Northeast Geobiology Meeting 2019 Abstracts

Talks

Calcium isotope fractionation during bacterially mediated carbonate precipitation

Hal Bradbury, Katie Halloran, Chin Yik Lin, Sasha Turchyn

The metabolic activity of microbial communities in ocean sediments can drive the precipitation of authigenic calcium carbonate minerals. In particular, the activity of sulfate-reducing bacteria can generate alkalinity and raise local pH, driving sedimentary carbonate precipitation. Geochemical signatures of this microbially mediated carbonate precipitation remain relatively unconstrained. To better understand the links between calcium carbonate precipitation and sulfate reducing bacteria, we examined the calcium isotope fractionation during the precipitation of calcium carbonate in pure cultures of the marine sulfate-reducing bacteria Desulfovibrio bizertensis. We show that there is a different calcium isotope fractionation when monohydrocalcite precipitates versus when calcite precipitates directly through microbial induction. Bacterial growth was then modulated with antibiotics, and the evolution of δ44Ca in solution was monitored under several different growth rates. The resulting calcium isotope fractionation factors can help us understand the link between calcium isotope fractionation and microbial metabolism in authigenically precipitated carbonate minerals.

Early marine diagenesis and mineralogical controls on the lithium isotopic composition (δ^7Li) of shallow marine carbonates

Jack Geary Murphy, John A. Higgins, Anne-Sofie C. Ahm, Peter K. Swart

Records of the lithium isotopic composition of seawater (□7Lisw) may provide important information about the role of silicate weathering in the geological carbon cycle. While shallow-water carbonates may serve as an archive of the lithium isotopic composition of past oceans, interpreting the seawater isotopic signal in carbonate sediments is complicated by the effects of both mineralogy (calcite vs. aragonite) and diagenesis. Here we present bulk carbonate □7Li measurements paired with calcium isotope (□44Ca) values and trace element abundances in Neogene shallow marine carbonates from Ocean Drilling Program Leg 166 and the Bahamas Drilling Project. Measured samples exhibit systematic stratigraphic variability in □7Li values that correlate with mineralogy, sediment □44Ca values, and trace elements. The observed stratigraphic trends in □7Li values differ from coeval planktonic foraminifera □7Li records, indicating that any signal of global change in the □7Li of seawater is overwhelmed by local effects of mineralogy and diagenesis. Positive covariation between bulk sediment □7Li and □44Ca values with the same mineralogical composition is interpreted to reflect differences in the 'openness' of the diagenetic system; samples with high □44Ca and □7Li values are interpreted to have formed in fluid-buffered conditions, whereas samples with low □44Ca and low □7Li values underwent diagenetic alteration in sediment-buffered conditions. These results highlight the need to understand the effects of both mineralogy and diagenesis when interpreting lithium isotopic signatures of shallow-water carbonate sediments in the geologic record.

Bulk and clumped isotope signature of aerobic methane reveals production pathway

Lina Taenzer, D. Rumble, E.D. Young, J. Labidi, P. Carini, B. Bourguez, S. Lincoln, X. Feng, J. Gaube, W.D. Leavitt

The discovery that certain aerobic bacteria produce methane (CH_4) has served to explain a long-term puzzle of supersaturated concentrations observed in the world's surface oceans, and has revolutionized the previous consensus that biogenic methane is solely produced by anaerobic microorganisms [1]. The release of CH_4 by specific oxygen- or nitrate-reducing bacteria has been shown to occur in oxygen rich but phosphate-starved ecological niches that characterize large areas of Earths oceans, some lakes and soils. These microbes are able to acquire P by breaking down organic matter bound alkyl phosphonates, such as methylphosphonate (MPn) [1,2]. Through the metabolic decomposition of MPn methane is released. The release of this potent greenhouse gas in P-starved surface oceans may be the primary source of ocean to atmosphere methane flux.

In this study we determine the stable isotopic fractionations upon MPn degradation to CH_4. Using pure cultures of representative marine and freshwater microorganisms, we determined the bulk $\delta^{13}C$ and $\delta^{2}H$ compositions of both reactants and product, as well as the clumped isotopic compositions, $\Delta^{12}CH_2D_2$ and $\Delta^{13}CH_3D$, of product methane. Methane produced during MPn degradation shows little to no fractionation from the substrate in bulk $\delta^{13}C$ values, and some depletion from medium water $\delta^{2}H$. Clumped isotope values deviate from equilibrium reflecting the effects of the underlying biological production pathway. When the organisms are cultivated in deuterium enriched water there is a positive shift in $\Delta^{12}CH_2D_2$ values, but the $\Delta^{13}CH_3D$ remains unchanged. To elucidate the factors that control clumped isotope signals we are analyzing methane produced from bacterial growth on media of different hydrogen isotopic composition.

The enzyme complex, C-P lyase, required for the catabolism of MPn, has been identified in numerous key marine microbes, including strains of Trichodesmium erythraeum, Pelagibacterales sp. (SAR11), and the main strain studied herein, Pseudomonas stutzeri HI00D01, indicating that phosphonate breakdown coupled to methane production is possible throughout oligotrophic surface oceans [2]. This work presents the potential to identify a unique process-specific set of stable isotopic fractionation factors for aerobic methane production during phosphonate oxidation.

1: Repeta et al., (2016) Nature Geoscience 9, 884-887.
2: Carini et al., (2014) Nature Communications 5, 4346.

Nitrogen isotopes in chlorophyll track taxonomic shifts in a natural phytoplankton community

Jenan J. Kharbush, Derek Smith, Henry A. Vanderploeg, David Fanslow, Rebecca S. Robinson, Gregory J. Dick, Ann Pearson

Nitrogen (N) is a limiting nutrient for phytoplankton in aquatic ecosystems, and therefore an important control on phytoplankton community structure. Chlorophyll is a N-containing molecule produced by all photosynthetic organisms, making it an ideal target for compound-specific isotopic studies of phytoplankton N utilization in aquatic environments. In laboratory cultures of phytoplankton, the difference between the N isotope ratio ($\delta^{15}N$) of chlorophyll and the $\delta^{15}N$ of biomass, known as ε_{por}, varies taxonomically (i.e. between eukaryotic algae and cyanobacteria). These taxonomic patterns could be used to study productivity in both modern and ancient environments, but have not yet been demonstrated robustly in nature. Here we take advantage of the annual cyanobacterial bloom in Lake Erie, USA, which results in a transition from a eukaryotic algae-dominated to cyanobacteria-dominated community. The resulting time-series shows that environmental and laboratory observations agree, and because the range and sensitivity of εpor is the same in nature as in the laboratory, the Lake Erie data advocate for εpor as a reliable tracer of the relative contributions of cyanobacteria and eukaryotic algae to primary production in aquatic environments. Furthermore, the agreement between culture studies and the environment suggests that there is likely a fundamental biosynthetic or physiological explanation for why chlorophyll N isotopes are fractionated differently among major algal groups, independent of growth condition or original N source. Because chlorophyll biosynthesis is closely linked to cellular N assimilation and allocation, we hypothesize that differences in fractionation between major algal groups may be explained by differences in intracellular N partitioning.

Using membrane lipids produced by marine diatoms and *Thaumarchaeota* to reconstruct sea surface temperatures from 3.5-1.5 Ma near the outlet of the Indonesian Throughflow

Rebecca A. Smith, Isla S. Castañeda, Jeroen Groeneveld, David De Vleeschouwer, Jorijntje Henderiks, Beth A. Christensen, Willem Renema, Kara Bogus, Stephen J. Gallagher, and Craig S. Fulthorpe

Ocean gateways force global climate by limiting the transport of water between ocean basins. In particular, the Indonesian Throughflow (ITF) influences global thermohaline circulation by controlling the movement of water from the Pacific into the Indian Ocean. Previous studies suggest that the ITF underwent shallowing and constriction from ~5-2 Ma (Cane and Molnar, 2001), however only a limited number of studies have been able to reconstruct ITF changes across the Plio-Pleistocene due to an overall lack of continuous marine Plio-Pleistocene sediment records regionally. Here we apply a suite of organic geochemical biomarker proxies, namely TEX86 (Schouten et al., 2002; Tierney and Tingley, 2014), LDI (Rampen et al., 2012), and MBT'5ME (De Jonge et al., 2014; Weijers et al., 2007), to sediments extending from 1.5-3.5 Ma that were collected during IODP Expedition 356 from Site U1463 off the coast of Northwest Australia, in order to reconstruct changes in both sea surface temperature (SST) and continental air temperature (MAAT) and constrain shifts in the ITF constriction and shallowing. All three records capture glacial-interglacial cyclicity (Lisiecki and Raymo, 2005), particularly during Marine Isotope Stages (MIS) 82, 84, 92, G6, G18, G20, G22 and M2. Notably the TEX86 record captures stronger cooling during MIS G18, G20 and G22 relative to the widely recognized cooing event at MIS M2, which may indicate that SSTs near the outlet of the ITF capture a stronger regional vs. global temperature signal. All SST and MAAT records indicate relatively stable and warm temperatures across the Pliocene, with the exception of TEX86 cooling at ~3.3 Ma after MIS M2, and a very pronounced cooling signal beginning at ~1.7 Ma. The latter cooling signal may reflect the global increase in meridional SST gradients beginning at ~2.0 Ma (Brierley and Fedorov, 2010). Results from this project help inform modelers on climate forcing mechanisms, ocean gateway variability in particular, across the mid-Pliocene Warm Period (mPWP), which serves as a critical analog for modern climate change due to similar-to-modern CO2 and temperature conditions.

Biological pump driven by diatom-diazotroph symbiosis during past ocean anoxia

Felix J. Elling, Jordon D. Hemingway, Ann Pearson

Periods of marine anoxia in the Mesozoic-Cenozoic are associated with high burial rates of organic matter. We propose these episodes result from a positive feedback in the nitrogen (N) cycle in which an initial pulse in nutrients (P, Fe) or change in ocean circulation amplifies the rate of N loss which in turn favors the proliferation of rapidly sinking diatom-diazotroph symbiotic consortia, thereby sustaining the anoxia. Biomarker evidence from Pliocene-Pleistocene sapropels in the Mediterranean Sea supports this idea, showing that diazotrophic endosymbionts of mat- or raft-forming diatoms and anaerobic ammonium oxidizers (anammox) both were abundant. Bulk sedimentary δ15N values are as low as 2.8‰, reflecting strongly denitrifying conditions and compensating N2 fixation. Simultaneously, stable carbon isotope data show progressive deep-water δ13C-DIC depletion, consistent with an intensified biological pump. In this scenario, high biomass flux maintains the anoxia and concomitant N loss while also promoting the efficient phosphorous remineralization necessary to sustain high rates of primary production. It also resolves a long-standing conundrum of how comparatively small and buoyant diazotrophs can be associated with high export flux rates. Escape from the feedback loop may occur through i) changes in ocean circulation (e.g., for transient, localized events such as Mediterranean sapropels), or ii) O2 accumulation and deep ocean re-oxygenation (e.g., Mesozoic ocean anoxic events).

A theory of organic carbon preservation

Jordon D. Hemingway, Daniel H. Rothman, Katherine E. Grant, Sarah Z. Rosengard, Timothy I. Eglinton, Louis A. Derry, Valier V. Galy

The vast majority of organic carbon (OC) produced by life is respired back to carbon dioxide (CO_2), but roughly 0.1% escapes and is preserved over geologic timescales. By sequestering reduced carbon from Earth's surface, this "slow OC leak" contributes to CO_2 removal and promotes the accumulation of atmospheric oxygen and oxidized minerals. Countering this, OC contained within sedimentary rocks is oxidized during exhumation and erosion of mountain ranges. By respiring previously sequestered reduced carbon, erosion consumes atmospheric oxygen and produces CO_2. The balance between these two processes—preservation and respiration—regulates atmospheric composition, Earth-surface redox state, and global climate. Despite this importance, the governing mechanisms remain poorly constrained. To provide new insight, we developed a method that investigates OC composition using bond-strength distributions coupled with radiocarbon ages. Here I highlight a suite of recent results using this approach, and I show that biospheric OC interacts with particles and becomes physiochemically protected during aging, thus promoting preservation. I will discuss how this mechanistic framework can help elucidate why OC preservation—and thus atmospheric composition, Earth-surface redox state, and climate—has varied throughout Earth history.

