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Neoproterozoic substrate condition *vis-à-vis* microbial mat structure and its implications: Sonia Sandstone, Rajasthan, India

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ABSTRACT

The present study deals with the Neoproterozoic mat-infested substrate sculptured by inferred bioturbations, excellently preserved within the ca. 600 Ma Sonia Sandstone, northwest India. The bioturbations are horizontal, being preserved on the bed-surfaces and have been classified into linear grooves and discoidal structures. The linear grooves are of two types, one group represents a straight to meandering pattern with raised sand ridges on either side, while the other group represents a mostly meandering pattern with changing width along the length, without raised ridges. Both types of grooves resemble trails of advanced organisms. The discoidal structures have five internal lobes emerging from the centre and merging with the outer ring and may represent body impressions of an organism; alternatively may represent variants of Ediacara or other soft bodied organisms. The interaction of the substrate with these possible bioturbators has great significance in establishing the evolutionary history of the substrate and resulting bioturbations during the Proterozoic. Microbial mats possibly provided oxygen and nutrients to the organisms and played an important role in their preservation. The study also tries to extrapolate the life style of these trace-makers. All these traces may raise speculation about the onset-time of some higher order organisms.

1. Introduction

Life began on the Earth perhaps before 3.8 Ga (cf., Reysenbach and Cady, 2001), thereafter for another 3 Ga the earth belonged solely to the microbiota (Schopf, 1999). The mesoscopic and megascopic organisms probably appeared during the Meso- to Neoproterozoic (Knoll and Carroll, 1999; Martin et al., 2000; Knoll et al., 2004) and many soft bodied organisms reached their acme in the Neoproterozoic (Narbonne, 2005). The most discussed of these megascopic organisms are the Ediacaran fauna that are considered to follow the Neoproterozoic glaciations at 750–635 Ma, with maximum diversity during 560–540 Ma (Waggoner, 2003; Meert et al., 2011). However, records of bioturbations of such soft bodied life during this period are rare to sporadic and almost exclusively recorded from siliciclastic settings (Hofmann and Mountjoy, 2001). Overall, the Neoproterozoic substrate condition was unique and was characterized by the presence of microbial mat colonies (resulting in new sets of structures; e.g., "MISS", Noffke et al., 2001; Noffke, 2010 or e.g., "MRS", Eriksson et al., 2010; Sarkar et al., 2014) associated with the Proterozoic soft bodied organisms, including Ediacaran fauna (Gingras et al., 2011a). The microbial mats and these soft bodied organisms proliferated together, in other words, the soft bodied organisms grew on the then mat-infested seafloor making the close association between mat-related structures and traces of such organisms inherent obvious. These common associations sometimes create controversies. However, sponge-like fossils have recently been reported from Namibia of ca. 760 Ma age (Brain et al., 2012) and, although controversial, structures interpreted as colonial multi-cellular organisms from Gabon are dated at ca. 2.1 Ga (Albani et al., 2010). Many published accounts of biotic evidence of presumptive traces of soft bodied organisms from this period have been reinterpreted and reconsidered as microbial mat colonies, microbial mat remnants (cf. Banerjee et al., 2010), or pseudofossils (Retallack, 2012) and thus the range of variation of fossil records remains uncertain (Seilacher, 1999; Banerjee et al., 2010). Nevertheless, there are some examples that are in reality very difficult to understand whether they are biogenic, purely physical in origin, or results of interaction between biogenic and physical processes.

In the present paper some possible bioturbations of mesoscopic organisms from the ca. 600 Ma Sonia Sandstone (Sarkar et al.,

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2008) of the Jodhpur Group (Marwar Supergroup), western Rajasthan, India are described. Though very restricted in occurrence, these possible bioturbations are found on the fresh surfaces of bedding plane exposures and are unique in their appearance and morphology, showing close resemblance to Phanerozoic counterparts. Noteworthy is that these structures show close association with a wide spectrum of microbial mat-related structures (Gerdes et al., 2000; Parizot et al., 2005; Sarkar et al., 2008; Eriksson et al., 2010; Samanta et al., 2011), but do not share morphological similarities with any of them. On the other hand, recent findings of Acritarchs from different horizons of the Marwar Supergroup (cf. Prasad et al., 2010) and of *Cruziana* from the immediately overlying Girbhakar Sandstone Formation (Kumar and Pandey, 2008) suggest the possibility of the presence of mesoscopic life within the Sonia Sandstone, although no intact body fossil has so far been reported. The purpose of this paper is to emphasize that the range of morphologic variations of organisms and related bioturbations during the Neoproterozoic could have been more diversified than they have so far been speculated to have been. As the acme of Ediacaran and other soft-bodied fauna is around 560–540 Ma, the age-equivalent Sonia Sandstone (Sarkar et al., 2008) may possibly be a perfect contender to exhibit such a wide range of variations in life-forms. Proterozoic substrate conditions become significant in extrapolating and extracting information about their behavioural attributes including movement, locomotion and interaction with the substrates during deposition of the ca. 600 Ma Sonia Sandstone in the absence of remains of these bioturbators. Keeping in view the age of the Sonia Sandstone, the detailed study of these possible bioturbations and the prevalent substrate condition, can possibly unravel a significant part in evolution of the early life.

