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Origin and significance of lamination in Lower Cretaceous stromatolites and proposal for a quantitative approach

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ABSTRACT

Stromatolite lamination is typically defined as alternation of dark and light laminae. Study of Lower Cretaceous stromatolites from the Leza Fm (N Spain) supports this statement, but recognises additional complexities in lamination that have implications for interpreting accretion processes. These stromatolites are partial analogues of present-day coarse-grained carbonate stromatolites in the Bahamas and Shark Bay (Australia) that mainly form by trapping and binding carbonate sand. The Leza examples contain both grain-rich and micrite-rich laminae with scarce particles, suggesting that they accreted both by trapping and not trapping grains. Lamination in modern and ancient coarse-grained stromatolites is commonly defined by thin micritic crusts that formed during interruptions in accretion and separate contiguous grainy laminae (*repetitive lamination*). Leza examples also contain these thin hiatal crusts and locally show *repetitive lamination*, but their conspicuous macroscopic lamination is defined by thicker alternating grain-rich and micrite-rich laminae (*alternating lamination*). This indicates that, although hiatuses in accretion occurred, change in accretion process was the main cause of macroscopic lamination. These differences in accretion processes and lamination styles between Leza examples and modern coarse-grained stromatolites may reflect differences in their environmental settings. Modern examples occur in shallow marine tidal environments, whereas Leza Fm coarse-grained stromatolites developed in tide-influenced water-bodies in coastal-wetlands that experienced fluctuations in water salinity and hydrochemistry. Analysis of lamina-thickness in these Cretaceous stromatolites and similar published examples provides a quantitative approach to the processes that underlie stromatolite lamination.

1. Introduction

Lamination is a defining feature of the microbial sediments that Kalkowsky (1908) named stromatolites. Clearly visible in examples as old as 3.5 billion years (Hofmann et al., 1999; Allwood et al., 2006), lamination distinguishes stromatolites from other microbial carbonates such as dendrolites, thrombolites and leiolites (Riding, 2011). The shape, continuity, and stacking of laminae are important in stromatolite description and classification (Hofmann, 1969, 1973; Monty, 1976; Semikhatov et al., 1979; Grey, 1989; Grotzinger and Knoll, 1999), including the definition of stromatolite morphotypes (Maslov, 1960; Vologdin, 1962; Walter, 1972; Semikhatov and Raaben, 2000). Stromatolite lamination has been examined for periodicity (e.g. Jones, 1981; Takashima and Kano, 2008; Petryshyn et al., 2012) and pattern of arrangement (e.g. Zhang et al., 1993; Batchelor et al., 2000; Dupraz et al., 2006; Wagstaff and Corsetti, 2010; Petryshyn and Corsetti, 2011; Mata et al., 2012), but quantitative analyses of stromatolite lamina thickness are not common (e.g., Komar et al., 1965; Bertrand-Sarfati, 1972; Petryshyn et al., 2012).

Microbial mat communities can develop well-layered distributions in response to vertical physicochemical gradients (e.g., Schulz, 1936; Javor and Castenholz, 1981; Nicholson et al., 1987), but this biological stratification does not appear to be the principal precursor to the lamination that is preserved in lithified mats (Golubic, 1991). Early studies of present-day stromatolites and other laminated microbial deposits, such as oncoids, related layering to seasonal variations in growth and calcification (Roddy, 1915) and to the size of trapped grains and alternation of sediment-rich and organic-rich layers (Black, 1933). Subsequent work has supported and extended this view, and it is now widely accepted that primary lamination reflects episodic, in some cases iterative, changes in accretion variously related to variations in microbial growth and calcification, inorganic precipitation, and grain trapping (e.g., Cloud, 1942; Ginsburg and Lowenstam, 1958; Logan, 1961; Hofmann, 1973,

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1977; Doemel and Brock, 1974; Monty, 1976; Park, 1976; Semikhatov et al., 1979; Jones, 1981; Braga et al., 1995; Grotzinger and Knoll, 1999; Reid et al., 2000; Riding, 2000, 2011; Seong-Joo et al., 2000; Storrie-Lombardi and Awramik, 2006; Planavsky and Grey, 2008; Dupraz et al., 2009; Wagstaff and Corsetti, 2010; Petryshyn and Corsetti, 2011; Mata et al., 2012; Petryshyn et al., 2012).

A goal of stromatolite research is to be able to confidently discriminate between these accretion processes in order to interpret the origin of lamination. In ancient examples this effort is often hindered by poor preservation, but there is an additional complication in that lamination can also be generated by hiatuses, as observed in modern coarse-grained carbonate stromatolites (*sensu* Awramik and Riding, 1988) from Shark Bay and the Bahamas (Monty, 1976; Reid and Browne, 1991; Reid et al., 1995, 2000, 2003). This key distinction was recognised by Monty (1976) in a wide-ranging study of present-day stromatolites. He distinguished two main lamination styles: *alternating lamination*, produced by superposition of laminae of differing texture, and *repetitive lamination*, where hiatuses, marked by thin dark horizons, separate laminae of similar texture (Monty, 1976).

