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Indian Gondwana palynochronology: relationships and chronocalibration

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ABSTRACT

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The concept of Gondwana Sequence on the Indian Peninsula is discussed from the view point of time, geographical extent and environment. It has been ascertained that Talchir deposition began in the late Asselian (Early Permian) and not during the Permo-Carboniferous. The Karharbari succession is a distinct formation. The Barakar Formation should continue to be placed in the Lower Permian of the bipartite division of the Permian System. The Banspitali *Nala* section, in the south of Damodar River, Raniganj Coalfield, West Bengal, India, may be a suitable nonmarine reference section for the Permian-Triassic boundary. To determine the age-ranges of the palynozones through the Gondwana Sequence, there is a need for cross-correlation with sections in the Himalayan region and in other areas of Gondwanaland.

Key-words—Palynology, Gondwana, Palynochronology, Correlation, India.

भारतीय गोण्डवाना परागाणुकालानुक्रमिकी : सम्बन्धन तथा अंशशोधन के कुछ आयाम

रामशंकर तिवारी एवं राजीव कुमार

सारांश

काल, भौगोलिक स्थितियों तथा पर्यावरण को दृष्टिगत रखते हुए भारतीय प्रायद्वीप में गोण्डवाना अनुक्रम की अवधारणा का विस्तृत विवेचन किया गया। यह अभिपुष्ट किया गया कि तालचीर निक्षेप परमो-कार्बोनीफ़ेरस कल्प के दौरान होने प्रारंभ नहीं हुए थे, बल्कि ये अन्तिम एसीलियन (प्रारंभिक परमियन) कल्प के दौरान निक्षेपित हुए थे। करहरबाड़ी अनुक्रम एक सुस्पष्ट शैलसमूह है। बराकर शैलसमूह को परमियन तंत्र के द्विआधारीय प्रभाग के अधोपरमियन कल्प में ही पूर्ववत् रखना चाहिए। भारत के पश्चिम बंगाल के रानीगंज कोयला क्षेत्र अवस्थित दामोदर नदी के दक्षिण का बाँसपीतली नाला परिच्छेद पी.टी.बी. हेतु एक उपयुक्त असमुद्री सन्दर्भ परिच्छेद सिद्ध हो सकता है। गोण्डवाना अनुक्रम के माध्यम से परागाणु मण्डलों की आयु सीमाओं के निर्धारण हेतु हिमालय क्षेत्रों तथा गोण्डवाना भूमि के अन्य क्षेत्रों के परिच्छेदों से इनका संकर सहसम्बन्धन किए जाने की आवश्यकता है।

संकेत शब्द—परागाणुविज्ञान, गोण्डवाना, परागाणुकालानुक्रमिकी, स्थानिक सम्बन्ध, भारत.

INTRODUCTION

GONDWANA was a Supercontinent that assembled during the Neoproterozoic (1000 Ma to the beginning of Cambrian) from fragments of an older continent, Rodinia (Late Mesoproterozoic, *ca* 1 Ga : Unrug, 1996), and existed as an independent supercontinent through the major part of the Palaeozoic Era. But during the middle Carboniferous, the

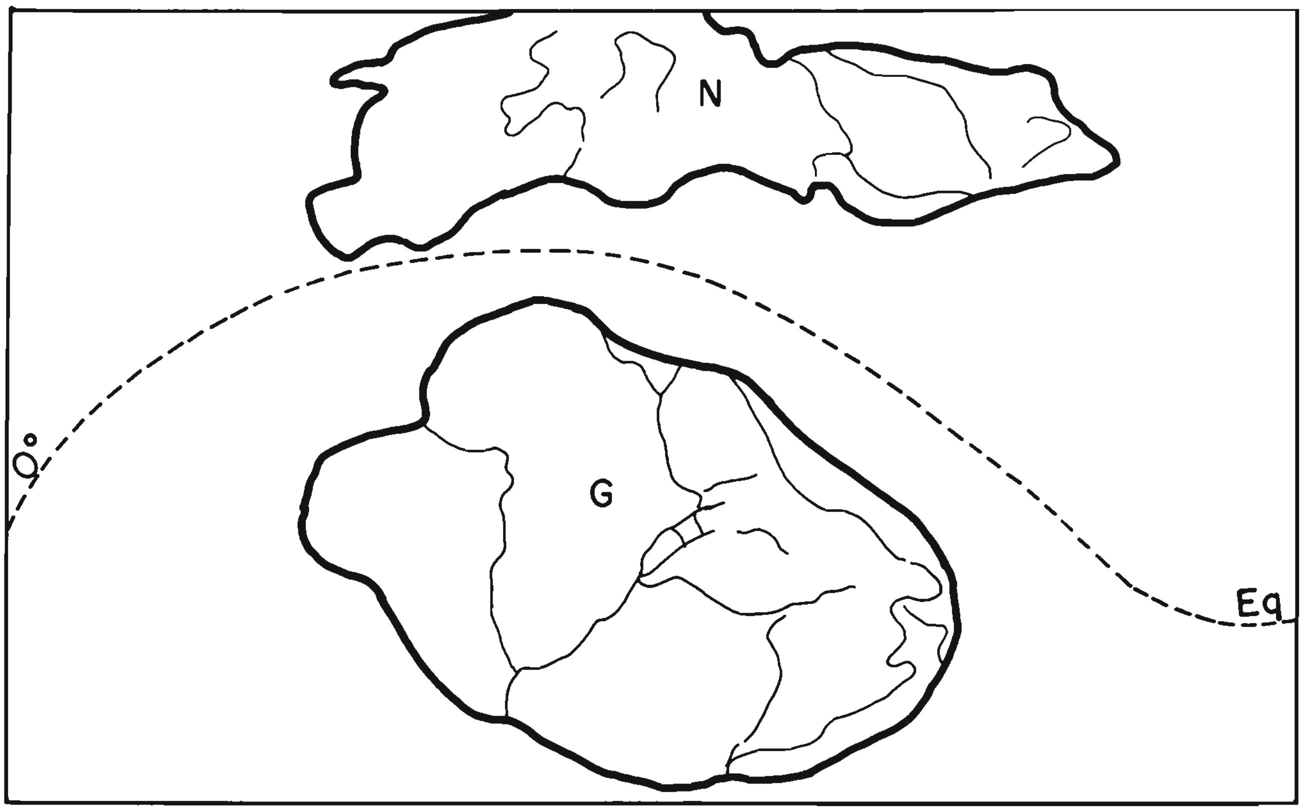

Fig. 1—Isolated Gondwana Supercontinent (G) during Neoproterozoic to middle Carboniferous, existing in the southern hemisphere independent of the northern landmass (N).

northern landmass (Laurasia, Baltica and Siberia) collided with Gondwana to form the supercontinent of Pangaea (Figs 1, 2), which continued to exist in the Mesozoic. Thereafter, its components began to drift apart, ultimately into the configuration of the present continents. Obviously, the Gondwana Supercontinent *sensu stricto* remained as a separate entity only up to the Late Palaeozoic; thereafter it became a part of Pangaea, and lost its identity before the first deposition of Gondwana facies on the southern continents.

However, the northern limits of the original cratons as well as the Neoproterozoic mobile belts of the original Gondwana Supercontinent continued to be well demarcated within Pangaea. Gondwanaland thus comprised the southern portion of Pangaea; and was partly separated from the northern landmass by an equatorial sea, the Tethys (Fig. 2).

The distinctive characteristics of the Gondwana facies are not because of its isolation as Gondwanaland but because of location of most of its land region occupied high latitude in the southern hemisphere thus providing a unique environment (Veevers, 1993). Under the influence of the Gondwanan climate, ecology and land-sea distribution as well as geotectonics, the typical flora and fauna of Gondwana maintained their identities during the Permian and most of the Mesozoic (Tiwari & Vijaya, 1995).

Eastern Gondwana was intact with its component continents even up to the Early Cretaceous (Aptian-Albian). The Gondwana Sequence on the Indian peninsula incorporating similar sediments with characteristic biota spanned through the Permian and most of the Mesozoic. In Australia and Antarctica, this succession continued even beyond the Early Cretaceous as these landmasses remained united up to the early Cenozoic, representing the last phase of existence of Gondwanaland.

The close correlation between floras throughout Gondwanaland during the Permian (*Glossopteris* floral province) and during most of the Mesozoic support the palaeogeographic configuration noted above. Palynofossils are the primary reference group for establishing spatial relationships in the regions of Gondwanaland and for calibration of chronostratigraphy through links with marine successions.

