Microbe-mineral interaction and long-term mineral diagenesis in lacustrine systems

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Introduction:

Stromatolites and other lithified microbial structures represent the most enduring evidence for life, stretching back 3.5 Ga, and forming in modern marine and continental environments. Lithification of soft microbial mats is achieved through precipitation of various minerals within the mat, mostly carbonates, but equally sulfates and silicates. Cyanobacteria, anoxygenic phototrophs and sulfate reducers are the main microbial consortia leading to carbonate precipitation (Dupraz et al., 2009). Microbial mats influence their immediate geochemical environment by either inducing or influencing mineral precipitation on an organic template (extracellular polymeric substance, EPS) (Chafetz & Buczynski, 1992; Dupraz et al., 2009). This organomineralization occurs in prokaryotes and differs from eukaryotic, organism-controlled biomineralization, such as shell precipitation. Additional processes of lithification in microbial mats include trapping and binding of sedimentary particles (Riding, 2000), heterotrophic decomposition of bacteria (Reid et al., 2000), as well as endolithic boring combined with cement precipitation.

Processes of modern mineral precipitation are reasonably well understood due to numerous field and experimental studies, both in continental and marine settings (see Dupraz et al., 2009 and references therein). On the other hand, tying modern microbial processes and their mineral and textural products to ancient microbial structures such as stromatolites, remains a challenge. Different microbial consortia may create similar microbial structures. The ‘maturity’ of organominerals is little studied - how do organominerals influence further diagenesis, namely mineral transformation, neoformation, and dissolution? What organominerals are diagnostic for specific ancient geochemical conditions?

Therefore, microbe-mineral interactions are important geological records of Earth’s coupled biological and geochemical evolution, for example oxygenation of the Earth’s atmosphere through the Precambrian. Microbe-mineral interactions equally serve as calibration points for potential extraterrestrial biosignatures. From an applied perspective, microbes played a role in the formation of unusual hydrocarbon reservoirs, and the interaction between organic matter, mineral diagenesis and microbial activity will shed important light on long-term processes of porosity generation and cementation in subsurface reservoirs.

Study Aims:

The study focuses on mineral precipitation in continental lacustrine environments. By comparing microbe-mineral interaction in different geochemical environments (brackish, saline, hypersaline and alkaline lakes) it will determine what active microbial processes and mineral precipitates are characteristic for each geochemical environment. Comparison with drill core from the same lakes, and with fossil microbial structures allows investigation of the processes and timescales of mineral diagenesis.

Project Summary:

The 4 lakes of this study represent different lake chemistries (Figure 1): Lago de Estaña, Spain (brackish), Laguna de Gallocanta, Spain (saline), Salada de Chiprana, Spain (hypersaline), and Lago Chungarál, Chile (alkaline). The Spanish lakes all lie in the Ebro basin, which is an endorheic basin with a distinctly semi-arid climate. A similar situation applies to the Chilean lake, which further lies in a volcanic
catchment area responsible for the alkaline lake chemistry (Sáez et al., 2007). In each lake, microbialite formation and carbonate precipitation has been documented by previous studies. In addition, the lake water chemistry, microbiology and climate for each lake have been intensely studied (e.g., Jonkers et al., 2003; Vidondo et al., 1993), and these data will be available for the project. Several lakes further have available drill core; new drill core will be obtained where necessary for the study.

A specific focus will be on the similarities and differences between each lake type. Shallow drill core (several meters long, representing a geological record between several 100 years and 20,000 years) allow an investigation how mineral diagenesis proceeded over relatively short timescales (Figure 2). It should be noted that lakes have undergone chemical variation due to changes in climate and water inflow. This will allow mineral comparisons not just within the same lake system, but also across lake systems. Miocene lake deposits in the Ebro basin allow a further comparison with deposits about 5 Ma old. The Miocene lakes formed in the same endorheic basin under arid and semi-arid climate, and contain microbial carbonate deposits (Zamarreno et al., 1997; Arenas & Pardo, 2000). They therefore provide an analogous fossil system to investigate long-term mineral diagenesis.

The study will characterize the mineralogy, geochemistry and microbial composition of mineral precipitates to infer the types of biochemical reactions and microbe-mineral processes responsible for mineral formation. The following analytical techniques will be employed:

- Standard thin sections, resin-hardened sections of smear samples, and SEM-EDS to study petrography and textures of precipitates and associated microbial matter. (Co-I’s: Corella, Schroeder, Wogelius)
- XRD, microprobe, Fourier transform infrared (FTIR) spectroscopy, TIC/TOC, pyrolysis, GC-MS and stable carbon isotopes to characterize mineralogy and geochemistry of bulk samples, mineral precipitates and microbial organic matter. (Co-I’s: Corella, Lloyd, Schroeder, van Dongen, Wogelius)
- Radiocarbon dating (at NERC Radiocarbon Facility East Kilbride) allows establishment of a chronostratigraphic framework for samples from the modern lakes.

Integration and comparison of this extensive data set across the different lake types and between modern and fossil examples allows establishment of predictive rules how organominerals form and evolve across relatively short geological timescales (millions of years).

The project provides training opportunities in a range of geochemical techniques, as well as in field techniques for sample collection. Collaboration between world-class researchers provides a multidisciplinary project with opportunities to work in different laboratories.

Figure 1: Lakes with microbial structures: A) Lake Chungará; B) Lake Estaña; C) Lake Chiprana; D) Lake Gallocanta.
Figure 2: Fresh sample (left) and thin section from core (right) showing the layering and typical facies of microbial mats in Lake Chiprana.

References: