7(e). Benthic microbial mats in black shale units from the Vindhyan Supergroup, Middle Proterozoic of India: the challenges of recognizing the genuine article

J. Schieber, S. Sur and S. Banerjee

The Palaeoproterozoic to Neoproterozoic sediments of the Vindhyan Supergroup (Fig. 7(e)-1) were deposited in a westward opening shallow epeiric sea (Bose et al., 2001). Its shallow marine siliciclastics and carbonates measure up to 4500 m in thickness, and are interpreted to have been deposited in an intracratonic rift basin that in later stages transformed into an intracratonic sag (Bose et al., 1997, 2001). A basin-wide unconformity subdivides the Vindhyan Supergroup into the carbonate-dominated lower Vindhyan (also known as the Semri Group) and the siliciclastic-dominated upper Vindhyan (Fig. 7(e)-1). Recent radiometric age determinations indicate that the Vindhyan Supergroup spans an age range from 1.75 Ga to 0.6 Ga (Ray et al., 2002, 2006; Rasmussen et al., 2002).

Minor deformation and only slight metamorphism of the Vindhyan have resulted in superb preservation of delicate sedimentary features, and microbially produced sedimentary features have been reported from both siliciclastics and carbonates (Sarkar et al., 1996; Banerjee, 1997; Chakraborty, 2004; Banerjee and Jeevankumar, 2005; Sur et al., 2006). Organic-rich shales (TOC > 1%) occur at three stratigraphic horizons, in the Kajrahat Formation, the Rampur Shale, and the Bijaigarh Shale (Fig. 7(e)-2). The oldest black shale, in the lower part of the Kajrahat Formation, is up to 12.5 m thick, and the Rampur Shale at the mid-level of the Vindhyan Supergroup occurs at the base of the Rohtas Limestone and is up to 55 m thick. In both of these black shales, carbonate beds alternate with shale intervals. The youngest black shale unit, the Bijaigarh Shale, is up to 70 m thick and occurs sandwiched between the Lower and Upper Kaimur sandstone (Fig. 7(e)-2). Prior petrographic studies found microbial mat related features within these black shales (Sur et al., 2006). Shales examined for this study occur in the area between Amjhore and Chopan in the eastern part of the Son valley (Fig. 7(e)-1).

Kajrahat Formation black shale

Of the three shale units, the black shale interval in the Kajrahat Formation (Fig. 7(e)-2) probably has the most compelling indications of microbial mat formation at the sediment surface. Features like thin carbonaceous fragments that apparently have been contorted, folded, and rolled up during transport (Fig. 7(e)-3A) point to the presence of cohesive carbonaceous films. This cohesive nature is not the likely behaviour of a simple settled mixture of clays and small organic particles, but is consistent with microbial surface binding. The lamina style itself (Fig. 7(e)-3B, -3D, and -3E) bears strong resemblance to wavy-crinkly laminae observed in other occurrences of Proterozoic carbonaceous shales that have been studied in some depth for microbial mat features (e.g., Schieber, 1986). The basal contacts of some of the black shale beds with underlying gray shales show inclined carbonaceous laminae and clay drapes suggestive of false cross-lamination (Fig. 7(e)-3C), produced when the lateral expansion of a mat through time is intermittently interrupted by pulses of sediment (see Chapter 5). In addition, some samples of the Kajrahat Formation black shale show even parallel laminae that reflect physical sedimentation, such as settling and current reworking. Thus, microbial mat colonization appears to have been

In: *Atlas of microbial mat features preserved within the clastic rock record,* Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., and Catuneau, O., (Eds.), Elsevier, p. 189-197. (2007)

intermittent and/or spatially limited and prone to interruption when sedimentation rates were too high or sedimentation pulses persisted for longer time periods.

Rampur Shale

The Rampur Shale contains abundant evidence of intermittent erosion of unconsolidated muds. Many thin sections show a wavy lenticular fabric that on first glance closely resembles microbial mat laminated carbonaceous shales from the Belt Basin (e.g., Schieber, 1986). However, what initially appears as wavy clay drapes that separate carbonaceous silty laminae (Fig. 7(e)-4A) looks upon closer inspection like stacked up clay-rich fragments that were soft when deposited and were squeezed together when compacted. This impression is reinforced when a cut parallel to lamination is made. If a laminated shale is cut parallel to bedding, multiple laminae are intercepted because of slight irregularities and when ground this surface shows a pattern that resembles the isolines of a topographic map. In contrast, when wavy lenticular laminated Rampur Shale specimens are ground parallel to lamination we see a surface that is strewn with shale particles (Fig. 7(e)-4B). At higher magnification one sees that the shale does indeed consist of discrete shale particles and that these fragments are compacted and deformed (Fig. 7(e)-4C). In plan view the irregular shaped shale particles are clearly visible at higher magnification (Fig. 7(e)-4D).

Other samples show layers of gray shale with irregular carbonaceous fragments that are up to 10 millimeters in size (Fig. 7(e)-5B). In thin section these fragments are quite thin (0.1-0.2 mm; Fig. 7(e)-5A) and may show deformation and folded over portions. This mechanical behaviour suggests a within-fragment cohesiveness that one should not expect if this material originated as a simple mixture of clays, silt, and organic matter. Such behaviour is, however, consistent with binding by microbial surface films. Intervals of the Rampur Shale that contain these fragments also show wavy anastomosing carbonaceous laminae interspersed with clay drapes (Fig. 7(e)-5C, -5D, -5E, -5F). In close-upview these bear striking resemblance (Fig. 7(e)-5D) to the lamina pattern in other examples of Proterozoic carbonaceous shales of microbial mat origin (Schieber, 1999).

In the Rampur Shale indications of surface binding by microbial mats appear to be less abundant than in the Kajrahat Formation black shale interval. The abundance of Rampur shales that consist of compacted shale fragments suggests an overall more energetic environment when compared to black shales in the Kajrahat Formation.

Bijaigarh Shale

Features that suggest microbial mat colonization in the Bijaigarh Shale are typically found in its upper third (Sur, 2004). One shale type (or facies) shows the same lenticular lamination as described from the Rampur Shale above. It shows discrete flattened shale particles (Fig. 7(e)-6A) in cuts perpendicular to bedding, and fragment strewn surfaces in cuts parallel to bedding (Fig. 7(e)-6B). Just like in the Rampur Shale, these features are interpreted to indicate erosion of a mud substrate by strong currents. The majority of thin sections from the upper third of the Bijaigarh Shale, however, show features that closely resemble those observed in microbial mat laminated Proterozoic black shales from elsewhere (Schieber, 1999). Many thin sections are either entirely characterized by wavy crinkly anastomosing carbonaceous laminae that alternate with clay drapes of variable thickness and continuity (Fig. 7(e)-6D), or show carbonaceous layers of this type interspersed with beds of non-laminated shale (Fig. 7(e)-6C). These shale beds are texturally comparable to microbial mat-produced Proterozoic black shales described by Schieber (1986, 1999). Petrographic observations by Sur (2004) and Sur et al. (2006) indicate the presence of cohesive carbonaceous surface films, suggesting microbial mat binding of the mud surface.

Reflected light and SEM studies of polished sections of Bijaigarh Shale from the upper third of the unit also show that fine crystalline early diagenetic pyrite is largely confined to carbonaceous laminae and displays a wavy anastomosing texture as well (Fig. 7(e)-6E, -6F). This has also been observed in the pyritic facies of microbial mat shales from the Middle Proterozoic Belt Basin (Schieber, 1989; and Chapter 7(b)). This facies of the Bijaigarh Shale also contains abundant clusters of phosphatic spheres (Fig. 7(e)-6G) that seem to fill in and accrete around original spherical structures of a few microns diameter. In places multiple spheres are encased in a single phosphatic overgrowth (Fig. 7(e)-6H). These phosphatic spheres resemble phosphate precipitation on bacterial cell walls from the Neoproterozoic of China (Xiao and Knoll, 1999), and may be the remains of coccoid bacterial clumps. Whether they were part of a mat forming community is an unresolved question.

In the lower two thirds of the Bijaigarh Shale, wavy anastomosing laminated carbonaceous shales (Fig. 7(e)-6C, -6D) seem absent. This portion of the succession is instead dominated by massive to evenly laminated carbonaceous shales (Fig. 7(e)-6I) that closely resemble their physically deposited Phanerozoic counterparts (see Chapter 5, Fig. 5-1).

Conclusion

That microbial mats can have an important impact on the preservation and modification of siliciclastic sediment surfaces is increasingly being recognized (e.g., Schwarz et al., 1975; Seilacher and Pflüger, 1994; Schieber, 2004). In the absence of grazing metazoans many Precambrian sediment surfaces, including muddy substrates, were probably covered with microbial mats and biofilms when a favourable balance existed between sedimentation rate, availability of moisture, and an energy source (Schieber, 1999). Yet, whereas microbial mats were a major producer of biomass in the Precambrian, not all carbonaceous shales of that age necessarily represent *in situ* microbial mats. Although there are indications for microbial mat colonization of mud surfaces in all of the three carbonaceous shales pictured here, there is also evidence in all instances of shale facies that either mimic microbial mat style lamination (Fig. 7(e)-4 and Fig. 7(e)-6A, -6B) or are evenly laminated and quite comparable to Phanerozoic non-mat carbonaceous shales (Fig. 7(e)-6I).

Chapter 7e: Figures and Captions

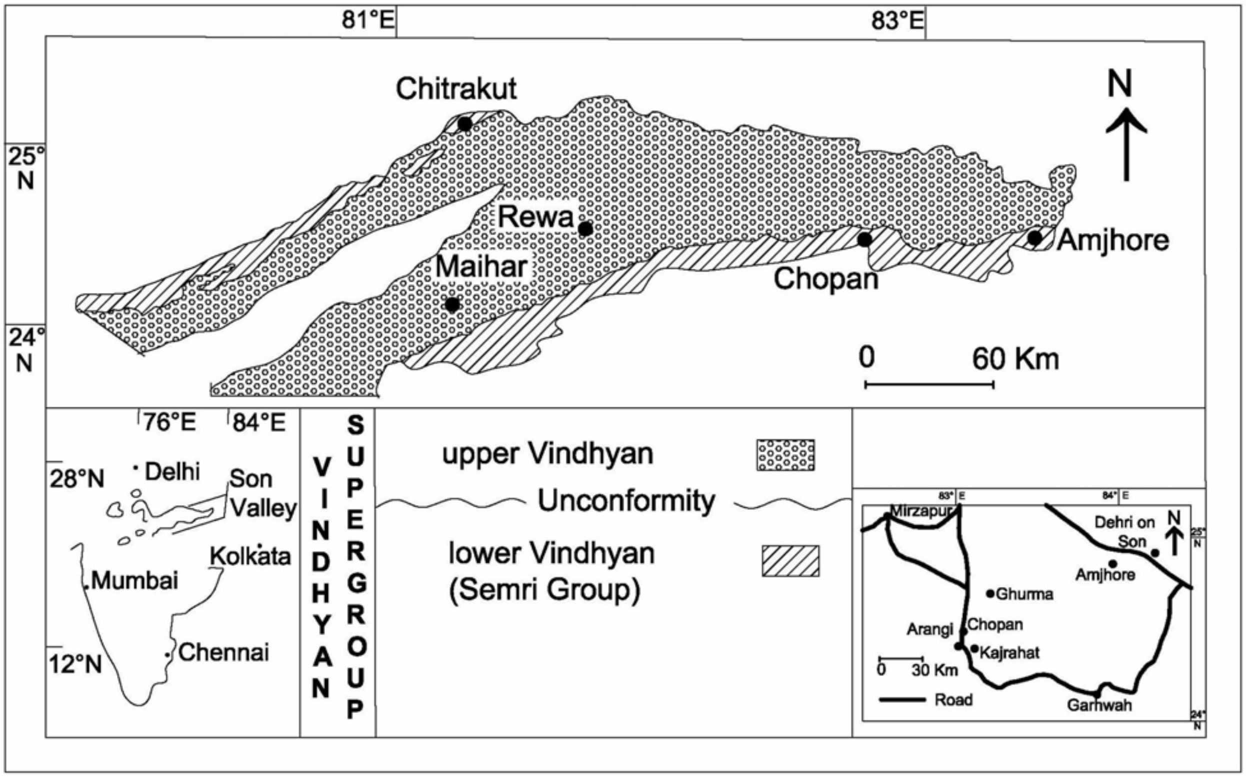


Fig. 7(e)-1: Geological map showing outcrop distribution of the Vindhyan Supergroup in central India (map of India within inset). Detailed road map is at bottom right.

In: *Atlas of microbial mat features preserved within the clastic rock record,* Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., and Catuneau, O., (Eds.), Elsevier, p. 189-197. (2007)

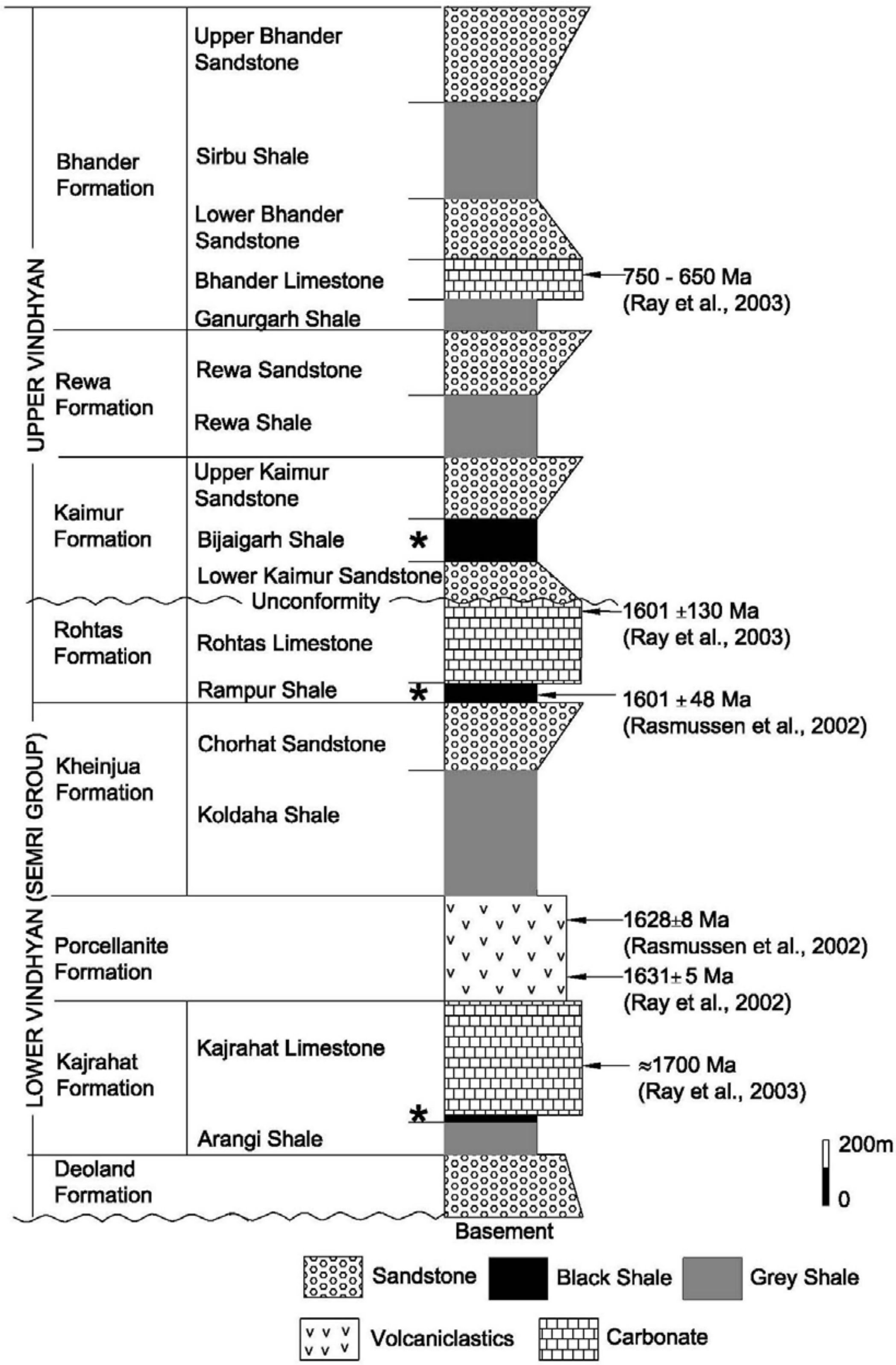
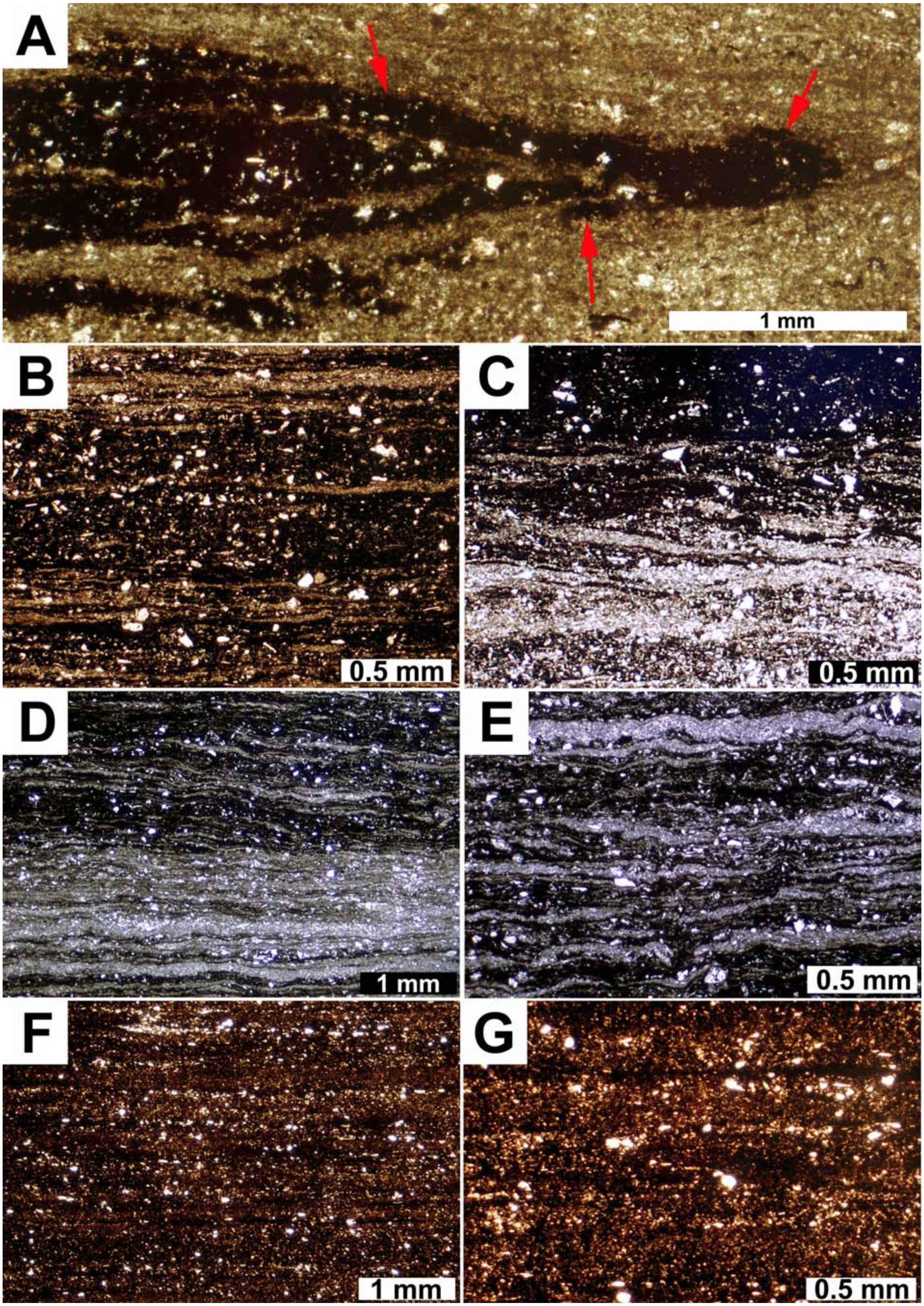