The Gondwana Sequence on peninsular India is basically non marine although evidence for marine episodes occur intermittently. Hence, the dictum that the Gondwana succession comprises only non-marine deposits has to be abandoned (Tiwari *et al.*, 1995; Chandra, 1996; Mukhopadhyay, 1996). Comparable situations exist in other regions of Gondwanaland where mixed marine and continental

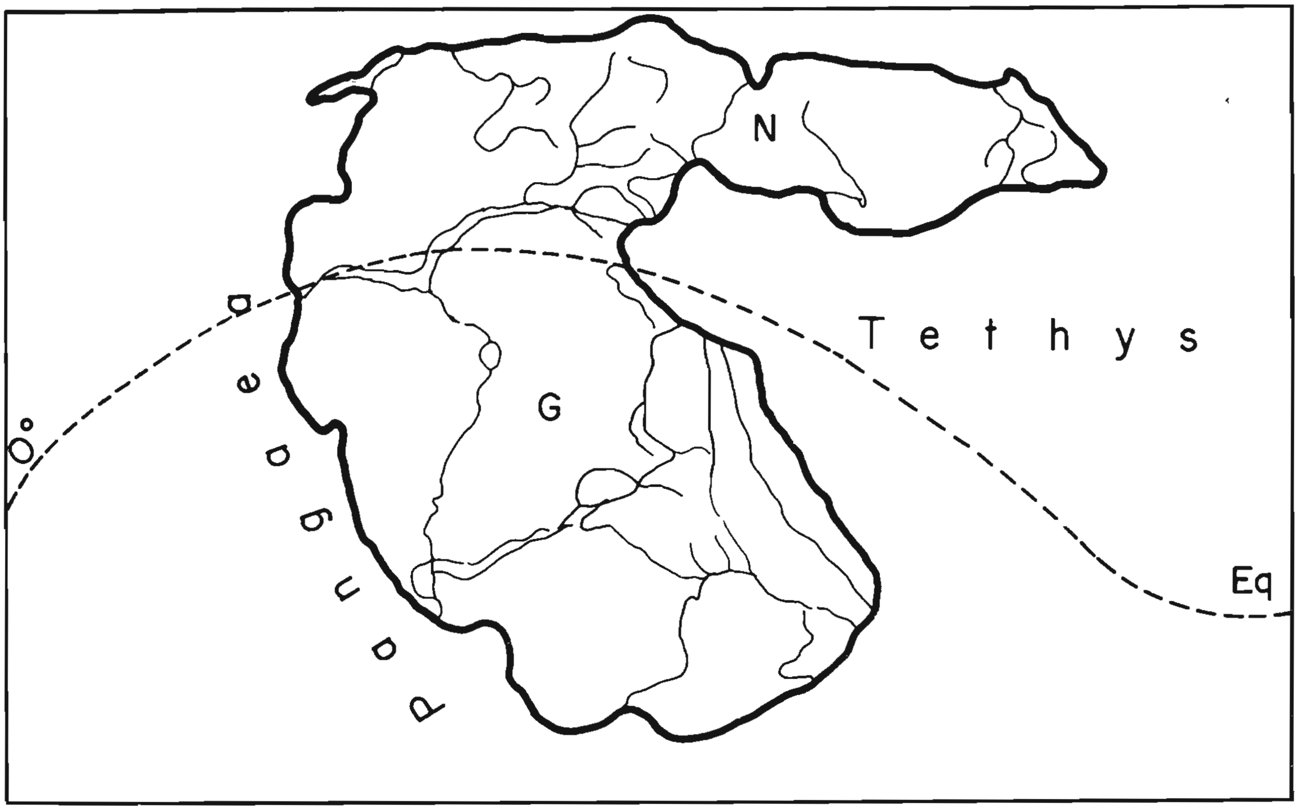

Fig. 2—Pangaea, formed during middle Carboniferous, resulted from collision of Gondwanaland (G) and the northern landmass (N); however, the northern limits of the former remained demarcated, in most of the region, by the Tethys sea.

environments are recorded from Permian to Early Cretaceous (e.g., Madagascar : Rakotosolofo *et al.*, 1998). In these situations, temporal correlations in nonmarine and marine successions need to be refined with reference to palynozones. The nonmarine nature of sediments should not hinder the attempts for global stratigraphic correlation based on multiple parameters.

Efforts continue to be made to fill the gaps in data and resolve the existing problems for achieving palynologically based chronology (i.e., palynochronology) of the Indian Gondwana Sequence; e.g., Tiwari and Tripathi (1992), Lindström (1995, 1996) and Tiwari (1999a, b). The data presented in these and other publications form the basic framework for further refinement of chronology based on palynology.

KEY ASPECTS IN PALYNOSTRATIGRAPHY

In the following account, key aspects of certain levels in stratigraphy are discussed :

1. The Talchir Formation : age status as Permo-Carboniferous ?
2. The Karharbari Formation : litho-, bio-, and temporal attributes.
3. Classification of Permian Gondwana and position of the Barakar Formation : Lower, Middle or Upper?
4. Permian-Triassic Boundary (PTB) at outcrop, south of Damodar River, West Bengal : a candidate for nonmarine stratotype?
5. Gondwana palynochronology.

1. The Talchir Formation: age status as Permo-Carboniferous?

On the peninsula of India, the deposition of the Gondwana Sequence commenced with the Talchir Formation, which lies unconformably on uneven Precambrian basement. Talchir sediments, present in all of the basins, are typically of glacial origin with intermittent intercalations of lacustrine and shallow marine tidal-flat deposits through most of the formation (Casshyap & Tewari, 1987). Two distinct levels of marine fossils have been recorded. In the older horizon (i.e., Manendragarh Bed in Madhya Pradesh), a *Eurydesma-Deltopecten* bivalve fauna of an Asselian age, while the younger level (i.e., Umaria Bed in Madhya Pradesh & Daltonganj, Bihar) is characterised by *Stephanoviella,* which implies a Sakmarian age. These two marine marker beds correlate with two transgressive phases

SYSTEM	SERIES	STAGE
E. TRIAS	SCYTHIAN	Olenekian
		Induan
L. PERM	LOPINGIAN	Changhsingian
		Wuchiapingian
M. PERM	GUADALUPIAN	Capitanian
		Wordian
		Roadian
E. PERM	CIS - URALIAN	Kungurian
		Artinskian
		Sakmarian
		Asselian

A

STAGE	SYSTEM
Olenekian	E. TRIAS
Induan	
Tararian	LATE PERMIAN
Kazanian	
Ufimian	
Kungurian	EARLY PERM
Artinskian	
Sakmarian	
Asselian	

B

Fig. 3—Currently accepted (A) and previous (B) chronostratigraphic classifications of System, Series and Stages of the Permian and Early Triassic.

of the Tethys sea. The occurrence of eurydesmids and productids in the Bap Formation of Rajasthan also correlates with the Early Permian of Salt Range on one hand and the Talchir Formation in Central India on the other, both indicating glacio-marine conditions (Rao *et al.*, 1977). In addition, there is evidence of marine signatures in other areas and basins (e.g., varied leiospherids) indicating widespread marine influence over the peninsula during Talchir deposition (Venkatachala & Tiwari, 1987; Tiwari *et al.*, 1995; Ravi Shanker *et al.*, 1996).

