Biota in the terminal Proterozoic successions on the Indian subcontinent: a review

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Abstract: On the Indian subcontinent, Late Proterozoic rocks form part of a continuous sequence grading into Cambrian, postdating the Sturtian glaciation (Cryogenian) and terminated by the Xingkaian/Pan African Orogeny (Late Cambrian). These sequences are restricted to the northwestern part of the Indian Shield, are overlain by Cenozoic sediments of the Indo-Gangetic Plain, and rest unconformably on the oldest platform sequences (Meso—Cryogenian) in many parts of the Lesser and Tethys/Higher Himalaya. Of these, the succession in the Krol Belt, Lesser Himalaya, divided into Baliana, Krol and Tal Groups, is fossiliferous. Changes in faunal composition of acritarchs and cyanobacteria are recorded in the upper part of the Baliana Group, as is the appearance and extinction of forms assigned to the Ediacara fauna in the overlying Krol. Such biotic change is accompanied by a significant depletion in $\delta^{13}C$ values in the 'cap carbonates'. Another $\delta^{13}C$ depletion is recorded in the upper part of the Krol Group along with appearance of spiny acanthomorphic acritarchs, scaphomorphs and hercomorphs, small shelly fossils, a variety of Early Cambrian trace fossils and trilobites in the overlying Tal Group. A review of biota reported from the oldest platform sediments (Vindhyan Supergroup, Karnool, Bhima Groups) suggests a Meso-Cryogenian (pre-Sturtian glaciation) age.

On the Indian subcontinent, the Late Proterozoic successions grade conformably into the Cambrian, after the major tectono-thermal events associated with Chengjiangian/Cadomian Orogeny in the Cryogenian period and after the Sturtian glaciation. They were deposited in the Palaeotethys-I sea (Shanker *et al.* 2002). Exposures occur in the northwestern part of the Indian Shield, unconformably overlying basement composed of the Malani Igneous Suite (Malani Rhyolite 745 ± 10 Ma; Siwana Granite 731 ± 14 Ma) of the Indian Shield, and are overlain by Cenozoic sediments of the Indus and Ganges plains. These successions extend to the Himalayas, where they rest unconformably on the oldest platform-deposits, referred to as the Salkhala Group, with dated granites (745 ± 50 Ma) or its equivalents the Simla-Jaunsar and Jutogh Groups. These sequences have been examined in detail by participants of IGCP Projects 29 and 303 and IUGS Project on Terminal Proterozoic (Kumar 1995; Kumar *et al.* 1997). In view of the controversies that exist around the identification of fossils ranging in age from Late Proterozoic into Cambrian, other sequences such as the Bhima, Karnool, Chattisgarh and Indravati Groups that occur in detached areas over the basement formed of oldest platform sediments (the Vindhyan or Cuddapah Supergroups over the Archaean–Palaeoproterozoic terrane of the peninsular India), this material have been reviewed and compared the geology and fossils from the Baliana-Krol-Tal succession. The record of microbiota of Late Proterozoic–Cambrian age from the Buxa or Chilleipam formations, of Arunachal Pradesh, Lesser Himalaya (Tewari 2003) appears to be dubious, as the succession is intruded by granite dated at 1536 ± 60 Ma (Kumar 1997) and hence is, not considered here.

Geological setting

The Indian subcontinent is an assembly of four distinct Archaean–Palaeoproterozoic crustal blocks/terranes, *viz.* Dharwar (DB), Bundelkhand (BB), Trans-Aravalli (TAB) and South Indian–Sri Lankan Granulite (SISLGB). Each has an independent geological history through Archaean and Palaeoproterozoic and are separated by a mobile belt. The first three blocks welded together *c.* 1600 Ma (Zhongyuan/Karelian Orogeny) to form the protocontinent Protorodinia, and the SISLGB welded to DB around *c.* 500 Ma (Xingkaian/Pan-African Orogeny) to form part of Gondwanaland (Shanker *et al.* 2002). Protorodinia formed basement upon which two sequences of platform sediments were deposited during the Precambrian related to two significant marine transgressions of differing magnitude and configuration. These seas are referred to as the Prototethys and Palaeotethys,

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each with many cycles related to global tectonothermal events (Shanker *et al.* 2002). Deposition of older sequence took place in the Prototethys commencing in the Mesoproterozoic (*c.* 1500 Ma) and ending with break-up of Rodinia *c.* 750 Ma (Chengjiangian/Cadomian Orogeny) in Cryogenian when sea regressed to the build-up of the Sturtian glaciation. Indicators of other tectonothermal events, *viz*. the Grenvillian (*c.* 1100 Ma) and Jinningian (*c.* 850 Ma) are also present. Relicts of this sequence are presently exposed on Indian shield—the Vindhyan Supergroup and its equivalents Chattisgarh in Central India; the Cuddapah-Karnool, Pakhal/Indravati, and Bhima groups in Southern India (Fig. 1); the Bahraich-Madhubani groups in the Indo-Ganges Plain and are referred to as the Vaikrita/Jutogh and Jaunsar groups in the Himalaya (Shanker *et al.* 1989).

With warming of the climate during the late Cryogenian, sedimentation in the Late Proterozoic commenced (*c.* 650 Ma) in the Palaeotethys-I, giving rise to sequences located on the northwestern Indian Shield and in many parts of the Lesser Himalayan and Higher/Tethys zones (Fig. 2). Such sedimentation was ended by the Xingkaian/Pan-African Orogeny during Late Cambrian (*c.* 500 Ma). In the Higher/Tethys Himalaya, this sequence is unconformably overlain by Ordovician–Early Carboniferous sediments while parts of the Lesser Himalaya and the Peninsular Shield remained positive areas until the Early Permian marine transgression. Successions located in the Krol Belt, Lesser Himalaya and northwestern part of the Indian Shield are siliciclastic low in the section with the development of thick carbonate–evaporite facies, with or without phosphorite, in upper part, whereas those in the Higher/Tethys Himalaya are dominantly siliciclastic throughout.

