2021 Northeast Geobiology Symposium

April 9$^{\text{th}}$ and 10$^{\text{th}}$

Dartmouth College, Hanover, NH

Talks

Session 1: Proterozoic Earth

9:05 a.m.

The rise of phosphorus recycling facilitated Earth's Great Oxidation Event

Lewis J. Alcott, Benjamin J. W. Mills, Andrey Bekker, and Simon W. Poulton

The rise of atmospheric oxygen during the Great Oxidation Event (GOE) ~2.4 billion years ago (Ga) was a defining transition in the evolution of global biogeochemical cycles and life on Earth. There is, however, abundant evidence for mild oxidative continental weathering and the development of ocean oxygen oases several hundred million years prior to the GOE. The GOE thus represents a threshold, whereby primary productivity and O_2 production overwhelmed the input of reduced species that consume O_2, and its timing is assumed to be related to a balance between the riverine input of the major limiting nutrient, phosphate, and the dynamics of the solid Earth. However, the sequence of events that ultimately facilitated persistent atmospheric oxygenation remains elusive. Here, we report novel geochemical analyses of ~2.65 to 2.43 Ga drill core samples from the Transvaal Supergroup, South Africa, which document an early rise of sedimentary phosphorus recycling as dissolved sulfide became more abundant in the ocean system, which itself was a progressive response to the onset of oxidative continental weathering. Biogeochemical modelling of the global implications for primary productivity shows that the evolution of phosphorus recycling was the critical step that enabled Earth's transition to a persistently oxygenated atmosphere.

9:25 a.m.

Depositional rates in the Ediacaran Nafun Group, Oman, and the wider late Proterozoic world

Marjorie D. Cantine, Alan D. Rooney, Andrew H. Knoll, and Kristin D. Bergmann

The depositional rates of sedimentary strata reflect fundamental controls on Earth surface systems, including accommodation space, sediment supply, and, in the case of chemical sediments, water chemistry. The rate at which sediments are deposited and buried in the ocean exerts a key control on their diagenetic history and on biogeochemical cycling within sediments. Noting thick deposits of carbonate strata near the Proterozoic-Cambrian boundary in a few Ediacaran (635–541 Ma) successions, some workers (e.g., Wood et al. 2017) have suggested that these thick carbonate successions reflect rapid depositional rates resulting from highly oversaturated seawater, contemporaneous with the first appearance of carbonate-biomineralizing metazoans. Interpreting and comparing depositional rates across locations and successions is challenging because the apparent depositional rate of a sedimentary package scales inversely with the length of time it spans (the Sadler Effect). This study leverages new Re-Os isochron-derived dates for the Ediacaran Nafun Group of Oman to determine depositional rates. These dates indicate an increase in sedimentary thickness and depositional rate in the late Ediacaran Period not wholly explained by the Sadler Effect. To see if this trend holds globally, 400+ depositional rates within globally distributed Ediacaran successions are tabulated. In some cases, high apparent depositional rates are best understood as a result of the Sadler Effect. Some locations in Western Gondwana record much thicker sedimentary packages and higher depositional rates in the second half of the Ediacaran Period, consistent with regional tectonic control on sedimentation and depositional rate. These successions contain thick deposits of carbonate, suggesting that ocean chemistry also played a role in generating these voluminous latest Proterozoic successions.

9:45 a.m.

Ediacaran Shuram carbon isotope excursion as a global oceanographic event

James F. Busch, Eben B. Hodgin, Anne-Sofie C. Ahm, Jon M. Husson, Francis A. Macdonald, Kristin D. Bergmann, John A. Higgins, and Justin V. Strauss

Marine carbonate carbon isotopes (δ^{13}C) have traditionally been used as a proxy for the global isotopic composition of dissolved inorganic carbon (DIC) in the oceans. The conventional model that δ^{13}C accurately represents DIC during major negative carbon isotope excursions (CIE's) has been challenged during the Neoproterozoic Era, as they are not easily explained in a simplistic model of Earth's steady state carbon cycle. In this study, we attempt to provide context for and insight into the conditions which produced the largest of the Neoproterozoic isotopic anomalies, the Shuram CIE. Through a global compilation of new geochemical and sedimentological data, we find that every succession that records the Shuram CIE experienced a common transgressive marine flooding history. The Shuram CIE initiated during a significant transgression coincident with a prominent change in sedimentary lithofacies and consistent shifts in a host of geochemical proxies. The transgression associated with the onset of the excursion reached its interval of maximum flooding roughly halfway between the deepest δ^{13}C values of the nadir and the return 0‰ and is estimated to be on the order of 10s to 100s of meters. The most negative δ^{13}C values all occur within relatively deeper-water environments compared with the pre- and post-Shuram intervals and contain a prominent enrichment in Mn/Ca. The most negative $\delta^{44/40}$Ca do not occur with the most negative δ^{13}C values, but rather coincide with the interval of maximum flooding and are marked by enrichments in Sr/Ca and U/Ca. After re-evaluating previously proposed mechanisms for the Shuram CIE in the context of these geochemical and sequence stratigraphic observations, the evidence presented here is in agreement with previous studies that argue against meteoric and burial diagenesis as drivers for this excursion. Instead, we suggest that models for the Shuram CIE must consider global climate change, and specifically warming, which was facilitated by the hypothesized transgression.

Session 2: Records of Life, Fossils and Fossilization

10:15 a.m.

Multicellular macroalgae from early Tonian marine strata of Wernecke Mountains, Yukon

Katie M. Maloney, Galen P. Halverson, James D. Schiffbauer, Shuhai Xiao, Timothy M. Gibson, Maxwell A. Lechte, Vivien M. Cumming, Alexie E.G. Millikin, Jack G. Murphy, Malcolm W. Wallace, David Selby, and Marc Laflamme

The Tonian (1000 to 720 Ma) represents a critical transition in Earth history between the Mesoproterozoic (1600 Ga to 1000 Ma) and the low latitude glaciations of the Cryogenian (720 to 635 Ma). Importantly, molecular clock analyses estimate that several key eukaryotic lineages evolved and began to diversify during the Tonian; however, the fossil record remains sparse as well-preserved exposures are rare. The Proterozoic inliers of Yukon present an opportunity to more accurately characterize the environmental conditions of the early Tonian and extract information on biospheric evolution at this time. Previously undocumented Tonian macrofossils were discovered in the ca. 950 Ma outer shelf marine facies of Dolores Creek Formation, Wernecke Mountains, Yukon. Macrofossils samples were recovered from seven horizons in an ∼1 km-thick section of the Dolores Creek Fm. near the headwaters of Hematite Creek. This section has been interpreted as slope deposits with macrofossils transported from shallow marine environments that were likely in the photic zone based on the occurrence of large stromatolite bioherms. The macrofossils include two size classes, smaller branching specimens and larger cm-scale fossils with an unbranching thallus composed of uniform cells with differentiated cell walls and punitive holdfasts. The larger specimens are interpreted as macroalgae with a likely green algal affinity while the simple morphology of the smaller specimens limits their interpretation, and their phylogenetic affinity remains unresolved. The Dolores Creek macroalgae, together with recently reported ca. 1000 multicellular chlorophyte from North China fill a gap in the timeline of algal evolution and provide evidence that benthic green algae inhabited shallow marine habitats by the early Tonian Period.

10:35 a.m.

The role of organic ligands in silica-mediated fossilization

Silvina Slagter, Lidya G. Tarhan, Weiduo Hao, Noah J. Planavsky, and Kurt O. Konhauser

Most of the earliest record of complex macroscopic life on Earth is represented by Ediacaran fossils of soft-bodied macro-organisms associated with matgrounds, enigmatically preserved in silica-cemented sandstones. The taphonomy of these Ediacara-style fossils has been vigorously debated, and recent paleontological, sedimentological, and experimental evidence indicates that early-forming silica cements were critical for their preservation. The lack of a significant biogenic silica sink in the Neoproterozoic and perhaps early Paleozoic oceans (e.g., siliceous sponges, radiolarians and diatoms) may have promoted diffusion of silica-rich fluids from the water column to the sediment, resulting in unique conditions conducive to the fossilization of these organisms. Organic substrates provided by buried carcasses and abundant matgrounds likely fostered silicification, but the mechanisms that trigger preferential nucle¬ation of silica onto organic tissues remain poorly constrained. In this study we used potentiometric acid-base titrations to experimentally test the silica-adsorptive properties of cyanobacteria and algae, as an approximation of the Ediacaran matgrounds with which Ediacara Biota organisms were closely associated. Further, we identified the key functional groups associated with silicification in our experiments via FTIR spectroscopy. Integration of these results indicate that high surface reactivities associated with carboxyl and amide groups in the microbial mats (in addition to amide and hydroxyl groups in the macroorganisms) may facilitate rapid silica precipitation. We suggest that the presence of diverse and widespread matgrounds associated with Ediacara Biota communities played an integral ecological role both in the development of complex benthic communities, as well as in Ediacara-style fossilization.

11:55 a.m.

Decoding the Life Histories and Geobiological Structure of a Remarkably Productive Methane Seep Chimney System.

Peter Schroedl, Devin Manzoori, Maria Valadez-Ingersol, R.L. Edwards, and Jeff Marlow

The recently discovered Point Dume (PD) methane seep system hosts unusual chimney structures whose microbial communities oxidize methane at exceptionally high rates in lab-based experiments. In order to illuminate key factors behind the elevated oxidation rates and clarify the environmental history of the chimneys, we sought to characterize their age, mineralogy, microbial community and physical controls on microbial abundance and community structure. Chimneys were sampled from the newly discovered methane seep chimney system near Los Angeles in the Santa Monica Basin at ~700 meter water depth. PD chimneys are notable in their extant chimney morphologies and high productivity, soliciting comparison to other seep systems of varied morphology, productivity and duration. In the lab, we analyzed distinct, roughly concentric layers of the approximately meter-tall, 0.5-3.5cm thick chimney structures for radiometric ages (U-Th), putative redox state (δ^{238}U), mineral assemblages (XRD), and stable carbon isotope composition (GC-MS). U-Th ages of carbonate precipitation ranged from the modern to ~20,000 years in the past. Measured δ^{238}U values are consistent with a suboxic setting. As with other methane seep chimneys, little variation in vertical U-Th ages was observed within error. The interior pattern of growth suggests an elaborate mineralization, dissolution and remineralization history for PD chimneys. Intriguingly, X-Ray Diffraction (XRD) and microscopy analyses identified complex, heterogeneous layering absent in characterized methane seep chimneys. Measured δ^{13}C values are isotopically light, consistent with characterized seeps. The spatial distribution of extracellular DNA and intracellular DNA concentrations across the chimney wall transect was assessed to identify possible hot spots of metabolic activity and active autochthonous and interim DNA pools. Knowledge gleaned from this remarkably productive system could be applied to engineered climate remediation systems. The longevity of high productivity methane seeps, the mineralogical and microenvironmental structure, as well as the carbon sources of methane oxidation and chimney formation will be consequential to accurately evaluate the role of methane, a potent greenhouse gas, in the biogeosphere.

