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Goo, glue, and grain binding: Importance of biofilms for diagenesis in sandstones

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INTRODUCTION

Have you ever heard of biofilms? They are slimy, glue-like membranes that are produced by microbes, like bacteria, fungi, algae and cyanobacteria, forming highly organized communities in order to colonize surfaces. A biofilm consists of the individual cells plus a goo-like extracellular polymeric substance (EPS). Within this framework microbial cells metabolize and reproduce thus extending the goo-like EPS (Decho, 1990, 2000). In marine and non-marine environments, microbial communities interact with the physical sediment dynamics in order to survive. Biostabilization, the trapping or sticking of sediment particles by microorganisms result in the formation of microbially induced sedimentary structures; however, if carbonate precipitation occurs in EPS, and these processes happen in a repetitive manner, a multilayered build-up can form known as stromatolites (Riding, 2000). The oldest known example of stromatolites and microbially induced sedimentary structures are found in microbial metacarbonates that are 3700 m.y. old, recording highly evolved microbial activity early in Earth's history (Noffke et al., 2013; Nutman et al., 2016). Microbial biofilms have also been attributed to the widespread preservation of the Proterozoic soft-bodied Ediacaran organisms in creating 'death masks' allowing enhanced preservation of these delicate organisms (e.g., Gehling, 1999; Laflamme et al., 2011).

The occurrence of EPS is of central importance in the formation of microbial carbonates where bacteria, cyanobacteria, and diatoms can all secrete copious amounts of EPS and actively encourage calcium ion precipitation and sediment trapping (see Riding, [2000] and Bosence et al. [2015]for recent reviews). Although important, the literature until recently has neglected the role EPS plays for grain sticking in non-cohesive sandy substrates that dominate the marginal marine sedimentary environment (Gerbersdorf and Wieprecht, 2015).

GRAIN BINDING OF SAND GRAINS BY BIOFILMS AND EPS

In marginal marine environments, most sediment is composed of non-cohesive, unconsolidated sand, physically cohesive muds, and sticky, cohesive EPS. The goo-like EPS that glues and binds detrital sedimentary grains together changes initial cohesive and physical binding properties of sand grains and associated clay particles. Recent research has demonstrated the profound influence of biological cohesion (biostabilization) on sedimentary bedform size and has identified how cohesive bonding mechanisms in different sediment mixtures govern the relationships (Malarkey et al., 2015; Schindler et al., 2015; Parsons et al., 2016). Important sources of EPS in shallow marine sands are microphytobenthos (mainly diatoms) and they contribute to the stability of intertidal sediments, protecting large areas of sedimentary surfaces against erosion (e.g., Stal, 2003; Schmidt et al., 2016). The biofilms and EPS matrix produced by these microbial assemblages prevent sand grains from moving independently due to their 'stickiness' (Garwood et al., 2015; Decho, 2000). Experimental and theoretical analysis of intertidal biofilms resulting from the secretion of EPS by microphytobenthic communities have demonstrated that surficial biofilm development completely suppresses sediment transport until flow velocities are sufficiently high to cause catastrophic failures in the biofilm and ultimately results in destabilization of the intertidal sands (Stal, 2010; Hagadorn and McDowell, 2012). Indeed, Graba et al. (2013) have shown that the density and the stability of biofilms can adapt to different flow regimes.

The adhesive properties of biofilms on sand grains have been noted to allow organics, clay minerals, and aggregates of diatoms to bind to the surface (Stal, 2003, 2010). EPS secreted by microphytobenthos at the surface of intertidal sediments tightly binds to sand grain surfaces, probably through bridging by divalent ions, and have provided valuable clues particularly on the role of biofilms controlling the formation of clay grain coats, with implications for diagenesis of coastal sediments (Stal, 2003)

Wooldridge et al. (2017, p 875 in this issue of *Geology*) provide the first direct evidence of how clay size particles overcome hydrodynamic segregation and are physically bound to the surface of sand grains in intertidal siliciclastic sediments from the Ravenglass Estuary in northwest England. They document the proportion of sand grains that are clay-coated within the surficial sediments and, through interpolation in ArcGIS of the field data sets, have revealed that in the estuarine sediments clay-coat coverage increases in a landward direction. This finding is supported by observations of sedimentary controls on the distribution of clay coatings in modern intertidal environments (see Dowey et al. [2012, 2017] for reviews). Most critically, Wooldridge et al. used chlorophyll-a concentrations as a proxy for diatom-produced biofilm abundance within the sediments (Stal 2003), and recognized a positive statistical correction between sediment biofilm abundance (chlorophyll-a) and distribution of clay-coats in the sandy sediments (Wooldridge et al.'s figure 4). Their analysis of the field data provides new insights that could potentially revolutionize the understanding of clay-coated sand grains for petroleum-reservoir quality prediction in ancient, deeply buried sandstones.

IMPORTANCE OF BIOFILMS FOR DIAGENESIS

Clay grain coats in sandstones act as effective barriers to inhibit quartz cement growth by blocking potential nucleation sites for quartz overgrowths, especially during prolonged burial diagenesis (Bloch et al., 2002). Authigenic chlorite and corrensite (a chlorite-smectite clay mineral) are the most commonly reported effective clay grain coats occurring in hydrocarbon sandstone reservoirs (e.g., Huggett et al., 2015; Stricker et al., 2016), and are likely to result from the transformation of clays formed during deposition or soon afterward (Bloch et al., 2002). The biofilm origin for the clay-coated sand grains reported by Wooldridge et al. could represent the precursor to authigenic clays reported in many sandstones, and lead to better predictive models of reservoir quality. It appears we have undervalued the importance of biofilms and the sticky goo of EPS in trapping clay particles, and perhaps sediments with higher mud content need to be better appraised for hydrocarbon reservoir potential. Furthermore, the influence of biofilms upon sediment stabilization, sediment dynamics, and adhesive properties of EPS needs to be further investigated for different sedimentary environments, and may have important consequences to the way we appraise sedimentary systems more generally.

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