Three-dimensional reconstructions and morphological analysis of Namapoikia, a putative Ediacaran sponge fossil, using GIRI

Akshay Mehra and Adam Maloof

One of the earliest biomineralizing organisms was Namapoikia, a putative sponge which encrusted the sides of microbial mounds within the Ediacaran Driedoornvlakte reef complex, Namibia. Although not the first example of a sponge in the fossil record, Namapoikia is unique because of its well preserved skeletal structure, which has been proposed to represent rapid and dynamic growth and a biological affinity to the coralline demosponge Vaceletia Sp. A detailed morphological study of Namapoikia provides an opportunity to better understand the growth habit, life-cycle, and environmental interactions of the organism, as well as to evaluate its proposed biological affinity.

We present the first-ever three dimensional reconstructions of Namapoikia, created using the Grinding, Imaging, and Reconstruction Instrument (GIRI) at Princeton University. We provide quantitative measurements of skeletal thickness, branching angles, porosity, and horizontal support structures. Our analyses suggest that Namapoikia was, in fact, not a sponge. Using morphological data, we present a new model for how Namapoikia grew and assess potential alternative biological affinities.

A fishy perspective on the Eocene-Oligocene Transition

Elizabeth Sibert, Michelle Zill, Ella Frigyik, Richard Norris

The Eocene-Oligocene Transition (EOT), 33.9 million years ago (Ma), was a period of rapid climate change and global cooling, and best marked by the growth of permanent ice sheets on Antarctica, a from greenhouse to icehouse Earth. The EOT is also associated with shifts in marine productivity, the origination of larger-bodied bulk-feeding marine whales, and the beginning of a productive Southern Ocean ecosystem. Here, we investigate the impact of the rapid climate and oceanic changes caused by the EOT on marine fish populations and evolution using a unique microfossil resource: ichthyoliths – tiny isolated fish teeth and shark dermal scales [denticles] – preserved in deep-sea sediments around the world. We calculated ichthyolith accumulation rates (IAR) for seven deep-sea sediment cores from around the world, ranging from the North Atlantic to the Southern Ocean, from 42 Ma to 29 Ma. IAR measures the abundance of fossils falling to the seafloor in a fixed interval of time, and is directly related to fish production of the overlying water column, which in turn is related to primary production. We find that there is no change in fish abundance across the EOT at any of the sites included in this study, suggesting that fish production was relatively robust to the significant shifts in ocean conditions during that time. Further, high latitude sites Southern Ocean have persistently low IAR throughout the entire study interval, suggesting that the EOT did not cause a significant shift in the overall production of the Antarctic food web, at least in the portion that included fish. Finally, an assessment of tooth morphotypes across the interval, finds that there are no significant turnovers in tooth diversity across the EOT: although the rate of origination exceeds the rate of extinction throughout the 13 million year study interval, these rates are constant, and the EOT is not a significant period for fish evolution. Together, these results suggest that while the EOT was a turning point in global climate, it was not a watershed event for marine ecosystems or fish evolution, and suggests that fish were relatively resilient during this time of rapid global change.

Correlates and Paleoecological Significance of Porosity of Planktonic Foraminifera

Janet E. Burke, Willem Renema, Michael J. Henehan, Leanne E. Elder, Catherine V. Davis, Amy E. Maas, Gavin L. Foster, Ralf Shiebel, Pincelli M. Hull

Planktonic foraminifera (forams) are single-celled organisms that live in the surface layer of the ocean. At the end of their life cycle, their calcareous tests sink to the bottom of the ocean and form a sedimentary record of great temporal and spatial resolution. Planktonic foraminiferal tests are perforated with small openings called “pores”, which have been used to make inferences about their habitats. Variation in average pore area, density, and porosity (the total percentage of a test wall that is open pore space) has been attributed to environmental, biological, and taxonomic correlates in the past, complicating such interpretations. Here we examine the environmental, biological, and evolutionary determinants of pore characteristics in 718 individuals, representing 17 morphospecies of planktonic foraminifera from 6 core tops in the North Atlantic with random forest models. These models identify test size and habitat temperature as the primary drivers of porosity, which are also key determinants of metabolic rates. In order to test this correlation, we cultured Globigerinoides ruber in three different temperature conditions, and found that porosity increased significantly with temperature. These results show that porosity can be plastic (changing in response to environmental drivers within the lifetime of an individual foraminifer). These results demonstrate the potential of porosity as a proxy for foraminiferal metabolic rates, with significance for interpreting geochemical data and the physiology of foraminifera in non-analog environments. It also highlights the importance of phenotypic plasticity (i.e., ecophenotypy) in accounting for some aspects of morphological variation in the modern and fossil record.

Radiolarians got bigger across the PETM at Mead Stream, New Zealand

Sophie Westacott, Christopher J. Hollis, Kristina M. Pascher & Pincelli M. Hull

Often cited as the closest analogue to anthropogenic global warming, the Paleocene Eocene Thermal Maximum (PETM) was an interval of high temperatures, ocean acidification, and elevated continental weathering. Thus far, open ocean planktonic responses to the PETM—including body size shifts—have been characterized in calcareous nannoplankton, dinocysts, and planktonic foraminifera. Less is known about the response of radiolarians, which share life modes and phylogenetic history with planktonic foraminifera but make their shells (tests) out of silica rather than calcium carbonate. Here, we measure radiolarian test size before, during, and after the PETM in assemblages from the Mead Stream locality, New Zealand, in which taxonomic turnover has previously been documented. Our results show a significant positive shift in whole-assemblage mean radiolarian test size concurrent with the onset of the hyperthermal. Surprisingly, radiolarians remained large well into the early Eocene and beyond the carbon isotope excursion recovery, suggesting that either the community-level selection response was locked in even as sea surface temperatures and other environmental variables rebounded ("ecological inertia"), or the conditions favoring larger tests continued for >1 m.y. Accelerated continental weathering during the PETM recovery increased the influx of silica to the global ocean, and we weigh silica availability as one of several possible drivers of test size variation in silicifying plankton.

A paradigm shift in banded iron formations?

Robbins, L.J., Planavsky, N.J., Alessi, D.S., and Konhauser, K.O.

Banded iron formations (BIFs) are enigmatic deposits that lack true modern analogues, and several aspects regarding their origin and deposition remain debated. The recent identification of early-preserved greenalite in the BIFs of the Hamersley Basin, western Australia has been proposed to reflect the earliest mineral phase, characteristic of the initial precipitates. This would require that the initial deposits were subsequently oxidized by meteoric waters during the formation of ore deposits in the region. This would require a re-evaluation of the current paradigm regarding our understanding of BIF deposition, where iron is either the directly or indirectly oxidized by microbial activity. Here, we present a basin-scale hydrogeological box model designed to test the feasibility of post-depositional greenalite oxidation and explore the resultant implications for the origins of greenalite and the activity of the ancient marine biosphere.

Local conditions initiating Paleoproterozoic iron formation and evolution of unique microbial communities

Athena Eyster and Kristin Bergmann

Following the rise of atmospheric oxygen, iron formations (>15 wt % iron) largely disappear from the geologic record, but reappear at ca. 1.8 Ga. Additionally, the distinctive morphologies and fossil assemblages in the 1.8 Ga iron formations document a biotic world not found in older rocks. This co-evolution of life with unique Earth conditions suggests that the environment that allowed the reemergence of iron formation must also have been conducive to diverse microbial communities. To identify local conditions involved in the initiation of these unique formations and the associated biotic assemblages, we present new stratigraphic and mapping relationships of the Ironwood Iron Formation

and the Emperor Volcanics located in the western Upper Peninsula of Michigan. This work is coupled with petrographic examinations to elucidate the original mineralogy, textures and possible biological influences on the local environment. Finally, implications for ocean redox and evolutionary trajectory of the Paleoproterozoic Era are explored.

Coupled carbon and silica cycle perturbations during the Marinoan Snowball Earth deglaciation

Donald E. Penman, Alan D. Rooney

The Snowball Earth hypothesis proposes that if polar ice sheets were to advance equatorward of a mid-latitude threshold, runaway ice albedo effects would lead to a stable, globally ice-covered climate state that would require extremely high atmospheric pCO2 levels (supplied by volcanic degassing over millions of years) to deglaciate. Geologic evidence, including globally-distributed and low-latitude glacial deposits, suggests that two such global glaciations occurred during the Neoproterozoic. We model the coupled carbon and silica cycles through a Snowball Earth event, including the extremely high pCO2 and dramatically accelerated chemical weathering of its aftermath. The enhanced delivery of dissolved weathering products to the ocean induces elevated sedimentary burial of CaCO3 (deposited as "cap carbonates") and SiO2. Uncertainty in the relative importance of carbonate vs. silicate weathering allows a wide range of possible CaCO3 burial, potentially dwarfing that of SiO2. However, total SiO2 burial is insensitive to weathering strengths, and is set by the amount of CO2 required for deglaciation (~10^19 moles). If such estimates of the snowball deglaciation pCO2 threshold are correct, the subsequent influx of dissolved silica to the oceans was likely the largest perturbation to the marine silica cycle in Earth history. Chert associated with Marinoan post-glacial cap carbonates is observed across the West African craton, corroborating modeled predictions of elevated SiO2 burial. West Africa may have been particularly conducive to silica deposition due its high paleolatitude and the temperature effect on SiO2 solubility, which favors precipitation at lower temperatures.

POSTERS

Paleobiology

Encrusters on corals from Pleistocene reefs on San Salvador and Great Inagua Islands, Bahamas (Poster 1)

Abigail Beckham, Agnese Mannucci, Bosiljka Glumac, H. Allen Curran, & David Griffing

The Cockburn Town Fossil Reef site on the western coast of San Salvador Island, Bahamas is an in situ exposure of Pleistocene coral reef deposits of the Cockburn Town Member, Grotto Beach Formation (Eemian; MIS 5e). The top of the reef is presently exposed ~3 m above sea-level and the reef succession is separated internally by an erosional discontinuity known as the Devil's Point unconformity into Reef I and II deposits. This succession is an important source of information about paleoenvironmental conditions and sea-level fluctuations during the last interglacial highstand.
Of particular interest is the presence of thick (up to 8-9 cm) crusts on branching corals in Reef I made by encrusting red crustose coralline algae, foraminifera, serpulids, stromatolites and clotted microbialites. Reef II corals are dominated by domal forms and lack thick encrustations. The transition from coral

growth to the formation of thick encrustations has been interpreted as a change in reef development from bank barrier to restricted backreef and lagoonal environments in response to sea-level changes.
This presentation summarizes the results of our field and petrographic work aimed at analyzing in detail the abundance, distribution and succession of various types of encrusters on corals from Cockburn Town Fossil Reef. Stable isotope analyses were conducted on the coral and encrusting organisms to provide insights into the depositional and diagenetic history of these deposits. A comparison is also made with observations from The Gulf site on the south coast of San Salvador where similar succession of encrusters on branching corals is observed in storm generated and transported boulders. Another comparison is made with an in situ reef exposure at Devil's Point on the west coast of Great Inagua Island in the southern Bahamas. The succession here is also separated into Reef I and II deposits, but corals generally have only typical taphonomic modifications with very thin algal encrustations. An in situ Reef II exposure of branching Acropora palmata corals, however, has a crust up to 2 cm thick made of red algae, serpulids and foraminifera, but lacking microbialites. On the other hand, our observations of displaced boulders from Matthew Town Marina excavation, also on the west coast of Great Inagua, revealed the presence of domal Orbicella annularis corals with microbial and algal encrustations similar to those on San Salvador. Our ongoing work aims at better understanding such important differences and similarities among fossil coral reefs in the Bahamas.

