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Microbial mat-induced sedimentary structures in the Neoproterozoic Bundi Hill Sandstone, Indargarh area, Rajasthan

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The communication records the development of wrinkle structures and desiccation cracks in the fine-grained Bundi Hill Sandstone belonging to the Neoproterozoic Bhander Group of the Vindhyan Supergroup. The presence of wrinkle structures in the sandstone suggests the role of microbial mats in binding sandy sediments and providing cohesion to the upper surface, which could produce the wrinkle structures and on drying could also produce the mat-related cracks.

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MICROBIAL deposits in the Precambrian carbonates as stromatolites are well known from all over the world since the end of the 18th century[1], but their presence in the siliciclastic rocks has only recently attracted global attention. In spite of the fact that the microorganisms are so abundantly recorded in Precambrian sediments, their presence is difficult to prove in siliciclastic sediments due to early destruction of organic content. When a wide variety of algal-induced sedimentary structures were discovered in modern siliciclastic sediments[2,3], efforts were also made to identify similar structures in the Precambrian siliciclastic sediments. There are several reports of microbial-induced sedimentary structures from the Proterozoic sediments[4–6]. We report here well-preserved wrinkle structures in the Bundi Hill Sandstone of the Neoproterozoic Bhander Group exposed on the southern face of the Indargarh Hill, about 35 km SSW of Sawai Madhopur, Rajasthan (Figures 1 and 2)[7]. Here we report microbial mat structures from the western part of the Vindhyan Basin, though a few reports are already available from the eastern part[8–12]. It is suggested that the wrinkle and associated structures were formed when the sand devoid of mud content was made cohesive by the presence of microbial mats. Even mat-related cracks are also associated with the wrinkle structures.

Wrinkle structures include runzelmarken, Kinneyia ripples, micro-ripples, wrinkle marks and 'elephant skin' structure[13,14]. In general, wrinkle structures are characterized by oddly contorted irregularly wrinkled pustulose, quasi-polygonal, commonly over-steepened surface morphologies that can occur on the top and bottom surfaces of beds. Such wrinkles are produced when strong wind blows over the sediment surfaces that are partly cohesive and are covered by a thin film of water up to 1 cm thick[15]. These structures are produced due to the cohesive nature of the sediments and have purely inorganic genesis. Aseismic soft sediment loading has also been invoked to explain these structures[16]. The basic requirement for the genesis of wrinkle structures is thus the cohesive nature of the sediments, and in noncohesive materials like sand it is not possible to produce this structure. If such structures are preserved in sand, it is obvious that some process was involved which made the sand cohesive. In sand which is devoid of mud, the presence of microbial mat is the only viable explanation for the presence of wrinkle structures in Proterozoic siliciclastic sediments. The microbial mats flourished in Proterozoic because of the absence of predators and other competing organisms.

The Bundi Hill Sandstone is an arenaceous horizon which conformably overlies the Samria Shale and underlies the Sirbu Shale formations of the Bhander Group of the

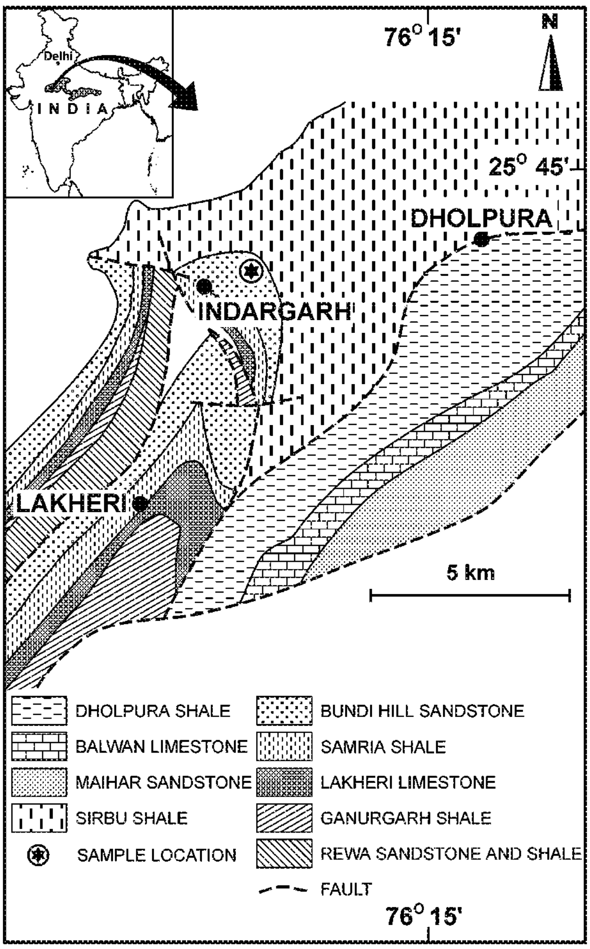

Figure 1. Geological and location map of the Indargarh area, Rajasthan (simplified after Prasad[7]).