The lower and upper boundaries of the Late Proterozoic (Ediacaran) are not precisely defined in the absence of diagnostic fossils or radiometric dates. However, (Knoll *et al.* 2006), the lower boundary of the Ediacaran is defined in the Lesser Himalaya as the base of the top Pink Limestone (Member G) of the Baliana Group. Significant depletion in $\delta^{13}C$ values is recorded in this pink carbonate (Kumar *et al.* 2000). The upper boundary with the Cambrian cannot be ascertained in terms of the GSSP due to absence of the characteristic Cambrian trace fossil of global Ichno-Zone II (Kumar *et al.* 1997). However, a significant depletion in $\delta^{13}C$ values has also been recorded in

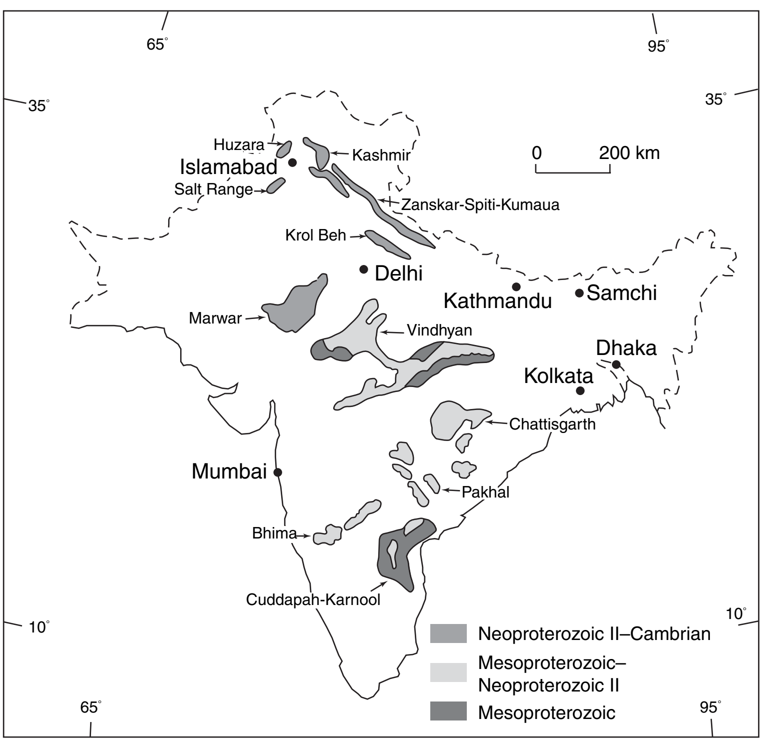

Fig. 1. Map of the Indian subcontinent with location of Mesoproterozoic, Mesoproterozoic Neoproterozoic II and Neoproterozoic II–Cambrian sequences.

Geological Time Scale	Himalaya – Tethys Himalaya – India: **Kashmir Valley** (Kumar *et al.* 1984)	Himalaya – Tethys Himalaya – India: **Zanskar-Spiti** (Srikantia & Bhargava 1998)	Himalaya – Tethys Himalaya – India: **Kumaun** (Kumar 2005)	Himalaya – Tethys Himalaya – India: **Arunachal** (Kumar 1997)	Himalaya – Tethys Himalaya: **Bhutan** (Bhargava 1995)	Himalaya – Lesser Himalaya – Pakistan: **Hazara** (modified after Butt 1989 *in* Kazmi & Jan 1997)	Himalaya – Lesser Himalaya – India: **Jammu Area** (Jangpangi *et al.* 1986)	Himalaya – Lesser Himalaya – India: **Kumaun (Krol Belt)** (Shanker *et al.* 1993)	**Indo-Gangetic Plain** – India: (Shukla *et al.* 1994)	Peninsular Shield – Pakistan: **Salt Range** (Kazmi & Jan 1997)	Peninsular Shield – India: **Northwestern** (after Kumar *et al.* 1997)
Early Cambrian	Lolab Formation	Kunzam La Fm.	Martoli Group: Milam Fm.	Lum La Formation	Pele La Group (Maneting Fm.); Deshichiling Fm. Singhi Fm.	Shekhan Bandi Fm. Hazira Fm.; Abbottabad Formation: Mirpur Mem.		Tal Group: Dhaulagiri Fm.; Deo Ka Tibba Fm.	?Karanpur Formation	Jutana Fm.; Kussak Fm.; Khewra Sandstone	Marwar Supergroup: Birmania Formation
Neoproterozoic – Ediacaran	Machhal Formation	Batal Fm.			Chekha Fm./ Naspe Fm.	Mahhdagali; Sangargali	Sincha Fm.	Krol Group: Kauriyala Fm.; Jarashi Fm. Mahi Fm.; Baliana Group: Infra Krol Fm.		Salt Range Fm. with Khewra Trap at the top	Nagaur Fm.; Hanseran Evaporite; Bilara Fm.
Neoproterozoic – Cryogenian	Ramsu Fm.					Tanaki Mem.	Bhimdasa Fm.	Blaini Fm.			Jodhpur Formation
	~~	~~~~~~~~~	~ ? ~~	~~~~~~~~	~~~~~~~~~~~~~	~~~~~~~~~~~~~~	~~~~~~~~~	~~~~~~~~~~~~~~~~~	~~~~?~~	~~~~~~~	~~~~~~~~~~~~~
Neoproterozoic – Cryogenian	Salkhala Group	Salkhala/ Vaikrita Group	Bilju Fm.	Sela Formation (?Archaean-Palaeoproterozoic)	Central Crystalline (?Archaean-Palaeoproterozoic)	Tanawal Formation	Gamir – Baila - Ramban Fms.	Jaunsar/Vaikrita Group	Bahraich Group; Madhubani Group: (Ujhani–Tilhar-?Karanpur Fms.)	Kirana Group	Malani Rhyolite & granite
Neoproterozoic – Tonian			Rilkot Fm.								
Mesoproterozoic			Dar Fm.								?

Fig. 2. Correlation chart of the Neoproterozoic–Early Cambrian sequences, Indian Subcontinent.

the upper part of carbonate facies of the Krol Group, between horizons yielding Ediacaran fossils and the Early Cambrian phosphorite beds containing small shelly fossils characteristic of the Meischucunian Zone I in the overlying Tal Group. This depletion has also been recorded in the Marwar Supergroup, below a phosphorite bed, and may be correlated with that recorded from Precambrian–Cambrian transition sequence.