Biotic and environmental records of the Frasnian-Fammenian (Late Devonian) extinction event in shallow marine paleoenvironments of New York and Pennsylvania (Poster 2)
Andrew M. Bush, Sarah K. Brisson, J. Andrew Beard, Jaleigh Q. Pier, Patrick R. Getty, James P. Kerr, Anjali M. Fernandes, & Michael T. Hren

The Lower and Upper Kellwasser (KW) Events comprise the Frasnian-Famennian mass extinction, one of the "Big 5" extinctions of the Phanerozoic. The Appalachian foreland basin preserves a thick package of Upper Devonian sediments in which these events can be examined along a paleoenvironmental transect thanks to revised correlations based on biostratigraphy and carbon isotope stratigraphy. We have collected macrofossils bed-by-bed through numerous sections that span one or both Kellwasser Events, which are separated by about 60 m of strata. The Kellwasser-equivalent beds consist of dark gray, silty shale. Previous trace metal studies of more distal sections indicated dysoxic to intermittently anoxic conditions during the deposition of these beds. Similar analyses in our field area have detected no evidence of anoxia, although dysoxic conditions were present. At some localities, body and trace fossils have been found within the Kellwasser beds. Many macrofossil species go extinct in the Lower Kellwasser Event in this region, including all strophomenid and atrypid brachiopods and large, shallow-water rugose corals. Patterns of extinction selectivity are consistent with climate cooling being an important kill mechanism. Evidence of dysoxia and anoxia during Kellwasser deposition may merely reflect an increase in water depth and the movement of deposition under low-oxygen conditions eastward. If animal species tracked their preferred habitats, then they would not necessarily have been affected by low oxygen conditions. Many new species appear soon after the Lower Kellwasser Event, particularly productid brachiopods. Ecological ordination indicates that surviving species generally maintained their habitat preferences across the event. Thus, although there was considerable taxonomic change, general onshore-offshore ecological structure was maintained. The Upper Kellwasser event only claimed a couple of victims, including the last species of atrypid brachiopod, which migrated into the basin after the Lower Kellwasser, and no new species of brachiopod appeared in its immediate aftermath.

Carbon isotopic analyses of single organic-walled microfossils: A case study from the Late Devonian and Hopes for the Proterozoic (Poster 3)

Phoebe A. Cohen, Ezekiel King Phillips, Christopher Junium, Susannah Porter, Quinlan Byrne, & Annalee Tai

One window into the biological record of the deep time is via organic carbon isotopes, which track the isotope systematics of fixed carbon. However, these measurements are almost always done on bulk samples that represent the entire biological community time averaged into a sedimentary sample, which limits our ability to use these measurements to reconstruct short-term carbon cycle dynamics and to probe the structure of ancient ecosystems. Recent advances in NanoEA-IRMS now allow us to reliably measure the carbon isotopic composition of a single organic microfossil and compare that value to the bulk δ13C. Here, we summarize existing work using this new technique to explore the Late Devonian Mass Extinction event in Upstate New York and also discuss our new project utilizing this technique on Proterozoic microfossils.

Our work on organic-walled microfossils (OWMs) and chitinozoans from the Upper and Lower Kellwasser events in Upstate New York (black shale intervals associated with the extinction) show that microfossil values are consistently heavier than bulk organic carbon. We see no differences in δ13C between different morphological groups of OWMs. Instead, our data suggests that all OWMs are sampling a pool of DIC with a distinct isotopic signal. We suggest this signal could be driven by high productivity and a strong biological pump driving an isotopic gradient, and that these factors may have contributed to deleterious environmental conditions that played a role in the end-Devonian extinction. Our Proterozoic work seeks to use this new technique to explore how organic carbon isotopes can illuminate persistent unknowns in the Proterozoic Earth-life system including: What were the habitats and metabolisms of early eukaryotes? What can single microfossil δ13C reveal about the controls on bulk δ13Corg in the Proterozoic stratigraphic record? What do these records tell us about the Proterozoic Earth system? We will summarize our proposed research framework and expected results.

Convergent Evolution Between the Mouthparts of Eurypterids and Modern Malacostracans (Poster 4)
Julia Fearon, Philipp Wagner, & Stan Rachootin

Are Eurypterid and Malacostracan feeding apparatuses convergent? Eurypterids were highly diverse and successful chelicerates from the Ordovician to the Permian periods. They dominated in a number of different environments and ecological roles, and ranged in size from a few centimeters to two meters long. Modern Malacostracans seem to embody the same diversity in form and niche among arthropods today. But are they an example of true convergent evolution? We aim to compare the feeding apparatus of the genus Eurypterida with that of the modern Red Swamp Crayfish (Procambarus clarkii). We conducted a morphological analysis of the mouth-adjacent segments in Eurypterus lacustris (Fiddler's Green Formation, New York, USA) and the maxillipeds in Procambarus clarkii to determine similarity of morphology in these two distantly related, medium sized arthropods. We created a morphospace to quantify and visualize these results. We also scanned an exceptionally preserved E. lacustis fossil using microCT to reconstruct the inner mouth and gut as a 3D model. Our analyses suggest that they may have eaten similar material, such as detritus and small invertebrates. Our work struggles with some of the difficulties in measuring convergence, and presents solutions using new technologies such as 3D modelling.

A regurgitalite from the Upper Triassic Chinle Formation of Arizona, containing soft tissue from Revueltosaurus (Poster 5)
Caleb M. Gordon, Brian Roach, & Derek E. G. Briggs

We describe a bone mass (YPM VP.061134) of extensive postcranial material from the Petrified Forest National Park (Chinle Formation, AZ). Synapomorphies in the teeth and dermal scutes suggest that these remains belong to the Triassic pseudosuchian archosaur Revueltosaurus, though the precise size and number of individuals remain unclear. The bones were compacted together and aligned in subparallel, semi-articulated clusters in the absence of fluvial clustering forces, indicating that this specimen represents a digestive residue (bromalite) and not a sedimentary accumulation, but it remained unclear whether it constitutes a regurgitalite or coprolite. Microstructural analysis revealed a lack of corrosion by digestive acids, suggesting minimal time spent in the digestive tract. In addition, soft tissue fragments are preserved, suggesting that the specimen did not pass through the gut and therefore originated as ejecta (a regurgitalite) and not a coprolite. Chemical analysis revealed minimal phosphate in the matrix surrounding skeletal elements, supporting this interpretation. We generalize our approach to offer a three-pronged method for distinguishing between different types of digestive remains. Regurgitalites and coprolites can be discerned on the basis of (i) phosphate concentration, (ii) degree of bone corrosion, and (iii) soft tissue preservation. We interpret the diagenetic history of the specimen and its implications for regurgitalite taphonomy.

Colonial organisms from the lower Cambrian Harkless Formation, Esmeralda County, Nevada: the first putative bryozoans? (Poster 6)
Alexia Leeser, Audrey Trossen, Olivia Leadbetter, Rhiannon Nolan, Emily F. Smith, & Sara Pruss

The lower Cambrian Harkless Formation consists of fossiliferous carbonate and siliciclastic strata and is well preserved in Esmeralda County, Nevada. This unit has been previously studied for its well-preserved archaeocyathan reefs and diversity of fossils, including corallomorphs. Recent work focusing on the carbonates overlying archaeocyathan reefs in the Harkless Formation focused on facies which largely consist of ooid and quartz-rich carbonates with siltstone and shale interbeds. Twenty-five samples were collected from promising facies and made into thin-sections to examine the fossil diversity. In thin sections from >5 samples of the carbonate facies, we discovered unusual colonial creatures with morphological characteristics similar to erect trepostome bryozoans. These organisms are mostly fragmented and deposited in the ooid and quartz-rich facies, suggesting some transport, and the fragments range in size from 50 μm to 1 mm. These fossils preserve features consistent with elongate zooecia and may be the first fossil occurrence of bryozoans globally, but further work is needed to confirm this taxonomic assignment.

Ophiuroid fragments in insoluble residues of limestones from the upper Lower Triassic Virgin Limestone Member, southern Nevada (Poster 7)
Vivienne Maxwell & Sara B. Pruss

The recovery period from the end-Permian mass extinction was a long one, perhaps a reflection of the devastation of this event. This recovery has been studied intensively, particularly from the upper lower Triassic (Spathian) Virgin Limestone Member of the western United States. In residues of limestones from these units, a new assemblage of minute fossils replaced by glauconite and apatite was recently described. In our work here, we describe newly-discovered fossils in insoluble residues of limestones collected from the Virgin Limestone Member at Lost Cabin Springs in southern Nevada. The assemblages in the limestones from Lost Cabin Springs were different than those previously examined from the Muddy Mountains locality in that in addition to snails and echinoderms, abundant brachiopods were found, as well as ophiuroid fragments. These ophiuroids are some of the first well-preserved ophiuroid fragments from the Lower Triassic, and although we have not yet identified these to the species level, they may represent a previously undescribed species. The ophiuroids, like fossils from the other assemblages, are replaced by apatite, which likely created stereomic molds during early diagenesis. Future work will involve imaging more ophiuroid fragments, identifying these fossils to the species level, and better characterizing their taphomomic environment.

Non-reef benthic communities during the rise and fall of archaeocyathan reefs, western United States (Poster 8)

Rhiannon Nolan & Sara B. Pruss

The first calcifying sponges of the Cambrian, the archaeocyaths, produced reefs that altered evolutionary diversity and abundance both in reefs and in surrounding benthic communities. The archaeocyathan sponges became extinct toward the end of the early Cambrian interval; their rise and fall is preserved in sections of the Poleta and Harkless Formations from the western United States. The extinction, which has been documented globally in temporally equivalent strata, has been placed in the uppermost Harkless, after a brief period of abundant reef-building in the Poleta and upper Harkless. Although the extinction of the archaeocyaths is well documented, the effect of this extinction on benthic communities living on and around the patch reefs has been less well-studied; these organisms may have been affected by the same environmental/ecological factors that caused the reef disappearance. Point counts of 178 thin sections from non-reef environments of the Poleta, Harkless and Mule Springs formations were completed and analyzed to compare skeletal production in benthic communities before, during and after the extinction. Before the extinction, in the upper Poleta and basal upper Harkless, samples contain an average of 12.4% skeletal material (range 0-25%), while after the disappearance of archaeocyaths, samples drop to an average of 1.8% skeletal material (range 0-13%). Pre-extinction facies are mainly grainstone containing a diverse assemblage of echinoderms, trilobites, brachiopods and Salterella. Post-extinction facies are dominated by oolite and oncolite, and skeletal diversity is much lower, composed of only rare echinoderms and trilobites. Overall, the abundance and diversity of skeletal organisms in benthic environments appears to decrease across the interval of the early Cambrian archaeocyath extinction in western United States sections.

Geobiology in the Makerspace (Poster 10)

Mark McMenamin

First offered in Fall 2018, Geosciences in the Makerspace the course was part lecture/demonstration format, part seminar/discussion format, and part workshop/design space format. Experience has shown that “drawing enforces careful observation.” Taking that concept into three dimensions, we utilized Mount Holyoke’s Makerspace to reconstruct and model many ancient organisms. Using Pixologic’s Sculptris, 3D printing, laser cutting, photogrammetry and associated software, we: built conodont elements to create a complete Conodont Apparatus; built functional teleost fish, coelacanth fish and palaeoniscid skull models (the latter student-designed); and used photogrammetry to document fossils in the Skinner Museum, printing out replicas of these in various sizes and media. Also as a class, we built a life-sized skull of the hadrosaur Olortitan, complete with sinus pneumatics for sound and display, plus a working model of its powerful pleurokinetic jaw mechanism. This pleurokinetic chewing ability is the main reason that hadrosaurs were the most successful dinosaurs. Future iterations of this course, to be taught in Mount Holyoke’s newly built Fimble Lab, are set to combine rapid student acquisition of “maker” skills with new insights into the morphology and behavior of ancient life forms.

Pyrite replacement of extant benthic foraminiferal tests of Carbla Beach, Shark Bay, western Australia (Poster 11)
Daniel Wood & Sara Pruss

Benthic foraminifera are common components of modern beach sand in many tropical settings. To investigate the ecology and taphonomy of benthic foraminifera in a hypersaline setting, we examined an extant assemblage of benthic foraminifera from Carbla Beach in Shark Bay, western Australia, collected during a field season in summer 2017. Eight samples of sand were taken along two transects, one along the beach and one onshore to offshore (supratidal to subtidal). The assemblage of Carbla Beach was found to be low in diversity (~25 species) with high abundances of four species: Dendritina striata, Spirolina aeritina, Peneroplis pertuses, and Peneroplis planatus. Initial imaging of foraminifera under a light microscope revealed that some individuals, particularly those in the small size fractions (180 to 149 μm), contain abundant black minerals in their tests. Multiple thin sections were made by imbedding foraminifera tests in epoxy resin, and petrographic examination showed that the dark minerals selectively replace the foraminiferal calcite rather than fill test chambers. Under the SEM, energy-dispersive spectra maps revealed enrichments in Fe and S in the black minerals within the foraminiferal tests, and subsequent XRD analyses of these minerals demonstrated that they are pyrite or pyrite precursors. This suggests that small individuals in extant foraminiferal assemblages in Shark Bay, western Australia, are experiencing reducing conditions shortly after death and near the sediment-water interface.

