2023 M-FED

Microbialite: Formation - Evolution - Diagenesis

October 5, 2023

Welcome Address

Dear Geomicrobiologists, Geochemists, Sedimentologists, friends of Microbialites and Microbial Mats,

The University of Lausanne, the University of Geneva, the University of Fribourg and the ETHZ are pleased to welcome you to the 2023 edition of the conference/workshop Microbialites: Formation, evolution, diagenesis (M-FED 2023) hosted in Leysin, Switzerland, and remotely, on October 11-13, 2023.

These three days are designed to discuss the emerging/state-of-the-art aspects of microbialite research. Day 1 will focus on the microbialite fossil record from the earliest traces of life to the Anthropocene, as well as the latest advances in microbialite analyses. Day 2 will explore the influence of microbial communities and the distinction between abiotic and biotic signatures. Day 3 will be dedicated to the emerging research field of microbial carbonates as a carbon storage system.

With a prominent contribution from Ph.D. students and postdoctoral researchers, we will scrutinize and build on current knowledge of microbialite formation, evolution, and diagenesis. We will hold keynote talks and contributed oral presentations, and posters sessions will take place on Day 1 and Day 2.

On Day 1, discussions in small breakout groups will occur on four specific topics: (1) community efforts for database building and sharing, (2) geochemical modelling used in microbialite research, (3) building educational kits, and (4) grant application writing. This conference/workshop will also provide the opportunity to examine part of the Microbialite Collection from the Museum National d'Histoire Naturelle de Paris, which includes specimens spanning more than three billion years of Earth's history.

An afternoon excursion to the top of the Berneuse is planned on Day 2, which will offer a unique view of the Alps, an opportunity discuss the geological context of the region, and possibly explore the area.

During these three days in the gorgeous village of Leysin, we encourage early-career scientists to interact with their peers, and we offer an opportunity to network with scientists of diverse backgrounds.

We are looking forward to a fruitful and exciting M-FED 2023 with you in Leysin.

The M-Fed 23 organization committee

Contents

Microbialite through the geological record

Microbialites as biological and environmental archives

11 Oct
8:45am
Keynote
Theater

Barlow E.
Pennsylvania State University

Precambrian microbialites are important biological and environmental archives. They provide us with insight into the type and diversity of life present on the early Earth, as well as the nature of life and environments through time. These insights have broad-reaching implications –from better understanding the origin and evolution of life on our planet, to knowing what to look for in the search for life elsewhere. In this talk, I will discuss the geological record of microbialites and highlight some physical and geochemical features we can use to identify microbialites in deep time. I will share examples of the types of biological and environmental information we can garner from studying ancient microbialites, and touch on what this can tell us about formation mechanisms, preservation, and inhabited environments through time. I will also propose a call to action for further research to be undertaken in characterising the 'abiological background', within a variety of both modern and ancient systems, so we can better understand the complex interplay between life and non-life processes in the formation of morphological structures of interest. Additional work in this area will improve our knowledge of microbialite formation and preservation in both modern and ancient settings, as well as reduce ambiguity in biosignature detection in both deep-time and non-Terran samples.

Stromatolite-like structures within microbially laminated sandstones of the Paleoarchean Moodies Group, Barberton Greenstone Belt, South Africa

11 Oct
9:15am
Oral
Theater

Heubeck C.[1], Reimann S.[1], Homann M. [2]
[1]Friedrich-Schiller-University Jena, [2]University College London

We report abundant small calcareous mounds associated with fossilized kerogenous microbial mats in tidal-facies sandstones of the predominantly siliciclastic Moodies Group (ca. 3.22 Ga) of the Barberton Greenstone Belt (BGB), South Africa and Eswatini. Most of the bulbous, internally microlaminated mounds are several cm in diameter and formed at the sediment-water interface contemporaneous with sedimentation. They originally consisted of Fe-Mg-Mn carbonate which is now largely silicified; subtle internal compositional laminations are composed of organic matter and sericite. Their presence for >6 km along strike, their restriction to the inferred photic zone, and the internal structure suggest that mineral precipitation was induced by photosynthetic microorganisms. Similar calcareous mounds in this unit also occur within and on top of fluid-escape conduits, suggesting that carbonate precipitation may either have occurred abiogenically or involved chemotrophic metabolism(s) utilizing the oxidation of organic matter, methane, or hydrogen, the latter possibly generated by serpentinization of underlying ultramafic rocks Alternatively or additionally, carbonate may have precipitated abiotically where heated subsurface fluids, sourced by the intrusion of a major Moodies-age sill, reached the tidal flats. In summary, precipitation mechanisms may have been variable. The calcareous mounds may represent "hybrid carbonates" that may have originated from the small-scale overlap of bioinduced and abiotic processes in space and time. Significantly, the widespread occurrence of these stromatolite-like structures in a fully siliciclastic, high-energy tidal setting broadens search criteria in the search for life on Mars while their possible hybrid origin challenges our ability to unambiguously identify a biogenic component.

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11 Oct
9:30am
Oral
Theater

3.2 Ga Biosignatures in Deltaic Microbial Mats of the Moodies Group

Orrill, B.I. [1], Czaja, A. D.[1], Tice, M.[2], and Zawaski, M.[2]

[1] Department of Geosciences, University of Cincinnati; [2] Department of Geology & Geophysics, Texas A&M University.

Atmospheric oxygen levels increased immensely 2.4 billion years ago during the Great Oxygenation Event (GOE), yet oxygen production likely began long before, producing local "oxygen oases" around microbial communities [1]. The 3.2-billion-year-old Moodies Group on the Kaapvaal Craton in South Africa contains marine deltaic sediments deposited 800 million years before the GOE, along with previously reported "microbially induced sedimentary structures" [2, 3]. We are examining these sediments for further evidence of biosignatures, with the end goal to test the hypothesis that oxidative photosynthesis existed at this time. Our initial work has involved analyses of well-preserved outcrop samples of coarse-grained sedimentary rocks from the Lomati Delta that contain dark finer-grained layers previously associated with and described as "crinklies" [4]. Micro X-ray fluorescence (μXRF) scans and Raman spectroscopy show the finer-grained laminations contain abundant heavy mineral (e.g., rutile) sand grains [5], although the strongest Raman signal throughout the rock is quartz. Raman spectroscopy also shows concentrated masses of fossil organic matter (kerogen) in these bands. At least two generations of kerogen have been identified in the layers and may record different degrees of thermal maturity. This work will be continued on the outcrop samples, as well as on scientific drill core samples that have been collected as these will be less oxidized and hopefully preserve evidence of redox processes from 3.2 billion years ago. This work to understand the Moodies Group deltaic geochemical paleoenvironment could also help us understand that of the siliciclastic delta deposits on Mars, such as those in Jezero crater, where the current Mars 2020 mission is exploring for signs of ancient life.

[1] Olson, S. L., Kump, L. R., and Kasting, J. F. (2013). "Quantifying the Areal Extent and Dissolved Oxygen Concentrations of Archean Oxygen Oases." Chemical Geology

362: 35-43;
[2] Homann, M., Heubeck, C., Airo, A., and Tice, M.M. (2015). "Morphological adaptions of 3.22 Ga-old tufted microbial mats to Archean coastal habitats (Moodies Group, Barberton Greenstone Belt, South Africa)." Precambrian Research 266: 47-64;
[3] Noffke, N., Eriksson, K. A., Hazen, R. M., Simpson, E. L. (2006). "A new window into Early Archean life: Microbial mats in Earth's oldest siliciclastic tidal deposits (3.2 Ga Moodies Group, South Africa)." Geological Society of America 34: 253-256;
[4] Heubeck, C., Engelhardt, J., Byerly, G. R., Zeh, A., Sell, B., Luber, T., Lowe, D. R. (2013) "Timing of deposition and deformation of the Moodies Group (Barberton Greenstone Belt, South Africa): Very-high-resolution of Archean surface processes." Precambrian Research 231: 236-262;
[5] Zawaski, M. J., Tice, M., Shapiro, R. S., Czaja, A. D., Orrill, B. (2023) "Microbial Mats and Sedimentary Conditions 3.2 Ga in Tidal Deposits from the Moodies Group." Presented at the Lunar and Planetary Science Conference, 2023.

Evidence against oxygenic photosynthesis influence 3.2 Ga in the Moodies Group microbial structures

11 Oct
9:45am
Oral
Theater

Zawaski M.[2], Welty E.[4], Tice M.[3], Shapiro R.[1], Czaja A.[3], Orrill B.[3]

[1]California State University, Chico, [2]Texas A&M University, [3]University of Cincinnati, [4]University of Zurich

The ~3.2 Ga Moodies Group (Barberton Greenstone Belt, South Africa) includes abundant crinkly laminations and other microbially induced sedimentary structures representing fossil microbial mats. Despite deposition ~0.8 Gyr before the Great Oxidation Event, it has been suggested that the communities which formed these structures may have included oxygenic photosynthetic organisms. As part of a preliminary study to test this hypothesis, we examined pyrite (FeS2) and chromite ($FeCr_2O_4$) grain populations from Moodies fossil mats collected from surface outcroppings to determine if these redox-sensitive grains preserve evidence of oxidation during mat growth.
In our X-ray Florescence spectroscopy (μXRF) investigations we identified evidence that microbial communities altered the cohesiveness of sedimentary layers, producing heavy mineral lag-associate structures that maintain greater cohesiveness than abiotic structures. We also used μXRF to map distributions of pyrite and chromite grains as well as redox-inert mineral grains with similar densities (ex. zircon, rutile, and apatite). All grain types were enriched along laminations in sedimentary current structures and on top of mat paleo-surfaces, indicating that pyrite and chromite grains were present as mobile sand- and silt-sized grains during mat growth.
To test for grain corrosion or, alternatively, grain overgrowths that could obscure evidence of early grain corrosion, we compared grain size distributions using a star-convex object detection algorithm. Although some samples show evidence of overgrowths which coarsened parts of their pyrite and chromite populations, the pyrite and chromite grains in most samples have size distributions statistically indistinguishable from rutile, zircon, and apatite grains. Moreover, iron is not enriched on their surfaces as might be expected had they been partially oxidized and converted to iron oxides. These preliminary results

suggest that Moodies microbial mats did not represent early “oxygen oases” where biologically produced oxygen reacted with geological reductants before it could be released to the atmosphere.

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11 Oct
10:30am
Oral
Theater

Mo isotope chemostratigraphy of a Mesoarchean carbonate platform: refining the microbialite Mo isotope record of pre-GOE oxygenation

Migeon, A.[2], Afroz, M.[1], Patry, L.[1], Sansjofre, P.[3], Lalonde, S.[1]

[1]Geo-Ocean/CNRS, [2]Geo-Ocean/UBO, [3]IMPMC/MNHN

Three billion years ago, the atmosphere and oceans were largely devoid of oxygen, except for possible localized oxygen oases in surface waters and shallow seas. Here we present a comprehensive analysis of molybdenum (Mo) stable isotope chemostratigraphy throughout the 2.87-billion-year-old (Ga) Red Lake carbonate platform, preserved today in the Ball Assemblage of the Red Lake Greenstone Belt, Ontario, Canada. Samples from two correlative drill cores were analysed in order to evaluate the presence of trace amounts of O_2 in follow-up to previous findings based on Mo stable isotope data from a limited number of outcrop carbonate samples from Red Lake that were suggested to indicate a potential oxygen oases at this locality. In fresh drill core samples, Mo isotopes show important variations throughout the different lithologies in both cores, ranging from -2.22 ‰ to 0.53 ‰ in $\delta^{98/95}$Mo, demonstrating important Mo isotope fractionation as far back to 2.87 Ga. Mo concentrations determined by isotope dilution in the carbonate samples are largely below crustal values, and Mo stable isotopes are largely unfractionated, indicating a seawater $\delta^{98/95}$Mo value of near 0 ‰ at the time of deposition. Banded iron formation and shale samples show isotopically lighter values consistent with fractionation during Mo adsorption onto Fe-oxides or partial uptake by reducing sediments, indicating a seawater reservoir that was near 0 ‰, as suggested by the carbonates. Combined, this evidence points to a largely unfractionated seawater Mo reservoir derived from anoxic chemical weathering or low temperature hydrothermal sources and arguing against important oxidative processing of Mo in seawater during the deposition of the Red Lake platform. These data call into question the previously reported heavy Mo carbonate isotope compositions from Red Lake outcrop samples, which may constitute a false positive due to secondary surface weathering. However, some rare samples from this study show Mo isotope systematics that may still indicate the presence of trace amounts of free O_2. Combined, these results provide important lessons and perspectives for the application of Mo stable isotopes as a redox tracer in ancient microbialites.

Are stromatolites ideal candidates to study the Archean N-biogeochemical cycle?