Session 3: Global Ocean Biogeochemistry

1:00 p.m.

The geologic history of seawater heavy REE enrichment and carbonate chemistry

Ben Davis Barnes and Lee R. Kump

The determination of ancient ocean carbonate chemistry from the geologic record is one of the most reliable methods to track the long-term evolution of Earth's climate and carbon cycle. By constraining any two variables, e.g., pH and pCO_2, one can fully characterize the carbonate system through ocean acidification and global warming events. Despite this utility, there are relatively few marine geochemical proxies for the carbonate system, and the proxy record is sparse through many key intervals. In order to expand our geochemical toolbox to generate novel paleoclimate and paleoceanographic reconstructions, we explore the rare earth elements (REE) preserved in calcite sediments as a novel carbonate ion (CO_3^{2-}) proxy. A persistent feature of the REE composition of ancient carbonates is the relative enrichment of the elements with increasing atomic number (i.e. heavy REE), a pattern which is maintained in modern seawater by complexation reactions with CO_3^{2-}. However, no work to date has compiled data to test if the relative enrichment of REE in carbonates evolves through time. We present a novel compilation of >9,876 published REE measurements in carbonate sediments spanning 3.5 billion years of Earth history. Our results demonstrate that the REE composition has varied significantly and coherently from the Archean to the recent. Furthermore, Phanerozoic trends in heavy REE relative enrichment show a first-order covariation with [Ca2+] reconstructions. This pattern suggests that that evolution of surface seawater [CO_3^{2-}] on 108-year time scales is primarily driven by seafloor hydrothermal inputs and a tendency for homeostasis of carbonate saturation state to maintain the carbonate sedimentation balance of continental weathering fluxes. The capacity of seawater to buffer against short-term climate-system disruptions has therefore varied significantly and episodically, forced by changes to [Ca2+] driven from the seafloor up.

1:20 p.m.

Clumped Isotopologue Signatures of Oceanic Hydrate-Bound Gases: A Global Perspective

Ellen Lalk, Thomas Pape, Danielle Gruen, Jen Karolewski, Gerhard Bohrmann, and Shuhei Ono

Oceanic methane hydrates form one of Earth's largest reservoirs of methane, a potent greenhouse gas and energy resource. In the seafloor, methane can form by microbial metabolisms or by thermal breakdown of organic matter. Hydrated methane could be sourced from in situ production at shallow depths, and/or migrated from depth. Carbon (δ^{13}C-CH_4) and hydrogen (δD-CH_4) stable isotope values, and methane/ethane+propane ratios (C1/C2+3) have been used to infer methane origin in hydrate deposits. However, the interpretation of these geochemical parameters can become complicated when methane is sourced from multiple sources and/or fractionated during migration. Several hydrate deposits with ambiguous geochemical signatures have been documented, and application of clumped isotopologue analysis has the potential to clarify origin and history. We analyze $\Delta^{13}CH_3D$, δ^{13}C-CH_4, and δD-CH_4 for 40 oceanic gas hydrates and associated seep gases from 9 regions of the world's oceans, building a global dataset of clumped methane values found in hydrate-bound gases. We find that hydrate-bound methane from pockmarks and cold seeps has a high $\Delta^{13}CH_3D$ value (4.5 – 6‰) and low apparent temperature (15–70°C), supporting a microbial origin, while hydrate bound methane that is oil-associated tends to have a relatively lower $\Delta^{13}CH_3D$ value (3.5 – 5‰) and higher apparent temperature (50 – 120°C). Hydrate bound gases associated with mud volcanoes yielded $\Delta^{13}CH_3D$ values inconsistent with conventional source attributions; for one mud volcano, high $\Delta^{13}CH_3D$ values (low apparent temperature) are observed for methane with δ^{13}C-CH_4, δD-CH_4, and C1/C2+3 values that are characteristic of thermogenic methane formation, and for another mud volcano field, low $\Delta^{13}CH_3D$ values (high apparent temperature) are observed for methane with δ^{13}C-CH_4, δD-CH_4, and C1/C2+3 values that are characteristic of microbial methane formation. We use apparent temperature from clumped isotopologue data, along with site specific geothermal gradients to estimate the depth at which methane was formed, as there is otherwise limited data that can be used for depth assignments of hydrocarbon formation.

1:40 p.m.

Triple oxygen isotopes ($\Delta'^{17}O$) as records of sulfur cycle drivers

Anna Waldeck, Weiqi Yao, Jordon Hemingway, Adina Paytan, and David Johnston

Here we introduce a novel, emerging record of the ^{17}O isotopic composition of seawater sulfate recorded in marine barites (spanning 134 million years ago to present). Using a recently published model - calibrated against the composition of the modern ocean - we interpret the sulfate ^{17}O composition in seawater as recording the relative balance of sulfur cycle processes that are both mass-independent (or impart large anomalies in ^{17}O – meaning $\Delta'^{17}O \neq 0$) and mass-dependent (largely wash away these large ^{17}O anomalies). Mass-independent isotope effects are sourced from high energy reactions in the atmosphere. Two subsequent processes can thus be considered relative to their MIF consequences. First, the weathering of sulfide minerals has been proposed to incorporate atmospheric O_2 ($\Delta'^{17}O << 0$) into product sulfate. The size of $\Delta'^{17}O$ anomaly in atmospheric O_2 is thought to scale to the atmospheric ratio of pCO_2:pO_2 over time, with an unknown fraction of O_2 being incorporated into sulfate. New work on river systems and sulfate generation (Hemingway et al., 2020, PNAS) challenges these direct interpretations, lessening the straightforward relationship to O_2. The second means of gaining MIF is via the oxidation of volcanic SO_2 following the injection of S via large igneous provinces ($\Delta'^{17}O >> 0$). A recent sulfur cycle model hypothesizes that large igneous provinces directly influenced the sulfur cycle over the last 120 million years by injecting significant amounts of SO_2 into the atmosphere (Laakso et al, 2020). If this model correctly predicts that SO_2 outgassing was significant during LIP emplacement, then this may be observable in the triple oxygen isotope composition of marine sulfate across these intervals. The degree to which these anomalies alter seawater sulfate oxygen isotope composition reflects the size of the marine sulfate reservoir as well as the extent of mass-dependent processes like biological recycling of sulfate that also act to augment or even erase these primary effects (Waldeck et al., 2019, EPSL). In our analysis of this new Cenozoic/Cretaceous dataset, we constrain the extent to which these processes (atmospheric influence, weathering, and biology) each shaped the ^{17}O composition of marine sulfate.

Session 4: Miocene, Microbes, and Mussels (Oh my!)

2:15 p.m.

Assessing the connection between Columbia River Basalt volcanism and the Miocene Climate Optimum with zircon geochronology

Jennifer Kasbohm, Blair Schoene, and Pincelli Hull

Large igneous province volcanism in the Columbia River Basalt Group (CRBG) has been suggested to play a causal role in the elevated global temperatures and pCO_2 of the Miocene Climate Optimum (MCO). However, assessing the connection between volcanism and warming depends on developing an accurate and precise chronology for both events. Until recently, the eruptive chronology of the CRBG was hindered by large analytical uncertainties in the previously used K-Ar and 40Ar/39Ar methods. Proxy records of the MCO have age models dependent on biostratigraphy or magnetostratigraphic correlation to the Geomagnetic Polarity Timescale (GPTS) but lack radioisotopic ages. Here, we use high-precision CA-ID-TIMS U-Pb geochronology on zircon-bearing volcanic ashes interbedded in the CRBG stratigraphy, to provide a detailed timeline of CRBG eruptions. Building on previous work (Kasbohm & Schoene, 2018), we present 6 new ages from the largest-volume formation of the CRBG and use Bayesian age modeling to better constrain eruption rates through the interval most likely to cause warming ($\sim$16.5-16.0 Ma). We also present the first high-precision zircon ages targeting the MCO from volcanic ashes in ODP Site 1000 (Nicaragua Rise), which has previously yielded a record of biostratigraphy, $\delta^{13}C$ and $\delta^{18}O$ across the MCO. Our preliminary new ages from Site 1000 improve upon the precision of prior biotite $^{40}Ar/^{39}Ar$ ages by an order of magnitude, pinpoint the interval of CRBG volcanism in the core, and show that the decline in $\delta^{18}O$, indicating the onset of warming at the site, occurred $\sim$18.5 Ma, differing from other records that place the warming onset at $\sim$17 Ma. Possible explanations for this offset include a precursor warming event in the lead-up to the MCO, global diachroneity of the MCO, errors in age calibrations of other MCO records, or alteration of the warming signal at Site 1000 through diagenesis. While CO_2 outgassing of the

CRBG has previously been invoked as the driver of the MCO, our new Site 1000 age model suggests that the CRBG was erupting during only a small portion (∼750 ka) of the MCO.

2:35 p.m.

