early Eocene in Indo-Pakistan. Our knowledge of early and middle Eocene whales has increased dramatically during the past three decades, and by the middle Eocene (~47.8 Ma) whales are known from almost all of the world's coastlines. One major exception to this is the Pacific coast of North America. While a few middle Eocene whales are known from western South America (Peru), early whales are currently unknown from the Pacific coast of North America except for a few fossils from Oregon, Washington and Vancouver Island, Canada, all of which have poor age constraints. It is currently unclear why early whales are unknown from this large area during the Eocene.

Both North and South American Pacific coasts have produced rich cetacean faunas from the Oligocene to the Holocene. There are also many fossils from both continents that have yet to be described that are housed in museums along both coasts. To date, these faunas have only been compared in a global study of marine mammal faunas . A more detailed comparison of these faunas is needed to determine what, if any, barriers to migration exist today, and to determine if and when these barriers to migration existed in the past.

Preliminary comparison of the cetacean faunas of these coasts show that in total, North America has about twice the number of occurrences when compared to South America. This is likely due to a known bias in the entire fossil record towards northern continents when compared to southern continents. Interestingly though, the North American occurrences were about equally balance between mysticetes and odontocetes, while South America had about three times as many odontocetes as mysticetes. In both continents about one third of the taxa are represented by mysticetes with about two thirds represented by odontocetes. Further study is needed of as yet undescribed museum specimens to determine how much these regions have in common with each other, and how they change along a north-south gradient in each hemisphere.

HYOLITH TAPHONOMY: DECAY PATTERNS

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Hyoliths represent a group of extinct Palaeozoic invertebrates whose systematic affinity remains unclear. Hyoliths were provided by aragonitic shells and have been often classified as *incertae sedis*, separate phylum or as a family within the phylum Mollusca. The recently published studies suppose a strong affinity of hyolithids to Palaeozoic lophophorates, mainly to brachiopods. The affinity of orthothecids is still unresolved.

The group Hyolitha is usually divided into two main orders. The order Orthothecida Marek, 1966 represents hyoliths with a conical shell of diverse cross-section (circular, elliptical, kidney-shaped...) closed by a planar aperture with retractable planar or slightly concave operculum. The order Hyolithida Sysoev, 1957 is characterized by a shell of diverse cross-section (triangular, oval, etc.) with prolonged venter, corresponding lower part of a non-retractable operculum and one pair of curved appendages called helens which protrude from the space between conch and operculum.

Hyoliths usually occur as disarticulated elements scattered at bedding planes. Well preserved fossil assemblages, including hyolith Lagerstätten, occur rarely on certain undisturbed bedding planes. The hyolith skeletons in such facies tend to be well articulated, commonly with conchs, opercula and helens preserved *in situ*. The studied material comes from the Cambrian to Devonian sites of Barrandian area of Czech Republic.

Hyoliths usually rapidly disintegrate into individual skeletal elements. The difference in composition of conch and opercula is supposed, based on usually distinct preservation. Disarticulation of hyolith exoskeleton was mediated by one or more of the following processes: mechanical disintegration after death of the animal, like current and/or wave agitation, macrofaunal shallow or deep bioturbation, bacterial decomposition of soft tissues, including muscles keeping exoskeletal parts together, etc.

The following stages of disarticulation of hyoliths are distinguished.

Stage 0 (exoskeletal parts are fully articulated): Hyolithida /Orthothecida – dead or moulted fully articulated specimen composed by all skeletal parts (conch, operculum and paired helens/conch and operculum) all preserved *in situ* and/or showing only a slight *post mortem* displacement.

Stage 1: Hyolithida – one or both helens are detached from the operculum and conch, but the two large skeletal parts are still connected and/or only slightly displaced or operculum is still connected with one or both helens and these two or three elements are detached from the conch.

Stage 2: Hyolithida/Orthothecida – helens, so far connected with the operculum and/or with the conch start to detach, consequently, the operculum becomes detached from the conch. All elements are free.

Stage 3: Full disarticulation of hard parts of hyoliths.

FROM BEACH BONES TO FOSSILS: TAPHONOMIC INSIGHTS FROM A NORTHERN ELEPHANT SEAL BREEDING COLONY

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Taphonomic processes dramatically shape the representation of different groups in the vertebrate fossil record. Pinnipeds (seals, fur seals, and walruses) have an unusual amphibious lifestyle causing them to be exposed to very different taphonomic processes depending on where they die (land versus water). Unfortunately, the potential effects of these different taphonomic processes are largely unexplored, which could be affecting the interpretation of the extensive fossil record of pinnipeds. The presence of an established northern elephant seal (NES, *Mirounga angustirostris*) breeding colony at Pt. Año Nuevo on the central California coast provides an exciting opportunity to observe the onshore taphonomy of NES and co-occurring California sea lion (CSL, *Zalophus californianus*). Here we present preliminary results of this taphonomic study. Direct observations along linear transects resulted in more than 350 isolated bones. 60% of these isolated bones corresponded to NES, followed by less than 10% assigned to CSL (the remaining fraction corresponded to indeterminate pinnipeds and other vertebrates). There is a strong bias in the NES bones towards the remains of pups (67%). The most represented skeletal remains are elements of the skull, vertebrae, and hind limbs, respectively. We also found 30 associated pinniped carcasses in variable states of decomposition, of which 70% correspond to NES pups. In addition, we found differences in the trajectory of decay and skeletonization processes between species of pinnipeds. In fact, adult NES have a longer process of decay and disarticulation compared to adult

CSL (months versus weeks). Furthermore, carcasses of NES pups were proportionately more affected by scavengers than adults, limiting their preservation. Overall, these results underline the need for new and more exhaustive taphonomic studies for accurate interpretation of the fossil and archaeological assemblages of pinnipeds.

APPLYING MURPHY'S 1977 TIME-STRATIGRAPHIC CONCEPTS TO SUBDIVIDE THE LOCHKOVIAN (LOWER DEVONIAN) IN THE SPANISH PYRENEES AND TEST ITS GLOBAL VALUE

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In seeking a stable and flexible stratigraphical nomenclature for naming and identifying stratigraphical units, Murphy proposed the use of a binomial nomenclatural system, which combines the names of the defining boundaries of each unit. Application of this methodological approach to the Lochkovian (Lower Devonian) conodont record in the Spanish Pyrenees has resulted in the construction of a detailed Pyrenean standard of reference that can be, for some parts of the scheme, globally correlated. The Lochkovian is subdividing into three parts. The lower part is poorly constricted by means of conodonts; nevertheless the evolutionary steeps within *Icriodus* and the innovation of *Ancyrodelloides* permit a threefold subdivision. The middle part is the best known globally due to the quick evolutionary and widespread distribution of its cosmopolitan components, mainly *Ancyrodelloides, Lanea, Flajsella* and *Masaraella.* The basic subdivision into worldwide correlatable units is based in the evolutionary steeps of *Ancyrodelloides*, and includes the first (evolutionary) occurrences from *Anc. transitans* to *Anc. kutscheri*. Further precision is achieved within these *"Ancyrodelloides*-bracketed" units by the succeeding entries of *Lanea* species(*L. omoalpha* to *L. telleri*), and *Flajsella* (*F. schulzei* to *F. streptostygia*). The lower boundary of the upper part of the Lochkovian is defined by the evolutionary first occurrence of *M. pandora beta* and is further subdivided by the evolutionary events within *Pedavis*.

Combined studies with the Nevadan material collected initially by Murphy and, completed jointly in the 90's, have provided a strong and sound dense correlation net for the middle part of the Lochkovian, becoming its stratigraphical units a standard of reference. This subdivision can also be applied to sequences in the classical Barrandian (Prague Synform) and Carnic Alps areas.

THE ROLE OF SPANISH CONODONTS IN THE REDEFINITION OF THE BASE OF THE EMSIAN STAGE (LOWER DEVONIAN)

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The Emsian GSSP is placed at the base of Bed 9/5 in the section Zinzilban in the Kitab State Geological Reserve (Uzbekistan) based on the evolutionary entry of *Polygnathus kitabicus*. This Bed is 35 cm above the base of the, relatively thin bedded limestone, Khodzha Khurgan Formation, which overlain the massive limestone of the Madmon Formation, and this marked lithological shift has been linked to a global sea level rise. Prior and, especially, after this GSSP definition long discussions and doubts regarding this position prompted the International Subcommission on Devonian Stratigraphy (SDS) to organize a fieldtrip and subsequent discussions in the Kitab reserve. The SDS agreed with reviewing the position of the boundary and placed it in a higher level to be coincident with the entry of *Pol. excavatus* 114, a taxon of the *excavatus* group bearing semi-crossed ridges, which evolved from the *pireneae-kitabicus* stock. This taxon occurs in the Iberian Chains (Spain) at the base of the Mariposas Fm. The fossil record of the lower part of the Mariposas Fm suggests that the classical German Emsian would correlate slightly above this level. Besides this index and its predecessor, *Pol. exc. excavatus*, no other polygnathid is recorded around this critical interval in the Iberian Chains. In contrast, the icriodontidae record is better and the lowest occurrence of *Icriodus sigmoidalis*, which seems to be synchronous with the entry of *Pol. excavatus* 114, stands out. In the Pyrenees, several sections in platy limestone of the Llaviero Member (Basibé Fm.) or its equivalent Castanesa Fm have yielded an extraordinary well preserved succession of icriodontidae and polygnathidae. The latter group comprises the evolutionary sequence from the earliest *Pol. pireneae* (the ancestor of *Pol. kitabicus)* to the descendant of *Pol. excavatus* 114. Several other taxa from lateral branches of this main polygnathid stock are recorded in the Pyrenean sections as well. Key *Icriodus* taxa are also present in the Pyrenean sections together with *Polygnathus*, conferring the Spanish Pyrenees an extraordinary valor for intercontinental and interfacial correlations across the Pragian/Emsian

boundary (either current or redefined GSSP). Therefore, the Spanish records are pivotal for the study and redefinition of the Pragian/Emsian Stage boundary.

EXPORT EFFICIENCY OF THE BIOLOGICAL CARBON PUMP LIMITED BURROWING BEHAVIOR IN THE EARLY PALEOZOIC

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Most of the present-day seafloor is inhabited by animals. Contemporay studies show that the feeding, moving and burrowing behavior of these benthic fauna, conjointly referred to as bioturbation, limits the burial of organic matter and pyrite, while promoting burial of phosphorus in the present-day seafloor. Burial of reduced carbon (in organic matter) and reduced sulfur (in pyrite) in the seafloor leads to an increase in atmospheric oxygen, while organic matter burial also decreases atmospheric CO_2 concentrations. Additionally, a decrease in oceanic phosphate concentrations limits primary production, thereby decreasing O_2 production and CO_2 consumption. Consequently, the evolution of shallow levels of burrowing has been suggested to trigger expanded ocean anoxia, high atmospheric CO_2 levels and global warming in the early Paleozoic. Throughout most of the Paleozoic, however, the burrowing intensity and depth seems to have been limited to a fraction of what it is today. To fully understand the role of bioturbation in the evolution of the Earth System, we have to better understand what limited the development of bioturbation throughout the Phanerozoic. Oxygen has been commonly put forward as the prime limiting factor for animal evolution, however, this can only invoked for the Cambrian radiation, and not for the limited evolution of burrowing afterwards. Additionally, other factors have received less attention.

Here, we present a global compilation of modern bioturbation intensities. Correlation analysis reveals that most of the variation in bioturbation intensity can be best explained by the difference in organic matter supply to the seafloor. Using an Earth System model (cGEnIE), we are able to show that an increasing net primary production in the oceans lead to an expanse of ocean anoxia, thereby limiting the areal potential of bioturbation. In contrast, increasing the carbon export efficiency increases the organic matter supply to the seafloor, while sustaining high enough oxygen concentrations to sustain complex ecosystems. We propose that ecosystem changes in the pelagic food webs and carbon cycling during the Phanerozoic could have played a primary role in the rise of the first benthic animal communities.

RESOLVING THE TAXONOMIC VALIDITY OF THE GIANT EXTINCT AUSTRALIAN MARSUPIAL *NOTOTHERIUM* (DIPROTODONTIDAE) AND ITS RELATIONSHIP TO *ZYGOMATURUS*

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The Diprotodontidae is a family of extinct megafaunal herbivores that were integral members of terrestrial ecosystems in Australia and New Guinea until the last species became extinct c. 40,000 years ago. Despite their iconic status as the largest-ever marsupials and the frequency with which their remains are encountered, key aspects of their systematics and evolutionary history remain poorly resolved. There is no clearer example of this than taxonomic confusion of the late Cenozoic genera *Nototherium* Owen 1845 and *Zygomaturus* Macleay 1858, which has persisted for more than 160 years. This is attributable to: 1) the highly incomplete fossil material upon which the species of *Nototherium* were founded; 2) the subsequent destruction of the lectotype of the type species, *N. inerme*, during World War II; and 3) marked similarities in the size and shape of the jaws and teeth of species referred to *Nototherium* and *Zygomaturus*. Most recently, *Nototherium* and its species have been relegated to *nomen dubium* status. However, new material recently uncovered, including two crania, has shed light on the taxonomy and distinctiveness of *Nototherium* and provides evidence for its revival. Here I reassess the systematics of *Nototherium* and *Zygomaturus* along with a preliminary diagnosis and geographic range of the two most convergent and oft-confused species, *Nototherium inerme* and *Zygomaturus trilobus*. This study reaffirms the case of *N. inerme* to be treated as the type species.

GLOBAL MARINE ANOXIA AS A FORCING MECHANISM FOR ZOOPLANKTON COLONISATION AND DIVERSIFICATION

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Episodes of instability in the global climate-oceanic state are recorded in strata of the Silurian System, and are marked by high-amplitude stable carbon isotope excursions. These reflect major disturbances in ocean geochemistry and notably of the oceanic C cycle. There is an emerging body of data that indicates these signatures, for many of the Silurian events and much like their Mesozoic counterparts, reflect developing ocean anoxia (OAE's) and the sequestration of large volumes of isotopically light carbon on the deep seafloor. The shifting environmental conditions linked to these episodes proved highly disruptive for marine life. The best-known of these events, the end-Ordovician Hirnantian event, is one of the Phanerozoic 'big-five' mass-extinctions. Many of the succeeding Silurian events are known to be linked to extinctions of certain groups of marine taxa. The middle Homerian 'Big Crisis' was a major graptolite extinction, known as the *lundgreni* event, eradicating all but two to three of species, compared to the c. 50 species of graptolites prior to the event. The event is documented within the uppermost part of the *Cy. lundgreni* graptolite biozone and seems to be largely synchronous with a pronounced but less dramatic extinction in conodonts known as the Mulde Event.

Whilst ocean anoxia may have been detrimental to much of the marine fauna, here we present data that demonstrates the apparent coincidence of the Mulde event with the first radiation of myodocope ostracods into the planktonic realm. Myodocope ostracods are small bivalve arthropod crustaceans that play a key role in recent planktonic ecosystems. When compared to their exclusively benthic cousins the Podocope ostracods, they display a larger and less calcified carapace that, associated with powerful swimming antennae, allowed them to colonize the water column during the Silurian. In this talk, we explore the stratigraphical and geochemical evidence that suggests that OAEs may be a fundamental driver of planktonic myodocope radiations, and by extrapolation, plankton in general.

