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The Role of Microbial Activity on Petrophysical Properties

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Microbialites have proved to be excellent reservoir facies with preserved primary porosity to great burial depth. The ability to resist compaction of the complicated pore system in microbialites is partly caused by early microbial processes that construct and strengthen the rock. Combining petrographic and petrophysical data show that early microbially-induced, micritic grain-grain cements are very effective in providing rock strength. This process is observed in cemented marine grainstones (modern marine hardgrounds) and in stromatolites (Figure 1). Likewise secretion along filaments provides bridging cements that strengthen the rock fabric, for example in some travertine deposits. As a result, microbialites are petrophysically characterized by high porosity and high velocity, although the pore types in microbialites are predominantly intergranular and intraframe.

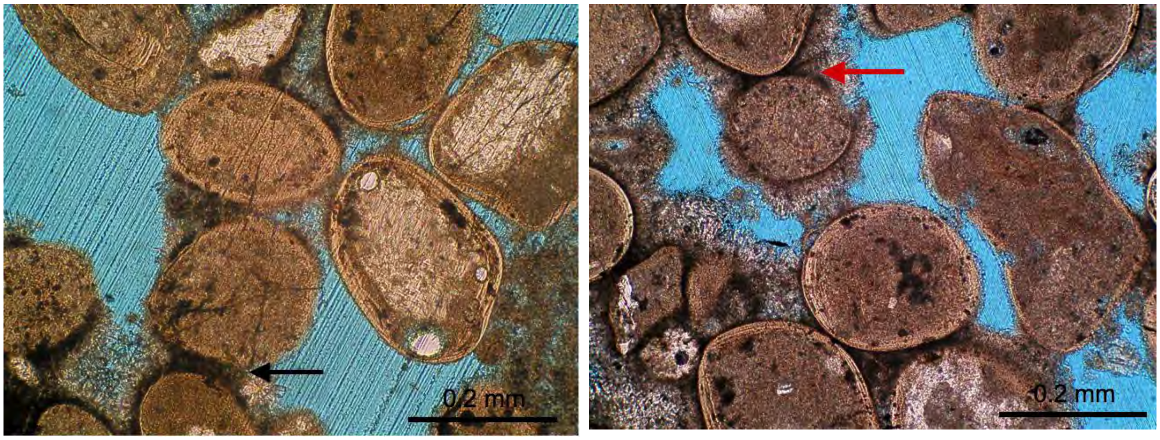

Figure 1: Photomicrographs of modern stromatolites from the Bahamas. Grains are cemented by dark micritic cement (arrows). Fine aragonite needles overgrow these micritic contact cements. In addition, micritic material is filling part of the pore space. The precipitation of the micrite is related to photosynthesis, combined with sulfate reduction and sulfide oxidation, of the microbial community within the stromatolite (Visscher et al., 1998).

Microbialites in a rock physics context

In rock physics models intergranular porosity rocks are usually considered to be weak with somewhat compliant pores, and consequently as rocks with low stiffness and slow acoustic velocity. In contrast, rocks with moldic and vuggy porosity are classified as stiff, high aspect ratio rocks, resulting in high bulk modulus and velocity (e.g. Nurmi, 1984; Lucia and Conti, 1987; Wang and Lucia, 1993). For microbialites this general rule is not always applicable, because their interparticle porosity can achieve stiffness and high velocity at relatively high porosity. Hillgärtner et al. (2001) first described micritic bridging cement in the marine realm to be the product of endolithic borings and precipitation associated with microbial activity. A similar process is occurring in stromatolites where microbial activity produces thin (20-50 µm) micritic crusts, which commonly overlie truncated, micritized carbonate grains (Visscher et al. 1998). These features are identical in many ancient stromatolites that also have a stiff frame and are acoustically fast.

Modern stromatolites as examples of high porosity and high velocity rocks

Eight samples from modern stromatolites have porosities between 12 -25% and permeability ranges between 70- 4600 mD (all but on sample have more than 350 mD). The velocities range between 4480 – 5420 m/s. These velocities are faster than the time average equation would predict (Figure 2). In comparison with the velocities of the limestone samples, the stromatolites are all at the high end of velocities at any given porosity. Thus, stromatolites are high permeability rocks with interparticle porosity and resulting high velocity even at high porosities.