The diversity and evolution of the MtrCAB extracellular electron transfer system

Isabel R. Baker, Bridget E. Conley, Jeffrey A. Gralnick, and Peter R. Girguis

The far-reaching impact that Bacteria and Archaea have on our planet is seeded in the incredible physiological diversity they harbor, and their colonization of almost every environment on Earth is an ode to their metabolic diversity. One facet of their metabolic range lies in the breadth of substrates they can use to harness energy. Some bacteria and archaea have even evolved the means to use extracellular electron donors and acceptors for energy metabolism, a phenomenon broadly known as extracellular electron transfer (EET). One such EET mechanism that has been especially well-studied is the transmembrane electron conduit MtrCAB, which transmits electrons derived from metabolic activity to electron acceptors, like Fe(III) and Mn(IV) oxides, outside the cell. However, the overwhelming majority of our understanding on MtrCAB-mediated EET is based on studies done in Shewanella oneidensis MR-1, and recent investigations in an Aeromonas and Vibrio species have revealed that the S. oneidensis MtrCAB is not as representative as previously thought. This begs the question of how widespread the capacity for MtrCAB-mediated EET is, the changes it has accrued in different lineages over time, and where these lineages persist today. We therefore employed a phylogenetic and comparative genomics approach to identify the species in which MtrCAB exists and how it has evolved. Not only did we find mtrCAB in the genomes of numerous diverse Bacteria from a wide range of environments, the patterns therein also strongly suggest that mtrCAB has been transmitted through several horizontal gene transfer events, each followed by modular diversification of both its core and accessory components. Our data point to an emerging story about the evolution of iron-oxidizing and -reducing metabolism, and with future functional characterization, can resolve how this mechanism may have co-evolved with Earth's redox landscape and inform biogeochemical models that implicate EET.

2:55 p.m.

Orphaned freshwater mussels collection reveals biogeography of sculptured species

Yu Kai Tan, Andy Tan Dick Yee, Ann C. Burke, and Ellen Thomas

The curation of old natural history collections can provide new material for scientific research. Wesleyan University (Middletown, CT) houses 'orphaned' natural history collections, including a freshwater mussel (Order: Unionoida) collection assembled in the 19th century. Several lots have been identified as syntypes, paratypes or topotypes received from collectors such as Charles Wheatley, Increase Lapham and Isaac Lea, who were well-known at the time. Such collections are of major interest for conservation biology as they were assembled before human impact caused ∼70% of North American mussel species to suffer population declines or extinctions. The collection had been neglected for >60 years, and was not well-documented, although many specimens had labels. We assigned current species names based on the Mussel Project Database (http://mussel-project.uwsp.edu/db/), and recovered metadata through archival research. We assigned new institutional collection numbers, imaged and digitized all lots to our Specify7 online relational database. We have documented 1794 specimens in 393 lots representing 153 species — 4 of which are extinct, and 28 of which are Critically-Endangered to Endangered. Our collections include almost half of the known North American species with the Tennessee-Cumberland and Ohioan regions well-represented. North America is the global diversity hotspot for freshwater mussels, with 302 of the known ∼800 species, but the driver of this diversity is unknown. Mussel larvae are obligate parasites of fish. We mapped the species-richness of mussels in North America, which conforms generally with fish diversity, with highest diversity occurring in the Tennessee-Cumberland region. Shell sculptures such as pustules and ridges, thought to be anti-scouring structures that secure mussels in their burrows, are defining characteristics of many morphological species. We created 3D scans of specimens using a structured-light Artec Space Spider scanner to reveal previously undocumented or debated subtle morphological traits including sulci, and collected absence/presence data of different sculpture types for each species. The percentage of sculpture-bearing species was mapped for each biofaunal province in North America. Our maps suggest the highest richness in sculpture-bearing species occurs in provinces with highest overall mussel species-richness, suggesting that shell sculpture as an anti-scouring functional morphology might have enabled adaptation to new habitats and driven diversification in the North American endemic subfamily, Ambleminae.

Posters

1. **Proterozoic atmospheric oxygen regulation by a microbial terrestrial biosphere**

Brian J. Beaty and Noah J. Planavsky

The stepwise pattern of Earth's atmospheric oxygenation is well-documented in the geochemical record, but the mechanisms that held atmospheric oxygen (pO_2) stable at low levels for over a billion years in the Proterozoic —and likewise those that held pO_2 close to present atmospheric level (PAL) for the most recent several hundred million years— remain unclear. Recent biogeochemical modelling suggests that severe nutrient limitation in the oceans may have throttled marine oxygenic photosynthesis for much of the Proterozoic, whereas a lack of such limits on land raises the possibility that terrestrial microbial mats may have contributed substantially to global O_2 production. However, the contribution of these mats toward oxygenation would have been negligible if their degradation consumed as much O_2 as they produced. Such a scenario is likely today given that most organic matter (OM) transported in continental drainages undergoes oxidation before reaching marine basins, but lower pO_2 in the Proterozoic would have suppressed oxidation rates, facilitating OM burial and the accumulation of terrestrially-sourced O_2 in the atmosphere. To test this idea, we estimate global O_2 production fluxes by land-based microbial mats in the Proterozoic, as well as O_2 consumption fluxes by heterotrophic bacteria. We model production as a function of soil moisture and temperature based on the physiology of modern mats. Alongside this, we are developing a rate law for microbial OM oxidation via experimental degradation of mats at low pO_2. We determine oxidation rates with optical sensors capable of measuring O_2 concentrations down to 10-3 PAL, near the theoretical lower limit for a persistently oxygenated atmosphere. Additionally, we determine organic carbon remineralization rates by simultaneous measurement of pH, dissolved inorganic carbon, and methane, allowing us to detect contributions from anaerobic respiration and incorporate substrate competition between aerobes and anaerobes in the final rate law. Combining the new rate law with estimated transport times in continental drainages will allow us to determine long-term burial fluxes of OM sourced from a microbial terrestrial biosphere, and consequently its contribution to atmospheric oxygenation. Future work on plant matter will test the idea that major shifts in the reactivity of terrestrial OM associated with the evolution of land plants shifted the upper limit for atmospheric oxygen accumulation across the Phanerozoic.

2. **Abundance and diversity of archaeal lipid cyclization genes in hot spring metagenomes**

Laura Blum, Daniel Colman, Eric Boyd, and William Leavitt

Thermoacidophilic Archaea are model organisms which allow us to understand how life thrives under the multiple extremes of high heat and low pH— conditions likely present on early Earth. Among the key adaptations to life in high heat and acid conditions, thermoacidophilic Archaea produce unique core tetraether isoprenoid membrane lipids, the glycerol dibiphytanyl glycerol tetraethers (GDGTs), and headgroups such as calditol. Within the hydrophobic core of each GDGT, up to eight cyclopentane rings (four per chain), are known to increase lipid packing and stability of the cell membrane under thermal stress. Previous work with thermoacidophiles demonstrated a correlation between ring abundance and temperature, acidity, as well as electron donor or acceptor availability. Analysis of microbial lipid composition within terrestrial hot springs has been used to show how environmental parameters such as pH and temperature correlate with the degree of lipid cyclization. However, our knowledge of the genes which compose the archaeal lipid biosynthesis pathway leading to cyclic GDGTs is incomplete. More recently, genes coding for ring synthesis enzymes (genes grsAB) were identified in the model thermoacidophile, Sulfolobus acidocaldarius. These ring synthase genes encode the metabolic capacity to generate cyclopentane-containing GDGTs (GDGT-1 through GDGT-8), making it possible to search for archaeal lipid cyclization potential in environmental metagenomes. Numerous metagenomic samples from terrestrial hot springs spanning a wide gradient in pH and temperature are available, and present an opportunity to study grs sequence diversity and abundance within well-characterized geochemical and ecological context. In this work, hot springs metagenomes will be searched for grs homologs using reference sequences from cultivated Archaea shown to synthesize cyclic GDGTs. The relationships of these gene sequences will be predicted using phylogenetics. Future work will aim to address whether the evolutionary history and abundance of grs sequences relates to the environmental conditions of hot springs.

3. **Multiple isotope signatures of ethylene produced by microorganisms**

Carter Boyd, William Leavitt, Alec Cobban, Beverly Chiu, and Jeemin Rhim

Vast swaths of the surface oceans are depleted in inorganic phosphorus. In these regions, aerobic bacteria break down organic phosphorus containing compounds to access C, N, and P, creating an important linkage in the global carbon and phosphorus cycles. These bacteria use the carbon-phosphorus (C-P) lyase enzyme to cleave carbon-phosphorus bonds in organic compounds like methylphosphonate (MPn), acting as emitters of the greenhouse gas methane (CH_4) with a characteristic stable carbon isotope fractionation factor (εMPn-CH_4) of 1.3‰ (Taenzer et al., 2020). In this novel research, I aim to characterize the carbon and hydrogen stable isotopic fractionation of a common marine bacteria, Pseudomonas stutzeri str. HI00D01, utilizing the same C-P lyase pathway to catabolize another common organic-P compound, 2-aminoethylphosphonate (2-AEP), releasing ethylene (C2H4) as a byproduct. Deuterium spiked media growth experiments were conducted in sealed serum bottles and the ethylene produced by P. stutzeri was harvested for C and H isotope analysis. Preliminary results suggest that the carbon isotope fractionation factor between substrate 2-AEP and product ethylene (ε2AEP-C_2H_4) is 3.60‰ (+/- error), which is substantially different from the carbon isotope fractionation factor for the catabolism of MPn via the C-P lyase enzyme, necessitating further refinement of this pathway's contribution to the global carbon budget. Careful study of microbial isotope fractionations can help us understand both the role of microbes in global geochemical cycling as well as the metabolic mechanisms underlying biochemical fractionation.

4. **Serpentinite-hosted Waters of the Coast Range Ophiolite Microbial Observatory (CROMO) wells**

Dawn Cardace

In August 2011, 8 groundwater monitoring wells were installed in ultramafic rocks of the Coast Range Ophiolite near Lower Lake, CA, as a NASA Astrobiology Institute project (Cardace et al., 2013). These wells have enabled repeated sampling and analysis of aqueous geochemistry in a shallow, hydrological flow regime sourced in serpentinites. The wells constitute the Coast Range Ophiolite Microbial Observatory (CROMO), plumbing groundwater percolating through a tectonic mélange of Jurassic-aged oceanic lithosphere. An array of geochemical trends and aqueous phase mixing histories are possible. Modeling of natural waters in this lithologic context generates Ca^{2+}-OH^- type to Mg^{2+}-$HCO3^-$ type product waters, some of which are gas-bearing and very high pH (up to 12+). CROMO groundwaters provide an exciting testbed for field, analytical, and experimental work tied to biogeochemical transformations in serpentinizing systems.