FILLING THE GAP IN THE HISTORY OF OTARIID SEALS IN THE SOUTHEASTERN PACIFIC OCEAN: NEW EVIDENCE FROM PERU

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Pinnipeds are conspicuous predators of upwelling ecosystems, such as the Humboldt Current System (HCS) in the southeastern Pacific. The understanding of the transition from the phocid seal faunas of the Miocene to the modern otariid fauna (*Arctocephalus australis* and *Otaria flavescens*) in the HCS has been hampered by the poorly known fossil record and imprecise geological framework during the Pliocene and early Pleistocene interval.

Here we report two new otariid skulls (MUSM 3608 and 3628), both coming from Quebrada Caracoles, a new site located along a small dry ravine of the Sacaco fossiliferous area in southeastern Peru. Four superposed lithostratigraphic units have been distinguished within the ravine area, informally named CAR, PO1, PO2 and TOT, the oldest of which (CAR) overlie the youngest Pisco Formation deposits (SAO level) and separated by an angular unconformity. Conflicting radiometric dating has been assigned for the SAO level ranging from 3.9 Ma to 5.89 Ma. The new fossil material comes from the CAR and PO2 units.

Craniodental and mandibular features of the new specimens were included in the character matrix of Vélez-Juarbe (2017) to evaluate their phylogenetic relationships within the Otariidae. A maximum parsimony analysis using New Technology was conducted in TNT, with all characters unordered and unweighted. One most parsimonious tree was recovered (CI=0.472, RI=0.579, length=451). Morphological and phylogenetic analyses indicate that both skulls pertain to a single new species with sister relationships to *Hydrarctos lomasiensis*, a fossil otariid previously recognized from the area. Both taxa differ in ten characters, including nasals, orbital margin, antorbital process, occipital exposure, and upper and mandibular dentition. The topology of the tree basically differs from previous contributions in the relationships between *Arctocephalus*, *Hydrarctos*, *Otaria* and the clade composed by *Zalophus* + *Eumetopias* + *Proterozetes*. A basal position of *A. australis* was also recovered elsewhere but in this analysis *Hydrarctos* is recognized as the

sister taxon of *Otaria*.

Up to now, *Hydrarctos* is the oldest extinct South American otariid and depicts early occupations of these coasts by Northern Pacific immigrants. The presence of two putative species of *Hydrarctos* suggests a local early diversification and reinforces prior hypothesis considering the southeastern Pacific as a major center of evolution of the southern otariids.

The specimens studied here are part of a faunal assemblage clearly different from the Tortonian/Messinian marine megafauna, the latter well documented in the Sacaco area. In turn, it might reflect an earlier unknown stage of the biota of HCS. Refining the ages of Quebrada Caracoles with new geological analyses and radiometric dating (in prep.) would shed light on the timing of the onset of the otariid communities in the southeastern Pacific and the causal connections of this event with the cooling trend of the Pleistocene.

EXCEPTIONAL PRESERVATION OF SHRIMP SOFT TISSUES BY MICROBIAL ENTOMBMENT: CRETACEOUS CRATO KONSERVAT-LAGERSTATTE, ARARIPE BASIN, BRAZIL

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The Aptian Crato Formation is worldwide renowned for its exceptionally preserved fossils in lacustrine limestones. Although they are widely known, taphonomic-based studies combined with detailed sedimentological data on the depositional environment of this Konservat-Lagerstätte (K-L) are still meager. The exceptional fossil assemblages are not widely distributed within the Crato Formation but are constrained to a 10-m-thick carbonate interval in the lower part of the unit. Our results indicate a widespread occurrence of distinct mat morphologies (i.e., microbial mats, domes, pseudo-columns, thrombolites, oncoids) throughout the carbonate unit. These multi-layered sheets of microorganisms were crucial in both protection and organic mineralization of some exclusively allochthonous to parautochthonous organic remains within the carbonate facies of the Crato lake, specially of exceptionally preserved decapod crustaceans. The shrimps are preserved in wrinkle laminites characterized by alternation of sparite and micrite. The micrite laminas are fully recovered by honey-combed organic structures interpreted as extracellular polymeric substances (EPS) secreted by microbial mats. The studied shrimps are entombed between sparite and micrite laminas, attached to the rock by µm-scale subhedral calcite extensions that resemble mineralized EPS filaments, which also partially covers the fossil. The original 3-D morphology is fully preserved in all specimens. This is possibly due to the presence of internal tissues preserved by pyritized EPS. The specimen is completely articulated and the carapace, antennae and appendages are preserved by calcium phosphate, including rostrum and eye. These are direct evidence that microbial mats entombed the dead carcass protecting it against physical and microbial degradation, and providing a site of in situ mineralization. In the geological record, the importance of microbial mats is mostly restricted to the Ediacaran and few Paleozoic K-L, where matgrounds developed in fully marine, siliciclastic-dominated bottoms acted as protectors against soft-bodied degradation until complete burial and diagenesis. This is distinct from other Mesozoic K-L developed in carbonate-dominated lakes and lagoons, particularly in the Cretaceous. In these low energy settings, microbial mats acted as both protection and early organic mineralization sites. This fossilization process was previously reported in a few studies in the specialized literature, and still neglected as a key preservational pathway among several K-L. Therefore, our data reinforces the key role of the microbial entombment in the genesis of the famous Crato Formation Konservat-Lagerstätte.

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SPECTACULAR APTIAN STROMATOLITE FIELDS AND ASSOCIATED BIOFACIES IN THE ROMUALDO FORMATION, ARARIPE BASIN, NORTHEASTERN BRAZIL

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The Aptian Romualdo Formation is a siliciclastic -dominated sedimentary unit recording the last marine ingression within the Cretaceous interior basins of northeastern Brazil. These basins were generated during the Gondwana break-up and South Atlantic Ocean formation. At the western margin of the Araripe Basin, rocks of the Romualdo Formation are mainly represented by carbonates resting abruptly on the crystalline basement. Detailed mapping and stratigraphic studies revealed two spectacular stromatolite fields that are here reported, illustrated and discussed for the first time. The stromatolite-bearing succession of the Romualdo Formation has a shallowing-upward stacking pattern, and was generated following a generalized, short-lived marine transgression in the basin. Stromatolites of the Romualdo Formation are strikingly distinct in their macro- (bioherms, biostromes and isolated stromatolites) and meso- (columns, domes, oncoids, thrombolites) morphologies. This suggests that an interplay of environmental (i.e., turbidity, energy, flux velocity) and biological factors driven their genesis at the depositional site. Echinoid-bearing strata are also recorded in association to lithified microbial mats. Taphonomic data suggests that echinoids moved (at least facultatively) within the soft substrate composed of microbial mats, probably searching for shelter and/or food. A cm-thick amalgamated bivalve rudstone, lying directly on the basement and representing a shell concentration formed above the fair-weather wave base is also recorded in the study area. Based on the regional distribution of the stromatolite types and associated sedimentary facies, we interpret the depositional environment as a local low-gradient carbonate ramp deepening to the east, developed in an embayment area surrounded by the crystalline basement. In this model, conical stromatolites were deposited in relatively deep subtidal low-energy environment, generated under low sedimentation rates, while subaerially exposed microbial mats and their reworked clasts point to high energy, shallow-water conditions, most probably in intertidal to supratidal settings. The vast majority of bioherms occur in the intertidal zone, including the echinoid-bearing microbialites. In this scenario, lag deposits above basement rocks originated by amalgamation of paucispecific shell-rich concentrations including bioclasts with high degrees of abrasion, sorting and rounding are suggestive of sedimentation in high-energy sedimentary settings (e.g., beach). The presence of autochthonous benthic invertebrates (echinoids) in the microbialites indicates that these lived and thrived in the same environment where microbial mats flourished, a condition analogous to that in the world-famous Hamelin Pool, Shark Bay, Western Australia.

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EXPLORING VARIATION IN LATE CAMBRIAN TRILOBITE *DIKELOCEPHALUS PYGIDIA* USING LANDMARK-BASED GEOMETRIC MORPHOMETRICS

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Pygidial shape variation of the trilobite morphospecies *Dikelocephalus minnesotensis* (late Cambrian, northern Mississippi Valley) is assessed using landmark-based geometric morphometrics including the use of semilandmarks. As opposed to patterns evident in cranidial morphology, ontogenetic variation plays little role in shape variance both within individual collections, and in the sample as a whole. Relative warp analyses of pygidial shape show that although pygidial morphospace occupation by *D. minnesotensis* from the St. Lawrence Formation shows some regionalization by collection, variance within collections is notable, and that overlap in shape occurs among almost all collections. Two morphological characters dominate the pattern of pygidial shape variation: the division of the pygidial pleurae and the position of the base of the posterolateral pygidial spine. Between collections and through time, a continuous gradient of morphotypes indicates a mosaic pattern of variation. The designation of St. Lawrence Formation *D. minnesotensis* as a single, highly variable morphospecies stands when analyzed with landmark (and semilandmark) based geometric morphometrics. These results support the view that St. Lawrence Formation *Dikelocephalus* were highly variable in form, and this might relate to environmental variability in this nearshore setting. More generally, results may also exemplify Rosa's rule of elevated morphological variation early in clade history. Further, by revealing distinctions from *Dikelocephalus* specimens of the underlying Tunnel City Group this analysis adds resolution to the sequence stratigraphic

model of the northern Mississippi Valley by revealing collection-related temporal distinctions.

JAW TRANSLATION AND DIETARY DIFFERENCES IN MARGINOCEPHALIAN DINOSAURS INFERRED FROM QUANTITATIVE DENTAL MICROWEAR

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Marginocephalians possess numerous anatomical specializations that converge with mammalian adaptations, indicating these dinosaurs present great utility for the exploration of trends in the evolution of vertebrate herbivory. Microwear striations from a variety of pachycephalosaur (2 species, 5 individuals) and ceratopsian taxa (15 species, 17 individuals) were quantified for length, width, angle, and *r* (length of the mean vector, a summary value indicating angular dispersion) to explore these proxies of chewing behavior and diet for greater resolution in the transitions associated with marginocephalian herbivory.

Where multiple modes of striation angles are present, a mode corresponding to the power stroke line of action can be determined. Data from power stroke striations were analyzed here because they are likely under the influence of the greatest masticatory forces. In addition to the overall *r* (O-*r*) for all striation angles, the power stroke *r* (PS-*r*) was calculated for comparison because it represents precision, or directional constraint of the jaws as the adductor muscles operated to subdivide food. Comparison of *r*-values gives an indication of translational variability within the jaw. When both values approach unity, and each other, most of the striations are oriented in the power stroke direction and the animal has relatively stereotyped motion. When these values differ greatly, more variation in jaw translation is present.

Pachycephalosaurs and non-ceratopsid ceratopsians generally have shorter striation lengths, whereas ceratopsids generally possessed longer striations, perhaps indicating greater occlusion for a longer duration than other marginocephalians. Width shows more separation between taxa, with most ceratopsid and leptoceratopsid taxa having widths ranging from 9 to 15 μm. Non-neoceratopsians and the earliest neoceratopsians have the lowest width values, ranging from 5.7 to 7.8 μm. Pachycephalosaurs showed values between 6 and 12.8 μm, but as a group are more like early ceratopsians in having narrower striations. Width variation suggests trophic separation, with ceratopsids and leptoceratopsids feeding on more course particulate foodstuffs, whereas pachycephalosaurs and early ceratopsians incorporated finer grained material.

Comparing O-*r* to PS-*r* values reveals several differences. Psittacosaurids have the same O-*r* and PS-*r*, indicating an exceptional degree of chewing precision in support of clinolineal mastication. Leptoceratopsids show the least disparity between *r* types, with early ceratopsians and pachycephalosaurs having slightly more translational variability. The most disparity occurs in ceratopsids, which have the greatest degree of translational variability, with the jaw moving in a less stereotyped cycle.

These data support a general trend within Marginocephalia from finer foodsuffs and more stereotyped mastication in early members to coarser material and greater translation in ceratopsids.

EXCEPTIONALLY PRESERVED FOSSILS FROM THE SILICA SHALE LAGERSTÄTTE (MIDDLE DEVONIAN) OF OHIO, MICHIGAN, AND INDIANA: XCT REVEALS DETAILED ANATOMICAL INFORMATION

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The Silica Shale of northwestern Ohio and adjacent areas of southern Michigan and northeastern Indiana contains a diverse assemblage of Middle Devonian fossils, many of which are preserved in part by pyrite. Body fossils have been collected from the Silica Shale for more than a century, and large collections have been amassed. Study of samples from the Silica Shale using X-ray Computed Tomography (XCT) reveals that internal nonbiomineralized or lightly biomineralized tissues of shelly taxa are commonly replicated by pyrite. Pyritized trace fossils also have been imaged in some layers. XCT scanning reveals the Silica Shale to be a remarkably rich Konservat-lagerstätte, and exceptional preservation by means of pyrite is present in localities stretching across the Silica Shale outcrop belt. Visualization of the internal soft tissues of some organisms has been aided further by 3D printing of digital models generated using XCT scans.

Using XCT, the internal soft tissues of trilobites, brachiopods, and corals have been imaged, and fine details have emerged in many specimens. Pyrite replication seems to have begun quickly after the death of many organisms present in the Silica Shale. Many enrolled trilobites (*Phacops*) have preserved

digestive systems, although preserved guts are rare in outstretched trilobites. This suggests that enrolled specimens were corpses, whereas most outstretched trilobites were probably molts. Many brachiopods show preserved brachidia and lophophores, and a few have pyritized muscles and organs. One remarkable example of *Paraspirifer*shows situs inversus of the brachidia, a condition previously unreported in fossil brachiopods. Rugose corals have pyritized structures resembling mesenteries. Results of XCT scanning on fossils from the Silica Formation open that possibility that other deposits rich in pyritized fossils also may yield similarly detailed preservation of nonbiomineralized anatomical structures.

OVERVIEW OF THE NEOGENE MARINE MAMMAL FAUNAS OF THE NORTH EASTERN PACIFIC

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Marine sedimentary deposits from the Eastern Pacific region provide us with a nearly continuous record spanning the last 30+ million years. Some of the major transition in the evolutionary history of marine mammals are recorded within these deposits and allow us to look at the timing of these events at different geographic scales. Herein we reviewed published and unpublished observations of Miocene-Pliocene marine mammals, with emphasis on collections housed at NHMLA and OCPC. Our data derives mainly from specimens collected from formations covering the region from Washington to Baja California Sur. Occurrences are vetted on a locality-by-locality basis when possible, and in combination with updated chronostratigraphic and taxonomic information, allowing for more precise first and last appearance dates.

Some of the patterns observed based on these preliminary observations hint at major changes around the middle Tortonian (~9-8 Ma) as follows. Platanistoids, which are present in the region since the Oligocene, disappear around nine million years ago, roughly coinciding with the first appearance of lipotids in the late Tortonian (~8 Ma). Kogiids appear by the late Tortonian and are known through the Pliocene. Kentriodontids are restricted to Aquitanian/Burdigalian through early Tortonian deposits, contrasting with Western Atlantic faunas where they persist until the Pliocene. Crown group delphinoids (i.e. monodontids, phocoenids, and globicephalines) appear by the late Tortonian and are still present, with monodontids restricted to the Arctic. In the late Tortonian, pinniped assemblages shift from those comprised of desmatophocids, stem otariids, and basal odobenids during the Burdigalian through Langhian to those dominated by large odobenids, including the appearance of neodobenians. Herbivorous marine mammals are present in Burdigalian-Langhian deposits, including multi-species communities of desmostylians and dugongids. However, by the late Serravalian through early Tortonian, herbivore diversity declines with the local extinction of dugongines and desmostylians, after which only hydrodamaline sirenians remain.

