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Prokaryotic and Eukaryotic Community Structure in Field and Cultured Microbialites from the Alkaline Lake Alchichica (Mexico)

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Abstract

The geomicrobiology of crater lake microbialites remains largely unknown despite their evolutionary interest due to their resemblance to some Archaean analogs in the dominance of in situ carbonate precipitation over accretion. Here, we studied the diversity of archaea, bacteria and protists in microbialites of the alkaline Lake Alchichica from both field samples collected along a depth gradient (0–14 m depth) and long-term-maintained laboratory aquaria. Using small subunit (SSU) rRNA gene libraries and fingerprinting methods, we detected a wide diversity of bacteria and protists contrasting with a minor fraction of archaea. Oxygenic photosynthesizers were dominated by cyanobacteria, green algae and diatoms. Cyanobacterial diversity varied with depth, Oscillatoriales dominating shallow and intermediate microbialites and Pleurocapsales the deepest samples. The early-branching Gloeobacterales represented significant proportions in aquaria microbialites. Anoxygenic photosynthesizers were also diverse, comprising members of Alphaproteobacteria and Chloroflexi. Although photosynthetic microorganisms dominated in biomass, heterotrophic lineages were more diverse. We detected members of up to 21 bacterial phyla or candidate divisions, including lineages possibly involved in microbialite formation, such as sulfate-reducing Deltaproteobacteria but also Firmicutes and very diverse taxa likely able to degrade complex polymeric substances, such as Planctomycetales, Bacteroidetes and Verrucomicrobia. Heterotrophic eukaryotes were dominated by Fungi (including members of the basal Rozellida or Cryptomycota), Choanoflagellida, Nucleariida, Amoebozoa, Alveolata and Stramenopiles. The diversity and relative abundance of many eukaryotic lineages suggest an unforeseen role for protists in microbialite ecology. Many lineages from lake microbialites were successfully maintained in aquaria. Interestingly, the diversity detected in aquarium microbialites was higher than in field samples, possibly due to more stable and favorable laboratory conditions. The maintenance of highly diverse natural microbialites in laboratory aquaria holds promise to study the role of different metabolisms in the formation of these structures under controlled conditions.

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Introduction

Microbialites are organosedimentary structures formed by microbially-mediated mineral precipitation and/or accretion [1]. Stromatolites are microbialites exhibiting a laminated macrofabric [2]. Their fossils are found throughout the geological record [3,4], the oldest being 3,43 Ga old (Pilbara Craton, Western Australia) [5]. After having dominated the Precambrian, stromatolite abundance declined steeply at the onset of the Phanerozoic [6,7]. Today, stromatolites are confined to very few marine or quasi-marine environments, such as the well-studied Shark Bay, Australia [8,9] and Exuma Sound, Bahamas [10,11]. Microbialites have also been described in alkaline lakes such as Lake Van, Turkey [12,13], Pyramid Lake, USA [14], the Indonesian crater lakes Satonda [15,16,17] and Niuafo'ou [18], but also in the freshwater Ruidera pools [19] and the hypersaline lakes LagoVermelha, Brazil [20] and Cuatro Ciénagas, Mexico [21].

Despite their geological and evolutionary importance, the precise stromatolite formation mechanisms remain poorly understood. It has been proposed that net carbonate precipitation results from a balance between concurrent microbial metabolisms [22]. Photosynthesis (both oxygenic and anoxygenic) and sulfate reduction lead to local carbonate supersaturation, whereas heterotrophic metabolisms induce carbonate dissolution [23,24,25,26]. In addition, massive cyanobacterial production of exopolymeric substances (EPS), which efficiently sequester cations such as Ca^{2+} or Mg^{2+},