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EA Lacustrine Carbonate Facies as Modern Analogues of Pre-Salt Units in Mexico*

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Abstract

Microbialites are three dimensional organosedimentary rocks that accrete and develop a synoptic relief related to the physicochemical factors of the depositional environment. Thrombolites and stromatolites are common microbialites with a long evolutionary history. As they grow, they generate a primary porosity, which in turn, may be modified by diagenesis and other biogenic factors such as bioerosion and bioturbation. Microbial mineral interactions taking place inside microbial carbonates are the subject of intense theoretical and technical exploration in order to understand the genesis, and to frame the exploration of ancient presalt reservoirs. The characterization of modern analogues as recent microbial carbonates is of great relevance for oil exploration, with a major emphasis in rift lacustrine deposits Rincon de Parangueo, a Quaternary lacustrine setting, contains thrombolitic bioherms with a characteristic clotted, laminated and cystoidal microfabric. In addition, RP contains laminated muddy structures that preserve a record of changing geochemical conditions. This work presents microbial sediments of a recent alkaline crater lake that may be considered a good modern analogue of ancient presalt systems. This recent volcano sedimentary setting may bear comparison with older volcanosedimentary deposits from northern Mexico. Non marine volcanosedimentary sequences and, although the regional geology is mainly dominated by volcanic and siliciclastic deposits, carbonates are present in some localities of northeastern Mexico, such as Huizachal Peregrina in Tamaulipas, Mexico, and Aramberri, Nuevo Leon.

Introduction

With a long evolutionary record that dates back to 3500 Ma strata, microbial mats and stromatolites are macroscopic manifestations of mineral microbial interactions that originate under a wide variety of environmental conditions. The oldest macroscopic evidence of life on Earth corresponds to stromatolites (Awramik et al 1976) which are dark and light layered organosedimentary rocks. Stromatolites accrete as consequence of the metabolism of microbial mat communities, and their morphology is considered to be shaped by the environment. In siliciclastic sedimentary environments, microbial mineral interactions have also left an ancient record known as microbially induced sedimentary structures or MISS (Noffke et al 2008). Besides this ancient and rich geobiological record, microbial sediments are of great interest for hydrocarbon exploration (Awramik and Buchheim, 2014). The exploration of presalt basins as carbonate reservoirs in Angola and Brazil

have promoted the interest in microbial carbonates derived from non-marine environments, especially from lacustrine settings. Lacustrine carbonates in volcanic settings where fracture development is probable, exhibit a relative high lateral facies variation, diverse pore types and a high microstructural heterogeneity. The aim of this work is to highlight the biosedimentological characteristics of recent continental microbialites as modern analogues of ancient presalt basins.

Geological Setting

The volcanoes around Valle de Santiago are part of the Michoacán-Guanajuato volcanic field, an approximately 40,000 km² area with more than 1000 monogenetic volcanoes distributed along a volcanic NNW trend belt (Aranda et. al., 2017). Most of these monogenetic volcanoes are formed by mild alkaline mafic volcanic rocks. The locality of Rincon de Parangueo (RP) consists of Quaternary deposits distributed around a central crater lake with a N30W direction, with its minor axis of ca. 1720 m in the N60E direction, and up to 290 m depth in its NW border. The RP maar forms part of a volcanic system integrated by an older subduction related continental lava shield volcano of Pliocene age, a rhyolitic lava dome and three more maar type volcanoes (Aranda et. al., 2013). This central lake is surrounded by trachyandesitic lava flows overlain by pyroclastics and fall deposits that was excavated by hydrovolcanic explosions approximately 137,000 years ago (Aranda, et. al., 2017). A discontinuous ring of thrombolites formed the external facies of the 1100 m paleolake, whose maximum depth was ca. 9 m. RP has been continuously under desiccation and therefore, the precipitation of evaporates such as trona, halite, eitelite among others, are common salty bottom sediments (Chacon et. al., 2018). ([Figure 1](#), [Figure 2](#), [Figure 3](#))

