Chapter 6
Early Life from the Proterozoic Sedimentary Basins of India

Supriyo Kumar Das and Neal Gupta

Abstract The documented history of research on Proterozoic evidence of life in India is almost 200 years old. Although systematic study did not start before the middle of twentieth century, significant advancement has taken place in recent years in the application of sophisticated techniques involving stable isotopes and organic geochemical methods. The last two decades have revealed application of biomarker principles with greater analytical rigor that challenge the first evidence of eukaryotes via conventional paleontological means. Such research also underpins timing of oxygenation of the atmosphere, developing chemical profiles for reconstructing deep time biology providing means for applying such methods alongside traditional micropaleontology as established protocols. Further research, particularly related to biostratigraphy, chemostratigraphy and geochronology, helps in understanding the Proterozoic record of life in India with greater resolution. This chapter reviews the earliest fossil records in India with an emphasis on the Mesoproterozoic, Neoproterozoic and Ediacaran Period.

Keywords Biomarkers · Biogeochemistry · Fossil record · Ediacara · Stratigraphy

6.1 Introduction

Evidence for the first life on Earth has been extensively researched by biologists, paleontologists and scientists from various disciplines to understand the co-evolution of biological and geological processes and to link the evolution of complex life forms, the prebiotic production of organic molecules (such as amino acids, nucleotides) and the rise of oxygen by correlating geochemical and morphological

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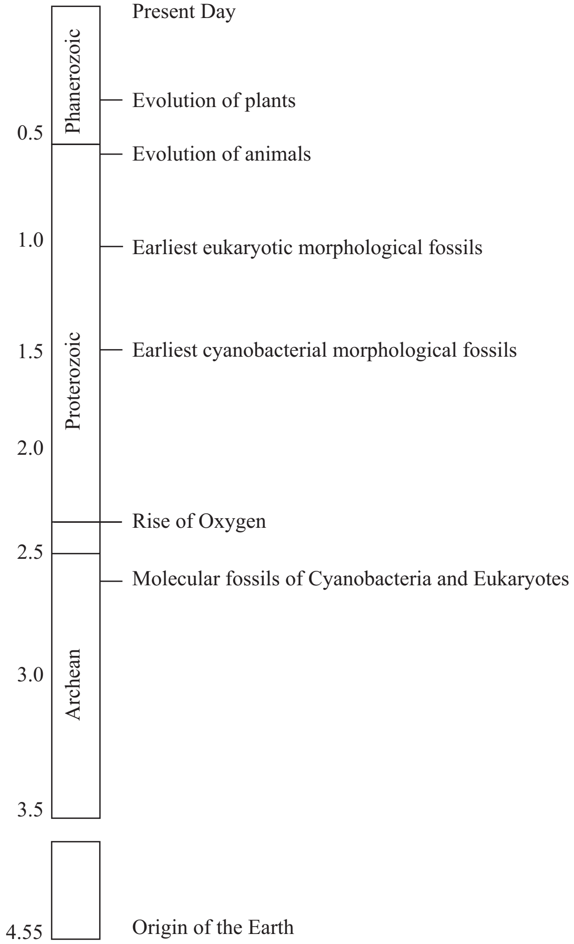
fossil evidences. Life emerged on this planet as early as 3.8 Ga, and microbial organisms evolved 3 billion years ago (Schopf 1999). The Archean time, 4 billion to 2.5-billion-year interval in the earth's history, has been the subject of extensive geobiological research. Archean hydrothermal deposits provide clues to understanding the earth's earliest biosphere (Reysenbach and Cady 2001), and microorganisms from modern hydrothermal systems provide analogies for interpreting the geological record as well as morphological features and isotopic signatures. Lipid biomarkers or chemical molecular fossils, which are natural biosynthetic products (often hydrocarbons) of specific biological origin, were reported in 2.7-billion-year-old samples from Western Australia (Brocks et al. 1999). This discovery suggests greater biological activity during the Archean than earlier thought and provides a separate geochemical means of assessment. A suite of lipid biomarkers, such as hopanes and steranes, indicates diagenetic molecular remnants of cyanobacterial membrane (organisms represent oxygen-producing photosynthesis) and molecular fossils of eukaryotic origin. This discovery pushed back the time of the origin of these biological taxa by at least 700 million years (Fig. 6.1). However, the 2.7 Ga sterane biomarkers, reported by Brocks et al. (1999, 2003), have subsequently been shown to be in error due to contamination (Rasmussen et al. 2008; French et al. 2015), or research suggesting noneukaryotic source of the putative Archean steranes that were taken as proxies for eukaryotic membrane sterols (Kirschvink and Kopp 2008).

The Proterozoic earth evidenced rapid biotic transition from a microbially dominated biosphere to the evolution of morphologically complex multicellular fauna and flora (Narbonne 2005; Erwin 2015). Fossil traces of mesoscopic and megascopic organisms started appearing during the Mesoproterozoic (Knoll and Carroll 1999; Martin et al. 2000; Knoll et al. 2004). The Ediacaran Period (terminal Proterozoic) constitutes an interval of time bound by decay of Marinoan ice sheets and the beginning of the Cambrian biological radiation (Fig. 6.2). Present evidence suggests that the Ediacara biota (575–542 Ma) marks the first appearance of large, architecturally complex organisms in the earth's history and includes stem- and crown-group radial animals, stem-group bilaterian animals and representatives of other eukaryotic kingdoms (Fig. 6.2; Narbonne 2005).

The Proterozoic sedimentary basins of India are shown in Fig. 6.3. They host thick, relatively undeformed and unmetamorphozed sandstone, shale and limestone rock sequences providing rich evidence of fossil records of Precambrian life. Some of the first observations of fossils were described in the memoirs of the Geological Survey of India. Jones (1909), for example, reported circular discs from Suket shale of the Vindhyan Supergroup where earlier geological reports failed to link these structures to primitive biological entities. The carbonaceous remains reported by Jones (1909) were later accepted as fossil impressions of the soft-bodied animal *Chuaria circularis* (Sharma et al. 2012). One of the earliest fossil evidences from the Precambrian of India was reported from the Daitari Greenstone Belt of the Singhbhum Craton (Jodder and Hofmann 2016).

Fig. 6.1 Column on the right denotes the geological time scale in Ga (numbers denote billions of years). The major events in evolution of life from paleontological evidence are presented against the time scale, including the rise of oxygen



6.2 History and Background of Research on Earliest Fossil Records in India

Stromatolites are one of the oldest recognizable organosedimentary structures that represent the existence of life in the Achaean and Proterozoic successions (Figs. 6.4 and 6.5). In India, the earliest evidence of stromatolites was documented as ring-like structures by McClelland (1834). Soon, similar-looking features were reported from the limestones of Cuddapah Supergroup and described as ‘Laminated and Segregated in peculiar Way’ (King 1872). Later Auden (1933) observed spheroidal body-like structures in Vindhyan limestones. The biogenic origin of such structures was not understood by Charles Oldham, William King, Robert Bruce Foote, McClelland and H.C. Jones (King 1872; Jones 1909; Auden 1933). The taxonomy of such form and their evolutionary significance and biostratigraphy was not fully understood

