7(d). Mat-related features from sandstones of the Vindhyan Supergroup in central India

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This section addresses mat-related features in sandstone in the Palaeoproterozoic-Neoproterozoic Vindhyan Supergroup in central India (Fig. 7(d)-1A, -1B) focusing upon the extraordinarily rich assemblages located within the 1.6 Ga Chorhat Sandstone (Rasmussen et al., 2002; Ray et al., 2002) and the 0.6 Ga Sirbu Shale (Ray et al., 2002). Both formations largely originated on prograding wave-dominated open shelves (Banerjee, 1997; Seilacher et al., 1998; Sarkar et al., 2002, 2005), that emerged eventually in the case of the Chorhat Sandstone and which remained permanently submerged for the Sirbu Shale. Since the relevant features in the Chorhat Sandstone are on the tops of sandstone beds or at interfaces between amalgamated ones and many of them have already been cited in Chapter 4, the present discussion dwells exclusively on those features not presented before or which have some new characteristic or appendage (Fig. 7(d)-2). Greater attention is paid to the features in the Sirbu Shale that are impressions of mat fragments preserved on the soles of storm-laid sandstone beds, and found only towards the base of the thickest shelf section where the strata are muddiest (Bose et al., 2001; Sarkar et al., 2002; Fig. 7(d)-3, -4, -5). The mud interbeds are generally thick, planar laminated but locally massive, while the sandstone beds are thin and massive or laminated, but more often wave-rippled at their tops. Presumably the mat fragments were swept down from the shallower shelf and redeposited in the deeper shelf where wave action was very limited (Bose et al., 2001; Sarkar et al., 2002). It is apparent that microbial mats have a better chance of preserving their primary biogenic features if they get buried rapidly. In the case of the Sirbu Shale microbial sole structures are concentrated locally.

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Figures

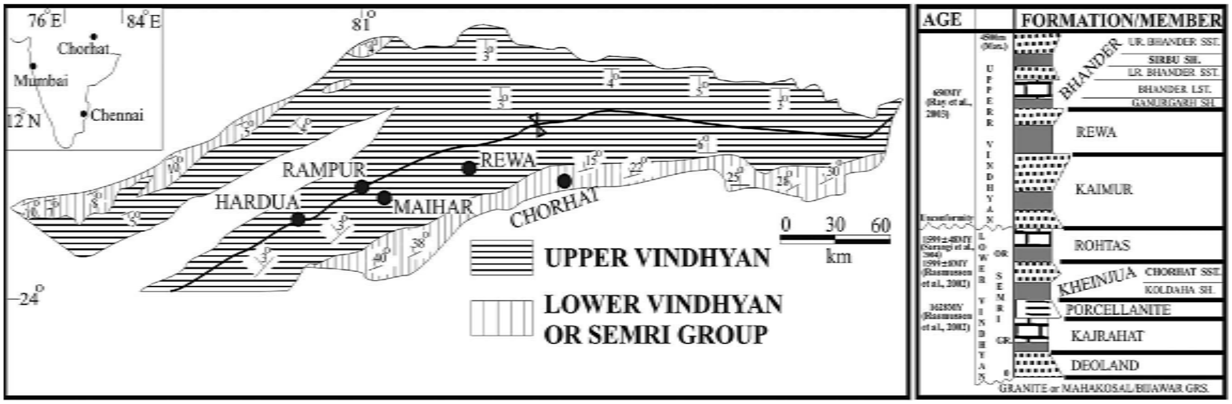

Figure 7(d)-1: Geological map and stratigraphy of the Vindhyan Supergroup.
Geological map of the Vindhyan syncline, showing its lower and upper (in black) divisions, with detailed stratigraphic subdivision of the Vindhyan Supergroup shown on the right.

