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Outcrop analogue of Pre-salt microbial series from South Atlantic: the Yacoraite Fm, Salta rift system (NW Argentina)

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The post-rift geological history of the South Atlantic Ocean is attracting geoscientists attention since exploration in the Brazilian pre-salt has resulted in important oil discovery for the past 4 years. The main reservoirs correspond to stromatolitic and bioclastic carbonate facies which were deposited in lacustrine to shallow marine depositional environments during the Sag phase. As only few subsurface data are available, the reservoir distribution as well as the reservoir heterogeneities are poorly constrained in a such peculiar setting. The present study is thus focused on the Yacoraite Fm, a carbonate-dominated series, that has been deposited during the sag phase of the Salta rift system, NW Argentina, and that represents an excellent outcrop analogue for these reservoirs. Indeed, the Yacoraite Formation shows a large diversity of stromatolitic facies that exhibit various sizes, macroscopic morphologies and microscopic textures.

We present hereafter new results in terms of microbial facies characterization and corresponding reservoir architecture. Based on their macroscopic morphologies, six types of bioconstructed facies can be distinguished (Figure 1).

- Oncoidal rudstone, mainly composed of oncoids (centimetre-scale), clasts of oncoids and rare bioclasts (gastropods), generally embedded in a silty matrix are mainly observed on the most proximal part of the sedimentary system. This facies is sometimes observed at the base of nodular stromatolites, where oncoids are coalescent and form the initial nuclei of the bioconstruction. It has been interpreted as tidal flat deposits.

- Planar-laminated stromatolites show planar to slightly undulating laminae, laterally continuous. It may 1) be organized in decimetric alternations with silty/mudstone facies; 2) show encrusting morphologies (at the top of oolitic beds); 3) form pluri-decimetric planar-laminated beds, laterally continuous. In the latter case, it forms the "substrate" over which nodular and bulbous structures have developed. The interpretation in terms of depositional environment of these laminated stromatolites is fairly dependant of the facies they are associated with and the fine-grained sediment they are interbedded with. In proximal tidal flat, they are mainly associated with silty shales to fine-grained sandtones facies. In restricted lagoon to back-shoal environments, they can laterally pass to branching or nodular stromatolites.

- "Mustach-like" stromatolites occur as decimetric intercalations within muddy / silty facies. The stromatolites themselves have a discontinuous morphology. They show wavy internal laminations and form "mustach-like" structures. These have been interpreted as ancient desiccation cracks (e.g. Black, 1933; Davies, 1970), encrusted by growing algal mats. They are found in tidal flat environments.

- Isolated nodular stromatolites consist of isolated decimetric to pluridecimetric domes (rarely more than 50 cm height). They generally grew up from the planar laminated facies and may be overlapped either by silty-muddy facies, or by oolitic grainstones (in high-energy environments). Laminae are slightly wavy and a framework porosity can be observed. The latter is sometimes partly filled by a dolomitic cement. Birdseyes structures are also present. Since this facies is associated with coarse-grained carpet made up of coated-grain grainstones, it could be interpreted as back- to inter-shoal deposits. Since this facies directly overlies fine-grained facies, with possible mudcracks and mud clast breccias, and are interpreted as lagoon to tidal flat deposits.

- Coalescent nodular to bulbous stromatolites are composed of the same structures than the previous facies, but are continuous laterally, as the domes are laterally coalescent. In that sense, they are close to the classical laterally-linked hemispheroids (LLH stromatolite type). They may form beds of several metres in height and a kilometre-scale lateral continuity. This facies generally shows important framework porosity, partly filled by a dolomitic cement. It has been interpreted as lagoon to restricted flat deposits.

- Finally, branching or tubular stomatolites formed isolated bioconstructions, pluridecimetric in height and width, with columnar (tubular) structure, sometimes branching. Laminae are regular (smooth), with a parabolic morphology. Between the tubes or columns, an internal sediment (mainly oolitic grainstones to packstones) has been observed. It has been interpreted as high-energy environment deposits (shoal related).

Spatial distribution of each of these facies at rift and reservoir scale has been examined. Generally speaking, the oolitic grainstones to stromatolitic limestones facies of the Yacoraite Fm are mainly located on a structural paleohigh along the rift axis, 50 to 100km away from both sides of the rift margin. The best reservoir facies (stacked highly porous stromatolitic limestones) occur preferentially on this paleohigh within an area of 30-50km long and 20-25km wide, and rapidly passes to muddy-dominated facies laterally. At reservoir scale, the main heterogeneities correspond to laterally continuous 10 to 50cm thick mudstone layers acting as permeability barriers.

Finally, the vertical occurrence of the different facies and their relationships within a sequential framework will also be discussed. The Yacoraite Fm records an overall transgressive trend from fluvio-aeolian sandstones passing upward to shallow marine/lacustrine carbonates (oolitic grainstones to stromatolitic limestones) in turn overlaid by lacustrine dark shales, halite, anhydrite and gypsum. This depositional sequence can be subdivided into four third-order sequences (e.g. Boll et al., 1987). During the deposition of Sequence 1, the sedimentation is characterized by mixed depositional environments dominated by restricted facies. Planar-laminated stromatolites are the dominant form. Sequence 2 records a flooding of the basin, probably coming from the west (foreshoal to outer platform facies). Encrusting branching forms associated to oolitic shoals are observed. Following a major maximum flooding surface (probably inducing a shut down in the carbonate production), Sequence 3 records a progressive abandonment of the basin ended by a major sequence boundary. Sequence 4 is characterized by restricted facies with very large development of nodular stromatolites.