Biota and organo-sedimentary structures

Biotic remains are known from the Ediacaran sequences in India, excepting the Marwar Supergroup. Of these Late Proterozoic successions significant biota has been recorded from the Krol Belt, Lesser Himalaya, and Kashmir Higher Himalaya. In Krol Belt (Baliana-Krol-Tal groups), fossil cyanobacteria and acritarchs are present as are fossils reminiscent of Ediacarans: calcareous algae, Conophytonoid and Gymnosolonid stromatolites along with evaporites and phosphate deposits. The sequence is conformably overlain by Early Cambrian Tal Group, which yields trace fossils of the global Ichno-Zone III (Landing 1994), small shelly fossils and stromatolites of the Meischucunian Zone and I & III (Tommotian), redlichid trilobites, microgastropods and inarticulate brachiopods of Qiongzhusian (Atdabanian) and Tsanglangpuian (Botomian) stages (Kumar 1984). Sequences in the Higher/Tethys Himalaya have yielded trace fossils of Ichno-Zone I, II and III, and Early Cambrian (Tommotian) to Middle Cambrian trilobites and brachiopods. Fossils of Late Proterozoic age are rare (Maithy *et al.* 1988) and the diagnostic trace fossils of global Ichno-Zone I are not recorded making precise demarcation of upper boundary of the Late Proterozoic difficult (Raina *et al.* 1983).

Lesser Himalaya: Krol Belt

The Cryogenian to Cambrian succession of this region is divided lithostratigraphically into three groups referred to as the Baliana, Krol and Tal groups. These are exposed in many synclinal outliers, such as the Pachmunda, Nigalidhar, Korgai, Mussoorie, Garhwal and Nainital synclines, in a linear zone stretching over 350 km in the region of the outer Lesser Himalaya (Shanker *et al.* 1993). This sequence rests unconformably on the Jaunsar Group and is transgressively overlapped either by Early Permian or by Late Cretaceous–Paleocene sediments in parts of the Garhwal and Mussoorie synclines.

Baliana Group

Divided into two formations, the Blaini and Infra Krol formations (Fig. 3).

Blaini Formation. Cyanophycean algae *Blainiella*, comparable to extant algal form *Hyella*, has been recorded from the black and bleached shales of the Mussoorie Syncline (Maithy *et al.* 1995). The form is characterized by a linear filament arranged with rectangular cells placed end to end. In extent *Blainiella*, reproduction is by endosporulation. Thick globular endospores form towards the terminal end of filament and release baeocytes by wall dissolution of endospores. Microbialite *Stratifera unduata* has been reported from the Mussoorie Syncline (Sharma *et al.* 1994).

Infra Krol Formation. Organic walled microfossils (OWM) have been reported from black chert nodules and silicified shale of the topmost litho-unit of the Baliana Group from a unit referred to as the Infra Krol at different locales in the Solon area (Pachmunda, Mussoorie and Nainital Synclines). These microfossils belong to Cyanophycean algae and acritarchs (Tiwari & Azmi 1992; Tiwari & Knoll 1994; Tiwari 1996). Large acanthomorphic acritarchs (*Ericasphera*, *Echinosphaeridium*, *Asterocapsoides*) and Cyanophycean remains similar to *Salome* are dominant forms.

In the Mussoorie Syncline (Prasad *et al.* 1990) and Nainital Syncline (Acharyya *et al.* 1989; Venkatachala *et al.* 1990; Tiwari 1996; Shukla *et al.* 2005) acritarchs included sphaeromorphids, sphaerohystrichomorphids along with vase-shaped microfossils, Synaplomorphitae and Nematomorphitae. The age of the Infra Krol has in the past been considered to post-date Marinoan glaciation and thus could predate the diversification of Ediacaran metazoans (Shukla *et al.* 2005).

Krol Group

The Krol Group has been divided into three formations: Mahi (Krol A), Jarashi (Krol B) and Kauriyala (Krol C, D & E) formations in ascending order (Fig. 3). It has yielded rich assemblages of what has been identified as Ediacaran fauna, acritarchs and stromatolites along with calcareous algae (Fig. 3). Prasad *et al.* (1990) assigned the acritarchs to the Sphaeromorphidae from Mussoorie. The acritarch assemblage is characterized by smooth and sculptured-walled forms.

Mahi Formation. Kumar & Rai (1992) noted algal filamentous forms, coccoid acritarchs and spheroid colonies. Subsequently, Gautam & Rai (1997) reported empty sheaths of unbranched filaments, branching filaments resembling eukaryotic forms and a form comparable to Bangiophyceae also known from the Pachmunda Hills in the Solon area. Ediacaran metazoans have been assigned to *Nimbia* cf. *N. occlusa*, recorded from the Mahi Formation (Shanker *et al.* 2004).

BIOTA	Baliana Group								Krol Group				
	Blaini Formation							Infra Krol Fm. (380 m)	Mahi Fm. (254 m)	Jarashi Fm. (54 m)	Kauriyala Formation		
	Member												
	A (137 m)	B (805 m)	C (452 m)	D (398 m)	E (249 m)	F (55 m)	G (Cap Carbonate) (4 m)				L. Mem. (Krol C) (134 m)	Mid. Member (Krol D) (636 m)	Upper Member (Krol E) (228 m)
Ediacaran:													
Kimberella sp.										--			
Pteridinium sp. cf. *P. carolinaense*										--			
Charniodiscus sp. cf. *arboreus*										--		---------	
Beltanelliformis sp.												---------	
Medusinites sp.												---------	
Tirasiana sp.												---------	
Cyclomedusa sp.												---------	
Beltanella sp.												---------	
Sekwia sp.												---------	
Irridinitus sp.												---------	
Nimbia sp. cf. *N. occlusa*									-----				
cf. *Dickinsonia*												---------	
Conomedusites sp.												---------	
Acritarcha:													
Sphaeromorphida:													
Leiosphaeridia crassa								-----					
L. effusa								-----					
Baltisphaeridium perraum								-----					
Margominuscula simplex								-----					
Granomarginata primitiva								-----					
Gorgonisphaeridium maximum								-----					
Trachyhystrichosphaera vidalii								-----					
Microconcentrica incrustata								-----					
Trachysphaeridium attenuatim		--------------	--------	------				-----				---------	
Saharidia downii													----
Protosphaeridium volkovae		---------------	--------	------									
P. densum													-------
Vavosphaeridium sp.													-------
Favosphaeridium sp.													-------
Orygmatosphaeridium plicatum		---------------	--------	------									
Symplassoapheridium sp.		--------------	--------	------									
Sphaerohystrichomorphida:													
Ericiasphaera spjeldnaesii								-----					
Echinosphaeridium maximum								-----					
Asterocapsoides sp.								-----					
Micrhystridium echinuatum								-----					
M. tornatum								-----					
Microconcentrica incrustata								-----					
Germinosphaera unispinosa								-----					
Paracrassosphaera dedalea								-----					
Micrhstridium echinuatum								-----					
M. regulare								-----					
M. eatonensis								-----					
Archaeohystrichosphaeridium celluare								-----					
A. semireticulatum								-----					
Cyanobacteria (Cryptarch):													
Synaplomorphitae:													
Blainiella polymorpha		---------------	--------	------									
Globophycus rugosum								-----					
Tetraphycus hebeinsis								-----					
Eomicrocystis malgica								-----					
Bavlinella faveolata								-----					
Satka colonialica								-----					
Palaeoanacystis vulgaris								-----					
Eosphaera sp.								-----					
Nematomorphitae:													
Gunflintia sp. cf. *G. minuta*								-----					

