INTRODUCTION TO STROMATOLITES

Stromatolites are laminated, typically domal or columnar rocks that form by accretionary growth from an initiation point or surface (Semikhatov et al., 1979). Historically, they have been interpreted as microbial fossils, with lamination and doming attributed to the trapping and binding or mineral precipitation activities of microbial mats, and this is how they are usually described in textbooks. Undoubtedly, some stromatolites form this way, but analogous stuctures can form abiotically (Grotzinger and Knoll, 1999), and distinguishing biogenic from abioiogenic structures is not straightforward. (For a nuanced interpretation of stromatolites, see Bosak et al. [2013])

From a paleoentologic and astrobiologic perspective, stromatolites and other microbialites provide potential records of microscopic organisms that a field geologist (or rover) can recognize in an outcrop with the naked eye (or camera). In less ancient systems, they may indicate special or extreme environmental conditions where microorganisms were dominant. In modern systems, such conditions include restricted marine basins, alkaline lakes, and hot springs, where microbes thrive, due perhaps to a lack of competition and/or grazing by eukaryotic organisms (Garrett, 1970).

Recently, stromatolites have attracted the attention of petroleum geologists with the discovery of oil reservoirs associated with stromatolites in the South Oman Salt Basin and the “pre-salt” deposits in the Santos and Campos Basins offshore Brazil, the pre-salt being one of the most important recent oil discoveries. Different forms of stromatolites, resulting from different environments and/or microbiota (or lack thereof), have greatly different properties—e.g., connectivity, porosity, and permeability—critical to oil recovery. Thus, there is interest in understanding the formation of stromatolites so that their behavior as reservoir rocks can be predicted (Bosence et al., 2015). However, the extensive pre-salt stromatolites and enigmatic related carbonate deposits have no modern and few (if any) ancient analogs.

The giant stromatolites described in this issue of Geology (Awramik and Buchheim, 2015, p. 691) occur in the Green River Formation, deposited in a system of extensive alkaline lakes that covered much of Wyoming, Colorado, and Utah (western USA) for several million years in the Eocene (Roehler, 1993). This formation is one of the best-studied paleolake systems, spanning millions of years of transgressive and regressive cycles. Included in the cyclic deposits are extensive carbonates, including diverse stromatolites. This has led some researchers to use it as an analog for the Brazilian pre-salt deposits (Awramik and Buchheim, 2012; Bosence et al., 2015).

GROWING GIANTS

Stromatolites vary greatly in size and morphology, typically ranging from centimeter-scale layers or encrustations to multi-meter-scale monoliths. Modern stromatolites rarely exceed 1 m in height, and both ancient and modern lacustrine stromatolites typically fall on the smaller end of the size range. Awramik and Buchheim’s (2015) lacustrine “Giant Stromatolites” (herein referred to simply as the Giant Stroma) are truly giants, standing up to 5.5 m tall. How did they get so big? What does that tell us about other giant stromatolites?

There are general trends in stromatolite morphology through time (Awramik and Riding, 1988; Frantz et al., 2015), but the mechanisms controlling morphology are not well understood (Grotzinger and Knoll, 1999; Bosak et al., 2013). Awramik and Buchheim (2015) suggest that a combination of factors contributed to the extraordinary growth of the Giant Stroms, including the mixing of calcium-rich spring water or runoff water with alkaline lake water (promoting the precipitation of carbonate, of which stromatolites are composed), sufficient accommodation space where the steep edge of the lake abutted the Uinta Mountains (much of the lake had much shallower slopes), and what they were growing on.

The Giant Stroms grew around tree stumps (some contain the impressions of bark!) from flooded forests, which provided a raised template (and perhaps nutrient substrate?) for their growth. Many stromatolites have a total height significantly greater than their synoptic relief (the distance that the stromatolite stuck out above the sediment surface while it was growing), but the Giant Stroms do not, suggesting that the colonizing community (if indeed they are biogenic) covered the entire stump, growing outward as carbonate layers formed, rather than upward, due to a race against burial by sedimentation. The size of the Giant Stroms thus appears to be determined by the height of the initial stump template. Basinward, stumps give way to logs and then flat lake sediment, and in this direction, the stromatolites become smaller and eventually are no longer found. Thus, while chemistry was a critical factor permitting carbonate precipitation and preservation, the Giant Stroms’ growth to large sizes relates to the vertical relief of the template on which they were growing.