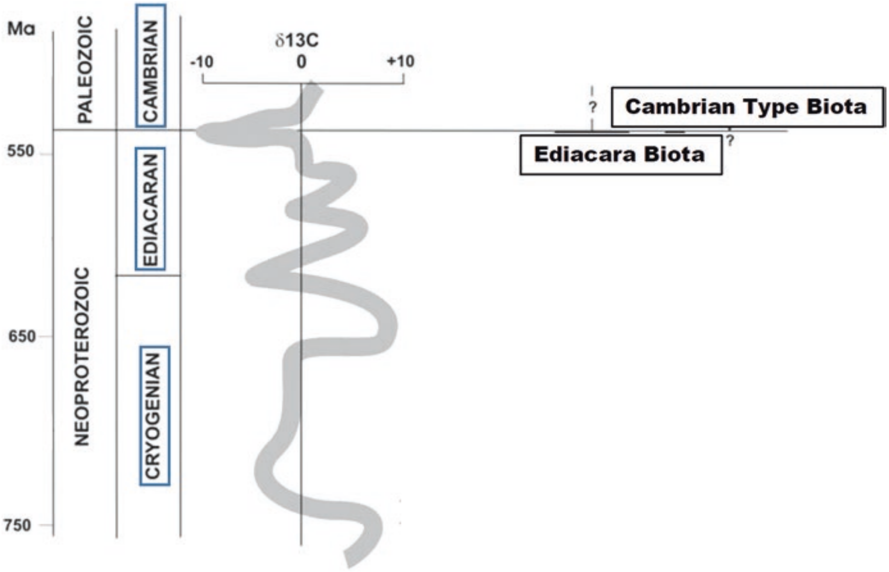


Fig. 6.2 Stratigraphic setting of the Ediacara biota in relation to Neoproterozoic global change underpinning carbon isotope excursions. Data and graph adapted and influenced from Narbonne (2005) for synthesizing this figure

until the 1960s when stromatolites in most Precambrian rocks of India were systematically documented. Research on fossil evidence of Precambrian life in Indian basins, by studying trace, micro and mega fossils, found momentum following discoveries made by Tyler and Barghoorn (1954). This developed a platform for more recent research work (e.g. Viswanathiah and Venkatachalapathy 1980; Sharma and Shukla 2009a; Guhey et al. 2011; Sharma et al. 2012). Stromatolite-like features in siliciclastic rocks were documented in recent years in Late Paleoproterozoic Chaibasa Formation of Singhbhum Craton (Loon van and Mazumder 2013). Such forms, known as Chaibasa laminated structures, were inferred as formed by microbial activity most likely due to accumulation of fine siliciclastic particles on top of biofilm (Sharma et al. 2016). Pandey (2014) reported clotted fabric of thrombolite in Upper Vindhyans.

6.3 Mesoproterozoic Record

Mesoproterozoic era witnessed the last common ancestor of modern eukaryotes (Bengtson et al. 2017). Oldest morphologically complex organic-walled eukaryotic microfossils were documented in the Paleoproterozoic–Early Mesoproterozoic Chitrakut Formation (>1600 Ma old) of the Vindhyan Supergroup (Singh and Sharma 2014). This report predates the oldest (~1500 Ma) reported eukaryotic

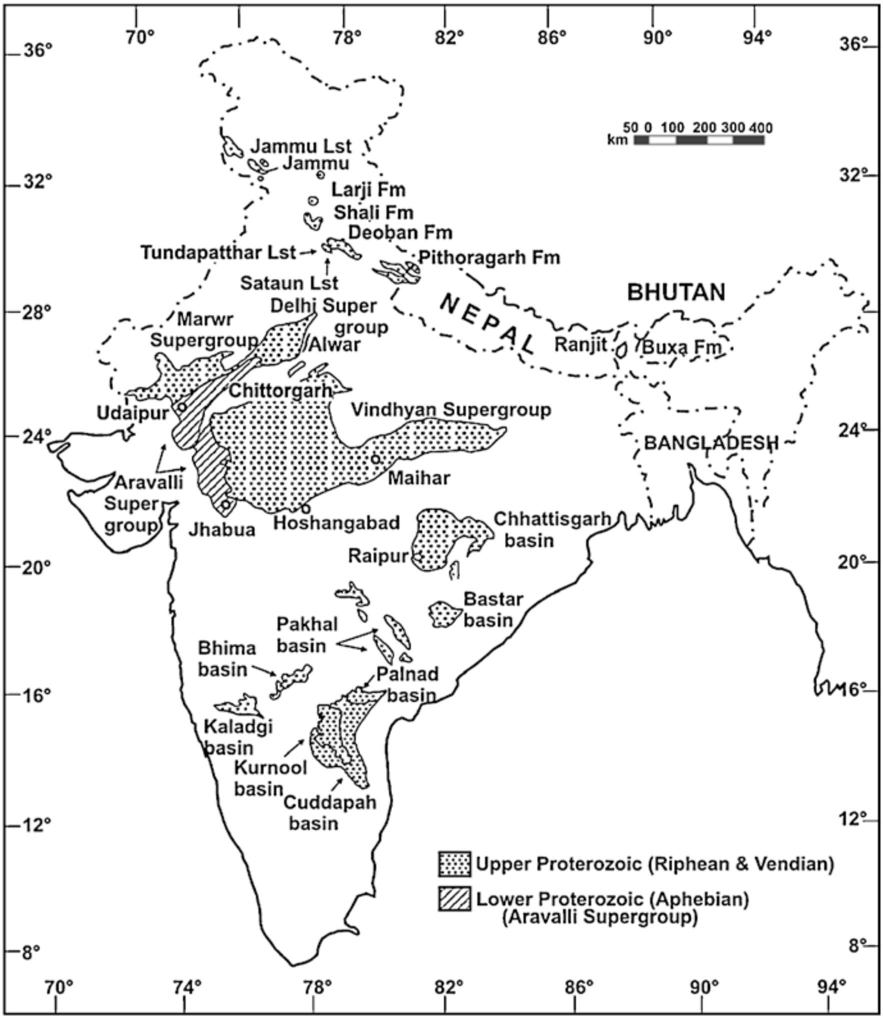


Fig. 6.3 Distribution of different Proterozoic basins in India. Featured in Sharma et al. (2012) after Raha and Shastry (1982). Reused with permission from Springer for publication in this Springer volume: Sharma et al. (2012)

fossils (Javaux et al. 2003). Acritarchs, which are small microfossils of unknown biological affinities (Evitt 1963), were reported from the permineralized cherts of Infra-Krol, Deoban and Buxa Limestones in Eastern Himalaya (Sharma et al. 2012). Shukla and Tiwari (2014) documented well-developed and diverse assemblage of large Ediacaran acanthomorphic acritarchs in cherts of Krol Belt of Lesser Himalaya although the occurrence of acanthomorphic acritarchs was documented infrequently in the Mesoproterozoic (Hofmann and Schopf 1983). Well-preserved fossils of cyanobacteria, interpreted as crown-group rhodophytes, were