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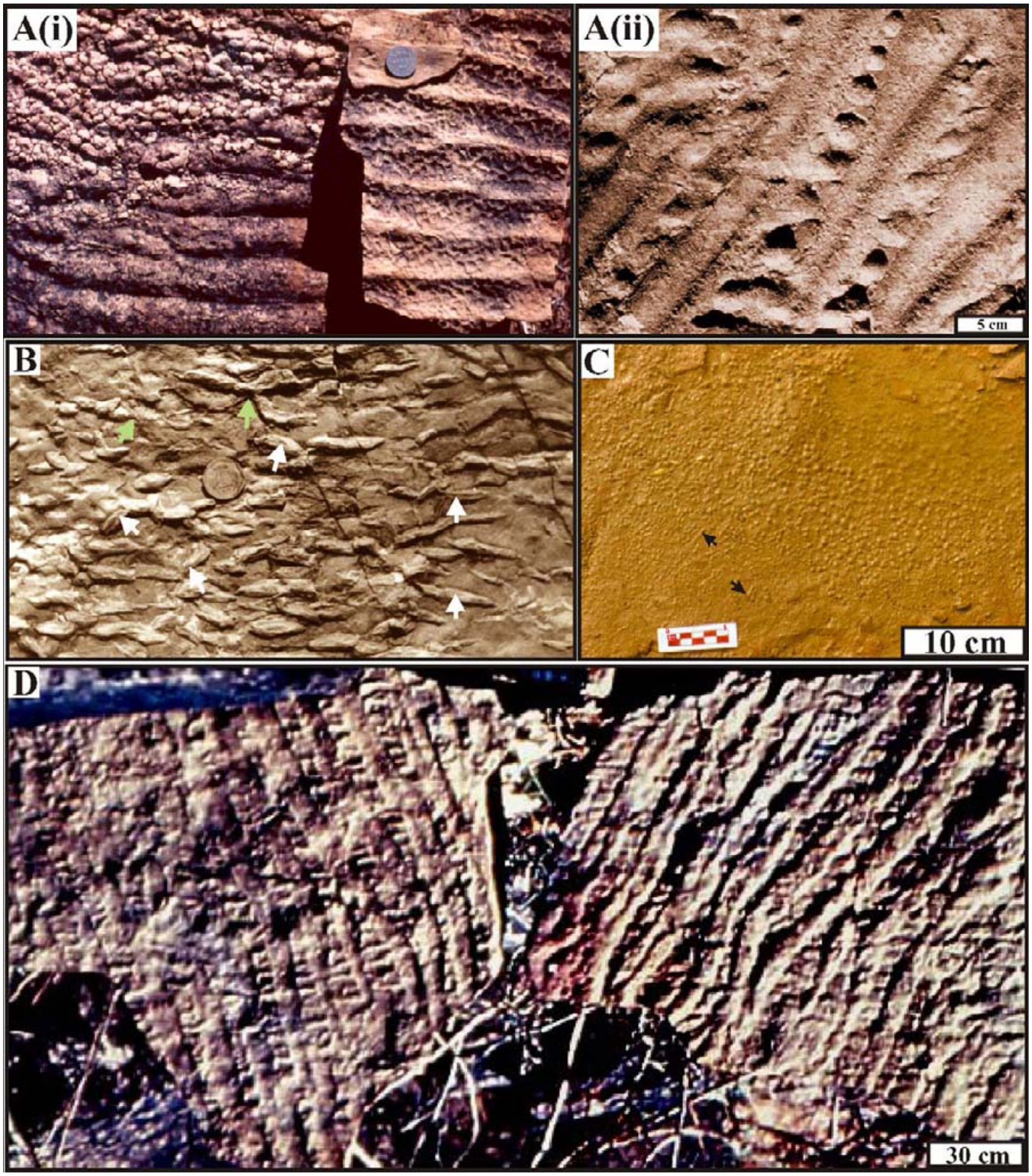

