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Discriminating stromatolite formation modes using rare earth element geochemistry: Trapping and binding versus in situ precipitation of stromatolites from the Neoproterozoic Bitter Springs Formation, Northern Territory, Australia

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ABSTRACT

Stromatolites consist primarily of trapped and bound ambient sediment and/or authigenic mineral precipitates, but discrimination of the two constituents is difficult where stromatolites have a fine texture. We used laser ablation-inductively coupled plasma-mass spectrometry to measure trace element (rare earth element – REE, Y and Th) concentrations in both stromatolites (domical and branched) and closely associated particulate carbonate sediment in interspaces (spaces between columns or branches) from bioherms within the Neoproterozoic Bitter Springs Formation, central Australia. Our high resolution sampling allows discrimination of shale-normalised REE patterns between carbonate in stromatolites and immediately adjacent, fine-grained ambient particulate carbonate sediment from interspaces. Whereas all samples show similar negative La and Ce anomalies, positive Gd anomalies and chondritic Y/Ho ratios, the stromatolites and non-stromatolite sediment are distinguishable on the basis of consistently elevated light REEs (LREEs) in the stromatolitic laminae and relatively depleted LREEs in the particulate sediment samples. Additionally, concentrations of the lithophile element Th are higher in ambient sediment samples than in stromatolites, consistent with accumulation of some fine siliciclastic detrital material in the ambient sediment but a near absence in the stromatolites. These findings are consistent with the stromatolites consisting dominantly of in situ carbonate precipitates rather than trapped and bound ambient sediment. Hence, high resolution trace element (REE + Y, Th) geochemistry can discriminate fine-grained carbonates in these stromatolites from coeval non-stromatolitic carbonate sediment and demonstrates that the sampled stromatolites formed primarily from in situ precipitation, presumably within microbial mats/biofilms, rather than by trapping and binding of ambient sediment. Identification of the source of fine carbonate in stromatolites is significant, because if it is not too heavily contaminated by trapped ambient sediment, it may contain geochemical biosignatures and/or direct evidence of the local water chemistry in which the precipitates formed.

1. Introduction

Microbialites, i.e., organo-sedimentary deposits accreted by microbial communities (Burne and Moore, 1987), have the most continuous record through Earth history of any fossil group and, despite controversy over the biogenicity of some examples (e.g., Lowe, 1994; Grotzinger and Rothman, 1996), laminated forms called stromatolites are commonly considered biogenic and dominated the Precambrian fossil record (Walter, 1994; Awramik and Grey, 2005). Confidence in interpreting ancient stromatolites as traces of life or as abiotic precipitates is critical for understanding the history of life on Earth. However, stromatolite origins are commonly debated because their morphology reflects a complex interplay between biological activity and physico-chemical constraints imposed by the ambient environment (Serebryakov, 1976; Hofmann, 1973; Semikhatov et al., 1979; Grotzinger and Knoll, 1999; Riding, 2011a), and abiotic structures may have superficially similar laminated morphologies (Grotzinger and Rothman, 1996; Mcloughlin et al., 2008).

Biological stromatolites accrete by two major processes – trapping and binding of ambient sediment, termed agglutination by Riding (1991), and/or precipitation of carbonate minerals on or within microbial mats/biofilms (Grotzinger, 1990; Riding, 1991, 2011a; Grotzinger and James, 2000; Visscher et al., 2000; Aloisi et al., 2006; Dupraz et al., 2009; Spadafora et al., 2010; Warthmann

