DECIPHERING ANCIENT SABKHAS: THE OUTSTANDING STROMATOLITE-BEARING CARBONATE-EVAPORITE SEQUENCES OF THE ONCALA GROUP. EARLY CRETACEOUS, IN SPAIN

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Sabkhas are groundwater driven mudflats characterized by syndepositional, intrasediment capillary evaporites (Warren, 2006). They are periodically flooded, but for most of the time, the mudflat surface is dry and subaerial, and it is fed by capillary moisture from a shallow saline water table lying a few cm to 1-2 m below the sediment surface. Since the discovery of sabkha environments in the Trucial Coast in the 1960s, a vast amount of studies have been carried out in this setting because it is considered a good analogue for abundant evaporite deposits in the geological record. However, although present-day sabkha deposits are essential for understanding similar ancient sediments, they provide a very limited record compared to the wide variety of settings and processes in which sabkhas could have been developed in the past. For this reason, a good comprehension of ancient examples, which have not been so thoroughly studied, is also necessary to understand the sedimentary processes and evolution of sabkhas along time. The studied deposits provide an exceptional case study because they show extraordinarily well exposed sabkha sequences.

The Oncala Gr was deposited during the Berriasian in the Cameros Basin, a Lower Cretaceous extensional basin located in northern Spain, and comprises up to 2500 m of stratigraphic record, made up essentially of laminated carbonate-evaporitic deposits formed in coastal, shallow salinas, which pass laterally westwards to siliciclastic fluvial-tidal deposits (Quijada et al., 2013). The studied sabkha deposits are located in the northeastern area of the basin, in which the stratigraphic record of the Oncala Gr is much thinner comprising only up to 120 m of sediments. In this area, the lower part of the unit is composed of mixed siliciclastic-carbonate deposits that gradually pass upwards to predominantly carbonate deposits, which are the objective of the present study.

The studied deposits are characterized by conspicuous sedimentary sequences (< 1.5 m thick, Figure 1A), which consist of laminated carbonate deposits that pass upwards to stromatolites and carbonate breccias, and may show a truncation surface at the top. Abundant pseudomorphs after anhydrite nodules occur within the carbonate facies of the sequences.

Laminated carbonate deposits are made up of pelletoidal packstone laminae, which may show unidirectional cross-lamination, and mudstone laminae. Laminated carbonates pass upwards to stromatolite layers, which mainly consist of closely-spaced laterally-linked domes (up to 40 cm high and 40 cm across). Under the microscope, the stromatolites are composed of several interlaminated microfabrics, which include filamentous, agglutinated clastic (mainly pellets and ostracods), dense micrite, and clotted-peloidal microfabrics. Moreover, interbedded with these microfabrics, up to 400 µm-thick laminae of calcite and quartz pseudomorphs after gypsum are observed. The space between the stromatolite domes is mainly filled with micrite, pellets, and abundant carbonate breccias, which are composed of coated, rounded, flat stromatolite fragments up to 1 cm long, within a matrix of pellets and dense micrite (Figure 1B,C). Carbonate breccias commonly cover the stromatolite domes (Figure 1D), and pass laterally to eroded stromatolites. The domal morphology of the stromatolites gradually becomes less apparent upwards, eventually passing to flat-laminated stromatolites. Bioturbation is very abundant in the stromatolite layers, and it is also present in the carbonate breccias. Desiccation mudcracks, brecciation, or karstification, are present at the top of abundant stromatolite layers, and truncation surfaces may erode the stromatolites or carbonate breccias at the top of the sequences (Figure 1D).

Carbonate laminated deposits, stromatolite layers, and carbonate breccias are displaced and replaced by subspherical coalescing nodules up to 40 cm in size (Figure 1D-F), which commonly form continuous layers generally parallel to the stratification. These nodules are composed of aggregates of calcite and quartz pseudomorphs after crystals displaying acicular and orthorrombic habit, which is characteristic of anhydrite laths (Ortí & Rosell, 1997). Carbonate matrix is deformed around the nodules, suggesting displacive growth of the anhydrite, although nodules contain abundant matrix inclusions, such as pellets or micrite, indicating that the anhydrite also replaced the carbonate matrix. Interestingly nodules occurring at the upper part of the sequences may also be eroded by truncation surfaces.

Towards the upper part of the studied stratigraphic succession, stromatolites and carbonate breccias are less abundant, and laminated carbonates dominate. These laminated carbonates consist of alternating laminae of mudstone, and pelletoidal and oolitic packstone (commonly cross-laminated), which display occasionally wavy and lenticular bedding (Figure 1G). Calcite and quartz pseudomorphs after lenticular gypsum crystals occur within the laminated carbonates. Laminated carbonates are sporadically interbedded with flat pebble breccias, which consist of up to 10 cm-long coated fragments of laminated carbonates, and commonly stand on edge and are packed together to form fans of edgewise breccias (Figure 1H). Up to 20 cm-spaced laterally linked domes occur on top of the flat pebble breccias (Figure 1H).