In summary, the main pattern observed based on our data is a change around the middle Tortonian (~9-8 Ma) that includes the local extinction of platanistoids, kentriodontids, desmatophocids, and desmostylians, and the evolution and diversification of several modern groups such as delphinoids and neodobenians. The appearance and predominance of benthic-feeding taxa, and kelp-eating sirenians by the late Miocene can be correlated with increasing upwelling along the north Eastern Pacific which led to changes in benthic productivity and the evolution of large, fast growing algae. Additional work aimed at narrowing the chronostratigraphic range of poorly constrained formations in California and Mexico, as well as further documenting occurrences, will allow us to improve upon these observations.

TERRESTRIAL GASTROPOD DIVERSITY DECLINE IN THE MODERN: ENDEMIC SPECIES AND THE CONSEQUENCES OF HABITAT LOSS

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Modern terrestrial molluscs are among the most globally threatened of all metazoans. Endemic gastropods worldwide, many of which have short-ranges and uneven and patchy distributions, face habitat loss, introduced and invasive species, and temperature changes as a result of global warming. The number of taxa in some places, such as southern California, may also be under-estimated, and shell-less members of the region's malacofauna (i.e. slugs) are under-studied and likely to have left little fossil record. Locally and worldwide, there has been a homogenization of urban malacofaunal biodiversity and a loss of endemic populations in urban and urban-adjacent environments. Community/Citizen science is a public-engaging approach that the Natural History Museum of Los

Angeles County is taking to document and track terrestrial mollusk biodiversity in southern California. Results are producing distribution maps for poorly-known native species as well as tracking the ranges of introduced non-native species.

EVOLUTION AND EXTINCTION OF CABALLINE HORSES IN ICE AGE BERINGIA

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Arctic mammals are highly vulnerable to the effects of climate-associated fluctuations on habitats. Shifts in habitat productivity and availability have potentially broad evolutionary consequences by both creating and destroying barriers to dispersal for many species. Here, we explore the influence of the Bering Land Bridge on the evolution and diversification of caballine horses, *Equus caballus*, during the Late Pleistocene. We use four high-coverage nuclear paleogenomes, including two new paleogenomes that we isolated from a collection of 30,000- and 33,000-year-old horses found in Klondike, Canada's Yukon Territory. These represent the first high coverage ancient horse paleogenomes from North America. Using coalescent simulations on a set of genome-wide SNPs, we infer that the ancestors of North American and Eurasian *E. caballus* diverged around one million years ago. After this divergence, the evolution of horses on both continents continued in the presence of extensive gene flow across the Bering Land Bridge. Our results provide new insights into the role of barriers to gene flow in shaping genetic diversity and mitigating extinction risk.

TEACHING AT THE INTERSECTIONS OF PALEONTOLOGY AND CULTURE: BRINGING NEW MEANING TO THE STUDY OF THE FOSSIL RECORD

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The history of paleontology as a discipline is full of fascinating interpretations of fossils and specimens preserved in unique cultural contexts. The historical significance of fossils globally is strongly linked to culture as well. Typically, such stories are only given a cursory glance in readings when exploring the fossil record, but much more potential exists for instructors to elevate these connections for individuals as a way to deepen the meaning of learning about paleontology through a cultural lens.

Themes of diversity and inclusion are often not at the forefront of conversations regarding best practices for guiding students in learning about the history of life, despite the fact that paleontologists are well-versed in understanding the importance and benefits of diverse communities from an ecological perspective. Our discipline is still in crisis with respect to diverse representation among professionals and public perception regarding the value of paleontology remains muddled, perhaps in part due to a lack of connecting with diverse audiences. We are not doing enough to effectively reach individuals who may range in abilities, identities, and backgrounds, both in the classroom and beyond.

To address the disconnect between who students are as individuals and how best to learn about the fossil record, intentional pedagogy could be adopted to integrate more cultural connections in studying specimens and concepts in paleontology. Part of the challenge, however, is that many paleontologists are not inherently knowledgeable about various intersections between paleontology and culture or how such examples could be incorporated into learning about the fossil record. Publications that specifically focus on linking paleontology and culture as a way to broaden participation are limited, although interest is growing even if a suite of approaches or resources are not yet readily available for educators. Work being conducted at Georgia State University, a minority-serving institution in Atlanta, GA, is focusing explicitly on this issue by developing a digital directory to highlight connections between paleontology and culture in an effort to help spread the knowledge about these intersections and facilitate easier implementation into instruction.

USING HABITAT-LEVEL VARIATION IN MODERN SMALL MAMMAL COMMUNITIES TO RECONSTRUCT PAST ENVIRONMENTS

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Approximately 1000 years ago, the space that is currently Jasper Ridge Biological Preserve (JRBP) in Woodside, CA was home to native peoples who subsisted on local resources and manipulated their environment in a variety of ways. The animal skeletons extracted from the resulting archaeological site (CA-SMA-204) provide a window into the faunal communities and environment surrounding JRBP's early residents. In particular, the small mammal remains from CA-SMA-204 are useful in paleoenvironmental reconstruction both because small mammals are more likely than other fauna to enter the archaeological record without direct human mediation and because they are sensitive environmental indicators. While previous studies have aimed to reconstruct the paleoenvironment of various regions of the San Francisco Bay Area, the complicated topography and geology of the foothills of the Santa Cruz Mountains make such broad studies less useful when working at finer spatial scales. I aim to more precisely reconstruct the paleoenvironment of site CA-SMA-204 by analyzing the small mammal community from the site and comparing it to the modern small mammal communities found in the various habitat types of JRBP.

Although site CA-SMA-204 had been analyzed previously for its faunal remains, aggregate smaller than ¼'' was not documented, leaving out much of the smallest teeth and bones. I resampled the fine (< ¼") material and identified small mammal teeth to the lowest taxonomic unit possible based on morphology. I found approximately 300 small mammal teeth useful for my analyses. The modern small mammal communities of JRBP were reconstructed 1) by morphologically identifying small mammal remains from an extensive collection of raptor pellets collected at various intervals over the last 20 years and 2) via live-trapping. I evaluated the relative abundances of small mammal species from 5 habitat types found at JRBP—riperian, chaparral, oak woodland, serpentine grasslands, and non-serpentine grasslands. Finally, I compared the composition of the small mammal communities from these different environments to the ancient assemblage from site CA-SMA-204.I also evaluated biases in both the ancient and modern small mammal assemblages in order to reconstruct the most accurate records possible, with applications to future zooarchaeological studies and prompting possible reevaluation of past reconstructions.

MOLLUSK FORENSICS IN ANTARCTICA: DO EPIBENTHIC SCALLOPS EXHIBIT PREDATORY SHELL REPAIR?

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One of the most fundamental changes predicted to occur under warming scenarios for Antarctica is the invasion of durophagous (shell-breaking or peeling) predators—like decapod crustaceans—which were last common in Antarctic waters during the warmer Eocene Period, over 30 million years ago. Since then, Antarctica's shallow-water benthos developed Paleozoic (or deep-sea-like) ecosystems dominated by epibenthic echinoderms. Despite the looming predatory carnage, little is known about how predators structure shallow subtidal communities in Antarctica, especially in regard to predation on shelled prey. We therefore need to have a baseline of shell repair—if it occurs—prior to the initial invasion of crabs. Here, we assess whether the shell of the Antarctic Scallop, *Adamussium colbecki*, living in the shallow subtidal under sea ice, records an ontogenetic history of shell repair.

Shells of *A. colbecki*(n=623 valves; ~ 0.50 mm thick) were collected from shallow depths (6–24 m) within western McMurdo Sound, Ross Sea, from the coldest waters on Earth (-1.97 °C): Four sites in Explorers Cove (EC) with semi-permanent (decadal or more) sea ice and a Ferrar Glacier site (located ~30 km south of EC) with annual sea ice and icebergs. All sites were composed of fine sediments interspersed with glacial erratics that were more common at Ferrar than EC. Juvenile (≤ 50 mm) and adult portions of the shells were examined under a dissecting scope for shell repair.

Results indicate that repair did occur and was consistent with predatory damage: 1) valves had stereotypic damage patterns, both in style and spatial distribution; 2) there were five styles of repair ranging from typical crab-like (jagged) repair to elongate repair; 3) scallops living under ice scour regimes (Ferrar) did not have significantly different repair frequencies than those living under semi-permanent sea ice (EC sites); and 4) none of the shells had shell repair consistent with ice scour as described previously for *Laternula elliptica*, an Antarctic burrowing

bivalve. Frequency of repair varied between 0.04 and 0.26 for the five sites and depths (mean 0.10) and adults had the highest frequency of repair. The mean repair frequency is similar to infaunal *Laternula*from other semi-permanent sea ice sites in McMurdo Sound, but higher than those reported for epifaunal brachiopods from the Antarctic Peninsula where ice scour does occur. We posit that shell repair can be used as an indicator of durophagy in Antarctica: The forensic agents are unexpectedly sea stars and possibly fish. In a warming world, this scallop may not survive long withboth an increase in ice scour and the putative arrival of shell-breaking crabs at ~1 °C.

THE ORIGIN OF AVIAN BEAK FROM TOOTHED DINOSAUR ANCESTORS

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Feeding apparatuses are relatively conserved among different clades of vertebrates though the feeding models are diverse. Birds account for almost 99.9% of extant beaked vertebrates, and the adaptability of the beak has been a major contributing factor in birds' successful adoption of various dietary and ecological niches. However, the origin and the macroevolution of avian beak have long been controversial. Recent discoveries of exquisitely preserved non-avian and avian theropods dinosaurs have not only prompted studies of theropod tooth morphologies, but have also provided information about the origin and early evolution of avian beaks. Neontological evidence derived from the evolutionary developmental experiments performed on extant bird and alligator embryos even demonstrated the potential mechanisms underlying the change of snout shape during the transition from dinosaurs to birds. These works collectively suggest several major events of the feeding apparatus change during dino-bird transition, including (1) expansion of keratinous rhamphotheca, (2) reduction of teeth, and (3) changes of snout morphologies (including morphological changes of other craniofacial elements). Recent studies suggested at least the first steps of these events could have been regulated epigenetically, and these changes, together with the changes of the digestive systems, significantly remodelled the behaviour, metabolisms, growth and reproductive patterns of birds, thus have played important roles in the origin and early evolution of birds. Using the next generation sequencing and other developmental techniques, we update new molecular findings that provide new insights toward the development and evolution of avian beak.

DENTAL CARIES ON A PRIMITIVE BEAR, *PROTARCTOS ABSTRUSUS*, FROM THE PLIOCENE OF CANADIAN ARCTIC SUGGEST A HIGH SUGAR DIET OF BERRIES AND POSSIBLE HIBERNATION

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Fossils of a small bear were found at the Pliocene (>3.4 +0.6/-0.4 Ma) Beaver Pond fossil site in the High Arctic (Ellesmere I., Nunavut) of Canada. With a moderately complete skull and lower jaws with associated postcranials, the new material from the Canadian Arctic represents a remarkably primitive basal ursine most comparable to the genus *Protarctos* previously known in the Pliocene of Europe and Asia. These materials also match well with a small extinct bear, *Protarctos abstrusus* (Bjork, 1970), from the Pliocene Glenn's Ferry Formation of southwestern Idaho, and substantially increases our knowledge about this poorly known immigrant in North America. Our phylogenetic analysis suggests that *Protarctos abstrusus*, along with a closely related species, *P. yinanensis*, from a Pliocene cave deposit in Yinan County, Shandong Province and an early Pleistocene loess deposit in Linxia Basin, Gansu Province in North China, is close to the base of the Ursini clade that gave rise to most living bears (except the giant panda). This relationship between a high latitude North American bear and its North China relatives reconfirms Tedford and Harington's (2003) idea that the Pliocene Canadian Arctic shows a striking faunal similarity to that of East Asia. Such Eurasiatic zoogeographic and phyletic affinities are consistent with an active period of faunal interchange between Asia and North America, and offer a rare example of a High Arctic North American fauna with Chinese Yushean characteristics.

The Beaver Pond site has also yielded 12 other mammals, plus other fossilized remains of a boreal-forest community. Paleoenvironment of the Beaver Pond site was within a boreal larch (*Larix groenlandii*)-dominated forest near regional tree line. Evidences from insects, oxygen isotope, tree ring width, and bacterial tetraether composition in the peat suggest

a paleotemperature 15ºC to 19ºC warmer than present. Dentally, *Protarctos abstrusus* shows only modest specialization for herbivory, consistent with its basal position within Ursinae. However, the appearance of dental caries in the Beaver Pond bear suggest a diet high in fermentable carbohydrates. Fossil plants remains, including diverse berries, suggests that, like modern northern black bears, *P. abstrusus* may have exploited a high-sugar diet in the fall to promote fat accumulation and facilitate hibernation. A tendency toward a sugar-rich diet appears to have arisen early in Ursinae, and may have played a role in allowing ursine lineages to occupy cold habitats and to cross Beringia.

BLACK HOLE EFFECT: PATTERN OF MISTAKES IN BOTANY

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Mistakes are common in science. Correcting mistakes is a major way that science makes progress. Common mistakes are random, but not all are so. Identifying the pattern underlying various mistake usually is the first step leading to fundamental progress in science. Careful study shows that some mistakes in palaeobotany are random but appear systematic especially if some assumption is deemed correct. Canright (1960) claimed that the ovules in magnoliaceous carpels were borne on the ventral veins while his picture indicated that they were not so. Dilcher and Crane (1984) claimed that the ovules in *Archaeanthus* were borne on the ventral vein of the fruit while, at least, some of the ovules in their fossils were borne on the dorsal vein. Similar mistake was repeated in the famous *Archaefructus*: the dorsal insertion of the ovule was ignored in their fossil (Sun et al. 1998, 2002). Endress (2005) claimed that all vascular bundles in the carpel of *Brasenia* were collateral while his picture showed not so. Friis et al. (2009) claimed that there were two integuments in the ovule of *Monetianthus* while their figure showed only one integument. Mendes et al. (2014) claimed that the carpels in *Kajanthus* were free while they all fully fused….. People cannot help asking "How can these obvious mistakes escape the scrutiny of the reviewers, and get published?" The answer to this question is astonishing: All these mistakes were "theoretically correct" and rather "expected"! All these mistakes are centered around the hypothesis advanced by Arber and Parkin (1907), who were enlightened by Goethe's (1790) celebrated dictum "All is leaf." Fortunately, evidence of plants and fossils indicates that all is branch, and there is no megasporophyll in the plant world. Re-investigations indicate that the carpels of Magnoliaceae are actually composite organs derived from former ovuliferous branches and leaves (Liu et al. 2014, Zhang et al. 2017). Recent discovery of *Nanjinganthus* based on over hundred flowers from the Early Jurassic of China apparently (Fu et al. 2018) has broken the idol image of ancestral angiosperms, undermining Goethe, Arber, and Parkin's hypotheses, breaking the center and origin of the above mistakes. With the removal of the center (black hole) of these mistakes, it is hoped that new hypotheses based on real evidence (not imaginations) will bring botany and palaeobotany back to their scientific tracks.

NITROGEN ISOTOPES OF ANCIENT PROTEINS: NEW ANALYTICAL CAPABILITIES AND POTENTIAL APPLICATIONS IN PALEOBIOLOGY

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Ancient proteins preserved in fossils (e.g., corals, bones, and teeth) contain information about the host organisms as well as their past environments. However, as ancient proteins are mostly preserved in minute amounts, analytical challenges have limited the exploration of this rich archive. We have developed a sensitive method to measure the nitrogen (N) isotopic composition of ancient proteins from fossil materials, requiring as little as 5 nmol N and yielding a precision of 0.2 permil. Using coral as an example, we show that the N isotopic composition of proteins in modern coral skeleton are controlled by that of their food as well as the presence of algal endosymbionts. As such, the N isotopes of ancient proteins in fossil corals can be used to reconstruct coral's N source in the past and to detect algal endosymbionts. We will also discuss other potential applications of N isotopes in ancient proteins, including identifying the diets of ancient animals.