Palynologically, three species assemblage zones have been established through the Talchir Formation. From oldest to youngest these are : (1) —*Potonieisporites neglectus*, (2) — *Plicatipollenites gondwanensis*, and (3) —*Parasaccites*

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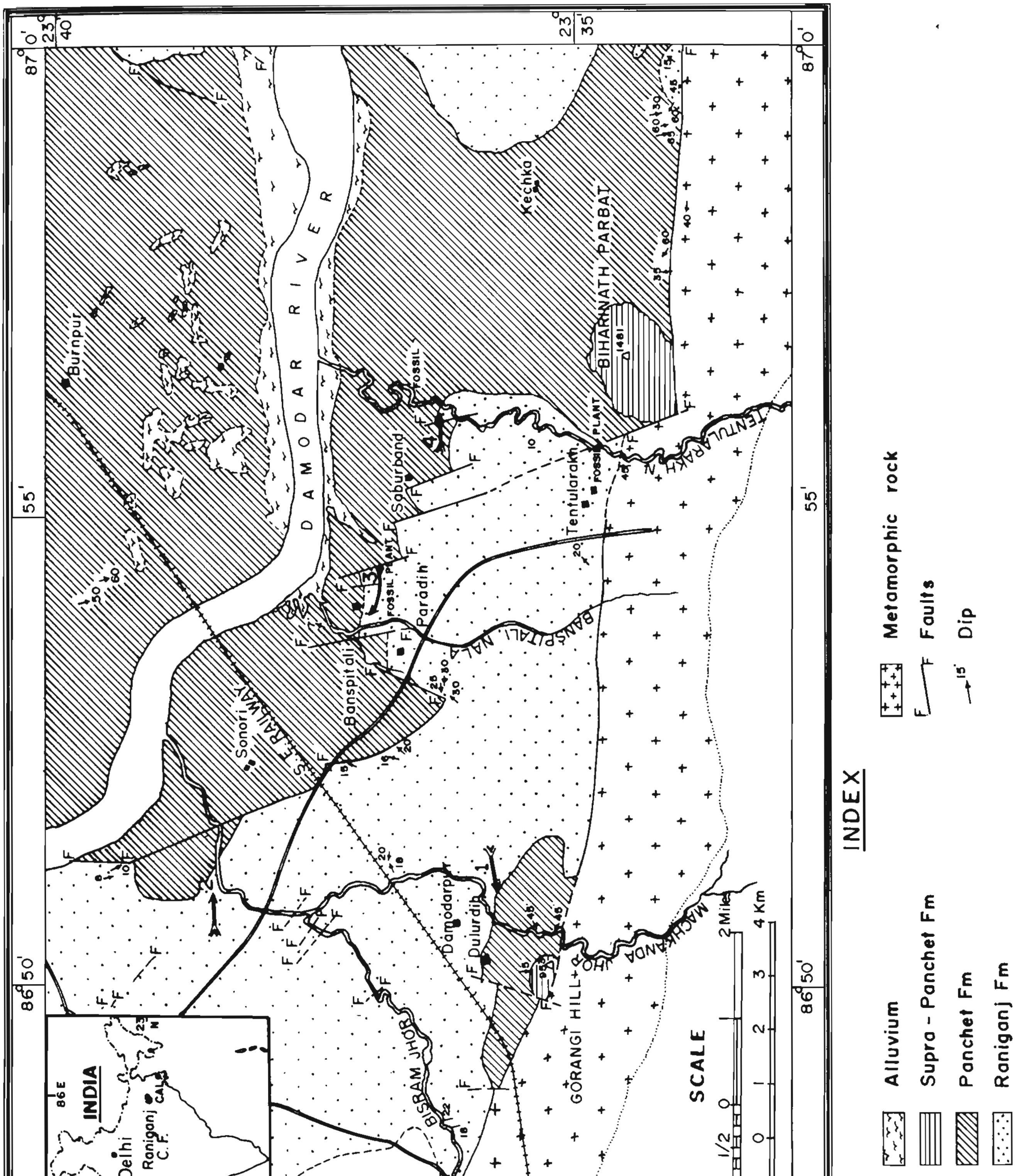
Fig. 4—Geological map of the area south of Damodar River, Raniganj Coalfield, West Bengal, depicting the Raniganj/Panchet Boundary in four sections. Bold arrows indicate the localities whence samples were collected for palynoanalysis : 1 Machhkanda Jhor, near Gorangi Hill; 2. Machhkanda Jhor, near its confluence with the Damodar River; 3. Banspitali Village, Section in Banspitali *Nala*; 4. Tetularakh *Nala*, near its confluence with the Damodar River (see also Fig.7).



87°0'
23°40'
23°35'
55'
86°50'
DAMODAR RIVER
Burnpur
Kechka
BIHARINATH PARBAT
Tentularakh
Saburband
Paradih
Banspitali
Sonori
S.E. RAILWAY
BANSPITALI NALA
TENTULARAKH N.
MACHKANDA JHOR
GORANGI HILL
Damodarpur
Dulurdih
BISRAM JHOR
PANCHET HILL
FOSSIL PLANT
INDIA
86E
Delhi
Raniganj C.F.
CAL
SCALE
mil
Km
2 Miles
4 Km
INDEX
Alluvium
Supra - Panchet Fm
Panchet Fm
Raniganj Fm
Metamorphic rock
Faults
Dip

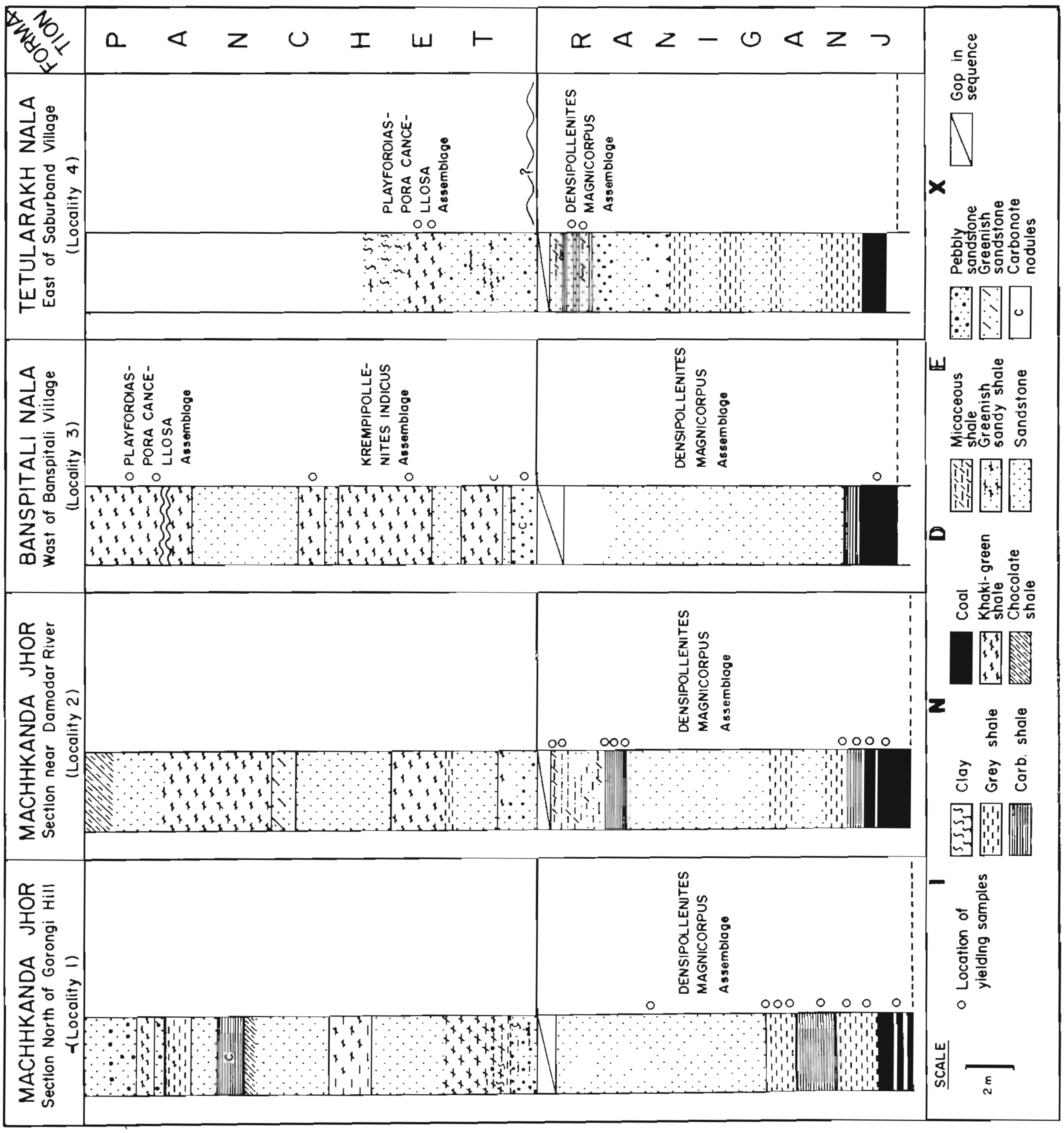


Fig. 5—Generalized sections and palynoassemblages recovered from the four localities depicted in Fig. 4.

korbaensis. For author and date attributions to these palynotaxa and others mentioned in this paper, see Tiwari (1999a).