Thrombolites Formed at the External Facies of a Paleolake

The continuous subsidence of the RP maar has promoted the asymmetry in the playa lake pavement with diverse laminated sediments. The RP thrombolites formed at the water-sediment interface of the former lake margins. Thrombolites show a mesostructure composed by a thrombolytic or clotted matrix with an upward radial cystoidal growth. Every single thrombolite exhibits a stromatolitic crust that contains a cyanobacterial lamination alternating with fine light laminae. Their lateral walls of their domal macrostructure show the lake level fluctuations. Other siliciclastic muddy deposits in RP may contain microbial mats occurring as finely laminated sediments in association with desiccation cracks. Microbialites and microbial mats associated to a loci of calcium precipitation show three main processes of accretion: trapping, binding and precipitation. They may occur simultaneously within the organic matrix or may occur at certain microenvironmental spaces inside microbial mats. They may also occur extensively through the organic matrix. ([Figure 4](#))

Microbial Microfabric

Microbial mats are complex bacterial communities that interact with sediments of different sizes, and therefore, trapping and binding processes are common interactions between microbes and sediments. Furthermore, other biogeochemical processes also influence the internal microenvironment, and thus, promote or inhibit carbonate precipitation. Other unicellular and multicellular eukaryotes may eventually integrate into microbial mats and generate new trophic interactions. The thrombolites in RP show an external stromatolitic crust and a thrombolytic matrix with a cystoidal texture during their accretion, but a combination of textures is common. Although lamination is the most notorious

feature of stromatolites, other microbial fabrics such microfabric (laminated, clotted, cystoidal, etc.) may also develop as microbialites accrete. The clotted fabric of thrombolites shows irregular calcification zones. During accretion and growth, microbial mats typically generate a primary porosity in the form of irregular fenestrae. The permeability and porosity depend on the microscale interaction between micrite and microbial population that secrete an extracellular polymeric material (EPS), which may bind and precipitate calcium carbonate (Dupraz et. al., 2009). Furthermore, dissolution by endolithic cyanobacteria may produce additional porosity and/or increase pore interconnectivity. At the same time, diverse microbial precipitates may obliterate and generate pores of variable size and shape. The multiple microbial interactions inside microbialites modify two basic petrophysical properties porosity and permeability. It has been long recognized that diagenesis also modifies the primary fabric, and promotes the development of secondary porosity diagenesis may also homogenize and occlude primary porosity ([Figure 5](#), [Figure 6](#), [Figure 7](#)).

Conclusions

The Sierra Madre Oriental (SMO) contains non marine sedimentary successions that include volcanosedimentary strata as red beds, shales and presumably lacustrine carbonates that have been specifically assigned to the Huizachal Formation and to La Boca Formation from Jurassic strata (Barboza Gudiño, 2018). The so called Huizachal Group is characterized by typical red beds, but only few reports have mentioned their intercalated carbonates. These continental deposits together with other carbonates from the Novillo Formation, represent a potential research area for presalt hydrocarbon accumulations in the Gulf of Mexico. Lacustrine deposits play a more important role in the generation of hydrocarbons, especially alkaline lakes in rift volcanic settings, as is the case for the South Atlantic Aptian “Pre-Salt” shrubby carbonate successions offshore Brazil and Angola (Mercado-Martin et. al., 2019; Bastianini et. al., 2019). Since microbial mineral interactions produce primary and secondary porosity, modifying the permeability of the matrix, and therefore their petrographic characterization is key. The pervasive distribution of thrombolites in Rincon de Parangueo represents an ideal modern analogue to study microbial carbonates with reservoir potential because it is an alkaline rift lake where fractures are common. This carbonate system has been microbially influenced, and this microbial sediment reworking can be reflected on the increment interconnectivity and the number of micropores. The RP maar is a very dynamic ecosystem where microenvironmental conditions can be monitored as a semi-closed system; this is an additional advantage of the RP maar as a modern analogue. In addition, the precipitation of evaporite minerals and the presence of siliciclastic microbial deposits are features that promote organic productivity and a rapid biogeochemical cycling.

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Figure 1. A) Central crater lake in Rincon de Parangueo, central Mexico;



B) Eroded muddy sediments in Rincon de Parangueo.