CLIMATE DRIVES STABILITY OF VEGETATION BIOMES AFTER THE LAST GLACIATION IN NORTH AMERICA

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Changing climates, human arrivals, and megafauna

extinctions in North America all had the potential to culminate in major shifts in vegetation communities and their stability on the landscape. We seek to determine the importance of these potential drivers of vegetation community stability following the last glaciation (20 ka BP to present). Quantifying dynamic responses of vegetation communities to these drivers has important implications for understanding biome resilience and management strategies under projected climate change.

We analyzed vegetation biome stability from two perspectives: biome dynamic stability represented by residence time, and recovery time following a shift in biome type. We used 16,043 fossil pollen assemblages from 310 sites in the Neotoma database to reconstruct vegetation community residence and recovery times across North America over the past 20,000 years, following the last glaciation. We used the established modern analog technique to categorize our pollen samples into 10 modern vegetation communities and the biomization method to identify two no-analog communities.

The median residence time of any given biome is 310 years. Forest biomes have a longer residence time (340 years) while shrub/herb biomes have a shorter residence time (260 years). Median recovery time of any given biome is 130 years, and nearly 84% of vegetation biomes recover following a shift in biome type. Residence time decreases and remains short before and during the Pleistocene-Holocene transition (14.7–11.7 ka BP), when climate changes abruptly. Residence time increases and remains high throughout the stable, warm Holocene, though residence time does decrease temporarily during climate events such as Mid-Holocene Warm Period (7–5 ka BP). Residence time displays another decreasing trend toward the present in the late Holocene after 3 ka BP under intensified human influences, especially after European settlement in North America (0.3 ka BP). Recovery time shows an opposite trend compared to residence time, with longer recovery times corresponding with shorter residence times. Neither residence time nor recovery time demonstrates a latitude gradient across North America, though biomes track glacial retreat during deglaciation. Landscape characteristics do not show strong relationships with either biome residence time or recovery time. There is no obvious change before or after megafauna extinction in residence time and recovery time.

Our work demonstrates that vegetation biomes in North America have short residence times, on the timescale of centuries. Vegetation biome stability is primarily controlled by climate, while top-down biotic influences had little impact on biome stability. Notably, relatively short biome residence times in North America indicate that rapidly shifting habitats are the norm and are likely to accelerate as temperatures change increasingly rapidly.

RECOVERY OF REEFS ON THE ADRIATIC CARBONATE PLATFORM FOLLOWING THE PALEOCENE-EOCENE THERMAL MAXIMUM

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Approximately 56 million years ago, warming in the late Paleocene led to a global collapse of reef ecosystems, leading to a "reef gap" across the Paleocene-Eocene Thermal Maximum. The Adriatic Carbonate Platform was a large, detached carbonate platform in the southern Tethys that existed from the late Cretaceous to the middle Eocene. On the Slovenian portion of the platform, reefs composed of microbes and corals collapsed late in the Paleocene, giving way to foraminiferal shoals. By the beginning of the middle Eocene, however (approximately 6-7 million years post-collapse), similar microbial-coral reefs returned to the region. Although broadly similar in composition (i.e., coral-microbial patch reefs), the paleoecology of these mounds has yet to be compared between the two time intervals. This study tests the following hypotheses: 1. The taxonomic diversity of coral-microbial reefs on the Adriatic Carbonate Platform is the same in the late Paleocene and middle Eocene. 2. The functional diversity of these coral-microbial reefs is the same in the late Paleocene and middle Eocene. 3. Given the overall low extinction rates of corals during this interval, the coral taxa in late Paleocene reefs will be the same taxa found in the Eocene reefs. Ordination, clustering, and similarity profiles are also used to test the hypothesis that the reef assemblages from the late Paleocene and middle Eocene are similar. Our work provides the first quantitative accounts of Eocene reef recovery from the Kras region of Slovenia and has implications for the response of reef systems following hyperthermal events.

IMPROVED BIOSTRATIGRAPHY FOR THE TARUTAO GROUP, THAILAND AND ITS GLOBAL SIG-

CANCELLED

NIFICANCE

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Thailand's Tarutao Group spans the Cambrian-Ordovician boundary with a series of fossiliferous sandstone beds and rhyolitic ash beds. The fossiliferous beds are most rich in trilobites but also contain brachiopods, cephalopods, and crinoids. The Tarutao Group is found on Ko Tarutao, Thailand which is part of Sibumasu (the Shan-Thai Block), a narrow Paleozoic Gondwanan outboard terrane extending from modern day northern Malaysia to through western Thailand, eastern Myanmar, and southwest Yunnan, China. With Cambrian-Ordovician ash beds spanning the uppermost Cambrian and Cambrian-Ordovician boundary, the Tarutao Group is a globally significant lithologic unit that can bring needed resolution to the geochronology of the Cambrian-Ordovician boundary. Recent excursions to the island (2016, 2018) have recovered material from four localities (Ao Talo Topo, Ao Mo Lae, Ao Talo Udang, and Ao Punte Malaka) for paleobiologic, geochronologic, and paleogeographic analysis. Detailed biostratigraphy and improved systematics, particularly for the abundant and diverse trilobites, are foundational to correlating the precise geochronology obtainable on Tarutao Island to the rest of Gondwana and the world. Recent revisions include improved spatial and temporal coverage of stratigraphic horizons, two new genera not previously identified on Tarutao, precise provenance of fossiliferous horizons relative to ash beds, and resolution of nomenclature left in ambiguous or open taxonomy in previous studies on the island. The faunal assemblages of Ko Tarutao are most similar to and directly correlatable with those in Australia but also bear strong resemblance to assemblages in North and South China, particularly the Korean fauna from the Taebaek basin.

RADIOLARIANS INCREASED TEST SIZE ACROSS THE PETM AT MEAD STREAM, NEW ZEALAND

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Often cited as the closest analogue to anthropogenic global warming, the Paleocene Eocene Thermal Maximum (PETM) was an interval of high temperatures, ocean acidification, and elevated continental weathering. Thus far, open ocean planktonic responses to the PETM—including body size shifts—have been characterized in calcareous nannoplankton, dinocysts, and planktonic foraminifera. Less is known about the response of radiolarians, which share life modes and phylogenetic history with planktonic foraminifera but make their shells (tests) out of silica rather than calcium carbonate. Here, we measure radiolarian test size before, during, and after the PETM in assemblages from the Mead Stream locality, New Zealand, in which taxonomic turnover has previously been documented. Our results show a significant positive shift in whole-assemblage mean radiolarian test size concurrent with the onset of the hyperthermal. Surprisingly, radiolarians remained large well into the early Eocene and beyond the carbon isotope excursion recovery, suggesting that either the community-level selection response was locked in even as sea surface temperatures and other environmental variables rebounded ("ecological inertia"), or the conditions favoring larger tests continued for >1 m.y. Accelerated continental weathering during the PETM recovery increased the influx of silica to the global ocean, and we weigh silica availability as one of several possible drivers of test size variation in silicifying plankton.

THE PALEOECOLOGICAL DIMENSION OF PALEOZOIC AMMONOID EVOLUTION

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Ammonoids are a long-lived, diverse, rapidly-evolving, and well-preserved clade, making them ideal model animal for macroevolutionary and macroecological studies in the fossil record. Most ammonoid conchs approximate a logarithmic spiral, so their disparity can be readily described by three easily-measured parameters: the whorl expansion rate (w), the umbilical width (U), and the thickness ratio (Th). In order to analyze the paleoecological patterns and trends of Ammonoidea from its origination to the end-Permian, we calculated these parameters for ~650 Paleozoic ammonoid species and placed them in Westermann Morphospace. Westermann Morphospace utilizes these somewhat abstract parameters to make explicit paleoecological predictions. This provides a convenient approach to quantifying the ecological effects of climate change, the rise of crown gnathostome fishes, and 5 distinct mass extinction events on ammonoid

evolution. Similar to marine vertebrates, the end-Famennian mass extinction appears to be the most significant event in Paleozoic ammonoid evolution.

LEVERAGING NATURAL HISTORY COLLECTIONS, ONLINE MEDIA, AND FIELD EXPERIENCES TO CREATE A NETWORK OF ENGAGED GEOSCIENTISTS

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The extensive fossil holdings and significant online resources at the University of California Museum of Paleontology (UCMP) are accessible through educational websites, databases, specimen photographs, and digital archival materials. UCMP websites, *Understanding Evolution*, *Understanding Science,* and *Understanding Global Change*, provide novel ways to engage the K-16 education community in how evolution and science works, and how the drivers and impacts of climate change are measured. UCMP continues to expand online resources through EPICC (Eastern Pacific Invertebrate Communities of the Cenozoic) virtual field experiences (VFEs) to classic paleontological field sites. These virtual visits digitally integrate outcrop images, fossils, site maps and gigapixel-resolution panoramas with video clips and explanatory text. As users navigate along virtual exposures, an analysis of fossil specimens invites a better understanding biodiversity changes in deep time.

While online and virtual resources are valuable for their accessibility, flexibility, and novel methods of engagement, actual field experiences occupy importance spaces in paleontological and geological instruction for underrepresented communities. Field trips help to shape and shift student attitudes and orientation toward geoscience, and often engender a positive sense of community. To improve upon the positive role of fieldwork in student training, UCMP is a partner in FIELD: Fieldwork Inspiring Expanded Leadership and Diversity. The FIELD project aims to make field activity more accessible, culturally sensitive, and inclusive. The preparation of instructional leaders within the FIELD network ensures greater awareness and skill in addressing barriers to success and an opportunity to create solidarity with diverse teams of students. Museum collaborations and the unique partnerships that occur through fieldwork result in dynamic networks with high-impact opportunities for all levels of learners.

BENTHIC INVERTEBRATE COMMUNITY ECOLOGY IN THE CENOZOIC OF ANTARCTICA

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Assessing changes in the ecological composition of fossil communities, and how this affected the evolution of marine life, gives insight into how modern communities will react to environmental change. Modern Antarctic benthic invertebrate marine communities are described as having an archaic retrograde nature, dominated by epifaunal suspension feeding organisms. Studies have suggested that this evolved in the Eocene, with cooling decreasing durophagous predation. However, several lines of evidence do not corroborate this hypothesis, and it is unclear when this community structure arose.

Following the Cretaceous-Paleogene (K-Pg) mass extinction, a distinct change in Antarctic benthic community ecology is not observed. However, other global signals, for example the radiation of the Neogastropoda within the first million years of the Danian, and a shift in dominance between bivalves and gastropods occur in the Paleocene.

During the Eocene, there was a radiation of many taxa. Stalked crinoids, the main line of evidence for the original hypothesis of community structure arising at this time, are present due to asynchronous timing in the Marine Mesozoic Revolution in the Southern Hemisphere, rather than being related to the origin of the modern Antarctic community structure.

Evidence of the first glaciations in the west Antarctica comes from King George Island in the South Shetland Islands. The Polonez Cove Formation and the Cape Melville Formation preserve marine sedimentary sequences from, the Oligocene and Miocene respectively. The presence of dropstones, diamictites and striated rocks confirm that they were deposited in a glacial environment. Both preserve abundant marine invertebrates, which represent Antarctica's first glacial sea floor communities. The youngest unit, the Cape Melville Formation, does not preserve invertebrate community with the modern ecological structure. It is dominated by infaunal bivalves, with a significant proportion of durophagous decapods. Overall, we

hypothesise that the the evolution of the modern benthic invertebrate community structure occurred more recently than previously thought.

MOLECULES MEET MORPHOLOGY: EVOLUTION, BIOGEOGRAPHY, AND THE FOSSIL RECORD OF A SPECIOSE PREDATORY SNAIL GENUS *PACIOCINEBRINA* HOUART, VERMEIJ & WIEDRICK, 2019

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The northeastern Pacific predatory snail genus, *Paciocinebrina* Houart et al. 2019, is a diverse muricid lineage with many members exhibiting a high degree of phenotypic plasticity, which has historically resulted in confusion about the accuracy of taxonomic identifications. An extensive assessment of literature, museum vouchers and specimens collected for molecular analyses, has resulted in the clarification of most known taxa, including distributions, frequencies of occurrence and, at times, ecological importance. An analysis of shell features, alongside a new combined mitochondrial (COI + 16S) and nuclear (28S + ITS2) analysis, provides insight to the diversification of this speciose group. The paucispiral protoconch of *Paciocinebrina* members suggests a mode of direct development, characteristically known to influence higher diversification compared to planktonic development and dispersal. The genus has an extensive Pliocene-Pleistocene fossil record, but a number of late Oligocene species, referred to from the genus *Ocinebrina*, are likely the earliest representatives of *Paciocinebrina* in the eastern Pacific. *Paciocinebrina* belongs to the muricid subfamily Ocenebrinae, whose oldest representatives are reported from the Paleogene of Europe, and the earliest purported species in California most closely resembles the genus *Jsowerbya* Merle, 2005, of Middle–Late Eocene age from the Paris and Hampshire basins. The lack of related species in the western Atlantic and the presence of similar Ocenebrinae in the fossil record of Japan suggests that ancestral *Paciocinebrina* migrated into the North Pacific via the Tethys seaway during the late Paleogene. Species richness within *Paciocinebrina* increases from 5 or 6 species during the late Oligocene through late Miocene, to as many as 16 named forms in the Pleistocene, and a modern day diversity of 19 species. Several additional Pliocene-Pleistocene species are currently unnamed. The genus presently is found between Alaska and Baja California, although most of the named fossil species are known only from California. Living *Paciocinebrina* primarily feed on barnacles and other gastropods and are most species-rich in the intertidal zone, although some species are known from greater depths. The rich fossil record of this genus, and its important role in the ecology of intertidal habitats, makes it an interesting case study for understanding the evolutionary and biogeographic history of the eastern Pacific marine biota. The use of modern phylogenetic techniques is here utilized in an attempt to reconstruct the biogeography and paleontology of these extensive and fascinating organisms, and to inform the interpretation of the fossil record.

BUILDING BIG DATA AND OPEN SCIENCE FROM THE LONG TAIL: COMMUNITY-CURATED DATA RESOURCES, NEOTOMA PALEOECOLOGY DATABASE, AND THE EARTH-LIFE CONSORTIUM

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Understanding the past dynamics of the earth system requires the assembly and analysis of thousands of individual site-level records, differing in type, scale, and complexity, and each representing years of effort and gathered knowledge. A key need is to develop data solutions that 1) handle both high data volumes and variety and 2) closely support and are supported by expert data generators and stewards. An emergent solution is community-curated data resources (CCDRs), defined as sociotechnological institutions that coalesce around scientific communities of practice, with a common IT platform and framework for modeling, sharing, and governing data, and with science-centered missions. Multiple CCDRs have formed and are increasingly interdigitating. Here I define CCDRs, identify common characteristics, and illustrate with examples drawn from the Neotoma Paleoecology Database, PalEON, and the Earth-Life Consortium.