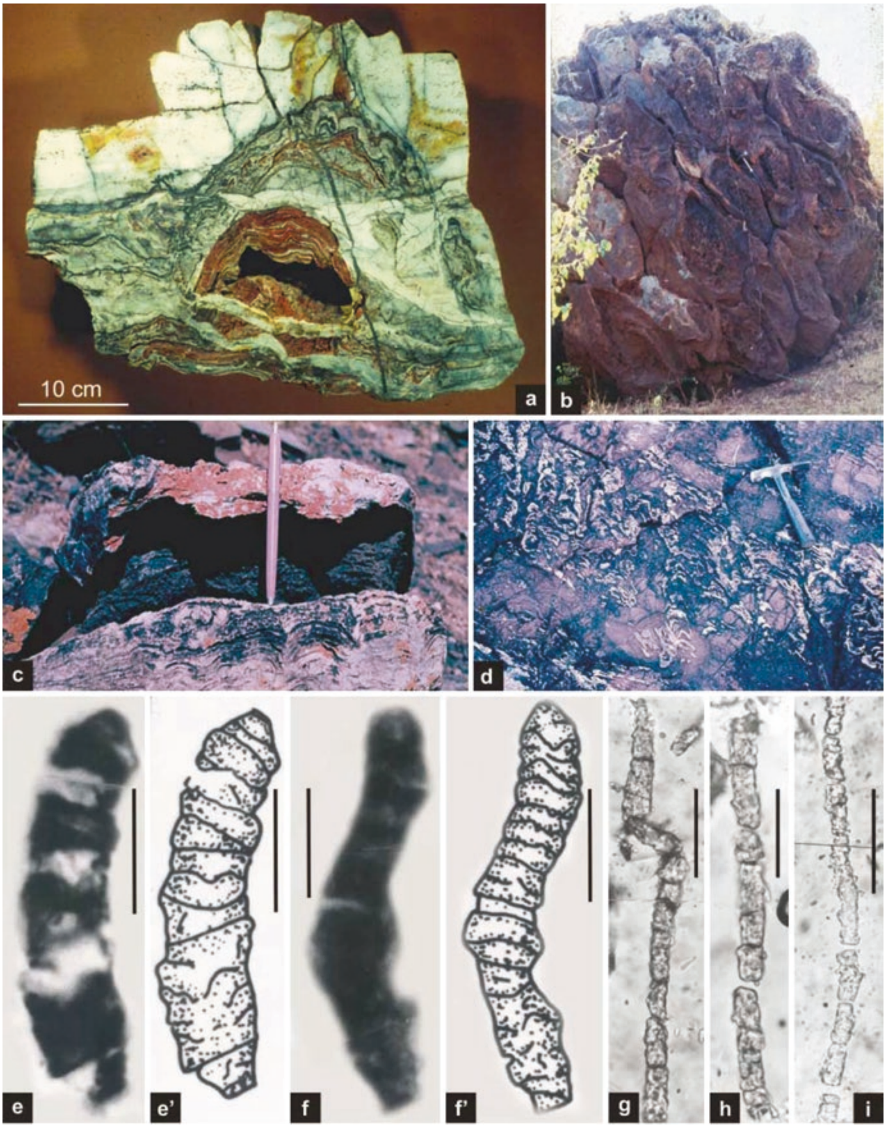


Fig. 6.4 (**a**) Archaean domal stromatolite from Warrawoona Group, Australia; (**b**) Batiola indica—Archaean stromatolite from Chitradurga Group, Karnataka, India; (**c**, **d**) Archaean stromatolite Marikanwe region Chitradurga Group, Karnataka, India; (**e**, **f**) Primaevifi lum conicoterminatum, Apex chert 3465 Ma, Western Australia; (**g**, **h**) Phormidella sandurense; (**i**) Phormidella tenue (scale for **e**, **f** = 10 μm; for **g**–**i** = 50 μm; hammer for scale in **b**, **d**; pen for scale in **c**). Reused with communication and permission from Springer: Sharma and Shukla (2009a, b)

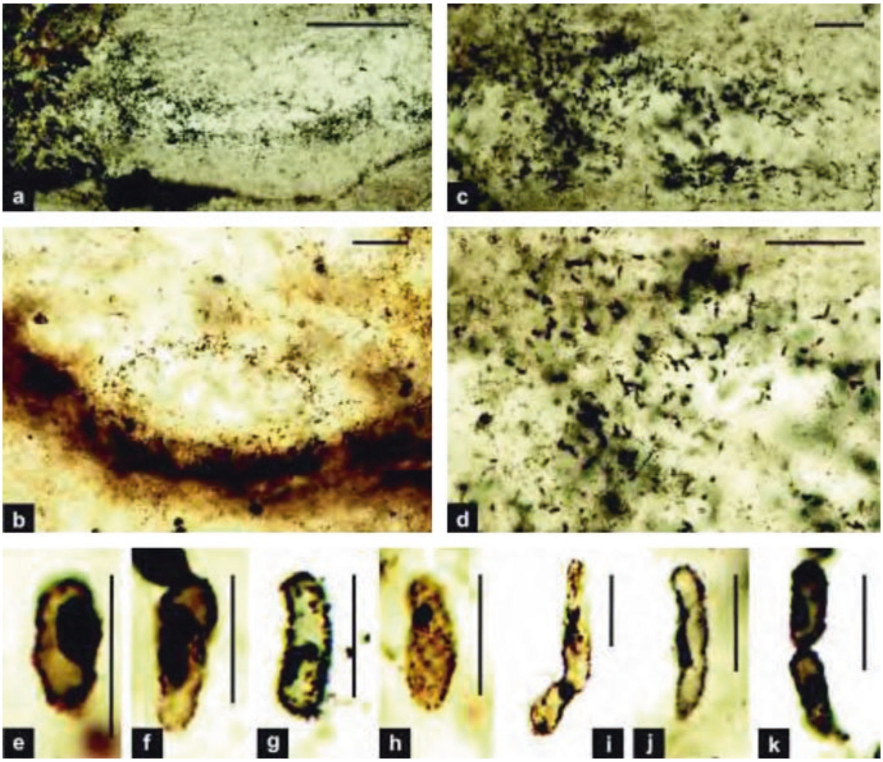


Fig. 6.5 An assemblage of akinetes of Nostocalean cyanobacteria recorded from the stromatolitic cherts of the Salkhan limestone, Semri Group. (**a**) A low magnification view of the cluster of different species of akinetes Archaeoellipsoides; (**b**) another cluster of Archaeoellipsoides at low magnification; (**c**, **d**) gradual high magnification view of (**a**); (**e**–**h**, **k**) Archaeoellipsoides minor; (**i**, **j**) Archaeoellipsoides major. Scale bar = 500 μm for (**a**); 100 μm for (**b**–**d**); 10 μm for (**e**–**k**). Reused with permission from Springer for publication in this Springer volume: Sharma and Shukla (2009a, b)

reported in Tirohan Dolomite of the Semri Group, Lower Vindhyan in Jankikund, Chitrakoot by Bengtson et al. (2017). Tirohan Dolomite is exposed north of the Son River Valley in the Chitrakoot region in Uttar Pradesh and Madhya Pradesh (Bengtson et al. 2017). The Jankikund rocks are stromatolitic carbonates, primarily dolostones, with phosphorite bands within and capping the stromatolites and intraclasts in the intercolumnar matrix (Bengtson et al. 2017). The authors reported filamentous and lobate organisms with features similar to modern eukaryotic algae. This finding pushed the appearance of the earliest accepted red algae about 400 million years earlier. The age of the Semri Group was assigned as Paleo-Mesoproterozoic by Sarangi et al. (2004), Ray (2003, 2006) and Basu and Bickford (2014), although based on fossil assemblages, an Ediacaran-Cambrian age was suggested by Azmi et al. (2008) and Prasad and Asher (2016). Both Ray (2006) and Azmi et al. (2008) drew support from published radiometric dates for their argument. Bengtson et al. (2017) questioned the inference drawn by Azmi et al. (2008) and assigned Paleoproterozoic to early Mesoproterozoic to Lower Vindhyan age based on Pb/Pb isochron of the fossiliferous phosphorite from Jankikund and other geochronologic evidence.