11 Oct
10:45am
Oral
Theater

Pellerin, A[3], Ader, M.[6], Havas, R.[3], Alleon, J.[2], Olivier, N.[5], Marin-Carbonne, J.[1], Thomazo, C.[4]

[1]Institut des Sciences de la Terre, Université de Lausanne, Lausanne, Switzerland, [2]LGL-TPE, Université de Lyon, Lyon, France, [3]Laboratoire Biogéosciences, UMR CNRS 6282, Université de Bourgogne, Dijon, France, [4]Institut Universitaire de France (IUF), Paris, France, [5]Université Clermont Auvergne, CNRS, IRD, Laboratoire Magmas et Volcans, Clermont-Ferrand, France, [6]Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, Paris, France

The nitrogen isotopic signature preserved in sedimentary rocks is one of the standard tools for investigating redox changes in the oceans associated with the evolution of the biosphere. Indeed, nitrogen is both a nutrient directly limiting biological productivity and a redox tracer taking part in redox-dependent biological pathways. Specifically, it has largely been used to uncover the evolution of the biogeochemical nitrogen cycle and interpreted as showing a rise of oceanic oxidants in Neoarchean oceans, followed by the progressive stabilization of a persistent nitrate reservoir. Similarly, Precambrian stromatolitic carbonate platforms have been the focus of many geochemical studies targeting the link between biological innovations and Earth's protracted oxygenation. Heavy nitrogen isotope signatures have been recorded in slope settings of the 2.58-2.50 Ga Campbellrand-Malmani platform (Transvaal Supergroup, South Africa), with δ^{15}N values centered around +5‰ and reaching up to +10‰ [1]. They have been interpreted as the onset of oxic nitrogen cycling with a nitrate pool sufficiently stable to sustain denitrification overtime.
Meanwhile, we explored shallower settings of the Campbellrand-Malmani platform, that are often considered to be niches for early aerobic systems. We report δ^{15}N values centered around 0‰ from dolomitized stromatolites representative of proximal depositional environments, displaying a signature of diazotrophic N^2-fixation. Such data invite us to rethink why, despite the presence of undisputed photosynthetic microbial remains and a $\delta^{13}C_{org}$ signature compatible with the development of an aerobic biosphere, the oxidative part of the nitrogen cycle is not expressed in these microbialites. This communication will examine several hypotheses, including alternative metabolisms such as anoxygenic photosynthesis, the presence of a quantitatively consumed "cryptic" oxygen reservoir, and sampling bias, in an attempt to determine whether stromatolitic carbonates provide relevant archives to target Early Earth oxygenation.

[1]Godfrey, L.V., Falkowski, P.G., 2009. The cycling and redox state of nitrogen in the Archaean ocean. Nature Geoscience 2, 725–729. https://doi.org/10.1038/ngeo633

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11 Oct
11:00am
Oral
Theater

Organic Remains Preserved within Ediacaran Phosphorites of the Doushantuo Formation in China – Remarkable Vestiges of Microbial Life

Lu, L.[1], Schönig, J.[2], Duda, J.-P.[1], Reitner, J.[1]

[1]Department of Geobiology, GZG, University of Goettingen, [2]Department of Sedimentology and Environmental Geology, GZG, University of Goettingen

Phosphorites of the Ediacaran Doushantuo Formation at Weng'an (China) provide a valuable window into the early evolution of life. For instance, these deposits preserve microfossils widely interpreted as animal embryos; an interpretation which is still somewhat controversial1. In order to better understand the nature of the microfossils, we analyzed the relationships between minerals and organic matter in the phosphorites with a variety of analytical imaging techniques (e.g., Raman spectroscopy, μXRF, EPMA). We found that outer wall surfaces of individual microfossils are enriched in organic matter, while inner parts of the walls are enriched in apatite. Furthermore, the interiors of the microfossils exhibit organic matter aggregates interwoven with apatite. The presence of abundant apatite within the deposit and distinct elemental sulfur enrichments associated with some of the microfossils support their interpretation as sulfur oxidizing bacteria (SOB) like Thiomargarita1. SOB might have been ecologically and taphonomically significant in the Weng'an environment, e.g. by driving the phosphorus cycle and by promoting authigenic mineralization. On the other hand, some microfossils share striking similarities with modern microbial communities enclosed in spheres consisting of EPS-related lectin. Today, such spheres are e.g. known from the Black Sea, where communities of anaerobic methanotrophic archaea and sulfate reducing bacteria are surrounded by a skin of lectin [2,3]. Microbial lectin spheres have important ecological functions (e.g. shielding against environmental stressors, detoxification of harmful metabolic substances) and thus potentially be useful in geobiological studies. We hypothesize that some of the Weng'an microfossils like Megasphera might be microbial lectin spheres, functionally (though not necessarily metabolically) similar to those known from today. In summary, our findings show that most of the studied microfossils in the Doushantuo phosphorites are remains of microorganisms, and stress the need for further studies on the Weng'an biota to fully appreciate its geobiological significance.

[1] Bailey et al. (2007) Nature 445(7124), p. 198–201
[2] Reitner et al. (2005) Facies 51(1), p. 66–79
[3] Reitner (2010) In: Microbial Mats (Eds: Seckbach & Oren), Springer, p. 207–220

Phyllosilicate-enhanced preservation of primary biogeochemical heterogeneities in Archaean (~2.9Ga) siliciclastic microbial mats

11 Oct
11:15am
Oral
Theater

Hickman-Lewis, K.2, Cavalazzi, B.4, Yi K.1, Hong, T.1, Byeon, M.1, Jang, J.[1], Choi, M.[1], Seo, Y.[1], Montgomery, W.[2], Cuadros, J.[2], Najorka, J.[2], Matlak, K.[3], Wolanin, B.[3], Smith, C.[2]

[1]Korea Basic Science Institute, [2]Natural History Museum, [3]Solaris Synchrotron, [4]Università di Bologna

Precambrian Konservat-Lagerstätten are primarily restricted to cherts, shales and phosphates, which promote the early, rapid and anoxic entombment of kerogenous materials in amorphous or fine-grained materials. Such horizons preserve biogeochemical heterogeneities over billions of years. Albeit rarely, siliciclastic sequences can also preserve organic traces of life with extremely high fidelity; however, the micro-scale geological mechanisms behind such preservation are poorly constrained. Herein, we report exceptional preservation of primary biogeochemistry in microbial mat horizons in sandstones from pristine core samples of the ~2.97–2.91 Ga Mosquito Creek Formation (Pilbara, Western Australia). Optical and electron microscopy (SEM, TEM, HRTEM) coupled with Raman and FTIR microspectroscopy shows that, despite the poorly sorted, fine–coarse sandy granulometry of most Mosquito Creek Formation siliciclastics, layers dominated by nanometric K-Al-phyllosilicates preserve microbial mats as fragments of kerogenous materials intercalated between elongate clay minerals. XRD analyses and SEM imaging suggest that this phyllosilicate phase is either illite or kaolinite altered to illite. HRTEM elucidates the ultrastructure of the kerogen, showing that it comprises largely amorphous carbonaceous materials with some poorly crystalline domains (turbostratic and poorly graphitised carbon), and that is intimately associated with crystalline phyllosilicates. Geochemical characterisation using FTIR, NanoSIMS, EELS and STXM demonstrates the retention of primary organic heterogeneity including aromatic, aliphatic, and other heteroatomic C-, H- and N-bearing compounds, correlated C and N enrichments, and negative carbon isotope fractionations. Localised and/or temporally restricted quiescent periods of phyllosilicate deposition are proposed as instrumental to the preservation of organic materials in these coarse siliciclastics and promote the presentation of relatively unaltered, biogeochemically diverse, amorphous carbonaceous materials despite the moderate metamorphism of these sequences. This opens the possibility for further detailed studies of Early Precambrian sandstones as highly promising non-traditional microbialite repositories. Similar occurrences of organic materials in fine–coarse-grained sandstones and in association with phyllosilicates in Martian sedimentary sequences, such as deltas and other fluvio-lacustrine deposits, may provide similar havens of biosignature preservation potential. Such samples have already been collected by the Perseverance rover at Jezero crater and will be returned to Earth in the 2030s, whereupon a similar multi-technique approach to their characterisation may be applied.

11 Oct
11:30am
Oral
Theater

Tales written in stone: The impact of bidirectional fabric evolution on the elemental geochemistry of Hamelin Pool microbialites

[2]Pollier C., [2]Vitek B., [2]Duchâtellier G., [1]Suosaari E., [2]Reid R., [2]Oehlert A.
[1]Smithsonian Institution, [1]University of Miami

Microbialite lithification involves various microbial metabolisms contributing to the biogeochemical cycling of life-sustaining elements, enriching metals and metalloids within microbial organic matrices and associated carbonate minerals. Previous work revealed that significant metal and metalloid enrichment occurs in the initial accretionary fabric of microbialites from Hamelin Pool, Australia[1]. While such enrichments are critical in reconstructing microbial processes and comprehending the formation of ancient carbonate rocks created by microbes, they undergo notable changes throughout the evolutionary history of microbialites. In Hamelin Pool microbialites, the internal microfabrics result from the bidirectional evolution of the original accretionary mat types[2]. Initially, the accretionary mat type changes as the head grows upward, creating a sequence of successive microfabrics unique to each of the four mat types. Subsequently, early taphonomic processes driven by organic matter degradation result in the downward modification of the original depositional architecture. The resulting complex internal fabric could complicate the use of metal(-loid)s as reliable indicators of life in fossilized microbialites. Therefore, it is crucial to better comprehend the nature, timing, and rate of geochemical changes that occur during the bidirectional evolution of microbialites.
Using an enhanced sequential leaching method for the analysis of microbialite samples using triple quadrupole ICP-MS, we conducted a comparative analysis of taphonomic changes in four different microbial mats from Hamelin Pool. Preliminary results showed similar geochemistry in the initial products of the four mat types, but distinct geochemical alterations induced by taphonomic processes. Some chemical biosignatures were enhanced or lost during early taphonomy, while unrelated geochemical artifacts might be incorporated into the microbialite structure after its initial formation. Consequently, a dynamic geochemical signal arises, which may vary over time as dictated by distinct taphonomic stages and across space due to the presence of various mat types. These findings resonate with the Microbial Balancing Act (MBA) framework[3], providing a geochemical significance to this conceptual model that links environmental conditions and microbes in the formation and evolution of microbialites.

[1] Pollier, C.G.L. et al. Goldschmidt Conference (2023)
[2] Vitek, B.E. et al. The Depositional Record (Accepted)
[3] Reid, R.P. et al. AR Marine Science (Accepted)

Diagenetic formation of Mg-silicates in a microbialite-hosting Mexican lake

11 Oct
11:45am
Oral
Theater

[5]Benzerara K., [4]Muller E., [6]Rapin W., [5]Caumartin J., [7]Jézéquel D., [5]De Wever A., [1]Thomazo C., [1]Havas R., [3]Lopez-Garcia P., [3]Moreira D., [2]Tavera R.

[1]Smithsonian Institution, [1]Biogéosciences, CNRS, Université Bourgogne Franche-Comté, [2]Departamento de Ecologıa y Recursos Naturales, UNAM, [3]Ecologie Systématique Evolution, CNRS & Université Paris-Saclay, [4]IFP Energies nouvelles, [5]IMPMC, CNRS, MNHN & Sorbonne Université5, IRAP, CNRS, OMP, [6]Université de Toulouse, [7]Institut de Physique du Globe de Paris & UMR CARRTEL

Authigenic Mg-silicates have been abundantly described in microbialites and can provide some information about the chemical conditions prevailing during their formation (e.g., [1]). No authigenic Mg-silicate forms in the shallow microbialites of Lake Alchichica in Mexico, most likely because the concentration of orthosilicic acid is low (<26 μM) in the water column. By contrast, we found a high abundance of these phases in the sediments collected at the bottom of the same lake, with an early diagenetic origin. Here we combined bulk mineralogy, microscopy and solution geochemistry approaches to analyze the chemical evolution of porewaters and sediments along depth in a sediment core of Lake Alchichica [2]. Below ca 3 cm in depth, diatom frustules are progressively pseudomorphized with exquisite details into Al-poor Mg-silicates, corresponding to stevensite, a smectite phase. Meanwhile, porewaters become saturated with 'amorphous sepiolite', a solubility line determined early on by Wollast et al. (1968)[3]. This diagenetic process is massive and the resulting Mg-silicate represents between 30 and 53 wt.% of the sediment content at all depths. From these observations we can derive several consistent chemical equations describing this diagenetic process, all indicating that, in this case, Mg-silicate formation releases protons. Overall, this observation questions the possibility to infer lake palaeochemistry from the presence/absence of Mg-silicates in the sedimentary record. Moreover, it refines the conditions under which Mg-silicates authigenesis occurs, in particular by determining the solubility of these phases. The formation of Mg-silicates is known as reverse weathering in the geochemistry community. The proportion of reverse weathering associated with the solubility constant that we determine could be higher than previously predicted based on experiments. We will discuss the global impact that this process may have over geological timescales, in particular regarding the global carbon cycle.

[1] Zeyen N. et al. (2015). Frontiers in Earth Science, doi: 10.3389/feart.2015.00064
[2] Muller E. et al. (2023). Sedimentology, 70, 1013-1038.
[3] Wollast, R. et al. (1968). Am. Min., 53, 1645–1662.

11 Oct
12:00am
Oral
Theater

S-isotope microbial fractionation ($^{34}\varepsilon$-$^{33}\lambda$) viewed through the lense of microscale isotopic observations.

Pasquier V.[1], Marin-Carbonne J.[1], Halevy I[2].