CCDR are sociotechnological institutions because 1) they require close partnerships among scientists, data modelers, and software developers and 2) new data models and data services are needed to support scientific missions of large-scale insights from networks of

site-level data. Scientific governance sets community standards for fair data use, metadata norms, acquisition priorities, and driving questions. Data modelers and developers are charged with developing new systems for finding, sharing, and analyzing paleodata in their many forms. CCDRs vary in governance model and data system, but ideally should achieve the following: 1) FAIR principles that data be open, findable, accessible, interoperable, and reusable, 2) transparent governance, with clear roles, rewards, and pathways for joining, 3) support data citation and annotation, and 4) emphasize living data that closely support the rapid evolution of new scientific research questions and analytical methods.

Neotoma now holds over 4 million observations of micro-and macro-fossil distributions from 31,000 datasets and 15,000 sites, and is open to new members, contributors, stewards, and constituent databases. Neotoma is governed by a Leadership Council and distributes governance via its Constituent Databases, organized by data type and region. Neotoma data are accessible via Neotoma Explorer, digital object identifiers (DOIs), and programmatic interfaces (APIs); others now linking to Neotoma data include NOAA/NCEI-Paleoclimatology, Flyover Country, and the Global Pollen Project. PalEON offers one example of how Neotoma data can be leveraged to support reproducible workflows that support quantitative reconstructions of past environments and integration with ecosystem models. Neotoma has partnered with the Paleobiology Database (PBDB) and others to 1) build APIs that can jointly query Neotoma and PBDB (http://earthlifeconsortium.org/) and 2) launch the Earth-Life Consortium (ELC), a non-profit with the mission of supporting open access to paleobiological and paleoenvironmental data.

ACRITARCHS AND SMALL CARBONACEOUS FOSSILS FROM FINLAND

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Organic-walled microfossils (OWMs), including acritarchs and small carbonaceous fossils (SCFs), are well known from a range of Neoproterozoic–early Palaeozoic siliciclastic sediments across the palaeocontinent Baltica. Previous studies of equivalent strata in Finland have thus far produced only biostratigraphically long-ranging or ambiguous and low-diversity palynological assemblages that have, rather inappropriately, been used for age assessment. Here we present a detailed account of an array of OWMs from Proterozoic-Cambrian sediments preserved in different lithological successions across Finland. By using standard palynological processing as well as low-manipulation and hand-picking techniques we have recovered a wide range of OWMs previously undocumented from this part of the world. Recovered material include acritarchs, filamentous forms and metazoan-derived SCFs (including flattened 'proto-conodonts' and chaetae that may represent the oldest known annelid remains). Renewed attention should be directed to – 'SCF-style' processing that can reveal hitherto undetected, age-informative microfossils that are otherwise selectively removed in conventional palynological studies.

MAMMALIAN FAUNAS FROM THE DECCAN VOLCANIC PROVINCE AND THE CRETACEOUS-PALEOGENE TRANSITION IN INDIA

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Our understanding of Cretaceous-Paleogene (K/Pg) dynamics in terrestrial ecosystems is largely based on paleontological and geological data from western North America (NA). Those data are abundant and well studied, but they represent a mostly coastal lowland paleoenvironment from a single geographic region situated relatively close to the bolide impact site (Yucatán Peninsula, México). The Deccan Volcanic Province (DVP) of central and western India provides a much-needed, geographically disparate counterpoint to NA. Its fossil-bearing infra- and intertrappean deposits span the interval of both peak volcanism and the bolide impact (ca. 67–64 Ma). Importantly, this region is near antipodal from the impact crater and represents 'ground zero' for Deccan Trap volcanism, a proposed causal factor in the K/Pg mass extinction.

Here, we review the mammalian fossil record from the infra- and intertrappean beds of the DVP and report on new fossils from the states of Telangana and Karnataka. The new fossils provide new dental and mandibular data for *Deccanolestes* and evidence of

at least three new eutherian taxa. These data add to the emerging picture of DVP mammals, consisting of mostly small-bodied eutherians, an endemic gondwanatherian, and a relictual haramiyidan. We are also improving the geochemical and geochronological framework for the DVP, which will provides us the opportunity to refine the ages and stratigraphic relationships of the individual mammalian local faunas. Geochemical analysis of basalt samples that bracket the Naskal and Rangapur localities (Telangana) and the Gokak locality (Karnataka) stratigraphically correlate to the upper Ambenali Formation and the transition between the Ambenali and Mahabaleshwar formations, respectively—and all lie within chron 29R. Although intertrappean vertebrate fossil localities have mostly been considered latest Cretaceous in age, new geochemical, geochronological, and palynological data imply that the Naskal, Rangapur, and Gokak local faunas might both be earliest Paleogene in age. Accordingly, we infer that *Deccanolestes* and the gondwanatherian *Bharattherium* survived the K/Pg mass extinction. As sample sizes and age determinations from these and other DVP localities improve, we will have our first robust view of K/Pg dynamics in terrestrial ecosystems outside of NA and at 'ground zero' for volcanism.

HYDRAULIC CONDUCTIVITY AND CONSTRAINTS AMONG PALEOZOIC PLANTS

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Plants are unique among multicellular organisms because much of their physiology is biophysical, rather than behavioral, and the anatomy that defines these biophysical capabilities is preserved in the fossil record. Mathematical models, when applied to fossilized plant organs—particularly roots, stems, and leaves—can provide quantitative insight into the physiology and ecology of plants that have been extinct for hundreds of millions of years. Comparing the physiology of extinct plants with strategies that are currently employed by living plants sheds light on ecophysiological trajectories in plant evolutionary history and the history of plant-environment coevolution.

Mathematical models of xylem structure can be applied to macerated or thin-sectioned permineralized xylem. Key parameters, including conduit diameter, pit dimensions, and pit frequency, are measured directly from individual cells from specimens. In this presentation, I will describe the history of water transport in land plants and focus on key plants from the Euramerican Carboniferous tropical forests, including*Medullosa*, a morphologically diverse genus of Carboniferous plants that evolved fronds and stems capable of high rates of transpiration, *Psaronius*, the stem group marattialean tree fern with divergent hydraulic strategies in its stem xylem and root mantle xylem, and two sphenopsid genera with distinct hydraulic capacities and constraints, *Arthropitys* and *Sphenophyllum*. Each of these plants contains anatomical features that result in novel physiologies, and together they represent the early evolution of hydraulic complexity—and the capability to influence regional climates and biogeochemical cycles—in terrestrial ecosystems.

SEAFOOD SALAD: A DIVERSE FLORULE FROM THE LATE CRETACEOUS-AGE HELL CREEK FORMATION OF MONTANA

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The Cretaceous-Paleogene (K/Pg) boundary marks a major mass extinction resulting in global faunal turnover, notably the extinction of non-avian dinosaurs. The pattern of floral extinction at the K/Pg is well-studied in areas such as the Western Interior (including North Dakota) and New Zealand with results indicating an extinction rate as high as 80%. The Hell Creek Formation in northeastern Montana contains some of the most well-studied vertebrate localities recording this mass extinction, however, very little is known of the floral record in this area.

As part of an effort to reconstruct floral changes across the K/Pg in northeastern Montana, this study presents a highly diverse flora from the Seafood Salad locality, located 65 m below the K/Pg boundary in the Hell Creek Formation, Garfield County, Montana. Leaves, stems, and reproductive structures (e.g., cones and seeds) are preserved in massive, bedded siltstones as compression fossils. Seafood Salad is significant in that it is represents a "pre-disaster" community before the end-Cretaceous mass extinction. It also constitutes a unique taphonomic setting with abundant bivalve and gastropod shells preserved along with plant material. We interpret the plants in these deposits as reflecting a local riparian community.

Preliminary study indicates that the Seafood Salad flora was diverse and dominated by angiosperm trees, with abundant conifer specimens of a few taxa, and some few ginkgoes and ferns. So far, we have described

over 20 morphotypes and sought to establish their affinity to modern groups and to contemporaneous taxa found in Montana, North Dakota, and New Mexico. Many taxa are found in previously published, lower Hell Creek Fm floras as well as the Hell Creek floral zones of North Dakota, but there are significant differences in taxa and abundances between these assemblages indicating that the regional vegetation in the latest Cretaceous exhibited significant spatial and temporal heterogeneity.

THE ROLE OF CONSERVATION PALEOBIOLOGY IN RESTORATION OF THE GREATER EVERGLADES ECOSYSTEM

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The Greater Everglades Ecosystem of south Florida is undergoing major restoration and paleontological data are playing a significant role in guiding this effort. Resource managers responsible for implementing the Comprehensive Everglades Restoration Plan (CERP) have been interested in the historic perspective provided by paleo-analyses since the early planning stages. Paleontological information significantly extended the short-term observational data sets initially used to establish baselines and set restoration targets; however, direct application of paleo-data to target setting was problematic. CERP guidance documents encourage the use of models to hindcast parameters of the ecosystem and the managers originally believed the paleoecologic assemblage analyses did not fit their requirements for rigorous numeric modeling and analyses.

Implementation of modern analog techniques and use of statistical models allowed the paleontological analyses to transition from "interesting information" to data restoration managers can use. Paleo-salinity estimates were developed for the coastal region using molluscan assemblages in sediment cores and a modern analog data set from south Florida. The paleo-based estimates were then used to adjust the regional-scale hydrologic model (Natural System Model – NSM) to reflect conditions at the beginning of the 20th century, prior to significant anthropogenic change. Observational data from water monitoring stations were used to develop linear regression models (LRMs) that linked freshwater stage and flow to salinity in the estuaries; by substituting paleo-salinity in the LRM equation, we were able to hindcast stage and flow at the beginning of the 20th century. To test the results of the estuarine analyses, we applied the same methodology to wetlands cores. Water level in the freshwater wetlands was estimated using pollen assemblages, the paleo-based water level was used to adjust the NSM, and flow at the beginning of the 20th century was hindcast using the LRMs. The results using two different proxies (mollusks and pollen) in two different habitats (estuary and freshwater marsh) provided very similar estimates for early 20th century flow.

The paleo-salinity estimates are the basis for current performance measures and restoration targets for the Everglades estuaries. Hindcast flow results from both estuarine and freshwater analyses are being considered as targets for the freshwater wetlands. However, the most important role paleontological data will ultimately play in any restoration effort is providing an understanding of natural ecosystem and species-level responses to change and applying this information to forecast future responses to change. The goal of restoration should not be to return to a pre-existing state but to return an ecosystem to its natural trajectory of change; only paleontological and geological archives can provide the long-term perspective required to identify these trajectories.

COMMUNITY ANALYSIS OF THE GERSTER LIMESTONE: REEVALUATION OF THE LATE PERMIAN MARINE FAUNA IN THE WESTERN USA

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Recent radioisotopic dating introduces a profound ~10 Myr shift in the age of iconic strata within the Permian Phosphoria basin in the Western USA. The Meade Peak Phosphatic Shale Member of the Phosphoria Formation is now constrained to be latest Capitanian in age, significantly younger than previous biostratigraphic estimates. This revision has significant repercussions for both biostratigraphy and community structure for the basin's correlative strata, including the Phosphoria Formation, Park City Formation, and Park City Group. The updated age model merits greater scrutiny on traditional paleobiologic interpretations of this region.

As a case study, we assessed the relative biostratigraphic and paleoenvironmental stability of benthic invertebrate fossils of the Gerster Limestone based on bioassociations first established by Wardlaw (1977).

The Gerster Limestone is well-sampled across a broad geographic region (northeastern Nevada and northwestern Utah). The Gerster interfingers with the Rex Chert Member of the Phosphoria Formation, which directly overlies the Meade Peak Phosphatic Shale Member. The Gerster Limestone has five established biostratigraphic zones, defined in ascending order by the brachiopod genera: (1) *Thamnosia*; (2) *Kuvelousia*; (3) *Petasmatherus*; (4) *Yakovlevia*; and (5) *Kochiproductus*. We attempted to reproduce these taxonomic associations using k-means cluster-analysis. Both a five-cluster solution, as established, and a six-cluster solution, the ideal clustering via visual assessment of an elbow plot, were tested. In both clusterings, *Thamnosia* stood as a distinct group, however, in the five-cluster solution all other genera were grouped together, and in the six-cluster *Kuvelousia*, *Yakovlevia*, and *Kochiproductus* grouped together. Next, species and stratigraphic data were visualized using non-metric multidimensional scaling (MDS) fitted to three-axes. Along MDS axis 1, the *Thamnosia* group appears distinct, which we interpret to support the association's biostratigraphic significance. Along MDS axis 3, two clusters separate well when points are coded for broader taxonomic category (Strophomenata and Rhynchonellata). This may indicate that broader ecologic tolerance could be significant. Reassessment of these foundational bioassociations is critical for further field observations and regional paleoecological reconstructions within the Phosphoria Formation at large.

WHAT DEFINES CRUSTACEANS? INSIGHTS FROM THE CAMBRIAN FOSSIL RECORD AND FROM PHYLOGENOMICS

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Pancrustaceans, including insects and the paraphyletic crustaceans, boast impressive diversity, abundance, and ecological impact on the biosphere. Molecular clock estimates suggest an early Cambrian divergence for the major pancrustacean groups. The early evolution of these groups has remained elusive due to the difficulty of recognizing shared derived characters between Cambrian forms and extant representatives. We present new data from multiple exceptionally preserved Early Cambrian fossil deposits with complimentary forms of preservation. We employed X-ray computed tomography to reveal the three-dimensionally preserved appendage morphology of the bivalved euarthropod *Ercaicunia multinodosa* from the Chengjiang biota of Yunnan, China. *E. multinodosa* displays characters shared with extant crustaceans, such as differentiated tritocerebral antennae and epipodite-bearing biramous trunk appendages. We also present three-dimensional larval crustaceans from Orsten-type biotas, exhibiting further details linking these fossils to extant crustaceans. Early evolution of pancrustacean limb differentiation and feeding morphology are illuminated, and the crown and stem groups of pancrustaceans are identified. A complex evolutionary history, with substantial character loss in the crown-group of early diverging lineages (e.g. the less-studied Oligostraca), is proposed in the context of recent phylogenomic hypotheses.

RESOLVING THE SHALLOW MARINE CENOZOIC FOSSIL RECORD OF NEW ZEALAND: UNDERSTANDING VARIATIONS IN BIODIVERSITY AND PATTERNS OF COMMUNITY EVOLUTION AT DIFFERENT SPATIAL SCALES

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Global patterns of biodiversity in shallow marine ecosystems through the Phanerozoic have long been a focus of paleobiology; however, patterns of biodiversity at smaller spatial and temporal scales and their relationships are understudied. How are variations in biodiversity, and patterns of community evolution, manifested at different spatial scales? New Zealand provides a model system to test this question because of its exceptional Cenozoic sedimentary stratigraphic record and shallow marine fossil record that extend to the Recent, regarded as the most complete in the southern hemisphere. In addition, due to New Zealand's geographic isolation following the breakup of Gondwana, many of the fossil and extant taxa are endemic.

Here I focus on Cenozoic patterns of stratigraphy and biodiversity of shallow marine (i.e., shelfal) molluscs in New Zealand at regional (New Zealand wide) and local (basinal) spatial scales. Data sources include the unique and comprehensive Fossil Electronic Database (FRED) and two fieldwork based case-studies in exemplary Pliocene-Pleistocene sections in Hawke's Bay and Whanganui. Patterns of stratigraphy are characterised using sequence stratigraphy and macrostratigraphy. Macrostratigraphy is also used to infer

temporal variation in environmental heterogeneity. Sampling biases are considered by adopting statistical methodologies from both ecology and paleontology, within the framework of diversity partitioning.