Fig. 3. Distribution of biota and organo-sedimentary structures in the Baliana-Krol Groups, Krol Belt, Lesser Himalaya.

Eomycetopsis robusta								-----	-----				
Salome hubeiensis									-----				
Siphonophycus sepatum									-----				
S. robustum								-----	-----				
S. rugosum									-----				
S.inornatum								-----					
Eomorphidium orculiformis								-----					
Satka colonialica								-----					
Obruchevella sp.								-----	-----				
Vase-shaped Microfossil:													
Melanocyrillium hexadiadema								-----					
Calcareous Algae:													
Renalcis sp.											---		-----
Epiphyton sp.									-----				-----
Stromatolites:													
Stratifera undata							--						
Stratifera irregularis												----------------	
Conophyton garganicus												----------------	
Baicalia baicalia												----------------	
Colonella sp.												----------------	
Paniscollenia sp.												----------------	
Patomia sp.												----------------	
Aldania sp.												----------------	
Algal oolites:											---		
Trace Fossils:													
Gordia sp.												----------------	
Bilinichnus biserialis												----------------	
Ichnogenus A												----------------	

Fig. 3. (*Continued*).

Jarashi Formation. Ediacaran fossils, cf. *Pterinidium carolinaense* (Fig. 4) and cf. *Charnodiscus arborens* (Shanker *et al.* 2004) have been reported from this sequence.

Kauriyala Formation. Consists of the Krol C, Krol D and Krol E members. Fossil content includes the calcareous algae *Renalcis* along with *Oleckmia* from the Krol C (Lower Member) of the Kauriyala Formation of the Nainital Syncline (Gansser 1964).

Ediacaran fossils have also been reported from many locales in the Krol D Member (Fig. 3) (Mathur & Shanker 1989, 1990; Shanker & Mathur 1992; Shanker *et al.* 1997; Mathur & Srivastava 2004). Forms that have been named are *Cyclomedusa* (Fig. 5), *Conomedusites* (Figs 6, 7), *Charniodiscus* (Fig. 8), *Kimberella* sp. cf. *K. quadrata* (Fig. 9), *Dickinsonia* sp. (Fig. 10) and *Beltanella* sp. cf. *B. gilesi* (Fig. 11). The reported *Zolotytsia* is a dubiofossil.

Stromatolites are known from Krol D in the Nainital and Mussoorie synclines (Fuchs & Sinha 1974; Singh & Rai 1977; Tewari 1984). Linked *Conophyton*, *Stratifera*, *Aldania* and *Irregularia* and branching stromatolites are dominant. Calcareous algae similar to *Epiphyton* and *Renalcis* are also known from Krol E Member (Singh & Rai 1983). The reported Archaeocyatha, according to Debrenne *et al.* (1990), is an invalid record.

Fig. 4. *Pteridinium* sp. cf. *P. carolinaense.* GSI No 21129. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI. Reproduced from Mathur & Srivastava (2004).

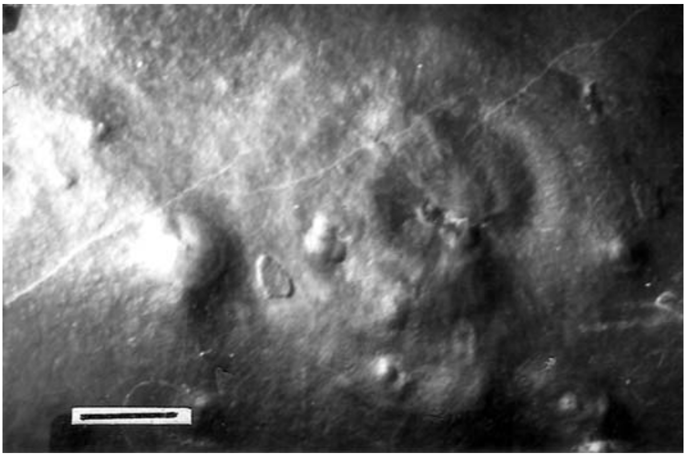

Fig. 5. *Cyclomedusa davidi.* GSI No 20426. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI. Reproduced from Shanker *et al.* (1997).

Higher/Tethys Himalaya, Kashmir

Organic walled microfossils have been described by Kumar *et al.* (1984) and Maithy *et al.* (1988) from the upper 480 m of the Machhal Formation to 580 m of the overlying Razdain Member of the Lolab Formation of the Kashmir Valley. This assemblage contains sphaeromorphida acritarchs, tubular cyanophytes along with globular colonies. This sequence appears to be of Late Proterozoic age as noted by the above authors.

Trace fossils form two assemblages: Assemblage I *Planolites beverleyensis*, *P. reticulatus* in association with *Skolithos* and *Bergaueria* from the Razdain Member, Lolab Formation, Kashmir (assigned to Late Proterozoic). Assemblage I is older than Assemblage II which yields Early Cambrian forms in the Upper part of the Lolab Formation (Raina *et al.* 1983; Kumar *et al.* 1984).