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Figure 7(d)-2: Features in the Chorhat Sandstone (coin for scale is 2.6 cm in diameter).
(A) Load balls and their casts. (i) Steep-flanked load balls at the sole of a rippled sandstone bed, clustered so closely together that they almost touch each other (left block, upper part) and casts of similar load balls separated by very thin boundaries, on top of another rippled sandstone bed (right block). A thin sandstone bed still adhering to the top of the latter bears at its sole the load balls that would correspond to these load casts. The load casts are distributed nearly uniformly over the ripple crests and troughs. However, as noted in the left block, loading in a bed may be localised, with the size of load balls decreasing downward from a cluster above. No mud is present at the bed interface, not even within the depressions. Liquefaction of sand in response to rapid settling of another mass of similar sand is inferred. Growth of a gelatinous microbial mat presumably made the sand that had already settled thixotropic. Lateral size variation of the load balls depended possibly on thickness variation in the mat. A palimpsest ripple (just above the coin on the right-hand block) replicated from the underlying bed is further evidence of mat growth at the bed interface. Light in this photo is from the top. (ii) Load casts (bowl-like depressions) here occur only along ripple troughs (light in photo is from top left). Such a preferred occurrence is expected because of preferred growth of mats within ripple troughs. The structures in this figure are documented from the immediate outskirts of the town of Chorhat, central India. Associated Structures: thin, often less than a centimetre thick sandstone beds, internally massive, but wave rippled at their tops and frequently amalgamated. Palaeoenvironment: outer shelf near the storm wave base. (B) Spindle-shaped ridges with a median furrow. Numerous spindle-shaped ridges with local cross-cutting relationships (black arrows) that support their synaeresis origin: note median furrows within many of the spindles (white arrows). Although it is likely that cracks were modified into these ridges, their characteristic median furrows relate them preferably to synaeresis rather than desiccation; their cross-cutting relationships corroborate this.
The following sequence of events can perhaps explain the genesis
of these features best: (i) a surface layer of a buried sand bed, made cohesive with mat growth, cracked and sand derived from the overlying bed filled the cracks; (ii) sediment flowage from the sides under ever increasing confining pressure tended to close the cracks on top of the crack-fill; (iii) in the process, the two sides of the latter curled up and approached each other creating a median furrow between them; (iv) partial exhumation later presented the now-modified crack-fills as spindles raised above the bed surface. The structure is documented at the western outskirts of the town of Chorhat. Associated structures: thick (often more than 10 cm) sandstone beds with massive bases, followed upwards by planar and quasi-parallel stratification and wave ripples at the top; with carved tool marks at bed soles, frequently amalgamated. Palaeoenvironment: inner shelf. (C) Sand bulges with setulfs attached. Small sand bulges in a cluster decrease gradually in diameter from 0.1 to <0.3 cm towards the left bottom of the figure. While the larger bulges are circular in plan, the smaller ones have minute setulfs (Friedman and Sanders, 1974) elongated both ways along a preferred alignment (steeper ends arrowed). The 'tail'-like setulfs are likely to have formed through limited reworking of sand bulges by waves propagating to-andfro, and not because of accretion of wind (unidirectional)-deflated sand on the lee of the bulges, otherwise the larger bulges would have served better as current obstacles. Larger bulges were apparently not reworked. This fact suggests that the latter formed where the mat grew thicker, while thinner mat covers on smaller bulges were subsequently easily modified by waves. Location: on the roadside 4 km west of the town of Chorhat. Associated structures: thicker sandstone beds with occasional partings of thin, centimetre-thick laterally impersistent reddish silty mudstone. The bases of the beds are often enriched in oxidised mudclasts and are massive. Planar laminae, centimetres-thick cross-laminae and wave ripples follow upwards from the massive base. Wave ripples are often interfering or superimposed. Parting lineations and rill marks are preserved locally. Palaeoenvironment: intertidal zone. (D) Preservation of delicate ripples. Multiple sets of delicate wave ripples (right block) and their casts (left block) are found preserved upon prising open an interface between two essentially similar amalgamated storm sandstone beds, which are generally massive internally. Ripples in one of the sets have an amplitude of only about a millimetre, yet they too are spectacularly preserved and perfectly mirrored at the sole of the bed overlying them. Abundant sand fall-out on the ripples from a subsequent storm-induced highly turbulent flow is implied. In the total absence of mud even within the ripple troughs, it is difficult to infer any means other than the influence of a microbial mat, to conserve delicate structures like these, including the minute ripples, despite storm onslaught. Associated structures: thin amalgamated sandstone beds (centimetre-scale), internally massive at the base followed upwards by planar laminae at places, but almost always wave-rippled at the top. Soles of the beds often bear tool marks. Palaeoenvironment: between fair-weather and storm wave-base; location: three kilometres southwest of Chorhat. All photographs by Subir Sarkar, Santanu Banerjee and Pradip K. Bose.