The sequences that characterize the studied succession are interpreted as the result of the shallowing-upwards evolution of a carbonate-evaporite tidal flat. The lower part of the sequences composed of laminated carbonates was probably deposited in the subtidal to lower intertidal zone, which allowed alternating periods of calm and agitation probably related with tidal currents and/or storm episodes: deposition of parallel-laminated mudstone and pelletoidal packstone occurred under calm conditions, and sedimentation of cross-laminated pelletoidal packstone during agitated periods. Similar lime mud and pelletal mud occur in present-day lagoons and low intertidal zones of the Trucial Coast (Tucker & Wright, 1990).

The stromatolite layers overlying the laminated carbonates probably started to grow in the lower to middle intertidal zone, in which tidal currents provided a constant source of grains to be trapped in the agglutinating stromatolite microfacies (see Suarez-Gonzalez et al., 2015). Stromatolite grew under well-oxygenated and frequently agitated waters, as suggested by the abundant bioturbation and by their association with carbonate breccias. Carbonate breccias were probably the result of intermittent dessication of stromatolites, during which laminae were broken, and subsequent reworking of carbonate fragments, during which the pebbles were rounded and coated.

The progressive accretion of the stromatolites produced a gradual shallowing from the lower to the upper intertidal zone, which probably caused the gradual change from closely-spaced domal stromatolites to flat-laminated ones, because stromatolite morphology is frequently related with agitation conditions, being columnar stromatolites typical from areas exposed to high agitation and planar morphologies typical from protected areas (Tucker & Wright, 1990). As stromatolites accreted, their surface reached the supratidal zone and became subaerially exposed, as indicated by desiccation cracks, karstification, and brecciation at the top of them. The presence of pseudomorphs after anhydrite nodules displacing and replacing the carbonate facies indicate that a sabkha was developed in the supratidal flat and sequences remained above the water table for long periods of time, because this mineral only precipitates in the capillary zone (Warren, 2006). The truncation surface at the top of several sequences implies deflation of the sediment raised out of the capillary zone by intrasediment growth of anhydrite, which is characteristic of sabkha environments (Warren, 2006).

Towards the upper part of the succession subtidal to lower intertidal conditions dominated, as suggested by the predominance of laminated carbonates and the scarcity of subaerial exposure evidence and anhydrite nodules. Tidal currents were important in these environments, as suggested by the presence of wavy and lenticular bedding (Reineck & Wunderlich, 1968), and would have produced flat pebble (commonly edgewise) breccias, which are typical in tidal channels of carbonate tidal flats (Demicco & Hardie, 1994). Domal stromatolites nucleated on top of breccias, a common process occurring in both modern and ancient stromatolites (Eardley, 1938; Demicco & Hardie, 1994).

Several features of the studied deposits are similar to modern examples of sabkhas from the Trucial Coast, such as the development of shallowing-upwards sequences including mud and pelletal subtidal sediments, microbial laminated intertidal sediments, and intrasediment capillary evaporites formed in the supratidal flat, as well as truncation surfaces at the top of the sequences (cf. Tucker & Wright, 1990; Warren, 2006). However, noteworthy differences with the modern analogue are the absence of marine fossils and the presence of well-developed columnar stromatolites in the studied Cretaceous succession. Lack of marine fossils in the studied deposits may be a result of high salinities that inhibited marine biota, as occurs in some restricted areas of the Trucial Coast (Tucker & Wright, 1994). This higher salinity could have also favoured the development of domal stromatolites. Laminar microbial mats of the Trucial Coast are restricted to the middle-upper intertidal flat because mat growth is precluded in low intertidal and subtidal areas by the grazing activities of cerithid gastropods (Tucker & Wright, 1994). Contrastingly, higher salinities in the lower intertidal areas of the Oncala Group would have enabled the development of stromatolites also in the lowermost zones of the tidal flat, which could accrete forming up to 40 cm-thick domes.

Consequently, the extraordinary exposure and the unique sedimentary features of the carbonate-evaporite sequences of the Oncala Gr make them an exceptional case study to understand ancient shabka deposits, even lacking marine fossils, and may be useful to comprehend other sabkha deposits in the geological record.