2. Geological setting

The present paper deals with the shallow marine interval of the unmetamorphosed and undeformed Sonia Sandstone, belonging to the Marwar Supergroup, that are exposed immediately north of Jodhpur city, Rajasthan, India (Fig. 1; Pareek, 1981). The Marwar Supergroup is exposed in an elongated area and is bounded by basin-margin fault systems trending roughly NNW–SSE and N–S (Sarkar et al., 2012). Geophysical investigation suggests that the Bouger gravity anomaly contours are widely spaced and values ranging between −10 mgals and −30 mgals indicate that the basin was relatively shallow with a very thin sediment cover (Balakrishna, 1980; Chauhan, 1999). The deposition is inferred to have taken place in an intracratonic rift or a sag basin (Chauhan, 1999; Samanta, 2009; Sarkar et al., 2012).

The Marwar Supergroup is divisible into three groups, namely, the Jodhpur Group, Bilara Group and the Nagaur Group in ascending order (Fig. 1a). The Sonia Sandstone is the lowermost formation of the Jodhpur Group of the Marwar Supergroup (Fig. 1a). This sandstone is subdivided into two intervals, the lower subaerial interval and the upper coastal marine interval (Fig. 1b; Sarkar et al., 2005; Samanta, 2009; Samanta et al., 2011). This formation is thought to be of Neoproterozoic age (ca. 600 Ma) on the basis of radiometric dating of acid volcanic rocks (Rathore et al., 1996, 1998) that unconformably underlies the formation (Paliwal, 1998; Malone et al., 2008; Sarkar et al., 2005, 2008). The base of the coastal marine interval is marked by a transgressive lag and is unconformably overlain by the non-marine interval of the Girbhakar Sandstone Formation (Samanta, 2009; Samanta et al., 2011; Sarkar et al., 2012). The thickness of the coastal marine interval is about 60 m and it is composed of three facies ranging in inferred palaeogeography from deeper neritic to supralittoral (Fig. 1b; Sarkar et al., 2008; Samanta, 2009). The lower facies, characterized by repeated alternations between planar laminae and cross-laminae (facies A), strongly suggests deposition in the upper shoreface (Hill et al., 2003). However towards the top of this facies are preserved some rare remnants of washed out dunes, local bi-modal and bi-polar cross-strata orientations, diverse wave ripple orientations and interference ripples, indicating building up to the lower littoral setting. The middle facies (facies B), is characterized by planar laminae, infrequent wave ripples and rill marks, and indicates deposition in the littoral zone (Sarkar et al., 2008). Occurrence of adhesion laminae, translatent strata, grainfall–grainflow cross-strata of aeolian origin towards the top of this facies indicates a depositional palaeo-environment extending up into the supralittoral zone. The upper facies (facies C) is characterized by cosets of trough cross-strata separated by granular wave-winnowed lags that are stacked vertically in relatively less well

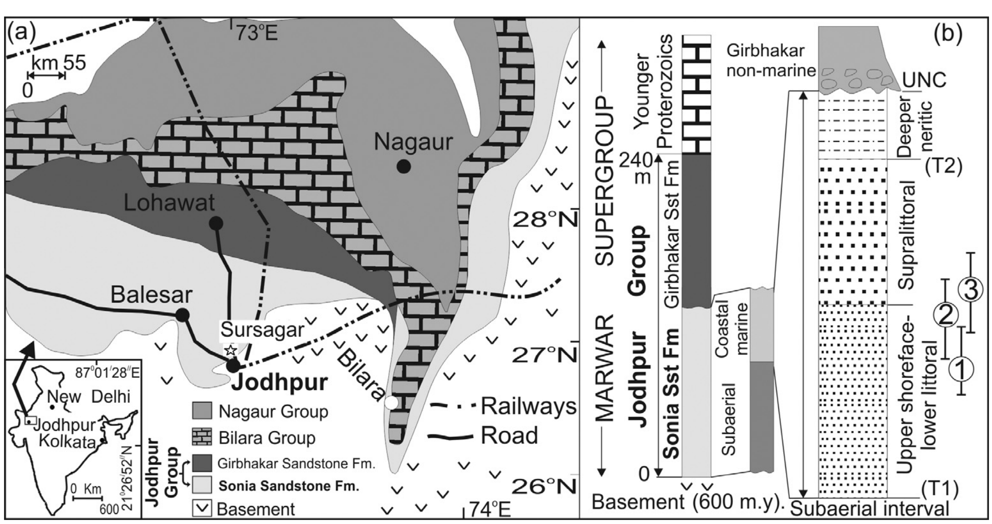

Fig. 1. Geological background of the study area: geological sketch map showing distribution of the Sonia Sandstone and associated younger Ediacaran formations. Asterisk within the map represents the location of the area from where the inferred bioturbations are reported (Fm. = Formation) (a). The relevant stratigraphic column and subdivisions of the Sonia Sandstone Formation are shown on the right. The palaeoenvironmental ranges of the marine segment of the Sonia Sandstone have also been shown. Note that the stratigraphic age of the dated rock (basement) has been mentioned. UNC = unconformity and T = transgressive lag. Also note that the stratigraphic position of bioturbations for the individual type has been shown in the stratigraphic column: (1) burrow with intact roof, (2) trails with spill-over sand and (3) discoidal structures (b). Map of India within inset. Note the rectangular area, surrounding Jodhpur, showing the location of the study area.