In this study, we examine well preserved Cretaceous stromatolites from the Leza Formation (Cameros Basin, N Spain) that exhibit both *repetitive* and *alternating lamination*. These examples mainly consist of ooids, peloids and bioclasts, together with micritic laminae. Their fabrics resemble those of well-known present-day coarse-grained carbonate stromatolites (Logan, 1961; Golubic and Hofmann, 1976; Monty, 1976; Dravis, 1983; Dill et al., 1986; Awramik and Riding, 1988; Reid and Browne, 1991; Riding et al., 1991a; Reid et al., 1995, 2000, 2003; Macintyre et al., 1996, 2000; Feldmann and McKenzie, 1998; Planavsky and Ginsburg, 2009; Dupraz et al., 2011; Jahnert and Collins, 2011, 2012, 2013). The Leza Fm contains some of the earliest known examples of coarse-grained carbonate stromatolites, and these are unusual in exhibiting both of the lamination styles defined by Monty (1976). Co-occurrence of these contrasting lamination styles sheds light on their processes of formation. They reveal how lamination can be produced by either hiatuses in accretion or by changes in the process of accretion (i.e. trapping and binding of grains *vs.* in-situ calcification of microbial mats without significant grains), and how these in turn reflect environmental controls. It also draws attention to distinct differences in macroscopic appearance: repetitive lamination is much less conspicuous, and the prominent lamination that characterises Leza coarse-grained stromatolites in field occurrences and hand-specimens is dominantly alternating lamination. We develop a metrical methodology to quantitatively describe and distinguish these lamination styles, which could be applied in other studies of ancient and present-day stromatolites.

2. Geologic setting

The stromatolites studied here belong to the Lower Cretaceous Leza Formation in the Cameros Basin, the northernmost basin of the Mesozoic Iberian Rift System (Mas et al., 2002b) (Fig. 1). The Cameros Basin developed during Tithonian (latest Jurassic) to Albian (late Early Cretaceous) times, and records up to 6000 m of continental and transitional sediments (Alonso and Mas, 1993; Quijada et al., 2010, 2013a, 2013b; Suarez-Gonzalez et al., 2010, 2013, in press). The upper Barremian–lower Aptian Leza Fm was deposited in a series of small fault-bounded depressions on the northern margin of the basin (Fig. 2) (Suarez-Gonzalez et al., 2013, in press). It consists of up to 280 m of carbonates with variable siliciclastic input (Suarez-Gonzalez et al., 2010, 2013, in press). The depositional setting of the Leza Fm has been interpreted as a system of coastal-wetlands formed by broad and relatively vegetated

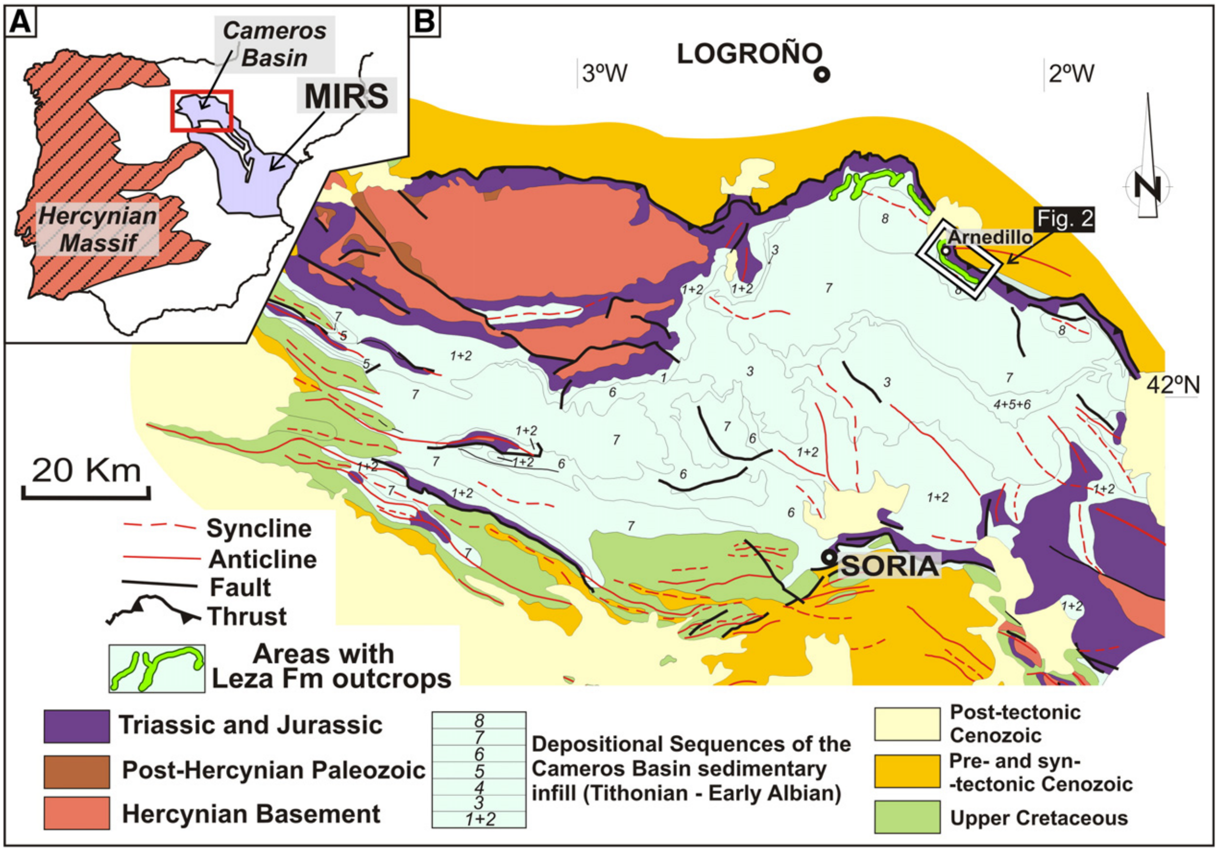

Fig. 1. A: Location of the Mesozoic Iberian Rift System (MIRS) and the Cameros Basin in the Iberian Peninsula. B: Geological map of the Cameros Basin. Outcrops of the Leza Fm are outlined in green and a rectangle shows the location of the eastern outcrops of the Leza Fm, mapped in Fig. 2. Modified after Mas et al. (2002a).