Searching for molecular biomarkers in Atacama microbialites (N Chile). Relevance for astrobiological exploration of rocky planets

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Abstract

Microbialites are organo-sedimentary structures formed via the metabolic activity of microbes (majorly cyanobacteria), which influence and drive biological processes associated with sediment capture and microbiologically induced organo-mineralization (Burne and Moore, 1987). These deposits, typically made of calcite, grow attached to the substrate, arising vertically and producing a variety of morphological, volumetric and biogeographic structures. Microbialites may exhibit different internal textures, in form of laminated (i.e. stromatolites), irregular clotted (thrombolites), dendritric (dendrolites), or aphanitic (leiolite) fabrics (Riding, 2011). During formation, microbes are active on the microbialite surface layer, producing microbial carbonates by the interaction of microbial growth and metabolism, cell surface properties, and extracellular polymeric substances with mineral precipitation and grain trapping. The early lithification that is essential for the accretion and preservation of benthic microbial carbonates is both biologically mediated and environmentally dependent. Consequently, in addition to be interpreted as trace fossils of microbial mat evolution as lithified remnant of former microbial surface communities, microbialite history reflects also long-term changes in seawater and atmospheric chemistry that have influenced microbial metabolism. Microbialite deposits built up very slowly, with a single 1 m-height structure possibly being 2,000 to 3,000 years old, but the tiny microbes that make up modern microbialites are similar to organism that existed 3.5 billion years ago. Thus, microbialites have great value as modern examples of the earliest known life forms on Earth. The study of microbialite biosignatures may be key to understand early life evolution on Earth and to give clues for the search of signs of life in other planetary bodies.
Here, we studied three microbialite structures from the Atacama Desert (Northern Chile) searching for molecular biomarkers. The three microbialites date from the Rhaetian (upper Triassic) to Hettangian (lower Jurassic) stages (i.e. 199-208 Ma). The three structures showed different morphologies, showing cactus (Strom-2), coral (Strom-3), or algae (Strom-4) aspect.

A multianalytical approach was applied to determine biological and metabolic signatures,

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where metaproteomics were applied for metabolic information, a 200 polyclonal-antibodies microarray interrogated for detecting biological polymers and microbes from extant or well-preserved extinct life structures, solvent-extractable lipids analyzed by GC-MS and GCxGC-TOF-MS for source and preservation diagnosis, and the compound-specific isotopic composition of lipids studied to identify dominant carbon cycling pathways. Mineralogy was identified with X-ray diffraction and inorganic anions and low molecular-weight organic acids measured by ion chromatography.

The analysis of proteins revealed preserved sequences from bacteria, archaea, and eukaryotes, with differences between the samples (19 proteins in Strom-2, 6 in Strom-3, and 1 in Strom-4). Most bacterial and eukaryotic proteins were related to general metabolic processes for cell maintenance and growth, with certain detection of resistance to high temperature and radiation, or degradation capability under anaerobic or aerobic conditions. The multiplex immunoassay revealed metabolic traits related to iron, sulfur, and metal binding, nitrogen fixation, or perchlorate reduction. Lipid biomarkers of cyanobacteria, sulfate-reducing bacteria, methanotrophs, thermophiles or algae were detected and their compound-specific isotopic analysis associated to a dominant Calvin cycle as carbon fixation pathway in the three stromatolites. The combined results revealed compositional and preservation differences in the organic fraction of the three calcite-dominated structures, with Strom-4 showing the highest diversity of immunosignals and greatest preservation of lipids.