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High-Relief Microbial Boundstone Platforms

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Carbonate platforms with high-relief, steep depositional slopes and margins dominated by microbial boundstone do not occur in present-day tropical marine sedimentary environments. These types of platforms (defined as M-type carbonate factory by Schlager, 2003) are, however, well-represented in the Phanerozoic geologic record. They accumulated following mass extinction events of reef-building marine organisms with a rigid carbonate skeleton, in particular during the late Paleozoic (post Frasnian) and Mesozoic. This study aims to outline some common characteristics of high-relief microbial platforms with respect to platform geometry, facies belts and lithofacies types based on the evaluation of several case studies from outcrops and published literature of Late Devonian, Carboniferous, Permian, Middle Triassic and Early Jurassic age.

The term microbial boundstone is here meant to include those reef lithofacies consisting of variable proportions of: 1) microbial micrite and microspar, 2) early marine cement, and 3) skeletal biota.

1) Laminated and clotted peloidal micrite and microsparitic fabrics are precipitated in situ by microbially mediated processes such as biologically induced and influenced carbonate precipitation in association with cyanobacteria, heterotrophic bacteria and their EPS-rich (extracellular polymeric substances) biofilms. These fabrics are gravity defying and build a rigid framework that isolates primary cavities up to centimeters in size. 2) Early marine cement fills primary boundstone voids and generally consists of botryoidal aragonite and/or radial and radiaxial fibrous cement. Marine cement can constitute more than 50% of the boundstone lithofacies. 3) Skeletal biota can range from scarce to abundant and vary in composition according to the geological period; they do not act as rigid framework builders although they might contribute to it. Common biota include calcareous and siliceous sponges, calcareous green and red algae, bryozoans, brachiopods, mollusks, foraminifers, echinoderms and corals.

Microbially mediated precipitation can take place through various organomineralic processes, which are mostly light independent and associated with degradation of organic matter from biofilms and sponge tissues in dysoxic conditions. Thus, the microbial boundstone carbonate producing factory is not limited by light penetration within the water column and can extend well beyond the depth of the photic zone. This constitutes a fundamental difference with respect to the coralgal reef-building facies of the modern tropical carbonate realms.

Observations from multiple examples show that the microbial platforms are characterized by high-relief (several hundred meters) geometry with steep slope (> 30^0), lack of a raised rim at the margin, a flat platform interior and a gradual transition from the platform-top interior into the slope through a set of outermost platform beds, slightly dipping basinward. The slope clinoforms vary from planar to exponential and the cement-rich microbial boundstone can accumulate in situ on the slope contributing to the stability of the steep clinoforms.

In terms of lithofacies belts, the well-bedded meter-scale cyclic platform interior is basinward transitional to subtidal facies. In such outer platform subtidal facies, cyclicity is less pronounced and microbial boundstone lenses can often alternate with coated grain and skeletal grainstone and packstone. The outer platform facies belt can be a few hundred meters or only tens of meters wide. At the platform break and along the upper slope, microbial boundstone lithofacies dominate and can accumulate in situ on the slope to depths of 300-400 m. At these depths, corresponding to the upper to lower slope transition, microbial boundstone tongues interfinger with detrital breccias consisting mostly of slope-derived resedimented microbial boundstone clasts. At the toe of slope, horizontally bedded basinal deposits interfinger with platform-derived resedimented rudstone, grainstone and packstone, including slope-derived boundstone clasts and platform- and slope-derived coated and skeletal grains. Platform-derived resedimented grains generally by-pass the steep upper slope through grain and turbidity flows and accumulate at the toe of slope. The analyzed microbial carbonate platforms seem to export less platform-derived sediment relative to the amount of microbial boundstone precipitated on the slope. Some of these platform examples, but not all, are characterized by matrix-free clast-supported lower slope breccias cemented by radiaxial fibrous calcite transported downslope via avalanches and non cohesive debris flows. At the toe of slope, clast-supported breccias may lack cementation and be compacted with sutured grain contacts. Detrital carbonate mud along the slope and at the toe of slope is scarce explaining the clast-supported matrix-free character of the breccia deposits. This might be attributed to the fact that most of the micrite was precipitated in situ to form the boundstone rather than being detrital carbonate mud resedimented downslope.

A key element of microbial platforms is that their steep slopes consist of a large percentage (>50%) of sediment produced directly on the slope down to subphotic depths rather than being the site of prevalent accumulation of platform-derived detrital material. This characteristic has significant implications for the style of growth of the depositional system (progradation vs. aggradation), the evolution of its geometry and the responses of the carbonate factory to changes in accommodation space and eustatic sea level (cf. Kenter et al. 2005). In terms of rates of carbonate production, accumulation and progradation, microbial platforms are estimated to be equivalent to, if not more productive than, present-day fast-growing carbonate systems.

The development of microbial platforms seems favored in, but not exclusive of, confined basins with starved basinal sediment that turns anoxic to dysoxic due to limited bottom current circulation rather than by open ocean upwelling settings. Confined basins might have provided the ideal chemical, physical and biological conditions to sustain microbial boundstone and early marine cement precipitation for a time scale of million years; such conditions might include high supersaturation of seawater with respect to carbonate minerals, nutrient levels, weak competition by skeletal metazoans and availability of stable substrates for microbial life.

In terms of reservoir potential microbial boundstone facies at platform margins and along slopes of high-relief platforms are characterized by large size primary porosity and they might be associated with adjacent anoxic organic-rich basinal deposits (potential source rocks). Microbial boundstone depositional pore network might, however, be poorly connected or occluded by early marine cementation unless secondary diagenetic dissolution and fractures enhance the connectivity of the pore system.

References

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