Sedimentology and Geochemistry

Assessing diagenesis of the basal Cambrian carbon isotope excursion in the southwest United States (Poster 12)
M.C. Lonsdale, A-S. Ahm, J.A. Higgins, & E.F. Smith

A negative carbon isotope excursion informally marks the base of the Cambrian Period, overlapping temporally with the extinction of Ediacaran biota and the subsequent radiation of Cambrian metazoans. The relationship between this carbon isotope excursion and the first appearance datum (FAD) of Treptichnus pedum, the formal definer of the base of the Cambrian, was established in the southwest USA (Corsetti and Hagadorn, 2000), but it has since been recognized globally and used to correlate stratigraphic sections and construct age models.

Mount Dunfee, NV is one of the southwestern localities in which this excursion was first documented. In this section, limestones from the Esmeralda Member of the Deep Spring Formation feature oscillating $\delta^{13}C$ values that rise from -4.91 to -2.57‰, drop to -9.47‰, rise to 0.25‰, and stabilize at ~ -2.0‰ (Smith et al., 2016). The FAD of T. pedum was discovered in siltstones a few meters above the nadir of the carbon isotope excursion. Here we present $\delta^{44/40}Ca$ values and trace element ratios (Sr/Ca, Mg/Ca) and compare them with this variable $\delta^{13}C$ record. We find $\delta^{44/40}Ca$ values range from -0.69‰ to -1.40‰ and display a negative covariance with $\delta^{13}C$. We also find covariation between Sr/Ca ratios and $\delta^{44/40}Ca$ values, though Sr/Ca ratios have a narrow range of 0.09 to 1.23 mmol/mol. These data suggest that the stratigraphic variability in the Esmeralda Member is a result of local differences in the preservation of sediment chemistries rather than global changes in seawater chemistry. The $\delta^{44/40}Ca$ values that trend towards ~ -1.5‰ and correlate with high Sr/Ca ratios are interpreted to record neomorphism of aragonite under sediment-buffered conditions, preserving the $\delta^{13}C$ values of the primary sediment. In contrast, the $\delta^{44/40}Ca$ values that trend towards ~ 0.0‰ and correlate with low Sr/Ca ratios are interpreted to record neomorphism under fluid-buffered conditions and resetting of the primary δ13C values during early marine diagenesis. These results demonstrate the need for careful diagenetic screening of carbonate rocks before they can be used to correlate sections globally and construct age models.

The carbon-isotopic composition of carbonate platform sediments (Poster 13)
Anne-Sofie C. Ahm & John A. Higgins

Shallow marine carbonate sediments have been deposited on the ocean seafloor for more than ~3 billion years and are the most continuous geological archive of past seawater chemistry. Yet, these sediments are deposited in shallow restricted environments where the chemistry of the surface waters are significantly offset from the chemistry of the open ocean. As a result, it is difficult to directly link the geochemistry of these ancient sediments with changes in global geochemical cycles. Here we explore how local processes may be important in controlling the geochemistry and carbon-isotopic composition of platform carbonate sediments. First, we explore if submarine ground water discharge could be an important source of isotopically light DIC in carbonate platform environments. Second, we consider if anaerobic respiration in the water-column (methane oxidation and/or methanogenesis) could have a role in setting the carbon isotopic composition of ancient platform sediments. Finally, we propose that kinetic isotope effects associated with air-sea gas exchange of CO_2 may have an important, and yet unexplored, impact on the carbon-isotopic composition of carbonate sediments forming in shallow marine environments.

Early Paleozoic Reef-Margin Sedimentation and Biostratigraphy of the Ogilvie Platform at Nadaleen Mountain, Yukon, Canada (Poster 14)
James F. Busch, Maxwell H. Saylor, Tyler J. Allen, Karol Faehnrich, John F. Taylor, & Justin V. Strauss

The Cambrian–Devonian Bouvette Formation outcrops over large parts of central Yukon, Canada. Despite its broad lateral and temporal extent, relatively little is known about its precise age range, facies distribution, depositional history, and significance for early Paleozoic paleogeographic reconstructions of northwestern Laurentia (North America). At Nadaleen Mountain in east-central Yukon, the Bouvette Formation is remarkably well exposed and provides new insight into the transition between the southeastern Ogilvie platform and northern Selwyn basin. Here, we present preliminary data collected from this region during 2017 and 2018, including measured stratigraphic sections, biostratigraphic data, and detailed imagery acquired from Unmanned Aerial Vehicles (UAVs), in order to test the hypothesis that the Bouvette Formation locally preserves a platform margin reef and forereef succession. Preliminary field observations suggest the Bouvette Formation unconformably overlies previously undescribed coarse-grained volcaniclastic and carbonate rocks that record the initial establishment of the Ogilvie platform in the terminal Cambrian. These potential rift-related strata are overlain by a distinct forereef to upper slope succession with spectacular exposures of reef-margin facies. Preliminary biostratigraphic data from these strata provide Late Ordovician to Early Silurian age constraints. These observations not only provide an important new contribution to Yukon's early Paleozoic sedimentation history, but also identify an exceptional location to study carbonate platform–margin depositional environments.

The Kaltag-Porcupine fault system of Yukon and Alaska – evaluating large-scale terrane displacement in the Arctic (Poster 15)
Karol Faehnrich, Justin V. Strauss, William C. McClelland, & Maurice Colpron

The poorly documented Kaltag-Porcupine fault system of northern Yukon and Alaska may play a major role in accommodating mid-Paleozoic terrane transfer across the Arctic, as well as strike-slip displacement during the Mesozoic opening of the Arctic Ocean. This fault zone separates the North Slope subterrane of the composite Arctic Alaska terrane from autochthonous Laurentia. During the summer of 2017 and 2018, we conducted field work along the Porcupine River in northwestern Yukon and northeastern Alaska to: 1) assess the stratigraphy and provenance of Neoproterozoic–middle Paleozoic(?) strata along the Kaltag-Porcupine fault system, and 2) examine the displacement history of this major structure. Mesoproterozoic(?) to Neoproterozoic siliciclastic and carbonate rocks exposed along the Porcupine River form semi-coherent to incoherent fault-bounded blocks with evidence for polyphase folding, faulting, and pervasive brecciation. Mafic dikes of presumed Neoproterozoic (ca. 720 Ma?) age cut the aforementioned strata and are locally highly deformed. Ongoing field- and lab-based research aims to address stratigraphic correlations (or lack thereof) between these strata within the Kaltag-Porcupine fault system and coeval units on the opposite sides of the structure through a combination of carbon and strontium isotope chemostratigraphy, Nd isotope geochemistry, and U-Pb/Hf detrital zircon geochronology. Our preliminary results confirm that the Kaltag-Porcupine fault system is a profound margin-bounding strike-slip fault that must be accounted for in tectonic models for both Paleozoic terrane transfer and the Mesozoic opening of the Canada Basin.

Tonian Geobiology of Svalbard (Poster 16)

Timothy M. Gibson, Justin V. Strauss, Ross P. Anderson, Alexie E.G. Millikin, Alan D. Rooney, Eva Legge, Tyler J. Mackey, Kristin D. Bergmann, & Roger E. Summons

Global paleontological and biomarker datasets suggest that eukaryotes diversified and rose to ecological dominance in the middle Neoproterozoic Era; however, many compilations that form the basis of these interpretations lack substantial data from early Neoproterozoic sedimentary successions. The ca. 950–820 Ma Veteranen Group of Svalbard, Norway, represents a largely unexplored record to expand our current understanding of the nature and pace of Tonian eukaryotic diversification. Here we present preliminary data and outline future plans for interrogating this understudied sedimentary succession as a means to calibrate biological evolution and global environmental change through the Tonian Period.

The Veteranen Group comprises ~4 km of mixed carbonate and siliciclastic strata at the base of the Hecla Hoek series in Svalbard, Norway. A remarkably well-preserved and nearly complete exposure of the Veteranen Group outcrops along Lomfjorden in northeastern Spitsbergen. However, lowermost Veteranen Group carbonate units are only exposed on the adjacent island of Nordaustlandet, and correlations between these locations remain unresolved.

We use carbon isotope chemostratigraphy in conjunction with sedimentological and sequence stratigraphic analysis to correlate lower Veteranen Group carbonate facies across the islands of Spitsbergen and Nordaustlandet. These results represent the first step towards reconstructing the depositional history and stratigraphic architecture of this sedimentary basin and will provide critical paleo-environmental context for future data generated through this project.

We also present preliminary hydrocarbon biomarker data from Veteranen Group organic-rich carbonate samples, collected using rigorous sampling and preparatory procedures that significantly reduce the risk of contamination. This ongoing work may shed light on the critical interval between the emergence of crown group eukaryotes and their ascent to ecological dominance. Alternately, if intact biomarkers are not preserved in these samples, the data may offer an indication of the thermal maturity of this sedimentary package. Ultimately, this project aims to generate age-calibrated paleontological and biomarker datasets within a robust paleo-environmental framework from one of the best preserved Tonian successions in the world.

How do shallow-water carbonates record sea level and seawater chemistry? (Poster 17)
Emily C. Geyman & Adam C. Maloof

Much of our understanding of Earth history comes from shallow-water carbonates because deep ocean archives tend to get metamorphosed or subducted at plate margins. However, little work has been done to calibrate how sea level, ocean chemistry, and early marine diagenesis are recorded in modern shallow carbonates. As a result, interpretations of climate and environmental change from ancient stratigraphy have large and unquantified uncertainties. Modern Bahamian surface sediments vary from -6 to +9 permil in d13C and -7 to +2 permil in d18O. If we include meteorically altered late Pleistocene sediments in the Bahamas, the d13C range increases to -11 to +9 permil, the full range of the Neoproterozoic Era. We present 5,000 new measurements of the trace element and carbon and oxygen isotopic composition of benthic forams, solitary corals, calcifying green algae, ooids, coated grains, and lime mud from the modern Bahamas. We integrate these geochemical data with new water depth and sedimentary facies maps, and implement probabilistic techniques to calculate the relative likelihoods that observed facies transitions and d13C fluctuations in ancient stratigraphy represent global changes in sea level and ocean chemistry rather than natural intra-shelf variability.

Abiologic formation process of nodular and digitate siliceous structures in the Mars-analog hot spring environment of El Tatio, Chile (Poster 18)
Jian Gong, Carolina Munoz, John Roma Skok, & Mark van Zuilen

Nodular and digitate silica sinters are distinctive features in hot spring environments on Earth. Their laminar growth patterns and association with microbial mat communities have previously been interpreted as a morphological biosignature. The recent discovery of digitate structures in a silica sinter on Mars, however, has prompted the question whether a purely abiologic process can be responsible for their formation. Here we demonstrate that digitate structures in silica sinters of the El Tatio geothermal field in Chile are all growing against the locally prevailing eastward wind direction, and have laminar growth patterns of silica, halite, and sand grains that coincide with day-night cycles of thermal- and wind-driven evaporation and rewetting. Filamentous cyanobacteria mainly inhabit subaqueous, etched-out cavities that are cross-cutting the primary laminations of the digitate structures. By implication, we suggest that the digitate silica structures observed on Mars, were formed by this purely abiological wind-driven evaporation process as well.

Three-dimensional reconstructions of recent and ancient oolites (Poster 19)
Bolton Howes, Akshay Mehra, & Adam Maloof

The presence and shape of ooids are sensitive paleoenvironmental indicators of water depth and mode of transport. On modern carbonate platforms, the size and shape distribution of ooids vary between environments, suggesting they could be used to produce more specific paleoenvironmental reconstructions of ancient carbonate platforms. Unfortunately, the similar physical properties of ooids and the lithifying cement prohibits physical separation or computed tomography. The inability to make measurements on the full three-dimensional (3D) ooid has led to researchers relying on measurements from thin sections or polished surfaces, which underestimates the true diameter and precludes measurements of the shape metrics such as sphericity.