Indo-Gangetic Plain (Ganges Plain)

The Vindhyan sequence of Central India unconformably overlies the Bundelkhand Gneissic

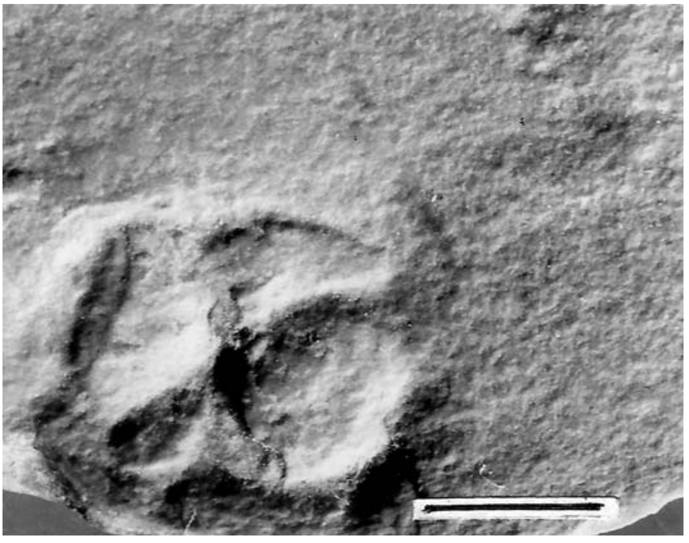

Fig. 6. *Conomedusites* sp. cf. *C. lobatus* (internal mould). GSI No 20429. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI. Reproduced from Shanker *et al.* (1997).

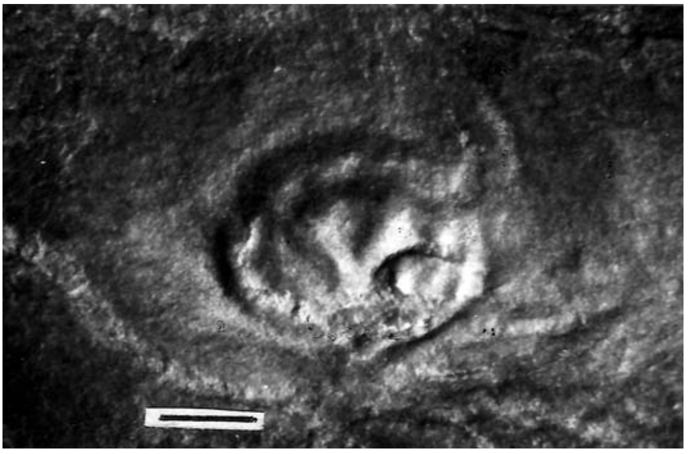

Fig. 7. *Conomedusites* sp. cf. *C. lobatus* (external mould). GSI No 20430. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI. Reproduced from Shanker *et al.* (1997).

Complex in the north and is concealed below Cenozoic sediments. These sediments are divided into the Bahraich and Madhubani groups, the latter further subdivided into the Ujhani, Tilhar and Karanpur formations in ascending order (Shukla *et al.* 1994). Of these, the Bahraich Group has yielded acritarchs belonging to sphaeromorphid Group. The Ujhani Formation contains acritarchs assigned to the genera *Granomarginata*, *Orygmatosphaeridium*, *Vavosphaeridium*, *Kildinella*, *Nucellosphaeridium* along with algae (*Myxococcoides*, *Palaeoanacystis* and *Gunflintia*) (Maithy *et al.* 1983). *Protosphaeridium* and *Vavosphaeridium* are reported from the Tilhar Formation. *Leiosphaeridia*, *Granomarginata*, *Lophosphaeridium*, *Ellipsaletes* and *Dictyotidium* (Prasad & Asher 2001) have been reported from the Karanpur Formation. The Bahraich and Ujhani groups are considered lateral equivalents of the Semri Group (Mesoproterozoic), while the Tilhar and Karanpur formations are correlated with the Bhander Group of Mesoproterozoic to Cryogenian (pre-Sturtian glaciation) age. However, Prasad & Asher (2001). considered the Madhubani Group to span from the latest Ediacaran to earliest Devonian on the basis of microbiota

Fig. 8. *Charniodiscus* sp. (holdfast). GSI No 20432. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI. Reproduced from Shanker *et al.* (1997).

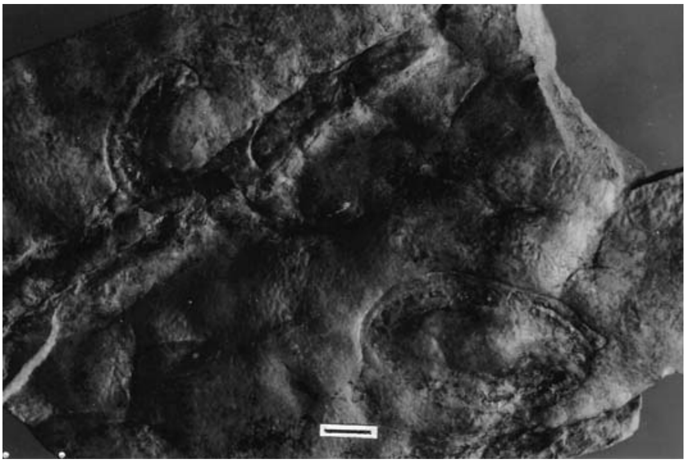

Fig. 9. *Kimberella* sp. cf. *K. quadrata.* GSI No 20399. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI. Reproduced from Shanker & Mathur (1992).

they described. A review of the overall organic walled microfossils indicates that the assemblage is dominated by ornate acritarchs in association with simple ones and Chitinozoa have simple morphologies. In the Silurian and Devonian, acritarchs with complex spines (branched) and ornamentation are known along with complex Chitinozoa and trilete spores. The absence of these forms in Madhubani Group raises doubts as to the conclusion drawn by Prasad & Asher (2001). The present analysis, however, indicates the youngest of the sediments are only Cambrian. Further detailed collecting from drill-core and careful analysis of the microfossils would help resolve this issue.