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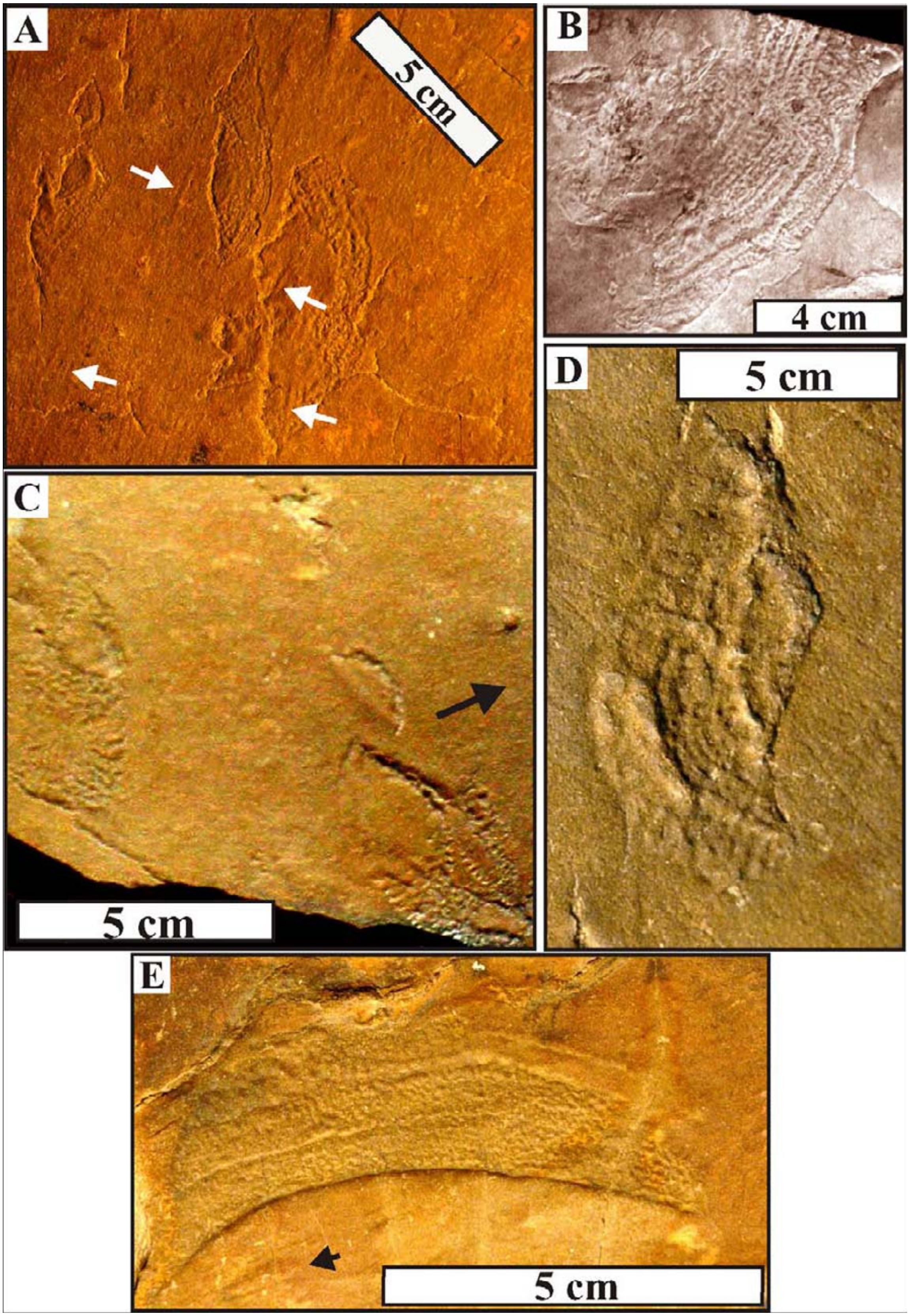