Preliminary results reveal that regional marine biodiversity peaks in the Oligocene and Miocene with a notable decrease in spatial turnover of faunas during the Late Oligocene, coinciding with the maximum flooding of New Zealand during the Cenozoic. Local scale patterns show high variability of biodiversity during the Pliocene and Pleistocene, which when consolidated into equivalent time bins to regional data show contrasting trends, suggesting local processes are prevalent in determining local diversity. Rates for environmental heterogeneity from macrostratigraphy at the regional scale show positive correlation with beta diversity, indicating that variation in environmental heterogeneity may explain variationin beta diversity.

PHASED ORIGIN OF BIOMINERALISATION, HABITAT EXPANSION, AND THE RISE OF HETEROTROPHY

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The appearance and diversification of large and diverse calcareous metazoan skeletons in the Ediacaran-Cambrian, marks a step change in both biotic innovation and the carbon cycle. The nature of these earliest skeletons has not, however, been subject to critical evaluation. Here we establish objective criteria to distinguish between fossil taxa that show a) early post-mortem, diagenetic calcification of an organic scaffold, b) environmentally-controlled calcification during life of an organic scaffold, c) biologically induced biomineralisation (disordered, heterogeneous skeletal microstructures), or d) biologically controlled biomineralisation (well-ordered skeletal microstructures and species-specific crystal habits).

Application of these criteria reveals that most Ediacaran (~550–540 Million year ago (Ma)) skeletal taxa show only either diagenetic calcification or biologically-induced biomineralisation of a pre-existing organic template, and were found exclusively in shallow marine carbonate settings. Demonstrable biological control over biomineralisation appeared in the latest Ediacaran (~540 Ma). These taxa were diverse and widespread, butshow only fibrous skeletal microstructures from 540–532 Ma, after which prismatic and lamello-fibrillar appear. We propose three phases in the early evolution of calcareous skeletons; 1) organic skeletons only (~571–~550 Ma), 2) environmentally-controlled calcification and biologically induced biomineralisation (~550–540 Ma), and 3) biologically controlled biomineralisation (from 540 Ma), with increasing skeletal complexity appearing from 532 Ma. We hypothesize that early metazoan calcification may have been facilitated via the acquisition of heterotrophic, particulate feeding modes which allowed invasion of the previously unoccupied low nutrient, shallow marine carbonate settings, where the low cost calcification of pre-existing organic scaffolds would be promoted by minimal presence of carbonate inhibitors such as phosphate and Mg, and enhanced by elevated alkalinity and carbonate supersaturation.

FOSSIL PHYLOGENIES REVEAL THE TIMING, MAGNITUDE, AND DURATION OF THE LARGEST RADIATION OF MARINE ANIMAL LIFE

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The Ordovician Radiation refers to an interval spanning the greatest single increase in Earth's global biodiversity in the history of animal evolution. However, there is considerable disagreement on the timing, duration, magnitude, and cause(s) of biodiversity increase. We assembled a comprehensive dataset of 598 species of early Paleozoic (Ordovician—early Silurian) fossil invertebrates belonging to a major marine clade, the crinoid echinoderms, and placed them in a phylogenetic context to estimate species-level rates of diversification throughout the early Paleozoic. Using phylogeny-based birth-death-sampling models, we find diversity increased throughout the Ordovician and reached peak lineage richness during the Late Ordovician (Katian). In contrast with previous hypotheses asserting a more protracted diversification, we find increased rates of net diversification were restricted to the Middle Ordovician, with net diversification patterns decoupled from absolute rates of speciation and trends in species richness. This result is robust to sampling artifacts, uncertainties in tree topology, and divergence times among clades. Results indicate the Ordovician Radiation was driven by ecological innovation facilitated by changes in ocean redox, increase in

habitable shelf area, and biologically-mediated positive feedbacks.

COMBINATION OF MULTIPLE NOVEL REGULATORY MODULES IS REQUIRED FOR THE SCALE-FEATHER FATE CONVERSION

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Amniote skin appendages such as feathers, hairs and scales, provide thermoregulation, physical protection, display different color patterns to attract a mate or frighten an adversary, locomotion, etc. The evolution of feathers eventually enabled feathered dinosaurs and early birds to venture into new ecological niches. Studying how feathers and scales are developmentally specified provides insight into how a new organ evolves. In addition, we are interested in the long-standing question about whether "reptile scale" and "avian leg scales" are of the same origin. We identified feather-associated genes using genomic analyses. The feather forming ability of these genes was tested by expressing them in chicken and alligator scale forming regions. Ectopic expression of these genes induced different intermediate morphotypes with characteristics of both scales and feathers. Five cardinal morphogenetic events are revealed: localized growth zone, follicle invagination, branching morphogenesis, feather keratin differentiation and dermal papilla formation. In addition to molecules known to induce feathers on scales (retinoic acid, β-catenin), we identified novel scale-feather converters (Sox2, Zic1, Grem1, Spry2, Sox18) which induce one or more of the five regulatory modules guiding these morphogenetic events. Interestingly, some morphotypes resemble filamentous appendages found in feathered dinosaur fossils, while others exhibit characteristics of modern feathers.

Furthermore, we compared the molecular and cellular profiles in chicken feather, chicken scales and alligator scales and found that chicken scutate scales are similar to chicken feathers in morphogenesis at the early placode stage. When we compared the expression of the recently identified feather-specific genes and scale-specific genes in these skin appendages, we found that at the molecular expression in alligator scales are significantly different from both chicken feathers and chicken scales. Intriguingly, we identified a similarly diffuse putative stem cell niche in morphologically similar chicken and alligator scales. These putative stem cells participate in alligator scale regeneration. In contrast, avian feathers have a more condensed stem cell niche, which may be responsible for cycling. Thus, our results suggest that chicken and alligator scales formed independently through convergent evolution.

FOSSILS AND REDOX GEOCHEMISTRY IN THE TERMINAL EDIACARAN SHIBANTAN MEMBER

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Geochemical proxies for local and global redox conditions indicate that the terminal Ediacaran Period (ca. 551–539 Ma) is characterized by a major expansion of marine anoxia and dynamic redox conditions in shallow shelf environments where animals lived. It is thus possible that the ecology and evolution of terminal Ediacaran animals may have been impacted by redox instability. The terminal Ediacaran Shibantan Member of the Dengying Formation in South China offers an opportunity to analyze the relationship between animals and redox conditions, because it preserves abundant trace fossils and Ediacara-type soft-bodied macrofossils in limestones that are amenable to geochemical analysis.

Soft-bodied macrofossils in the Shibantan Member are characteristic of the Nama assemblage and include abundant vendotaenids, arboreomorphs, erniettomorphs, rangeomorphs, tubular fossils, various discoidal fossils, as well as a number of unnamed forms. Bilateralomorphs, triradialomorphs, tetraradialomorphs, pentaradialomorphs, and kimberellomorphs are absent from the Shibantan Member. Trace fossils are abundant on certain surfaces and bedding plane bioturbation intensity can reach 22–41%. Millimeter-sized shallow horizontal burrows dominate the Shibantan ichnofossil assemblage, but surface tracks and trails, vertical traces, lateral probes, and uniserially arranged burrow segments are common. Importantly, most Shibantan inchnofossils are closely associated with microlaminae interpreted as microbial mats.

Limestones of the Shibantan Member are characterized by exceptionally low $\delta^{238}U$ values (as low as −1.0‰ vs. CRM145), indicating a global expansion of oceanic anoxia. Locally, the Shibantan Member is characterized by dynamic changes in redox conditions,

with extremely low Fe concentrations probably related to the localized oxygen oasis in microbial mats. Integration of paleontological and geochemical data indicate that redox instability in shallow oceans indeed had a significant impact on the behavior and evolution of terminal Ediacaran animals.

CONTROLS ON CEPHALOPOD SURVIVORSHIP THROUGH OCEAN ANOXIC EVENT 2 WITHIN THE CENOMANIAN-TURONIAN WESTERN INTERIOR SEAWAY

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The Late Cretaceous Western Interior Seaway (WIS) of North America is one of the best-sampled ancient epicontinental basins and therefore provides a model system for investigating the interplay between abiotic factors and diversity dynamics within marine animal clades. During the early Late Cretaceous (Cenomanian and Turonian ages, C-T), global oceans experienced warming, sea level rise, and disruptions to the carbon cycle associated with Ocean Anoxic Event 2 (OAE2). To better understand how cephalopods within the WIS responded to these changes, species occurrences were compiled at the ammonoid biozone level of temporal resolution. These occurrences were integrated with isotopic proxy data and paleoceanographic models of water mass mixing within the WIS for the Late Cenomanian and Early Turonian (spanning OAE2) to test which abiotic parameters controlled cephalopod origination and extinction through this interval.

Cephalopod standing diversity in the WIS dropped in concert with carbon isotopic excursions. While species origination rates remained high throughout OAE2, extinctions occurred in two pulses in the Late Cenomanian, at the end of the *S. gracile* and *N. juddii* biozones. Prior to OAE2, cephalopod occurrences were distributed across the WIS, including many occurrences within the proposed mixing zone of northern and southern water masses. As OAE2 developed during the *S. gracile* zone, cephalopod occurrences became more concentrated in the south and especially the southwest portion of the WIS, which paleoceanographic models suggest was an unusual and somewhat isolated region of the seaway. By the *N. juddii* zone, no cephalopod occurrences were recorded from the mixing zone or areas north of it. Instead, most occurrences fell within the southwest corner of the WIS. While geographic range size is positively correlated with survivorship during biotic crises among many clades and across many events, within the WIS, cephalopods with larger geographic ranges were not more likely to survive the C/T event. Instead, during the *N. juddii* biozone, all occurrences of survivor species that crossed the C/T boundary were restricted to the southwest corner of the WIS. This region of the seaway appears to have been a refugium during OAE2, likely due to the presence of an oceanic front that at least partially isolated this area from warm, dysoxic waters entering the seaway from the south. Diversity recovered quickly in the earliest Turonian (*W. devonense* biozone), with re-occupation of the mixing zone and northern WIS by cephalopod species. These results suggest that extinction survivorship within basins may be associated with geographic restriction into refugia, explaining why global patterns linking geographic range and survivorship are not always seen in regional-scale studies.

FOSSIL LAND SNAILS SUGGEST HUMAN INFLUENCE ON PRESENT-DAY COMMUNITIES IN THE EASTERN ISLETS OF THE CANARY ISLANDS

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The conservation and survival of land snails, which are declining globally at a rapid rate, depend in part on our ability to predict the response of communities to natural environmental and anthropogenic stressors. Ecological (yearly/decadal)-scale studies are too limited in duration to understand long-term effects of environmental change on biological communities, and do not easily permit disentangling human from environmental influences. Here, I present pilot analyses from a multi-proxy investigation that integrates amino-acid-racemization age dating, stable-isotope geochemistry, and diversity metrics to investigate climatic and biological changes spanning the last glacial among Holocene and modern snail communities from the semiarid eastern islets of the Canary Archipelago. Prior research in the region indicates that the Canary Islands support diverse populations of modern land snails, with over 270 living species. They also contain a carbonate-rich fossil record of eolian deposits that does not appear taphonomically biased and exhibits high ecological fidelity, thus offering a natural laboratory for addressing multi-millennial-scale trends in snail communities. Results to date suggest that the eastern islets underwent aridification from the last glacial to mid-Holocene that caused a gradual decline in snail richness and diversity. Intriguingly,

present-day richness is higher than predicted based on current desertic conditions and on trends derived from the fossil record. It is hypothesized that the present-day enrichment may have resulted from the anthropogenic introduction of cosmopolitan species. This study illustrates how the fossil record can help disentangle human and environmental drivers of ecological change.

EARLY CAMBRIAN PHOSPHATIZED MICROBIAL PSEUDOMORPHS PRESERVING NON-MINERALIZED ANIMALS

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It is recognized that the radiation of skeletal animals during Cambrian Explosion is deeply rooted in non-mineralized ancestors in Precambrian period. Molecular data also suggests many clades of animal were originate much earlier than their first fossil record. However, those soft-bodied progenitors might have been expunged by taphonomy bias. That's why Konservat-Lagerstätten are keys to understand the evolution of early life, but even in those Lagerstätten with phosphatized micro fossils at the very beginning of Cambrian, soft bodies of non-mineralized animals are rare, although limited taxa were reported recently, such as the earliest scalidophoran animal and possible meiofaunal deuterostomes.

Microbial degradation of soft tissue is a common sense. But modern taphonomy experiments reveals that some bacteria aggregation can largely replicate the shape of the original organism (termed as microbial pseudomorph), and it has been proven crucial for some exceptionally phosphatized embryo fossils. While such experiments did not show clear link between microbial pseudomorph and the preservation of soft-body animal, and relevant fossil records during Neo-protozoic to early Cambrian remain unknown.

From Kuanchuanpu Biota (Fortunian, ~535 Ma) located in South China, we recognized 4 preliminary pseudomorphs types of phosphatized micro animals, which can be distinguished by the morphology and construction patterns of constituent microorganism: 1) Type-A: Tower-like fossil *Olivooiedes* preserved as dense cluster of large (diameter 20~40 μm) spherical microorganism; 2) Type-B: Worm-like animal pseudomorphs built by small (diameter 6~10 μm) spherical microorganism; 3) Type-C: Worm-like animals and some unknown fragments composed with small ellipsoidal (major axis 15 μm, minor axis 8 μm) microorganisms; 4) Type-D: *Olivooiedes* and some embryos preserved as pseudomorphs comprising filamentous microorganism with varied shapes and size.

The construction patterns of Type-A to C are similar. Constituent granules are integrated and separated clearly, Micro-CT reveals that the pseudomorphs are solid inside without any trace of internal organs, such as guts. They might form by the fast invasion and rapid growth of exogenous bacteria. The microbial colony was shaped by the more recalcitrant epidermis or cuticle and then mineralized as pseudomorph. Type-D is hollow and may represent a biofilm which stabilizing the morphology of ancient animals.

These discoveries suggest the mechanism and groups of responsible microorganisms are different from that pseudo-morphing embryos. What's more, it claims that such a Lagerstätte still yields the possibility of new pathway to preserve soft-body and increases the chance for us to retrieve non-mineralized animals in deeper time. Although they are soft and hardly preserved conventionally, they could be pseudo-morphed under some particular circumstances.

DEEP-SEA BIODIVERSITY IN SPACE AND TIME: WHAT HIGH TIME RESOLUTION MICROFOSSIL RECORDS TELL

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Deep-sea biodiversity changes both in space and time. Regarding spatial patterns, for example, there are more species in the tropics and less species in the Arctic Ocean, constituting the latitudinal diversity gradient, one of the most pervasive ecological patterns on Earth. We know much less regarding the biodiversity changes with time, because deep-sea long-term monitoring is difficult and do not persist beyond a few decades. Fossils are basically the only direct records of deep past biodiversity. Ostracods are small, bivalved crustaceans with the finest-scale fossil resolution of any metazoan, and thus an ideal model system to study deep-sea biodiversity both in space and time, allowing to obtain high time resolution fossil time series data, for example, of multidecadal and centennial time scales. This presentation will show a synthesis of the patterns and possible causes of deep-sea biodiversity variation for the last two million years, using benthic deep-sea ostracod as a model system. High time resolution microfossil records show that deep-sea biodiversity has clearly responded to global climate changes.