[1]University of Lausanne, [2]Weizmann Institute of Science

Reconstructions of past environmental conditions and biological activity are often based on the use of stable isotope proxies, which in the vast majority of cases are measured on bulk rocks. This is particularly true of the multiple-sulfur isotopic compositions of sedimentary pyrite ($\delta^{34}S_{PYR}$-$\Delta^{33}S_{PYR}$), which are used to reconstruct ocean-atmosphere oxidation state and track the evolution of several microbial metabolic pathways. In this presentation, we will change the scale of our isotopic investigations to harness previously published microscale $\delta^{34}S_{PYR}$-$\Delta^{33}S_{PYR}$ analyses between 3.8 and 2.2 Ga, to extract novel information on the structure and temporal evolution of Archean-Proterozoic surface environments. In doing so, we identified two arrays in the $\delta^{34}S_{PYR}$-$\Delta^{33}S_{PYR}$ isotopic space. In one array (Array 1), $\delta^{34}S_{PYR}$ values span a wide range from the lowest to the highest measured values while $\Delta^{33}S_{PYR}$ values stay relatively uniform and close to 0‰. In the other array (Array 2) $\delta^{34}S_{PYR}$ and $\Delta^{33}S_{PYR}$ values covary positively along the known Archean reference array [1]. We found a striking resemblance between Array 1 and various microscale investigations that we have conducted in well-dated and well-understood modern marine sediments. As such, we propose that Array 1 reflects mass-dependent processes related to microbial respiration of aqueous sulfate, its isotopic distillation, and the buildup of porewater sulfide over the timescale of pyrite precipitation. In addition, the magnitude of the isotopic fractionation between the lowest Archean $\delta^{34}S_{PYR}$ (and their associated $\Delta^{33}S_{PYR}$) and the expected Archean seawater sulfate composition appear to be consistent with the limited microbial fractionation (i.e., by few tens of ‰) we have found in low-sulfate natural environments. Interestingly, this array is mostly, if not exclusively, observed in sedimentary rocks younger than ≈2.5 Ga, which might attest to the increasing microbial sulfur recycling leading up to the Great Oxygenation Event (GOE).

[1] Farquhar J, Bao H, Thiemens M. Atmospheric influence of Earth's earliest sulfur cycle. Science 289, 756-759 (2000).

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11 Oct
1:30pm
Oral
Theater

Precipitation, Lithification, and Structure-Building: Geochemical and Nanoscale Insights into Microbialite Morphogenesis from the Salar de Atacama

Oehlert, A.[6], Pollier, C.[6], Joens, M.[5], Suosaari, E.[3], Lascu, I.[3], Sharang, S.[5], Duchatellier, G.[6], Daza, R.[2], Palma, A.[2], Dupraz, C.[4], Purkis, S.[6], Piggot, A.[1], Reid, R.[6],

[1]AP Research Inc, [1]FisioAqua, [3]Smithsonian Institution, [4]Stockholm University, [5]Tescan, [6]University of Miami, Rosenstiel School of Marine, Atmospheric, and Earth Science

Modern microbialites are living analogues for Earth's oldest ecosystems. The diverse morphological expressions of modern microbialites range from non-lithifying microbial mats to lithified, discrete microbial buildups like stromatolites. Quantitative understanding of modern microbial ecosystems can provide insight into early Earth's habitability and can define depositional settings that fostered ancient microbial life. Study of modern microbialites suggests that variations in both the morphology of microbialites and the timing of their lithification reflect a dynamic balance between changing environmental conditions and intrinsic metabolic activity of the microbial consortia. Since oscillations between these factors are expected through space and time, it can be difficult to disentangle the influences of microbes versus the environment when interpreting drivers of microbialite lithification and structure-building in the ancient geological record. Here, we leverage a new conceptual model, the Microbialite Balancing Act (MBA [1]), which enables the proposition of testable hypotheses for unique modes of microbialite accretion and preservation. Using microbialite samples from the Salar de Atacama in Northern Chile, we contrast the geochemistry and nanoscale morphology of endmember microbialites, including a flat-lying, non-lithifying mat, and lithified discrete microbial buildup with topographic relief. Our characterization includes chemical analysis of water samples, along with stable carbon isotope analysis, mineralogical assessment using X-ray diffraction (XRD), and elemental analysis via scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (SEM-EDS) of the microbialites. We also present focused ion beam nanotomography (FIB-SEM) to investigate the distribution of microbes and minerals in these settings using in-built machine learning algorithms for microbialite component segmentation. Initial results show that structure-building microbialites have different geochemical signatures and nanoscale compositional characteristics than non-lithifying mats, highlighting the important role of the initial microbialite architecture for setting the evolutionary pathway towards preservation in the geological record and the establishment of diagnostic chemical and morphological biosignatures.

[1] Reid, R.P., Suosaari, E.P., Oehlert, A.M., Pollier, C.G.L, and Dupraz, C. (accepted) Microbialite Accretion and Growth: Lessons from Shark Bay and the Bahamas. Annual Review of Marine Science.

Latest advances in microbialites analyses

Novel high-resolution geochemical methodologies for quantitative element maps and authigenic stable metal isotopic compositions in microbialites

11 Oct
01:45pm
Keynote
Theater

Hohl S.V

Tongji University

Microbialites are lithified remnants of microbial communities that hold the key to studying the earliest life on Earth and in extreme environments that are non-hostile to higher organisms. Various microbes can produce extracellular polymeric substances, which trap and bind ambient detrital sediment grains but also act as a substrate for carbonate nucleation. Authigenic minerals forming microbialites or stromatolites incorporate trace elements without significant fractionation from ambient fluids of neritic lacustrine and marine environments. Analysing trace element concentrations and isotopic compositions of authigenic minerals of the stromatolite geochemical archive offers the chance to directly study nutrient availability, cycling, and redox conditions in microbial habitats through deep-time. In this presentation, I will summarise recent advantages in two fields of microbialite geochemistry:

i) In-situ analyses of microbialites via laser ablation coupled to inductively coupled plasma time-of-flight mass spectrometry (ICP-TOF-MS) and internal calibration to matrix-matching nano-powder carbonate reference materials obtain rapid high-resolution quantitative trace element maps. These maps show bio-intrinsic layering of bioactive trace metals enriched in authigenic minerals, while immobile elements are enriched in detrital coatings of microbialites. Their purpose is to understand better metal cycling between the microbial matter and ambient fluids as well as aiding in the search for regions least affected by diagenesis and detrital contamination for follow up U-Pb dating of the microbialite.

ii) Layer-specific probing and sequential leaching before novel stable metal isotope analyses are established as the gold standard for studying bio-geochemical metal cycling in microbialites. The past years have seen publications from workgroups focusing on isotopic compositions of bioactive trace metals (Ni, Cd, Ba), redox-sensitive metals (Fe, Mo, Cr, U) or carbonate nucleation (Mg). Although microbial communities' behaviour and fractionation processes are partly incompletely understood, stable metal isotope proxies have a unique potential to understand better redox conditions, metal availability and (biogenic) metal cycling processes in microbial habitats. I present insights into a few potential isotope applications, emphasising the Cd, Ba and Ni isotope systems and their future perspectives as isotope biomarkers to bridge the gap between geochemistry and microbiology and better understand the evolution of microbial life on Earth and beyond.

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11 Oct
02:15pm
Oral
Theater

How fast do stromatolites grow? New insights into stromatolite accretion rates from ^{14}C dating of recent specimens

Fogret L.[2], Sansjofre P.[2], Lalonde S.[1]

[1]Institut Universitaire Européen de la Mer, [2]Museum national d'Histoire naturelle, Paris.

Stromatolites are laminated organo-sedimentary structures preserved in sedimentary records since at least 3.4 Ga and serve as important paleoenvironmental archives. Although they have been studied for over a century, stromatolites show significant diversity in their morphology, complexity, composition, and depositional environments, both today and in the fossil record, making their definition ambiguous at times. The accretion rate of stromatolites is thought to be a complex function of environmental conditions, microbial activity, and, on longer time scales, tectonic factors such as sediment supply and subsidence. However, there exist few direct temporal constraints published in literature on stromatolite growth rates. Two opposing models have been proposed for stromatolite growth: the first considers continuous cyclic or periodic growth driven by seasonal or daily fluctuations in mineral precipitation rates, while the second proposes punctuated accumulation, with bursts of rapid growth interspersed with prolonged periods of stasis or even erosion. The latter appears to be the case for the most well-studied modern specimens, the Shark Bay stromatolites, for which ^{14}C dating has revealed that the oldest laminae date back to 1250 BP (uncalibrated). Significant variation in growth rates between specimens, depending on position in Shark bay, are observed. However, few data exist outside of the Shark bay stromatolites, and growth rates in different environmental settings remain poorly constrained. Here we provide new high-resolution ^{14}C-based growth chronologies for recent stromatolites from three different localities, all dominated by chemical carbonate precipitation, but from contrasting depositional environments. We find that, regardless of the deposition environment, stromatolites from these three localities show carbonate accretion rates that are all of the same order of magnitude (around 20 µm/year), are linear over time, and does not appear to vary as a function of laminae thickness or number. In other words, there appears to be no correlation between the age of the stromatolite and the number of laminae in our sample set. These data are surprising as they indicate against the idea that carbonate stromatolite growth is governed by the periodic precipitation of minerals driven by biological activity and seasonality.

Quadruple sulfur isotope signatures in microbialites from modern Mexican redox-stratified lakes

11 Oct
02:30pm
Oral
Theater

Havas R.[5], Thomazo C.[5], Lopez-García P.[4], Surma J.[2], Nakagawa M.[2], Jézéquel D.[6], Iniesto M.[4], Moreira D.[4], Tavera R.[3], Benzerara K.[1], Ueno Y.[2]

[1]Sorbonne Université, [2]Tokyo Institute of Technology, [3]Universidad Nacional Autónoma de México, [4]Université Paris-Sud, [5]Université de Bourgogne, [6]Université de Paris, UMR CARRTEL, INRAE and USMB

Microbialites represent the oldest undisputed traces of life on Earth and result notably from complex microbial interactions within biofilms harboring steep redox gradients. As sulfur is both a highly redox-sensitive element and ubiquitous in metabolic processes, its major stable isotope signatures (reported as $\delta^{34}S$) have been used from ancient to modern microbialites to characterize their formation mechanisms and environment of growth and the microbial diversity composing them. However, minor sulfur isotope compositions (reported as $\Delta^{33}S$ and $\Delta^{36}S$) in microbialites have yet received very little attention. This is particularly true in modern examples, although they offer the possibility to be more thoroughly constrained (e.g. absence of late and burial diagenesis, metagenomes characterization, isotopic compositions of the sources).

Here, we analyzed the quadruple S isotope compositions of bulk pyrite in living and subfossil microbialites, together with the lakes' dissolved sulfate (SO_4) and microbialite carbonate-associated sulfate (CAS) from several modern redox-stratified lakes from Mexico. The lakes show different SO_4 concentrations (from ~ 1 to 12 mM) and isotopic signatures ($\delta^{34}S_{SO4}$ from 0 to +19 ‰, $\Delta^{33}S_{SO4}$ ~0.01 ‰ and $\Delta^{36}S_{SO4}$ ~-0.7 ‰, VCDT). The microbialite pyrites show a relatively large variation in $\delta^{34}S_{py}$ (-40 to 0 ‰), $\Delta^{33}S_{py}$ (+0.05 to +0.19 ‰), and $\Delta^{36}S_{py}$ (-0.2 to +1.1 ‰; all vs. VCDT, respectively). These isotopic signals vary according to the different studied microbialites mineralogies and facies, but not to the sulfate concentrations.

While $\delta^{34}S$ mostly reflects bacterial sulfate reduction, quadruple S isotopes also allow us to discuss the possible involvement of other metabolisms (e.g. sulfur disproportionation), different local conditions of formation (e.g. open vs. disconnected porewaters), and the importance of the lakes redox-stratification and its fluctuations with time. A subset of samples also allows us to assess the effect of early sulfide oxidative alteration. Finally, the signatures of the CAS samples suggest different degrees of pyrite oxidation in our samples and allow differentiating between biotic and abiotic origin of this process. Therefore, we show how combining multiple S isotope analyses in several S-bearing reservoirs (pyrites, CAS, lake sulfate) provides strong constraints on the microbialites history and conditions of formation.

How microbial communities influence microbialite formation

Exploring diel gene expression through metatranscriptomics in microbialites of Mexican crater lakes

12 Oct
9:45am
Oral
Theater

Moreira D.[2], Iniesto M.[4], Zivanovic Y.[2], Bertolino P.[2], Benzerara K.[3], Thomazo C.[1], Lopez-Garcia P.[2]

[1]University of Fribourg, [2]University of Haifa, [3]University of Hamburg, [4]University of Münster

Microbialites are organosedimentary formations fully or partially generated by the activities of microbial communities. Laminated microbialites, commonly known as stromatolites, have gained significant recognition because their fossilized remains represent the oldest known evidence of life on Earth (3.5-3.7 billion years ago). However, understanding the diversity, spatial arrangement and metabolism of the different microorganisms found in microbialites is crucial to understand how they influence the formation or dissolution of minerals, particularly calcium carbonate. To identify microbial activities that could be relevant for the formation of freshwater microbialites, we conducted an in situ experiment to study the 24 h-evolution (at 4 collection times) of gene expression at the community level in microbialites from three Mexican crater lakes (Alchichica, Atexcac, and Alberca de los Espinos) located along an alkalinity-salinity gradient, each with distinct morphology and mineralogical composition. Using a metatranscriptomic approach, we observed that the global pattern of diel gene expression was shared by the three lakes, with several pathways consistently overexpressed at the same moment of the day, such as photosynthesis during the day and genes related to biogenesis (in particular carbohydrate and amino acid biosynthesis) during the night. Although we found that photosynthesis was primarily performed by Cyanobacteria, samples from Alchichica and Atexcac demonstrated that eukaryotes, mainly green algae, also played a significant role in primary production, validating previous observations from metagenomic analyses. We also detected a consistent chemoautotrophic activity, mainly carried out by Actinobacteria, which did not show clear expression differences across the different lakes or at different moments of the day, in contrast with photosynthesis. Globally, our metatranscriptomic analyses reproduced the overall phylogenetic relative abundance described in previous metagenomic studies, indicating the effectiveness of predictive approaches based on gene presence/absence. However, we found that several groups were overrepresented at different times of the day, suggesting that their role in microbialite formation might be greater than previously anticipated. This gene expression study uncovers complex interconnections between metabolic activities and taxa that are involved in the formation of microbialites.

