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Organic-compounds catalyzed mineralization: a new paradigm for exobiology?

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Abstract

The identification of microbial signatures in sediments formed in extreme environments is often complicated by the interplaying of biotic, abiotic processes, or a combination of all. This poses a limit to our capacity to identify organominerals, and can directly affect our capacity of detecting evidences of life outside our planets. Aim of this research is to advance knowledge on the formation of minerals, and particularly carbonates, formed in extreme, continental environments by unravelling crystallographic pathways in the spring carbonates from the Great Artesian Basin (GAB, South Australia). Here CO_2 degassing and evaporation induced an increase in alkalinity, resulting in precipitation of carbonates. The abundant organic matter in the spring water likely supported the nucleation of micrite by providing a favorable substrate for nucleation. Whether this is biologically-influenced mineralization (organomineralization *s.l.*) or simply crystallization facilitated by the presence of any organic compound, not necessarily related to microbes, is the crucial issue.

1. Introduction

The GAB spring mounds are fed by discharge of meteoric groundwater originating from the western margin of the basin. These mounds have a tremendous scientific significance because they can potentially provide information on the biogeochemical processes active in evaporative setting. As such, they are potential analogue of the Equatorial Layered Deposits (ELDs) of Mars where mounded morphologies have been interpreted as deposited in a playa lake setting fed by groundwater upwelling [1]. Although the Martian implication for the GAB mounds is appealing, there is still little knowledge on the biogeochemical processes that lead to their formation. In our quest to find microbial life outside our planet there are still many open questions, for instance: are we expecting to find mineralized filaments in extraterrestrial sediments? Or the evidences of life will present themselves in a different way? If we want to be prepared to all possible scenario we have to improve our ability to discriminate what is evidence of life and what is not using new approaches and proxies. Aim of this work is to use GAB mounds as case study to unravel processes that resulted in different carbonate facies, and explore implications for extraterrestrial research providing i) new insight on the interactions between microbial communities and carbonates crystallization pathways; ii) a new perspective in the identification and characterization of potential Life signatures in extraterrestrial evaporative environments.

2. The role of organomineralization in exobiology

Sediment architectures and micromorphologies, such as laminated carbonates ad peloidal micrite, have been extensively used to pinpoint products related to microbial activities. Recent studies have demonstrated that these products can be formed by a continuum of biotic and abiotic processes where the latter are often dominant. Micromorphologies alone cannot, therefore, unambiguously point to biologically controlled/induced processes, including organomineralization *s.l.* [2]. Organomineralization *s.l.* encompasses both biologically-induced and -influenced mineralization [2], meaning the mineral can precipitate by direct action of life (prokaryotes) or using organic compounds like Exo-Polymeric Substances (EPS) as templates. Organominerals are therefore usually considered unequivocal evidences of life. The critical issue remains that organomineralization products have the same morphologies of abiotic crystals [3].

Laminated tufa of the GAB preserves evidences for microbial communities thriving in an extreme environment (e.g., filaments, UV-protectant compounds) but lack unambiguous evidences of EPS. Other lithofacies from the GAB spring deposits lack direct evidences of microbial mat but they can be laminated and consist of clotted peloidal micrite. Hence the extent to which microbial communities have contributed to nucleation and growth of minerals and formation of these facies cannot be assessed by classical petrographic methods. Therefore, implying that calcite precipitation through organomineralization *s.l.* is dictated by the presence of organism and/or life-related organic molecules is an oversimplification. Research at the nano-scale suggests that calcite precipitation can be fostered by the presence of organic compounds, such as fulvic acids, which are not related to EPS and therefore independent from microbial mat. This seems to be the case of part of the spring deposits from the GAB. In synthesis, it is possible that part of the GAB micrite was not the product of organomineralization s.l., as there is no unequivocal indication to the active/passive role of microorganisms except for the lithofacies that clearly preserve microbial filaments. In this case, we suggest that the term to be used is organic-compound catalyzed crystallization. The term would avoid prejudiced interpretation of laminated micrite as necessarily related to the presence of microbial mats, which is important for the accurate interpretation of potential Martian/exoplanet structures.

3. Summary and Conclusions

The discovery of widespread evaporitic deposits on Mars (playa deposits) linked to regional scale groundwater upwelling [1] has boosted the interest for microbial mats living in spring deposits formed under extreme evaporitic and hypersaline conditions. A crucial aspect of these ‘comparative’ studies is our ability to disentangle abiotic and biotic processes as our main goal is to pinpoint, without doubt, the presence of signatures (being either geochemical, mineralogical or micro-morphological) of life. The critical issue with this type of deposits is that inorganic, bio-mediated and biologically controlled (including passive or active microbial processes) crystallization may yield crystals with the same morphologies and similar fabrics because crystallization pathways are similar.

Our petrographic and biogeochemical investigation suggests that the sole crystal morphologies and microfabrics are not sufficient to provide robust evidence that Life somewhat participated to the formation of carbonates (or other sedimentary minerals). Only a multi-proxy approach to organomineralization allows unravelling if organominerals are preserved in sediments such as those identified on Mars [1]. Our study invites to be cautious when interpreting minerals and fabrics as the product of organomineralization as non-classical crystallization pathways may be more common than previously thought. The concept of organomineralization *s.l.* needs to be revised, as it may lead to an overestimation of the role of EPS over that of inorganic processes. Organic molecules, rather than microbes, play a fundamental role in carbonate textural features and the preservation of the original products of crystallization. In this case, the more appropriate term to use is organic-compound catalyzed crystallization. This term would avoid prejudiced interpretation of laminated micrite as necessarily related to the presence of microbial mats.

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