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Figure 7(d)-3: Impressions of mat fragments (possibly originally circular or elliptical in form) with smooth curved margins, at sandstone bed-soles in the Sirbu Shale (arrows point to prod marks, or their directions). (A) Impressions of four discrete, elongated, lenticular objects of broadly similar nature, but of different sizes, all aligned roughly parallel to the prod marks, and thus explicitly swept by currents during their genesis. One of their boundaries is invariably smooth and curved, and the other definitely jagged. Within them, two sets of fine ridges are in orthogonal relation (better preserved in the larger two examples at the centre). One of the sets runs parallel to the curved boundary that seems intact, but gradually becomes fainter away from this. Ridges of the other set are straight and seem to radiate from an unseen centre to meet the curved ridges almost at right angles. From their curved geometry in one set and radiating arrangement in the other, the ridges cannot be current-generated and none of them are parallel to the prod marks either. The internal structure of the objects thus appears biogenic. Prod marks clearly visible on the surrounding sediment as well as on the larger impression (white arrows) indicate that the objects whose impressions are preserved were thin, sheet-like and soft enough, possibly gelatinous, to yield under impact of particles impinging upon them. The objects thus appear to be pieces torn from the fringes of microbial mats, probably of disc-like shape. Associated structures: sandstone beds, around a centimetre-thick, and with sheet-like geometry, alternate with thicker shale beds. The sandstone beds are either massive or partly ripple cross-laminated, but bear tool marks on their bases and wave ripples on their tops. Shale beds are generally planar laminated. Palaeoenvironment: mid–outer shelf transition; locality: ca. 10 km south of Uchaihra, and from the basal segment of the Sirbu Shale shelf succession. (B) Impression of a discrete lenticular fragment that has one margin (right) which is smooth, curved and also a bit undulating, apparently deformed, and with the other margin being highly irregular and jagged. Thin and close-spaced ridges run roughly parallel to its seemingly uninterrupted, but slightly folded right margin and the other set of fainter ridges runs across them at a high angle. Because they grow increasingly small and less distinct away from the right margin and replicate folding of the same margin, the first set of ridges may not be intrinsic to the parent object, but may be folds (wrinkles) created by gentle wave action. It is imperative then that the parent object had been thin, sheath-like and soft. However, this argument does not eliminate the possibility that these ridges are biogenic. In that case inward blurring of the ridges can perhaps best be attributed to an increasing amount of newer mat overgrowth towards the inner or, in other words, older part of the microbial colony, of possible discoid shape. The other set of minute ridges at high angle to the presumed primary margin on the right, is also equivocal in its current-derived or possible biotic origin. Associated structures: as for A, but shale beds are often partly massive. Palaeoenvironment: outer shelf; locality: as for A. (C) Two elongated leafshaped impressions (at the left- and right-bottom; the latter is better preserved); within them close-spaced ridges in two sets cut across each other. One of the sets comprises straight parallel ridges running perpendicular to the median axes of the 'leaves'. Ridges of the other set are comparatively wider and not so precisely mutually parallel, although they are roughly parallel to the median 'leaf'-axis. They are at a high angle to the prod mark orientation (arrow), and thus are either primary, or in other words biogenic, or were created by contraction of a thin sheet-like object because of flow shear across its margin. Ridges of the first set, on the other hand, being more or less parallel to the prod marks, may indeed be current markings. If they are current markings, their distinct prominence confined within the impressions would suggest that the parent material had been very thin and soft, like gelatinous microbial mats, readily amenable to marking. Associated structures: as for B. Palaeoenvironment: outer shelf; locality: as for A. (D) Impression of a discrete lenticular fragment with a smooth left margin, which is curved without any marked undulation; in contrast, the right margin is bevelled, angular and a bit irregular. It bears prominent ridges (positive on the bed-sole) that conform to the seemingly intact left margin, and another set of finer straight and radiating ridges cuts across them. The intact margin of the object and also the ridges parallel to it, unlike their counterparts in Figure 7(d)-3C, are so regular in form that they seem to be primary, presumably biogenic, and not generated by secondary wave action. The ridges radiating from an unseen centre and maintaining an orthogonal relationship with the left margin are, on the other hand, almost certainly biogenic. Their possible origin through current action can be readily discarded, firstly on the basis of their radiating arrangement and then for the high angle they generally make with the mutually parallel current-generated ridges present outside the object. Associated structures: as in B. Palaeoenvironment: outer shelf; locality: as for A. (E) A discrete, elongated, parallel-sided and smoothly curved impression of an object that looks like the swerving track of a tyre. Two prominent, but partially preserved ridges (positive on the bed-sole), running parallel to the curved margins, divide the band-like form into three longitudinal segments. Numerous finer ridges, mutually parallel, run at a high angle to these ridges. None of the ridge-sets is parallel to the prod mark orientation (arrow) and they cannot therefore be current marks, and are very likely biogenic in origin. Associated structures: as for A. Palaeoenvironment: mid–outer shelf transition; locality: as for A. All photographs were taken by Subir Sarkar, Snehasis Chakraborty, Santanu Banerjee and Pradip Bose.