References

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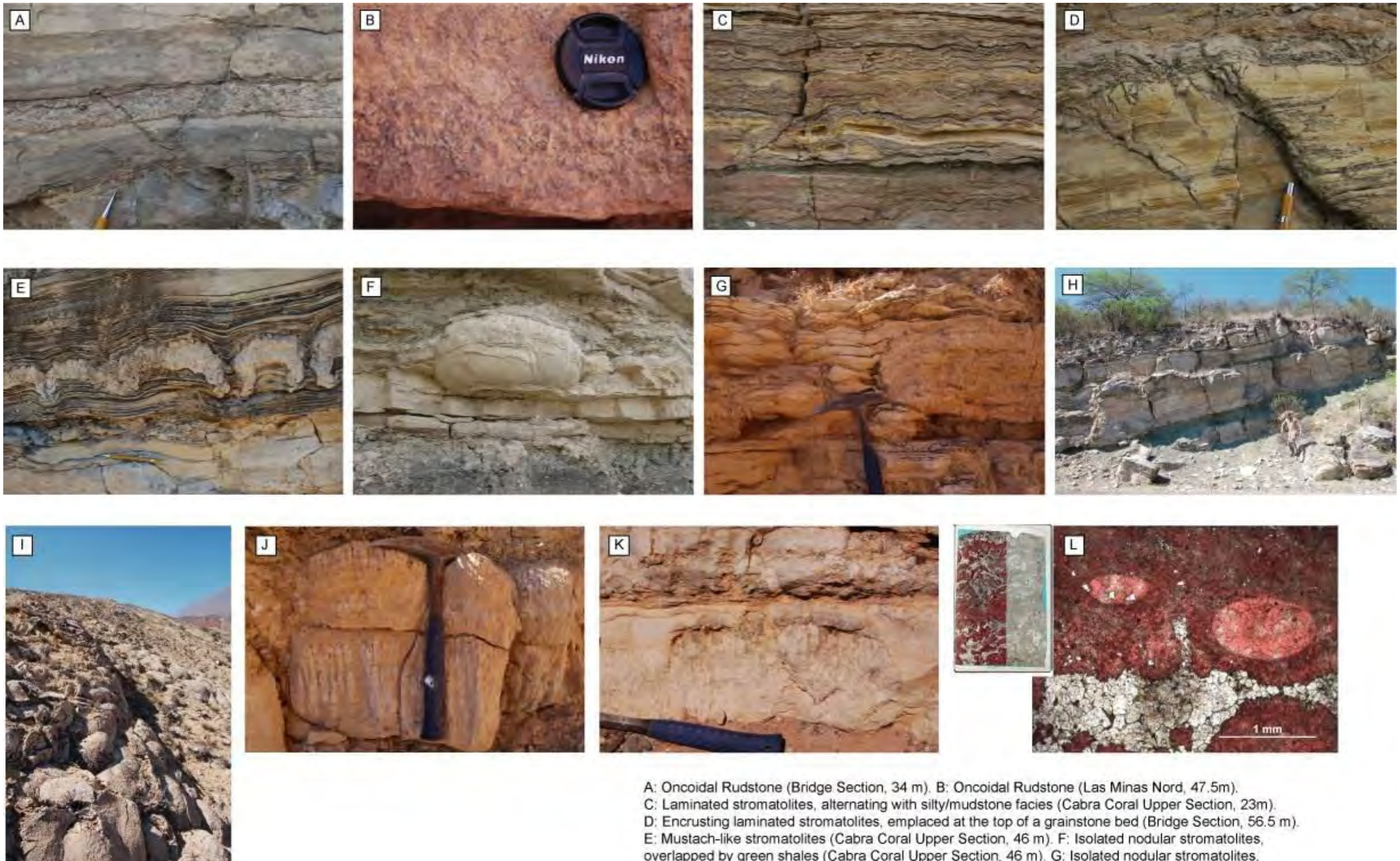

A: Oncoidal Rudstone (Bridge Section, 34 m). B: Oncoidal Rudstone (Las Minas Nord, 47.5m).
C: Laminated stromatolites, alternating with silty/mudstone facies (Cabra Coral Upper Section, 23m).
D: Encrusting laminated stromatolites, emplaced at the top of a grainstone bed (Bridge Section, 56.5 m).
E: Mustach-like stromatolites (Cabra Coral Upper Section, 46 m). F: Isolated nodular stromatolites, overlapped by green shales (Cabra Coral Upper Section, 46 m). G: Isolated nodular stromatolites, overlapped by oolitic grainstone with wave ripples (Cerro Negro Section, 30 m).
H and I: Coalescent nodular stromatolites (respectively Cabra Coral, 78 m and Cerro Negro, 88 m).
J: Tubular stromatolites (Cerro Negro, 17.5 m). K: Branching stromatolites (Cerro Negro, 20.5 m).
L: Photomicrograph (PPL) and scan of a thin section realized in a nodular stormatolite (sample CH5, Las Cardones). The thin section has been stained with alizarin red-S and shows a dolomitic cement in the framework porosity.