12 Oct
10:30am
Oral
Theater

Geomicrobiology and sulfur cycling in gypsum microbialites: insights into extreme evaporitic ecosystems

Kotopoulou E.[1], Benzerara K.[2], Iniesto M.[1], Lopez-Garcia J.[4], Aloisi G.[3], Guibourdenche L.[3], Moreira D.[1], Lopez-Garcia P.[1]

[1]University of Fribourg, [2]University of Haifa, [3]University of Hamburg, [4]University of Münster

Gypsum microbialites and microbial-rich gypsum formations occur in drylands worldwide and host diverse evaporitic ecosystems. The ongoing desertification, affecting over 45% of exposed land, is expected to promote the expansion of these ecosystems. However, compared to carbonate microbialites, the geomicrobiology and formation processes of gypsum microbialites remain understudied. To address this knowledge gap in the face of climate change, we conducted a multidisciplinary study focusing on modern and fossil gypsum microbialites and microbial-rich gypsum formations from saline to hypersaline lakes in the Danakil evaporitic depression, NE Ethiopia. We identified different gypsum microbialites and formations in different lakes along a salinity gradient, representative of a specific stage in the evolution of evaporitic basins in drylands, namely: i) gypsifying mats transitioning into ii) modern gypsum stromatolites, iii) fossil gypsum stromatolites analogous to those found in the Mediterranean area, and iv) gypsum-formations in hypersaline context composed of cm-sized crystals that host epi- and endo-lithic communities adopting mound structures similar to those reported from some Chilean salars.
Using various microscopic, spectroscopic, and diffraction techniques such as Synchrotron-based X-ray fluorescence, X-ray absorption spectroscopy at the sulfur K-edge, and transmission electron microscopy, we examined the mineralogy and sulfur speciation of gypsum formations, at different scales. To trace sulfur cycling within the gypsum microbialites, we measured multiple sulfur isotopes on living and fossil gypsum microbialites and lake waters. Through 16S and 18S rRNA gene metabarcoding, we characterized the prokaryotic and eukaryotic communities present in different categories of gypsum microbialites and compared them to the well-studied carbonate ones. Microbial community composition varied along the salinity gradient and gypsum-structure types. Cyanobacteria and anoxygenic photosynthetic Alphaproteobacteria, were abundant in mats and stromatolites, accompanied by a diversity of other taxa, while Deltaproteobacteria and halophilic archaea increased in relative abundance under hypersaline conditions. Taxon-based inference of microbial dominant metabolisms suggests a differential role of microbes in sulfur oxidation, notably associated with anoxygenic photosynthesis, and sulfate reduction conducive to gypsum dissolution in, respectively, gypsum stromatolites and other gypsum structures. Multivariate statistical analyses incorporating biotic and abiotic parameters, suggest an interplay between physicochemical conditions and microbial communities in gypsum-based microbialite formation.

Diversity and function of a microbialite reef analogue for early Earth biostructures

12 Oct
10:45am
Oral
Theater

Vignale F.[4], Lencina A.[3], Castillejos Sepúlveda A.[6], Soria M.[7], Carrizo D.[2], Sánchez-García L.[1], Klatt J.[5], Garcia Alai M.[4], Farias M.[7]

[1]Centro de Astrobiología (CSIC-INTA), Department of Molecular Evolution, Madrid, Spain, [2]Centro de Astrobiología (CSIC-INTA), Department of Planetology and Habitability, Madrid, Spain, [3]Centro de Investigaciones y Transferencia de Catamarca, Nunez del Prado 366, 4700 Catamarca, Argentina, [4]European Molecular Biology Laboratory (EMBL), [5]Microcosm Earth Center, Max Planck Institute for Terrestrial Microbiology and Philipps-Universität Marburg, Germany, [6]Microsensor Group, Max Planck Institute for Marine Microbiology, Bremen, Germany, [7]PUNABIO S.A. Campus USP-T Av. Solano Vera y Camino a Villa Nougués, San Pablo, Tucumán, Argentina

The Salar de Antofalla in the Argentinian Central Andes harbors unique microbial ecosystems due to its extreme environmental conditions, such as high altitude, low barometric pressure, high solar and UV radiation, low rates of precipitation, high rates of evaporation, high salinity, strong winds, wide daily range in temperatures and the occurrence of hydrothermal activity. Combining mineralogy, scanning micro X-ray fluorescence (μXRF), scanning electron microscopy (SEM), metagenomics, physicochemical, and molecular and isotopic (stable carbon and hydrogen) analyses, we have characterized modern microbialites in Laguna Pozo Bravo, a small hypersaline lake placed at 3,300 m a.s.l in the western margin of this salt flat.

The microbialites studied are mainly formed by calcite ($CaCO_3$) and exhibit a wide range of external morphologies including domal, discoidal, tabular, and horseshoe-like bioherms which vary considerably in size, as well as large biostromal terraces. However, the distinctive feature of these microbialites is their composite internal structure characterized by a gradual transition from a thrombolitic core to dendrolitic structures and a sharply overlying stromatolitic layer. The prokaryotic community of the microbialites is dominated by the phylum Pseudomonadota throughout the year. The phyla Cyanobacteria, Bacillota, Bacteroidota, and Deinococcota are also well-represented, but their abundances are highly variable between seasons. Cyanobacteria, Bacteroidota, and Deinococcota are abundant in fall, while Bacillota is abundant in winter and spring. Regarding the eukaryotic community, diatoms are key structural components in these microbialites. Normally, they form nano-globular carbonate aggregates with filamentous cyanobacteria and other prokaryotic cells, suggesting their participation in the mineral precipitation process. The metagenomic analyses revealed a great abundance of genes involved in photosynthesis and sulfate reduction, metabolisms that increase alkalinity and promote carbonate precipitation, supporting the role of these microorganisms in the formation of the microbialites.

This work expands our comprehension of the microbial ecosystems in the extreme environments from the Central Andes region and we hope it will provide a stimulus to further study and preserve these unique ecosystems.

12 Oct
11:00am
Oral
Theater

Microbial polymers influence the mineralogy and organic preservation potential of hydrated magnesium carbonate minerals

Baldes M.[1], Gong J.[1], Bosak T.[1]

[1]Massachusetts Institute of Technology1

Hydrated magnesium carbonates are rare on Earth, but may be important targets of the search for biosignatures on Mars. On Earth, these minerals form in environments colonized by microbes and can even build microbialites, but biological influences on the formation of hydrated magnesium carbonates and the potential for these minerals to retain organic signals remain poorly constrained.

This study addressed this by experimentally evaluating the contributions of metabolically induced pH increases in cultures of the coccoidal cyanobacterium C. cubana and a filamentous cyanobacterium along with a range of cyanobacterially produced and commercially available organic polymers to the mineralogy, morphology, and precipitation rate of hydrated magnesium carbonates. Extracellular polymeric substances (EPS) extracted from cyanobacterial cultures enabled the precipitation of spheroidal dypingite ($Mg_5(CO_3)_4(OH)_2\cdot 5H_2O$), whereas acicular nesquehonite ($MgCO_3\cdot 3H_2O$) precipitated in media that lacked organic amendments or were amended by commercial polysaccharides. Cyanobacterial photosynthetic activity enabled the nucleation of carbonate minerals by increasing the pH and the saturation of hydrated magnesium carbonate minerals, but organic polymers produced by these organisms determined the mineralogy of precipitates in saturated solutions. The composition of these polymers affected the extent of mineralization in microbial mats. Dypingite precipitates fully mineralized C. cubana mats that produced un-sulfated EPS within two months while only sporadic precipitation occurred in filamentous cyanobacterial cultures with sulfated EPS in the same period. Dypingite spheroids that encapsulated coccoidal cells of C. cubana also contained distinct hollow centers. These biological textures and the detection of bands with maxima at 1510 cm^{-1} by Raman spectroscopy in precipitates from microbial cultures point to a potential means of recognizing past organic influences on mineral formation.

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12 Oct
11:15am
Oral
Theater

Diagenesis of a Norian bioherm and the adjacent intraplatform limestone in the Dolomia Principale of the Lombardy Basin (Southern Alps, NE-Italy)

Müller M.[1], Hemingway J.[1], Picotti V.[1] and Bernasconi S.[1]

[1]ETH Zurich

Numerous bioconstructed bodies that comprise the Dolomia Principale depositional system have been studied previously [1-4]. However, the diagenesis and dolomitization of bioconstructions is still poorly constrained. Here, we investigated Upper Triassic carbonates from the Monte Zenone area in the Southern Alps, NE-Italy because of their well-known paleogeographic setting and the preserved platform-slope-basin transitions. Particularly, this research answers how and why the degree of diagenesis varies between adjacent lithologies, namely the Monte Zenone bioherm and the basinal Calcare di Zorzino limestone. Petrographic observations are combined with X-ray diffraction and stable isotope analyses to reconstruct successive events of dolomitization and dolomite cement precipitation. Effects of early marine diagenesis, burial diagenesis and late diagenesis on the primary oxygen (δ^{18}O) and carbon (δ^{13}C) isotopic signatures are assessed. Our dataset suggests an early diagenetic dolomitization of both lithologies in the shallow subsurface, and provisional clumped isotope data (Δ^{47}) indicate a trend of increasing recrystallization temperatures during progressive burial until maximum temperatures of about 60°C. This study highlights the importance of microbial processes for bioherm dolomitization, particularly the biogeochemical cycling of sulfate and sulfide . We propose that sediment loading and subsidence of the intrabasinal limestone triggered an advective flow of sulfidic and alkaline fluids towards the rigid bioconstruction, creating hydrofracture networks, which promoted both matrix dolomitization and dolomite cement precipitation in veins.

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[3] Zamparelli, V., Cirilli, S., Iannace, A., Jadoul, F., Berra, F., Boni, M., Claps, M., Climaco, A., Cozzi, A., Podda, F., Ponton, M. & Trombetta, L. (1999), Paleotectonic and paleoceanographic controls on microbial-serpulids communities in the Norian-Rhaetian carbonates of Italy: a synthesis, Palaeopelagos Special Publication. Bioevents and Integrate Stratigraphy, 3: 7-84.
[4] Flügel, E. (2002), Triassic reef patterns, in W. Kiessling, Flügel E. & J. Golonka, eds, Phanerozoic reef patterns, SEPM Society for Sedimentary Geology, 72: 391–463.

Morphogenesis and microbial community composition of hydromagnesite microbialites of an alkaline lake; Lake Salda, SW Turkey

12 Oct
11:30am
Oral
Theater

Güneş Y.[1], Şekerci F.[1], Balci N.[1]
[1]Istanbul Technical University

Lake Salda's hydromagnesite microbialite formations provide valuable insights into the factors influencing the formation of hydrated magnesium carbonate minerals and the preservation of biological signals. This study aims to describe the distribution, morphology (internal and external), and microbial diversity of microbialites in Lake Salda. Microbialites in Lake Salda range from a few centimeters in height along the shoreline to 1-2 meters high at water depths of 5-20 meters. Microbialite growth patterns closely correspond to water depth and sediment flux. Shoreline microbialites exhibit radial horizontal growth with a smooth surface, while microbialites at 15 meters depth display upward branching with a pinnacle surface structure. Microbial mat structure consists of a top diatom layer, followed by sections dominated by filamentous and coccoidal cyanobacteria. Occasional purple layers were observed below the diatom layer, primarily in samples below 5 meters depth. Microbialites in Lake Salda exhibit diverse external morphologies, including domical, columnar, and bulbous formations. Stromatolithic thrombolites, characterized by cauliflower-shaped external morphology with inner clotted texture transitioning into outward laminations, are the predominant form. Petrographic observations revealed abundant filaments, micro laminations, and peloids of varying sizes. These features were also observed in fossil counterparts in the forms of filamentous voids with occasional marginal crusting. Analysis of 16S rRNA sequences shows a high abundance of Cyanobacteria and Chloroflexi phyla (28-50%) in microbialites. Dominant strains include filamentous cyanobacteria (Leptolyngbya, Coleofasciculus, Nodosilinea) and Luteolibacter (Verrucomicrobiota) capable of degrading organic molecules and utilizing EPS. SEM reveals hydromagnesite globules associated with an EPS-based organic matrix. The diatom-rich top layer shows a high abundance of Exiguobacterium (93%). Exiguobacterium may play a key role in Lake Salda due to its extensive biofilm formation and production of indole-3-acetic acid (IAA), promoting microalgae and diatom growth. The new insights showed Lake Salda's hydromagnesite microbialites exhibit diverse morphologies and microbial compositions influenced by the depth and sediment flux. Microbialite growth in Lake Salda involves oxygenic photosynthesis, anoxygenic phototrophy, heterotrophy, and symbiotic relationships. Changes in the growth environment are reflected in microbialite structure and diversity. The findings contribute to our understanding of microbialite formation processes and the complex interactions between microorganisms in alkaline lake ecosystems.

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12 Oct
11:45am
Oral
Theater

Authigenic carbonate precipitation across the sediment water interface: insights from modern microbialites (Laguna Negra, Argentina)

Matic M.[1], Gomez F.J.[1], Perez V.P[1], and Rodler A[2]

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Early diagenesis occurs at the sediment water interface in both marine and lacustrine systems, where organic matter remineralization is produced by a cascade of biogeochemical reactions. The occurrence of carbonate dissolution or precipitation depends on the net balance between alkalinity consuming and alkalinity producing reactions. This also controls major, minor and trace elements cycling and partition between the fluid and mineral phases, particularly those elements that are associated with organic matter or controlled by redox conditions. Authigenic carbonate precipitation at this interface has changed over time and recent studies have shown that this authigenic carbonate factory is more important than previously realized.