Fig. 7(e)-2: General lithology, age and stratigraphy of the Vindhyan Supergroup up to member level (after Bose et al., 2001). The black shale units are marked by asterisks.

In: *Atlas of microbial mat features preserved within the clastic rock record,* Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., and Catuneau, O., (Eds.), Elsevier, p. 189-197. (2007)



In: *Atlas of microbial mat features preserved within the clastic rock record,* Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., and Catuneau, O., (Eds.), Elsevier, p. 189-197. (2007)

Fig. 7(e)-3: Photomicrographs of the Kajrahat black shale:

(A) A folded over and rolled up thin carbonaceous fragment (arrows) in a gray shale matrix. (B) Wavy carbonaceous laminae in black shale. Continuous clay films accentuate the lamination. (C) Base of black shale bed overlying gray shale. At the base carbonaceous and clay laminae are inclined to the right, resembling false cross-lamination shown in Fig. 5-3A of chapter 5 in this book. (D) Wavy carbonaceous laminae with variable thickness and intercalated clay drapes. (E) Close-up view of same thin section as in D. Shows strong resemblance to lamina style in microbial mat deposits from the Newland Formation of the Belt Basin (Schieber, 1986; and Fig. 5-1A of chapter 5 in this book). (F) Even parallel laminae in a bed of carbonaceous shale from the Kajrahat Formation. (G) Close–up view of laminae in F. Wavy crinkly texture that is so obvious in D and E is absent. Lamination is caused by slight compositional variations from lamina to lamina.