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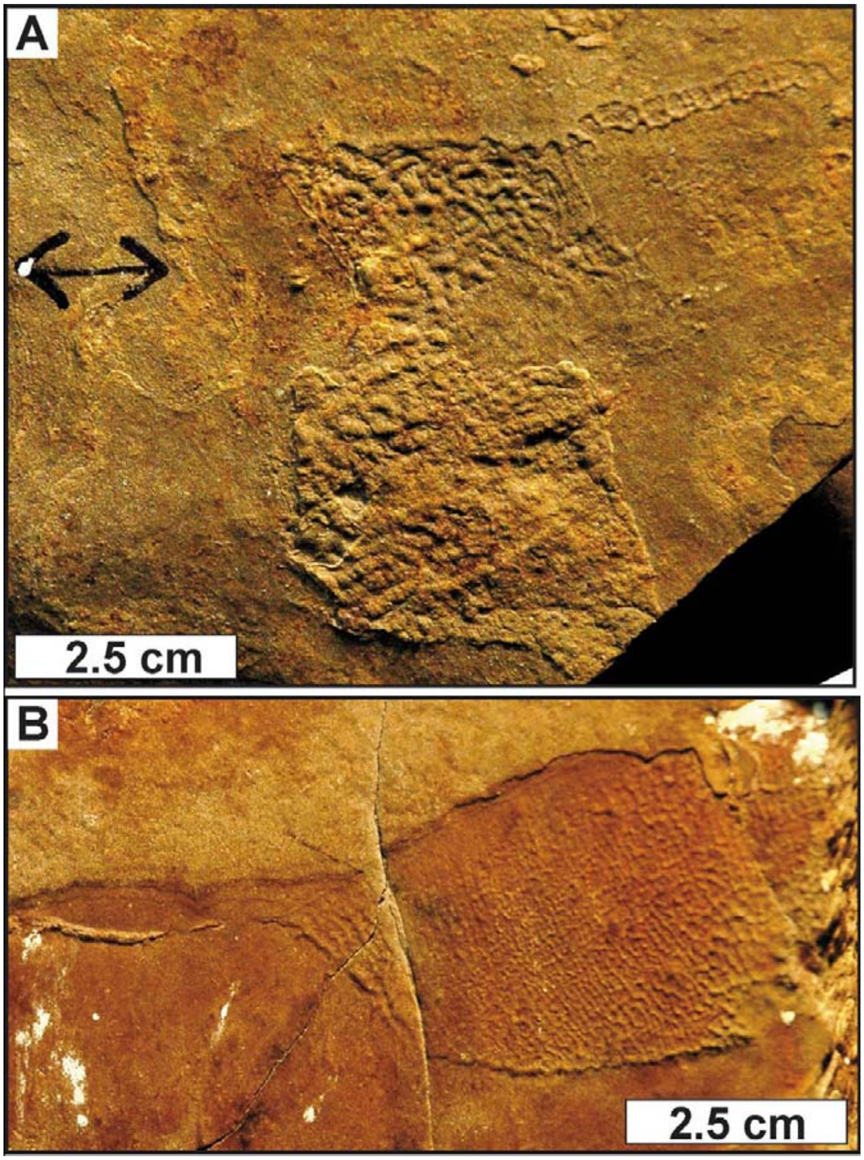

Figure 7(d)-4: Impressions of mat fragments bearing two sets of straight ridges at a high angle to each other, at sandstone bed-soles, in the Sirbu Shale.
(A) Impression of a roughly rectangular object with a narrow, long extension attached at one end, bears two sets of ridges at high angles to each other, continuing into the extension. The ridges of the comparatively more prominent set are roughly parallel to the general prod mark orientation as indicated by the bidirectional arrow and thus may be current-generated grooves now seen in reverse. The first set almost certainly does not have any relation to current or wave action and is inferred to be biogenic. The feature, being present on the sole of a bed, is illustrated on a fragment of a rock slab pulled out from under a pile of beds. Associated structures: as for Figure 7(d)-3A. Palaeoenvironment: mid-shelf; locality: ca. 10 km south of Uchaihra, and from the basal segment of the Sirbu Shale shelf succession. (B) A roughly circular impression, with discrete, sharp boundary, bears two sets of fine, well-defined closely spaced ridges subtending an acute angle between themselves, unlike the ridge-pairs in the previous case, A. Sand grains impinging upon the object might have created one of the sets, but then the other set is almost certainly biogenic. Preservation of grain impingement structures would mean that the object had been thin, sheet-like and soft, non-elastic. Associated structures: as for Figure 7(d)-3A. Palaeoenvironment: mid-shelf; locality: as for A. All photographs were taken by Subir Sarkar, Snehasis Chakraborty, Santanu Banerjee and Pradip Bose.