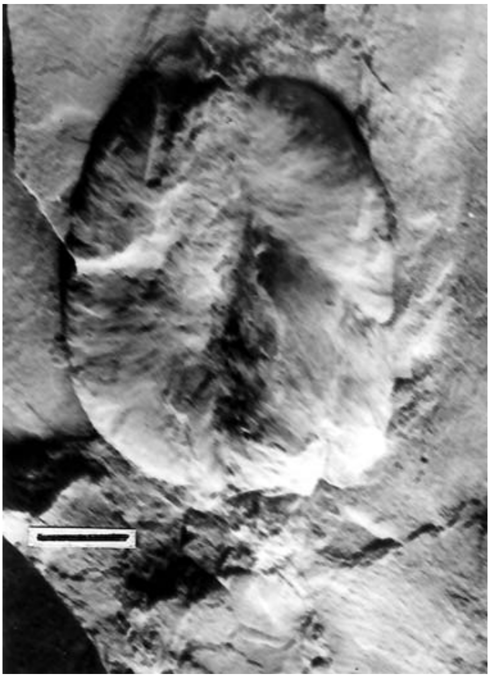

Fig. 10. *Dickinsonia* sp. GSI No 21149. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI. Reproduced from Mathur & Srivastava (2004).

Peninsular India

Sediments of Ediacaran age are lacking from the greater part of the Peninsular India (central and southern India) except in the NW where represented by the Marwar Supergroup. In view of the claims of Ediacaran–Cambrian fossils in the Vindhyan Supergroup and Bhima Group, these successions and others, such as Karnool, Cuddapah and Chhattisgarh sequences are also reviewed in Fig. 12.

Marwar Supergroup

The Marwar Supergroup unconformably overlies the Malani Igneous Suite (Malani Rhyolite dated at 745 $\pm$ 10 Ma; Siwana Granite 731 $\pm$ 14 Ma) or Palaeoproterozoic metasediments. The Marwar Supergroup is divided is ascending order into Jodhpur, the Bilara (Lower Carbonate), the Hanseran Evaporite, and the Nagaur and Birmania (Upper Carbonate) formations. A significant depletion in $\delta^{13}C$ values occurs in the upper part of the Bilara Formation and a short lived positive excursion of $\delta^{13}C$ values occurs in the Birmania Formation at the phosphorite levels (Kumar *et al.* 1997).

Fig. 11. *Beltanella* sp. cf. *B. gilesi.* GSI No 20311. Scale bar, 5 mm. Repository: Museum, Geological Survey of India, Kolkatta (India). Courtesy: V. K. Mathur, GSI.

Stromatolites *Collenia pseudocolumanaris, Collenia* sp., *Concollenia, Cryptozoan accidentalis, Irregularia* sp. and *Stratifera* are recorded from the Bilara Formation (Burman 1980).

Vindhyan Supergroup

Stromatolites, macro- and microfossils have been reported in abundance from the Vindhyan Supergroup (Fig. 12). Two distinct types of stromatolite assemblages are known. The Semri Group is characterized by an abundance of coniform stromatolites, columnar forms and unnamed, passively branched forms. The assemblage is suggestive of an Early to Middle Riphean age. No stromatolites have been recorded from the Kaimur and Rewa groups, due to absence of carbonates. Stromatolites of the Bhander Group include *Baicalia* and *Tungussia*, which are assigned a Late Riphean age.

The carbonaceous macrofossils *Chuaria* and *Tawuia* have been reported from the Baghwar (Suket) Shale (Semri Group), the Jhiri Shale (Rewa Group), the Sirbu Shale and the Bhavpura (Dholpura) Shale of the Bhander Group (Maithy 2003). The record of the *Chuaria–Tawuia* association in the youngest formation of the Vindhyan indicates that the entire Vindhyan succession was deposited before the Sturtian glaciation. Hofmann (1992) has speculated that *Chuaria* and *Tawuia* may be one and the same taxon, the two forms representing an alternation of generations of a eukaryotic organism. Maithy (2003) noted that *Chuaria* and other discoidal forms are the gametophytic generation and he also suggested that *Tawuia* and other elongated forms represented the sporophytic generation of an extinct alga.

Acritarchs are well known from sediments ranging from youngest strata of the Semri Group: Bhagwar Shale, Kaimur Group, Rewa Group and Bhander Group (Maithy 2003). Available data indicate that the Semri, Kaimur and Rewa groups are dominated by Leiosphaeridia *sensu* Jankauskas. In the younger Bhander Group, the sphaeromorphid acritarchs are present: *Nucellophaeridium* with walls boasting a broad reticulum, *Favosphaeridium* and *Cymatosphaera* with encircling narrow wing-like structure. Additionally, a few acanthomorphid acritarch vesicles are recorded, with simple, short processes: *Baltisphaeridium* and *Michrystridium*. The Neoproterozoic vase-shaped microfossil *Melanocyrillium* is important (Maithy & Babu 1997). Until now, typical Cambrian acritarch groups Ellipsomorphida, Ooidomorphida and Versimorphida were unknown, thus indicating an absence of Late Proterozoic organisms in the Vindhyan sequence of India.

Azmi (1998) reported a variety of small shelly fossils from the topmost part of the Rohtasgarh Limestone and Shale in the Semri Group in the lower part of the Vindhyan sequence from two areas, Maihar and Rohtas in the Son Valley. He concluded that these sequences represent basal Meischucunian/Tommotian stages (Early Cambrian in age). This has been debated and examined by several workers (Bhatt *et al.* 1999). Most did not agree with the biogenicity of many of the reported 'fossil' specimens and considered them produced diagenetically as 'cone-in cone' structures with pointed apices which flare outwards and possess undulatory surfaces or perhaps mineral growths or fibrous calcite/secondary calcite veins (Sharma 2003).

Claims of the presence of ichno-fossils in the form of surface trails and tubes have also been made by many workers studying the Semri and Bhander groups, but most of these reports have