The structure of these zones does not indicate a Late Carboniferous age for the Talchir palynoflora (Tiwari & Tripathi, 1992; Vijaya, 1996; Tiwari, 1999a, b). These palynozones are dominated by radial or bilateral monosaccate pollen with monolete or trilete germinal mark (species of *Potonieisporites, Parasaccites, Virkkipollenites* and their morphological variants). A progressive incremental innovation of morphologies takes place from the oldest to the youngest zone. Consequently, the First Appearance Datums (FADs) of zonate-cingulate spores (*Jayantisporites* cf. *conatus*), and bilateral (*Parasaccites bilateralis*) and striate pollen (*Crescentipollenites fuscus* and *Faunipollenites perexiguus*) are recorded in Zone II. Further proliferation of forms is

Formation	Assemblage	Spore-pollen species
Panchet Formation	*Playfordiaspora cancellosa* Assemblage (in khaki green shale, sst of upper reaches)	*Arcuatipollenites asansoliensis, Ringosporites fossulatus, Indotriradites mamillatus, Playfordiaspora cancellosa, Verrucosisporites narmianus, Guttatisporites ambiguus, Osmundacidites senectus, Goubinispora morondavensis*
	Krempipollenites indicus Assemblage (in lower shale, sst khaki-green shale suit)	*Alisporites landianus, A. asansoliensis, Callumispora gretensis, Lundbladispora brevicula, Lundbladispora microconata, Verrucosisporites narmianus, Densoisporites playfordii, Densoisporites contactus, Krempipollenites indicus, Arcuatipollenites pellucidus, Arcuatipollenites damudicus, Lahirites triassicus*
Raniganj Formation	*Densipollenites magnicorpus* Assemblage (in uppermost coal-shales-sst suit)	*Densipollenites magnicorpus, D. densus, D. indicus, Gondisporites raniganjensis, Barakarites indicus, Leiotriletes virkkii, Kendosporites striatus, Columinispora* sp., *Laevigatosporites colliensis, Crescentipollenites fuscus, Striatopodocarpites tiwarii, Rhizomaspora triassica, Striatopodocarpites decorus, Lundbladispora* sp., *Verticipollenites secretus, Platysaccus* sp., *Striatites sewardii, Scheuringipollenites maximus, Cedripites priscus, Falcisporites nuthallensis, Arcuatipollenites ovalis, Krempipollenites* sp. *Striatopodocarpites diffusus*

Fig. 6—Occurrence of important spore-pollen species across the Raniganj/Panchet Boundary based on studied sections, emphasising a transformation from Permian to Triassic palynofloras.

evidenced by the cruciform-saccus-bearing monosaccate pollen (*Crucisaccites latisulcatus*), simple bisaccates (*Scheuringipollenites maximus*), and a trilete spore species with well-established stratigraphic index-value in Australia and Antarctica (*Microbaculispora tentula*) commencing in the Zone III.

Palynozone I is highly impoverished, possibly because of adverse climatic conditions or taphonomic factors. So far, no typical Carboniferous palynomorphs (e.g., *Diatomozonotriletes, Lycospora, Cristatisporites*, lycosporoid elements with small cingulate-zonate spore species, *Convolutispora, Pustulatisporites*) have been identified in the Talchir assemblage. Plant megafossils characteristic of a Carboniferous age are also absent from horizons of peninsular Gondwana. *Lepidodendron* forest existed in the southern hemisphere prior to the *Glossopteris* flora; inception of the latter coincides with the base of the Talchir Formation. The genera *Cyclostigma, Archaeosigillaria, Nothorhacopteris* (*Rhacopteris*), *Rhodeopteridium*, which are characteristic elements of the Carboniferous in the southern hemisphere, are absent from the Gondwana Sequence of India.

Accordingly, the Talchir succession cannot be dated as Carboniferous, or even Permo-Carboniferous. A recent reinterpretation by Apak and Backhouse (1998) of the Permo-Carboniferous stratigraphy of the Canning Basin, Western Australia provides further support for this conclusion. The Grant Group of the Canning Basin has been now redefined and divided into (1) Reeves Formation (previously known as Lower Grant Group), and (2) Upper Grant Group. None of the assemblages, or their component taxa, that are typical of the Reeves Formaion representing a Carboniferous palynological complex, is present in the Talchir Formation (for details see Apak & Backhouse, 1998; Backhouse, 1998). With the revised stratigraphic scheme, all sediments included within the younger 'Grant Group' (new delimitation) belong to the *Pseudoreticulatisporites confluens* Zone of Foster and Waterhouse (1988). The palynologically defined Stage 2 of Australia has thus become vague in its limits. The Talchir assemblages are broadly correlated with *P. confluens* Zone (Asselian) of the younger Grant Group.

From an analysis of Early Permian deglaciation in eastern Gondwanaland, Wopfner (1999) suggested that deglaciation extended from the latest Asselian to about the mid Sakmarian. The change from a glacial climate to cool temperate post-glacial conditions is reflected by a change in the mineralogical composition of the sediments (*see* Wopfner, 1999). The massive shales at the top of the Talchir sequence, partly associated with *Eurydesma, Deltopecten* and *Linoproductus*, probably represent this deglaciation event (Wopfner &

Sample No.	Lithology	Thickness of samples (in m)	Remarks	Formation
B-1	Coal	1.5	Lowermost sample: Topmost coal of Raniganj Formation	Raniganj
B-2	Sandstone, massive	20	Roof sandstone (Gorge)	Contact
			Gap (alluvium cover)	
*	Calcarious pebbly bed	5		Panchet
B-3	Khaki-green & Greyish shale	1		
*	Sandstone	0·30	Parting	
B-4	Khaki-green & Grey shale	2		
*	Sandstone	1	Parting	
B-5 to B-8	Khaki-green shale	4		
*	Sandstone	0·50	Parting	
B-9	Khaki-green shale	1	Dip 15° N	
*	Sandstone	4		
B-10 to B-12	Khaki-green shale	3		
*	Sandstone	2·00		
B-13 to B-15	Khaki-green shale }	0·50		
*	Sandstone	0·50		
			Gap	
B-16 to B-26	Khaki-green shale Sequence	Meter wise 11 samples	Bottom Run of a hillock section Top	
		50	Gap	
B-27	Khaki-green shale	1·5	Ahead of confluence of two branches of *nala*	
*	Thick sandstone	30		
B-28	Khaki-green + Red clay	2	Appearance of red-chocolate colour	Upper Panchet
*	Massive sandstone yellow colour			
B-29	Red-chocolate mixed with khaki-green shale	1		
B-30	Red-chocolate mixed with khaki-green shale	1	Topmost	
B-31	Red clay	1	samples	

Fig. 7—Lithological sequence (ascending stratigraphic order) encompassing Raniganj/Panchet Transition and major part of the Panchet Formation in the Banspitali *Nala* section near Banspitali Village.

Casshyap, 1997; Wopfner, 1999). This indicates an Asselian to Sakmarian age for the beds containing invertebrates and the younger deposits of the Talchir Formation.

Waterhouse (1976) opined that the *Eurydesma* fauna is of Kurmanian age (youngest Asselian substage). If accepted, this ties the Manendragarh marine bed of the Talchir Formation in Madhya Pradesh, having this fauna, with the late Asselian. The numerical age-range for the Asselian is from 295 ± 5 Ma (Permo-Carboniferous Boundary) to 287 Ma (Asselian-Sakmarian Boundary) as estimated and synthesised by Ross *et al.* (1994). The beginning of the Talchir Formation coincides with the second half of this period.

Further analysis of the palynological succession through the Carboniferous-Permian sequence in Australia and India reveals that, although the main stocks of radial and bilateral monosaccates and nonstriate bisaccates appear in the

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Fig. 8—Sequence and inferred age of palynozones through the Gondwana Sequence of India (based on Tiwari, 1999a, b with addition of few new palynozones, FADs and Dominance Datums (DOD); Index DOD; in certain cases the dominance datum is not determined by counts but estimated by relative abundance of taxa).

