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Alternation of microbial mounds and ooid shoals (Middle Jurasssic, Morocco): Response to paleoenvironmental changes

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ABSTRACT

The occurrence of neritic microbial carbonates is often related to ecological refuges, where grazers and other competitors are reduced by environmental conditions, or to post-extinction events (e.g. in the Late Devonian, Early Triassic). Here, we present evidence for Middle Jurassic (Bajocian) microbial mounds formed in the normal marine, shallow neritic setting of an inner, ramp system from the High Atlas of Morocco. The microbial mounds are embedded in cross-bedded oolitic facies. Individual mounds show low relief domal geometries (up to 3 m high and 4.5 m across), but occasionally a second generation of mounds exhibits tabular geometries (<1 m high). The domes are circular in plan view and have intact tops, lacking evidence of current influence on mound preferred growth direction or distribution patterns, or truncation. The mound facies consists almost entirely of non-laminated, micritic thrombolites with branching morphologies and fine-grained, clotted and peloidal fabrics. Normal marine biota are present but infrequent. Several lines of evidence document that microbial mound growth alternates with time intervals of active ooid shoal deposition. This notion is of general significance when compared with modern Bahamian microbialites that co-exist with active subaquatic dunes. Furthermore, the lack of detailed studies of Middle Jurassic, normal marine shallow neritic microbial mounds adds a strong motivation for the present study. Specifically, Bajocian mounds formed on a firmground substratum during transgressive phases under condensed sedimentation. Furthermore, a transient increase in nutrient supply in the prevailing mesotrophic setting, as suggested by the heterotrophic-dominated biota, may have controlled microbial mound stages.

1. Introduction

Microbialites (*sensu* Burne and Moore, 1987) have been important contributors to carbonate environments for the last 3.5 billion years (Grotzinger and Knoll, 1999; Hofmann et al., 1999; Allwood et al., 2007; Burns et al., 2009). They encompass a wide range of types of accumulation, including carbonate stromatolites and thrombolites, authigenic accumulations such as some tufa, travertine, speleothem and spring, seep and vein deposits (see Riding, 2011 and references therein for a review) and develop in a wide number of depositional settings (i.e. freshwater, marine, evaporitic, alkaline etc.). After the advent of grazing metazoans in the Paleozoic, many neritic marine microbialite communities withdrew to ecological refuges, where predatory stress is limited (Riding, 2000 and references therein). Previous workers (Grotzinger, 1990; Arp et al., 2001; Riding, 2006) also stressed that secular changes in sea water chemistry may have controlled the long-term distribution of neritic microbial carbonates.

During the Mesozoic, microbialites colonized a variety of neritic marine environments across all latitudes (e.g., Triassic: Riding, 1992; Leinfelder and Schmid, 2000, Late Jurassic: Leinfelder and Schmid, 2000 and early Aptian: Rameil et al., 2010). This widespread distribution pattern is contrasted by the present-day world, characterized by a rather limited occurrence of actively growing stromatolites and thrombolites. Examples include high-energy settings such as Shark Bay, Australia (Logan, 1961; Reid et al., 2003; Jahnert and Collins, 2013) and Eleuthera Bight and Exuma Islands, Bahamas (Dravis, 1983; Dill et al., 1986; Reid et al., 1995, 2000; Andres and Reid, 2006). There, metazoan competition is limited due to non-normal marine environments or high current velocities resulting in constantly moving subaquatic dune substrates that represent significant obstacles for benthic grazers. The Bahamian case examples provide the – at present – perhaps best modern examples of contemporaneously active ooid shoals and microbial carbonate facies. The co-occurrence of these facies types

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is not without problem as instable substrates (Dravis, 1983; Ginsburg and Planavski, 2008) is often viewed as a critical factor preventing microbialite development. Given the fact that the Jurassic outcrops documented and discussed in this paper refer to combined shoal/microbialite facies in an inner ramp setting, this discussion is of interest here.

Obviously, besides the nature of substratum, a complex suite of environmental characteristics including sedimentation rate (Sun and Wright, 1989; Braga et al., 1995), carbonate saturation state (Fischer, 1965; Grotzinger, 1990; Riding and Liang, 2005), trophic and oxygen levels (Hallock and Schlager, 1986; Leinfelder et al., 1996; McCook, 2001; Camoin et al., 2006), illumination and bathymetry affect microbial carbonate precipitation and result in a bewildering diversity of macro- and microfabrics (Burne and Moore, 1987; Riding, 2000; Reid et al., 2003; Dupraz et al., 2009). This diversity is used as a proxy to infer changes of environmental conditions or biological communities (Harwood and Summer, 2011; Riding, 2011), but different workers seem to disagree in many aspects. With reference to the recent Bahamian examples, stromatolites exhibit laminated and coarse agglutinated fabrics with incorporated detrital, ooid and sand-size components (Dravis, 1983; Dill et al., 1986; Reid et al., 1995; Feldmann and McKenzie, 1998), whereas thrombolites show irregular clotted fabrics with ooids and other detrital particles in unbound-sediment pockets between the mesoclots (Aitken, 1967; Kennard and James, 1986; Feldmann and McKenzie, 1998). This variation might correspond to different benthic communities linked to changes in environments with water-depth (Feldmann and McKenzie, 1998). According to these authors, thrombolites are dominated by algal ecosystems and form in subtidal setting during intervals of sea-level rise, whereas stromatolites consist mainly of cyanobacterial benthic communities and occur in intertidal settings. In contrast, Planavsky and Ginsburg (2009) proposed that clotted thrombolitic fabrics result from the taphonomic remodeling of a precursor (laminated) fabric. Moreover, Riding et al. (1991) describe stromatolites and thrombolites with coarse-grained fabrics growing together in subtidal shoal environments in Miocene deposits of southern Spain and Jahnert and Collins (2013) document the ocurrence of thrombolitic and stromatolitic fabrics in microbial deposits in Shark Bay (Australia) arranged laterally within the same environment.

