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Microbialites in Zechstein Cycle 2 Carbonates (NE England and Poland): Types and Source Rock Perspectives

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The Upper Permian (Zechstein) carbonates cropping out in north-east England (Roker Formation) and their equivalent in the subsurface of Poland (Main Dolomite) form the 2nd (Z2) cycle carbonates across the entire Southern Permian Basin of Europe. The Main Dolomite (Ca2) is an important oil- and gas-bearing unit of the Netherlands, Germany, Denmark and Poland. Microbialites are a major component of Z2 carbonates.

The Roker Formation consists of shallow-water platform carbonates up to 60 meters thick, with a shelf-like margin dominated by oolites. Slope-apron turbidites and laminated hemipelagites form the more basinward, ramp-like margin where the Z2C is ~100 m thick. Stressed environmental conditions are suggested by the lack of macrobiota within this succession. The platform is dominated by microbialites in the form of stromatolites and peritidal facies, interbedded with oolitic grainstones. Stromatolites form low circular biostromes up to 10 meters across. The lowest, transgressive part of the Z2C (20 meters thick) includes a distinctive 1.4 m thick unit called the Crinkly Bed which has also been interpreted as an abiotic precipitate. However, petrographic fabrics show this bed to be a microbialite where physical processes strongly influenced its features; thus it can be regarded as a type of microbially-induced sedimentary structure (MISS). It consists of fine, micritic, even laminae ((couplets ~500 µm thick) that display a high degree of lateral continuity. Filament-like structures extend upwards from the micritic laminae. Macroscale structures of up to three orders of scale are seen. First-order structures (which correspond to the gross morphology of the stromatolites) are mostly domical and show varying degrees of convexity; the largest are flat-topped structures that commonly reach over 10 m in width, with 1 m of relief. They are mostly linked. Second-order structures (synoptic relief ~ 10 cm) form symmetric ridge-like and ellipse-shaped features that appear peaked or rounded in cross-section. They display the same relative orientation and are believed to have originated as wave-generated megaripples. Third-order structures (synoptic relief ~ 1 cm) show a wide variety of form, particularly in the Crinkly Bed, and include asymmetric curvilinear and linguoid / arcuate ripple-like features as well as cone-shaped structures. Their form, distribution and orientation exhibit considerable spatial variation and they appear to have been controlled by the second-order structures. The ripple-like structures are believed to have been formed by a combination of unidirectional wave and tide-generated currents, the cone-shaped features forming by the interference of the curvi-linear structures and upward growth of a biofilm.

The most common organosedimentary structures within the Main Dolomite carbonates of Poland are stromatolites and thrombolites, mostly developed in a tidal-flat environment. Stromatolites show four types of growth structure: low-relief domal contiguous, columnar, planar, and crinkled. The domal and columnar stromatolites are small forms (<10 cm high at the core scale) and are characterized by a wavy lamination. Laminae are 1-2 mm thick and contain trapped ooids. Planar stromatolites are mainly composed of an even lamination which consists of an alternation of light (muddy)-grey dark (organic) couplets of microsparitic dolomite and dark-grey micritic dolomite. Crinkled stromatolites consist of alternations of light grey (20-50 µm) to dark-grey laminae (20-50 µm). Light grey laminae may contain trapped ooids. Thrombolites are recognized by their clotted micritic fabrics. Micrite clots are mainly formed by grey dolomite surrounded by anhydrite cement and spherical bodies. Thrombolites, probably formed by coccoid-dominated spherical calcimicrobes, coexist with stromatolites and form thrombolite-stromatolite complexes greater than 10 m thick.

Within the inner oolitic shoal/tidal flat and tidal-channel lithofacies, thin microbial veneers are present which may well have stabilized the loose, grainy (ooidal-oncoidal) sediment. The grainy interlayers (up to 1 cm thick) are composed of well-sorted sediment particles (mainly ooids and oncoids). They form single to multiple biolaminae units up to 10 cm thick. They have a pale colour, wavy shapes and are from several microns to 1-3 mm thick. The total thicknesses of this coarse (grainy) biolamination may reach more than 10 m.

Inter- to supra- tidal microbial boundstones are mainly composed of planar stromatolites (<50 cm in thickness). Thrombolites form beds less than 20 cm in thickness. Ooids, oncoids, vadoids and peloids are very common. Oncoids and peloids form grainy planar stromatolites, grainstones and packstones but both are components of the thrombolites, and peloids are common in the stromatolites. Peloids form micropeloidal micrite and clumps. Oncoids in some places form aggregate grains. Cortices of some oncoids are formed of several overlapping tangential laminae that are similar to those of the stromatolites (crinkled and wavy). Oncoids might have originated from a shallow, low-energy, slightly-to-moderately agitated subtidal environment which is inferred from the existence of fine, thin biofilms, with the concentric growth of the oncoids suggesting periodic higher energy. Ooids with sizes from 0.1 to 2 mm are spherical, consisting of smooth and regular concentric laminae around a nucleus. No microbial crinkly laminae were found. Their cores are usually dissolved forming oomoldic porosities and their cortices are commonly filled with oil. Vadoids are oval or irregular in shape and 2-3 mm in size. They typically have a relatively big nucleus coated by irregular alternating black and dark laminae of variable thickness. The nucleus is usually built of fine crystalline dolomite containing microbial relics, dolomite spar and micritic dolomite clots while the laminae consist of fine crystalline dolomite (lighter laminae) and possible bacterial laminae dark in colour. Microbial boundstones of this zone coexisted with phylloid and dasyclad algae and *Archaeolithoporella*.

In the subtidal facies, the microbial carbonates are mainly low-relief domal contiguous, columnar, and crinkled stromatolites and thrombolites. Columnar-domal stromatolites at core scale are up to 10 cm in thickness. Crinkled stromatolites occur on the slope and can reach a higher thickness (<20 cm), whereas on steeper parts of the slope fragments of stromatolites occur. The latter are usually broken, elongated forms indicating sliding of material down the slope. Thrombolites have higher thicknesses than stromatolites, reaching up to 20-30 cm.

Petrographic studies revealed fair reservoir properties in bioclastic packstones which have well-developed mouldic porosity and in ooid-oncoid packstones/grainstones, stromatolitic and thrombolitic intervals. Generally porosity in the latter varies from below 1% to almost 20% depending on diagenetic changes. The pore system is mainly intergranular with some mouldic contribution and was created or enhanced during early burial dissolution through dolomitization. Subsequently, porosity properties were lowered because of later anhydritization of the Ca2 rocks which led to occlusion of pores.

The total organic carbon (TOC) values obtained from microbial boundstones (stromatolites and thrombolites) are low and range from 0.01 to 0.30 wt. % (Kotarba et al. 2003). This suggests that stromatolites and thrombolites cannot be regarded as potential source rocks but rather reservoir rocks for hydrocarbons. The highest TOC values were noted within biolaminated lime mudstones deposited on the Ca2 slope, which range from 0.5 to 1.2 wt. %, and lagoons, and these can be classified as source rocks.