Megascopic carbonaceous microfossils, with wide varieties of forms and outlines (e.g. spiral *Grypania*, circular *Chuaria*, wide bands with rounded ends of *Tawuia*), started appearing in early Mesoproterozoic in the areno-argillaceous successions of the Vindhyan, Kurnool, Bhima and Chhattisgarh basins (Kumar 1995; Srivastava 2002; Sharma 2006b; Srivastava and Bali 2006; Sharma et al. 2009; Sharma and Shukla 2009a, b, Fig. 6.6). In particular, the *Chuaria-Tawuia* assemblage constitutes the most significant megascopic carbonaceous remains. Description of early Mesoproterozoic microfossils includes pre-Ediacaran large filamentous forms that consist of both prokaryotes and eukaryotes (Sharma and Shukla 2012a, b). The carbonaceous fossils, especially *Chuaria-Tawuia* assemblage, in the Chorhat Sandstone (Kheinjua Formation, Semri Group) represent the oldest dated fossils in the Vindhyan Supergroup and indicate an evolutionary phase from micro- to megascopic organisms (Srivastava and Bali 2006). Megascopic microfossils, preserved in cherts; hosted in a thick, unmetamorphosed sequence of sandstone, shale, carbonate and volcanoclastic rocks; and primarily formed in the peritidal to tidal environments, were reported from Deoban Limestone, Infra-Krol and Krol Formations in the Lesser Himalaya and Vindhyan Supergroup (Srivastava 2006, 2009; Sharma 2006a; Bengtson et al. 2017).

Microbial mats in the Precambrian siliciclastic sequences provide records of ancient prokaryote life forms. Microbial mat-related structures (MRS) were reported from the Marwar (Sonia Sandstone), Vindhyan (Chorhat Sandstone and Koldaha Shale Formations) and Chhattisgarh Supergroups and from the Khariar Group and linked to the Precambrian shallow-marine coastal depositional environments (Ahmad and Kumar 2014; Banerjee and Jeevankumar 2005; Banerjee et al. 2006, 2010; Sarkar et al. 2006, 2011, 2014, 2008; Samanta et al. 2015; Sur et al. 2006; Chakraborty et al. 2012). Samanta et al. (2011) observed enhanced preservation of microbial remains in pyrite produced by diagenetic alteration of microbial mat. Banerjee and Jeevankumar (2005) described variation of wrinkle structures within a highstand systems tract in response to continued progradation. Banerjee et al. (2006) linked the occurrence of organic-rich (total organic carbon content >2%) microbial mat-originated laminated pyritic carbonaceous shales to flooding surfaces (Sur et al. 2006; Schieber et al. 2007). The MRS, in the form of discoidal colonies, was reported in the Gulf of Cambay (Banerjee 2012), and Chakraborty and Das (2013) linked varieties of bedding plane structures to microbial mat in Chhattisgarh and Khariar basins. Deb et al. (2007) reported similar microbial mat from the Mesoproterozoic Somanapalli Group in Pranhita-Godavari basin. Banerjee et al. (2010) reported microbial mat with features resembling metazoan burrows, tracks and trails and metazoan body fossil impressions from the shallow-marine sandstones of the Semri Group of the Vindhyan basin. Sarkar et al. (2014) observed features such as petee ridges, sandcracks, gas domes, multidirected ripples, reticulate surfaces and sieve-like surfaces to shallow parts of the marine basins, in upper

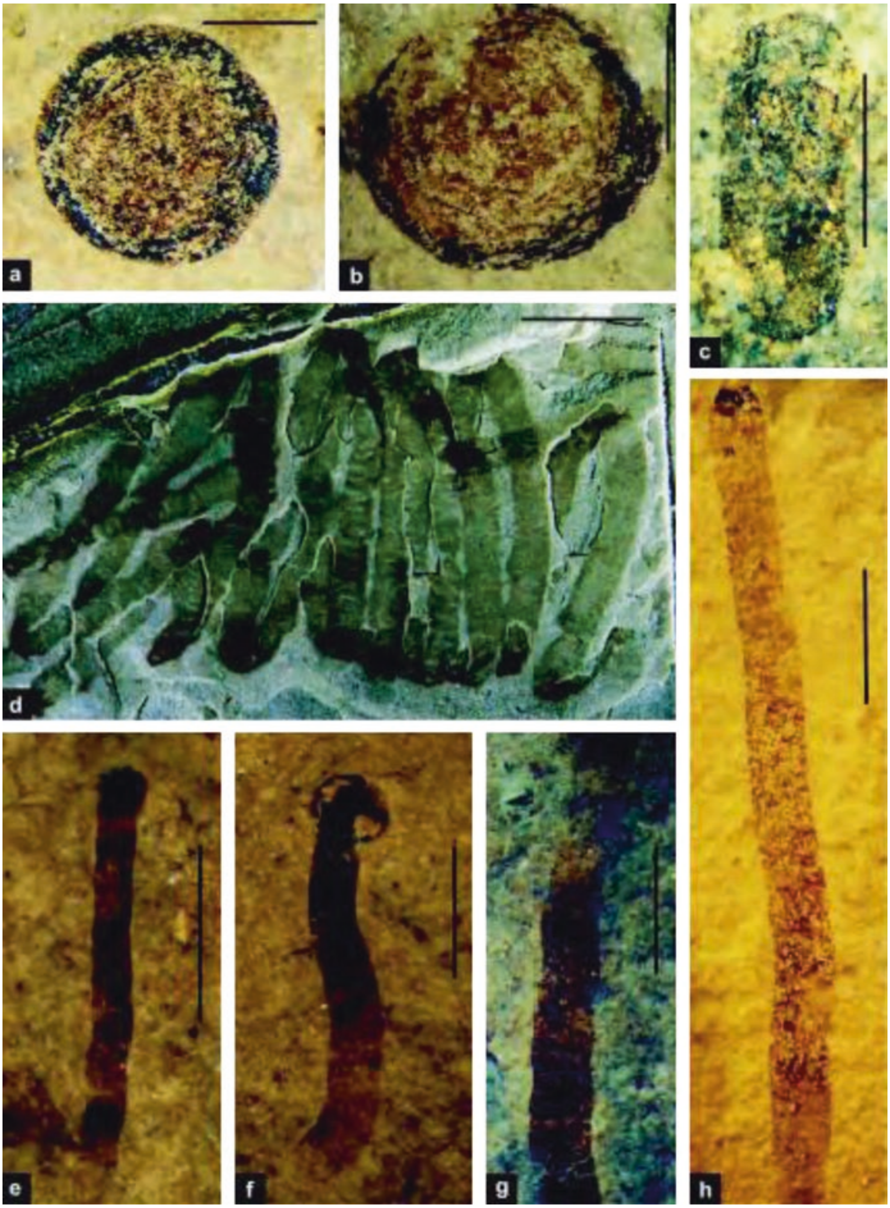


Fig. 6.6 Varied carbonaceous remains recovered from the Proterozoic sedimentary basins of peninsular India. (**a**, **b**) *Chuaria circularis* showing thick rim on the periphery of specimen noted in the Halkal Formation of the Bhima basin; (**c**) *Tawuia dalensis* recorded from the Halkal Formation of the Bhima basin; (**d**) *Katnia singhii* preserved on the parting surfaces of grey shale from the Rohtas Formation, Vindhyan basin; (**e**, **f**) Protoarenicola baiguashanensis; (**g**) Sinosabellidites huainanensis; (**h**) Pararenicola huaiyuanensis all recorded from the Halkal Formation of the Bhima Group. Scale bar for (**a**) = 1 mm, for (**d**) = 5 mm and for the rest of the specimen = 2 mm. Reused with permission from Springer for publication in this Springer volume: Sharma et al. (2012)

intertidal to supratidal conditions by drawing inference from their modern analogues, whereas the wrinkle structures, roll-up structures and patchy ripples were linked to broader range of paleogeographic settings ranging from the supratidal to subtidal conditions. Such megascopic carbonaceous microfossils continue till the Late Neoproterozoic. The soft-bodied organisms grew on the mat-infested Proterozoic seafloor producing close association between the traces of such organisms and mat-related structures. The microbial mat colonies provided favourable habitat conditions to the soft-bodied organisms. The unique Neoproterozoic substrate conditions preserved the microbial mat colonies along with the soft-bodied organisms including Ediacaran fauna (Gingras et al. 2011).