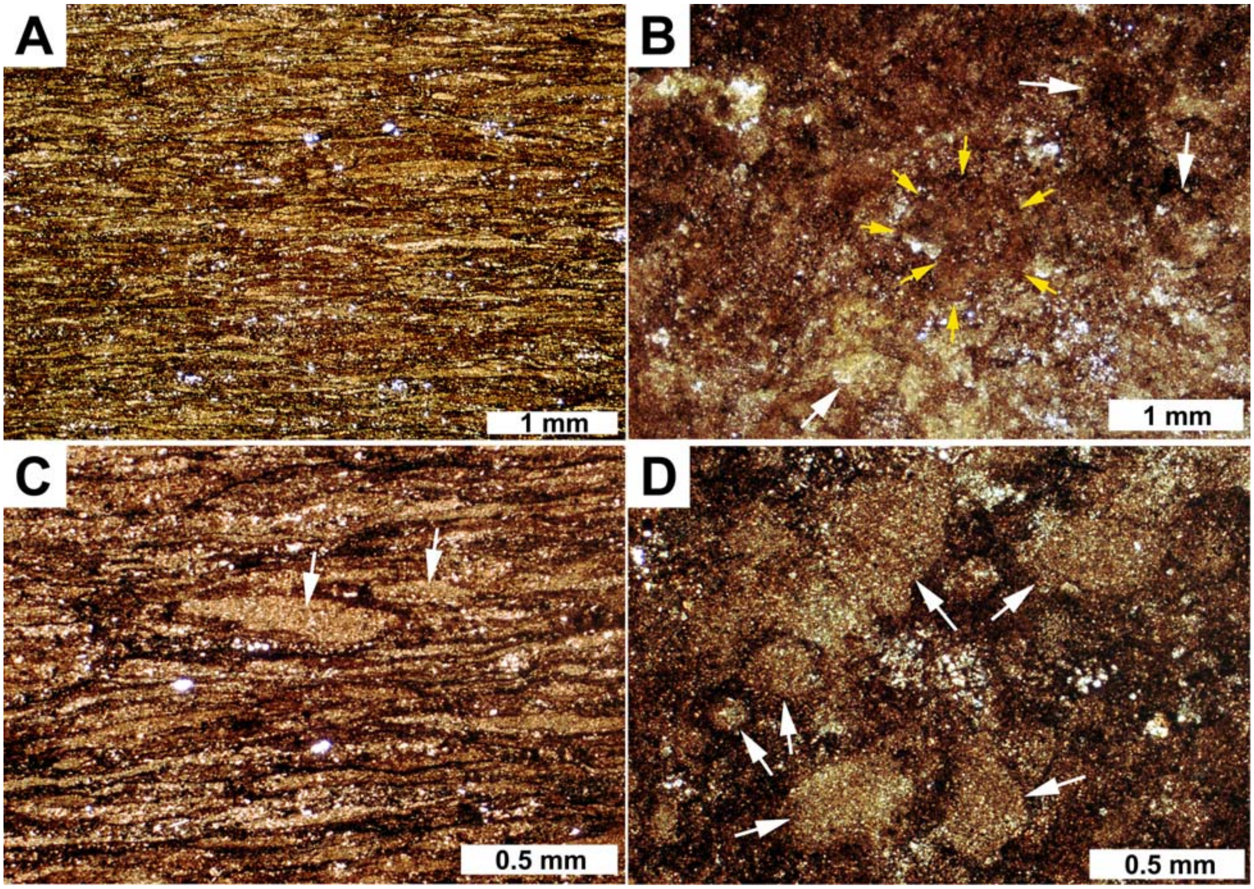


Fig. 7(e)-4: Photomicrographs of the Rampur Shale:

(A) Wavy lenticular lamination that appears to be the result of piled up and compressed fragments clay-rich mudstone. (B) A thin section of the same sample cut parallel to bedding. It shows that lamina surfaces are covered by discrete particles. Large particle in centre is marked by yellow arrows, other particles pointed out by white arrows. (C) Close-up view of wavy-lenticular laminated shale as in A. Arrows point out particles with distinct boundaries that are most likely shale fragments. (D) A thin section of the same sample cut parallel to bedding. As in B lamina surfaces are covered by discrete particles that are pointed out by arrows.