MACROEVOLUTION OF ANOMALOCARIDS AND ITS IMPLICATIONS FOR THE CAMBRIAN EXPLOSION

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The anomalocarids were an iconic group of 'weird wonders' rising during the Cambrian explosion of animals. Their peculiar body plan shows some of the key transitional features from basal panarthropods to euarthropods, providing crucial insights into the origin and early evolution of arthropods. The anomalocarids also played as arguably the earliest apex predators in the Phanerozoic marine food webs. Continuous fossil discoveries from the Paleozoic exceptional fossil deposits in past decades have revealed a previously unexpected taxonomic diversity of anomalocarids through space and time, including a cosmopolitan biogeographic distribution and a long evolutionary history from the early Cambrian to the Ordovician or possibly the Devonian. Among these fossil discoveries, the Burgess Shale-type Lagerstätten in China have yielded a rich anomalocarid fossil record from the early to late Cambrian, offering indispensable data for reading the tempo and mode in evolution of anomalocarids. On the basis of information from these new materials, expanded and updated datasets of anomalocarids are built and analyzed by using phylogenetic and disparity methods. The reconstructed phylogeny shows new topologies and better resolution with higher robustness under both parsimony- and probability-based inference models. The morphological disparity of anomalocarids between groups and through time is investigated by using different quantification measures and a phylomorphospace approach. The results reveal an early diversification of anomalocarids in the Cambrian Age 3 and a major shift of anomalocarid groups temporally correlated to the Cambrian extinctions at the early to middle Cambrian transition. The adaptive radiation and biotic replacement witnessed by anomalocarids, who were 'weird-wonder' monsters and high-level predators in the Cambrian seas, indicate the macroevolutionary processes during the Cambrian Age 3 to 4 were more under the Phanerozoic realm. Thus the macroevolutionary history of anomalocarids provides further evidence to constraining the duration of Cambrian explosion.

ORIGIN OF LARGE, 'ORSTEN'-TYPE CARBONATE CONCRETIONS IN THE HURON SHALE MEMBER OF THE OHIO SHALE (DEVONIAN) OF OHIO

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Carbonate layers and concretions formed of carbonate minerals are common in organic-rich black shale deposits of Paleozoic age. Their occurrence is rather enigmatic, as carbonate minerals require alkaline conditions for precipitation, and organic-rich shales were putatively deposited under acidic, dysoxic to anoxic conditions. These carbonate layers and concretions are important, as they often yield exceptionally preserved fossils. The relationship between decay of organic matter and localized alkalinity, and the source of large volumes of carbonate, are essentially unexplained.

Carbonate concretions from the Huron Shale Member of the Ohio Shale (Devonian) of central Ohio are unusually large, similar to the 'Orsten' (Cambrian) in Scandinavia. Another similarity is the occurrence of exceptionally preserved fossils in some concretions. Study using Scanning Electron Microscopy (SEM) yields evidence suggesting an organic origin for Ohio Shale concretions. Delicate fossils resembling algae have been recovered from concretionary material in the Huron Member of the Ohio Shale. The taxonomic affinities and original composition are not well understood, but it seems likely that this material formed the basis for initiating concretion growth, as suggested by the presence of an inferred microbial decay halo. Others fossils known from the concretions include radiolarians, hexactinellid sponge spicules, placoderm plates, vascular plant material, and spores. Fe- and Mg-rich carbonates, silica, calcium phosphate, organic carbon, and aluminosilicates (clay minerals) are important components of the central portions of Ohio Shale concretions. Subsidiary minerals include pyrite and barite. Preservation of algal remains implies fast initial mineral replication and initial concretion growth. Exceptional preservation seems to be concentrated in the central region of the large concretions, however, which suggests that concretion growth continued beyond an initial phase.

LATE TRIASSIC FLORA OF THE XIAOPING FORMATION AND PALAEOENVIRONMENTAL SIGNIFICANCE IN CENTRAL GUANGDONG, CHINA

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The Triassic-Jurassic (T–J) Boundary marks one of the largest mass extinctions, which occurred ca 201.3 Myr ago. Recent studies demonstrate that during the T–J transition, great biological and geological events happened. These events were correlated with the strong greenhouse effect by a marked increase in atmospheric carbon dioxide levels and massive volcanism in the Central Atlantic Magmatic Province (CAMP). The deposits of the T–J transition are well developed in China. In the Central area of Guangdong Province, the Late Triassic coal-bearing series of marine and terrestrial alternating deposits are well developed. In particular, the Upper Triassic Xiaoping Formation in Central Guangdong yields a variety of marine and terrestrial fossils. The Xiaoping Formation shows potential for new research on biodiversity variation and great geological events across the T–J Boundary.

Diverse and rich plant fossil records of Late Triassic were recently found in the Xiaoping Formation in Tanbu Town, Huadu District, Guangzhou City, Central Guangdong Province. The Tanbu flora shows a high diversity, including 89 species of 40 genera. Among them, there are eight species of four genera of Horsetails, 29 species of 12 genera of ferns, nine species of five genera of Seed ferns, 31 species of 10 genera of cycads, six species of four genera of Ginkgophytes, three species of two genera of conifers and three species of two genera of incertae sedis. This flora is dominated firstly by gymnosperms (57%), and secondly by pteridophytes (43%). The Filicales accounts for a high percentage (32.6 %), represented by the families Dipteridaceae (10.1%) and Osmundaceae (4.5%) (or 13.5%, include *Cladophlebis*, which may belong to Osmundaceae), as well as Angiopteridaceae, whereas Matoniaceae, Gleicheniaceae and Schizaeaceae appear individually. The Bennettitales (28.1%) is slightly less abundant than the Filicales taxa. In addition, Cycadales (6.7%), Pteridospermophyta (10.1%), Sphenopsida (9.0%), Ginkgoales (6.7%) and a small amount of Coniferales plants (3.4%) are also present. On the bases of previous research, we discovered some new types. Among them,*Williamsonia* and *Stachypteris* were found in Late Triassic of Guangdong Province for the first time.

Most of the species were common in the Late Triassic; only rare types extend into the Jurassic and were recorded in other parts of Southern China. Therefore, it can be inferred that the geological age of the Xiaoping Formation flora most likely is Late Triassic. According to botanical affinity analysis, the vegetation in Guangzhou belonged to tropical-subtropical vegetation type during the Late Triassic.Furthermore, the Xiaoping Formation is characterized by a series of glutenite, sandstone, carbonaceous shale, sandy shale and coal bed (or lines). It is interpreted as a transitional environment, such as delta and peat mire. From the above fossil plant evidence, the Tanbu region of Guangzhou was a warm and humid delta or peat mire in the Late Triassic period.

RECONSTRUCTION OF *TRICALYCITES*, AN EARLY WINGED FRUIT TYPE FROM THE CRETACEOUS OF THE GULF COASTAL AND EASTERN COASTAL PLAINS OF NORTH AMERICA

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The Cretaceous winged fruit genus *Tricalycites* has been considered a mysterious plant. The formal description was published in 1895, for these enigmatic winged disseminules. Fossils of this genus have since been reported from 15, mid- to upper Cretaceous sediments localities distributed in New Jersey, New York, Massachusetts, Rhode Island, Alabama, and Texas. However, the genus has not been investigated since early in the last century and has been overlooked in recent treatments of the Cretaceous angiosperm flora. New information from epifluorescence microscopy and micro-CT scanning, is helping to better characterize the morphology and possible affinities.

Historically, two species have been attributed to *Tricalycites*. The first described, *T. papyraceus*, originally based on specimens from the Raritan Formation, in Woodbridge, New Jersey, has a single wing with three prominent lobes arising from a small globose body (1–4 mm) borne on a narrow pedicel. The wing lobes are approximately equal in size, usually diverge from each other at angles of about 45°, and have fine, subparallel venation, with veins diverging from the base and forking and anastomosing, ultimately ending in the margins. The second species to be recognized was *T. major*, from the Magothy Formation, in Glen Cove, Long Island. This differs significantly by having three separate unlobed wings, rather than a single one. The wings arise from a globose body (3–6 mm), on a thick pedicle. The two lateral wings of this species are

relatively long, whereas the middle wing is shorter. The wings are diverging from each other at angles less than 20°. Althoughvenation of *T. major*similar to*T. papyraceus*, the differences in basic morphology lead us to question whether they belong in the same genus. We have re-investigated specimens from localities in the Tuscaloosa Group of Alabama that E.W. Berry placed in the species *T. papyraceus*. They have three wings arising independently from the body and therefore appear to be more closely related to *T. major*. Micro-CT scanning of the specimens from Alabama have revealed features that were not previously known, including a pair of distinctively branched spiny appendages arising from the base in addition to the three wings. Cuticle preserved on the wings shows obvious stomatal complex and differences between two kinds of *T. papyraceus*, which have not been reported before. The original material of *T. papyraceus*has anomocytic type stomata and lacks trichome bases. However, the Alabama specimens have variable stomata including anomocytic, paracytic and actinocytic types and have trichome bases. The above results give us more evidence to amend the diagnosis of *T. papyraceus* and to distinguish *T. major*, and the specimens from Alabama, as a separate genus.

Improved knowledge of the morphology and affinities of these plants will help to provide a better understanding of late Cretaceous coastal vegetation, and the diversification of angiosperms.

THE EDIACARAN-CAMBRIAN TRANSITION OF NORTH CHINA

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The central mountain range, known as the backbone of China, separates the country into North China and South China, which are different from each other in geology, geography, climate, and culture. The Precambrian-Cambrian transition of South China has received much attention of world scientists for beautiful sections and numerous fantastic fossil-Lagerstätten. However, the Ediacaran-Cambrian sequences of North China have some attractive points as well. The lowermost Cambrian of North China, the Xinji Formation, unconformably overlies Precambrian rocks of various ages, from Archean to late Ediacaran. The Xinji Formation is rich in SSFs of Cambrian Epoch 2 aspects and thus the Terreneuvian is absent throughout North China. The Xinji SSF assemblage is taxonomically dominated by molluscs and hyoliths, which are represented by 26 and 12 species, respectively. A number of molluscan taxa are conspecific with Australia, Antarctic and Laurentia, and thus have biostratigraphical and paleobiogeographical values. Remarkably, shell microstructures are well preserved in molluscs and hyoliths, which demonstrate how these Cambrian animals use minute mineral crystals to build their shells. Additionally, shell microstructures shed new light on the phylogenic links between the groups. Ediacaran rocks developed in marginal regions and cratonic basins. Along the south and west margins of North China, the Dongpo/Tuerkeng Shale/Slate immediately underlies the unconformity and overlies the Luoquan/Zhengmuguan Diamictite which is poorly constrained in age. The shale/slate unit above the diamictite yields a diverse form of macroscopic, soft-bodied fossils, e.g., the annulated tubular form *Shaanxilithes*, the form of a string of beads *Horodyskia*, the WiFi symbol-like form *Palaeopascichnus*, an unnamed form resembling a string of rings (which might be a segmented organism composed of many repetitive units), and small clew-like fossils of unknown affinities. Algal fossils are abundant but simple in complexity and poor in diversity. The presence of *Shaanxilithes* and *Palaeopascichnus* suggests an age of late Ediacaran. New specimens demonstrate that *Shaanxilithes* is composed of a cone-in-cone internal tube encased in a flexible external tube with irregular cross annulations. Such a morphological reconstruction is analogous to the contemporary *Cloudina* and other tubular organisms. New findings in North China would provide new insights into the biotic evolution of the Ediacaran-Cambrian transition.

BRACHIOPODS WITH SOFT PARTS FROM THE EARLY CAMBRIAN WULONGQING FORMATION (SERIES 2, STAGE 4) OF YUNNAN, SOUTHERN CHINA

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Similar to brachiopods from the Chengjiang biota (Zhang et al. 2008; Zhang & Holmer. 2013), the brachiopods with soft tissue preservation from the Wulongqing Formation are strongly crushed and compressed parallel to the bedding plane (Hu et al., 2013; Zhang et al., 2011). The fine preservation of soft parts in the brachiopods comprises setal fringes, variable imprints of the lophophore, mantle canals

and pedicles (Hu et al. 2010, 2013). These younger records from the

Wulongqing Formation have the ability to give us a much more complete picture of brachiopod evolution and functional morphology and ecology during the Early Cambrian.

Despite great similarities to the Chengjiang fauna, in terms of preservation, the Guanshan biota exhibits a dramatic change in faunal composition, with taxa at the genus and species level distinct from their precursor representatives of the Chengjiang fauna (Zhang and Holmer 2013). The Chengjiang brachiopod assemblage consists of 10 documented species, tentatively assigned to 10 families within seven superfamilies and seven orders (Zhang and Holmer 2013); it is dominated numerically by the fossils of Lingulellotreta (Lingulellotretidae), *Heliomedusa* (Mickwitziidae) and *Diandongia* (Botsfordiidae). By contrast, the brachiopod assemblage in the Epoch 4 Guanshan fauna is composed of at least eight identifiable species, unambiguously assigned to nine genera. The Guanshan fauna and Chengjiang biota share no common taxa at species level. The Guanshan (Stage 4) brachiopods are numerically dominated by abundant eobolids (rather than the lingulellotretid Lingulellotreta malongensis), neobolids, and some small-sized acrotheloid and acrotretoid brachiopods. The occurrence of *Nisusia* sp. in Stage 4 represents the FAD of the superfamily Nisusioidea in the Cambrian of eastern Yunnan. *Diandongia pista*, the most common component of the brachiopod assemblages in Stage 3, have disappeared and have been suddenly replaced by abundant Neobolids (*Neoobolus wulongqingensis* sp. nov.) and acrothelids (*Shijiangjunthele gubaiensis*) in the Guanshan biota (Stage 4) of eastern Yunnan, China.

In conclusion, the brachiopod assemblage from the Guanshan biota represents a complete genus- and species- level turnover of the Chengjiang brachiopods in the soft muddy-substrate seafloor during the temporal interval of Cambrian Epoch 3–4 transition. This turnover coincides with the trilobite (*Palaeolenus-Megapalaeolenus*) assemblage replacement events (Luo et al., 2008), suggesting that the brachiopod faunal assemblages were affected by the same factors that affected mobile trilobites.

THE CHENGJIANG-TYPE FOSSIL ASSEMBLAGES FROM THE LOWER CAMBRIAN YU'ANSHAN FORMATION OF QUJING, EASTERN YUNNAN AND ITS TAPHONOMIC AND PALEOECOLOGICAL SIGNIFICANCE

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Some Chengjiang-type fossil assemblages from the lower Cambrian Yu'anshan Formation have been documented from Qujing, eastern Yunnan, differs significantly to the classical Chengjiang fossil assemblages from Haikou and Chengjiang area in taxonomic composition. The detailed sedimentological and quantitative taphonomic and paleoecological analyses based on the specimens from the Kuanshan section, Nanzhang section in Malong County, and Wenquan section near to Qujing City, reveals the wide distribution of Chengjiang-type fossils in Malong-Yiliang-Qujing area. Investigation of these fossil assemblages show the dominance of arthropods, associated with priapulids, sponges, lobopods and some other taxa. Taphonomic analysis indicates a relatively lower energy and low rates of sedimentation recorded by fossil preservation and the hosting mudstones. The fossils have been strongly affected by late diagenetic and weather processes, and the quality of soft-bodied fossil preservation is poorer than in the classical Chengjiang fossil localities, but some specimens still preserve exquisite anatomical details. Comparisons between the fossil localities of Qujiang and classic Chengjiang-type localities from the Chengjiang and Haikou areas, as well as from some fossil sites in neighbouring Guizhou Province are made in both taxonomic and taphonomic aspects. The chengjiang-type fossils of similar age widely distributed in region, making eastern Yunnan a unique area to reveal the early evolutionary history of animals and palaeocommunity dynamics during the ''Cambrian explosion''.