5. **An investigation into the feeding strategies of archaeocyaths through computational fluid dynamics (CFD)**

Max Chipman, Brandt M. Gibson, and Marc Laflamme

Archaeocyaths, the earliest calcifying animal reef builders, emerged and quickly dominated Early Cambrian (535-510Ma) reef ecosystems before rapidly declining, and nearly going extinct by the Middle Cambrian. The question of how archaeocyaths effectively gathered nutrients (fed) has been debated and has, in part, supported their interpretation as calcifying sponges. Previous studies have suggested that these organisms could have fed entirely through passive (or unaided) filter feeding, relying on external currents to circulate water through their skeletons. This differs from most modern sponges who use flagellated collar-cells (choanocytes) to actively pump water through their skeletons to feed. We use three-dimensional models, based on a variety of species and morphotypes, and computational fluid dynamics (CFD) to analyze the fluid flow through a range of archaeocyath body plans. These data are used to examine the functional significance of structural differences between species of Archaeocyatha. Our preliminary results suggest that a solely passive filter feeding lifestyle, as suggested in previous flume tank experiments, may have been unlikely, and that morphological differences within archaeocyathans may have represented morphological adaptations to different flow conditions.

6. **Chemostratigraphy and facies analysis of the Limbunya Group, Birrindudu Basin, Northern Territory – Australia**

Angelo dos Santos, Marcus Kunzmann, Teegan Ojala, Pascale Daoust, and Galen Halverson

The Greater McArthur Basin preserves Paleo- to Mesoproterozoic strata deposited in a series of broadly correlative basins in northern Australia, consisting of the South Nicholson, the Fitzmaurice, McArthur, and Birrindudu basins. The Birrindudu and the McArthur basins are geographically separated by hundreds of kilometers, and they have been tentatively correlated based mainly on general lithological similarities and limited geochronology. The McArthur Basin has attracted attention from an economic perspective due to world-class Zn-Pb deposits and key petroleum plays. Thus, the identification of stratigraphically related units elsewhere is of economic interest and may clarify the tectonic-stratigraphic framework of the Greater McArthur Basin. However, relatively little is known about the architecture and geodynamic evolution of the western portion of the basin-system, the Birrindudu Basin. The Limbunya Group of the Birrindudu Basin consists of 1300m of cyclic mixed siliciclastic and carbonate strata. We examined two drill cores covering 700m of stratigraphy of the Limbunya Group, comprising mixed siliciclastic carbonate rocks, mainly dolomitic, with interbedded siltstone and mudstone, and less extensive sandstones and intraclast conglomerate. We defined eleven lithofacies grouped in three facies associations: coastal-continental, intertidal, and deep subtidal. Chemostratigraphy reveals that carbon isotope values, $\delta^{13}C_{carb}$, gradually increase throughout the upper portion of the Limbunya Group from ca. -3 ‰ to ca. -1‰, while in the lower portion values fluctuate around ca. -1‰. The carbon isotope profile generally does not correspond to major shifts in the facies associations. Although an important pattern is noted at the onset of the Fraynes Formation that can be related to the Barney Creek Formation on the McArthur Basin. Combining facies analysis and $\delta^{13}C_{carb}$ profile we aim to propose basin-wide and cross-basin correlations. We plan to test these correlations for the Greater McArthur basin through applicant of U-Pb zircon geochronology to tuff beds interspersed through the upper Limbunya Group.

7. **Rodinia Supercontinent Reconstruction Model**

David A.D. Evans

Rodinia is the purported supercontinent that existed in early Neoproterozoic time. Most currently viable Rodinia models, i.e., consistent with both the geological/geochemical record and geophysical constraints from paleomagnetism and reasonable plate kinematics, include Laurentia in a central position, flanked on nearly all sides by about 6-8 other cratons. Details of the history of Rodinia formation depend critically on the ages of orogens within those bounding cratons, some of which might have closed as late as ∼900 Ma. Rodinia's initial breakup likely coincided with voluminous large igneous province emplacement at ∼800 Ma, lasting until final separations as young as ∼600 Ma. The Rodinian-era paleomagnetic database of reliable poles is growing steadily, but still requires augmentation for most cratons. Enough poles are available in key intervals (especially ca. 1110 and 760 Ma) that kinematic models can be constructed that plausibly evolve toward better-established Paleozoic reconstructions. A new synthesis-based model of Rodinia assembly and breakup is briefly introduced herein, which includes Tarim craton in a "missing link" role between Laurentia and proto-Australia, as well as South China and India in their recently proposed inverted orientation near the supercontinent's southern paleo-margin.

8. **Cryptic terrestrial fungus-like fossils of the early Ediacaran Period**

Tian Gan, Taiyi Luo, Ke Pang*, Chuanming Zhou, Guanghong Zhou, Bin Wan, Gang Li, Qiru Yi, Andrew D. Czaja, and Shuhai Xiao**

The colonization of land by fungi had a significant impact on the terrestrial ecosystem and biogeochemical cycles on Earth surface systems. Although fungi may have diverged ∼1500–900 million years ago (Ma) or even as early as 2400 Ma, it is uncertain when fungi first colonized the land. Here we report pyritized fungus-like microfossils preserved in the basal Ediacaran Doushantuo Formation (∼635 Ma) in South China. These microorganisms colonized and were preserved in cryptic karstic cavities formed via meteoric water dissolution related to deglacial isostatic rebound after the terminal Cryogenian snowball Earth event. They are interpreted as eukaryotes and probable fungi, thus providing direct fossil evidence for the colonization of land by fungi and offering a key constraint on fungal terrestrialization.

9. **Biosulfidogenesis mediates in situ remediation of extreme acidity and metal concentrations in acidic mine pit lakes**

C.M. van der Graaf, J. Sánchez-España, I. Yusta, A. Ilin, S. A. Shetty, Nicole J. Bale, Laura Villanueva, A.J.M. Stams, and I. Sánchez-Andrea

Acidic mine pit lakes (APL) are abandoned open pit mines filled with acid mine drainage (AMD), waters with extreme acidity and metal concentrations. Physicochemical profiles of two APLs in the Iberian Pyrite Belt of Spain, Filón Centro (FC) and La Zarza (LZ), indicated the natural attenuation of acidity and metal concentrations in the water column, which was most pronounced in the monimolimnion. We hypothesized that this was the result of microbial sulfide (H_2S) production (biosulfidogenesis): biosulfidogenesis would enable removal of metals by precipitation as metal sulfides, and an increase of pH through the consumption of protons required for sulfate reduction at low pH. We investigated this hypothesis through combined physicochemical and microbiological characterization of the water column. Depth profiles showed that FC and LZ are both meromictic, stratified lakes, which can be classified as oligotrophic based on their nitrogen and phosphorus content. The attenuation of acidity along the water column was most pronounced in FC, ranging from pH 1.9 in the mixolimnion, to pH 4.8 in the monimolimnion. In FC, copper and zinc sulfides were detected in the monimolimnion, indicating sulfidogenesis in the water column. This was further supported by microbial community analysis: microbial taxa with known sulfidogenic metabolism were detected in both FC and LZ. In the monimolimnion of FC, the putative SRB genus Desulfomonile represented $58.5 \pm 3.5\%$ of bacterial reads, whereas in the more acidic and metal-enriched LZ, putative elemental sulfur (S0)-reducing Acidianus and Thermoplasma spp., and S0-disproportionating Desulfocapsa spp. were more abundant. Notably, the detection of reads classified as the SRB genus Desulfosporosinus spp. ($4.4 \pm 6.0\%$) in the lower layer of LZ represents one of the lowest pH values (2.9) at which this genus has been reported so far. The detection of S80-reducing and -disproportionating taxa in LZ, compared to SRB in FC, where pH alkalinization has progressed further than in LZ, suggests that reductive S80 metabolism precedes sulfate reduction in the natural attenuation of these lakes. Our results provide more insight into the role of reductive microbial sulfur metabolism in the physicochemical development of APLs. Furthermore, SRB thriving in the extremely acidic, metal-rich water column of APLs are potentially more resistant to extreme conditions compared to SRB found in AMD sediments, making them of great interest for the application in bioremediation technologies.

10. **Quantitative Correlation of Large Igneous Provinces and Phanerozoic Extinctions**

Theodore Green and C. Brenhin Keller

Large Igneous Provinces (LIPs) have long been qualitatively linked with Phanerozoic mass extinctions. Here we quantitatively evaluate this correlation and expand it to include the periods of faunal turnover that define Phanerozoic stage boundaries. Both at the six mass extinctions and across all Phanerozoic stage boundaries, we find a significantly greater than chance relationship between the timing of continental LIP eruptions and periods of faunal turnover. This suggests a causal relationship between continental LIP eruption and biotic crises. We also define a rate threshold that separates continental LIPs known to

correlate with mass extinctions from those with less deadly effects. In contrast to continental LIPs, oceanic LIPs are less well correlated with mass extinction, with lower extinction percentages than would be expected to result from a continental LIP of similar eruption rate. We propose that this discrepancy may result in part from diminished degassing of volatiles including CO_2, SO_2, Cl, and F in submarine LIPs. Though other mass extinction drivers have been proposed, most notably the Chicxulub impactor at the K-Pg, our results suggest volatile emissions from continental LIPs as a major kill mechanism in Phanerozoic biotic crises, including at the big six mass extinctions.

11. **Incorporating the Thule Supergroup into the evolving tectonstratigraphic framework of the late Mesoproterozoic Bylot basins**

J. Wilder Greenman, Angelo D. dos Santos Junior, Mollie Patzke, Alessandro Ielpi, and Galen P. Halverson

Intracratonic basins preserved in the Canadian Arctic have long been recognized for their tectonostratigraphic importance in reconstructing arctic Laurentia through the amalgamation and breakup of the supercontinent Rodinia. The Bylot basins in northeastern Canada (Borden, Fury and Hecla, Hunting and Aston) and northwestern Greenland (Thule) were long considered to have initiated coeval with the emplacement of the Mackenzie Large Igneous province ca. 1270 Ma due to the occurrence of mafic flows and sills at the base of the basin fill. However, recent dating of shales in these basins suggests both that the bulk of Bylot strata is ca. 1100–1050 Ma and that a long-duration (>200 m.y.) unconformity must exist between lower volcanic flow-bearing strata and middle shale- and carbonate-rich strata. The updated chronological framework for the Bylot basins demonstrates that they are broadly coeval with the Midcontinent Rift and implies a connection between their evolution and collisional tectonics and mantle dynamics related to the Grenville orogeny. This new chronology is also important because Bylot basin strata contain important fossils and chemostratigraphic archives that record diversification of early eukaryotes and a transition towards a more oxygenated Earth surface environment. Recent field mapping and geochronology in the Fury and Hecla and Thule basins reinforce tectonostratigraphic similarities with the better studied Borden Basin and provide the opportunity to further refine models for the evolution and tectonic significance of the Bylot basins. We integrate previously published data and new observations to develop a refined tectonostratigraphic model consistent with available geochronological and stratigraphic constraints in all of these basins.