6.4 Neoproterozoic Record

Multicellular eukaryotes became predominant around the Proterozoic–Phanerozoic transition. The Neoproterozoic successions in India provide records of one of the most remarkable periods in earth's history owing to the emergence of macroscopic animals (e.g., Knoll 2000) and the evolution of Precambrian life forms. Sphaeromorphs and morphologically complex acanthomorphs, herkomorphs, netromorphs, prismatomorphs and pteromorphs were common Proterozoic acritarchs. Some of these microfossils had close association with fossils of extant Chlorophyceae, and many large sphaeromorphs had close affinity with prasinophytes. Megasphaeromorphs (~200 μm) show significant occurrence in the terminal Proterozoic (Tappan 1980), and acanthomorphic acritarchs were well documented in Neoproterozoic (Schopf 1992). Acritarchs were reported from the Gangolihat Formation (Tiwari and Pant 2009) and Vindhyan Supergroup, which contain several taxonomically and biostratigraphically important acritarch genera (Prasad and Asher 2001; Prasad et al. 2005, 2010).

The microfossils in the chert nodules of Infra-Krol deposits were attributed to non-septate and septate cyanobacterial filaments, coiled filaments, coccoids, large sphaeromorphs, small and large acanthomorphic acritarchs and vase-shaped microfossils (VSMs). The cyanobacterial filaments and coccoids were identified as *Siphonophycus typicum*, *Siphonophycus robustum*, *S. kestron*, *S. inornatum*, *S. punctatum*, *Polytrichoides bipartitus*, *P. lineatus*, *Obruchevella parva*, *O. magna*, *Oscillatoriopsis media*, *Oscillatoriopsis* sp., *Eomicrocoleus crassus*, *Polybessurus crassus*, *Salome hubeiensis*, *Myxococcoides* sp., *Sphaerophycus parvum*, *S. medium*, *Huroniospora psilata*, *Palaeoanacystis vulgaris*, *Tetraphycus* sp., *Wengania globosa*, *Bavlinella faveolata* and *Melanocyrillium horodyskii* (Sharma et al. 2012). Large sphaeromorphic and acanthomorphic acritarchs were identified as *Leiosphaeridia crassa*, *Ericiasphaera spjeldnaesii*, *Echinospheridium maximum*, *Asterocapsoides sinensis*, *Asterocapsoides* sp. and *Cymatiosphaeroides yinii*.

Neoproterozoic successions reveal the presence of relatively simple forms of eukaryotes in primitive oceans that contain much less oxygen compared to oxygen levels in modern ocean (Knoll and Carroll 1999; Knoll 2000). The relatively smaller forms of organisms were likely driven by low dissolved oxygen content in the ancient ocean water. The marine ecosystems were inhabited by a variety of oxygenic and anoxygenic prokaryotes including regular chlorophyll-containing algae. However, the exact time of appearance of green algae is debated. Evolution of multicellular animals is considered the most remarkable event of the terminal Neoproterozoic (Narbonne 2005; Shu et al. 2014) that leads to the Cambrian explosion of life.

6.4.1 Ediacaran Trace Fossil

The appearance of soft-bodied animals on earth during Ediacaran Period, following the Neoproterozoic glacial event, marks an important episode in the evolution of life on Earth. The Vendian Period marks the rise and fall of soft-bodied, megascopic metazoans preserved in unique taphonomic conditions. The Vendian organisms are represented by Neoproterozoic Ediacara faunas. The appearance of multicellular Ediacaran life is consistent with the hypothesis that increase in atmospheric oxygen level played a significant role in metazoan evolution. During this time, the evolution of megascopic organisms is considered to follow the Neoproterozoic glaciations at 750–635 Ma, with maximum biological diversity found during 560–540 Ma (Waggoner 2003; Meert et al. 2011). However, bioturbation evidence of such soft-bodied organisms is sporadic in geological record and primarily recorded in siliciclastic settings (Hofmann and Mountjoy 2001). High benthic population, attached forms, overall absence of scavengers and predators, absence of post-burial disturbances by deposit feeders, shallow water habitat, rapid burial and sediment stabilization by algal and cyanobacterial mat were some of the controlling factors that promoted preservation of the soft-bodied biota. The Ediacaran assemblages, including *Pteridinium simplex*, *Charniodiscus*, *Zolotystia*, *Beltanelliformis*, *Kimberella*, *Conomedusites* sp., *Cyclomedusa davidi*, *Sekwia* and *Irridinites* (Mathur 2008; Maithy and Kumar 2007), are best exposed in Krol successions and the Spiti sections in the Himalaya. In the Peninsular India, *Twitya discs*, *Cyclomedusa* and *Obruchevella* burrow structures in the Kurnool Group represent Ediacaran trace fossils (Sharma 2008; Sharma and Shukla 2012b). Soft-bodied megascopic metazoans showing faunistic, ecological and taphonomic affinities to known Ediacaran fossil assemblage, represented by coelenterate (*Tribachidium*, *Eoporita*, *Kaisalia*, *Cyclomedusa*, *Ediacaria*, *Nimbia*, *Paliella*, *Medusinites* and *Hiemalora*) and arthropod (*Spriggina*) genera, were reported from the Vindhyan basin (De 2006). Seilacher et al. (1998) reported old triploblastic metazoan traces from the Lower Vindhyan sequence. De (2006) further reported forms (*Ediacaria* and *Hiemalora*) similar to Ediacaran assemblages from the Late Neoproterozoic Bhander Group of the Upper Vindhyan. Interestingly, many Ediacaran fossils reported earlier in the Vindhyan Supergroup have now been discarded as artefacts (Kumar and Sharma 2012) although Prasad and Asher (2016) reported abundant and well-preserved Ediacaran complex acanthomorph acritarchs in drill cores through allegedly Lower Vindhyan sedimentary rocks in the western Vindhyan sub-basin, Chambal Valley, Rajasthan.

It is necessary to mention that uncertainties in age calibration based on occurrences and events in fossil record affect the linear divergence of the phylogenic trees. A fossil only gives a minimum age for the lineage in the fossil record where preservation potential of the fossilized organism along with the availability of a suitable depositional environment plays crucial role. Scarce occurrences of fossiliferous deposits, low preservation and the controversial nature of the fossils increase the uncertainty of calibration intervals in Proterozoic (Bengtson et al. 2017).