Figure 2. A) Locality of Rincon de Parangueo within the Trans Mexican volcanic Belt in central Mexico and associated microbialites.



B) Desiccation cracks in Rincon de Parangueo.

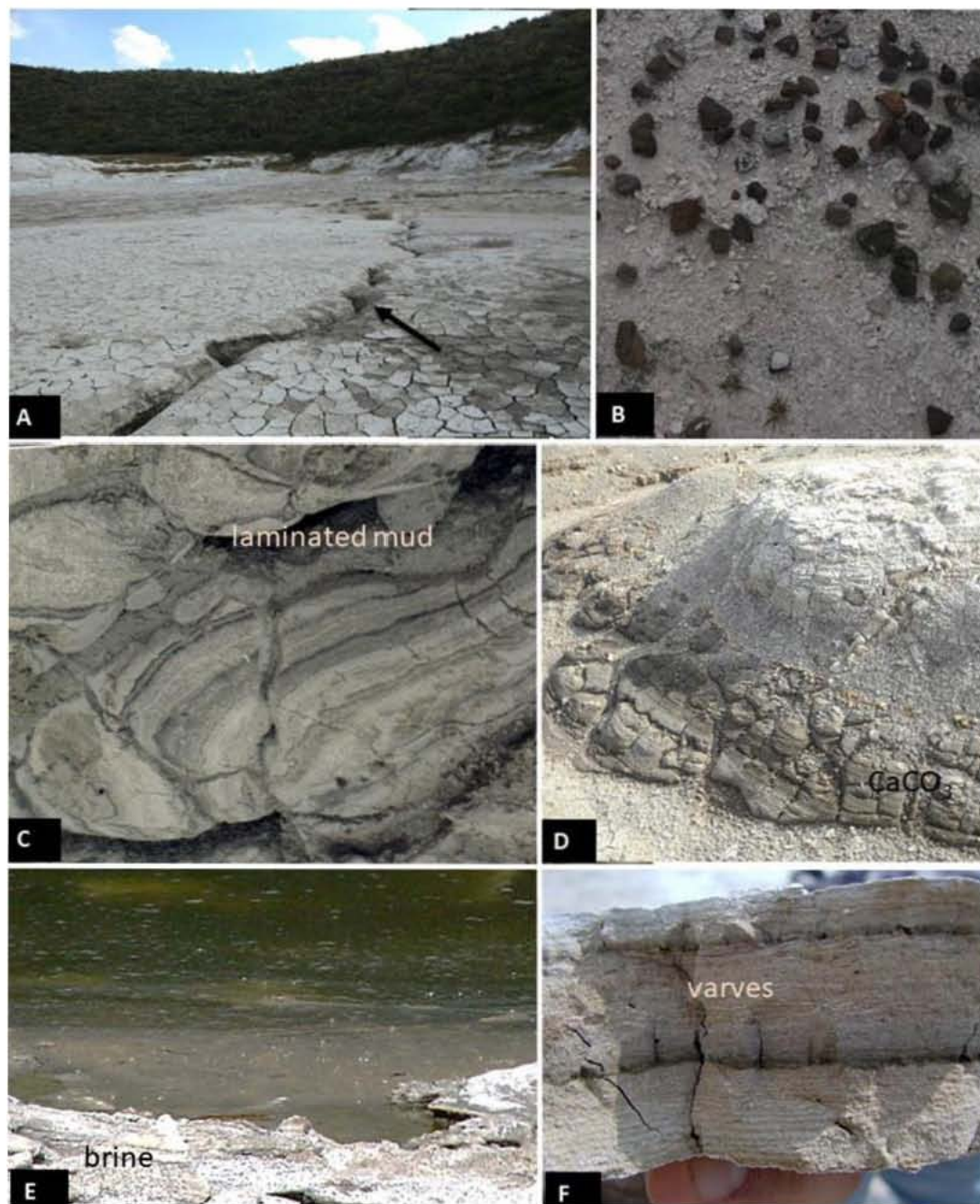


Figure 3. Sedimentary facies in Rincon de Parangeo.