12. **New insights on redox conditions during the Cambrian SPICE Event, western Newfoundland, Canada**

Amy Hagen, David S. Jones, David A. Fike, Nicholas J. Tosca, and Sara B. Pruss

The later Cambrian SPICE (Steptoean Positive Isotopic Carbon Excursion) event was a global change in carbon isotope values coeval with a regional shift in sea level at the Sauk II-III boundary and a rapid turnover of trilobites. Despite the many documented examples of the SPICE event globally, the mechanisms for the excursion and related environmental changes remain unconfirmed. Our study has focused on an outcrop of the SPICE in the Port au Port Group, a mixed carbonate and siliciclastic succession located along the southern shore of the Port au Port Peninsula in western Newfoundland. Geochemical analysis of this section has revealed that small mercury enrichments are associated with the carbon isotope excursion. Both initial mercury concentration measurements and mercury to total organic carbon ratios show slightly elevated mercury concentrations surrounding the SPICE but a return to baseline during the excursion. Normalization of mercury concentrations to total clay mineral abundance (from XRD analyses) yields a similar pattern as previous data, suggesting that mercury enrichments occur independently of TOC and clay fluctuations. Further, XRD analyses have detected glauconite as well as trace amounts of berthierine/chamosite, indicating potentially complex redox conditions throughout the SPICE event. These findings are comparable to those from a SPICE section in Scotland, supporting the hypothesis that mercury may act as a local redox indicator.

13. **Hydrogen isotope fractionation during lipid biosynthesis by Sulfolobus acidocaldarius**

Carolynn Harris, Yujiao Zhang, Sebastian Kopf, Felix Elling, Yuki Weber, Ann Pearson, and William Leavitt

Archaea produce ether-bound lipids that can be well-preserved over thousands to millions of years. These lipids are gaining attention as biomarkers because of their potential to record past biogeochemical conditions. For example, the hydrogen isotopic composition (δD) of archaeal lipid biomarkers may encode current and past environmental information just as the δD of leaf wax has been shown to reflect the δD of growth water, and thus indicates local hydrology. Our ability to interpret the H-isotopic composition of archaeal lipid biomarkers is limited because the vast majority of experiment work on lipid H isotopes has been conducted on bacteria and eukaryotes. To address the lack of archaeal studies, we examined controls on hydrogen isotope fractionation during lipid biosynthesis in pure culture experiments utilizing the model thermoacidophile, Sulfolobus acidocaldarius. In these experiments we varied the H isotope composition of the growth water and of the electron donor and carbon source (glucose). Preliminary results show that biphytane δD is strongly correlated with the δD of water in all cultures. Cultures grown on D-labeled glucose produced biphytanes that were more D-enriched relative to cultures grown on unlabeled glucose. These results indicate that $\delta D_{\mathrm{water}}$ and $\delta D_{\mathrm{substrate}}$ influence the δD of biphytanes to different degrees. Avenues for future work include (1) conducting the same suite of experiments on S. acidocaldarius grown in a chemically defined medium to better constrain lipid synthesis pathways, and (2) conducting similar experiments on other model archaeal systems that thrive in different environmental conditions, including halophiles and psychrophiles. It is important to examine archaea adapted to different environments because they produce different suites of lipids and may utilize different lipid synthesis pathways. Ultimately, these experiments will help develop an interpretive framework for archaeal lipids as proxies for environmental conditions in modern and ancient systems.

14. **Modeling Near-Surface Serpentinizing Systems on Mars Using Meteorite Protoliths as Subsurface Analogs**

Roger Hart and Dawn Cardace

Mars possibly hosts habitable microenvironments hosted in Fe and Mg-rich rock units in the near-subsurface. Meteorites known to be from Mars (SNC) show distinct rock-water reaction paths when modeled using Geochemist's Workbench ver 12.0. Meteorite compositions (ALH 77005, Nahkla, Chassigny, and SNC mean) reacted with 6 putative Mars groundwaters at both 273K and 373K, under constant pressure and temperature conditions were completed in this study. The plausible Martian groundwater systems $NaClO_4$, $Mg(ClO_4)_2$, $Ca(ClO_4)_2$, $Mg(ClO_4)_2$, Mg-$Na_2(ClO_4)_2$, Ca-$Na_2(ClO_4)_2$, Mg-$Ca(ClO_4)_2$ (Toner et al., 2015), the terrestrial analog Death Valley waters (Lowenstein and Risacher, 2008), Mars wet chemistry experiments from Rosy Red, a Phoenix lander site (Toner et al., 2014) served as the initial starting fluids with present day Martian atmospheric physicochemical properties. Here, we contrast the mineral, gas, and aqueous products of these reactions, showing different habitable niches emerge in different protoliths. We take the habitable niche to be a composite, controlled by thermodynamic stability of co-existing minerals and solutions; each geochemical-mineralogical assemblage constrains the habitability of pore spaces in a fundamental sense. Minerals common to all meteorite alteration reaction paths include phyllosilicates such as serpentine polymorphs and saponite clays. Magnetite was also produced with the initial Chassigny protolith across reaction paths and was not produced in abundance in other protoliths. Gaseous species evolution varied across reaction progress between aqueous simulations. Across all simulation paths, the initial Chassigny protolith resulted in the greatest fugacity value for H_2 (g). The initial aqueous solutions evolved across the reaction path and resulted in many cases to deviate from the initial starting condition major ion chemistry. Important differences in these mineral, aqueous, and gaseous species show that the Martian near subsurface (and perhaps deeper subsurface) have varying habitability, as many of these co-occurring mineralogies and aqueous species on terrestrial analog sites have geobiological potential utilized mainly by chemolithoautotroph organisms. Future work will clarify where bioenergetic yields for possible metabolic reactions drop to negligible, and where substantial, sustained bioenergetic drive persists.

15. **Changing Relationships Between Mercury and Host Phase Indicators in the Road River Group**

Peter Kannam, Akshay Mehra, and Justin Strauss

The rise of the use of sedimentary mercury (Hg) as a geochemical proxy for ancient volcanism has led to an increased scrutiny over the interpretation of concentrations found in the global sedimentary record. Most Hg studies follow the dominant logic that sedimentary Hg is hosted by organic matter, and therefore normalize to Hg concentrations to total organic carbon concentrations (TOC). Recent studies have found examples of Hg hosted in sulfide and clay minerals and note the importance of statistically determining, using Pearson Correlation coefficients or multiple linear regression, a host phase before normalizing Hg and interoperating the results. However, these studies rely on datasets that are limited in both sample number and stratigraphic range meaning their determining statistics may not hold if used with a larger sample size and their ability to account for changing relationships between Hg and potential host phases is restricted. This study builds on the statistical methods of previous studies of Hg host phases by using them in tandem with window sampling on the 2,470 m (n= 776) late Cambrian to middle Devonian deep water stratigraphic section of the Road River Group in Yukon, Canada. While the basic statistics of previous studies fail to determine a definite host phase, when they are used with window sampling, they indicate the relationships between Hg and potential host phases vary greatly over the Road River Group despite relatively unchanging environment. These findings, while preliminary, call into question the assumption of consistent host phase that many Hg studies rely on when comparing Hg concentrations from different locations or interoperating the peaks of normalized Hg concentrations as markers for ancient volcanism.

16. **Ironstones of Yukon: insights into marine iron cycling in the early Neoproterozoic**

Maxwell Lechte, Galen Halverson, Malcolm Wallace, Timothy Gibson, Ashleigh Hood, Changle Wang, Noah Planavsky, Alexie Millikin, Katie Maloney, and Kelsey Lamothe

The early Neoproterozoic Tonian Period (1000–720 Ma) witnessed the rise of eukaryote-dominated ecosystems. This transformation of the biosphere may have resulted from changes in global biogeochemical cycles, yet the cause-and-effect relationship between these processes remain contentious. This is due, in part, to a paucity of paleoenvironmental information from Tonian strata. Iron-rich chemical sediments deposited in shallow marine settings, known as ironstones, may be important tracers of ancient surface conditions. Typically characterised by the presence of concentrically coated grains ('ooids') composed of iron oxides and/or ferrous iron silicates, ironstones can potentially offer valuable insights into the redox conditions of shallow seawater and porewaters. However, the use of ironstone geochemistry as a paleoredox proxy is limited due to conflicting interpretations regarding the genesis of these enigmatic deposits. Here we describe ca. 850 Ma ironstones from the Katherine Group (Yukon), the first described example of an ironstone from the Tonian Period. These ironstones are hosted by quartz arenites and siltstones of the Katherine Group, interpreted to have been deposited in a peritidal setting characterised by migrating sandbars. The Katherine ironstones are well-preserved and feature complex coated grains with concentric interlaminations of hematite and berthierine. Iron isotope evidence indicates that the hematite is the product of partial oxidation of ferrous iron. We suggest that these ironstones formed by the variable precipitation of iron oxyhydroxides and authigenic berthierine precursor gels from ferruginous seawater near a redox boundary between suboxic and anoxic conditions, with vigorous iron cycling. Ferruginous conditions and partial iron oxidation in shallow seawater likely require very low atmospheric oxygen levels during the middle Tonian, which may have exerted an environmental control on organismal physiology and ecological complexity during this time.