Here we explore these processes by characterizing microbial carbonates and associated carbonate crusts of the Laguna Negra (high altitude hypersaline lake in Catamarca, Argentina). These carbonates grow at the sediment water interface where they develope morphologies similar to those observed for manganese nodules that normally show hydrogenetic and diagenetic growth. The Laminar crusts zone is represented by mm to cm thick, dome to planar shaped crusts forming patchy to laterally extensive pavements. These are not associated with the presence of microbial mats or biofilms, and micro textural analysis

suggests that carbonate precipitation is mostly related to physicochemical processes. Although they can be concentrically laminated, they preferentially exhibit upward directed lamina accretion leading to asymmetrical growth. The Oncoids zone is represented by cm to dm scale concentrically laminated discs, spheres, and domes. These are associated with thick, laminated microbial mats and biofilms influencing micro textures. The oncoids grow in-situ, without significant transport or movement, exhibiting symmetrical growth patterns when compared to laminar crusts, and can show preferential growth towards the lower hemisphere (which was submerged in the sediment at sampling time).
Asymmetric growth in the oncoids might relate to organic matter remineralization, occurring within the sediment, and increasing alkalinity. Contrarily, the upward growth pattern in the laminar crusts must be related to the increase in carbonate saturation state driven by physico chemical processes (evaporation and CO_2 degassing). We are currently exploring the influence of microbial mats on trace element behavior at this interface and their incorporation into the carbonates (particularly redox proxies such as Cr, U isotopes and REE).

Modern thrombolites from strobel lake (patagonia, argentina): implications for the understanding of ancient thrombolite

12 Oct
12:00am
Oral
Theater

Rivarola E.[1,2,3], Gomez F.J. [1,2,3], Tutolo B.[5], Mlewski E.C.[4]
[1]Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET); [2]Centro de Investigaciones en Ciencias de la Tierra (CICTERRA); [3]Universidad Nacional de Córdoba (UNC); [4]Instituto Multidisciplinario de biología Vegetal (IMBIV); [5]Department of Geoscience, University of Calgary

Thrombolites (clotted, non-laminated microbialites) record the interactions between microorganisms and their physical environment, thereby providing value for understanding Earth's ancient microbial ecosystems and potentially the record of life beyond our planet. Here We present field observations, mineralogical, petrographic, SEM, Raman and isotope analyses of modern thrombolites from the Strobel Lake (Patagonia, Argentina), a closed alkaline-freshwater lake developed on a basaltic plateau. It harbors a microbial carbonate belt and an associated delta system, making it an excellent analogue for the Jezero Crater (Mars) that NASA is currently exploring, highlighting its astrobiological significance.
Different carbonate levels (L1 submerged and L2, L3 and L4 exposed) were recognized, although L1 and L2 may represent a single terraced level (subaerial exposure of L2 can be a combination of recent lake evolution and/or seasonal lake level changes). L1 is represented by dome-shaped "living" thrombolites, colonized by thin biofilms and cyanobacteria (Nostocales-like). L2 is similar to L1 but composed by recently exposed thrombolites. L3 is characterized by thick thrombolite crusts and big (m-scale) mound shaped thrombolites. L4, the highest level, is represented by thin (mm-scale) carbonate stains and botryoidal crusts covering the basalt boulders. Thrombolite-like crusts cement megapores between basaltic blocks (levels L3 and L4).
The internal architecture consists of fine-grained (micrite and microsparite) and sparite carbonate clots. Clots are subrounded (subcircular to polylobate) masses of calcite, Mg-calcite and monohydrocalcite. We differentiate a Sparite Framework (SF) and a Micrite-Microsparite Framework (MMF). MMF is mostly found in the modern/recent thrombolites

(L1 and L2), where SF is less represented. L3 and L4 microbialites are mostly formed by SF. Monohydrocalcite is abundant in L1, progressively decreasing in L2, and absent in L3 and L4 deposits. This suggests a textural/mineralogical evolution from MMF and less stable carbonate phases (monohydrocalcite and Mg-Calcite), to SF where monohydrocalcite progressively disappears. Organic matter and pigments associated with meso-micropores were identified. C-O stable isotopes (L2, L4) show differences that could be related to either the lake evolution and/or physicochemical processes involved in carbonate precipitation. The close relationship between cyanobacteria distribution, organic components, and clot micro-textures suggest some biological control on carbonate precipitation in this system.

How to distinguish abiotic and biotic signatures in stromatolite

Exploring the formation mechanisms and biosignature preservation potential of martian carbonates

13 Oct
8:45am
Keynote
Theater

Bosak T.[2], Baldes M.[2], Mansbach E.[2], Scheller E.[2], Gong J.[3], Hall J.[2], Daye M.[1]

[1]Baylor College of Medicine, [2]MIT, [3]University of Wyoming

Orbitally detected hydrated magnesium carbonates in Jezero crater, Mars, formed at the margin of the former lake and on the sedimentary fan deposit around 3.8 to 2.6 billion years ago. The marginal carbonates were likened to calcium carbonate deposits from microbially colonized environments on Earth. Whether martian carbonates can preserve organic matter and record potential (pre)biotic processes is unclear because of the limited understanding of how organic compounds and microbes influence the formation, hydration state, morphologies, and composition of magnesium- and iron-containing carbonates. We address this by experimentally precipitating magnesium- and iron-containing carbonates under a range of biotic and abiotic conditions. Microbes, organic compounds and chemical conditions were all found to influence the formation of various calcium, magnesium, and iron-containing carbonates. No precipitate formed in sterile anoxic media that contained sulfide and 5% pCO_2, but microbes grown in the media amended by Mn(II) precipitated ordered dolomite that preserved information about the distribution of microbial cells and extracellular polymers in biofilms. The addition of Fe(II) to the same medium stimulated the precipitation of anhydrous ankerite around microbial cells. Cyanobacteria and organic polymers in Mg-rich aerobic media altered the morphology of precipitates and stabilized dypingite over the abiotically precipitated nesquehonite. These experiments demonstrated that iron- and magnesium-containing carbonates in Jezero crater could preserve potential textural and organic biosignatures. Experiments that explored abiotic mineral precipitation during the alteration of basaltic and olivine grains found a dependence of carbonate formation on sediment composition. Mixed iron- and magnesium-containing carbonates precipitated evaporatively when pure olivine grains were incubated anaerobically in the presence of water and 5% pCO_2, but only amorphous silicates were detected when silt-sized, glass-rich basaltic grains were incubated instead of olivine over similar timescales. These experiments emphasized the importance of environmental controls on the availability of cations, redox conditions and mineral saturation states. The Perseverance rover is yet to encounter carbonate deposits at the margin of the former Jezero lake, but the carbonate minerals examined by the rover to date are consistent with those that precipitated abiotically during the aqueous alteration of olivine-rich sediments in our experiments.

12 Oct
9:15am
Oral
Theater

Digitate silica sinters of the El Tatio geothermal field, Chile: Is their morphogenesis driven by local microbial communities, by local environmental factors, or both?

van Zuilen M.[1], Gong J.[4], Wilmeth D.[2], Munoz-Saez C.[3]

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Hot spring environments worldwide contain various types of silica sinter structures with distinct morphologies and internal layering that could constitute a macroscopic biosignature. Distal, low-to mid-temperature regimes (<50°C) of silica-saturated geothermal outflows often contain thick cyanobacterial mats. The cell surfaces, resistant sheaths, and extracellular polymeric substances (EPS) of these organisms can act as templates for silica precipitation, generating silica sinters with various stromatolitic morphologies. In high-temperature regimes (>50°C) directly surrounding geyser mounds or spring pool rims, thick silicified microbial mats are absent, but silica spicules, nodules and columnar sinters are found in which thinner biofilms of (hyper)thermophile micro-organisms occur that could have acted as a template for silica precipitation as well. Microenvironmental factors, however, can affect the local rate of silica precipitation and therefore the process of silica sinter morphogenesis. These factors include local hydrodynamics, pH, and fluctuations in temperature, humidity, wind and steam. Silica sinters in geothermal settings thus represent a dynamic interplay between microbial templating and microenvironmentally-driven silica precipitation, but the relative contributions of both processes is often unclear. In this presentation we discuss digitate silica sinter formation in distal, low-temperature regimes of the El Tatio geothermal field, Chile. This high-altitude geothermal field is extremely dry and windy, and has one of the highest silica precipitation rates in the world. We find that digitate silica sinters at El Tatio always accrete into the prevailing eastward wind direction and exhibit laminar growth patterns coinciding with day-night cycles of wind- and thermally-driven evaporation and rewetting. Subaerial parts of the digitate sinters lack evidence of microbial surface colonization, while filamentous cyanobacteria only inhabit subaqueous cavities that crosscut the primary laminations. Several key traits of these digitate structures –angle of repose, non-isopachous layering, and fractal dimension –will be discussed and compared with typical biologic stromatolite structures. We conclude that the saltation of sand grains and precipitation of silica by recurrent wind- and thermally-driven environmental forcing at El Tatio is an important, if not dominant factor, in shaping the morphology of these digitate structures.

Rock solid evidence: distinguishing true microbial biosignatures from false positives in ancient rocks

12 Octv
9:30am
Keynote
Theater

Cosmidis J.[2], Mughal S.[2], Hirsch S.2, Nims C.[1]
[1]University of Michigan1, [2]University of Oxford

Stromatolites and other ancien sedimentary formations contain numerous examples of microscopic organic filaments and spheres, commonly interpreted as fossil microorganisms. Microfossils are among the oldest traces of life on our planet, making their correct identification crucial to our understanding of early evolution. Yet, spherical and filamentous microscopic objects composed of organic carbon and sulfur can form in the abiogenic reaction of sulfide with organic compounds. These objects, called carbon-sulfur biomorphs, spontaneously form by self-assembly under geochemical conditions relevant to sulfidic Precambrian environments,. These biomorphs adopt a diversity of morphologies that closely mimic a number of microfossil examples from the ancient rock record. Here, I will present results on the formation conditions of the C-S biomorphs and preservation potential in rocks. I will also discuss other examples of self-assembly mechanisms that may generate false biosignatures in ancient rocks and blurry our understanding of the early micropaleontological record.

The paleobiological significance of heavy mineral lags in microbial mats and microbialites

12 Oct
10:00am
Oral
Theater

Tice M.[3], Ewing R.[3], Nachon M.[3], Zawaski M.[3], Fisher K.[2], Shapiro R.[1], Czaja A.[4]
[1]California State University-Chico, [2]NASA Johnson Spacer Center, [3]Texas A&M University, [4]University of Cincinnati

Microbial mat-bearing sediments commonly include laminations enriched in small heavy mineral grains (i.e., grains composed of minerals having densities >2.9 g cm^3) relative to grains composed of lighter minerals. Such enrichments, or lags, have been previously interpreted to result from differential trapping of these grains as they are transported across sticky and slowly accreting surface mats (e.g., Gerdes et al., 2000; 2010; Noffke et al., 2021), with heavy minerals selectively deposited based on preferential transport close to the mat surface or based on the inherent roughness of the mat surface itself (Tice et al., 2011). Alternatively, mat-lining lags could result from the tendency of fine grains to be trapped against or shielded by coarser grains as they are rolled together over stationary surfaces.

We use scanning x-ray fluorescence spectroscopy (μXRF) to demonstrate the presence of heavy mineral lags in examples from modern, eolian and seasonally inundated microbial mats and crusts of South Padre Island, Texas (USA); analogous fossil mats from the Jurassic Entrada Sandstone, Utah (USA); intertidal to subtidal fossil mats from the Paleoarchean Moodies Group, South Africa; and shallow-water stromatolites of the Mesoarchean Nsuze Group, South Africa. The formation of lags across this variety of depositional environments and ages suggests that heavy mineral enrichment on mats is a general process that is unlikely to depend critically on fluid properties or mat composition. We also show that grain size distributions for heavy minerals having contrasting densities reflect sorting by

rolling rather than by differential settling or transportation modes in the fluid.
Mat- and microbialite-associated heavy mineral lags therefore reflect the prolonged rolling of grains across sedimentary surfaces stabilized by the mechanical cohesion of the mats. Thus, when alternative mechanisms for lag heavy mineral sorting or bed stabilization can be eliminated (ex. ripple/dune migration, rapid deposition from dense sediment suspensions, or incorporation of clay minerals), the presence of heavy mineral lags can provide supporting evidence for the past presence of mat communities or guide the search for other biosignatures.

Microbial carbonate as carbon storage system

Understanding microbial carbonate formation in alkaline lacustrine settings and its potential as a carbon storage system

13 Oct
10:45am
Keynote
Theater

Tutolo B.
University of Calgary1

Alkaline lakes are standing water bodies with elevated pH, elevated carbonate alkalinity, or both. Importantly, achieving these defining characteristics requires a unique confluence of hydrologic, geochemical, and geomorphologic processes. Most importantly, alkaline lakes occur in dry continental environments where evaporative fluxes outstrip hydrologic input for at least part of the year. To achieve their elevated pH and alkalinity, specific inflowing water chemistry, wherein $[HCO_3^-] > 2\ [Ca^{2+}]$ (where the brackets indication concentration in molal units) is required. As the waters evaporate, Ca precipitates as carbonates and HCO_3^- increases to maintain charge balance with other, conservative alkaline cations such as Na^+ (hence some alkaline lakes' designation as 'soda' lakes). Hence, due to the insolubility of Ca^{2+} in alkaline lake waters, additional, groundwater inputs of Ca^{2+} are typically invoked to explain observed alkaline lake microbialites. It follows, then, that microbial carbonate formation in alkaline lakes is at least partially dictated by influxes of dissolved Ca into alkaline lake waters.