Figure 4. Microbial carbonates at the margins of ephemeral ponds and as associated microbialites; cross sections of RP thrombolites.

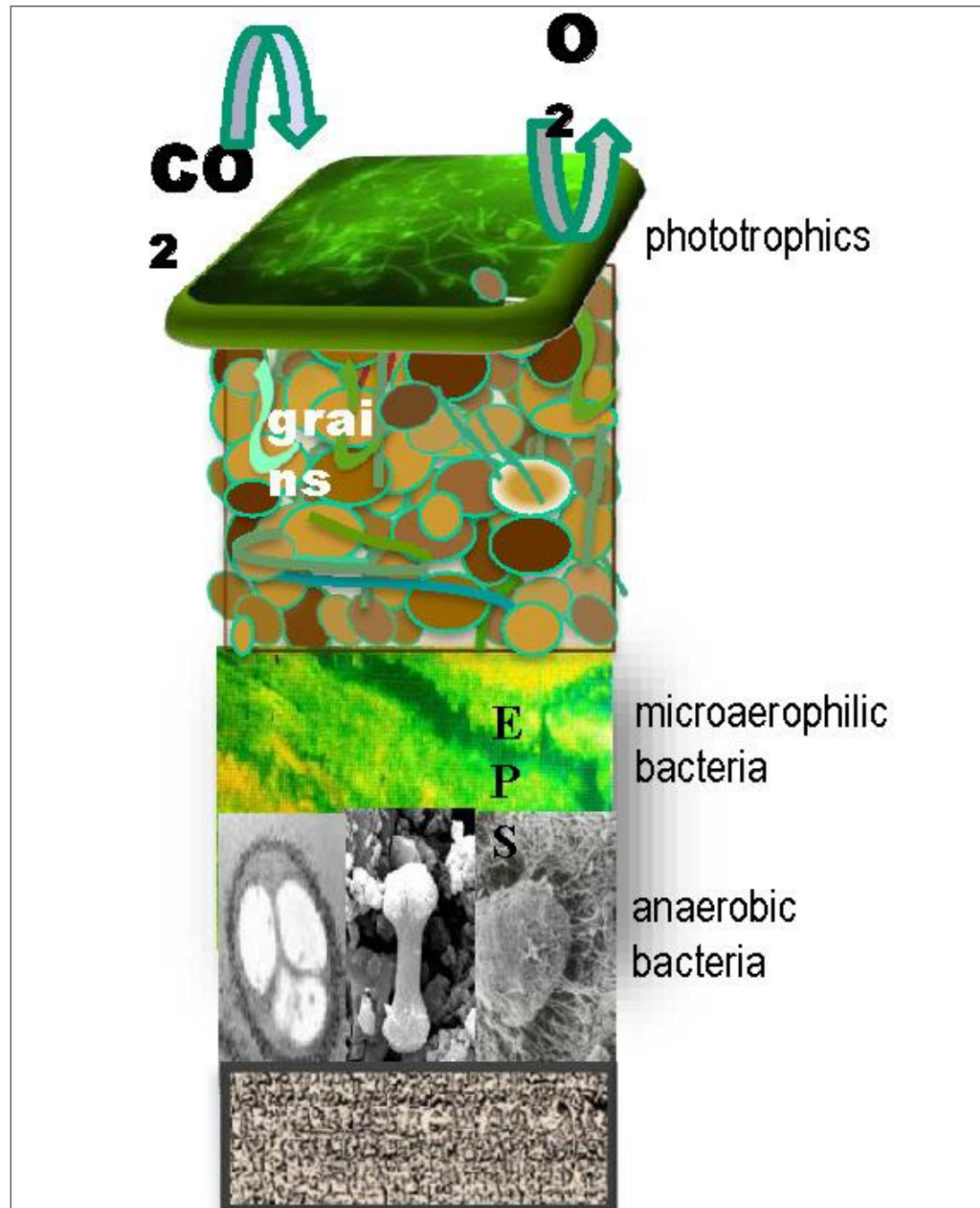


Figure 5. General model of biogeochemical gradients in microbial mats.