6.4.2 Biogeochemical Records

Stable isotopes and organic geochemistry-based chemostratigraphy have been used as a tool to trace the earliest evidence of life on earth, but such records from Indian Proterozoic successions are relatively less in number. Major paleobiological and carbon (C)-stable isotope ($\delta^{13}C$) records reflecting rapid evolution and diversification of multicellular life during terminal Neoproterozoic were reported in the Indian Lesser Himalaya (Tewari 2003). The Neoproterozoic–Early Cambrian chemostratigraphy of the Blaini–Krol–Tal succession reflects the Precambrian–Cambrian transition in the Lower Tal Formation ($\delta^{13}C = -4‰$). The Krol belt in the Lesser Himalaya is characterized by positive $\delta^{13}C$ value (1–6‰), and the pink cap carbonate of the Blaini Formation, the base of the terminal Proterozoic System in the Lesser Himalaya, shows negative $\delta^{13}C$ value (−3‰) (Tiwari and Sial 2007). Positive $\delta^{13}C$ values (3.7–5.4‰) were also reported from the terminal Neoproterozoic Buxa Dolomite in Lesser Himalaya (Shen and Schidlowski 2000; Tewari 2003; Tiwari and Sial 2007). The oxygen isotope record ($\delta^{18}O = -2.2‰$) in the Upper Krol is consistent with the increase in atmospheric oxygen that played a significant role in metazoan evolution and Cambrian explosion (Tiwari and Sial 2007). Studied phosphate content and stable isotopes of C and nitrogen ($\delta^{15}N$) in Paleoproterozoic carbonates of Aravalli Supergroup and linked cyanobacterial blooms and Great Oxidation Event to the increased phosphate availability during Paleoproterozoic Lomagundi–Jatuli event and the Neoproterozoic Cryogenian and Ediacaran periods. Studied $\delta^{13}C$ and oxygen (O) isotope ($\delta^{18}O$) in Neoproterozoic carbonates of Sirohi Group and linked the variations in $\delta^{18}O$ and $\delta^{13}C$ to contact metamorphism and changing C cycles, respectively. Studied C, O and strontium (Sr) isotopes in carbonate rocks of Proterozoic Bhima basin and postulated effect of diagenetic alterations on $\delta^{18}O$ and Sr isotope ($^{87}Sr/^{86}Sr$) signatures. Studied $\delta^{18}O$ and $\delta^{13}C$ and Sr, barium (Ba) and rare earth elements (REE) composition in Paleoproterozoic cap-carbonate unit of Paleoproterozoic Sausar Group in central India and drew parallel of the lithological association and chemostratigraphy with Neoproterozoic cap carbonates in Canada, the USA, South Africa and Australia.

Organic geochemical study of Proterozoic successions in India is primarily limited to hydrocarbon exploration. For example, organic geochemical analysis of shale from Proterozoic Sirban Formation and Vindhyan successions was performed for estimating hydrocarbon prospects (Prasanna et al. 2013; Mani et al. 2014), and lipid biomarkers were documented from crude oils and rock extracts recovered from the Marwar Supergroup. Compared lipid biomarker and $\delta^{13}C$ signatures of oil from Bikaner-Nagaur basin of Rajasthan in western India with oils from Oman and eastern Siberia. Raju et al. (2014) inferred oil generation under anoxic hypersaline conditions from marine clastic source rock and biodegradation of the oil using aromatic hydrocarbons, isoprenoid alkane ratio and sterane and hopane ratio. Steroids derived from squalene precursor are an important constituent of membrane lipids of all eukaryotes (Summons et al. 2006). Reported significant presence of C_{29} and C_{30} steranes in Neoproterozoic–Early Cambrian samples from the Bikaner-Nagaur basin and inferred significant contribution from both eukaryotes (demosponges) and prokaryotes (green algae). However, migration of oil makes it difficult to establish the exact age of the biomarkers as the source of the oil is not known. Dayal et al. (2014) inferred conducive pathways for migration of the hydrocarbons towards the surface soil by using compound-specific $\delta^{13}C$ of desorbed gaseous hydrocarbon (methane and ethane) in outcrop shale samples of Semri and Kaimur Groups in Vindhyan basin. Nonetheless, the biggest analytical challenge for Precambrian organic geochemical studies is contamination from hydrocarbons of a different age in the samples being studied. Precambrian rock samples may contain significant amount of organic C by weight, and biomarker compounds are present in these rocks only at trace amount (parts per billion or less), making contamination from other petroleum sources a possibility (Waldbauer et al. 2009). Despite the challenges, Patranabis-Deb et al. (2016) inferred rare algal presence in bacteria-dominated Proterozoic ocean from the absence of steroids and abundance of hopanes in the late Mesoproterozoic carbonates in Chhattisgarh. The study indicated that Proterozoic basin had little eukaryotic abundance relative to prokaryotic bacteria. Hoshino et al. (2017) reported C_{27}–C_{29} steranes in pyritic black shale from the Krol Group in the Mussoorie syncline and linked this to the rise of green algae to global dominance of marine ecosystems.

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References

Ahmad S, Kumar S (2014) Trace fossil assemblages from the Nagaur Group, Western India. J Palaeontol Soc India 59:231–246

Auden JB (1933) Vindhyan sedimentation in Son Valley, Mirzapur district. Mem Geol Sur India 62:141–250

Azmi RJ, Joshi D, Tiwari BN, Joshi MN, Srivastava SS (2008) A synoptic view on the current discordant geo- and biochronological ages of the Vindhyan Supergroup, central India. Himal Geol 29:177–191

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

Banerjee S, Dutta S, Paikaray S, Mann U (2006) Stratigraphy, sedimentology and bulk organic geochemistry of black shales from the Proterozoic Vindhyan Supergroup (central India). J Earth Syst Sci 115:37–48

Banerjee S, Sarkar S, Eriksson PG, Samanta P (2010) Microbially related structures in siliciclastic sediment resembling Ediacaran fossils: examples from India, ancient and modern. In: Seckbach J, Oren A (eds) Microbial mats: modern and ancient microorganisms in stratified systems. Springer-Verlag, Berlin, pp 111–129

Banerjee S (2012) Discoidal microbial colonies. Int J Earth Sci 101:1343

Basu A, Bickford ME (2014) Contributions of zircon U-Pb geochronology to understanding the volcanic and sedimentary history of some Purana basins, India. J Asian Earth Sci 91:252–262

Bengtson S, Sallstedt T, Belivanova V, Whitehouse M (2017) Three-dimensional preservation of cellular and subcellular structures suggests 1.6 billion-year-old crown-group red algae. PLoS Biol 15:e2000735

Brocks JJ, Logan GA, Buick R, Summons RE (1999) Archean molecular fossils and the early rise of eukaryotes. Science 285:1033–1036

Brocks JJ, Buick R, Summons RE, Logan GA (2003) Composition and syngeneity of molecular fossils from the 2.78 to 2.45 billion-year-old Mount Bruce Supergroup, Pilbara Craton, Western Australia. Geochim Cosmochim Acta 67:4321–4335

Chakraborty PP, Das P, Saha S, Das K, Mishra SR, Paul P (2012) Microbial mat related structures (MRS) from Mesoproterozoic Chhattisgarh and Khariar basins, Central India and their bearing on shallow marine sedimentation. Episodes 35:1–11

Chakraborty PP, Das P (2013) Microbial mat related structures (MRS) from Mesoproterozoic Chhattisgarh and Khariar basins, Central India and their bearing on shallow marine sedimentation. Episodes 35:513–523

Dayal A, Mani D, Madhavi T, Kavitha S, Kalpana M, Patil D, Sharma M (2014) Organic geochemistry of the Vindhyan sediments: implications for hydrocarbons. J Asian Earth Sci 91:329–338

De C (2006) Ediacaran fossil assemblage in the Upper Vindhyans of Central India and its significance. J Asian Earth Sci 27:660–683

Deb SP, Scheiber J, Chaudhuri AK (2007) Microbial mat features in mudstones of the Mesoproterozoic Somanapalli Group, Pranhita Godavari basin, India. In: Schieber J, Bose PK, Eriksson PG, Banerjee S, Sarkar S, Catuneanu O, Altermann W (eds) An atlas of microbial mat features preserved within the clastic rock record. Elsevier, Boston, pp 171–180

Erwin DH (2015) Early Metazoan life: divergence, environment and ecology. Philos Trans R Soc B 370:20150036

Evitt WR (1963) A discussion and proposals concerning fossil dinoflagellates, hystrichospheres, and acritarchs, II. PNAS 49:298–302

French KL, Hallmann C, Hope JM, Schoon PL, Zumberge JA, Hoshino Y, Peters CA, George SC, Love GD, Brocks JJ, Buick R, Summons RE (2015) Reappraisal of hydrocarbon biomarkers in Archean rocks. PNAS 112:5915–5920