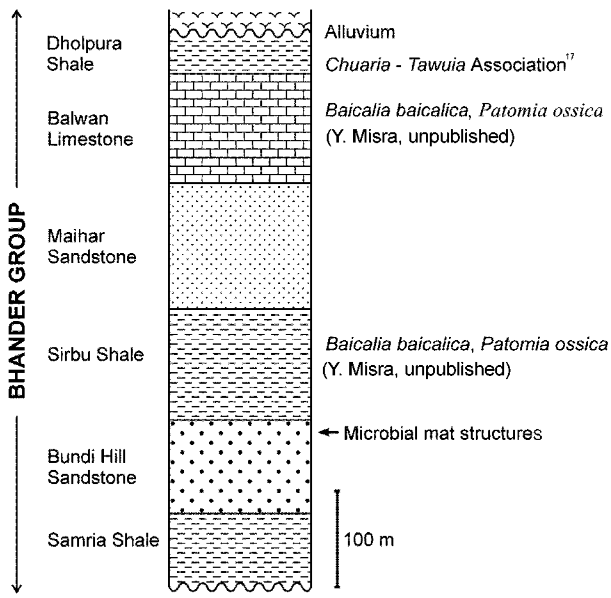

Figure 2. Litholog of the upper part of the Bhander Group showing the position of the wrinkle structures within the Bundi Hill Sandstone, Indargarh area, Rajasthan.