17. **Constraints on atmospheric O_2 and biological productivity during the Mid-Proterozoic from a photochemical model of atmospheric oxygen isotope cycling**

Peng Liu, Jingjun Liu, Aoshuang Ji, Christopher T. Reinhard, Noah J. Planavsky, Dmitri Babikov, Raymond G. Najjar, and James F. Kasting

Reconstructing the history of biological productivity and atmospheric oxygen partial pressure (pO_2) is a fundamental goal of geobiology. Recently, mass-independent fractionation of oxygen isotopes (O-MIF) has been used as a tool for estimating pO_2 and productivity during the Proterozoic. O-MIF, reported as δ17O, is produced during the formation of ozone and destroyed by isotopic exchange with water by biological and chemical processes. Atmospheric O-MIF can be preserved in the geologic record when pyrite (FeS_2) is oxidized during weathering and the sulfur is redeposited as sulfate. Here, sedimentary sulfates from the ~1.4 Ga Sibley Formation are reanalyzed using a detailed one-dimensional photochemical model that includes physical constraints on air-sea gas exchange. Previous analyses of these data concluded that pO_2 at that time was <1% PAL (times the Present Atmospheric Level). Our model shows that the upper limit on pO_2 is essentially unconstrained by these data. Indeed, pO_2 levels below 1% PAL are possible only if the Sibley O-MIF data were diluted by reprocessing before the sulfates were deposited. Our model also shows that, contrary to previous assertions, marine productivity cannot be reliably constrained by the O-MIF data because exchange of O_2 between the atmosphere and surface ocean is controlled more by air-sea gas transfer rates than by biological productivity. Improved estimates of pCO_2 and/or improved proxies for δ17O of atmospheric O_2 would allow tighter constraints to be placed on Mid-Proterozoic pO_2.

18. **Recent developments in the paleobiology and taphonomy of trilobites from the Walcott-Rust Quarry (Upper Ordovician)**

Sarah R. Losso and Javier Ortega-Hernández

Trilobites are the dominant group of macroscopic euarthropods throughout the Paleozoic, and are known primarily from their biomineralized dorsal exoskeletons. Despite their impressive diversity (ca. over 20,000 described species) the appendicular ventral anatomy of trilobites is only known from 31 taxa, most of which consist of highly compressed macrofossils. In 1879, Charles Doolittle Walcott reported the preservation of trilobite appendages preserved in 3D from the Spillway Member (Rust Formation; Trenton Group) in Herkimer County, New York. Over 280 thin-sections from this site are housed at the Museum of Comparative Zoology at Harvard, most of which belong to the phacopids Cerausus pleurexanthemus and Flexicalymene senaria. Walcott-Rust trilobites show that non-biomineralized tissues are exceptionally preserved by an isopachous rim of fibrous calcite perpendicular to the exoskeleton, and sparry calcite crystals that completely fill the void formed by the body. The occurrence of calcite had previously been attributed to a microenvironment created during decay (Brett et al., 1999). This peculiar mode of calcite preservation captures exceptional detail, including delicate structures such as exopod lamellae and endopod endites. However, the precise appendicular morphology of C. pleurexanthemus and F. senaria has been controversial given the difficulty of interpreting the preserved anatomy from obliquely-cut thin sections. Here, we provide an updated account of the work on this iconic locality, focusing on the taphonomy of non-biomineralized tissue preservation, distribution of calcite preservation within the Rust Formation, and trilobite limb morphology. Extensive restudy of the thin-sections shows that calcite occurs in veins and nodules throughout the matrix, and are not isolated within the fossil specimens. Whereas all previous findings of calcite preservation were from Layer 3 in Spillway Member, new discoveries demonstrate a stratigraphically wider distribution. Comparisons of thin-sections with computed tomographic scans of partially enrolled trilobite specimens allow to better understand the orientation of the thin sections, and facilitate making precise morphological interpretations. Future work will characterize the taphonomic pathway through use of elemental and isotopic analysis, compare the calcite preservation of Walcott Rust with that of the Silurian Herefordshire Biota in England, and reconstruct the 3D limb morphology of C. pleurexanthemus and F. senaria. The Walcott-Rust specimens provide a unique opportunity to study exceptional 3D preservation of animal soft tissues during the Ordovician.

19. **A Ca and Mg isotope record for a diverse set of late Tonian carbonate platforms**

Scott MacLennan and Peter Crockford

The late Tonian (ca. 815 to 715 Ma) is a critical time period in Earth history in terms of biological innovation and extreme climate change leading into the Cryogenian. The carbon isotope record, as preserved in shallow water carbonates across this interval, is broadly characterized by a ca. +5 ‰δ^{13}C "background". Interrupting this background are long (ca. 10 Ma) and short (ca. ¡1 Ma) lived carbon isotope excursions that reach ca. -10 ‰d13C. These isotopic trends have traditionally been interpreted as a reflection of changes in organic carbon burial on a global scale and have been important chronostratigraphic markers in the Precambrian where the only available temporal constraints are radiometric. Observations of modern carbonate platforms and non-traditional stable isotope studies of Neoproterozoic carbonates have challenged this canonical view and motivate consideration of local processes as potentially driving such variation. In order to better understand the carbon isotope record from this period of time we present Mg and Ca stable isotope measurements from a globally distributed sample set (N = 600) to help determine the original mineralogy and diagenetic history of Tonian carbonate platforms and whether they can be considered faithful recorders of global carbon cycle dynamics.

20. **Dense Archaeocyathid branching and habitat engineering during the Cambrian Explosion**

Ryan A. Manzuk and Adam C. Maloof

The major pulses of animal originations during the Lower Cambrian coincide with the rise of Earth's first animal-built framework reefs. Given the importance of Scleractinian coral reefs as facilitators of biodiversity in modern oceans, we are investigating Archaeocyathid reefs as potential drivers of the Cambrian Explosion of animal biodiversity. In this study, we present high-resolution, three-dimensional reconstructions of branching Archaeocyathid individuals from three localities on the Laurentian paleocontinent. In addition to highlighting a previously unrecognized prevalence of branching frameworks in the Lower Cambrian, these models provide an opportunity to make one-of-a-kind 3D measurements such as branching angle, branch inclination, and diameter. When compared to analagous measurements made of modern Acroporid corals, these data demonstrate the ability of Archaeocyathid sponges to withstand and manipulate the flow of water, as well as build topographically complex and stable structures. Through these basic functions, modern coral reefs facilitate the majority of biodiversity in today's oceans. We pair our models and measurements with high-resolution mapping of each reef in the field based upon drone-derived ortho-photographs and elevation models, as well as a dGPS-constrained observations and sample grids. Through quantitative image analysis of a thin section from each sampled point, we are able to constrain lithology and biodiversity trends on each reef spanning both space and time. Analyzing these reef-scale patterns in concert with the 3D morphology of Archaeocyathids, we identify the potential influence of reef construction on Lower Cambrian ecology and evolution.

21. **Unusual taphonomy and description of a new ophiuroid genus and species from the Lower Triassic Virgin Limestone Member, Moenkopi Formation, western United States**

Vivienne Maxwell, Ben Thuy, and Sara B. Pruss

Recent work on samples of the Lower Triassic Virgin Limestone Member of the Moenkopi Formation has yielded small fossils preserved by apatite and glauconite. These fossils preserve minute versions of several familiar organisms from macrofossil assemblages, with the exception of a few new occurrences. One such occurrence is a new genus and species of ophiuroid from a single fossiliferous packstone collected at the Lost Cabin Springs locality in Nevada, US. The ophiuroid fragments were incredibly abundant within the >250 µm fraction of sample LC-18-34 (∼70 elements in 10 g of dissolved material) and include all major parts of the ophiuroid skeleton: lateral and ventral arm plates, vertebrae, radial shields, oral and genital plates. A morphology-based Bayesian phylogenetic analysis places the new ophiuroid at the base of the Ophintegrida, one of the two extant superorders of ophiuroids, suggesting a pivotal position in the early evolution of the living clades following the end-Permian mass extinction. Energy-dispersive X-ray spectra (EDS) of the fragments indicate the ophiuroid fossils were preserved by apatite. Most echinoderm fossils are preserved as low magnesium calcite or more rarely dolomitized or silicified. Phosphatization is an uncommon mode of preservation for the echinoderm fossil record and appears quite rare for ophiuroid fossils in particular.

22. **Mercury content and stable isotope data as a tool for stratigraphic correlation and environmental interpretation: A case study of Ediacaran black shales of the Doushantuo Formation, South China**

Morrison Nolan, Shuhai Xiao, Benjamin Gill, Rachel Reid, Zhou, David Jones, Anwen Zhou, Jiubin Chen, Wang Zheng, and Swapan Sahoo

Key environmental changes and evolutionary events during the Ediacaran Period set the stage for the Cambrian radiation (e.g., Wood et al., 2019). The Doushantuo Formation of South China hosts an important record of the fossil and geochemical history of these events (e.g., McFadden, et al., 2008). Proper interpretation of this record requires stratigraphic correlation among disparate sections of the Doushantuo Formation, especially with regards to black shale units associated with the formation. The Member IV black shale at the top of some Duoshantuo sections in the Huangling Anticline has been stratigraphically correlated to either (1) the Lower Black Shale, Upper Dolostone, and Miaohe Member black shale sequence in other sections or (2) just the Lower Black Shale, meaning the Upper Dolostone and Miaohe Member correlate to the younger Dengying Formation (An et al., 2015). These competing correlations greatly impact the interpretation of the age and duration of major geochemical events in the Doushantuo Formation (Zhou et al., 2017). We intend to resolve these correlations by supplementing existing lithostratigraphic and carbon isotope chemostratigraphic data with mercury (Hg) content and isotopic composition to test these correlations and to provide insights into environmental conditions such as chemical weathering and redox conditions (e.g., Selin, 2009; Grasby et al., 2019). Hg has strong affinity with organic matter and sulfides and is thus often enriched in black shales. In each of the seven sections of the Doushantuo Formation we measured, we identified at least one stratigraphic horizon with elevated Hg concentration in the Miaohe Member and the upper Member IV, along with a horizon of elevated Hg concentration in the lower Member IV and the Lower Black Shale; these results are consistent with the traditional stratigraphic interpretation of the member IV to the Lower Black Shale through Miaohe Member sequence. This pattern persists when Hg concentration is normalized by total organic carbon content to account for differential sedimentation rates. Additionally, Hg isotope ratios in the most complete Doushantuo section at Jiulongwan, when supplemented with other recently published Doushantuo Hg isotope data, imply changing sediment input and environmental conditions including redox conditions in the black shale intervals.