Gingras M, Hagadorn JW, Seilacher A, Lalonde SV, Pecoits E, Petrash D, Konhauser KO (2011) Possible evolution of mobile animals in association with microbial mats. Nature Geoscience Letters 4:372–375

Guhey R, Sinha D, Tewari VC (2011) Meso-Neoproterozoic stromatolites from the Indravati and Chhattisgarh basins, Central India. In: Tewari VC, Seckbach J (eds) Stromatolites: interaction of microbes with sediments. Springer, Berlin, pp 23–42

Hoshino Y, Poshibaeva A, Meredith W, Snape C, Poshibaev V, Versteegh GJM, Kuznetsov N, Leider A, van Maldegem L, Neumann M, Naeher S, Moczydłowska M, Brocks JJ, Tang Q, Xiao S, McKirdy D, Das SK, Alvaro JJ, Sansjofre P, Hallmann C (2017) Cryogenian evolution of stigmasteroid biosynthesis. Sci Adv 3(9):1–7

Hofmann HJ, Schopf JW (1983) In: Schopf JW (ed) Earth's earliest biosphere. Princeton University Press, Princeton, pp 321–360

Hofmann HJ, Mountjoy EW (2001) Namacalathus-Cloudina assemblage in Neoproterozoic Miette Group (Byng Formation), British Columbia: Canada's oldest shelly fossils. Geology 29:1091–1094

Javaux E, Knoll AH, Walter MR (2003) Recognizing and interpreting the fossils of early eukaryotes. Orig Life Evol Biosph 33:75–94

Jodder J, Hofmann A (2016) Carbonaceous cherts of the Daitari Greenstone Belt, Singhbhum Craton, India: a well preserved record of early life. Abstract, 35th Inter. Geol. Cong. 27th Aug to 4th Sept. 2016, Cape Town, South Africa

Jones HC (1909) In general report. Records Geol Sur India 3:66

King W (1872) The Kadapah and Karnul formations in the Madras Presidency. Mem Geol Sur India 8:124–258

Kirschvink JL, Kopp RE (2008) Palaeoproterozoic ice houses and the evolution of oxygen-mediating enzymes: the case for a late origin of photosystem II. Philos Trans R Soc Lond Ser B Biol Sci 208:2755–2765

Knoll AH, Carroll SB (1999) Early animal evolution: emerging views from comparative biology and geology. Science 284:2129–2137

Knoll AH (2000) Learning to tell Neoproterozoic time. Precambrian Geology 100:3–20

Knoll AH, Walter MR, Narbonne GM, Christie-Blick N (2004) A new period for the geologic time scale. Science 305:621–622

Kumar S (1995) Megafossils from the Mesoproterozoic Rohtas formation (the Vindhyan Supergroup), Katni area, Central India. Precambrian Res 72:171–184

Kumar S, Sharma M (2012) Vindhyan Basin, Son Valley Area, Central India: PSI field guide-4. Palaeontol Soc India:145

Loon van AJ, Mazumder R (2013) First find of biogenic activity in the Palaeoproterozoic of the Singhbhum Craton (E India). Andean Geol 19:185–192

Mathur VK (2008) Ediacaran multicellular biota from Krol Group, Lesser Himalaya and its stratigraphic significance—a review. Palaeobotanist 57:53–61

Maithy PK, Kumar G (2007) Biota in the terminal Proterozoic successions on the Indian subcontinent: a review. In: Vickers-Rich P, Komarower P (eds) The rise and fall of the Ediacaran Biota, Geol. Soc London, Special Publication, vol 286, pp 315–330

Mani D, Patil DJ, Dayal AM, Kavitha S, Hafiz M, Hakhoo N, Bhat GM (2014) Gas potential of Proterozoic and Phanerozoic shales from the NW Himalaya, India: inferences from pyrolysis. Int J Coal Geol 128–129:81–95

Martin MW, Grazhdankin DV, Bowring SA, Evans DAD, Fedonkin MA, Kirschvink JL (2000) Age of bilaterian body and trace fossils, White Sea Russia: implications for metazoan evolution. Science 288:841–845

McClelland J (1834) Notice of some fossil impressions occurring in the transitional Limestone of Kumaun. J Asiatic Soc Bengal 3:628–631

Meert JG, Gibsher AS, Levashova NM, Grice WC, Kamenov GD, Ryabinin AB (2011) Glaciation and ~770 Ma Ediacara (?) Fossils from the Lesser Karatau Microcontinent, Kazakhstan. Gondwana Res 19:867–880

Narbonne GM (2005) The Ediacara biota: Neoproterozoic origin of animals and their ecosystems. Annu Rev Earth Planet Sci 33:421–442

Pandey SK (2014) Thrombolites from the Neoproterozoic Bhander Group, Vindhyan Supergroup, Central India. In: Rocha R, Pais J, Kullberg J, Finney S (eds) STRATI 2013. Springer Geology. Springer, Cham

Patranabis-Deb S, Słowakiewicz M, Tucker ME, Pancost RD, Bhattacharya P (2016) Carbonate rocks and related facies with vestiges of biomarkers: clues to redox conditions in the Mesoproterozoic ocean. Gondwana Res 35:411–424

Prasad B, Asher R (2001) Biostratigraphy and lithostratigraphic classification of Proterozoic and Lower Paleozoic sediments (Preunconformity sequence) of Ganga Basin, India. Paleontographica Indica 5:1–155

Prasad B, Uniyal SN, Asher R (2005) Organic walled microfossils from the Proterozoic Vindhyan sediments of Son Valley, Madhya Pradesh, India. Palaeobotanist 54:13–60

Prasad B, Asher R, Borgohai B (2010) Late Neoproterozoic (Ediacaran)-Early Paleozoic (Cambrian) acritarchs from the Marwar Supergroup, Bikaner-Nagaur Basin, Rajasthan. J Geol Society of India 75:415–431

Prasad B, Asher R (2016) Record of Ediacaran complex acanthomorphic acritarchs from the Lower Vindhyan succession of the Chambal Valley (east Rajasthan), India and their biostratigraphic significance. J Palaeontol Soc India 61:29–62

Prasanna MV, Rasheed MA, Patil DJ, Dayal AM, Reddy BR (2013) Geo-microbiological studies in conjunction with different geo-scientific studies for the evaluation of hydrocarbon prospects in Proterozoic Vindhyan Basin, India. J Pet Sci Eng 108:239–249

Raha PK, Shastry MVA (1982) Stromatolites and Precambrian stratigraphy in India. Precambrian Res 18:298–318

Raju S, Mathur N, Sarmah M (2014) Geochemical characterization of Neoproterozoic heavy oil from Rajasthan India implications for future exploration of hydrocarbons. Curr Sci 107:1298–1305

Rasmussen B, Fletcher IR, Brocks JJ, Kilburn MR (2008) Reassessing the first appearance of eukaryotes and cyanobacteria. Nature 455:1101–1104

Ray JS, Veizer J, Davis WJ (2003) C, O, Sr and Pb isotope systematics of carbonate sequences of the Vindhyan Supergroup, India: age, diagenesis, correlations and implications for global events. Precambrian Res 121:103–140

Ray JS (2006) Age of the Vindhyan Supergroup: a review of recent findings. J Earth Syst Sci 115:149–160

Reysenbach AL, Cady SL (2001) Microbiology of ancient and modern hydrothermal systems. Trends Microbiol 9:79–86

Samanta P, Mukhopadhyay S, Mandal A, Sarkar S (2011) Microbial Mat structures in profile: the Neoproterozoic Sonia Sandstone, Rajasthan, India. J Asian Earth Sci 40:542–549