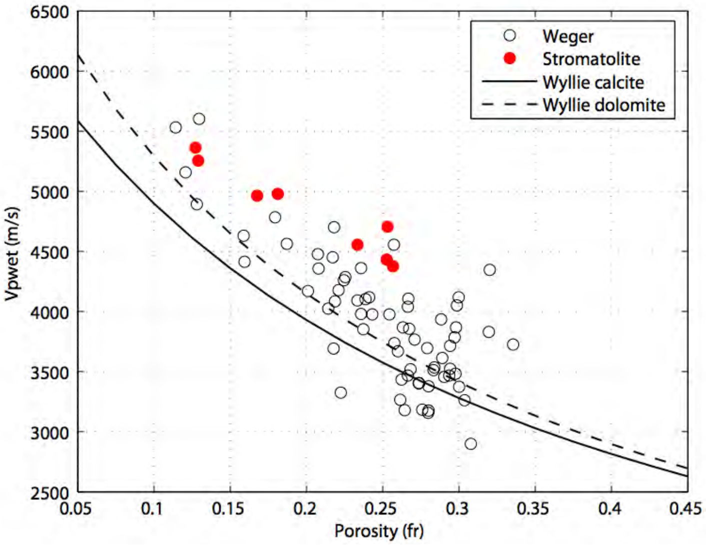

Figure 2: Velocity-porosity cross plot of limestone samples from Weger et al. (2009) data set (circles) and modern stromatolites (red dots). The stromatolites have mostly interparticle porosity but their acoustic velocity is approximately 1 km/s faster than what Wyllie's time-average equation predicts at a given porosity.

The Modern Hardground Samples

Micritic and fibrous aragonitic cements are the dominant cements in the Holocene submarine hardgrounds. The first cement is often a micritic rim around the ooid grains. The fibrous aragonite cement subsequently forms an isopachous cement in the pore space (Figure 3). At many grain contacts a dark micritic cement is observed that is reminiscent of the marine meniscus cement described by Hillgärtner et al. (2001).

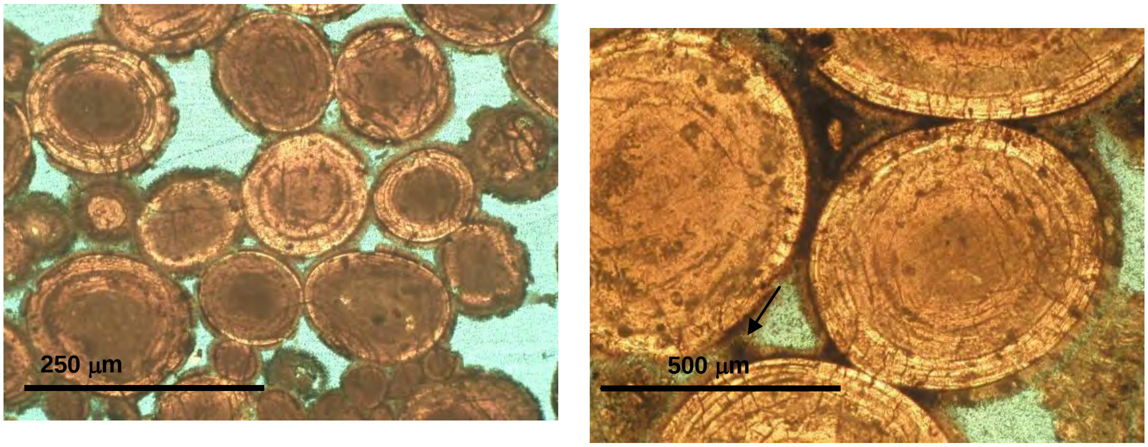

Figure 3: Photomicrographs of two submarine hardground samples. Left: Ooid grains are coated by a micritic rind that is overgrown by fibrous aragonite cement. Right: Micritic meniscus cement (arrow) welding two ooids together. In addition, micritic material is filling part of the pore space.