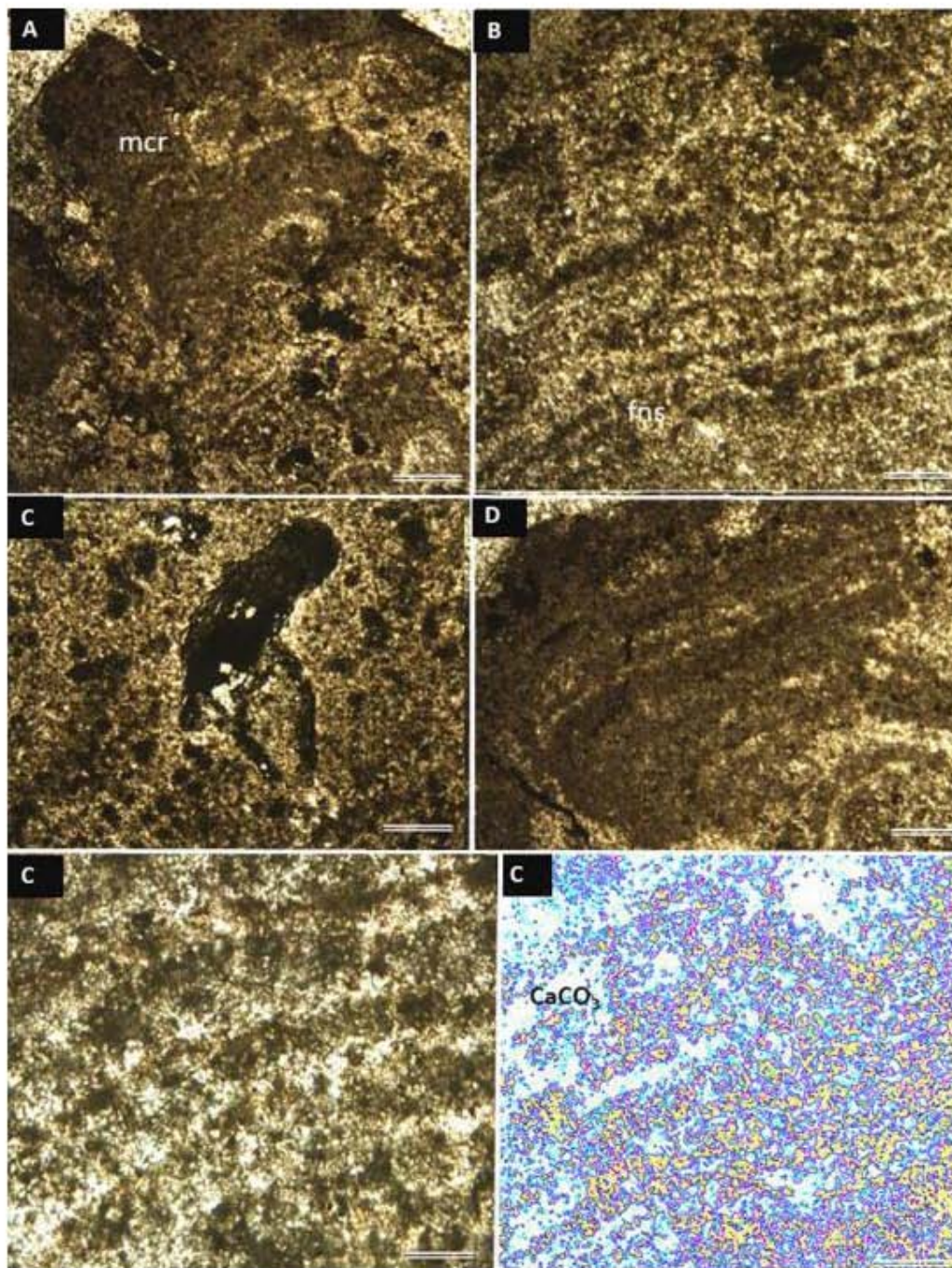


Figure 6. Microbial sediments preserved in RP thrombolitic matrix may modify porosity and interconnectivity.