PERIOD	EPOCH	AGE	PALYNOASSEMBLAGE ZONES	PALYN. COMPL.	FAD	DOD/INDEX DOD
CRETACEOUS	K_1	ALBIAN	(A1) Appendicisporites distocarinatus	ANGIOSPE-RMIDS	← Murospora truncata	DISTALTRIANGULISPORITES
		APTIAN	(AH-I) Retitriletes eminulus (AH) Coptospora cauveriana (AG-I) Callialasporites reticulatus	CICATRICOSISPORI-TES COPTOSPORA	← Asteropollis vulgoris ← Clavatipollenites hughesii ← Retimonocolpites peroreti-culatus	COPTOSPORA
		BARREMIAN	(AG) Cyclosporites hughesii		← Coptospora cauveriana	CYCLOSPORITES
	Neocomian	HAUTERIVIAN	(AF) Microcachryidites antarcticus		← Podosporites tripakshi	PODOCARPI ARAUCARIA.
		VALANGINIAN	(AE) Foraminisporis wonthaggiensis			
		BERRIASIAN	(AD) Cicatricosisporites australiensis			CICATRICOSISPORITES
JURASSIC	J_3	TITHONIAN	(AC) Callialasporites segmentatus (AB) Callialasporites turbatus/dampieri	CLASSOPOLLIS - CALLIALASPORITES	← Contigni. globulentus	
		KIMMERIDGIAN	(AA) Murospora florida			
		OXFORDIAN				
	J_2	CALLOVIAN	(Z) Callialasporites trilobatus		← Calliala. monoalasporus	CALLIALASPORITES
		BATHONIAN				
		BAJOCIAN				
		AALENIAN				
	J_1	TOARCIAN				
		PLIENSBACHIAN	(Y) Classopollis minor		← Callialasporites dampieri	CLASSOPOLLIS
		SINEMURIAN				
		HETTANGIAN				
TRIASSIC	Tr_3	RHAETIAN	(X) Rhaetipollis germanicus	ARCUATIPOLLENITES 'ALISPORITES'		NONSTRIATE BISACCATE
		NORIAN	(W) Enzonalasporites ignacii (V) Dubrajisporites triassicus (U) Brachysaccus ovalis		← Dictyotriletes aulius ← Stauro. quadrifidus	MINUTOSACCUS DUBRAJISPORITES BRACHYSACCUS
		CARNIAN	(T) Rajmahalispora rugulata			RAJMAHALISPORA
	Tr_2	LADINIAN	(S) Rimaesporites potoniei (R) Dubrajisporites isolatus			STAUROSACCITES PLAYFORDIASPORA
		ANISIAN	(Q) Limatulasporites fossulatus (P) Goubinispora morondavensis		← Lundbladi willmotti	LIMATULASPORITES GOUBINISPORA
	Tr_1	OLENEKIAN	(O) Playfordiaspora cancellosa		← Triplexi. playfordii	ARCUATIPOLLENITES
		INDUAN	(N) Krempipollenites indicus		← Verrucosi. narmianus	KREMPIPOLLENITES
PERMIAN	P_2	TATARIAN	(M) Densipollenites magnicorpus (L) Guttulapollenites gondwanensis	STRIAT. DENSI.	← Densoisporites playfordii	CRESCENTIPOLLENITES/
		KAZANIAN	(K) Gondisporites raniganjensis		← Didecitriletes ericianus	STRIATOPODOCARPITES/
		UFIMIAN	(J) Densipollenites indicus		← Gondi. raniganjensis	DENSIPOLLENITES
	P_1	KUNGURIAN	(I) Faunipollenites varius	SCHEU. FAUNI.	← Guttula. hannonicus	FAUNIPOLLENITES /
		ARTINSKIAN	(H) Scheuringipollenites barakarensis		← Densipollenites indicus	SCHEURINGIPOLLENITES
		SAKMARIAN	(G) Crucisaccites monoletus (F) Virkkipollenites obscurus (E) Rugasaccites obscurus (D) Parasaccites korbaensis (C) Plicatipollenites indicus	PLICATIPOLLENITES PARASACCITES	← Marsupi. triradiatus ← Microbaculi. tentula	CALLUMISPORA / PARASACCITES /
		ASSELIAN	(B) Plicatipollenites gondwanensis (A) Potonieisporites neglectus		← Tuberisaccites tuberculatus	PLICATIPOLLENITES

Spelaeotriletes ybertii Zone (now dated as Namurian : Vijaya & Tiwari, 1992; Apak & Backhouse, 1998), the Talchir palynoflora typically consists of a much more diversified and highly evolved Permian spore-pollen assemblage including *Caheniasaccites decorus, C. densus, C. distinctus, C. ovatus, Crescentipollenites fuscus, Crucisaccites latisulcatus, Faunipollenites perexiguus, F. maximus, Jayantisporites conatus, J. indicus, J. pseudozonatus, Microfoveolatispora foveolata, Parasaccites bilateralis, P. densicorpus, P. korbaensis, Plicatipollenites distinctus, P. indicus, P. trigonalis, Potonieisporites crassus, P. magnus, Rugasaccites obscurus, Scheuringipollenites maximus, Tuberisaccites tuberculatus, T. varius,* and several others; these forms are not recorded from the *S. ybertii* Zone.

The Talchir palynofloras are much more similar to the Lower Permian Karharbari (*Crucisaccites monoletus* Assemblage Zone) and Barakar (*Scheuringipollenites barakarensis* and *Faunipollenites varius* Assemblage Zones) palynofloras than to the Carboniferous Stephanian (*Deusilites tenuistriatus* Assemblage), Westphalian (*Diatomozonotriletes birkheadensis* Assemblage) or Namurian (*Spelaeotriletes ybertii* Assemblage) palynofloras. Clearly, the Talchir Formation must be regarded as Permian in age.

2. The Karharbari Formation: litho-, bio-, and time-attributes

The Indian Gondwana Sequence was initially subdivided into formational units on the lithological characteristics and biota, or exclusively on the latter. Subsequent researches established a close relationship between these parameters in most of the successions which ultimately acquired chronostratigraphical ranks. However, at times, the correlation of lithology and biota are not compatible. The Karharbari Formation, although now defined lithologically in most basins of the peninsula, cannot be delimited in certain sections in spite of its typical plant fossils. Wherever it is distinctly delineated, it is distinguished from the underlying Talchir Formation by the presence of high-grade coal seams, grey, carbonaceous shales, and generally coarse-grained, gritty or pebbly sandstone containing recycled material from khaki-green shales of the Talchir Formation.

The lithologically distinctive characters and mappability of the Karharbari Formation have been strongly supported by Ghosh *et al.* (1964) and Ghosh and Basu (1967) in several basins; however, in a few areas it is not clearly distinguishable from the Barakar Formation unless it contains identifiable plant remains (Sastry *et al.*, 1977). The typical Karharbari flora has been referred to the *Gondwanidium-Buriadia* Assemblage Zone (Shah *et al.*, 1971). Chandra (1992) revealed that the leaf genera *Gangamopteris* and *Noeggerathiopsis,* both lacking midribs, are dominant, whereas *Buriadia, Dolinitia, Euryphyllum, Ginkgophyton, Gondwanidium* and *Palmatophyllites* have their first appearance in this formation. Other plant fossils which may be present are *Arberia, Glossopteris, Neomariopteris, Ottokaria, Phyllotheca* and *Vertebraria.*

Palynology further circumscribes the Karharbari Formation which contains *Crucisaccites* palynozone (Vijaya & Tiwari, 1992). The Talchir palynoflora reaches its climax of diversity at the base of the Karharbari Formation without any extinction of morphotypes. Many new palynomorphs derived from the Talchir stock developed from the monosaccate, nonstriate bisaccate and striate bisaccate groups. In addition, the FADs of *Barakarites gondwanensis, Callumispora barakarensis, Crescentipollenites limpidus, C. rhombicus, Crucisaccites monoletus, Densipollenites indicus, Marsupipollenites triradiatus, Scheuringipollenites barakarensis, Stellapollenites talchirensis, Tiwariasporis gondwanensis, Welwitschiapites magnus,* and a few others, are recorded within the Karharbari succession.

The Karharbari Formation, with coal seams and characteristic plant fossils, conformably overlies the Umaria marine bed (in Madhya Pradesh) of Early Sakmarian age; hence a Sakmarian to Artinskian age has been assigned to the former

PLATE 1 ⟶

Characteristic spore-pollen taxa of the Raniganj Formation at the transit-sequence in outcrop sections of the south of Damodar River, Raniganj Coalfield, West Bengal. All figures are ca x 500. The slides are deposited at the repository of the Department of Applied Geology, Barkatullah University, Bhopal (DAG BUB). Registered Numbers are given against each figure.