Samanta P, Mukhopadhyay S, Sarkar S, Eriksson PG (2015) Neoproterozoic substrate condition vis-à-vis microbial mat structure and its implications: Sonia Sandstone, Rajasthan, India. J Asian Earth Sci 106:186–196

Sarangi S, Gopalan K, Kumar S (2004) Pb–Pb age of earliest megascopic eukaryotic alga bearing Rohtas Formation, Vindhyan Supergroup, India: implications for Precambrian atmospheric oxygen evolution. Precambrian Res 132:107–121

Sarkar S, Bose PK, Samanta P, Sengupta P, Eriksson PG (2008) Microbial mat mediated structures in the Ediacaran Sonia Sandstone, Rajasthan, India, and their implications for Proterozoic sedimentation. Precambrian Res 162:248–263

Sarkar S, Banerjee S, Samanta P, Jeevankumar S (2006) Microbial mat-induced sedimentary structures and their implications: examples from Chorhat Sandstone, M.P., India. J Earth Syst Sci 115:49–60

Sarkar S, Samanta P, Altermann W (2011) Setulfs, modern and ancient: formative mechanism, preservation bias and Palaeoenvironmental implications. Sediment Geol 238:71–78

Sarkar S, Banerjee S, Samanta P, Chakraborty N, Chakraborty PP, Mukhopadhyay S, Singh AK (2014) Microbial mat records in siliciclastic rocks: examples from four Indian Proterozoic basins and their modern equivalents in Gulf of Cambay. J Asian Earth Sci 91:362–377

Schieber J, Bose PK, Eriksson PG, Banerjee S, Sarkar S, Altermann W, Catuneanu O (eds) (2007) Atlas of microbial mat features preserved within the siliciclastic rock record. Elsevier, Amsterdam. 311 p

Schopf JW (1992) In: Schopf JW, Klien C (eds) The Proterozoic Biosphere: a multidisciplinary study. Cambridge University Press, Cambridge. 1348 p

Schopf JW (1999) Cradle of life. The discovery of Earth's earliest fossils. Princeton University Press, Princeton, NJ, p 367

Seilacher A, Bose PK, Pflüger F (1998) Triploblastic animals more than 1 billion years ago: trace fossil evidence from India. Science 282:80–83

Sharma M (2006a) Small-sized Akinetes from the Mesoproterozoic Salkhan Limestone, Semri Group, Bihar, India. J Palaeontological Soc India 51:109–118

Sharma M (2006b) Late Palaeoproterozoic (Statherian) carbonaceous films from the Olive Shale (Koldaha Shale), Semri Group, Vindhyan Supergroup, India. J Palaeontological Soc India 51:27–35

Sharma M (2008) Neoproterozoic biotic signatures in the Peninsular Indian Basins—an overview. Mem Geol Soc India 74:119–131

Sharma M, Shukla Y (2009a) The evolution and distribution of life in the Precambrian Eon-Global perspective and the Indian record. J Biosci 34:765–776

Sharma M, Shukla Y (2009b) Taxonomy and affinity of Early Mesoproterozoic megascopic helically coiled and related fossils from the Rohtas Formation, the Vindhyan Supergroup, India. Precambrian Res 173:105–122

Sharma M, Shukla Y (2012a) Megascopic Carbonaceous compression fossils from the Neoproterozoic Bhima basin, Karnataka, South India. Geol Soc Lond, Spec Publ 366:277–293

Sharma M, Shukla Y (2012b) Occurrence of helically coiled microfossil Obruchevella in the Owk Shale of the Kurnool Group and its significance. J Earth Syst Sci 121:755–768

Sharma M, Mishra S, Dutta S, Banerjee S, Shukla Y (2009) On the affinity of Chuaria–Tawuia complex: a multidisciplinary study. Precambrian Res 173:123–136

Sharma M, Tiwari M, Ahmad S, Shukla R, Shukla B, Singh VK, Pandey SK, Ansari AH, Shukla Y, Kumar S (2016) Palaeobiology of Indian proterozoic and early cambrian successions—recent developments. Proc Indian Natl Sci Acad 82:559–579

Sharma M, Kumar S, Tiwari M, Shukla Y, Pandey SK, Srivastava P, Banerjee S (2012) Palaeobiological constraints and the Precambrian biosphere: Indian evidence. Proc Indian Natl Sci Acad 78:407–422

Shen Y, Schidlowski M (2000) New C isotope Stratigraphy from southwest China: implications for the placement of the Precambrian–Cambrian boundary on the Yangtze platform and global correlations. Geology 28:623–626

Shu D, Isozaki Y, Zhang X, Han J, Maruyama S (2014) Birth and early evolution of metazoans. Gondwana Res 25:884–895

Shukla R, Tiwari M (2014) Ediacaran acanthomorphic acritarchs from the Outer Krol Belt, Lesser Himalaya, India: their significance for global correlation. Palaeoworld 23:209–224

Singh VK, Sharma M (2014) Morphologically Complex Organic-Walled Microfossils (OWM) from the Late Palaeoproterozoic—Early Mesoproterozoic Chitrakut Formation, Vindhyan Supergroup, Central India and their implications on the antiquity of eukaryotes. J Palaeontol Soc India 59:89–102

Srivastava P (2002) Carbonaceous megafossils from the Dholpura Shale, uppermost Vindhyan Supergroup, Rajasthan: an age implication. J Paleontol Soc India 47:97–103

Srivastava P, Bali R (2006) Proterozoic carbonaceous remains from the Chorhat Sandstone: oldest fossils of the Vindhyan Supergroup, Central India. Geobios 39:873–878

Srivastava P (2006) Meso–Neoproterozoic coated grains and palaeoecology of associated microfossils: the Deoban Limestone, Lesser Himalaya, India. Palaeogeogr Palaeoclimatol Palaeoecol 239:241–252

Srivastava P (2009) Trachyhystrichosphaera, an age marker acanthomorph from the Bhander Group, Upper Vindhyans, Rajasthan. J Earth Syst Sci 118:575–582

Summons RE, Bradley AS, Jahnke LL, Waldbauer JR (2006) Steroids, triterpenoids and molecular oxygen. Philosophical Trans Royal Soc B 361:951–968

Sur S, Schieber S, Banerjee S (2006) Petrographic observations suggestive of microbial mats from Rampur Shale and Bijaigarh Shale, Vindhyan basin, India. J Earth Syst Sci 115:61–66

Tappan H (1980) The Palaeobiology of plant protists. WH Freeman and Company, San Fransisco. 1028 p

Tewari VC (2003) Sedimentology, palaeobiology and stable isotope chemostratigraphy of the Terminal Neoproterozoic Buxa Dolomite, Arunachal Pradesh NE Lesser Himalaya. Himal Geol 24:1–18

Tiwari VC, Sial AN (2007) Neoproterozoic–Early Cambrian isotopic variation and chemostratigraphy of the Lesser Himalaya, India, Eastern Gondwana. Chem Geol 237:64–88

Tiwari M, Pant I (2009) Microfossils from the Neoproterozoic Gangolihat Formation, Kumaun Lesser Himalaya; their stratigraphic and evolutionary significance. J Asian Earth Sci 35:137–149

Tyler SA, Barghoorn ES (1954) Occurrence of structurally preserved plants in Precambrian rocks of the Canadian shield. Science 119:606–608

Viswanathiah MN, Venkatachalapathy V (1980) Microbiota from the Bababudan iron formation, Karnataka. J Geol Soc India 21:16–20

Waggoner B (2003) The Ediacaran biotas in space and time. Integr Comp Biol 43:104–113

Waldbauer JR, Sherman LS, Sumner DY, Summons RE (2009) Late Archean molecular fossils from the Transvaal Supergroup record the antiquity of microbial diversity and aerobiosis. Precambrian Res 169:28–47