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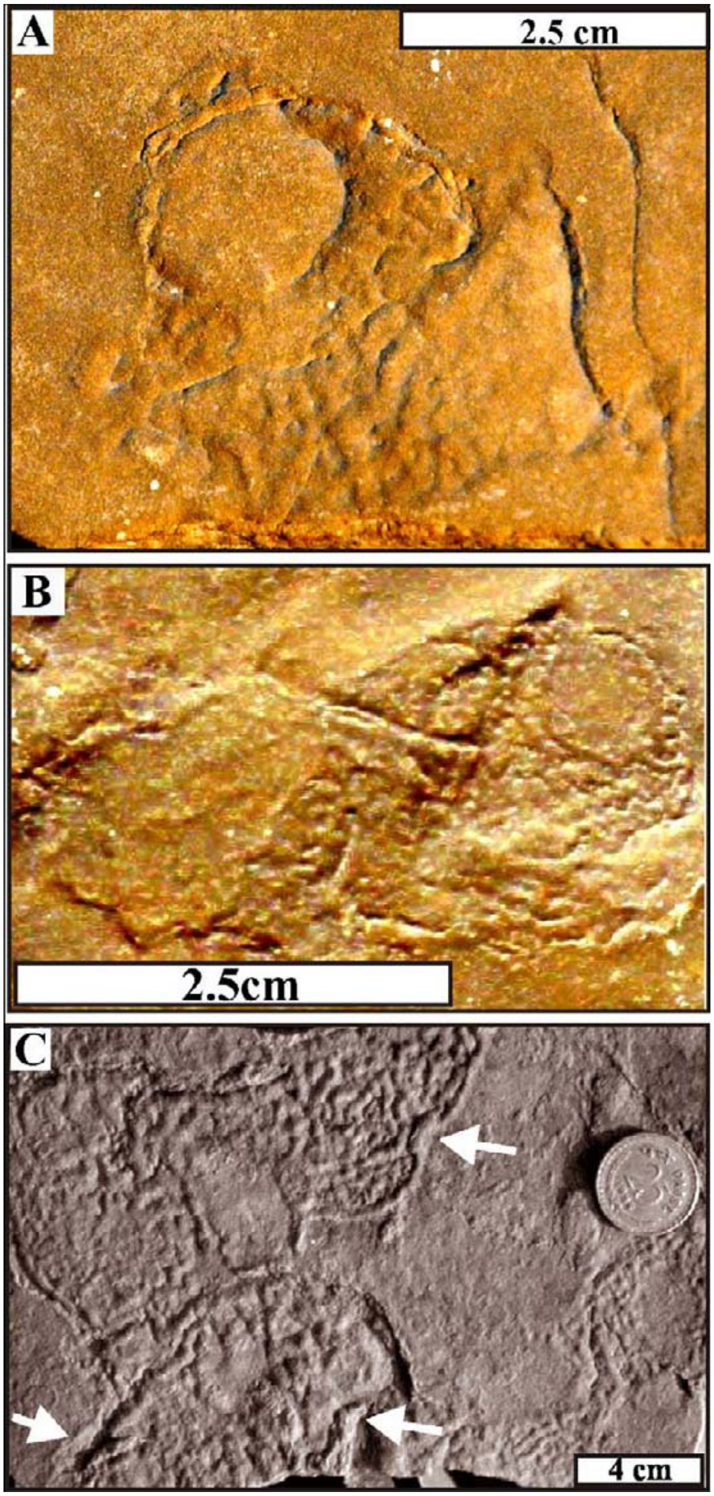

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Figure 7(d)-5: Impression of wrinkled (microbial) mass.
(A) Impression of an object that included a nearly circular structureless part, of diameter about 2.0 cm, delimited by a thin raised rim, now seen in reverse as a hair-thin furrow. Immediately outside this object, a textured area suggests the presence of a frill of maximum width about 1.2 cm attached to the central disc. The frill bears two sets of irregular wrinkles cutting across each other at an acute angle, and is preserved on one side of the rim. Lateral continuity of the wrinkles suggests wave action (cf. Hagadorn and Bottjer, 1997; Bougouri and Porada, 2002) rather than gas expulsion (Pflüger, 1999) or burial diagenesis (Noffke et al., 2003a) for their origin. The rimmed, circular, structureless part suggests the presence of some kind of substrate attachment mechanism. Associated structures: as for Figure 7(d)-3B. Palaeoenvironment: mid-shelf–outer shelf transition; locality: as for C. (B) Impression of a wrinkled mass with a circular structureless part with a diameter of ca. 2.0 cm (top right). The rim defining the circular part is wider and segmented, unlike that in the immediately preceding figure. The wrinkled frill around the rim reveals, on close examination, two sets of crinkled ridges at high angles to each other. As suggested in the previous case the circular part likely represents some kind of attachment mechanism, but a wider knobby collar apparently strengthened this. Associated structures: as for Figure 7(d)-3B. Palaeoenvironment: mid-shelf–outer shelf transition; locality: as for C. (C) The impression is in highly irregular patches interconnected by narrow ‘bridges’, while the patch boundaries are well defined. Thickening of the margin of these patches at places (arrows) suggests a tendency for ‘flipping-over’ of a sheet-like mat. The patches bear wrinkles in two nearly orthogonal sets, not as regular as in the preceding figures. These irregular wrinkles may be a mirror-image of a myriad of mutually overlapping gas expulsion pits, or of pits created by impinging particles or, more likely, minor folding generated by gentle wave action (Banerjee and Jeevankumar, 2005). The appearance of the interconnected patches suggests a gelatinous nature for the mat, portions of which were torn away by currents or waves. Associated structures: shale interspersed with laterally impersistent siltstone beds which are either massive or faintly normally graded, bearing minute tool marks at their bases and minute ripples at their tops. Shale beds are planar laminated or massive. Palaeoenvironment: outer shelf, near the storm wave base. The inferred mat fragments were found in deeper shelf facies where fair-weather waves either could not reach or touched the sea-bottom only marginally. However, the inferred mats must have colonised the upper reaches of the shelf. Locality: ca. 10 km south of Uchaihra, and from the basal segment of the Sirbu Shale shelf succession. All photographs taken by Subir Sarkar, Snehasis Chakraborty, Santanu Banerjee and Pradip Bose.