We use the Grinding, Imaging and Reconstruction Instrument (GIRI) in conjunction with a machine learning image classification routine to build 3D models of a Holocene oolite from the Bahamas. We use such models to directly measure the size and shape of lithified ooids. Additionally, we reconstruct Neoproterozoic giant ooids from the Etina Formation in Australia and establish that the volume-shape history preserved in the lamellae provide a growth history of the giant ooids. By comparing the size and shape of ooids estimated from 3D models to two-dimensional measurements from randomly generated planes intersecting the rock, we show that studies of size, shape, and growth histories of ooids require 3D data because two dimensional measurements introduce substantial uncertainties and errors.

Abundant 4-methyl diasterenes with enriched carbon isotopic compositions in the Maoming carbonaceous shale, SE China (Poster 20)
Yujiao Zhang, Hong Lu, Guoying Sheng, & Ping'an Peng

In this study we analyzed the organic biomarkers and their carbon isotopic compositions from a lacustrine carbonaceous shale from Eocene deposits located in Maoming in Southeast China. Diasterenes (C27~C29) and 4-methyl diasterenes (C28~C30) were more abundant than most n-alkanes in the TIC chromatogram of the saturated hydrocarbon fraction. Moreover, the rearranged 4-methylsterenes contained much heavier δ13C values (-17.2 to -18.1‰ V-PDB) occurred, which were larger than those of n-alkanes (-23.4~-28.7‰). Most importantly, the δ13C values of diasterenes were also similar to those of C30 4-methyl steranes (-13.1 to -16.4‰).

Together the similar distributions and stable carbon isotopic compositions indicate that the rearranged 4-methylsterenes shared the same biological source as the saturated 4-methylsterane homologues, which usually regarded deriving from dinoflagellates [1]. Considering the dinoflagellate species had been reported in the Maoming oil shale [2], which not only possess the CO2-concentrating mechanism but also provide the initial 4-methyl cholesterols for the backbone rearrangement, their heavy δ13C values of these steroids with 4-methyl diasterenes and steranes in this study could be well explained by its assimilating HCO3- as carbon source since bicarbonate C is usually 8.1‰ enriched (in δ13C) over dissolved CO2 [CO2(aq)] in lake water [3]. The presented obvious backbone rearrangement of the sterenes could be attributed to the presence of high amounts of kaolinite (54.4%) which dominated the clay mineral compositions of the shale [4].

[1] Volkman (2008) Appl Microbiol Biotechnol. 60, 495-506. [2] Fu et al. (1985) Geochimica. 2, 99-114. [3] Hoins et al. (2016) J Exp Mar Biol Ecol. 481, 9-14. [4] Sieskind et al. (1979) Geochim Cosmochim Ac. 43, 1675-1679.

Using sulfate 17O isotope records to understand the global sulfur cycle (Poster 21)
Anna Waldeck & David Johnston

The triple oxygen isotope composition (16O,17O,18O) of seawater sulfate records information about atmospheric composition (pO2/pCO2), weathering, and microbial sulfur metabolisms. An understanding of these processes through time is dependent on the history of seawater sulfate, as recorded in ocean sediments in the form of barite (BaSO4) and ocean basins as sulfate evaporite (CaSO4). The marine barite record extends over the past >100 million years, is highly resolvable, and has been measured for δ18O as well as δ34S. Marine evaporites have also been measured, and have the potential to cover older time periods, though they do not form a continuous record. Although powerful, the use of δ34S and δ18O leaves many features of the Cenozoic – Cretaceous record of weathering and metabolisms unexplained. This is largely due to uncertainties about the isotopic fractionation associated with each process within this cycle. The 17O isotope carries different information from 18O, but does carry a level of isotopic predictability (i.e. fractionations within the ocean are strictly mass-dependent). A complementary record of the Δ17O of marine sulfate will deepen our understanding of climate stability and atmospheric pO_2/pCO_2 through time. Here I present measurements of δ18O and Δ17O of marine barite $BaSO_4$ (Cenozoic to modern) and sulfate evaporites (Triassic). I interpret these measurements in the context of the sulfur cycle to make a prediction for changes in atmospheric pO_2/pCO_2 through time.

A positive test for the Greater Tarim Block at the heart of Rodinia: Mega-dextral suturing of supercontinent assembly (Poster 22)

Bin Wen, David A.D. Evans, Chao Wang, Yong-Xiang Li, & Xianqing Jing

The Tarim craton and neighboring terranes in Central Asia, i.e., the Greater Tarim Block (GTB), have been proposed to occupy a “missing-link” position at the heart of the Neoproterozoic Rodinia supercontinent between Australia and Laurentia. Such a reconstruction is tested with new paleomagnetic data from the GTB, and it is found that high-quality paleomagnetic poles conform to a stable missing-link configuration enduring from ca. 900 to 720 Ma. Integrating the new results with compilations of tectonomagmatic activity and geochronology throughout the GTB, we propose a novel paleogeographic model for Rodinia assembly. In our model, following initial phases of quasi-orthogonal subduction and collisions between southern GTB-Australia and northern GTB-Laurentia at ≥1070 Ma, the Rodinia supercontinent completed its assembly through a mega-dextral transpressional shearing along the Tarimian orogen. This scenario has noteworthy parallels to the history of collisions that created Pangea, and implies a more complicated geodynamic process for supercontinental assembly than previously proposed.

Ediacaran-early Cambrian Geomagnetic Field: A Unique Geophysical Circumstance Surrounding the Explosion of Multicellularity (Poster 23)

Zheng Gong & David A.D. Evans

It is well known that Earth’s magnetic field is crucial to life. With a rapid growing paleomagnetic dataset, our understanding of the Ediacaran-early Cambrian geomagnetic field should, in principle, provide a solid framework for interrogating influences of the geodynamo on the biological evolutions at the dawn of animal life on Earth. Yet, reconstructions of Ediacaran-early Cambrian geomagnetic field have been notoriously difficult to generate, due primarily to the baffling variance of paleomagnetic data, even from individual continents within brief time intervals on the order of a few million years or less. Several models have been proposed to reconcile the enigmatic paleomagnetic data, and each has profound implications on the biotic extinction and innovation across the Ediacaran-Cambrian boundary. For example, true polar wander has been suggested to explain the incompatible Ediacaran paleomagnetic data. True polar wander occurs when Earth rotates with respect to its spin axis to reorient its moments of inertia. Rapid true polar wander could initiate large-magnitude of sea level fluctuations, disturb the ocean geochemical cycles and presumably influence the directions of biotic radiation. Other models argue that the geomagnetic field was significantly different from the modern in either its structure, or intensity, or both. Paleointensity and magnetostratigraphic studies show that the Ediacaran field was much weaker and reversed hyperactively. Such behaviors would effectively reduce the magnetic shielding of the solar wind, and enhance the possibility of oxygen escaping into interplanetary space, both of which play important roles in life evolution. In this presentation, we would like to summarize our current knowledge on the Ediacaran-early Cambrian geomagnetic field gained from paleomagnetic studies, and discuss its biotic significance.

A Pangea-like Rodinia in the Tonian Inertial Interchange True Polar Wander frame (Poster 24)
Xianqing Jing, Zhenyu Yang, Yabo Tong, David Evans, & Yingchao Xu

A new paleomagnetic and geochronological study was conducted on the Tonian Chengjiang Formation from Yunnan province, South China, to examine the recent reported inertial interchange/ true polar wander event during 825-750 Ma and clarify the position of South China in Rodinia. Detailed thermal demagnetization revealed a high temperature component (H1) with unblocking temperature up to 690ºC. Passing both the fold test and reversal test, and recording at least 5 polarity chrons suggest that the H1 is a primary remanence. Paleomagnetic pole (CJH1, 33.4°N, 56.1°E, dp/dm=7.3/8.9) calculated from the H1 has no similarities to the Phanerozoic apparent polar wander path of South China. SHRIMP II U-Pb zircon data from a tuff bed near paleomagnetic sampling sites suggest the H1 pole is ~800 Ma. Combined the reported Tonian paleomagnetic results from South China and Svalbard, we suggest a ~63° IITPW event during 825-805 Ma, and then a weak TPW event until 790 Ma. Under this IITPW paleomagnetic frame and using the reliable Tonian paleomagnetic results from other continents, we reconstruct the main part of the Rodinia. This new configuration of the Rodinia demonstrates that South China and India located at its north periphery, and within the polar or high latitude zone during ~900-750 Ma. The Tarim was located between Australia-Mawson and Laurentia as a missing-link block. This reconstruction of Rodinia suggests lots of continents distributed at the high latitude-polar zone in both hemisphere, which is similar to the Pangea. In addition, it seems that the evolution of Rodinia and its impacts on the Earth's system were parallel to the Pangea during the late Paleozoic period.

Volcanic controls on seawater sulfate over the past 120 million years (Poster 25)
Tom Laakso, Anna Waldeck, Francis Macdonald, & David Johnston

Past environmental change is recorded in marine sediments, where biogeochemical processes translate environmental signals from seawater into mineralized forms. Changes in the late Mesozoic/Cenozoic sulfur cycle are inferred from the sulfur isotopic composition of marine barite. These data have been interpreted as step-wise change sulfur cycle at ~50 and ~100 Ma due to shifts in biogeochemical cycling or tectonic forcing, but the mechanisms remain debated. Here we demonstrate that long-term changes in burial processes, punctuated by sulfur outgassing associated with emplacement of large igneous provinces, cleanly explains the structure in late Mesozoic/Cenozoic marine sulfate concentration and isotopic records. This solution provides a quantitative picture of the last 120 million years of change in the ocean's largest oxidant reservoir.

Methane in the Precambrian Atmosphere (Poster 26)
Tom Laakso & Dan Schrag

Biological methane production occurs in anoxic terrestrial wetlands and in sulfate depleted marine sediments. It has been suggested that methanogens may have flourished in the anoxic and sulfate-poor environments of the Precambrian ocean, generating large amounts of methane that would have accumulated in the atmosphere and warmed the early Earth. However, modern ferruginous and sulfate-poor environments such as Lake Matano are not very efficient at generating methane, converting only about 5% of organic carbon to CH_4 despite the lack of alternative remineralization pathways. We apply this restriction to a simple model of marine carbon cycling in order to generate new estimates of methane concentrations in the Precambrian atmosphere. Our results suggest that atmospheric methane concentrations did not exceed 1 ppm, or about twice the pre-industrial value, at any time during the Proterozoic. Following the evolution of oxygenic photosynthesis, the maximum methane concentration in the Archean atmosphere was order 100 ppm, but no more than 1 ppm if steady state oxygen concentrations were greater than 10^-8 present atmospheric levels. Substantially larger methane concentrations are only possible before the evolution of oxygenic photosynthesis.

The triple oxygen isotope composition of Precambrian chert (Poster 27)
Frasier L. Liljestrand, Andrew H. Knoll, Nicholas J. Tosca, Phoebe A. Cohen, Francis A. Macdonald, Yongbo Peng, & David T. Johnston

The temperature and chemistry of early seawater have both been inferred from the isotopic composition of Precambrian chert (SiO2), a precipitated rock formed on or within sediments of known basinal distribution. The δ18O of cherts robustly shows a linear increase through time, but this signal has been interpreted in a number of conflicting ways. For example, changing δ18O has been hypothesized to reflect the product of cooling ocean temperatures, but also as the signature of evolving seawater δ18O composition or the product of later stage diagenesis (where measured δ18O reflects the composition of diagenetic fluids). We suggest this uncertainty can be resolved through the additional measurement and interpretation of the minor oxygen isotope 17O (noted as Δ'17O) in conjunction with δ18O. We present a suite of triple oxygen isotope data on stratigraphically constrained Precambrian cherts (both peritidal chert nodules in carbonates and iron formation silica). These mineralogically well-defined data allow for the first stratigraphic tests of the fidelity of 17O in SiO2. We apply a Monte Carlo resampling model approach to test the features of the competing hypotheses noted above but here include critical constraints from 17O. The results suggest that there has been no systematic change in ocean temperature through time, nor a structured shift in the δ18O of seawater. Instead the chert δ18O and Δ'17O records are a product of diagenesis with secondary, higher-temperature, meteoric-derived groundwater.