The main pore type of all hardground samples is interparticle, containing simple pores with variable sizes. Using digital image analysis parameters this uniform pore structure can be quantified (Figure 4). The aspect ratio ranges between 0.54 and 0.62, reflecting the similar pore type. Likewise the Perimeter over Area (PoA), which is a measure of the complexity of the pore structure, displays little variations; it ranges between 0.32 – 76.4 mm^{-1}. The dominant pore size (DOMsize) on the other hand shows large variations from 203 – 1100 µm.

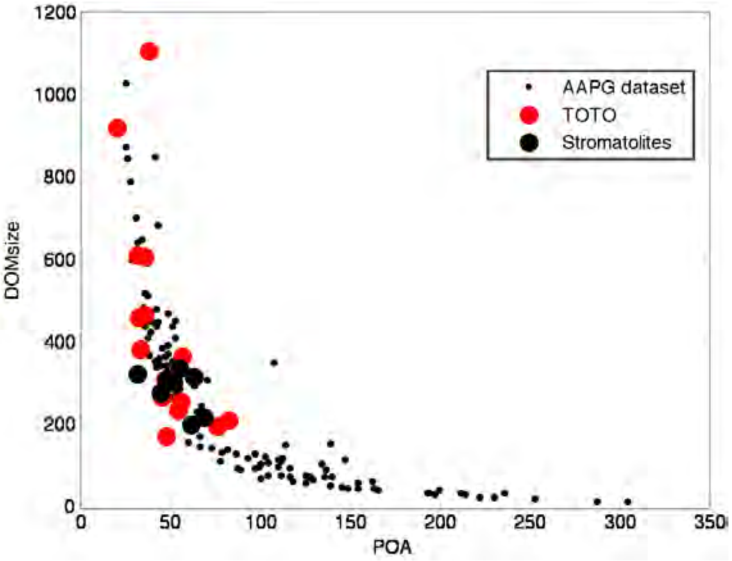

Figure 4:

Characterization of the pores system in marine hardground samples (TOTO) with digital image analysis parameters and a comparison with stromatolites and the data set of Weger et al. (2009).

The TOTO samples have simple (small PoA) pores of variable size (DOMsize).

Vp values of stromatolites and marine hardgrounds range from 3094 to 4995 m/s, while porosities range from 13 – 42%. The most important characteristic of the acoustic behavior is the lack of velocity increase with increasing pressure (Figure 5). In most (low and high velocity) samples, velocity remains nearly constant when pressure is increased to 35 MPa.

Conclusions and Implications

This lack of increase of velocity with pressure documents the strength of the rock and its resistance to compaction. This characteristic is produced primarily by early microbially induced cementation and growth, combined with the strength of the growth frame work provided? microbialites with the quality to maintain primary porosity do great burial depth.

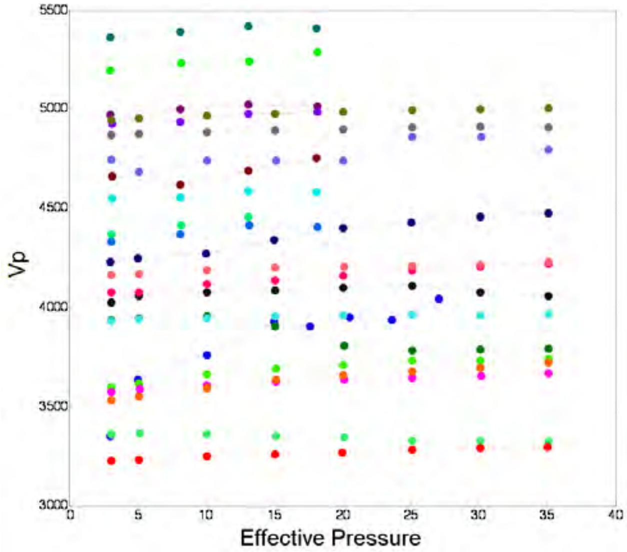

Figure 4: Vp versus effective pressure of hardground samples (3-35MPa) and stromatolites (3-20 MPa). Most samples display little increase of velocity with increasing pressure, indicating the ability of these rocks to endure compaction without significantly changing the petrophysical properties.

References

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