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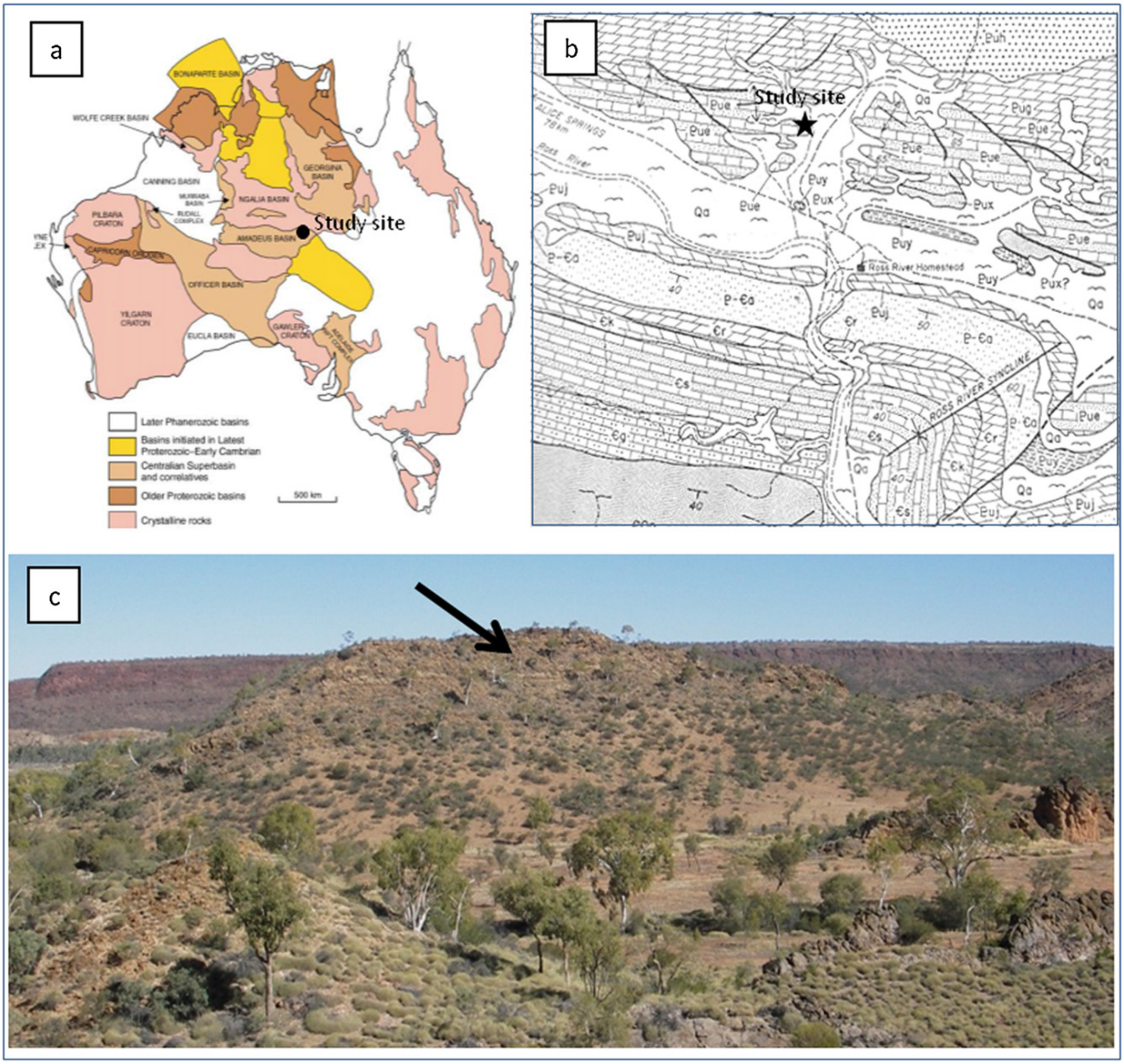

Fig. 1. Study site in Amadeus Basin, central Australia (a and b). View south of stromatolite locality (hill marked by arrow) in Loves Creek Member, Bitter Springs Formation, (c). The prominent ridge in the distance is the Cambrian Arumbera Sandstone.
Adapted from Planavsky and Grey (2008) and Kennard et al. (1986).

et al., 2011; Webb and Kamber, 2011). Mineral precipitation forms a continuum between inorganic and biologically induced processes (Hofmann, 1973; Burne and Moore, 1987; Grotzinger, 1990; Riding, 2011b) and is constrained to a degree by the chemistry of the water in which the biofilms grew, with precipitation in either case being favoured by high alkalinity. However, additional kinetic effects (Sumner and Grotzinger, 1996; Grotzinger and Knoll, 1999) and the degree of confinement in microenvironments (Webb and Kamber, 2011) are also important factors. Living marine stromatolites in Shark Bay, Western Australia (Logan, 1961) and the Bahamas (Dill et al., 1986) are primarily agglutinated forms demonstrably consisting of coarse, trapped and bound sediment. However, their accretion by microbially induced precipitation of microcrystalline carbonate (micrite), both as framework and as cement, is now recognised as fundamental in their formation (Visscher et al., 2000; Reid et al., 2003; Riding, 2011c). In contrast, many ancient stromatolites consist entirely of fine micritic textures that could reflect either finely crystalline precipitates or trapped and bound fine-grained ambient sediment. Unfortunately, textural criteria alone are insufficient to interpret the origin of stromatolites with fine textures. Recrystallisation is likely to have obscured original grain or crystal boundaries through time, irrespective of the origin of the carbonate. Additionally, fine sediment can accumulate in stromatolites even in the midst of coarser ambient sediments because microbial communities may preferentially trap and bind only the finer sediment fraction owing to the greater ease with which fine particles might adhere to sticky mucilage (Awramik and Riding, 1988; Riding, 1991). Regardless, Riding (2000) concluded that micritic stromatolites generally represent fine precipitates that formed in or on organic matter within microbial biofilms and only rarely represent agglutination of fine-grained ambient sediment.

Trace element geochemistry is increasingly used to study microbialites, and the rare earth elements (REE, plus yttrium – REY) in particular are analysed with increasing frequency to