Early Paleozoic Bioturbation and its Influence on the Global Marine Phosphorus Cycle (Poster 28)
Lidya G. Tarhan, Mingyu Zhao, & Noah J. Planavsky

Bioturbation critically shapes not only seafloor ecology and sediment properties but also ocean-wide biogeochemical cycling. In light of strong bioturbation-biogeochemical feedbacks in modern systems, the evolutionary development of the sediment mixed layer likely had important implications for contemporaneous biogeochemical (e.g., C, P, O and S) cycling. Multiple lines of evidence indicate that, following the appearance of the first sediment-penetrative burrows during the late Ediacaran and early Cambrian, the development of bioturbation was a protracted process, and that the appearance of intensively and deeply mixed sediments lagged significantly behind relatively early advances in infaunal seafloor colonization. However, the precise biogeochemical impact of early Paleozoic bioturbation has, particularly for the P cycle, remained more poorly resolved, in part because attempts to model C-P-O feedbacks have neglected key parameters that could shape the global P cycle.

To address this issue, we have developed a new, multi-component reaction-transport diagenetic model that includes the complexity necessary for a full parameterization of marine P burial—foremost, formation of carbonate fluorapatite (CFA), the primary marine P sink—allowing us to explore the impact of both bioturbation and other environmental factors on P cycling. Like previously published modeling exercises, we find that increases in bioturbation intensity and depth can be associated with increases in CFA and total P burial. However, we observe that the relationship between bioturbation and P burial is complex and non-linear. Different types of bioturbation (i.e., biodiffusion and bioirrigation) have competing effects upon P burial. Moreover, in contrast to recent modeling efforts, we find that, rather than operating as a stabilizing feedback, bioturbation appears to enhance the sensitivity of the C-P-O system to perturbation.

How should we interpret 17O signals of geologically preserved sulfate? Insights from modern Himalayan rivers (Poster 29)
Jordon D. Hemingway, Haley Olson, Alexandra V. Turchy, Edward T. Tipper, David T. Johnston

Tropospheric O2 carries a mass-independent minor isotope signal (17O/16O, reported as Δ’17O), the magnitude of which has been shown to scale with the pO2 / pCO2 ratio. This tropospheric Δ’17O signal is thought to be incorporated within riverine sulfate (SO42-) during oxidative weathering of iron-sulfide minerals such as pyrite (FeS2) on land. The 17O composition of geologically preserved sulfate is thus becoming a widely used proxy to reconstruct past atmospheric compositions. However, the utility of this proxy is hindered by the current dearth of sulfate Δ’17O measurements in modern river systems. To remedy this, here we report Δ’17O values of sulfate from a suite of nested rivers draining the southern flank of the Nepal Himalaya. We find that Δ’17O is positive in sulfate-rich headwaters that drain pyrite-rich terrain, thus precluding significant direct incorporation of tropospheric O2. Δ’17O signals decrease moving downstream, likely due to isotopic overprinting by microbial sulfate reduction and subsequent re-oxidation. These results carry implications for interpreting Δ’17O signals of geologically preserved sulfate.

The Microbial World

Iron-Oxidizing Bacteria in an Iron-Oxidizing World: Consequences for Physiology and the Environment (Poster 30)
Isabel Baker & Peter Girguis

Some three billion years ago, life evolved the means to mediate redox reactions. This biologically-mediated electron transfer from a reduced donor to an oxidized acceptor molecule enabled organisms to govern the rates of flux, and to directly harness energy from redox reactions. This biological leveraging of electrochemistry has been a major boon to life. That said, biologically-mediated reactions are only viable if the substrates are available in the environment, at biologically relevant concentrations and oxidation states. The challenge for life on Earth—especially at the onset of atmospheric oxygenation—is that redox reactions can occur abiotically, sometimes at rates so rapid that the biologically-available electron donors and acceptors react before microorganisms can access them for energy metabolism. Aerobic iron oxidizing bacteria (FeOB) face some of the greatest challenges in this regard as they continuously compete compete with potentially high rates of abiotic iron oxidation in today's oxidizing atmosphere and ocean. However, based on our preliminary data, FeOB have evolved sophisticated systems to compete with abiotic processes. In an ongoing investigation of the oxygen physiology in a vent-dwelling FeOB, we have observed that, in comparison to abiotic and killed controls, FeOB actively change the redox chemistry of their environment. We are currently exploring the molecular, physiological, and ecological mechanisms by which this is possible. We hypothesize that iron-oxidizing microbes play a key role in mediating the redox state of their environment and thus, potentially, its habitability.

Structural and phylogenetic argument for the uniqueness of microbial sulfur disproportionation (Poster 31)
E. Bertran, L. Ward, B. Kaçar, & D. T. Johnston

Microbial sulfur disproportionation (MSD) drives the oxidative sulfur cycle, and occupies a narrow environmental niche. As such, MSD and its isotopic signature have been used to address changes in the nature of the sedimentary oxidative sulfur cycle over earth history. MSD bears similarities in terms of its biochemistry, evolutionary history, and sulfur isotope fractionation behaviors to microbial sulfate reduction (MSR). Full genome sequencing and enzyme extract studies reveal sulfur disproportionating prokaryotes (SDP) possess the full enzyme machinery for MSR, a vastly more energetically favorable metabolic pathway. However, these strains are incapable of growth in the presence of sulfate as electron acceptor. Understanding the mechanistic differences between MSR and MSD can open new avenues for the nature of this metabolic plasticity, or lack thereof, and refine our understanding of the evolutionary history of these metabolisms, and their respective isotopic signatures. We hypothesized that differences in the structure of key enzymes fully or partially hinders function. We built models for the enzyme APS reductase, a key component of both MSR and MSD, for a number of sulfate reducing bacteria, and SDP. Our findings suggest the existence of metabolism-specific structural features, including a substantial truncation in the C-terminus of the subunit, and altered surface electrostatic potential distribution around the channel entrance of the subunit together with the systematic substitution of Arg160 for a lysine in SDP. These bear potential consequences for enzyme regulation, oligomerization, and interaction with electron carriers. Using the truncated C-terminal sequence as a marker, phylogenetic relationships derived from the alignment of a wider set of taxa suggests a shared capacity for MSD among lineages possessing this marker, with the potential to pinpoint evolutionary transitions between MSR and MSD. This combined protein structure and genetic marker approach allowed the identification, for the first time, of a potential enzymatic mechanism and a phylogenetic tool to differentiate MSD and MSR. This will enable revisiting their shared evolutionary history, and respective role in the sulfur cycle through Earth history.

How do Zetaproteobacteria oxidize Fe(II)? Validating the Fe oxidation pathway via meta-omics at Fe-rich hydrothermal vents (Poster 32)
Sean M. McAllister, Shawn W. Polson, & Clara S. Chan

Zetaproteobacteria create extensive Fe oxide mineralized mats at deep sea hydrothermal vents, making them an ideal model system for microbial Fe oxidation. Comparative isolate genomics has revealed a hypothetical Fe oxidation pathway featuring the putative Fe oxidase Cyc2, but this pathway requires further support, particularly in the environment. Toward this, we analyzed the core genome and metatranscriptomes of marine Fe-oxidizing Zetaproteobacteria, taking advantage of 53 new high-quality metagenome assembled genomes that we reconstructed from Fe mats sampled at hydrothermal vents at the Mid-Atlantic Ridge, Mariana Backarc, and Loihi Seamount, Hawaii. We confirm the widespread distribution of the putative Cyc2 Fe oxidation pathway within all represented Zetaproteobacteria lineages, with no other known alternative energy-generating metabolisms found in the core genome. Using metatranscriptomics, we were able to validate the high expression of the putative Fe oxidation pathway in diverse Zetaproteobacteria under multiple environmental conditions, as well as shipboard incubations. The putative Fe oxidase gene, cyc2, was highly expressed in situ, often as the highest expressed gene. The cyc2 gene also showed increased expression for all Zetaproteobacteria after Fe(II) addition to dormant samples. Our results help validate the Cyc2-based Fe oxidation pathway and demonstrate its significance in marine Fe-mineralizing environments.

The role of geranylgeranyl reductase in Sulfolobus islandicus GDGT lipid cyclization (Poster 33)
Beverly K. Chiu, Alice Zhou, Changyi Zhang, Yuki Weber, Rachel J. Whitaker, Ann Pearson, Jacob Waldbauer, & William D. Leavitt

The membranes of numerous Archaea are adapted for extreme conditions by the incorporation of cyclopentyl rings in their isoprenoid membrane lipids, glycerol dialkyl glycerol tetraethers (GDGTs). The mechanism for GDGT cyclization is unknown, though numerous factors, such as temperature, pH, and electron donor or acceptor availability, are known to affect the degree of GDGT cyclization. A recent hypothesis suggested that cyclization is dependent on geranylgeranyl reductase (GGR), an enzyme known to saturate the double-bonds in the isoprenoid lipid precursor digeranylgeranyl glycerol-1-phosphate (DGGGP) to form GDGT-0, which contains no cyclopentyl rings. It was proposed that electron-limiting conditions would slow GGR cofactor regeneration, limiting DGGGP saturation reactions and instead lead to DGGGP cyclization, producing GDGTs with increasing ring numbers (e.g., GDGT-1, GDGT-2, etc.). Here we investigate this hypothesis by performing GGR over- and under-expression experiments with the thermoacidophilic archaea Sulfolobus islandicus. Preliminary results showed that relative to baseline GGR expression, GGR over-expression had a significant effect on S. islandicus growth phenotypes and lipid profiles, while GGR under-expression did not have significant effects. The over-expression of GGR caused slower growth rates, decreased maximum optical density, and a subtle decrease in the degree of GDGT cyclization (ring index number) over the course of growth. To better interpret these results, quantitative proteomics and transcriptomics are underway to compare the effects of GGR over-expression versus baseline expression in S. islandicus across a number of growth conditions. These approaches will help us understand the mechanism(s) by which GGR over-expression affects GDGT cyclization under optimal and sub-optimal environmental conditions.

Quantifying the effect of environmental drivers on lipid composition shifts in S. acidocaldarius (Poster 34)
Alec Cobban, Alice Zhou, Beverly Chiu, Yuki Weber, Felix Elling, Ann Pearson, & William Leavitt

The composition and abundance of archaeal lipids are commonly used in paleotemperature proxies due to the longevity of the core lipids in marine and lacustrine sediments. These paleotemperature reconstructions rest on the observation that the relative abundance of cyclopentyl and cyclohexyl rings in membrane lipids change in a predictable manner as cells respond to the physiological environment. We performed experiments to control the environmental conditions and produce systematic shifts in the cyclization of isoprenoid lipids of the model thermoacidophile Sulfolobus acidocaldarius. We independently varied the pH, temperature and agitation speed of the cultures and determined their growth rate and lipid composition. The average degree of cyclization in Glycerol Dialkyl Glycerol Tetraether lipids (GDGTs), commonly calculated as the ring index (RI), correlated with growth rate for specific environmental conditions. RI was linearly correlated with changes in temperature, weakly linearly correlated with changes in pH and non-linearly correlated with changes in agitation speed. These results are consistent with previous literature for temperature and pH and are novel in the case of agitation speed. We are currently testing how changes in dissolved oxygen concentration affect growth rate and lipid compositions by providing both fixed gas flow rates and agitation. Our results to-date further our understanding of how environmental parameters drive archaea to alter their membrane compositions and highlights the need for detailed experimental work on a wide array of environmentally relevant strains. Results from these experiments allow us both to better analyze new archaeal lipid data and to reanalyze existing paleoclimate interpretations to account for a broader range of environmental drivers

The ecology and physiology of extracellular electron uptake by deep sea hydrothermal vent microbes (Poster 35)
Brandon C. Enalls, Jennifer Delaney, & Peter Girguis

Deep sea hydrothermal vents are characterized by the emission of hot, chemically reduced fluids from the seafloor into cold, oxic seawater through geological structures called chimneys. These chimneys have lower reduction potentials than the ambient oxygenated seawater. It has been hypothesized that microbial communities living on the outer surface of a chimney can respond to this shuttled source of electrons, and as such, we are interested in examining the effects that conductive electron-rich surfaces have on the composition and activity of native hydrothermal vent microbial communities. Through the use of a continuous-flow bioelectrochemical system, chimney samples were incubated in the presence of carbon cloth electrodes. Preliminary 16S rRNA gene analyses reveal distinct microbial communities found on cathodically-poised electrodes compared to those held on open circuits. The combination of bioorthogonal non-canonical amino acid tagging (BONCAT) and fluorescence in situ hybridization (FISH) will allow the use of fluorescence microscopy to visualize and taxonomically identify organisms that are metabolically active under these experimental conditions. This study will help us understand how electroactive surfaces might stimulate microbial communities in situ, shedding light on novel geomicrobiological interactions at hydrothermal vent environments.