23. **Vanadium isotope evidence for expansive ocean euxinia during the appearance of early Ediacaran biota**

Chadlin M. Ostrander, Haifeng Fan, Maureen Auro, Hanjie Wen, and Sune G. Nielsen

For reasons that remain unclear, the initial appearance of large, morphologically complex life on Earth seems to have taken place in deep-marine environments. We provide new perspective on this topic by applying a new and novel heavy metal isotope paleoredox proxy: vanadium (V) isotopes. We use shales in two different sections that preserve Doushantuo Member IV (South China) to reconstruct a global seawater V isotope composition ($\delta 51V = \sim -0.23 \pm 0.06‰$) during the late-Ediacaran (∼567 to 560 million years ago) that is much lighter than today. A mass-balance model informed by this composition is only reconciled by a global ocean in which hydrogen sulfide-rich (i.e., "euxinic") conditions were commonly present on continental shelves. In this presentation, I will discuss the negative impact that euxinic conditions could have had on early Ediacaran biota. I will also discuss how some plausible drivers of widespread euxinia (e.g., increased surface temperatures) could have further negatively impacted these biota – especially those that inhabited settings closer to shore.

24. **Cooling of the deep North Atlantic Ocean across the Cenozoic greenhouse-icehouse transition**

Alison Piasecki, Victoria Taylor, Steven Bohaty, Paul Wilson, and Nele Meckler

Approximately 34 million years ago (Ma), Earth abruptly transitioned from the warm largely unglaciated climate state of the early Paleogene to conditions sufficiently cool to sustain large dynamic ice sheets on Antarctica. Oxygen isotope records from deep-sea benthic foraminifera provide the backbone of information on this pivot point in Cenozoic climate history, but further progress is hindered by the ongoing challenge to deconvolve the ice volume and temperature signals embedded in records that span the transition. Here we report the first independent record of deep-sea temperature for the late Eocene to early Oligocene using clumped isotope thermometry on benthic foraminifera from the Newfoundland margin in the Northwest Atlantic Ocean. We document an overall 3-4°C cooling in the deep North Atlantic Ocean between the late Eocene and early Oligocene subepochs. In detail, we observe a ∼2°C cooling associated with the establishment of a large Antarctic Ice Sheet followed by a further transient ∼3°C cooling and freshening event within the early Oligocene (centered around 33.4 Ma). We attribute the transient cooling event to reorganisation of deep water mass structure, with important implications for global climate, heat redistribution, and the stability of the early ice sheet. Our study provides quantitative constraints on temperature change in the deep ocean across the most pivotal event in Cenozoic climate history and helps to pave the way for a detailed deconvolution of the benthic foraminiferal δ^{18}O record for temperature, salinity, and ice volume.

25. **Experimental investigation of factors controlling the hydrogen isotope composition of archaeal lipids: building the interpretative framework for a potential paleoenvironmental proxy**

Jeemin H. Rhim, Sebastian Kopf, and William D. Leavitt

Hydrogen (H) plays a crucial role in most metabolic processes and is incorporated into biological molecules, often with distinct isotope fractionation patterns. Among different biomolecules, lipid membranes of microbes are of particular interest for biogeochemists because H in lipid-bound hydrocarbons can remain isotopically stable over geologically relevant time scales (from 10,000 to a billion years). The mechanistic understanding of H isotope dynamics in microbial lipids can be gained from controlled laboratory experiments and provide an interpretative framework for the H isotope compositions of biomolecules preserved in both modern and ancient environmental systems. While extensive studies have been conducted on the H isotope compositions of bacterial lipids, little work has been done for the archaeal domain of life. This study aims to investigate the H isotope compositions of archaeal lipids by conducting laboratory experiments under a range of experimental conditions and archaeal representatives with different central metabolisms. The effect of energy availability will be tested by growing a pure culture of Archaeoglobus fulgidus on lactate and different electron donors with a range of redox potentials (lactate/sulfate, ΔG0 = –595 kJ/mol; lactate/thiosulfate, ΔG_0 = –635 kJ/mol; and lactate/perchlorate, ΔG_0 = –990 kJ/mol at 85 °C). In addition, A. fulgidus is a facultative autotroph and will be grown autotrophically on H_2/CO_2 (ΔG_0 = –326 kJ/mol) and heterotrophically on lactate (ΔG_0 = –635 kJ/mol), both with thiosulfate, in order to investigate the effect of carbon metabolism on the H isotope composition of its lipids. All experiments will be done with varying H isotope compositions of growth media to apportion the relative contributions of H from three different sources—protons in water, hydride carrier molecules and organic substrates—to the final lipid products. We anticipate that the results of these experiments will help us elucidate the relative importance of environmental and physiological factors and aseess the potential application of the H isotope composition of archaeal lipids as paleoenvironmental proxies.

26. **Skeletal Abundance in the Lower Ordovician Catoche Formation, western Newfoundland, Canada**

Ashley Rivas, David S. Jones, and Sara B. Pruss

The Ordovician Radiation is known for a significant increase in preserved skeletal abundance in many localities, yet the progression of this evolutionary change throughout the Lower Ordovician is unconstrained in western Newfoundland. We examined Lower Ordovician sedimentary rocks from the Catoche Formation, Western Newfoundland, Canada, to quantify skeletal abundance and identify depositional environment(s) which may have influenced temporal changes in abundance. The first ∼40 meters of the succession has a low skeletal abundance of 3% fossils including those unclassified where echinoderms make up 0.20% of the major fossils, gastropods/cephalopods make up 0.90%, and brachiopods make up 0.30%. Although the first few meters of the Catoche Formation are characterized by abundant peloidal sediment, the overlying succession contains an abundance of flat-pebble conglomerates, demonstrating the common occurrence of storms at the locality. Additional environmental information may lead to more findings about the environmental influences or triggers in skeletal evolution during the period leading up to the Ordovician Radiation (Middle Ordovician). Our continuing work seeks to understand the occurrence of skeletal biomass during the Lower Ordovician and how this applies to other successions at different localities to possibly determine larger spatial and temporal trends.

27. **An Early Miocene extinction in pelagic sharks**

Elizabeth C. Sibert and Leah D. Rubin

Sharks populations have been decimated in recent decades due to over-fishing and other anthropogenic stressors, however the long-term impacts of such changes in marine predator abundance and diversity are poorly constrained. We present evidence for a previously unknown major extinction event in sharks that occurred in the Early Miocene, approximately 19 million years ago (Ma). During this interval, sharks virtually disappeared from open-ocean sediments, declining in abundance by >90%, and morphological diversity by >70%, an event from which they never recovered. This extinction occurred independently from any known global climate event, and ∼2-5 million years prior to diversifications in the highly migratory, large-bodied predators that dominate today, indicating that the Early Miocene was a formative period of rapid, transformative change for open ocean ecosystems.

28. **An ultra-high spatial resolution multi-spectral macro-imager for geological samples**

Devdigvijay Singh, Ryan Manzuk, Akshay Mehra, and Adam Maloof

Feature detection in optical imagery relies on color and textural differences between objects of interest and their surroundings. For fifty years, satellite remote sensing has leveraged multispectral imaging, combining information in visible, near infrared, and shortwave infrared channels to better differentiate features such as vegetation or rock types. However, there is a trade-off between spectral and spatial resolution, where higher spectral resolution requires larger pixels that can gather enough light from narrow wavelength bands. Furthermore, at short focal distances, chromatic aberration makes it difficult to capture focused images simultaneously at multiple wavelengths. We describe a new multispectral macro-photography setup that can acquire 1:1 magnification images with 150 megapixel spatial resolution, 8-band (470-940∼nm) spectral resolution, and ultraviolet (365∼nm) activation. The macro setup is integrated with the Grinding, Imaging, and 3D Reconstruction Instrument (GIRI), so that thousands of multispectral images can be acquired in an automated way as GIRI grinds through a specimen as thick as 21.5∼cm, and/or mosaics over a specimen as large as 20x26∼cm. We demonstrate a variety of examples where multispectral information is crucial for accurate segmentation of features such as skeletal fossils, ooids, cements, minerals, and chondrules.

29. **Microbial cycling of sulfated polysaccharides in peritidal pustular mats from Shark Bay, Australia**

Emilie J. Skoog, Kelsey R. Moore, Lily Momper, Elise Cutts, and Tanja Bosak

Fossil evidence of cyanobacteria embedded in extracellular polymeric substances (EPS) can be found in pustular marine microbial mats dating back to the Proterozoic. To understand the nature and importance of EPS, we collected modern peritidal pustular mats from Shark Bay, Australia, conducted biochemical analyses of EPS produced by the cyanobacteria enriched from these modern mats, sequenced and assembled 83 medium-to-high quality metagenome-assembled genomes (MAGs) from these pustular mats, and analyzed these MAGs for the genomic potential to produce or degrade sulfated EPS. Biochemical analyses of EPS extracted from cultured cyanobacterial pustules revealed the presence of sulfated polysaccharides. Genes necessary for synthesizing sulfated polysaccharides were present in two of three cyanobacterial MAGs. Multiple members of the surrounding community – including Bacteroidetes, Chloroflexi, Hydrogenedentes, Myxococcota, Verrucomicrobia, and Planctomycetes – contained genes necessary for the degradation of sulfated polysaccharides. The spatial distribution and abundance of some of these microbes within the pustular mats may reflect their ability to degrade fresh sulfated polysaccharides produced by cyanobacteria. Sulfated polysaccharides have likely protected pustular mat communities against stresses specific to peritidal environments, contributed to the biogeochemical cycling of carbon and other elements, and influenced fossilization potential of these mats for at least two billion years.