1. *Gondisporites raniganjensis* Bharadwaj 1962, Reg. No.103;
2. *Densipollenites densus* Bharadwaj & Srivastava 1969, Reg. No.104;
3. *Densipollenites magnicorpus* Tiwari & Rana 1981, Reg. No. 104;
4. *Densipollenites indicus* Bharadwaj 1962, Reg. No. 105;
5. *Columinisporites* sp. Reg. No. 105;
6. *Kendosporites striatus* (Salujha) Surange & Chandra 1975, Reg. No.103;
7. *Scheuringipollenites maximus* (Hart) Tiwari 1973, Reg. No. 105;
8. *Striatopodocarpites decorus* Bharadwaj & Salujha 1964, Reg. No.105;
9. *Striatites sewardii* (Virkki) Bharadwaj 1962, Reg. No.106;
10. *Verticipollenites secretus* Bharadwaj 1962, Reg. No.107;
11. *Striatopodocarpites diffusus* Bharadwaj & Salujha 1964, Reg. No. 105;
12. Inner body-like objects in a bisaccate pollen. Reg. No. 108;
13. *Alisporites asansoliensis* Maheshwari & Banerji 1975, Reg. No.109;
14. *Striatites sewardii* (Virkki) Bharadwaj 1962, Reg. No.106;
15. *Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.* 1974. Reg No.105;

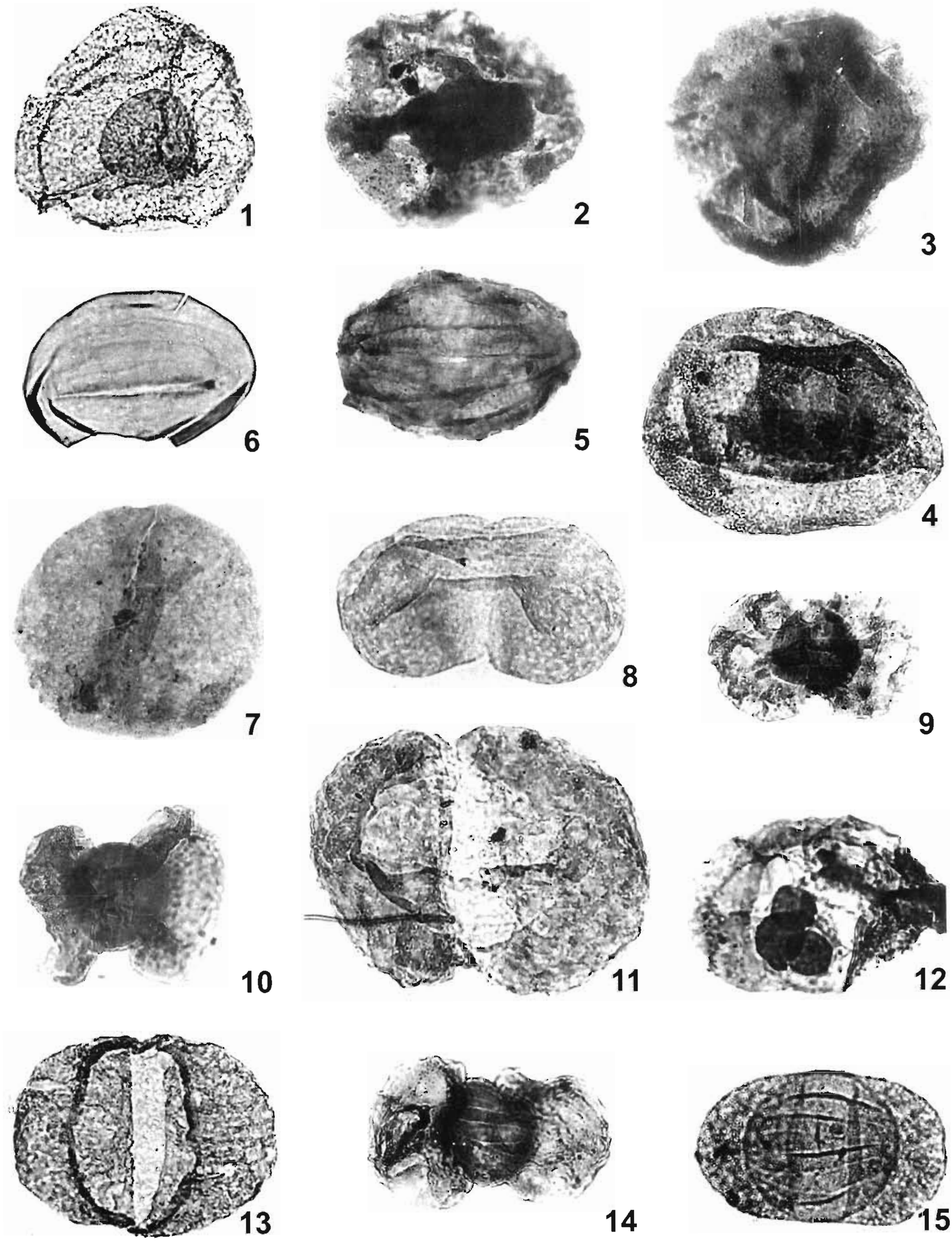

PLATE 1

(Tiwari, 1999a). The Karharbari plant megaflora is also generally similar to that of the Gangamopteris Bed (*sensu stricto*) of Kashmir which has been dated as late Sakmarian to Artinskian (Ravi Shanker *et al.*, 1996). The marine fauna of the Garu Formation, Arunachal Pradesh, establishes a Sakmarian age for the associated palynoflora which, in turn, is closely, correlated with that in the Karharbari Formation (Singh, 1987). Further, a Sakmarian dating of the Karharbari Formation is reinforced by a recent discovery of a closely similar spore-pollen palynoflora in coal-balls occurring in the Bomte Member of the Garu Formation, west Siang District, Arunachal Pradesh. These coal-balls contain typical marine fauna (e.g., brachiopods *Costatumulus, Cyrtella, Strophlosia, Tivertonia, Tomiopsis, Trigonotreta*) of Sakmarian age (Archbold & Singh, 1993; Srivastava & Bhattacharya, 1998).

In Gondwanaland, a broad-based relationship has been suggested (Tiwari, 1999a, b) between the Karharbari palynoflora and those of the following: Beacon Super Group of Dronning Maud Land and the Mount Glossopteris Formation in Trans-Antarctica (Antarctica); Stage 3 of Australia; and Karoo Zone 3 of the Middle Ecca Series in South Africa.

An analysis of the depositional history of the Karharbari Formation by Casshyap and Tewari (1987) revealed that the basal Karharbari contains conglomerate bodies which are clast-supported, elongated channel-like and massive to cross-bedded. The conglomerate facies merges into pebbly, gritty and coarse to medium sandstones. The succeeding Karharbari Formation is sandy, becoming finer upwards. The coal seams are relatively thin and laterally impersistent. The cycles are asymmetrical in which the lower sandstone member exceeds the upper shale and coal.

The overlying Barakar Formation differs in comprising recurring fining upward, symmetrical cycles of coarse to medium sandstone interbedded with fine sandstone, siltstone, shale and coal. The increased thickness of fine facies usually distinguishes it from the Karharbari Formation, but even where it is not readily differentiated its plant megafossil and palynological content is diagnostic in almost all of the basins. The coal-shale-sandstone sequence of the Karharbari reflects deglaciation, amelioration of climate and proliferation of vegetation.

It is concluded that the Karharbari Formation is a generally recognisable lithological succession that yields plant megafossils and palynomorphs of late Sakmarian-early Artinskian age.

3. Classification of Permian Gondwana and position of Barakar Formation: Lower, Middle or Upper?

The redefinition, new classification and revised names and boundary levels for series and stages of the Permian System, based on marine sections, have been recently approved by the Permian Subcommission of the International Commission for Stratigraphy (ICS; see Fig. 3) despite strong opposition and lack of unanimity amongst the world's stratigraphers. The stratotypes for the Upper Permian units of the Standard Global Chronological Scale (SGCS) outside of the classical Volga-Urals regions are now selected because of the mostly nonmarine nature of sections in this region. The Permian System has now been divided into Cis-Uralian, Guadalupian and Lopingian, corresponding to Lower, Middle and Upper Permian, respectively. The type sections for exclusively marine successions have been selected from the Urals for Cis-Uralian, the USA for Guadalupian, and South China for Lopingian. Hence, the Permian System is now based on a unified and composite sequence with its three subdivisions based on widely separated regions, broadly situated within low palaeolatitudes.

PLATE 2 →

Characteristic spore-pollen taxa of the Panchet Formation at the transit-sequence in outcrop sections of the south of Damodar River, Raniganj Coalfield, West Bengal. All figures are ca x 500. The slides are deposited at the repository of the Department of Applied Geology, Barkatullah University, Bhopal (DAG BUB). Registered Numbers are given against each figure.

