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Microbial mat structures in profile: The Neoproterozoic Sonia Sandstone, Rajasthan, India

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ABSTRACT

Ubiquitous microorganisms, especially cyanobacteria preferably grow on the sediment surface thereby producing microbial mats. In the absence of grazers and bioturbators, microbial mat is a unique feature of the Proterozoic. Most of the papers so far published described a wide variety of bed surface microbial mat structures with rare illustrations from sections perpendicular to bedding. Nonetheless, bed surface exposures are relatively rare in rock records. This limitation of bed surface exposures in rock records suggest that a study of microbial mats in bed-across sections is needed. The 60 m thick coastal marine interval of the Sonia Sandstone Formation is bounded between two terrestrial intervals, a transgressive lag at the base and an unconformity at the top, and has been chosen for exploration of microbial mat structures in bed-across sections. A wide variety of microbial mat-induced structures in bed-across sections are preserved within the coastal interval of the Sonia Sandstone. Though many of these structures are similar in some aspects with bed surface structures, some of those presented here are new. The palaeogeographic range of these microbial structures extends from supralittoral to neritic. Diagenetic alterations of microbial mats produce pyrite and those zones are suitable for the preservation of microbial remains. SEM and EDAX analyses show fossil preservation of filamentous microbial remains that confirm the presence of microbial mats within the coastal interval of the Sonia Sandstone. Effects of proliferation of microbial mats in the siliciclastic depositional setting are numerous. The mat-cover on sediment surfaces hinders reworking and/or erosion of the sediments thereby increases the net sedimentation rate. Successive deposition and preservation of thick microbial mat layer under reducing environments should have a great potential for hydrocarbon production and preservation and therefore these Proterozoic formations could be a target for exploration.

1. Introduction

Microbial mat-related structures in siliciclastic rocks although gradually gaining attention, still remain largely unfamiliar to most geologists, and are not as promptly recognized as ripplemarks, cross-beds or carbonate mat stromatolites (Schieber, 1998; Noffke et al., 2001). Knowledge of significant controls of mat growth on siliciclastic depositional systems and sequence building is in the reckoning, but a long way from authentication (Sarkar et al., 2005, 2008; Catuneanu and Eriksson, 2007). These structures are studied far more commonly in present day environments than in ancient settings because their genetic interpretation is, at best, tenuous in the latter (Gerdes et al., 1985, 2000). Limited availability of bed-across sections in present day environments therefore puts overwhelming dependence on the recognition of bed surface structures for study. The term 'bed-across' is used here refers to a view at considerable angle to the bedding plane, i.e., a side-view or profile. Paradoxically microbial mat growth had been far more prolific and extensive before the advent of grazers and burrowers (Seilacher and Pflüger, 1994) and bed surface exposures are relatively rare in the rock record. Post-exhumation weathering and erosion also modifies and obliterates the bed surface mat structures that are, in nature, very delicate. Notwithstanding these limitations, the preference for bed surface still prevails in the study of ancient mats and severely restricts our understanding of the geological significance of mat growth, especially during the time of the greatest flourish of microbiota in the Proterozoic. This paper attends to microbial mat-related structures in bed-across sections in the Neoproterozoic Sonia Sandstone, from where many bed surface mat structures are already reported (Sarkar et al., 2008). It does not pretend to be the first of its kind (Noffke, 2000; Schieber, 2004; Schieber et al., 2007), but is a follow up of the task highlighting the great potential of bed-across sections in identifying and evaluating microbial mat-related structures. Since some structures described here do not have any bed surface counterpart, the study

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further adds to the spectral variation of siliciclastic microbial mat structures.

The primary intention of this paper is to encourage search for siliciclastic mat structures in the rock record and proper evaluation of the role of microbial mat growth in depositional systems. Various microbial mat structures have been described and interpreted from bed-across sections in the field. Bed-across polished hand specimens and thin sections were utilized to further augment the study. The paper also presents Scanning Electron Microscopy (SEM) structures resembling cyanobacterial filaments in mat layers, though only briefly, as there is no way to eliminate the possibility of recent contamination, notwithstanding adoption of the best methodology to avoid it (O'Brian and Slatt, 1990).