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References

Anketell, J.M., Cegla, J., Dzulynski, S., 1970. On the deformational structures in systems with reversed density gradients. Rocznik Polskiego Towarzystwa Geologicznego 40, 3-30. (not cited in text).

Banerjee, S., 1997. Facets of Mesoproterozoic Semri sedimentation, Son valley, M.P. Ph.D. Thesis, Jadavpur University, Kolkata, India.

Banerjee, S., Jeevankumar, S., 2005. Microbially originated wrinkle structures on sandstone and their stratigraphic context: Paleoproterozoic Koldaha Shale, central India. Sediment. Geol. 176: 211-224.

Bose, P.K., Sarkar, S., Chakraborty, Banerjee, S., 2001. Overview of the Meso- to Neoproterozoic evolution of the Vindhyan basin, central India (1.4-0.55 Ga). Sediment. Geol. 141/142: 395-419.

Bouougri, E., Porada, H., 2002. Mat-related sedimentary structures in Neoproterozoic peritidal passive margin deposits of the West African craton (Anti-Atlas, Morocco). Sediment. Geol. 153: 85-106.

Chakraborty, S., 2002. Sedimentation sequence of the three youngest Members of the Vindhyan Supergroup, Central India. Unpublished Ph.D. thesis, Jadavpur University, Kolkata, 150 pp.

Fedonkin, M.A., 1990. Systematic description of Vendian Metazoa. In: Sokolov, B.S., Iwanowski, A.B. (Eds.), The Vendian system: Paleontology, vol. 1. Springer-Verlag, Berlin, pp.71-120.

Hagadorn, J.W., Bottjer, D.J., 1997. Wrinkle structures: Microbially mediated sedimentary structures common in subtidal siliciclastic settings at the Proterozoic-Phanerozoic transition. Geology 25, 1047-1050.

Noffke, N., Gerdes, G., Klenke, T., Krumbein, W.E., 2001. Microbially induced sedimentary structures - a new category within the classification of primary sedimentary structures. J. Sediment. Res. A71: 649-656.

Noffke, N., Hazen, R., Nhleko, N., 2003. Earth’s earliest microbial mats in a siliciclastic marine environment (2.9 Ga Mozaan Group, South Africa). Geology 31: 673-676.

Parizot, M., Eriksson, P.G., Aifa, T., Sarkar, S., Banerjee, S., Catuneanu, O., Altermann, W., Bumby, A.J., Bordy, E. M., Louis van Rooy, J., Boshoff, A. J., 2005. Microbial mat-related crack-like sedimentary structures in the c. 2.1 Ga Magaliesberg Formation sandstones, South Africa. Precambrian Res.138: 274-296.

Pflüger, F., 1999. Matground Structures and Redox Facies. Palaios 14: 25-39.

Rasmussen, B., Bose, P.K., Sarkar, S., Banerjee, S., Fletcher, I.R., Mc Naughton, N.J., 2002. 1.6 Ga U-Pb zircon ages for the Chorhat Sandstone, Lower Vindhyan, India: possible implication for early evolution of animals. Geology 30: 103-106.

Ray, J.S., Martin, M.W., Veizer, J., 2002. U-Pb zircon dating and Sr isotope systematics of the Vindhyan Supergroup, India. Geology 30: 131-134.

Seilacher, A., 1999. Bio mat-related lifestyles in the Precambrian. Palaios 14: 86-93.

Seilacher, A., Bose, P.K., Pfluger, F., 1998. Triploblastic animals more than 1 billion years ago: trace fossil evidence from India. Science 282: 80-83.

Sarkar, S., Banerjee, S., Samanta, P., Jeevankumar, S., 2006. Microbial mat-induced sedimentary structures in siliciclastic sediments: examples from the 1.6 Ga Chorhat Sandstone, Vindhyan Supergroup, M.P., India. J. Earth Sys. Sci.115: 49-60.

Sarkar, S., Chakraborty, S., Banerjee, S., Bose, P.K., 2002. Facies sequence and occult imprint of sag tectonics in Sirbu Shale. In: Altermann, W., Corcoran, P.L. (Eds.), Precambrian Sedimentary Environments: a Modern Approach to Ancient Depositional Systems. Special Publications of International Association of Sedimentologists 33, Blackwell, Oxford, pp. 369-381.