The groundwater hydrology of alkaline lakes is unique. While they share many features with other lakes, their elevated density and salinity create unique chemical and hydraulic gradients in the subsurface. Indeed, as Ca-poor, alkaline lake waters are increasingly evaporated, they become denser than dilute, Ca-bearing groundwaters, potentially driving Rayleigh-Taylor instabilities in addition to regional hydraulic head gradients. Although these hydraulic interactions between inflowing groundwaters and alkaline lake waters have often been invoked for understanding microbial carbonate formation in alkaline lake settings, the factors that lead to abundant versus limited carbonate formation remain poorly understood. Here, I will present the results of recent and ongoing geophysical and reactive transport modeling investigations into the hydrogeology of alkaline lake systems. Specifically, I will present Electrical Resistivity Tomography-derived imaging of brine and groundwater in the subsurface underlying modern alkaline lakes. I will build upon this effort with a series of reactive transport simulations that explore the processes that lead to abundant versus limited carbon storage in alkaline lake systems. I will conclude by discussing recent advances in efforts to optimize cultivation of alkaliphilic cyanobacteria and their implications for improving our understanding of microbial carbonate formation.

13 Oct
11:15am
Online
Theater

Microbial carbonate as carbon storage system

Thaler C.
Marble

To prevent the worst impacts of climate change, the world needs to reach net zero around mid century. This means two things: slash global emissions from the equivalent of 60 gigaton annual to near zero, and remove CO_2 from the atmosphere on a multi gigaton scale. The last IPCC report estimates that 5 to 16 gigaton of carbon direct removal from the atmosphere will be required each year after 2050 to keep global temperature increase as close to 1.5°C as possible. Reaching such levels in just a few decades is a herculean feat and will require many approaches.
Carbon mineralization combined to an alkalinity source is considered as a lever to fight climate change for 3 main reasons: it primarily requires elements available in relevant quantities, the measurement of CO_2 capture is straightforward, and sequestration as rocks ensure maximum permanence. Carbon mineralization naturally immobilizes 1.1 gigaton of CO_2 annually and could be shaped to reach multi-gigaton scale carbon removal by 2050.
However, human driven carbon mineralisation operations to date have been limited by several key challenges. In that framework, biomineralization is considered a promising biotechnological tool that will tackle these challenges by increasing reaction rates, lowering energy inputs, replacing excessive fresh water use by saltwater and preventing leakage risks by kipping appropriate reactive element concentrations.
Moreover, mineral carbonates formed by organisms can be recovered and engineered to serve industrial purposes, promoting a circular economy, lowering emissions and expediting the shift to a low-carbon world.

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13 Oct
11:30am
Oral
Theater

From microscale observation to macroscopic flux quantification: linking picoplankton dynamics and calcite precipitation in a large hardwater lake

Escoffier N.[1], Many G.[1], Mucciolo A.[1], Bedel R.[1], Perga M.-E.[1]
[1]University of Lausanne

In hardwater lakes, calcite precipitation is a major process coupling alkalinity loss with autotrophic microbial activity. While recent studies refined the magnitude and biogeochemical conditions underlying calcite precipitation at fine scales, the mechanisms supporting the nucleation of calcite are poorly described. In the pelagic realm of deep oligotrophic lakes, calcite nucleation has often been associated with autotrophic picoplankton, however, direct observations remain scarce. Here, we focused on the largest hardwater lake of western Europe, Lake Geneva, and combined depth-resolved high-frequency with discrete sample data to investigate the coupled dynamics of calcite precipitation and picoplankton populations. Calcite precipitation during periods of lake thermal stratification and high productivity coincided with peaks in the abundance of distinct picoplankton populations that were characterized based on specific spectral fluorescence signatures using flow cytometry. The vertical distribution of the dominant picocyanobacteria population over time

evidenced maximum abundances at depths of enhanced water column stability and alkalinity depletion. Moreover, sorting of this phycoerythrin rich population combined with imaging by SEM-EDX enabled analyzing diverse patterns of association between calcite crystals and picoplankton cells. These results provide a refined understanding of calcite nucleation mechanisms and allow inferring the relevance of this biologically mediated process for the lacustrine carbon cycle.

Exploiting induced carbonate precipitation to improve reservoir storage integrity and geothermal system efficiency

13 Oct
11:45am
Online
Theater

Salter P.[1], Dobson K.[1], Minto J.[1], Warnett J.[2]

[1]University of Strathclyde, [2]University of Warwick

Biomineralization, through microbially, thermally, or enzyme induced carbonate precipitation (MICP/TICP/EICP), is a cost-effective cementation process that seals inaccessible microfractures and pore throats. This study aims to optimize compositional and injection parameters for biomineralization fluids in subsurface applications related to the low carbon energy transition. This includes enhancing CO_2 storage integrity by reducing permeability around legacy wells, and improving thermal performance in geothermal and thermal energy storage systems.

Understanding interactions between geochemical reactions and the transport properties of fluid at the reservoir scale first requires biomineralization experiments to be carried out at the pore (micron) scale. These studies are essential for understanding principles of crystal formation, growth and hydrodynamic feedback mechanisms. Using real-time in situ x-ray computed tomography, the complex and synergistic factors involved can be better understood. Correlation of microstructural and macroscopic properties during repeated precipitation and dissolution events will allow refinement of reactive transport models for different injection strategies.

Carbon Capture and Storage: Creating low permeability regions may prevent leakage and enhance injectability. Two-phase EICP can be hindered by improper injection angles and flow rates, limiting fluid mixing and permeability reduction. Single-phase thermally-delayed, and pulsed EICP strategies are explored to improve homogeneity of precipitation in real-world systems. Multiple injection cycles target significant permeability reductions for modifying CO_2 and gas flow behaviour in various target minerologies and grain size distributions.

Thermal: Conventional grouts have low thermal conductivities (<1 W/m K) and may form poor seals at rock/soil interfaces. $CaCO_3$ crystals formed between soil grains following MICP significantly increase thermal conductivity, especially in unsaturated conditions. Highly conductive additives enhance this effect further, while integrating phase change materials increases specific heat capacity for thermal energy storage. Specialized geothermal grouts/backfill reduce costs by allowing shallower boreholes. The project's outcomes impact the commercialization of engineered biomineralization and its role in the subsurface energy transition.

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13 Oct
12:00am
Online
Theater

Sustainable construction: Harvesting Cementous Materials

Kolodkin-Gal I.

Scojen Institute for Synthetic Biology, Reichman University, Herzliya, IL

In natural settings such as the plant and soil microbiomes, bacteria reside in multicellular differentiated communities, referred to as biofilms. Biofilms formed by soil microbes can participate in bioremediation, carbonate mineralization, carbon dioxide sequestration, and the generation of eco-friendly cementous materials. Thus, the study of biofilm development is of technological, agricultural, and ecological importance.

We employ interdisciplinary approaches to investigate the biomaterials that account for microbial multicellular behaviors. So far we uncovered several ways by which microbial biomaterials produced by soil and rhiszosphere bacteria coordinate the structure and function of the community. In short, our work exposed crystalline $CaCO_3$ scaffolds that are essential to complex biofilm morphology and function. The accumulation of calcium and bicarbonate intracellularly and its subsequent secretion leads to the formation of structured mineralized scaffolds while sequestering atmospheric carbon dioxide. These dense calcium carbonate sheets are incorporated into EPS (exopolymeric substances) matrices and act as diffusion barriers that further regulate the diffusion of liquids across the biofilms [1-4]. We now utilize many of the molecular mechanisms developed by in this context to generate renewable cementous materials for sustainable construction, relying on synthetic biology to enhance our newly discovered gene circuits.

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[3] Keren-Paz, A., Brumfeld, V., Oppenheimer-Shaanan, Y., and Kolodkin-Gal, I. (2018). Micro-CT X-ray imaging exposes structured diffusion barriers within biofilms. NPJ biofilms and microbiomes 4, 8. 10.1038/s41522-018-0051-8.

[4] Kolodkin-Gal, I., Parsek, M.R., and Patrauchan, M.A. (2023). The roles of calcium signaling and calcium deposition in microbial multicellularity. Trends in microbiology. 10.1016/j.tim.2023.06.005.

Poster

Fossil stromatolites of Salar de Huasco (Tarapacá region, Chile): geological blueprints of ancient paleolake evolution in the Andean Altiplano

Lopez-Garcia J.[2], Kotopoulou E.[2], Rosales I.[4], Sevillano A.[2], Moreira D.[1], Aguilar P.[3], Cubillos C.[4], Dorador C.[3], Lopez-Garcia P.[1]

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Modern microbialites are organosedimentary deposits increasingly described in lacustrine environments, including diverse salars of the Andean Altiplano (average altitude, 3700 m asl). Salt lakes and salt flats (salares) form by evaporation of water bodies in the altiplano-hosted closed endorheic basins under local arid or semiarid climate. Microbial ecosystems, sometimes forming microbialites, dominate under the local extreme conditions, including intense UV radiation, high salinity, extreme temperature fluctuations, widespread hydrothermal activity and/or oligotrophy. Andean salt lakes are ca. 14 million years old and have experienced environmental change over time, including wet and dry periods punctuated by water level fluctuations. Evidence of those changes, we report here the discovery of fossil stromatolites present at different altitudes above the actual salt pan of Salar de Huasco, in the Andean Altiplano of Chile. We observed stromatolites in Cerro Charcollo, a c.a. 20 m high Miocene-Pliocene volcanic hill (c.a. 3810 m asl.) located at the east limit of the actual salt pan (3790 m asl.), and along an ancient lake terrace (c.a. 3825 m asl.) covering Miocene ignimbrites at the south of the actual salt-pan. We use a hierarchical multiscale approach to characterize the morphological traits of these microbialites. The smallest microbialites are mm- to cm-thick planar laminated structures encrusting fractures on the basalt substrate in the lower outcrops, that can develop small domical heads that build up over them in wider fractures. In higher outcrops of Charcollo and the southern lake terrace, wider spaces host larger, cm-dm thick, stromatolites with predominant domical to branched forms, with commonly ornamented projections, and columnar morphologies with connecting bridges. The largest stromatolites locate on top of the hill, forming bioherms up to c.a. 1 m in diameter, including nested domical, columnar and fascicular forms. These bioherms coalesce yielding microbialite reefs of decametric extension. We use polished slabs, optical microscopy and SEM images to study the microstructure of laminar microbialites, as well as XRD and EDX mapping for bulk microscale chemical and mineralogical analyses. Finally, we hypothesize that venting of hydrothermal water circulation along fractures of the basaltic basement was a major driver in the development of these microbialites.

Arsenic incorporation and speciation in microbial biomass of modern oxygenic and anoxygenic microbial mats

Madrigal Trejo D.[2], Fakra S.[1], Bosak T.[2]

[1]Advanced Light Source, [2]Massachusetts Institute of Technology

Arsenic (As) is a toxic and ubiquitous metalloid that occurs as arsenite [As(III)] and arsenate [As(V)] in natural waters. Microbes can oxidize arsenite and reduce arsenate in catabolic reactions, or detoxify either species using a set of phylogenetically widespread mechanisms. The presence of arsenic inclusions in organic-rich globules in carbonate stromatolites from 2.7 billion years ago (Ga) was interpreted as evidence for some of these processes during the Archean Eon. Here, we ask how the signals of arsenic cycling are preserved in microbialites by characterizing: 1. distribution of genes involved in arsenic metabolisms in lithifying anoxygenic and oxygenic microbial communities; 2. tolerances of these communities to amendments by arsenate and arsenite and 3. distribution and speciation of arsenic in microbial cells, EPS, carbonates and other minerals. High-throughput sequencing of modern lithifying microbial mats from Shark Bay indicates that ars genes involved in detoxifying arsenate are distributed among different microbial phyla including Cyanobacteria, Planctomycetes and Bacteroidetes, whereas aox genes involved in arsenite oxidation are confined to a few Proteobacteria. These observations suggest an enhanced resistance of the Shark Bay community to As(V). This was confirmed by culturing oxygenic pustular mats from Shark Bay and anoxygenic sulfidic mats from Fayetteville Green Lake, New York, in solutions amended by 500 uM and 5 mM As(III) and As(V). Enrichment cultures of Shark Bay pustular mats grew similarly in the absence of As(V) and the presence of up to 5 mM As(V). Anoxygenic Green Lake mats show a similar behavior. Both mat types accumulated less biomass in the presence of As(III) relative to As(V). The distribution of arsenic in these biofilms, extracted EPS and minerals will be mapped using SEM-EDS and its speciation assessed by As K-edge XANES at the Advanced Light Source. In addition to arsenic being incorporated into biomass and its potential to preserve arsenic biosignatures, the formation of arsenic-incorporating minerals will enable the documentation of arsenic-preserving pathways in microbialites.