Vindhyan Supergroup (Bhattacharyya 1996)			Chhattisgarh Supergroup (After Murti 1987)		Pakhal Supergroup/ Indravati Group (After Rao 1987; Ramakrishnan 1987)		Cuddapah Supergroup & Karnool Group (After Ramam & Murty 1997)		Bhima Group (After Misra *et al.* 1987)	Characteristic biota
Upper Vindhyan sequence	Bhander Group	Bhavpura					Karnool Group	Nandyal Sh.	Harwal	**Carbonaceous remains**: ***Chuaria – Tawuia***; Sponge: ***Palaeophragmodictaya***
		Balwan Limestone						Koikuntla Limestone.	Katamdevarhalli Limestone.	Algae: ***Vindhyacapsiopsis, Palaeoglauocystis;*** Acritarchs***:Granomarginata***
		Maihar/ Shikaoda Sst						Paniam Quartzite		
		Sirbu Shale						Owk Shale	Halkal Shale	**Acritarchs**: ***Leiosphaeridia, Granomarginata, Baltisphaeridium, Favosphaeridium;*** Cryptarchs***: Eomycetopsis, Sphaerocongregus, Obruchevella, Gloeocapsomorpha***; Carbonaceou s remains: ***Chuaria circularis – Tawuia dalensis, Sinosabellidites huainanensis, Beltina danai, Protoarenicola baiguashansis***
		Bundi Hill Sst.	Raipur Group	Tarenga Formation						
		Lakheri Limestone		Chandi Formation	Penganga Gp.	Putnur Limestone		Narji Limestone	Shahabad Limestone	Stromatolites: ***Baicalia,Tungussia and Gymnosolen;*** Siliceous sponge spicules; ***Sekwia excentrica***, ?Trace fossils
		Ganurgarh Shale		Gunderdehi Formation		Takalapalli Arkose		Baganapalli Quartzite	Rabanapalli Conglomerate	Acritarchs: ***Leiosphaeridia, Orygmatosphaeridium, Granomarginata, Vavosphaeridium, Nucellosphaeridium, Cymatisophaerides, Polytrichoides***
	Rewa Group	Govindgarh Sandstone		Charmuria Formation						
		Jhiri Shale								Carbonaceous remains: ***Chuaria circularis, Tawuia dalensis***
		Asan Sst.								
		Panna Shale								
	Kaimur Group	Dhaundraul Quartzite								
		Mangesar Formation								
		Bijaigarh Shale								Acritarchs: ***Leiosphaeridia, Archaehystrichosphaeridium, Lophosphaeridium***
		Ghaghar Sandstone								
		Susnai Breccia								
		Sasaram Fm.								
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Fig. 12. Correlation of Mesoproterozoic–Neoproterozoic sequences in Peninsular India, based on organic remains.

Semri Group (Lower Vindhyan)	Rohtas Subgroup	Bhagwar Shale								Algae: ***Myxococcoides, Aphanocapsaopsis, Palaeoscytonema, Oscillatoriaceae;*** Acritarchs : ***Granomarginata, Symplassosphaeridium, Orygmatosphaeridium, Palaeoanacystis, Vavosphaeridium, Archaeofavosina, Kildenella, Nucellosphaeridium, Zonosphaeridium, Tasmanites, Leiosphaeridia;*** Carbonaceous: ***Chuaria circularis, C. minima, Tawuia dalensis, Grypania spiralis, Grypania, Tyrostenia, Daltaenia, Beltenia, Krishnania, Longfengsahnia choparensis***
		Rohtasgarh Limestone								
	~~	~~~~~~~~~~~~~~~~~~								
	Kheinjua Subgroup	Rampur Formation			Mulag Group	Laknavaram / Mulag Shale				
						Pattipalli/ Mulag Quartzite		Srisalam Quartzite		
		Salkhan Limestone				Enchencheruvu Dolomite		~~~~~~~~~~~		Stromatolites: ***Conophyton***, ***Collenia, Colonnella***: Algae: ***Obruchevella, Myxococcoides, Eosynechcoccus, Sphaerophycus, Tetraphycus,*** cf. ***Palaeopleurocapsa, Glenobotrydion, Eoentophysalis, Gunflintia, Huroniospora, Siphonophycus, Oscillotoriopsis, Palaeolyngbya*** cf. ***Eomicrocoleus, Eomycetopsis, Bactrophycus, Kheinjuasphaera, Coniunctiophycus, Archaeoellipsoides; Oscillatoripsis, Siphonophycus, Palaeolyngbya,*** cf. ***Eomicrocoleus;*** Acritarchs: cf. ***Trachysphaeridium, Leiosphaeridium***
		Koldaha (Olive) Shale				Polaram Fm				
						Jakram Arcose	Nallamalai Group	Cumbum Fm		
					Mallampalli/Indravati Group	Pandikunta Shale		Bairenkonda Quartzite		
	Mirzapur Subgroup	Deonar Fm						~~~~~~~~~		
		Kajrahat Limestone				Gunjeda Dolomite/ Kaner Limestone	Chitravati Group	Gandikota Quartzite		Stromatolites: ***Conophyton, Jacutophyton, Kussiella, Colonnella***
		Arangi Formation	Chanderpur Gp.	Kansa Pathar Formation		Bolapalli / Tirathgarh-Cherrakur Formation				
				Chaporadih Formation				Tadpatri Fm		
		Deoland Fm		Lohardih Formation				Pulivendla Quartzite		Stromatolites: ***Kussiella kussiensis***

Fig. 12. (*Continued*).

been dismissed as of inorganic in origin (Maithy 2003; Sharma 2003). Recent reports of trace fossils attributed to triploblastic animals from Chorhat Sandstone belonging to Kheinjua Formation (Semri Group) exposed in Madhya Pradesh (Seilacher *et al.* 1998) have also been debated. Knoll & Carroll (1999), and Kumar (1999) have doubted the original 'inorganic' interpretations. However, surface trails in single and paired rows recovered from the Nagod (Lakheri) Limestone near Bainkurian in the Rewa district and large diameter burrows collected from the Bundi Hill Sandstone, Bhander Group from Maihar need careful analysis for their biogenic or abiogenic origin to be assessed (Maithy 2003).

Sekwia, a Neoproterozoic form, reported from Lakheri Limestone, Bhander Group, has been considered to be 'cocoons' of annelids (Maithy & Babu 1997), and the Neoproterozoic sponge genus *Palaeophragmodictya* was reported from the youngest beds of Vindhyan, Bhavpura Shale, Lakheri, Rajasthan (Shanker *et al.* 2000). The presence of these possible metazoan remains and traces needs detailed investigation. Their possible presence in the Vindhyan sequence is supported by molecular clock estimates suggesting that the divergence of protostome and deuterostome animals took place as early as 1000–1300 Ma (Sharma 2003).