1 *Cedripites priscus* Balme 1970, Reg. No. 109;

2. *Densoisporites contactus* Bharadwaj & Tiwari 1977, Reg. No.110;

3 *Densoisporites playfordii* (Balme) Dettmann 1963, Reg. No. 106;

4 *Densoisporites contactus* Bharadwaj & Tiwari 1977, Reg. No. 110;

5 *Lundbladispora brevicula* Balme 1963, Reg. No. 106;

6, 7 *Krempipollenites indicus* Tiwari & Vijaya 1995, Reg. No. 111;

8. *Arcuatipollenites ovalis* (Goubin) Tiwari & Vijaya 1995, Reg. No. 105;

9. *Arcuatipollenites damudicus* (Tiwari & Rana) Tiwari & Vijaya 1995, Reg.No. 112;

10. *Callumispora gretensis* (Balme & Hennelly) Bharadwaj & Srivastava 1969, *emend.* Tiwari *et al.* 1989, Reg. No. 113;

11 *Arcuatipollenites pellucidus* (Goubin) Tiwari & Vijaya 1995, Reg. No.106;

12. *Goubinispora morondavensis* Tiwari & Rana 1981, Reg. No. 110;

13. *Verrucosisporites narmianus* Balme 1970, Reg. No.113;

14. *Indotriradites mamillatus* Bharadwaj & Tiwari 1977, Reg. No. 114;

15. *Guttatisporites ambiguus* Tiwari & Rana 1980, Reg. No. 115.

16. *Playfordiaspora cancellosa* (Playford & Dettmann) Maheshwari & Banerji 1975, Reg. No.116;

17. *Osmundacidites senectus* Balme 1963, Reg. No. 115;

18. *Alisporites landianus* Balme 1970, Reg, No.117;

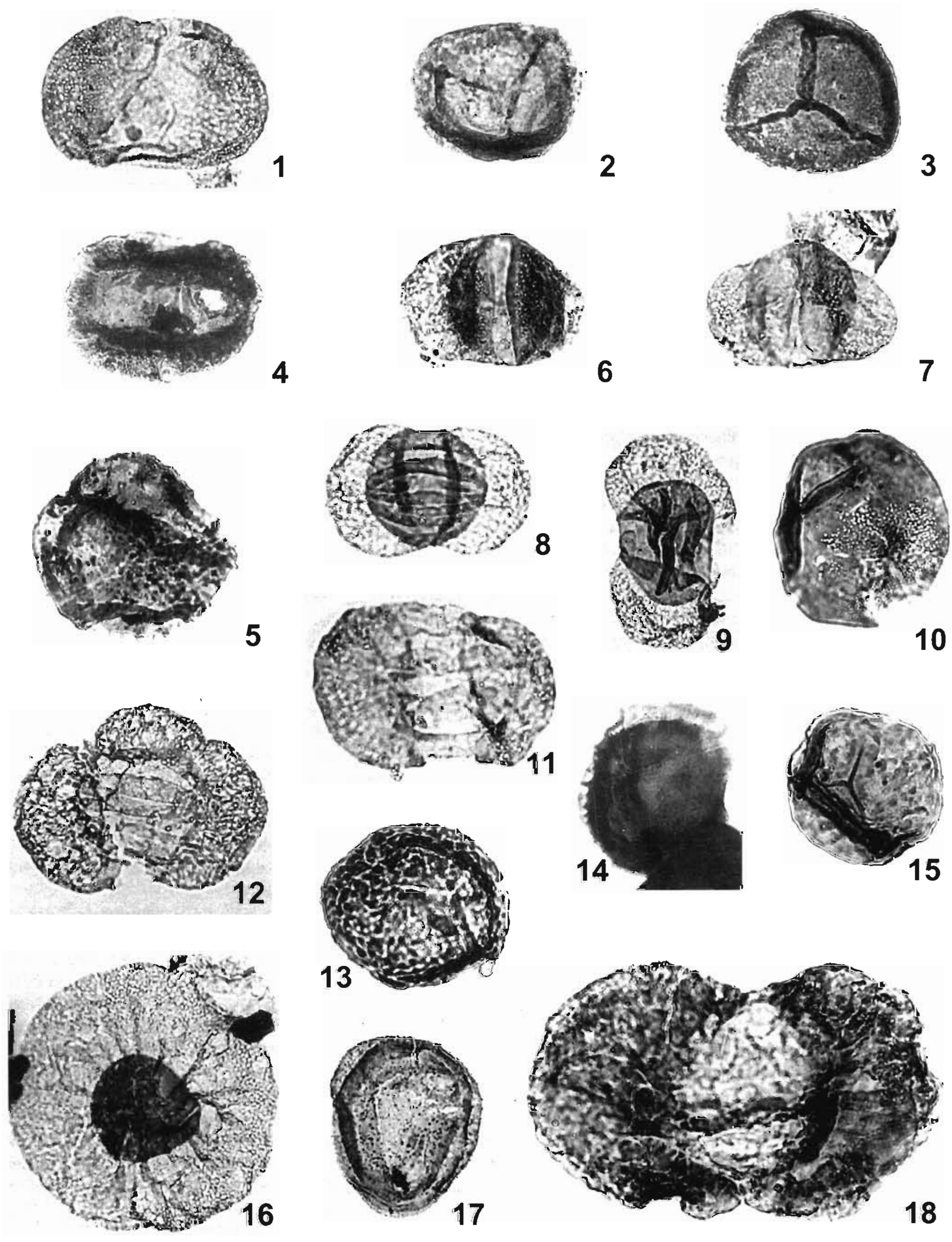

PLATE 2

It is not intended to discuss here the merits and demerits of this classification because vigorous exchange of ideas has already taken place through the international forum (*see* News Letters of the Subcommission of Permian Stratigraphy; *Permophiles*, 1995-2000). Hence, only brief observations are made below on the adoption of the revised scheme with respect to the Permian Gondwana Sequence, particularly on the Indian peninsula.

World marine faunas are all subject to well-marked provinciality because of varied temperatures, water currents and chemical composition in habitats and latitudinal situations. An ideal correlation based on faunal or floral remains across the globe is not possible. Correlation between marine and nonmarine sequences is impossible unless it is based on shared fossils, such as palynomorphs, and even then it is by no means easy. The correlations between different floral provinces, based on palynomorphs, that have been attempted so far are inadequate because they are based on 'Apparent Form Similarity' in spore-pollen morphology, rather than real similarity. Palynomorphs produced by unrelated types of vegetation may show superficial gross comparable features but differ in intricate details of exine and organisation (Tiwari, 2000). Correlations based on such discrepancies cannot be sustained. The Permian Gondwana in India is basically nonmarine, and even palynology fails to cross-correlate with the northern marine sequences for SGCS because of the marked dissimilarities in the morphologies of palynomorphs from different floral provinces. As a result, no objective basis for determining the three divisions of the Permian in India has been established.

As opined by Archbold and Dickins (1997), the two-fold subdivision, based on the traditional Russian type-sections has proved useful to Gondwana workers. The American and Chinese sections may perhaps be regarded as supplementing this classical scale. The Russian stages have long been established and substantiated in continuous successions in a single large region, a point that is very much in their favour by comparison with the three-fold system which, moreover, is not applicable outside of the palaeo-equatorial belt. It is therefore suggested that use of two-fold division of the Permian on peninsular India and in other regions of Gondwanaland should be continued for the time being.

As already discussed, the Early Permian sequence in Gondwana basins of peninsular India is represented by the stratigraphic continuum of the Talchir, Karharbari and Barakar formations. The lower part of the Barakar Formation consists of braided channel deposits. In the mid Barakar, meandering channel systems are recognised. In places, deltaic/brackish water conditions may also be indicated. In the upper part, marine indicators are more common, suggesting a close proximity to an epicontinental sea. A pronounced hiatus above the Barakar Formation delimits the top of the Lower Permian. Thus, according to the bipartite division of the Permian system, the Barakar Formation is positioned at the upper Lower Permian. Two palynological zones have been identified within the formation : *Scheuringipollenites barakarensis* Assemblage Zone (Lower Barakar), and *Faunipollenites varius* Assemblage Zone (Upper Barakar), dated as Artinskian and Kungurian, respectively.

The Barakar palynoflora is more similar to successively younger palynofloras of the Upper Permian Kulti and Raniganj formations than to that of the underlying Karharbari Formation. Yet an Early Permian character is also evident in the form of a fair representation of radial monosaccate pollen and persistence of *Potonieisporites, Plicatipollenites, Parasaccites* and *Virkkipollenites*, species of which generally terminate at the top of the Barakar Formation. This formation was deposited during a time when vigorous floral diversification was taking place; hence, its transitional content of floras from earlier Early Permian and Late Permian (Tiwari & Tripathi, 1992; Tiwari, 1999a).