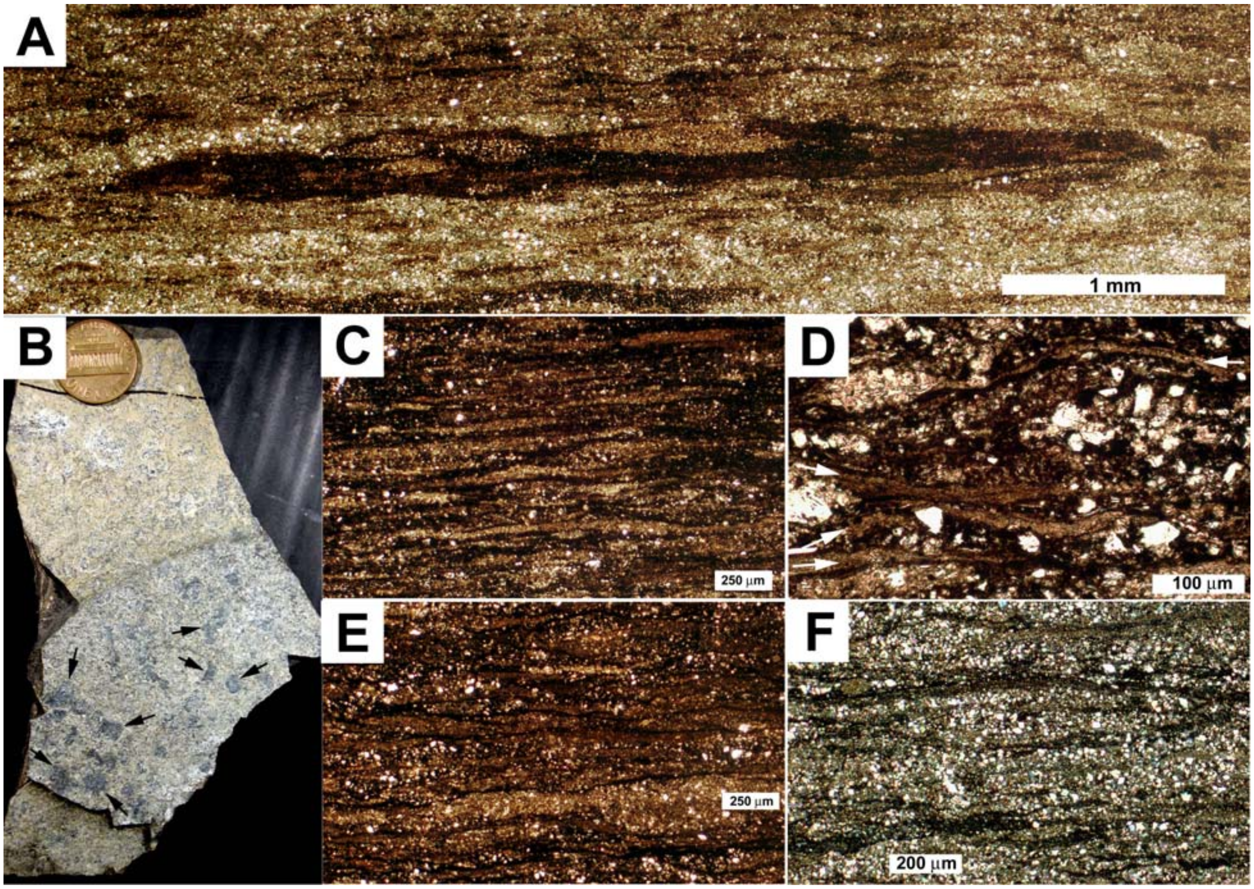
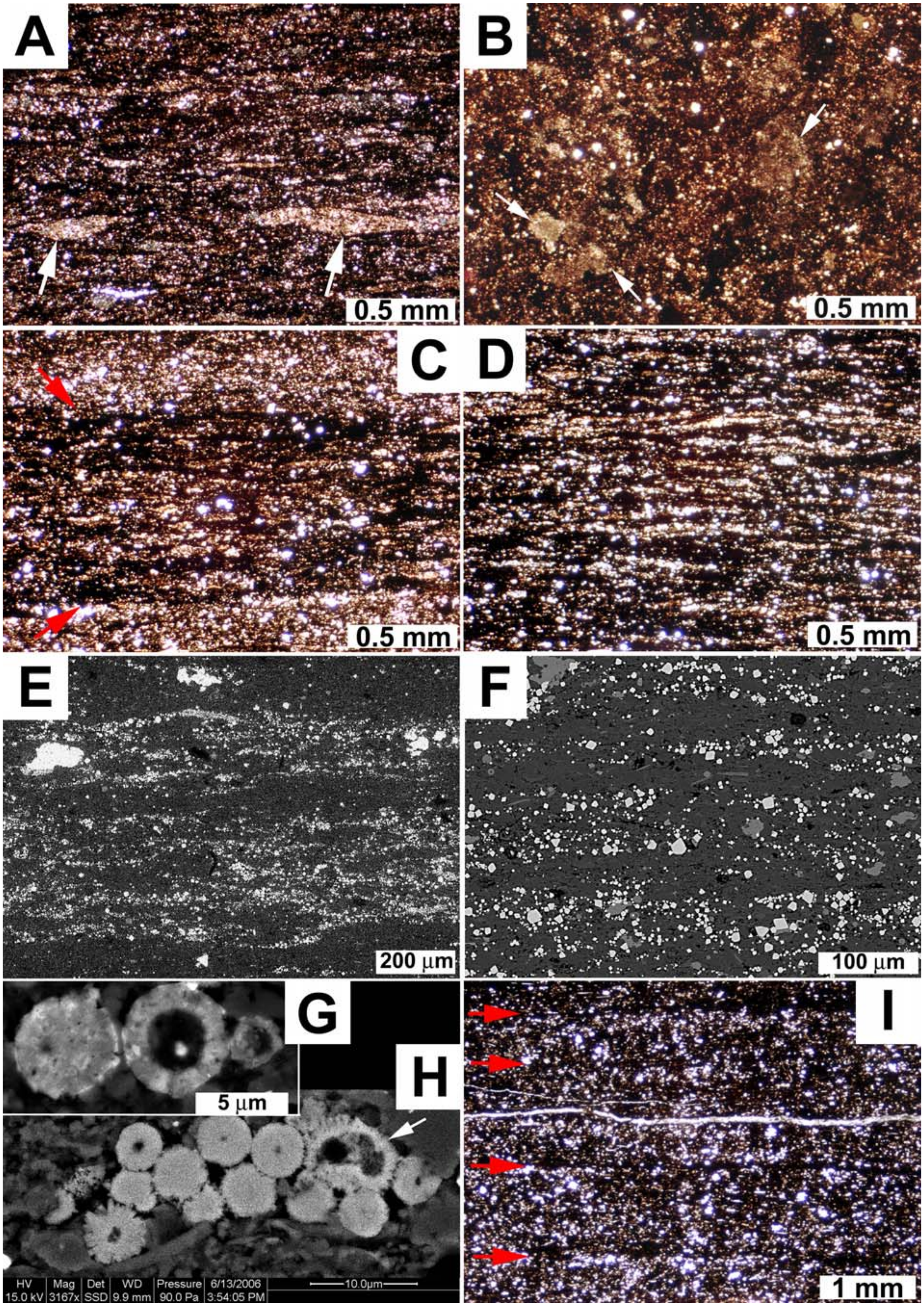


Fig. 7(e)-5: Photographs of the Rampur Shale:

(A) Photomicrograph of large elongate and possibly folded over carbonaceous fragment, as well as numerous smaller fragments, in a matrix of clays, quartz silt, and fine crystalline calcite. (B) Hand specimen with irregular carbonaceous flakes (arrows) on bedding planes. The photomicrograph in A was made from a thin section cut from this sample. (C) Wavy anastomosing carbonaceous laminae (dark-black) interspersed with clay drapes. (D) Close-up view of laminae in C. Shows "lumpy" looking carbonaceous silty laminae that alternate with thin clay drapes (arrows). (E) Carbonaceous shale with wavy carbonaceous laminae. Clastic layers (clay drapes) form a larger proportion of the overall rock. (F) Similar to E, but with large proportion of calcite grains in clastic layers (crossed polarizers).