Stromatolites commonly form on templates with significant vertical relief (organic, such as the flooded forest described above, or inorganic, such as boulders or other carbonates), but many do not, so it cannot be assumed that stromatolite size and shape always reflect some underlying substrate serving as template.

GIANT STROMATOLITES IN THE GREEN RIVER FORMATION: ANALOGUES TO PRE-SALT STROMATOLITES?

Green River Formation carbonates have been proposed as analogs to pre-salt carbonates because they share a similar origin (in extensive alkaline lakes) and specific carbonate forms and microstructural textures (Awramik and Buchheim, 2012; Bosence et al., 2015). Are the Giant Stroms, with their giant size and comparable microfabrics (including shrubs, an important element in the pre-salt carbonates) good analogs?

Probably not. Although exactly how extensive and laterally continuous the Brazilian pre-salt stromatolite reservoirs are is unclear, their abundance—even dominance—in cores (Bosence et al., 2015) suggests that they are not an isolated occurrence. In contrast, Awramik and Buchheim’s (2015) Giant Stroms are found only in an ~1 km² area, and may have formed due to local factors (groundwater and fluvial input of calcium, flooded forest template). If this interpretation is correct, it would not explain the pre-salt reservoirs. True analogs to the Brazilian pre-salt carbonate deposits may not exist (making them all the more interesting). However, understanding a variety of stromatolite forms, including the exceptional Giant Stroms, may aid interpretations of pre-salt carbonates.

STROMATOLITES AS PALEOENVIRONMENTAL RECORDS

The Green River Formation Giant Stroms may not be great analogs for the large-scale pre-salt deposits, but they provide clues that help us better understand their environment of formation. The Green River Formation records the Early Eocene Climatic Optimum, the most recent global hothouse
with concurrent high levels of CO₂ (Zachos et al., 2008), and through its study we gain insights into terrestrial responses to climate extremes.

What do the Giant Stroms tell us? First, their formation tells a story of a flooded forest. They additionally suggest that lake conditions were variable over the lifetime of the stromatolites, which are composed of layers of different microfabrics. Changes in microfabric reflect changes in water chemistry and/or in microbial activities and community (due in turn to changes in local conditions). In addition, carbon and oxygen isotope records vary in different parts of the stromatolite. This could be explained as a combination of changes in water chemistry (local freshwater input, evaporation, and/or recharge), changes in the source of entrained carbonates (though it is implied that the stromatolite carbonate formed in situ), changes in carbonate mineralogy and formation kinetics, and/or changes in porewater chemistry due to microbial activities. That water conditions impacting stromatolite growth would be variable, especially locally, is not at all surprising.

Second, chemical and petrographic evidence in stromatolites and other carbonates in the region suggest there was a lateral chemical gradient in the lake waters due to spring water discharge and/or local fluvial input. Evidence for this is found in a basinward increase in aragonite content (aragonite is favored over the other common form of CaCO₃, calcite, when temperatures and the concentrations of some ions including sulfate and magnesium are high). Awramik and Buchheim (2015) claim that the aragonite in the Giant Storms was produced in whiting events triggered by mixing fresh, calcium-rich water with brackish, alkaline lake water. They also attribute differences in oxygen and carbon isotope values to a gradient with alkaline, saline water diluted by shoreward freshwater input (although this is based on a single basinward point, and thus rather speculative). Given the localized nature of the stromatolite deposits, a gradient in lake conditions seems a more likely scenario than invoking changes in basin-wide chemistry. If this hypothesis is true, it might challenge assumptions of homogenous lake chemistry in geochemical models relating lake fill to carbonate isotope chemistry in the Green River Formation. Two such models claim large changes in lake volume and extent driven by tectonics (Doebbert et al., 2010) and short-term climate variability (Frantz et al., 2014). However, unlike the Giant Storms, the carbonates that formed the basis for both models were laterally extensive (indicative of homogenous conditions).

ON THE IMPORTANCE OF SCALE

I wish to conclude this Research Focus by highlighting a critical point in the study of stromatolites and sedimentology in general: only by a thorough analysis of the stromatolites at multiple scales—gathering multi-kilometer-scale contextual information from the greater formation, measuring a multi-meter-scale stratigraphic sequence at the outcrop where the stromatolites formed, tracing and measuring the chemistry from centimeter-scale layers across individual stromatolites, and analyzing micron-scale microstructural features within stromatolites—could a complete picture of the formation of the Giant Stroms, and their environmental context, be painted (cf., Shapiro, 2000).

REFERENCES CITED


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