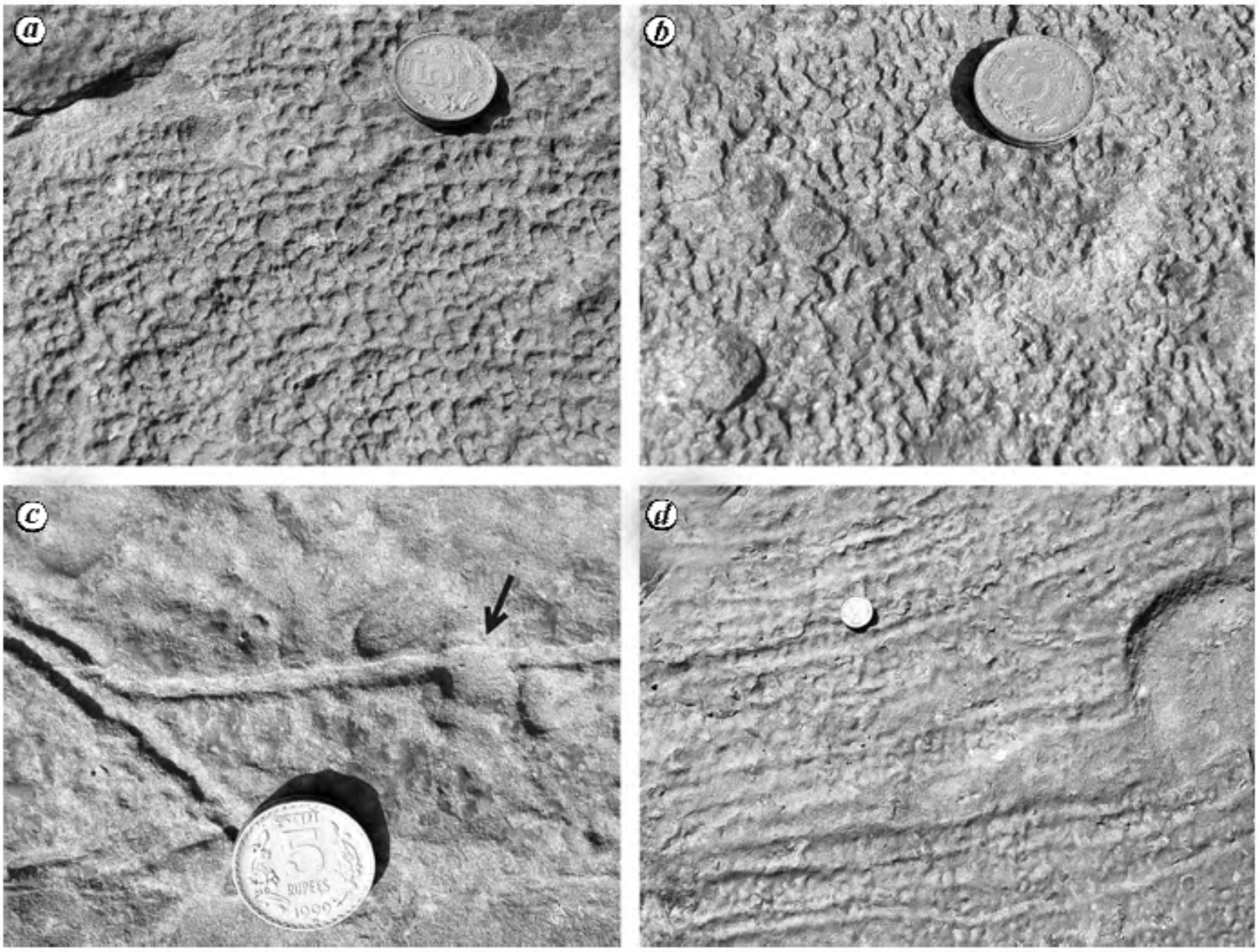

Figure 3. ***a***, Wrinkle structure in fine-gained sandstone. ***b***, Wrinkle structure in fine sandstone. In the top right corner, the crests are flat and can be compared with the Kinneyia ripples. ***c***, Desiccation cracks in sandstone. Cracks are modified by a second generation of microbial mat formation. Arrow marks the area where crack is modified by the formation of second generation of microbial mat. ***d***, Wrinkle structure in the form of parallel ridges. The diameter of the coin is equal to 2.3 cm.

Table 1. Lithostratigraphic succession of the Bhander Group in Bundi-Indargarh area, Rajasthan (after Prasad[7])

	Group	Formation	Lithology
Vindhyan Supergroup		Dholpura Shale	Sandstone and shale
(Upper Vindhyan)		Balwan Limestone	Limestone and shale
		Maihar Sandstone	Sandstone
	Bhander Group	Sirbu Shale	Shale and sandstone
		Bundi Hill Sandstone	Sandstone
		Samria Shale	Shale, siltstone, sandstone and limestone
		Lakheri Limestone	Limestone and shale
		Ganurgarh Shale	Shale and sandstone
	Rewa Group		
	Kaimur Group		

Upper Vindhyans (Table 1, Figure 2)[7]. It is represented by different shades of pale, pink, grey, red, brown to white, fine-to-medium grained, compact and ferruginous sandstone. Generally, it shows massive bedding, parallel bedding, mega cross-bedding and ripple bedding. The age of the Bundi Hill Sandstone can be considered on the basis of its stratigraphic position. The overlying Sirbu Shale shows good development of *Baicalia baicalica* and *Patomia ossica* (Y. Misra, unpublished) and the youngest horizon of the Bhander Group in this area, the Dholpura Shale, shows the presence of *Chuaria–Tawuia* association, suggesting a Precambrian age[17]. The underlying

Balwan Limestone also shows excellent development of *B. baicalica* and *P. ossica* (Y. Misra, unpublished). Though no radiometric age data are available for the Bhander Group, the available $^{87}Sr/^{86}Sr$ ratio data[18] suggest Neoproterozoic age. On this basis a Late Neoproterozoic age can be suggested for the Bundi Hill Sandstone, as no Cambrian fossil has so far been reported from any horizon of the Bhander Group.

In the Indargarh area, Sawai Madhopur district, Rajasthan, the white, grey and light-brown coloured, thickly bedded Bundi Hill Sandstone is exposed on the dip slopes of the Indargarh Hill, about 2 km NE of Indargarh city. Wrinkle structures are recorded on the top of the bedding surfaces of a light brownish, fine-grained sandstone (GPS value 25°43.9′3″N; 76°11.9′25″E). The sandstone is a quartz–arenite with mean grain size of 0.29 mm ($N = 150$). The winkle marks show the morphology of honeycomb structures and occur in patches on the bedding surface. The relative size of the wrinkle marks differs at places or even at the same place perhaps due to difference in the composition of the microbial community. The ridges are flat, rounded or sharp. The slopes of the ridges also vary. The ridges also show parallel disposition which can be traced to tens of centimetres and are 0.5–3 cm apart. These are more or less straight to slightly curved. Troughs are concave and also show presence of smaller crests. At places, the wrinkle structures are present along with the desiccation cracks. Cracks are more or less straight. It appears that the cracks were formed due to drying of the microbial mat which developed over the sandy top. A second generation of algal mat formation has modified the cracks. At one place the ridges show flat surface and can be compared with the Kinneyia ripples whose origin has also been explained by the presence of algal mats[19]. Microbial mats in the siliciclastic sediments are abundantly recorded in the modern supratidal flats in Redfish Bay, Texas[13].

The Vindhyan sandstones and shales appear to be a good repository of microbial mat structures, as these have now been reported from both Lower and Upper Vindhyans[8–12]. This highlights the importance of microbial mats during the Vindhyan sedimentation. It has been noted that the stromatolite assemblages, which also represent microbial mats, are distinctly different in the Lower and Upper Vindhyan carbonates (Y. Misra, unpublished). There is a possibility that the microbial communities in both Lower and Upper Vindhyan siliciclastic sediments might have produced different morphologies which may also help in correlation. This may open a new window for understanding the interaction of biogenic processes and sediments. Detailed work is in progress.

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