30. **Utilizing organic geochemical biomarker proxies to reconstruct Plio-Pleistocene continental air temperatures in northwest Australia**

Rebecca A. Smith and Isla S. Castañeda

Branched glycerol dialkyl glycerol tetraethers (brGDGTs) are a suite of organic geochemical compounds, likely produced by bacteria, which provide a fingerprint of climatic conditions at the time their source organism(s) once lived. Accumulation of these compounds in soils, rivers, lakes or marine sediments preserves a record of past climate change over geologic time. Here we apply the MBT'5ME proxy, based on the degree of methylation of brGDGTs, to reconstruct continental mean annual air temperatures (MAATs) in northwest Australia from 3.5-1.5 Ma. Samples were collected from IODP Expedition 356 Site U1463, which is located off the coast of northwest Australia and under the influence of the Indonesian Throughflow (ITF). The timing of oceanographic changes near and around the ITF remain a topic of debate; therefore, the main objective of this study is to utilize brGDGTs to elucidate ITF behavior and its influence on Australian continental MAAT across the Plio-Pleistocene. In order to correlate MBT'5ME to continental air temperature, we first applied the #Ringstetra proxy to determine the source of brGDGTs preserved at Site U1463. Results indicate that all brGDGTs at this site originated in continental soils and were transported offshore via aeolian deposition; therefore, MBT'5ME reflects continental air temperature. The MBT'5ME derived MAAT record indicates relatively stable and high temperatures for most of the Pliocene and early Pleistocene, and cooling between 1.7-1.5 Ma. This trend corresponds to previous studies that identified sea surface temperature cooling at Site U1463 from 1.7-1.5 Ma, as well as a significant increase in continental aridity across northwest Australia after $\sim$2.4 Ma. Here we suggest that both sea surface and continental air temperature cooling after 1.7 Ma reflect an interval of constriction around the Indonesian Gateway, which restricted warm water reaching Site U1463 and forced cooling in continental northwest Australia. This study provides the first continuous, Plio-Pleistocene MAAT record in northwest Australia, and Western Australia as a whole.

31. **The Redox Fate of Hydrogen Peroxide in the Marine Water Column**

Kevin M. Sutherland, Kalina C. Grabb, Jennifer S. Karolewski, Lina Taenzer, Colleen M. Hansel, and Scott D. Wankel

Marine microbes produce extracellular reactive oxygen species (ROS) such as superoxide and hydrogen peroxide (H_2O_2) as a result of regulated and non-regulated physiological and metabolic reactions. ROS production can be a sink and cryptic recycling flux of dissolved oxygen that may rival other key fluxes in the global oxygen cycle, however, the low abundance and high turnover rate of ROS makes this figure difficult to constrain. One key step in determining the disparity between the gross production of ROS and the net sink of dissolved oxygen lies in understanding the degradation pathways of H_2O_2 in the marine water column. In this study, we use isotope labeling techniques to determine the redox fate of H_2O_2 in a range of marine environments off the West Coast of California. We find that H_2O_2 reduction is greater than or equal to H_2O_2 oxidation at most sampled depths, with notable exceptions in some surface and intermediate water depths. The observation that H_2O_2 oxidation can exceed reduction in the dark ocean indicates the presence of an oxidizing decay pathway that is not among the known suite of microbially mediated enzymatic pathways (i.e. catalase and peroxidase), pointing to an abiotic and/or a non-enzymatic decay pathway at intermediate water depths. These results highlight the complexity and heterogeneity of ROS decay pathways in natural waters and their unconstrained regulation of oxygen levels within the ocean.

32. **Nutrient Supply to Planetary Biospheres from Anoxic Weathering of Mafic Oceanic Crust**

Drew D. Syverson, Christopher T. Reinhard, Terry T. Isson, Cerys H. Hostege, Joachim Katchinoff, Benjamin M. Tutolo, Barbara Etschmann, Joel Brugger, and Noah J. Planavsky

Phosphorus is an essential element for life, and the phosphorous cycle is widely believed to be a key factor limiting the extent of Earth's biosphere and it's impact on remotely detectable features of Earth's atmospheric chemistry. Continental weathering is conventionally considered to be the only source of bioavailable phosphorus to the marine biosphere, with submarine hydrothermal processes acting as a phosphorus sink. Here, we use a novel 29Si tracer technique to demonstrate that alteration of submarine basalt under anoxic conditions leads to significant soluble phosphorus release, with an estimated ratio between phosphorus release and CO_2 consumption ($\Sigma PO_4^{3-}/\Sigma CO_2$) of 3.99 ± 1.03 µmol mmol^{-1}. This ratio is comparable to that of modern rivers, suggesting that submarine weathering under anoxic conditions is potentially a significant source of bioavailable phosphorus to planetary oceans and that volatile-rich Earth-like planets lacking exposed continents could develop robust biospheres capable of sustaining remotely detectable atmospheric biosignatures.

33. **Reinterpreting the diatom fossil record through modeling changes in biogenic silica preservation**

Sophie Westacott, Noah J. Planavsky, Ming-Yu Zhao, and Pincelli M. Hull

The rise of diatoms from their Mesozoic origins to their current status as major primary producers is one of the biggest ecological shifts of the Cenozoic, with critical implications for the marine silica cycle. However, the timing of this transition is debated, with recent Si isotope work suggesting an earlier rise than indicated by traditional interpretations of the fossil record. Using a diagenetic model, we look at how changes in deep sea temperature and sedimentation rates would have affected the preservation (burial efficiency) of biogenic silica over the Cenozoic. Our results suggest the fossil record of diatoms would have been largely overprinted by taphonomy, leaving little support for a ∼5-20 Ma increase in diatom abundance often invoked to link diatoms to declining CO_2 levels and to the rise of baleen whales and grasslands. Our results also call into question evidence for a positive correlation between radiolarian silicification and seawater silica concentration, another piece supporting the classic timeline of the evolution of the modern silica cycle.

34. **Cloudinids from the upper Ediacaran La Ciénega Formation, Sonora, Mexico**

Clara Wong, Lyle Nelson, and Sara B. Pruss

Cloudina and other cloudinids, biomineralizing tubular organisms from the late Ediacaran, provide important insights into the development of skeletonization within metazoan clades. Selectively to fully-silicified cloudinid fossils are preserved as dense monotaxic packstone/wackestone accumulations within a <5 meter interval of cross-bedded dolostone in the terminal Ediacaran La Ciénega Formation in Sonora, Mexico. Samples were dissolved in dilute acetic acid, and fossils were examined and imaged using a scanning electron microscope. All examined fossils demonstrate a general tubular morphology. Many of the tubes are broken into smaller fragments, yet the distinctive nested structure of the cloudinomorph group is still present in larger tubes. Some nested tubes have more consistent diameters, while others are more conical. In some cases, annulations preserved as ridges around the circumference of the tubes do not appear to be nested tubes. The tubes display corrugated and twisted textures, indicating that they had been pliable prior to silicification. Some cross-sectional fragments are elliptical in shape in contrast to the circular apertures of other tubes, indicating that they had been deformed before burial. These observations support the idea that the tubes were flexible skeletons. Further work will constrain the deposition and preservation of these dense cloudinid aggregates in shallow marine environments of the terminal Ediacaran and will contribute to the burgeoning understanding of how cloudinids constructed skeletons.

35. **Morphology of toxic metal distributions in biological soft tissue of deep-sea hydrothermal extremophile polychaetae Alvinella pompejana**

Laurel R. Yohe and Drew D. Syverson

Hydrothermal vent systems provide some of the most extreme environments on the planet, including extreme ranges in temperature, pressure, anoxic conditions, and exposure to toxic metals. However, the role of eukaryotic fauna and their interactions with extremophile prokaryotes in the biogeochemical cycling of toxic metals released from the vent systems is not well understood. Quantifying the extent to which metal species get "trapped" on the seafloor after immediately being released from the vent fluids is crucial to understanding metal distributions on a global scale and potential impact on the geological time scale. Alvinella pompejana, or the Pompeii worm, is a deep-sea polychaetae worm that is arguably among the most extreme-adapted marine invertebrates. In addition to high heat and anoxia, Alvinella also copes with H_2S concentrations beyond what would kill a human, as well as a number of other toxic metals (e.g. Hg, Pb, As, Cd). Several lines of defense likely contribute to the detoxification of the hydrothermal environment for the worm to survive, including secreted tubes to selectively diffuse compounds or epibiotic metal-resistant bacteria that may act as a "metal sunscreen". However, the tissues of both the body and tentacles have high concentrations of heavy metals that differ significantly in reducible or oxidized state, depending on the region of the worm. This suggests that the spatial distribution of minerals present within the tissue of the Alvinella are different regions of the animal metabolize and detoxify different metals and compounds. We applied pioneering imaging techniques including diffusible iodine-based contrast-enhanced µCT-scanning (diceCT) and laser-induced breakdown spectroscopy (LIBS) to understand the morphological distribution of different toxic metals in the soft tissues of Alvinella. Visualizing metal distributions in three dimensions offers a pioneering approach to quantifying the geobiological role of deep-sea organisms in metal cycling.

36. **A Bayesian framework for subsidence modeling in sedimentary basins: implications for the Precambrian**

Tianran Zhang, C. Brenhin Keller, Galen P. Halverson, Mark J. Hoggard, Alan D. Rooney, Kristin D. Bergmann, and Justin V. Strauss

Basin analysis is regarded as the standard method for quantitatively reconstructing the subsidence and thermal histories of sedimentary basins, yielding critical insights into the architecture and dynamics of continental lithosphere. Although this technique has been successfully applied to a number of Phanerozoic basins, a crucial component that has been missing from previous approaches is the robust integration of input parameter uncertainties relating to sedimentary compaction, paleowater depth, and geochronology. This shortcoming becomes especially problematic when reconstructing the evolution of Precambrian sedimentary basins due to their common lack of abundant and precise geochronological data. Here, we present a comprehensive approach for calibrating Precambrian sedimentation in simple rift basins. Building upon the classic sequence of decompaction, backstripping, and McKenzie-type thermal subsidence modelling, the main contribution of this new model is the incorporation and propagation of uncertainties using a Bayesian framework. Specifically, the following input parameters are treated as distributions rather than single values: 1) lithology-controlled physical properties (such as surface porosity, porosity-depth coefficient and grain density); 2) radiometric ages; and 3) stratigraphic height measurements. In addition, our model allows for inputs from multiple outcrops of the same succession, which accounts for along-strike variations. As a case study, we apply this model to the Tonian Akademikerbreen Group in northwestern Svalbard, Norway, where we also introduce new Re-Os depositional ages and detrital zircon maximum depositional age constraints. Our subsidence model outputs for this succession provide an updated age model for key global event horizons (e.g., the Bitter Springs and Islay carbon isotope excursions) and paleontological data. These results are then compared with existing ages from the contemporaneous Mackenzie Mountain and Windermere supergroups of northwestern Canada, and Tambien Group of Ethiopia. By integrating subsidence modeling with a Bayesian age-depth model, the age-height relationship generated in this study provides more reliable time constraints for key chemostratigraphic and biostratigraphic events, including a comprehensive assessment of their uncertainty, and will eventually lead to a more robust timescale for the Tonian Period.