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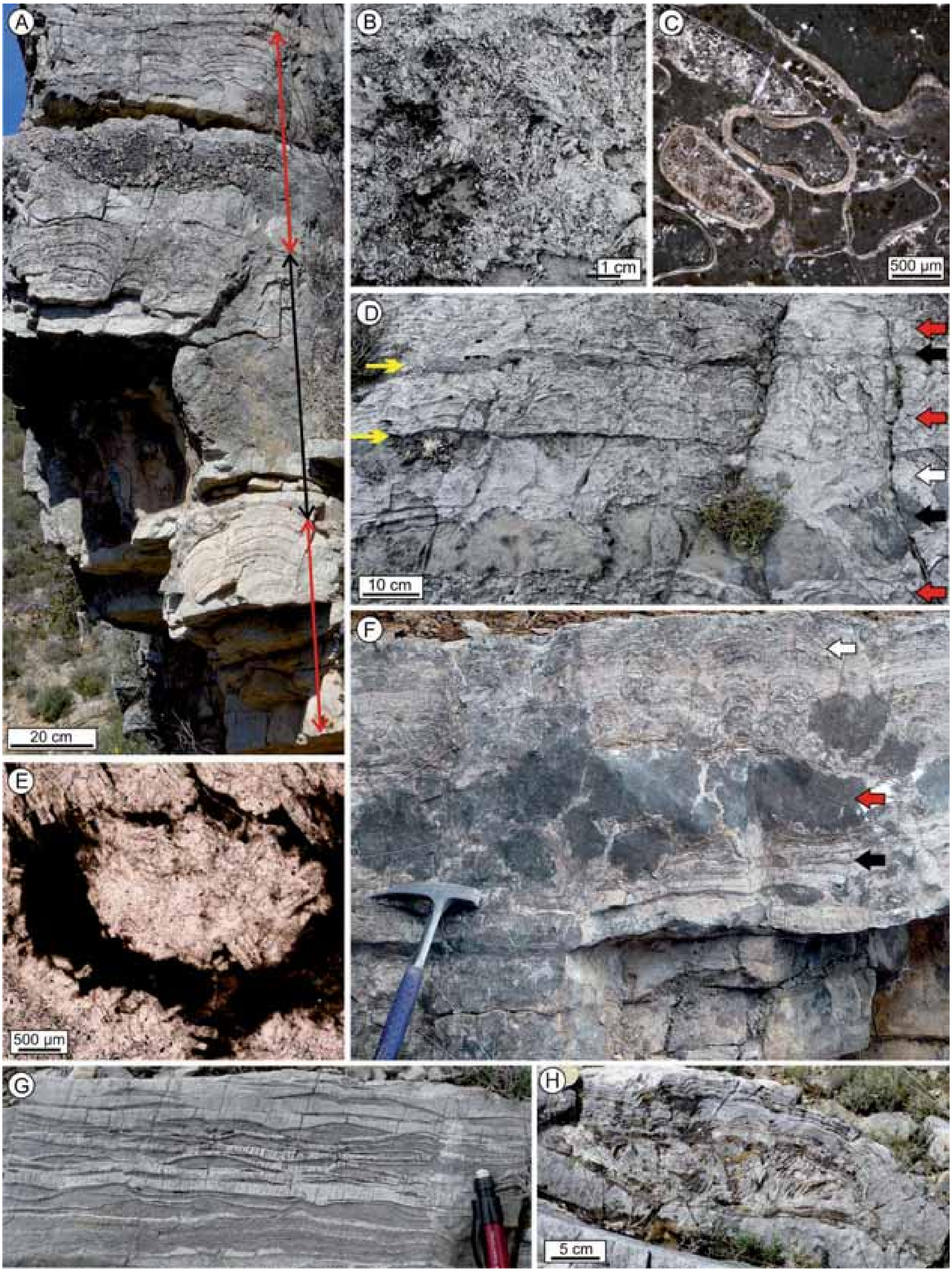

Figure 1. A) Characteristic sequences of the studied deposits. B) Carbonate breccia made up of flat stromatolite fragments. C) Microphotograph of a carbonate breccia composed of coated, rounded, stromatolite fragments within a matrix of pellets and dense micrite. D) Truncation surfaces (yellow arrows) at the top of stromatolite (red arrows)-breccia (white arrow) sequences. Note pseudomorphs after anhydrite nodules displacing carbonate facies (black arrows). E) Microphotograph of calcite pseudomorphs after orthorrombic anhydrite laths. F) Coalescent nodules of pseudomorphs after anhydrite (red arrow) displacing and replacing laminated carbonates (black arrow) and stromatolites (white arrow). G) Wavy bedding made up of alternating laminae of mudstone and pelletoidal packstone. H) Stromatolite on top of an edgewise breccia.