4. Permian/Triassic Boundary at outcrop, South of Damodar River: a candidate for nonmarine stratotype?

Ghosh *et al.* (1996) detailed the lithology, palynology, and conchostracans from the Raniganj/Panchet formational boundary interval exposed in three rivulets—Tetularakh *Nala*, Banspitali *Nala* and Machhkanda Jhor, in an area south of the Damodar River, Raniganj Coalfield, Damodar Basin, West Bengal. These authors also measured the sections and synthesised various parameters for locating the Permian-Triassic Boundary (PTB) in the Raniganj Coalfield. This led to the conclusion that the PTB in the area coincides the Raniganj/Panchet lithostratigraphic boundary (*see also* Bharadwaj *et al.*, 1979; Tiwari & Singh, 1983; Vijaya & Tiwari, 1986; Tiwari & Vijaya, 1992; Tiwari, 1999a, b). Of the three sections, Ghosh *et al.* (1996) recommended that the Banspitali *Nala* section be designated as type section for the continental Permian/Triassic Boundary on the basis of estheriid zonation, palynology and plant and animal megafossils.

With a view to further consolidating the data in favour of this proposal, we have undertaken a study of spore-pollen distribution in four sections (Locality Numbers 1-4, arrowed in Fig. 4). The generalised lithological sections, and the palynological assemblages recovered from various levels are illustrated in Fig. 5, and the overall occurrence of important species in successive levels is depicted in Fig. 6. In conformity with the observations of Ghosh *et al.* (1996), it is concluded from the present study, both field observations and palynological analysis, that the Banspitali *Nala*, near Banspitali Village (to its west : 86°54' : 26°37' — Locality 3 in Fig. 4) is the best section and has also yielded four fairly representative assemblages in succession (Pls 1, 2). These assemblages are from the Ranigaj/Panchet Transition, as shown below :

	Playfordiaspora cancellosa Assemblage Zone (in khaki-green shale-sst unit of upper reaches)	OLENEKIAN
PANCHET FORMATION	*Krempipollenites indicus* Assemblage Zone (in lower shale-sst khaki-green shales)	Early Triassic INDUAN
RANIGANJ FORMATION	*Densipollenites magnicorpus* Assemblage Zone (in uppermost unit of coal, shale-sst)	TATARIAN Late Permian

The determination of epoch and age of these assemblage zones has been discussed by Bharadwaj *et al.* (1979), Tiwari and Vijaya (1992), Ghosh *et al.* (1996), Tiwari (1999a, b, c), and others, based upon palynology, plant megafossils, estheriids, nonmarine vertebrate fossils, palynological cross-correlation with the well-dated Tethyan succession of the Himalaya, sequence stratigraphy and inter-regional relationship with comparable levels in Australia, Madagascar and Antarctica.

Notwithstanding such attempts, there remain several important points to be discussed for establishing the section as a stratotype for the nonmarine PTB. The Bansapitali *Nala* section is well exposed, easily accessible and shows a continuous sequence. The marker bed for the uppermost Raniganj, a 1·5 m thick seam, is well exposed. It is overlain by a massive sandstone (about 20 m thick). The Raniganj/Panchet Boundary is indicated by a few metres of alluvial deposits, followed by a calcareous pebbly bed, about 5 m thick, and then a continuous khaki-green shale-sandstone-sequence, typical of the Panchet Formation. The boundary section concerns only this part of the succession (Fig. 7) although the khaki-green shale-sandstone sequence continues upward to expose the entire Lower Panchet Formation until chocolate-coloured facies of the Upper Panchet become prominent (*see also* Ghosh *et al.*, 1996).

The alluvial deposit and calcareous pebble bed at the boundary may indicate a significant break, as in other sections, but it is not a major unconformity; the whole succession has a conformable aspect. Moreover, the palynological components do not indicate a sudden floral break. It is, therefore, inferred that the Raniganj/Panchet contact in the Banspitali *Nala* section records an episode of a subtle, perhaps climatic, change.

Hence, a team of experts in sedimentology, stratigraphy, palaeontology, geochemistry and geophysics should now analyse all aspects (including carbon – isotope and palaeomagnetic reversal studies) of the section, an approach that is necessary prior to allocating the type section of a system boundary. It should be noted that, although the palynological results so far obtained indicate a palynofloral shift across the boundary and the PTB could be located at this level, more closely spaced samples should be analysed because the palynological recovery has been only fair to poor.

Being a nonmarine succession, it cannot be referred directly to the standard marine stage. Hence a stratotype of Global Standard Section and Point (GSSP) is not required, merely a designated reference section. The Banspitali *Nala* section is potentially a good candidate for a PTB reference section in nonmarine deposits.

5. Gondwana Palynochronology

A study of the time significance of palynozones is palynochronology. During the last decade, a palynological zonation for the Gondwana succession on the Indian peninsula has evolved (Tiwari & Tripathi, 1992; Tiwari, 1999a, b). The chronological value of these palynozones is further enhanced by the fact that they can be applied beyond the Indian subcontinent, mainly elsewhere in Gondwanaland (Lindström, 1996; Warrington, 1996). The relevance of the Standard Global Chronological Scale (SGCS), exclusively erected on marine fossils, is obviously limited in case of nonmarine sequences.

In order to delimit the time significance of palynological zones in Indian Gondwana, the scheme given by Tiwari (1999 a, b; also Fig. 8) could form the basis for further discussion and filling in gaps. For such a goal to be achieved, promising areas where marine fossils occur along with abundant palynomorphs should be investigated. The lesser Himalaya and Tethyan sequence on the Indian subcontinent, northwest peninsula and the east coast are most suitable regions for such investigations because of their close floral relationship with the Gondwana basins on the peninsula. The Gondwana succession in Madagascar and Australia have intermittent marine control and can also provide comparative palynological data. To a large extent, the time connotations of the nonmarine fauna and flora of the peninsular India are also well established (*see* Borkar, 1993; Satsangi, 1987; Tiwari, 1996, 1999a, b, d; Bandopadhyay & Roy Chowdhary, 1996; Prasad & Jain, 1994; Prasad *et al.*, 1996; Kutty *et al.*, 1988; Prasad, 1997; Wopfner, 1999; Vijaya, 2000; Vijaya & Roy, 2000; and references therein). Event stratigraphic, radiometric and carbon-isotope studies could provide additional help in refining palynologically determined chronology.

CONCLUSIONS

The Gondwana succession of the Indian subcontinent is traditionally accepted to encompass a time span from the Permo-Carboniferous to Early Cretaceous. Its northern limit is the boundary of the greater Indian Plate in the Himalayas. It is a mainly nonmarine succession but there are some marine intercalations caused by epicontinental sea incursions on the peninsula; the marginal regions are predominantly marine yet they are allied to peninsular Gondwana. Most of the plant fossils have a Gondwana affinity; thus the Gondwana Sequence should not be defined exclusively on the basis of nonmarine deposits.

A Late Asselian (Early Permian) age has been determined for the beginning of Talchir deposition, and not Permo-Carboniferous, as previously thought. The succeeding sediments form a distinctive unit identifiable as the Karharbari Formation.

The practice of placing the Barakar Formation in the Lower Permian of the bipartite division of Permian should be continued until a satisfactory classification of the nonmarine succession has been established. The newly adopted tripartite divisional scheme for the Permian System, based on marine stratotypes from three widely separated regions in the palaeo-equatorial belt, does not seem appropriate for the Gondwana region and needs further assessment.

A continued search for greater precision in the location of PTB on the Indian peninsula has led to an outcrop section of the Raniganj/Panchet formations in the south of the Damodar River, Raniganj Coalfield, West Bengal. The palynology of this section conforms with those in other areas of the Damodar Basin, but if it is to be established as a reference section, a multidisciplinary study including further palynological work will need to be carried out.

Gondwana palynochronology is a challenging target to achieve so that the time significance of various palynozones can be established. Although a zonal framework for the Gondwana Sequence has been erected, several gaps in the record need to be filled. Palynological correlation with marine sections in the Himalayan region of the greater Indian Plate and also in other areas of Gondwanaland is necessary. Marine faunas or palynofossils from marine stratotypes from extra-Gondwana regions of the northern hemisphere have little relevance in erecting the nonmarine Gondwana biochronostratigraphy.

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