2. Geological setting

The paper focuses upon the shallow marine interval of the Sonia Sandstone exposed at immediate north of the Jodhpur city, Rajasthan, India (Fig. 1). The Sonia Sandstone forms the basal Formation of the Jodhpur Group of the Marwar Supergroup (Fig. 1; Pareek, 1984; Chauhan, 1999). The Formation is largely undeformed and unmetamorphosed, and overlies the Malani Rhyolites of Neoproterozoic age (Rathore et al., 1996, 1998; Malone et al., 2008). The Girbhakar Sandstone unconformably overlies the Sonia Sandstone and together these constitute the Jodhpur Group (Fig. 1). The Sonia Sandstone is divisible into two intervals, the lower interval is subaerial and the upper interval is coastal marine (Fig. 1; Samanta, 2009). The coastal marine interval has a transgressive lag at the base and is unconformably overlain by the non-marine interval of the Girbhakar Sandstone (Samanta, 2009). The coastal interval of the Sonia Sandstone is around 60 m thick and generally a well-sorted, well-rounded quartz arenite of mean grain size 1.27Φ. The coastal interval is composed of three facies namely A–C, in ascending order ranging in palaeogeography from neritic to supralittoral (Fig. 1; Samanta, 2009; Sarkar et al., 2008). Repeated alternations between planar and cross laminae characterize the basal facies A and strongly suggests deposition in the upper shoreface (Hill et al., 2003). Towards the top, however, this facies also displays some rare remnants of washed out dunes, local bi-modal bi-polar cross-strata orientation, diverse wave ripple orientation and interference ripples indicating building up to the lower littoral. The facies B, on the other hand, is characterized by well-sorted, well-rounded sand dominated by planar laminae, infrequent wave ripples and rill marks, and indicates deposition in the littoral zone. Towards the top this facies, however, reveals local presence of adhesion laminae, translatent strata, grainflow–grainfall cross-strata indicating extension of the depositional environment into the supralittoral zone. The facies C is characterized by vertical stacking of trough cosets separated by granular wave-winnowed lag in moderately sorted sandstone. In total absence of emergence features deposition in neritic environment is suggested, possibly at somewhat deeper setting than that of facies A. Gradational superposition of facies B above facies A in a coarsening and thickening upward succession is a clear indication of progradation. However, the upward transition of facies B–C indicates transgression and the sharp contact defined by a distinct granular lag sheet between them strongly corroborates this contention (Fig. 1; Sarkar et al., 2005, 2008).

3. Microbial mat structures in profile

Bed-across sections or profiles are important for identification of mat-induced structures where bed surface exposures are very scanty. Although the Sonia Sandstone preserves excellent examples of bed surface microbial mat structures (Sarkar et al., 2008), selected blocks derived from the neritic to supralittoral facies of the Sonia Sandstone also show mat-induced structures on polished surfaces sawn perpendicular to bedding planes. Petrographic studies, SEM and EDAX analyses have also been used for identification of microbial mats. Mat-induced sedimentary structures from the bed-across sections are described below:

3.1. Iron oxide laminae

The light reddish brown Sonia Sandstone is often interspersed with layers of darker rust red colour (arrowed, Fig. 2). The rust-coloured layers have, more or less, laterally uniform thickness (within the studied blocks) ranging in thickness up to ca. 2 mm and generally fade rapidly downward. These structures have been observed within the littoral and supralittoral facies of the coastal interval.

Petrographic studies under reflected light reveal the presence of numerous iron oxides within the darker reddish layer as well as within the darker brown cement patches (Fig. 3). The main cement is otherwise silica, mostly in form of quartz overgrowths. Dark reddish brown iron-staining along certain selected laminae is

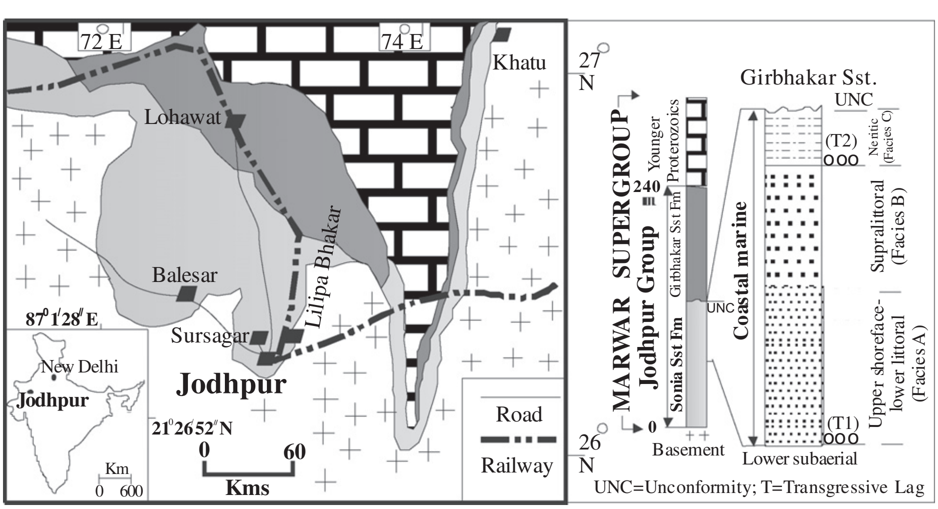

Fig. 1. Location map and geological setting of the study area: on the left, outcrop map showing the distribution of different formations constituting the Marwar Supergroup (map of India within inset). On the right, general stratigraphy of the Jodhpur Group with further elaboration about the unconformity-bounded Sonia Sandstone and vertical facies disposition within it. Note existence of granular transgressive lags at the base and also at an upper level of the coastal marine interval of the Sonia Sandstone.