Comparative Genomic Analysis of Iron-Oxidizing Thiomonas Isolates from Acid Mine Drainage (Poster 36)
Michelle Hallenbeck, Nanqing Zhou, Denise Akob, Kirsten Küsel, & Clara Chan

Certain acid mine drainage (AMD)-derived microorganisms can sequester and detoxify metals, which could be useful for bioremediation if we can determine the mechanisms and controls. We have been working with Thiomonas strains FB-6 and FB-Cd, isolated from an AMD site in Ronneburg, Germany. While Thiomonas spp. are known as mixotrophic sulfur-oxidizers and As-oxidizers, the FB strains could oxidize Fe, which would allow them to efficiently remove Fe and other metals via co-precipitation. However, Thiomonas Fe oxidation physiology and mechanisms are not well-established. Therefore, we conducted a genomic analysis to investigate their genetic mechanisms of Fe oxidation, other metal transformations, and additional adaptations, comparing the two FB strains with 12 other isolates. Phylogeny of the 16S rRNA gene and concatenated ribosomal protein sequences showed that the FB strains fall within a relatively novel group of Thiomonas (Group II), which includes the one other strain (b6) with evidence of Fe oxidation. All AMD-derived isolates, including the FB strains, have the putative iron oxidation gene, cyc2, but only the two FB strains possess the putative Fe oxidase genes mtoAB. Surprisingly, AMD-derived strain genomes showed few unique functions when compared to strains isolated from other environments; in fact, all 14 Thiomonas genomes included metal resistance genes, suggesting utility in other Thiomonas environments. However, AMD-derived strains did have a higher proportion of genes related to energy production and inorganic ion transport/metabolism. There is more genetic difference between the two phylogenetic groups I and II, implying that phylogeny determines genetic content more than source environment. The two FB strain genomes contain the highest number of strain-specific gene clusters, greatly increasing the known Thiomonas genetic potential. We will report on the FB strain pathways in the context of the Thiomonas pangenome, as well as culture-based evidence of iron oxidation, with implications for environmental roles and remediation potential.

Molecular characterization of natural dissolved organic matter from eukaryotic algae and cyanobacteria (Poster 37)
Rui Jin & Maya Gomes

It has recently been suggested that eukaryotic algae (EA) rose to prominence at ~0.65Ga. We hypothesize that this transition in the dominant biomass in the ocean from cyanobacteria to eukaryotic algae resulted in a major change in the composition of marine organic matter. Importantly, because remineralization reactions may operate at different rates using different carbon donors, a shift from cyanobacterial to eukaryotic algae biomass at ~0.65Ga may have affected how carbon is cycled through the ocean-atmosphere system. In order to test this hypothesis, we must first document the molecular characteristics of dissolved organic matter released by cyanobacterial versus eukaryotic algae biomass after cell death and how they influence rates of various organic carbon remineralization reactions.

We have conducted Orbitrap high resolution mass spectrometry (HRMS) with electrospray ionization in both positive and negative polarity modes on dissolved organic matter released by eukaryotic algae (Scenedesmus obliquus and Chlorella vulgaris) and cyanobacteria (Synechocystis sp. and Synechococcus leopoliensis), in order to determine the initial molecular characterization of phytoplankton dissolved organic matter. Three-dimensional van Krevelen diagrams show similar patterns as previous studies of eukaryotic algae. By also analyzing dissolved organic matter from cyanobacteria, we are able to document the differences between organic matter sourced from cyanobacteria versus eukaryotic algae. DNA sequencing of the biomass confirms their taxonomic affinity. Both experiments lay the groundwork for evaluating how the composition of dissolved organic matter changes as natural populations of microorganisms consume organic matter sourced from cyanobacteria versus eukaryotic algae and how these changes influence geochemical patterns preserved in the sedimentary record.

Phylogenetic history of scytonemin biosynthesis proteins (Poster 38)
Erik Tamre & Gregory P. Fournier

Cyanobacteria rely on access to sunlight for photosynthesis, but good access comes with considerable stress from UV radiation. To protect themselves, cyanobacteria make scytonemin, a photoprotective pigment absorbing in the UV range. In some high-albedo environments, the need for such a pigment is particularly obvious: high quantities have been found in the top layers of modern polar cyanobacterial mats, for instance. We present a phylogenetic history of proteins involved in scytonemin biosynthesis, looking out for differentiation, radiation, and transfer during periods when environmental conditions might make UV protection especially important. We particularly focus on the Cryogenian (720-635 Ma), since cyanobacterial photosynthesis in cryoconite ponds on top of the ice is one potential mechanism for continued primary production during the Cryogenian glaciations. This mechanism would expose cyanobacteria to a highly reflective environment under a thinner ozone layer than today – potentially a strong selective pressure on UV protection pathways. The study is intended as a first step in a broader search for a phylogenetic signature of Neoproterozoic glaciations.

Evolution of Photosynthesis in the Chloroflexi Phylum (Poster 39)
Lewis M. Ward, Patrick M. Shih, James Hemp, Shawn E. McGlynn, & Woodward W. Fischer

The Chloroflexi are a metabolically diverse phylum of bacteria including filamentous anoxygenic phototrophs possessing the 3-hydroxypropionate bicycle for carbon fixation. It has been proposed that the Chloroflexi were among the earliest phototrophic bacteria, but the recent discovery of diverse new Chloroflexi—including aerobic and anaerobic heterotrophs, photoheterotrophs, and phototrophs using the Calvin cycle for carbon fixation—has suggested a more complicated history for this phylum. Here, we integrate multiple approaches for understanding the evolution of metabolism in the Chloroflexi, including recovery of novel lineages from metagenomic datasets, phylogenetic analysis of phototrophy, respiration, and carbon fixation genes, and cross- calibrated Bayesian relaxed molecular clock-based estimates for the age of Chloroflexi lineages. We demonstrate that the phototrophic Chloroflexi are relatively young, having evolved after the Great Oxygenation Event and the acquisition of aerobic respiration. The 3HP bicycle evolved within the Chloroflexi less than 1 billion years ago. Furthermore, phototrophy, respiration, and carbon fixation have been received by and exchanged within the Chloroflexi via horizontal gene transfer. Overall, our analyses reveal a complicated history of metabolic evolution in this phylum driven by horizontal gene transfer, with major radiations having occurred after the Great Oxygenation Event.

On the Relationship Between Atmospheric Oxygen and the Origin of Eukaryotes (Poster 40)
Daniel P. Schrag & Christopher P. Kempes

Understanding the interaction between the evolution of the surface environment over Earth's history and the evolution of life is a fundamental objective of geobiology. Previous work has proposed an explanation for the rise of large, multicellular animals following the Marinoan glaciation, and then the extraordinary diversity that develops through the Cambrian Explosion as the result of a rise in atmospheric oxygen followed by the later evolution of predation, which resulted in an arms race in offensive and defensive adaptations. The endosymbiont theory proposed by Lynn Margulis includes no parallel explanation for the timing of the origin of the first eukaryotic organisms. We propose a simple theory based on observed scaling relationships between metabolic rates and cell sizes of prokaryotic and eukaryotic cells. We propose that prior to the Great Oxidation Event at approximately 2.4 Ga, very low oxygen levels ($<10^{-6}$ PAL) limited the benefit of predation, as early heterotrophs were limited by access to electron acceptors, not by food. In addition, anaerobic metabolism of organic carbon molecules provides far less energy than aerobic respiration, limiting the evolutionary advantage of larger cell size. Following the Great Oxidation Event, higher energy yields from aerobic respiration, combined with removal of the severe limitation of electron acceptors, made microbial predation attractive. We suggest Margulis's endosymbiosis occurred in response to the ecological pressure from the origin of such predation that was allowed by the change in surface redox conditions. We present various modern scaling relationships that support this idea - which is essentially the microbial analogue for the predation hypothesis for the Cambrian Explosion.

Developing model neutrophilic iron-oxidizing microbes for exploring Fe oxidation pathways by transcriptomics (Poster 41)
Nanqing Zhou, Sean McAllister, & Clara Chan

As the most abundant transition metal in the lithosphere, iron is involved in many significant geochemical reactions, notably the immobilization of metals and nutrients. Despite much study of the microbially-driven iron cycle, the mechanism of biotic iron oxidation by neutrophiles is still elusive. Recent genomics, proteomics and metatranscriptomics work on Fe-oxidizing bacteria isolates and microbial mats strongly suggests that an outer membrane c-type cytochrome, Cyc2, could be a common iron oxidase. Another outer membrane cytochrome c, MtoA, has also been put forth as a potential iron oxidase. However, it still remains unclear to which extent Fe-oxidizers use either one of these putative Fe oxidases.
The neutrophilic Fe-oxidizer Sideroxydans lithotrophicus ES-1 has both cyc2 and mtoA in its genome, giving the opportunity to explore both. Furthermore, ES-1 can also grow by thiosulfate oxidation, which will allow us to observe gene expression changes as ES-1 switches between Fe and thiosulfate oxidation. We have optimized growth conditions, showing that ES-1 can grow well when switching between thiosulfate and iron oxidation; the culturing regimen has been key to optimizing the RNA yield and quality. We will report on the results of transcriptome sequencing. Furthermore, we have been working to develop more iron-oxidizing model strains that are not currently (well-)established iron oxidizers. To achieve this, a group of isolates that contain cyc2 and/or mto/mtrA genes were chosen to test their iron oxidation behavior. A sulfur and potential iron oxidizer, Thiomonas delicata b6 showed iron oxidation capability, which expands the iron oxidation pathway to a broader spectrum of microbes. Overall, our work will provide key evidence for Fe oxidation genes and pathways, which will allow us to characterize and quantify the contributions of Fe-oxidizers in the environment.

Insights into early animal evolution from interdomain transfer of collagenases (Poster 42)

Chris Parsons & Greg Fournier

The emergence of animals in the Cryogenian (635 – 850 Ma) was necessarily associated with the introduction of a new suite of biogenic molecules into the biosphere. Any enzymes that use these molecules as substrates must have evolved their present functionality after the rise of animals. Collagen, the protein which provides most of the structural support to the animal extracellular matrix, is an excellent example of such a molecule, as it is inferred to have evolved along the metazoan stem and makes a large contribution to total animal protein mass. Several different groups of enzymes, termed collagenases, are known to cleave collagen and therefore likely arose in response to the introduction of collagen into the biosphere. Unusually, the matrix metalloproteinases (MMPs), a large clade of collagenases, have representatives in Metazoa, Bacteria, and Plantae, despite presumably having originated long after the divergences of these clades. To reconstruct the history of the MMPs, a maximum likelihood phylogeny was constructed and analyzed to identify candidate horizontal gene transfer (HGT) events. The resulting phylogeny provides support for two successive inter-domain HGTs, the first from Protostomia into Bacteria and the second from Bacteria into stem Embryophyta. The gene for this collagenase may have entered Bacteria in a lineage which lived in the gut of a nematode or arthropod and then, in a later bacterial host living in association with a stem embryophyte, been transferred into Plantae. If robust enough, these transfer events can in future be used as relative constraints on the timing of the origin of crown Embryophyta with respect to crown Protostomia, as well as provide an example of a novel mechanism of gene transfer between multicellular eukaryotes, an otherwise rare event.

Paleoclimate & paleoceanography

GDGT distributions in Lake El'gygytgyn (Far East Russia) sediments during and since the Pliocene (Poster 43)

William C. Daniels, Isla S. Castañeda, Jeffrey M. Salacup, & Julie Brigham-Grette

Lake El'gygytgyn ("Lake E"), Siberia is the only continental Arctic site containing a continuous paleoclimate archive extending to the Pliocene. During the Plio-Pleistocene, Earth underwent significant changes as Mid-Pliocene warmth gave way to colder conditions and Northern Hemisphere glaciations intensified. At Lake E, pollen data (Brigham Grette et al., 2013) indicate summer cooling of ~7 °C from the Pliocene to today, but thus far such a result has been enigmatic in proxies based on branched glycerol dialkyl glycerol tetraethers (brGDGTs) (e.g. Keisling et al. 2017). Here we present new brGDGT analyses from 3.4 to 2.4 Ma, together with previously analyzed geochemical and pollen data, to investigate both climate variability and environmental controls on brGDGT distributions at Lake E. We find a secular decrease in the abundance of 6-methyl brGDGTs over the past 3.4 Ma, suggesting long-term acidification of the lake as the climate cooled and became more arid. Recognition of this long-term trend in brGDGT isomerization, and the utilization of newer UHPLC techniques to fully separate 5- and 6-methyl brGDGT isomers (Hopmans et al., 2016), has led to improvements in brGDGT-based temperature reconstructions at Lake E. Application of a recent lacustrine brGDGT calibration by Russell et al. (2018), based on a subset of brGDGT isomers, suggests that warm-season temperature decreased by ~6°C from the Pliocene to today—approximately twice the global temperature change (Haywood et al. 2013). Furthermore, "superinterglacial" events at Lake E are, based on this calibration, 4°C warmer than Pleistocene glacials. H-shaped brGDGTs are present at this site and are relatively abundant in both cold and warm facies of the Lake E record, indicating that their production is likely related to factors other than temperature. Overall this work provides new insights into the application of brGDGT in lacustrine systems for reconstructing past temperature over long (million year) timescales.