MORPHOLOGICAL DEGRADATION OF FEATHERS: RESULTS FROM EXPERIMENTAL MATURATION

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Recent studies show that besides melanosomes, keratin protein can also be preserved in exceptional fossil feathers, giving unprecedented new details of feather evolution. Taphonomic experiments can provide important insights into such exceptional preservation. Previous studies using autoclaves to provide controlled temperatures and pressures to simulate an accelerated diagenetic process, have shown that

keratin can be completely degraded after being matured at 250 °C/250 bars for 24 hours. Here we assume that there should be a threshold of temperature and/or pressure, within which the ultrastructure and keratins of feather can survive or at least partially survive. In this study, we repeated the accelerated diagenetic experiments on feathers, but with more finely controlled conditions. The morphological degradation of feathers under controlled conditions is documented. Results show a clear degradation sequence of feathers. The morphological degradation occurs from outside to inside. Weakly matured feathers (100–150 °C/250 bars, two hours) retained overall feather morphology, only lacking the ultrastructure on the surface. Moderately matured feathers (150–200 °C/250 bars, 2 hours) lacked overall barbule morphology, with melanosomes exposed. Highly matured feathers (200–250 °C/250 bars, 2 hours) turned into ashes. Our results can help to interpret the structure preserved in fossil feathers.

THE EVOLUTIONARY HISTORY OF FUSULINIDS RECONSTRUCTED BY USING GBDB AND CONOP

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Fusulinoidea is a major group in the late Paleozoic with abundant well-documented distributions, and thus is used extensively for biozonation and correlation. Like most of shallow-water, tropical marine organisms, the diversity as well as geological distribution of fusulinids are interpreted to have strong correlation with global climate and paleogeographic framework. After Euramerina and Gondwana joining together, the distribution of fusulinids shows progressively compartmentalization and three major fusulinid realms have been recognized, i.e., the Tethyan realm, the Boreal or Franklinian-Uralian realm and the Midcontinent-Andean realm. In each of these realms, fusulinid evolved independently, which makes the global biostratigraphic correlation quite difficult.

The fossil records used in previous studies of taxonomic diversity are commonly limited by comparatively coarse temporal resolution such as ages, which are generally longer than 3 My in Carboniferous and Permian. Meanwhile, with the accumulation of biostratigraphic data and the application of computer science in stratigraphy, various quantitative methods have been developed for regional and global high-resolution stratigraphic correlation. Considering the size of the data set available for the present study, we choose the constrained optimization (CONOP) method to build a high-resolution fusulinoidean composite sequence. Using the simulated annealing heuristic algorithm, all the species' stratigraphic ranges appeared in quality-controlled sections are composited into a single, global, best-fit ordinal composite spanning the entire lifespan of the fusulinoidean clade (from the early Carboniferous to the end of Permian).

Our results show a steady accumulation of fusulinid diversity from the middle Mississippian to the Cisuralian, followed by a short decline in the late Cisuralian, which may have been partly related to the larger amount of overall species in Early Permian. After the Cisuralian fluctuation, diversity shows a stable plateau in most of Guadalupian, except for the rapid drop in the late Capitanian. It was suggested that at the end of Guadalupian the majority of fusulinids disappeared, known as the pre-Longpingian crisis, while a less significant drop in diversity is observed in the present research. Fusulinids diversity rebounded after the crisis and kept stable until the plunge of the end-Permian mass extinction.

CALCAREOUS ALGAE FROM THE WELL XIKE-1 IN XISHA ISLANDS AND THEIR PALEOECOLOGICAL IMPLICATIONS

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Calcareous algae provide important evidence for the stratigraphic division and paleoenvironmental reconstruction. Due to the shortage of materials, many aspects of calcareous algae in the South China Sea are largely unknown. With the samples from Miocene Sanya Formation to Quaternary Ledong Formation in the Well Xike-1 Xisha Islands, we established a biostratigraphic framework and discussed their environmental significance.

A total of twenty-six species in ten genera of Corallinaceae, one species in one genus of Dasycladaceae, and one species in one genus of Codiaceae were identified, including Melobesioideae *Archaeolithothamnium*, *Mesophyllum, Lithothamnium, Lithophyllum, Aethesolithon, Porolithon* and *Lithoporella*; Corallinae *Amphiroa, Corallina,* and *Jania*; Dasycladaceae *Cymopolia*; Codiaceae *Halimeda*. Based on their composition, four assemblages were recognized from the Sanya Formation to Ledong Formation: *Lithophyllum kuboiensis–Lithophyllum tenuicrustum* Assemblage, *Mesophylllum iraqense* Assemblage, *Corallina–Jania–Aethesolithon* Assemblage and *Amphiroa–Halimeda* Assemblage in ascending order.

Geniculate coralline red algae, such as *Amphiroa* and *Corallina*, with upright branches of the thallus, has a weak ability of wave resistance and generally grows in the low tide zone to 30m in shallow sea indicating the reef-flat to lagoon environments. In contrast, non-geniculate coralline red algae (e.g. *Lithothamnium* and *lithophyllum*) with a stronger ability of wave resistance are dominant in reefs. These algae lived in the intertidal zone within a depth about 100m. The green alga *Halimeda* is an important marker of lagoon deposits.

The results of the Well Xike-1 show that it was reef facies to reef flat facies, alternated with lagoon facies, in the early Miocene, and then it became reef flat facies to lagoon facies in the middle Miocene. The late Miocene was dominated by reef facies. It was fore-reef facies to reef facies, mixed with reef flat facies, in the Pliocene. Finally, reef facies to reef flat facies became predominant in the Quaternary. Although calcareous algae were not major framework builders, they helped to bind and stabilize skeletons, expanding the framework in reefs.

CONSTRAINING PALEOCENE-EOCENE THERMAL MAXIMUM CARBON CYCLING USING THE RECORD OF BIOTURBATION

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The Paleocene-Eocene Thermal Maximum (PETM, ~56 Ma) was an abrupt period of greenhouse warming during which thousands of gigatons of isotopically depleted carbon were added to the atmosphere over a few thousand years, leading to a global negative carbon isotope excursion (CIE) and carbonate dissolution. Deep sea sediment cores are the primary source of information for these changes in climate and global carbon cycling, but these are subject to alteration through animal activity within the sediments after deposition (bioturbation). One of the great challenges in paleoclimate research is identifying where and how the sediment record has been distorted through bioturbation or erased through dissolution. Across the PETM, differences in bioturbation intensity between ocean sites can provide unique insight into the benthic environment, and may correlate to spatial patterns in carbonate dissolution, changes in ocean oxygenation, CIE magnitude, and event recovery timescale. Here, we analyze the sedimentology and ichnofabric index from International Ocean Discovery Program (IODP) sites from all over the globe. We find major differences in the intensity of bioturbation between the different locations, with cessation of bioturbation found at some of the sites. We investigate the nuanced transitions of ichnofabric and identify unconformities to determine degree and timing of sediment alteration. We then compare bioturbation intensity with wt% $CaCO_3$ and bulk carbon isotopes from these sites. Our analyses of the cores show a lithology-dependent responses in bioturbation, and a delayed cessations relative to the carbon isotope excursion.

ENCRUSTATION PATTERNS OF *CLYPEASTER ROSACEOUS* TESTS FROM SAN SALVADOR, THE BAHAMAS

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Dead tests of *Clypeaster rosaceous* represent a common secondary substrate for infestation and bioerosion. Specimens of these clypeasteroid echinoids were collected from San Salvador Island (Bahamas) and analyzed in detail for diversity, intensity and site selectivity of bioinfestation. The oral and aboral surfaces of the echinoid show varying morphologies. The oral surface containing the periproct and the (highly indented) peristome as well as simple straight food grooves is flattened. The aboral surface contains the petals with ambulacral pores which is highly inflated. These features, along with numerous sunken tubercles on the surface of the test provide for highly differentiated substrate for bioinfestation. The aim of this study is to analyze the diversity and degrees of encrustation and bioerosion on the echinoid surface, to compare different areas of the test with respect to bioinfestation and, finally to assess the importance of these processes for preservation potentials.A number

of different taxa contribute to both encrustation and bioerosion. Encrusters include coralline and fleshy algae, foraminifera, serpulids, bryozoans and bivalves. Bioerosion consisting mostly of small round holes which is more common on the aboral surface. Differences in encrustation are clearly present between the oral and aboral test sides, especially in less encrusted forms. Coralline algae can cover complete specimens; they are however, more commonly found on the aboral surface where they often show protuberances as growth forms. Fleshy algae are also more common on the aboral surface. Encrusting foraminifera consist of *Homotrema rubrum* which is found slightly more often on the oral surface while flattened white to grey *Planorbulina acervalis* are more common on the aboral side. Especially *Homotrema* shows different states of preservation ranging from dark red, upright growing forms to heavily eroded pink forms. *Homotrema* predominates on heavily encrusted test, while *Planorbulina* is often found in early stages of encrustation. Three different serpulid growth forms were discerned: long thin tubes, short often highly sculptured thick tubes, as well as enrolled *Spirobis* types. Both long thin tubes as well as short thick tubes occur predominately on the oral surface while the opposite is true for the *Spirorbis* types.

In conclusion, there is a high variability of infestation ranging from pristine to completely encrusted tests. The higher the degree of infestation, the higher the differentiation between oral and aboral surfaces which can be discussed with respect to exposure and light intensity as well as differential morphology of the test surface. Especially encrustation by coralline algae leads to an increase of substrate thickness and thus test durability which, however, are then attractive to bioeroders which eventually weaken the test.

EXPLORING THE IMPACT OF STRATIGRAPHIC ARCHITECTURE ON THE PATTERN AND TIMING OF LATE ORDOVICIAN EXTINCTION EVENTS

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The Late Ordovician mass extinction (LOME) is commonly expressed as two clusters of last occurrences in the Hirnantian fossil record. These clusters appear to coincide with stratigraphic surfaces and facies shifts generated by the glaciation and the deglaciation of the supercontinent Gondwana. Consequently, glacioeustatic changes have been proposed as a principal driver of the LOME, with each cluster of last occurrences interpreted as a pulse of extinction. Sequence stratigraphic models show that extinctions are predicted to generate clusters of last occurrences at stratigraphic surfaces and facies shifts. This can result in clusters of last occurrences that misrepresent underlying extinction patterns, leading to misinterpretations of the drivers and pattern of an extinction event.

We use a modeling approach to test how glacioeustatic changes would affect the expression of a variety of possible LOME extinction scenarios. Using the sedimentary basin model Sedflux 2.1, we generate stratigraphic architecture based on a Late Ordovician sea level history from Anticosti Island (Québec, Canada). We combine this with a branching model of evolution and extinction, as well as ecological gradients, to simulate several plausible LOME extinction scenarios and a null model of constant extinction rates. Comparisons with our null model allow us to document how stratigraphic architecture influences the number, magnitude, and position of clusters of last occurrences associated with different LOME extinction scenarios.

Our simulations demonstrate that no single stratigraphic column or water depth will consistently and accurately represent the true underlying extinction pattern. For example, in shallow water columns analogous to epicontinental Hirnantian deposits, both single and double pulse extinction scenarios generate two clusters of last occurrences associated with the initial falling stage systems tract and final transgressive systems tract. Only by comparing stratigraphic columns with different water depth histories is it possible to differentiate among 1) hypothesized extinction scenarios and 2) clusters of last occurrences attributable to the mass extinction and those generated by stratigraphic architecture. A basin-wide assessment of the LOME fossil record in a sequence stratigraphic context is necessary to properly assess the pattern and timing of the extinction event.

REGIONAL-SCALE COLLAPSE OF BENTHIC BASELINE COMMUNITIES IN THE NORTHERN ADRIATIC SEA

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We studied the origin and collapse of Holocene benthic baseline communities in the northern Adriatic Sea from sediment cores and surface grab samples at eight widely spaced sites. They cover areas with sedimentation rates spanning two orders of magnitude, with different nutrient input and with different degrees of time-averaging, ranging from decadal to millennial temporal resolution. Data from sediment cores indicate that during the transgressive phase and maximum flooding, sea-level and establishment of the modern circulation pattern determined the development of benthic communities in shallow-water, vegetated habitats with epifaunal biostromes and, in deeper waters, with bryozoan meadows. After sea-level stabilization, the composition of these baseline communities remained relatively uniform and started to change markedly only with the intensification of human impacts in the late highstand, leading to a dominance of infauna and a decline of epifauna at all sites. This profound ecological change reduced species richness, increased the abundance of infaunal suspension feeders, and led to a decline of grazers and deposit feeders. Live-dead data from grab samples give deeper insight into the degree of anthropogenic impact in historical times. At all sites the living assemblages differ strongly from the death assemblages. At some sites from oligotrophic settings with low sedimentation rates, a total overturn in the community composition is obvious: formerly abundant species have disappeared completely, while the living assemblage is numerically dominated by species that were not present before. Even at sites, which are characterized by physically stressful conditions (i.e., high sedimentation rates in the Po delta), some species that were abundant in the death assemblage have totally disappeared from the living assemblage. Comparison with the dataset from sediment cores documents the recent establishment of an impoverished community, which has no analogue in the Holocene history of the northern Adriatic Sea.

PALAEOENVIRONMENTAL DISTRIBUTION OF *TEREBRATULA* (BRACHIOPODA) IN THE EARLY PLIOCENE OF SE SPAIN

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Today only about 400 brachiopod species exist, among which terebratulids are by far the most successful clade. The Cenozoic-Pleistocene genus *Terebratula* represents an exception to the Post-Permian trend in brachiopod retreat to cryptic and offshore habitats. It was very abundant in warm-temperate to subtropical shallow-water environments in the Mediterranean and Paratethys realms, despite the general dominance of bivalves and the pervasive bioturbation and predation pressure during the Neogene. However, *Terebratula* went extinct in the Calabrian (Pleistocene). Understanding the causes that drove this genus to extinction requires a better knowledge of the optimal environmental conditions during the heyday of *Terebratula*, which are currently poorly known. The aim of our study is to contribute to the knowledge about the environmental distribution of *Terebratula.* The Águilas Basin (SE Spain) is an ideal study area because *Terebratula* shell beds occur there cyclically in early Pliocene (Zanclean, MPl3 biozone) deposits. We studied 26 samples from the Cabezo Alto (CA) section, which has a continuous representation of the main facies in the study area and includes two *Terebratula* pavements. From the samples, assemblages of planktonic and benthic foraminifera were analyzed as palaeoecological proxies. Geochemical proxies include data from X-ray fluorescence from bulk sediment samples and oxygen isotopes from *Terebratula* shells. The CA section was used as a template to analyze three additional pavements and a spectacular *Terebratula* biostrome, all from the same sequence. Our results suggest that *Terebratula* preferred low sedimentation rates, relatively oligotrophic, well-oxygenated conditions and moderate to strong hydrodynamics at water depths of about 60–100 m. Oxygen isotopes suggest water temperatures of 17 to 20ºC (assuming the Águilas Basin sea water $\delta^{18}O$=1.5‰ VSMOW in the late Zanclean). Calibration of Axis 1 scores from Detrended Correspondence Analysis of our planktonic foraminifera dataset with extant samples from the literature even suggests paleo-sea surface temperatures ranging from ~20º to 25ºC. In the Águilas Basin, the terebratulid concentrations occur consistently at the toeset of subaqueous delta-scale clinoforms, with decreasing abundance of individuals proximally and distally from this subenvironment. The main hypothesis for the extinction of *Terebratula* thus remain the environmental stresses associated with the onset of major glaciations by the end of the Calabrian.

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