Raman spectroscopy on microbial carbonates: enhancing understanding of thrombolite formation processes and identification of preserved microbiological and microtextural features in carbonates

Rivarola E.[1], Gomez F.[2], Tutolo B.[3], Mlewski E.[4]

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Microbial carbonates, known as microbialites, represent unique geological formations holding valuable information about past environments. Understanding their formation and identifying preserved microbiological features (microtextural and compositional) within carbonates is crucial for reconstructing Earth's history and advancing our knowledge of microbial life evolution. Here, we show how Raman spectroscopy can contribute to our understanding of modern and ancient thrombolites. Raman spectroscopy is a powerful non-destructive analytical technique that provides molecular information about the composition and structure of materials. Its ability to identify organic compounds and mineralogy at the microscale makes it particularly suitable for the study of microbialites. Microbes can leave distinct structural and chemical signatures in carbonate minerals (organic remnants and mineralized microbial cells) that can thus be detected and mapped by Raman spectroscopy.

We acquire Raman spectra and integrate this information with other, complementary techniques (polarized light petrography, SEM, isotopic analysis) to study non-laminated clotted microtextures that characterize thrombolites from Strobel Lake (Santa Cruz, Argentina). Raman microscopy provides particularly useful insights into the origin of organic components filling micropores and mesopores, which thereby helps us to unravel the intricate processes involved in thrombolite formation.

Modern thrombolites from Strobel Lake are colonized by both biofilms and pustular to subspherical (mm to cm size) cyanobacterial communities (Nostocales-like). The thrombolite framework is represented by clots that usually show a mottled microtexture given by irregularly shaped darker-colored material. In thin-section, mesopores between clots (framework porosity) can be partially or fully filled by detrital and carbonate sediments, bioclasts, vegetal remains and black colored, subcircular and polylobate dark-colored balls (without a clear internal structure under polarized light microscopy). Gray mottled micrite and microsparite also cements detrital particles and fills the mesopores. Raman analysis allowed identification of monohydrocalcite composing the clots and organic material (pigments) related to cyanobacteria (in the black-colored subspherical structures). The dark irregular spots observed within the mottled clots were also identified as organic material that, when degraded, leave micropores that could be potentially considered as biosignatures. The close association of organic material and clot microtextures suggests some biological influence in the thrombolite framework construction.

Multivariate analysis to reveal patterns of trace elements in Mono Lake carbonates

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Mono Lake chimneys formed by mineral precipitation offer a unique geological record that sheds light on ecosystem dynamics, physicochemical processes, hydrological and climate evolution within lake systems. Consequently, there has been a growing interest in investigating the biogeochemical processes involved in the formation of carbonate chimneys around sublacustrine vents. This may be useful in the understanding the record of ancient or even extraterrestrial life in similar systems.

The enrichment of trace elements in sediments is intricately linked to biological activity and redox conditions given that some trace elements serve as bioessential components, while others exhibit redox-sensitive behavior. Given that carbonate minerals can adsorb

and incorporate trace elements during mineral precipitation, the distribution of these elements between the fluid and mineral phases provides valuable insights into biogeochemical processes and environmental conditions. This study aims to explore the patterns of trace elements within sedimentary carbonates of Mono Lake to unravel the associated processes. To achieve this, we have employed multivariate statistical methods to analyze an μXRF dataset (normalized to Ca) of trace elements in Mono Lake samples. Factor analysis, principal component analysis (PCA), and clustering techniques have been utilized to identify potential patterns among trace elements, which can infer specific redox conditions, the partitioning of bioessential elements, and/or the presence of detrital components.
The analysis has revealed that some trace elements that cluster, such as Co, Ni, Cu, Zn, and As, may be associated to a biological component. Detrital provenance is likely represented by elements such as Ti, Fe, Al, Mg, and Rb. Some laminae are enriched in redox-sensitive and biologically relevant trace metals (such as Mo, V, Fe) that could be associated to organic enrichment or other minerals such as pyrite.
Although this is a preliminar analysis, it is useful to focus further studies with more precise analytical techniques. Further research is crucial for refining and validating findings, providing a comprehensive understanding of microbialite formation, evolution, and diagenesis. Unraveling trace element patterns will enhances understanding of microbialite formation and their potential as indicators of ancient life forms.

Microbe-clay interactions and taphonomy in Proterozoic siliciclastic environments

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Fine grained siliciclastic sedimentary rocks are a rich archive of early life on Earth. In particular, phyllosilicate rich rocks such as mudstones have proven to be effective in the preservation of microbial textures and microfossils. Additionally modern studies have implicated marine microbial communities in the direct precipitation of phyllosilicate minerals such as nontronite, leading to insitu rapid preservation of microbial textures and microbial fossils. However, the geological record of microbial behaviour in mud rocks, particularly in distal marine settings, is relatively understudied. Specifically, it is currently unknown if the species of phyllosilicates present affect preservation of microbial textures and microfossils. Further, the effects of depositional setting on the preservation of microbial textures and microfossils are also relatively poorly understood in these settings.
To investigate these questions, we conducted an extensive investigation of the exquisitely preserved ~1.4 Ga Greater McArthur Basin (GMB), northern Australia. The GMB was a long lived stable cratonic marine basin, with clastic dominated sedimentation. Thanks to abundant drill core material, the GMB provides an easily accessible archive of Proterozoic life and environments. We examined an extensive sample set of lithologies extracted from 7 drill cores from the GMB. These cores represent temporally and spatially adjacent depositional settings which provide a proximal to distal transect of contemporaneous depositional environments across the basin.
Here we present early fossil, mineralogical, and sedimentological data which illustrate the abundance, diversity, and preservation quality or taphonomy of microbial textures and

microfossils within the basin. We also quantify the clay species associated with microbial textures and microfossils in each setting. Finally, we present a schematic depositional model for the basin and discuss the possible links between preservation, environment, and clays.

The rocks of the GMB provide a unique window into the early evolution of terrestrial life and environments. Additionally, understanding the exceptional preservation of microbial traces in mudstones is of particular significance to the search for life on Mars. As the presence and composition of phyllosilicates can be determined through remote sensing techniques, this knowledge provides a valuable tool in the search for signs of ancient life in Martian mud rocks.

Microbial sulfur-cycling inferred from metagenomes of gypsum stromatolites and microbialite-like formations

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Stromatolites are widely recognized as the oldest evidence of prokaryotic life. Such organo-sedimentary structures are still formed today by the complex interaction between microbial communities and the geochemical environment in several marine and lacustrine systems across the world. Although carbonate-based microbialites are largely dominant worldwide, gypsum-based stromatolites and microbialite-like formations can be found in evaporitic systems under saline to hypersaline conditions, such as the Danakil Depression, Ethiopia. Despite their implication on early life evolution and current expansion due to global warming and desertification, the processes behind the gypsum microbialite formation and the composition of microbial population are not as of yet fully elucidated. Here, we analyzed four metagenomes from gypsum-based microbialitic structures sampled in two saline lakes in the Danakil Depression. These included a gypsum-hosted endolithic community out of the water, a mineralizing microbial mat and an adjacent gypsum stromatolite in Lake Bakili, as well as an endolithic thin mat sandwiched between cm-sized gypsum crystals (~6 cm) in a nearby hypersaline lake. Applying a space-for-time approach, these samples could represent different steps along the formation of increasingly mineralized structures, from microbial mat to bona-fide stromatolite to mineral-hosted endoliths. The role of microorganisms as biogeochemical agents, particularly their impact on the sulfur cycle, was investigated through metagenome-based whole community functional analysis and Metagenome-Assembled-Genome (MAG) reconstruction. Among the clades harboring genes for the oxidation of reduced sulfur compounds were: Alphaproteobacteria, Myxococcota, Acidobacteriota and Gemmatimonadota. Interestingly, the capability for inorganic sulfur/sulfate reduction was found mainly in MAGs recovered from the gypsum endolithic mat, which strongly suggests that this community grows at the expense of gypsum crystals. Overall, functional annotation of retrieved MAGs revealed that gypsum-based microbialitic structures harbour an active sulfur cycle mediated by oxidation and reduction of organic and inorganic sulfur compounds.

Dolomitization in Lower Cretaceous carbonates of southern Apennines, Italy: Microbialites in dolomite geobodies

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Lower Cretaceous carbonates of Monti Lattari, southern Apennines (Italy) are under study to test reflux model of dolomitization. The stratigraphy of the study area is comprised of three units i.e., A (middle Berriasian –lower Hauterivian), B (upper Hauterivian –lower Barremian) and C (upper Barremian –lower Aptian). Units A and C consists of alternating limestones and dolomites while B is a completely dolomitized unit.

The current study presents dolomite rock textures/structures in units B and C. The presented data consists of outcrop/polished rock slabs observations, petrography and SEM-EDS analyses. The presence of mud-supported carbonates, burrows, skeletal (miliolids, biserial, uniserial forams, ostracods, microbialites) and non-skeletal components (intraclasts, peloids) indicate peritidal carbonates system.

In B-unit, there are alternations of microbial (algal) laminated and non-laminated carbonates for ~90 m. In most of the succession, the algal laminations are well preserved but at places laminations relics are noticed indicating depositional-textural (grain size) and compositional variations control the intensity of dolomitization. The algal laminations are layered stratiform, wavy and parallel millimetric scale. The microbial fabrics are dense micritic and micropeloidal laminations. The microfacies are algal laminated dolomudstones (having birds eye texture), non-laminated dolomudstones and crystalline dolomites. The algal laminated and non-laminated dolomudstones have very fine-fine dolomites while crystalline dolomites have fine-medium and coarse crystals. The dominant crystals are non-planar a with subordinate planar-s and planar-e crystals are rare. Coarse sparry dolomites are noticed in veins and vugs in B unit implying late-stage dolomitization.

Different types of dolomites noticed in C unit include matrix selective dolomitization, dolomitized burrows, zoned dolomites, corroded dolomites, and xenotopic dolomites mosaic. In C-unit, mineralized bacterial (spherical) remains are encountered at a stratigraphic level in dolomitic limestone. Such features imply microbial activities which may have a role in dolomitization. In the dolomitized B unit, the carbonates original depositional fabric (microbialites) is entirely replaced by small dolomite crystals but not destroyed by the dolomitization process. The abundance and consistent presence of microbialites in the completely dolomitized unit and sparsity in partially dolomitized carbonates gives an insight about possible and significant role of microbial processes in dolomitization.

Why the long gap between the origin of oxygenic photosynthesis and Earth surface oxygenation?

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We now have highly robust evidence for oxygenic photosynthesis in the Mesoarchean in the form of important negative Ce anomalies that occur in multiple stromatolitic carbonate platforms of Northern Canada and directly dated to 2.9 to 2.8 Ga using the ^{138}La-^{138}Ce radiometric chronometer. This result raises a critical but poorly explored issue regarding the early metabolic and redox evolution of Earth's surface: why did it take 400 million years or more for Earth's most important metabolism to oxidize the Earth's surface during the GOE ca. 2.4 billion years ago? Did oxygenic photosynthesis even play an important role? In this contribution I briefly review evidence for pre-GOE oxygenic photosynthesis and provide a synthesis of current and emerging thought as to what may have limited oxygenic photosynthetic production on the Archean Earth. Whether related to biological factors such as physiology, metabolic plasticity, toxicity, nutrient availability, or environmental factors such as ambient reductants, temperature, irradiation, hypsometry, tidal range, or seasonality, there are a variety of parameters that may explain, alone or together, how oxygenic photosynthesis managed to remain largely cryptic in the rock record for over 400 million years prior to the GOE. Finally, the role (or not) of oxygenic photosynthesis in the ca. 2.4 Ga GOE will be explored in light of alternative, but often overlooked, drivers of planetary surface oxygenation.

Occurrence of huntite, a rare carbonate ($CaMg_3(CO_3)_4$), in modern microbialites from Mexico

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Here, we will show how huntite ($CaMg_3(CO_3)_4$) has been detected in some modern microbialites from the alkaline Lake Alchichica (Mexico). This ordered calcium-magnesium carbonate is metastable under low-pressure and low-temperature conditions (Graf and Bradley, 1962 ; Deelman et al., 1999 ; Gamsjäger, Königsberger and Preis, 2000) and is also relatively rare. The general mechanisms known for its formation include the alteration of primary carbonates within fractures/porosities where, at some point, dissolved ion concentrations become compatible with the stoichiometry of huntite (Kinsman et al., 1968 ; Andrews et al., 2018). This may occur via meteoric percolation or diagenesis in magnesian sediments for example (Kinsman et al., 1968). While many modern microbialites are composed of magnesian carbonates (Caumartin et al., 2023), cases of huntite associated with microbialites have been reported only occasionally (Kuşcu, Cengiz and Kahya, 2017). However, despite a relative diversity of environments and precipitation hypotheses described in literature, the conditions and mechanisms of huntite formation remain poorly understood, especially involved precipitation reactions. Interestingly, huntite has been found in greater quantity below 20 m depth in the modern microbialites of Lake Alchichica. It forms in fracture zones from the microbialite surface and at the interface between aragonite ($CaCO_3$) and hydromagnesite ($Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$), which are the two dominant carbonates in the microbialites of Lake Alchichica (Zeyen et al., 2021). Its preferential distribution at depth, within the microbialites, and absence in surface biofilms altogether suggest that it replaces the two dominant primary carbonates through dissolution/reprecipitation processes. Here we propose that huntite is an early diagenetic phase replacing dominant carbonates of the Lake Alchichica microbialites. In this context, huntite is likely to erase the original information contained in the primary mineral phases (Bathurst 1975 ; de Boever et al., 2017), which raises the more general question of how to distinguish between primary and diagenetic phases in microbialites. Therefore, the study of the mineralogical composition of these deep modern microbialites is of interest not only to document the presence of huntite environment that have not yet been described but also to learn about some of early diagenesis implications on the microbialites mineralogy under alkaline conditions.