The "dark energy" of vital effects: intracellular controls on δ13C in planktonic foraminifera (Poster 44)

Daniel E. Gaskell, Ross Whiteford, Gavin L. Foster, & Pincelli M. Hull

The carbon-13 to carbon-12 ratio (δ13C) of foraminiferal calcite is one of the most widely-used tools in paleoceanography, so it is important to understand the biological processes that may influence this value. Inorganic precipitation experiments suggest that foraminiferal calcite should be elevated ~1‰ above the equilibrium δ13C of dissolved inorganic carbon (δ13CDIC) due to kinetic fractionation. Yet, the δ13C of planktonic foraminifera is often below equilibrium δ13CDIC, particularly in smaller individuals. This implies the presence of biological processes that reduce the δ13C of the foraminifera's carbon pool. Using chemical modeling, we demonstrate that current explanations for this phenomenon, involving uptake of respired carbon from the foraminifera's diffusive boundary layer, are insufficient. We propose instead that this phenomenon may be explained by ontogenetic changes in the rate of intracellular proton pumping. We show preliminary results from a model of this process.

Quaternary Paleoceanography of the Ross Sea, Antarctica based on Benthic and Planktic Foraminifera (Site U1523) (Poster 45)

J. L. Seidenstein, R. M. Leckie, R. M. McKay, L. De Santis, D. Kulhanek, & the IODP Expedition 374 Scientists

The West Antarctica Ice Sheet (WAIS) is currently thinning and retreating because of shifting oceanic currents transporting warmer waters to the ice margin, coupled with rising sea level. Previous geologic drilling projects into the sediments of the Ross Sea that potentially record the history of the WAIS (DSDP Leg 28, RISP, MSSTS, Cape Roberts Drilling Project, ANDRILL, IODP Exp 374), as well as modeling studies (Pollard and DeConto, 2009), show considerable variability of the ice-sheet extent during the Neogene and Quaternary including ice sheet collapse during times of extreme warmth. However, limited micropaleontological work has been done in the distal parts of the Ross Sea continental shelf. Ice sheet models indicate that the Ross Sea is highly sensitive to ocean heat flux especially in that area, so further studies are needed.

The International Ocean Discovery Program (IODP) Expedition 374 sailed to the Ross Sea in 2018 to study the history of the WAIS over the last 20 million years. Cores were collected at five locations from the outer continental shelf, slope, and rise. These new cores provide data to study ocean forcing and feedbacks and past ice sheet variability in the Ross Sea. This study is focused on Hole U1523A.

Based on the data of microfossils counts, planktic foraminifera per gram peaks around 1.3-1.0 Ma in the core and may indicate warming in the Ross Sea during Marine Isotope Stage 31 lead to an ice sheet collapse. The foraminifera record may also show a major change in Ross Ice Shelf cover from 1 Ma to present. From 1 Ma to present, there are generally less benthics and planktics (<300 forams/g), except for an increase to around 2000 forams/g of benthics and planktics around 140 ka (possibly corresponding to MIS Stage 5e) and the P/B ratio shows less planktics compared to benthics during this time. During this period, fragment ratios are higher, which could indicate some reworking of the sediment, or changing bottom water conditions affecting carbonate solubility. These initial results could indicate grounded ice conditions existing from 1 Ma to present, while 2.6-1.0 Ma could have more open water conditions.

How changing wind stress affected continental shelf carbon cycling during the Paleocene-Eocene Thermal Maximum (Poster 46)
Kalev Hantsoo, Lee Kump, Bernd Haupt, & Timothy Bralower

The Paleocene-Eocene Thermal Maximum (PETM), a transient greenhouse climatic interval spurred by a large release of carbon to the ocean-atmosphere ca. 56 million years ago, has been investigated as an analog for the potential effects of modern carbon emissions. However, global ocean-atmosphere models do not resolve continental shelf processes sufficiently to compare shelf proxy data to model outputs. Here we present high-resolution simulations of the pre-PETM and PETM North Atlantic basin using the terrain-following, eddy-resolving Regional Ocean Modeling System (ROMS), including the continental shelf along the eastern margin of North America in the Salisbury Embayment. In the PETM simulation, benthic oxygen concentration in the Salisbury Embayment decreases 18% and the benthic calcite saturation state declines from 4.4 to 2.3. These changes are driven by increased benthic oxic respiration and a higher seafloor flux of organic matter (OM) onto the shelf, even though there is no modeled net increase in shelf productivity. Instead, the rise of OM deposition to the shelf results from less vigorous off-shelf transport of organic matter due to (a) weakened along-shelf water currents and (b) weakened coastal upwelling that forces productivity closer to the shelf seafloor. This suggests that changes in atmospheric circulation during climatic perturbations can affect the balance between burial of OM on shelves versus export and respiration of OM in the deep ocean.

A case study of applying branched glycerol dialkyl glycerol tetraethers (brGDGTs) to lake 578 from southern Greenland (Poster 47)
Boyang Zhao, Isla Castañeda, Raymond Bradley, & Jeff Salacup

Southern Greenland has a unique geographical position and geomorphological features, which play a key role in both regional and global climatic change. Obtaining high-resolution climate records from southern Greenland is essential for understanding the key forcing mechanisms of northern hemisphere climate change in the past. Here, we use a developed Methylation of Branched Tetraethers (MBT) Index, MBT'5Me (De Jonge et al., 2014), an organic geochemical proxy for mean annual air temperature, to produce a decadally-resolved temperature record spanning the last 2000 years. The sediment core was collected in July 2016 from Lake 578 (W45°36', N61°04') in southern Greenland, and the age model is based on 137Cs activity and 14C dating of terrestrial macrofossils. To examine the source of brGDGTs in lake sediments, we investigated brGDGT distributions in fixed sediment trap samples, surface sediments, watershed soil samples, and a sediment core. We find that the in situ brGDGTs (directly produced from lake 578) have significant contribution to the total brGDGTs preserved in the sediments. Despite known complicating factors associated with the application of brGDGTs to lake sediments, we believe that the temperature variation derived from the MBT'5Me index at Lake 578 is robust. Our temperature reconstruction reveals a gradual cooling trend from the core bottom (~200 AD) to the top (2016 AD), which is in accordance with the decreasing trend of Northern Hemisphere insolation. However, other forcing factors were also likely to have been involved. The climate of the south Greenland coast is influenced by adjacent sea surface temperatures. We posit that decadal temperature changes in Southern Greenland may result from the variable intensity of polar water flux. When the cold East Greenland Current is stronger and becomes the dominant control of the South Greenland region, our site experiences colder conditions. Overall, our detailed investigation of brGDGT sources to Lake 578 sediments and application of the MBT'5ME index demonstrates the potential of brGDGTs for generating temperature records from Arctic lakes.

Behavior of the Kuroshio Current Extension during the mid-Pliocene Warm Period (Poster 48)

Solveig Schilling, Adriane Lam, R Mark Leckie, & Kenneth G. MacLeod

I am examining the degree in which the subtropical southern section of the Kuroshio Current Extension (KCE) warmed during the mid-Pliocene Warm Period (mPWP) (~3.2-2.9 million years ago), an interval of geologic time when atmospheric CO2 was slightly elevated compared to today's values. This interval is often studied as an analog to determine how our oceans will behave under increased warming. To date, no studies have characterized in detail how the KCE responded in the geologic past to warming events. I hypothesize that the entire KCE system became warmer as a response to expanded warm waters in mid-latitude regions. To address this hypothesis, deep-sea sediments from Ocean Drilling Program (ODP) Hole 1209A, located near the southern edge of the modern KCE, will be used to investigate the behavior of the KCE. Stable isotopic analyses (δ13C and δ18O) from surface-dwelling planktic foraminifera will be used to track the sea surface temperatures (SST) from 4-2.5 Ma. By monitoring SST, I will be able to interpret the movement of the KCE during the study interval. If low δ18O values are present, it can be concluded that the KCE had shifted north bringing warmer waters over Site 1209, while higher δ18O values will indicate an equatorial shift that brought cooler waters over the site. New isotopic data from Hole 1207A and Hole 1208A indicate an increase temperature gradient during the mid-Pliocene warm period. This may indicate a sharpening of the water mass boundaries during apex warming in the mPWP. Understanding western boundary currents, like the Kuroshio Current, are important since they play an essential role in ocean/atmospheric exchange and are responsible for regional weather patterns and climate. These mid-latitude regions have not been studied in great detail, thus this research project will provide valuable information about western boundary current migration and their response to warming climates.

Fundamental results from chemostat and batch experiments with Sulfolobus acidocaldarius help calibrate archaeal lipid proxies (Poster 49)

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To accurately reconstruct past ocean temperatures on a global scale, it is critical to understand the relationship between greenhouse-gas forcing, ocean circulation, and planetary climate sensitivity. The TEX86 paleotemperature proxy is based on the degree of cyclization of archaeal membrane lipids called glycerol dibiphytanyl glycerol tetraethers (GDGTs) and lends itself well to this goal, as GDGTs are ubiquitous (i.e. produced by cosmopolitan marine thaumarchaeota) and stable on geologic timescales. The link between GDGT cyclization and growth temperature rests on the notion that microorganisms which synthesize GDGTs can adjust their membrane fluidity and permeability by altering the number of cyclopentyl and cyclohexyl rings in their core isoprenoid lipids. Multiple approaches ranging from synthetic membrane experiments to molecular dynamics simulations all support the observation that increasing GDGT cyclization leads to membranes that are more tightly packed and thermally stable. However, temperature is not the only parameter that influences lipid membrane composition.

Cell membranes are inherently linked to cellular viability. The distribution of GDGTs produced by model marine thaumarchaeota has recently been shown to respond to environmental factors such as oxygen limitation (Qin et al. 2015) and nutrient and energy availability (Hurley et al. 2016). Similarly, research with terrestrial thermophiles demonstrates that non-temperature factors such as growth phase and pH also alter membrane composition (Pearson et al. 2008, Feyhl-Buska et al. 2016).

Here we present compiled results from batch and continuous culture work with the hyperthermophilic crenarchaeote Sulfolobus acidocaldarius DSM 639, a close relative of the organism in which the growth temperature-GDGT cyclization relationship was first recognized (De Rosa et al. 1980). Using a series of novel chemostat experiments, we demonstrate that specific growth rate as a function of electron donor and carbon limitation has a marked effect on GDGT profiles. The magnitude of change in average lipid cyclization across these growth rates exceeds anything observed thus far across our batch experiments.

Several major takeaways from these and related experiments (see Cobban, Zhou et al.) should be taken into consideration when interpreting environmental data associated with archaeal lipid proxies:

1. The distributions of GDGT species are important and can help inform the weighted averages published in proxy work. The relative amounts of different structures can shift significantly without a commensurate change in the indices typically reported (e.g. ring index or TEX86).
2. Energy limitation has a large effect on growth rate and GDGT distributions, favoring production of heavily cyclized variants and increasing ring index by a full unit—comparable to the entire range of variation seen in modern ocean sediments (Schouten et al. 2002).
3. S. acidocaldarius produces novel late-eluting isomers of GDGT-3, -4, and -5 at conditions furthest from growth optima (i.e. slowest growth rate, lowest pH, highest temperature). If marine thaumarchaeal strains are also capable of producing similar isomers, their occurrence could potentially be used as diagnostic signatures of “high-stress” environmental conditions.