With respect to the Middle Jurassic world, only few examples of microbially dominated reefal facies (*sensu* Riding, 1991) have been reported (i.e. North Pacific realm: Parcell and Williams, 2005; Ploynoi and Parcell, 2005). Conversely, Middle Jurassic microbialites are often associated with siliceous sponges in deeper water (e.g. Friebe, 1995; Bersán and Aurell, 1997) and with corals in shallower settings (e.g. Olivier et al., 2006; Reolid et al., 2009).

Here, we document and interpret Bajocian shallow-water thrombolitic situated in an inner ramp setting of the Amellago Canyon, High Atlas, Morocco (Figs. 1, 3). Similar to the modern Bahamian case examples, these Bajocian thrombolic mounds are embedded in cross-bedded oolitic facies. In contrast, the Moroccan examples consist of fine-grained clotted peloidal fabrics with scarce or absent detrital particles formed by *in situ* microbially-induced precipitation. Evidence is brought forward, that these two carbonate modes -microbial versus oolite shoals — reflect two temporarily separated, and hence alternating depositional modes.

The aims of this paper are: (i) to document the spatial and temporal relationships between microbial mounds and oolitic shoal facies, (ii) to shed light on the significance of alternating mound and oolite formation in its palaeo-environmental context including relative sea-level change, sedimentation rates, bathymetry, and hydrodynamic level, and (iii) to compare and contrast the Amellago mound case examples with ancient and modern microbial carbonates.

2. Setting

2.1. Regional geology, stratigraphy and sedimentology

The study area is located in the Amellago Canyon, approximately 50 km NW of the city of Rich, on the southern flank of the central High Atlas Mountain range of Morocco. The High Atlas Mountains are an intracontinental fold-thrust belt, formed by the inversion of a pre-existing Mesozoic rift system during the Cenozoic (Jacobshagen et al., 1988; Beauchamp et al., 1996). During the Late Triassic to Early Jurassic, the break-up of Pangea resulted in the opening of the North Atlantic Ocean and development of the ENE-WSW trending High Atlas Rift Basin, connected towards the NE with the western Tethys Ocean (Fig. 1). Ongoing Late Triassic-Jurassic rifting and associated block tilting, caused by normal faults, led to a major marine incursion from the western Tethys and to a hemipelagic depocenter bordered by carbonate platforms (Wilmsen and Neuweiler, 2008).

During the Early Toarcian to Bathonian rift-phase the High Atlas Basin was fragmentated into smaller sub-basins bounded by ridges that represent the crests of the tilted blocks (Brede et al., 1992; Laville et al., 2004). From the Late Toarcian to the Late Bajocian, the depocenters of these sub-basins were filled with hemipelagic marl,

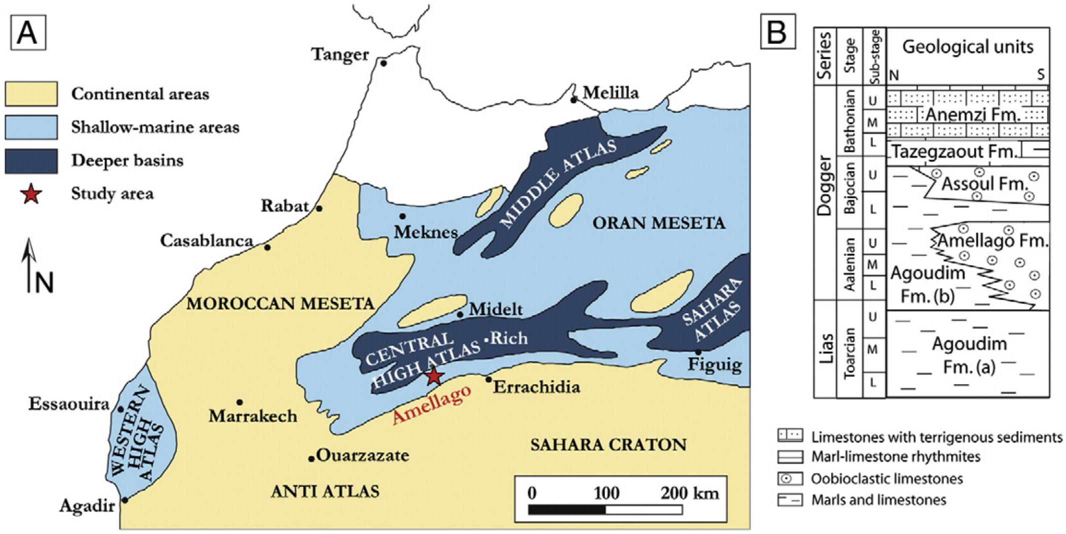

Fig. 1. (A) Map of Morocco showing the main geological units and the position of the village of Amellago in the study area. (B) Regional Middle Jurassic lithostratigraphy of the studied units in the Amellago region (modified after Amour et al., 2012).