Controls on formation and early diagenesis of gypsum microbialites at Lake Afdera, Ethiopia

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The Danakil Depression, located in the northern part of the Afar triple junction, plays a role in the break-up of the Afro-Arabian plateau as part of an active rift zone. Within the southern part of the Depression lies Lake Afdera, a NaCl-bearing hypersaline body of water that, despite showing a positive calcite saturation coefficient, features extensive gypsum deposits. These formations manifest mainly on Franchetti Island as crusts, concretions, and meter-sized mounds, encompassing cauliflower structures and laminated gypsum deposits associated with microbial mats. This study delves into the formation and early diagenesis of these gypsum structures, emphasizing the potential role of microbial films in creating micro-scale fabrics and centimeter to meter-sized structures.
The characterization of gypsum deposits and their evolution over time is achieved using a blend of standard sediment petrological techniques, fluorescence microscopy, XRD, and SEM+EDS. Samples collected during field expeditions in 2017 and 2019 from two proximal-distal transects (from the island's inland part to the open lake) facilitated these findings. The results indicate a correlation between macromorphologies, micro-scale fabrics, and a distinctive gypsum/anhydrite transition along the transects. SEM images further substantiate the close spatial relationship between gypsum crystals and biofilms.
In particular selenite crystal growth is controlled by the topmost cyanobacterial layer in

the mat. These crystals are not affecting the life of the bacteria themselves, acting as a protection.
Moreover, the presence of selenite only in open-lake exposed environment and not in the lagoon is the reflection of the high availability of new sulphate ions into the system.
This research also brings to light the value of Gypsum microbialites as accurate indicators of lake water level fluctuations showing a diminution of the water level of Lake Afdera trough time of about 8m.
This study provides new insights into the characteristics and formation of the Lake Afdera's gypsum microbialites.

The MNHN Microbialite collection

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Stromatolites are laminated microbial sedimentary structures which represent the oldest traces of life in Earth history. By their presence through geological time and in a wide range of depositionnal aqueous environments, they are exceptional geochemical archives and potential tracers of various environmental deposition settings. We present in here one of the largest stromatolite collections: The MNHN Microbialite Collection that now contains more than 1340 specimens, spanning more than 3.5 Ga of life history on Earth. This collection is now available for the scientific community. We present in this poster a synthesis of the collection, including basic geochemical data, informations on its curation, and details on how to participate, donate or request samples. The collection is linked to a movable exhibition. Additional information is available on the website microbialite.com.

Do chromium isotope compositions record signs of oxygenation in the Campbellrand-Malmani platform (2.56 to 2.52 Ga, South Africa)?

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The oxygenation history of Earth's surface remains a highly investigated topic, with an increasing number of studies indicating a dynamic change from anoxic to oxic conditions in the Precambrian. The Campbellrand-Malmani platform (Transvaal Supergroup, South Africa) was deposited in a shallow marine environment between 2.56 and 2.52 Ga [2], just before the Great Oxidation Event. The sedimentary rocks hold a large variety of stromatolites, which can produce oxygen through photosynthetic cyanobacteria. While some studies find indications of oxygen production (e.g., [1]), post-depositional alteration can challenge interpretations of data from non-traditional isotope systems. We present Cr isotope compositions (δ^{53}Cr) in sedimentary rocks from the Campbellrand-Malmani platform to better constrain the robustness of the Cr isotope system to post-depositional changes. Preliminary results show that even though detrital contribution is low, most dolostone and chert samples show δ^{53}Cr values of around -0.12 ±0.10 ‰ (2SD, n = 14) and are thus similar to the detrital δ^{53}Cr value. Only two samples fall off the detrital value, with one dolostones sample showing a positive δ^{53}Cr value of 0.26 ±0.05 ‰ (2SE). Our preliminary results indicate that many of the δ^{53}Cr values in the studied dolostones and cherts were overprinted by post-depositional processes. With the aid of additional isotope (S, N isotope compositions) and auxiliary data (trace metals), we seek to characterise the drivers of the observed δ^{53}Cr values.

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Arsenic and Old Microbialites

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Early Earth was dominated by volcanic activity, adding carbon dioxide, reduced iron and sulfur to surface waters. Other elements, including arsenic, may have been delivered in this way as well. The earliest evidence of life on our planet is arguably captured in 3.5-3.7-billion-year-old fossil stromatolites. These layered carbonate rocks formed through precipitation of carbonate minerals in microbial mats, in which entire microbial communities, not only phototrophs, play a role. Today, stromatolites and microbial mats, typically dominated by cyanobacteria, still thrive in extreme environments. These cyanobacteria, are major engines in carbonate precipitation and "inventors" of oxygenic photosynthesis that led to the Great Oxygenation Event (GOE) ~2.3 billion years ago. Certain heterotrophic bacteria also contribute to carbonate mineralization ultimately forming stromatolites. A major question that remains is how stromatolites formed in the anoxic world prior to the GOE.

Evidence from studies on the 2.72 billion stromatolites of the Tumbiana Formation, Pilbara, Western Australia indicate that not iron or sulfur, but arsenic cycling was associated with organic carbon formation. Furthermore, microbial mats in the Atacama Desert, Chile, that thrive under early-Earth like, permanently anoxic conditions, develop through arsenite and sulfide-supported photosynthesis and arsenate and sulfur/sulfate-sustained respiration. These respiration pathways include anaerobic methane oxidation by arsenate reducing microbes. Although we acknowledge that the Atacama mats are likely different from the mats that constructed the Tumbiana stromatolites, it unequivocally demonstrates that combined arsenic and sulfur cycling provides an alternative to oxygen in the anoxic early days of a young planet.

The Cañadón Asfalto paleolake, Argentina : A window into continental Middle Jurassic palaeoenvironmental conditions

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The Middle-Late Jurassic period was marked by repeated carbon cycle perturbations associated with global climate and environmental changes. Those perturbations are well understood in the marine realm but comparatively understudied in continental records. The Cañadón Asfalto Basin (Chubut Province, Argentina) evidence a unique continental record with the exceptional preservation of Middle-Late Jurassic fauna and flora. Constraining the palaeoenvironmental conditions is hence crucial in order to better understand the carbon cycle and its potential effect on the evolution of life.
This study focuses on the Cerro Cóndor paleolake of the Cañadón Asfalto Basin. Through sedimentological, mineralogical (whole-rock and clay assemblages), geochemical (organic matter characterization, carbon and oxygen stable isotopes, major and trace elements, total phosphorus), and radiometric (high-precision U–Pb ages) analysis palaeoenvironmental conditions are reconstructed. The lacustrine system was influenced by important volcanic activity and lake level fluctuations. The sedimentary succession is composed of organic matter-rich mudstone, sandstone and conglomerate, as well as an important contribution of volcanic and volcanogenic material. Lacustrine stromatolites are common in the studied area and represented by stromatolitic limestones and stromatolitic cherts. The paleolake was marked by well-oxygenated phases alternating with periods characterized by oxygen-deficient conditions. Last favorizes the selective preservation of organic matter. The integrative dataset provides new insights on how local environmental processes and volcanic activity drives regional depositional conditions and how to detangle regional from global environmental trends.

Novel in-situ Surface-enhanced Raman Spectroscopy reveals organic signatures in seep carbonates

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It has been said that "carbonates are born, not made", but it is unclear if this rationale extends also to authigenic carbonates. Their formation across different times scales is still a topic of debate. One challenge is the role and nature of microbial communities in carbonate mineral formation. Identifying the microbial communities involved in the formation of different carbonate mineral phases is challenging and often limited to rare indirect evidence, requiring large samples from a very small sample size.
Here, we present a novel non-invasive, in-situ method for identifying distinct organic compounds in carbonate minerals using surface-enhanced Raman Spectroscopy (SERS). Use of SERS allows to identify both, the mineralogical phase as well as elements of organic molecules such as methyl and methylene groups. To demonstrate and constrain the

use of SERS, we implement this method to authigenic seep carbonates from the Eastern Mediterranean Sea. These carbonates exhibit multiple and complex phases of cements. We contrast traditional biomarkers extracted from bulk material with the identification of organic compounds through SERS at single mineralogical phases.
By using the different ratio of methyl to methylene groups, one can easily identify the chain length or branching of organic compounds in specific carbonate phases and thus assign them to different formation processes. Through this ratio, it is possible to distinguish carbonates formed primarily during the presence of sulfate-reducing bacteria from those formed during the presence of a consortium of methanotrophic archaea and sulfate-reducing bacteria.

Approach to the middle Triassic microbial mats to sponge-microbial buildups links to the Permian–Triassic crisis aftermath, with outcrops around Leysin resort (Switzerland)

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Looking on the so called "algal mats, crypto-sponge and mudmound" of our published works on the middle Triassic carbonate of the neighboring Briançonnais epeiric sea [1,3] the outcrops of Chalex and Mont d'Or [1] near Leysin well recorded a first marine transgression, that occurred during the Lower-Middle Triassic transition about 247 My ago, characterized by a very large scale, dolomitic microbial mat deposition, showing a first similarity with the post extinction basal Triassic stromatolites of the Tethys described in [4]. During the Lower Anisian time (247-246 My), a new, large scale dolomitic microbial mat, caps the open shallow marine deposition of the 20m thick vermicular limestone of the Dorchaux Member defined in Mont d'Or sections. At the top the Lessus Member (middle Anisian about 246 My ago) defined in the Lessus quarry of St-Triphon locality, a dolomitic microbial mat was well recorded. A thrombolitic buildup up to 4 m thick is recorded in the Rothorn section of Diemtigtal (Central Switzerland), described in Baud, 1987, This unique "mudmound" is also showing a similarity to the post extinction basal Triassic sponge microbial buildups [2].
At the middle-upper Anisian transition between 245 and 244 My ago, the regressive top of the Saint-Triphon Formation is characterized by a very large scale dolomitic microbial mats deposit, recorded from central Switzerland to Franco-Italian maritime Alps.
The overlying Wildgrimmi Member of the Wiriehorn Formation (upper Anisian in age) consists of a 220 to 340 m succession of peritidal carbonate deposits with a shift to decametric scale shallowing-upward cycles, each topped by a dolomite bed possibly of microbial origin. This unit is well recorded in the Mont d'Or klippe and form the crest.
The upper regressive part of this Wiriehorn Formation, the Bodefluh Member 20-40m thick, is characterized by dolomitic beds partly built by stromatolites.
Higher up, in the Pralet Formation defined in Château d'Oex Mountains NE of Leysin, the upper regressive part, Ladinien in age (240- 238 My), due to arid climate and higher salinity, the carbonate factory moves to dolomitic production with increase in microbial activities and loss of skeletal material.

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From end Permian great extinction to lower Triassic anachronistic calcimicrobialites: look on Armenia, Iran, and Oman sponge-microbial records.

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As shown by [2,3], a major crisis occurred in Phanerozoic carbonate systems during the end-Permian mass extinction that involved a whole scale change in oceanic geochemistry. The prolific upper Paleozoic skeletal carbonate factory was abruptly replaced by a non-skeletal carbonate factory [1]. Microbial communities affected sedimentation in a variety of normal marine areas [1].
A post-extinction calcimicrobial unit occurs above the extensive Permian skeletal carbonate platform exposed in the shallow, low energy post-extinction carbonate ramp of the N Gondwana margin (Bukk Montains [9], Hungary, S Alps, Italy and Slovenia, Taurus, S Turkey, Zagros and N Oman [5,6]. Thrombolitic mounds and/or stromatolites represent this microbial episode in Central and E Elburz (Paleotethyan margin of N Iran).
The more distal open marine ramp studied in S Armenia Chanakhchi outcrop offers the opportunity to discover a new sponge-microbial community development in the aftermath of the end-Permian mass extinction [7]. The possible presence of keratose demosponge fibers was recently confirmed by [11]. The sponge-microbial build-ups are spaced from 5 to 20 m. and surrounded by thin-bedded platy lime mudstone deposited between the fair-weather wave base and the storm wave base. A giant buildup start growth on a basal carbonate fan crust overlain by a succession of thrombolitic domal forms, some of them up to 1.5m thick. The overturned cone-shaped buildup geometry has a top head diameter up to 8m width consisting of numerous thrombolite domes, and a usual height of up to 15m. The asymmetrical buildup growth hints to a steady bottom current and the overall duration of these post-extinction microbial buildups is estimated at 700'000 years according conodont

zones. Comparison was made with late Proterozoic Conophyton-Jacutophyton biostromes of the Atar area (Mauritania) showing decametric columnar branching buildups [3].
The basal Triassic distal open marine ramp worked in Central Iran contained so called ”crystal layers” or ”carbonate crust” according to [8] and to [9]. According to our investigations [4], the Kuh e Hambast section east of Abadeh city and the more distal Shareza section near Isfahan shows both in well dated basal Triassic successive levels of decimeter to meter scale elongated to cup shaped mounds. Thinly laminated candelabra or chimney-like structures are protruding from a common base and/or are growing side by side and consists of branching columnar stromatolites. Calcite replacement of keratose demosponge fibers is widely present in the lime mudstone matrix.
Studying unusual lower Olenekian red ammonoid limestone deposit in the Oman Mountains we first focused on thrombolites and carbonate textures, such seafloor aragonite fans, sheet cracks, large botroidal cement, bacterial sheaths, coccoids and frutexites-bearing microbialites [12]. As many stromatactis cavities were also linked with these microbial-induced features, new analysis reveals numerous sponge spicules around small cavities. This confirms the collapse of soft sponge bodies. As consequence, the thick red stromatactis beds are now reported to sponge – microbial build-ups. This Oman data is adding new area and new distal open marine facies for sponge – microbial growth. Background studies also suggest a low oxygen concentration and supersaturation with respect to $CaCO_3$ within the water column [3]).

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