Chhattisgarh Supergroup

This supergroup has been divided into Chanderpur and Raipur groups separated by an unconformity (Fig. 12). There is some disagreement in further subdivision of the Raipur Group: one proposal by Murti (1987) and another by Moitra (1990). However, two distinct stromatolitic zones have been noted (Moitra 2003). The lower zone contains the characteristic forms *Kussiella*, *Conophyton cylindricus*, *Jacutophyton*, *Anabaria* and *Colonnella* of Middle Riphean age, comparable to assemblages in the Semri Group (Vindhyan Supergroup). The upper zone hosts *Gymnosolen*, *Tungussia*, *Baicalia*, *Linella*, *Acaleilla* and *Inzeria*, comparable to assemblages in the Bhander Group of the Vindhyan and assigned to Upper Riphean of Ediacaran age. Organic walled acritarchs have been reported by Moitra (1999) and three distinct zones identified. The lower two zones were assigned an Aphebian to Ediacaran age (Vendian) and the upper one an Early Cambrian age. Analysis of the upper zone biota does not support the view of Moitra (1999) who assigned these sequences an early Cambrian age but rather it appears to be from pre-Sturtian glaciation in the Neoproterozoic.

Bhima Group

The Bhima Group unconformably overlies the Cuddapah Supergroup (Fig. 12). Das Sarma *et al.* (1992) reported the presence of the macrofossil *Sabellidites* from the Halkal Formation, Bhima Group and considered the sequence to represent the Late Proterozoic. The Sabellidites specimen is strap-shaped with fine transverse partitions. The figured specimen now housed at the Geological Survey of India (Hyderabad) was reexamined in 1994 and fresh collections were made during a field trip under the aegis of IGCP Project 303 (Precambrian–Cambrian event stratigraphy). The flattened ribbon-like compressions or impressions are both straight and curved, but not twisted, with both end rounded, margins entire, surface with fine, closely-spaced transverse thickenings. Transverse thickenings have been formed by compacting packed compressed globular structures. Some specimens preserve carbonaceous matrix but no chitinous material. In overall morphology the original fossil is similar to *Tawuia dalaensis*. Associated with the newly-collected form is *Chuaria circularis* and additional *Tawuia* possessing circular structures at the terminal end, as well as *Beltina* (Maithy & Babu 1996). Similar forms are now well known from Meso-Neoproterozoic sequences of India. These forms are now considered to represent different stages of life cycle of *Chuaria–Tawuia* (Maithy 2003). The acritarch assemblage from the same sediments is dominated by sphaeromorphids; Leiosphaeridia has been recorded from the Halkal Formation (Maithy & Babu 1996). This assemblage compares well with the acritarch assemblage of Suket Shale, which is considered ± 1000 Ma in age. The stable carbon isotope values are in the range ± 1.2 to 3.4 PDB in the Bhima Group (Bhattacharya *et al.* 1996). Based on this data we suggest that the Bhima Group was deposited before the Sturtian glaciation.

Karnool Group

The Karnool Group unconformably overlies the Cuddapah Supergroup (Fig. 12) and a *Chuaria–Tawuia* assemblage has been reported from the Owk Shale in this sequence (Sharma & Shukla 1999).

Discussion

The oldest platform sediments represented in India range in age from Mesoproterozoic to Early Neoproterozoic and seem to have been deposited in an ancient sea, the Prototethys (Shanker *et al.* 2002). Until now, much of the evidence presented indicating the presence of an Ediacaran biota of Late Proterozoic age has proved to be dubious

(Maithy 2003). The presence of *Chuaria–Tawuia* association recovered from the Sirbu and Bhavpura (Dholpur) Shale in the Bhander Group, Vindhyan Supergroup, from the Halkal Formation, Bhima Group, and the Owk Shale in the Kurnool Group indicate that these rocks are older than the Sturtian glacial sediments. The Halkal Formation was considered by Das Sarma *et al.* (1992) to be Late Proterozoic in age as they reported the presence of Sabellidites. Maithy & Babu (1996) doubted their identifications, as the fossil is a carbonaceous impression with no chitin preserved. The specimen is now identified as *Tawuia*. Furthermore, the sediments are also dominated by a simple acritarch, Leiosphaeridia, which are known to occur in the beds ranging age from 1000–900 Ma (Maithy & Babu 1996). Stable carbon isotope values in the Bhima Group are in the range of ± 1.2 to 3.4 PDB. Azmi (1998), based on his finding of brachiopods and small shelly fossils in the Rohtasgarh Formation, Semri Group of the Vindhyan sequence exposed in the Badanpur section (near Maihar, Madhya Pradesh) and in the Ramdhira Quarry section (near Rohtasgarh, Bihar), assigned the sediments to Late Proterozoic–Early Palaeozoic. This finding is questioned here as the reported fossils appear to be of non-biogenic nature (Bhatt *et al.* 1999; Bhatt 2003). The absence of Late Proterozoic sediments is also supported by the organic walled microfossils from the younger succession of Vindhyan Supergroup. The assemblage is dominated by sphaeromorphids, most belonging to the acritarch *Leiosphaeridia*. Ornamented sphaeromorphid acritarchs are extremely rare. However, in the Bhander Group, *Sphaerocongregus*, *Polytrichoides* and *Obruchevella*, all of Late Proterozoic age, are present. Stromatolites also indicate an older Neoproterozoic age as the typical Vindhyan and Chhattisgarh sequence lack the stromatolite assemblage of *Baicalia-Tungussia-Inzeria*.

Conclusions

An analysis of the organic remains and organosedimentary structures from the Neoproterozoic of the Indian subcontinent suggest that:

1. There is some evidence of organic remains and trace of Late Proterozoic are in sediments of the Lesser Himalaya—in the Krol Belt, Higher/Tethys Himalaya, Kashmir, and possibly in the Karanpur Formation of the Madhubani Group, and the Ganga Plain and Marwar supergroups in the northwestern part of the Indian Shield. Evidence for a Late Proterozoic age of the Vindhyan Supergroup, Chhattisgarh Supergroup, Bhima Group and Karnool Group is absent. The stromatolite record suggests a Late Riphean age. The presence of the macroscopic fossil *Chuaria–Tawuia* suggests a date of deposition older than the Sturtian glaciation. This is supported by the acritarch record.
2. Fossil evidence does not support that the Palaeotethys Sea extended south of Son-Narmada Lineament during Late Proterozoic–Cambrian. The lack of sediments of Late Proterozoic age in the greater part of peninsular India is likely due to uplift and thus regression of the Prototethys Sea during Chengjiangian/Cadomian Orogeny (Shanker *et al.* 2002).

Formation detailed work and better quality illustrations are certainly needed to confirm these identifications. A joint trip for IGCP493 is expected to visit critical sites in 2007.

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