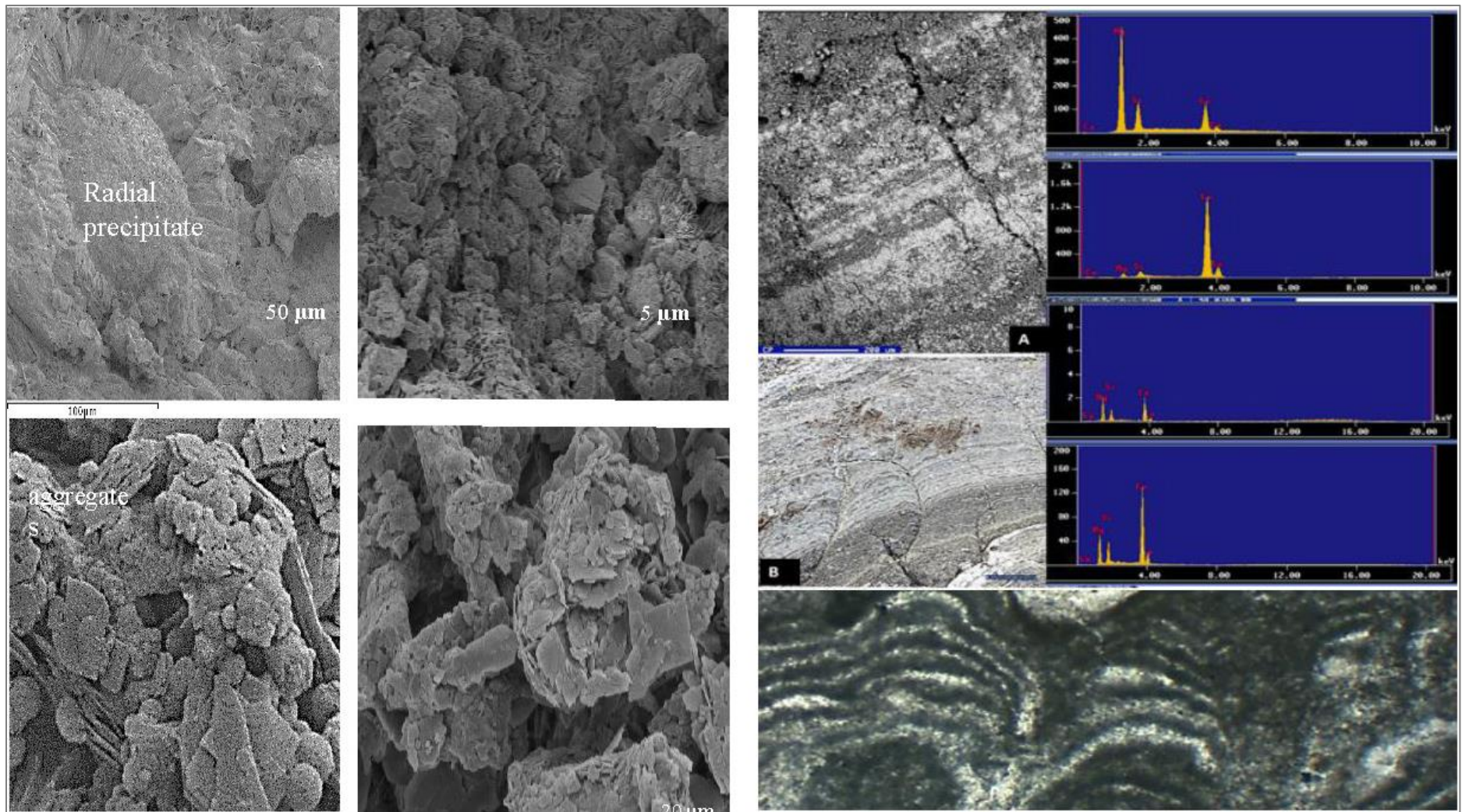


Figure 7. Microfabric of RP thrombolites clotted texture alternate lamination with a well-developed porosity and cystoidal textures.