In: *Atlas of microbial mat features preserved within the clastic rock record*, Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., and Catuneau, O., (Eds.), Elsevier, p. 189-197. (2007)

Fig. 7(e)-6: Photomicrographs of carbonaceous shales from the Bijaigarh Shale:

(A) through (H) are from the upper portion of the Bijaigarh Shale, image (I) is representative of carbonaceous shales in the lower portion. (A) Wavy lenticular laminae in carbonaceous shale that appear to be the result of piled up and compressed fragments of clay-rich mudstone, just like in Fig. 7(e)-5 from the Rampur Shale. (B) A thin section of the sample in A cut parallel to bedding. Just like in the Rampur Shale (Fig. 7(e)-5), lamina surfaces are covered by discrete particles that are pointed out by arrows. (C) Thin layer of shale with wavy anastomosing carbonaceous laminae (lower and upper boundary pointed out by arrows). The layer is under- and overlain by non-laminated shale, analogous to striped shales from other studies (e.g., Schieber, 1986). (D) A thicker bed of silty carbonaceous shale with wavy anastomosing laminae.(E) Backscatter electron image of thin shale layer with wavy anastomosing pyritic laminae. (F) Close-up view from E. Shows the confinement of scattered pyrite grains to discrete (carbonaceous) laminae. (G) Hollow and fully mineralized phosphatic spheroids. (H) Clump of phosphatic speroids. Note joined spheres pointed out by arrow. (I) Even laminated silty carbonaceous shale from the lower portion of the Bijaigarh Shale. Lamina boundaries pointed out by arrows.

References

Banerjee, S., 1997. Facets of Mesoproterozoic Semri sedimentation, Son valley, M.P. Ph.D. Thesis (unpubl.), Jadavpur University, Kolkata, 137 pp.

Banerjee, S. and Jeevankumar, S., 2005. Microbial mat response to physical process generating varied forms of wrinkle marks in sand: evidences from Mesoproterozoic Koldaha Shale, central India, Sedimentary Geology 176: 211-224.

Bose, P.K., Banerjee, S. and Sarkar, S., 1997. Slope-controlled seismic deformation and tectonic framework of deposition of Koldaha Shale, India. Tectonophysics 269: 151-169.

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

Chakraborty, P.P., 2004. Facies architecture and sequence development in a Neoproterozoic carbonate ramp: Lakheri Limestone Member, Vindhyan Supergroup, Central India. Precambrian Research 132, 29-53.

Rasmussen, B., Bose, P.K., Sarkar, S., Banerjee, S., Fletcher, I.R. and McNaughton, N.J., 2002. 1.6 Ga age for the Chorhat Sandstone: implications for the early evolution of animals. Geology: 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.

Ray, J.S., 2006. Age of the Vindhyan Supegroup: a review of recent findings. Journal of Earth Systems Science 115: 149-160.

Sarkar, S., Chakraborty, P.P. and Bose, P.K., 1996. Proterozoic Lakheri Limestone, central India: facies, paleogeography and physiography of the Lakheri Limestone. In: Bhattacharyya, A. (Ed.), Recent Advances in Vindhyan Geology. Memoir of the Geological Society of India 36, 5-26.

Schieber J 1986 The possible role of benthic microbial mats during the formation of carbonaceous shales in shallow Mid-Proterozoic basins; *Sedimentology* **33,** 521–536.

Schieber J 1989 Pyrite mineralization in microbial mats from the Mid-Proterozoic Newland Formation, Belt Supergroup, Montana, U.S.A; *Sedim. Geol.* **64** 79–90.

Schieber J 1999 Microbial mats in terrigenous clastics: The challenge of identification in the rock record; *Palaios* **14,** 3–12.

Schieber J 2004 Microbial mats in the siliciclastic rock record: a summary of diagnostic features. In: *The Precambrian earth: tempos and events* (eds) Eriksson P G, Altermann W, Nelson D R, Mueller W U, Catuneanu O (Amsterdam: Elsevier), pp. 663–673.

Schwarz H U, Einsele G and Herm D 1975 Quartz sandy, grazing contoured stromatolites from coastal embayments of Mauretania, West Africa; *Sedimentology* **22,** 539–561.

Seilacher A and Pflüger F 1994 From biomats to benthic agriculture: A biohistoric revolution; In: *Biostabilization of sediments: Bibliotheks und Informationssystem der Carl von Ossietzky Universit¨at Oldenburg (BIS)* (eds) Krumbein W E, Paterson D M, Stal L J (Germany: Oldenburg), pp. 97–105.

Sur, S., 2004, An integrated sedimentological, stratigraphical and geochemical study of two proterozoic black shales from Vindhyan Supergroup, India. M.S. Thesis, Indiana University, Bloomington, Indiana, 176p.

Sur, S., Schieber, S. and Banerjee, S., 2006. Petrographic observations suggestive of microbial mats from Rampur Shale and Bijaigarh Shale, Vindhyan basin, India. Journal of Earth Systems Science 115: 61-66.

Xiao, S., and Knoll, A.H., 1999, Fossil preservation in the Neoproterozoic Doushantuo phosphorite Lagerstatte, South China. Lethaia, v. 32, p. 219-240.