The Palaeobotanist **36** : 87 101, 1987.

Palynological zones and their climatic inference in the coal-bearing Gondwana of peninsular India

R. S. Tiwari & Archana Tripathi

Tiwari, R. S. & Tripathi, Archana (1988). Palynological zones and their climatic inference in the coal-bearing Gondwana of peninsular India. *Palaeobotanist* **36** : 87-101.

On the basis of relative abundance of morphotype groups through the coal-bearing Gondwana Sequence (i.e. Permian) a palynological succession has been reconstructed. Six major compositions have been identified. Palaeoclimatic interpretations have been attempted on the basis of morphographic characters. Eleven such characters have been identified, viz., the overall organization of the saccus, their construction, nature of central body, structure of the saccus, striations and taeniae and tetrad of spores. Cumulative abundance and sum total of the characters have helped in recognising eleven climatic 'Suites' The palynological inferences reflect two more cooling phases after the extreme cold climate in the Lower Talchir; one in Upper Karharbari and another in lower part of Lower Panchet. The palynological composition and morphographic characters also suggest a humid climate instead of arid, both in Kulti as well as Panchet formations.

Key-words—Palynozonation, Palaeoclimate, Gondwana, Coal-bearing strata, Permian (India).

R. S. Tiwari & Archana Tripathi, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India

सारॉंश

प्रायद्वीपीय भारत के कोयला-धारक गोंडवाना में परागाणविक मंडल तथा इनका जलवायवी अनुमान

रामशंकर तिवारी एवं अर्चना त्रिपाठी

कोयला-धारक गोंडवाना अनुक्रम (परमी) में विद्यमान चित्रप्ररूप समूहों की आपेक्षिक बाहुल्यता के आधार पर एक परागाणविक अनुक्रम बनाया गया है। छः मुख्य संरचनायें भी अभिनिर्धारित की गई हैं।

आकारिकीय लक्षणों के आधार पर पुराजलवायवी व्याख्यायें करने का प्रयास किया गया है। इस प्रकार के ।। लक्षण अभिनिर्धारित कर लिये गये हैं इनमें कोष्ठ की कुल मिलाकर संरचना, इनका निर्माण, केन्द्रीय काय की प्रकृति, कोष्ठ की बनावट, धारीयाँ एवं टीनियाँ तथा बीजाणु के चतुष्क सम्मिलित हैं। संचयी प्रचुरता एवं सम्पूर्ण लक्षणों से ।। जलवायवी 'सूट' अभिनिर्धारित किये गये हैं। परागाणविक अनुमानों से अधरि तालचिर में अत्यधिक ठंडी जलवायु के पश्चात् दो और शीत-प्रावस्थायें प्रदर्शित होती हैं इनमें से एक उपरि करहरबारी में तथा अन्य अधरि पंचेत के निचले भाग में है। परागाणविक संरचना एवं आकारिकीय लक्षणों से कुल्टी एवं पंचेत शैल-समूहों में शुष्क के बजाय नम जलवायु प्रदर्शित होती है।

THE climate experienced by an area at a particular time depends upon its continentality and latitudinal position. The palaeogeography and palaeocontinentality of peninsular India has been determined with a fairly high degree of confidence by palaeomagnetic data. During Permian and Triassic time, the western Indian margin was flanked by Africa and Malagasy while the eastern by Antarctica (Text-fig. 1). The northern margin was bordered by Tethys. The palaeolatitudinal position of India was between 20°-45°S during Permian (Smith, Hurley & Briden, 1981), and in this frame of palaeogeography most of the Gondwana coals were deposited between 35°-45°S palaeolatitude. At present, the

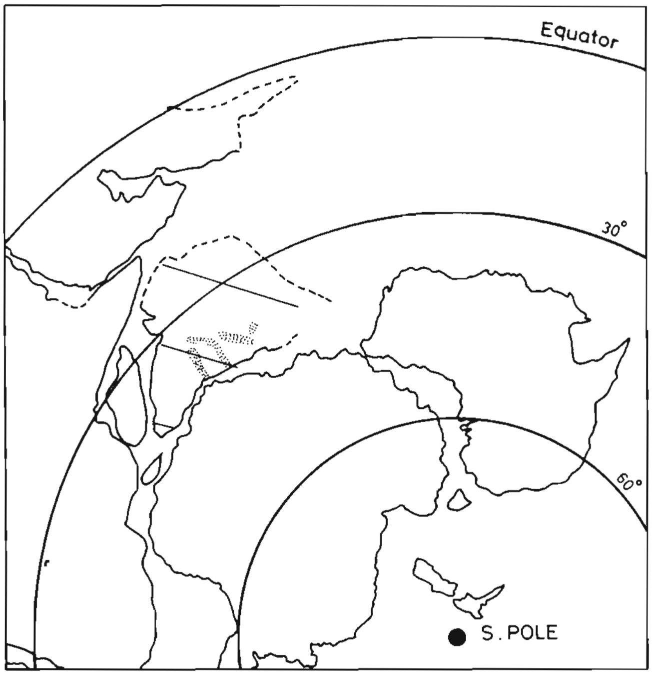
Concepts, limits and extension of the Indian Gondwana
(Editors : B S Venkatachala & Hari K Maheshwari)
Publisher Birbal Sahni Institute of Palaeobotany, Lucknow

Lower Gondwana coal deposits of India lie between 25°-16°N latitude in a triangular pattern distributed along main river valleys, viz., Damodar, Son-Mahanadi, Satpura and Pranhita-Godavari. The generalised stratigraphic sequence in Lower Gondwana is as follows:

	Panchet Formation	
Lower Gondwana	Damuda Group	Raniganj Formation
		Kulti Formation
		Barakar Formation
	Talchir Group	Karharbari Formation
		Talchir Formation

The major coal deposits of Lower Gondwana are restricted to the Karharbari and Barakar formations of Early Permian and Raniganj Formation of Damodar Basin of Late Permian age.

The Lower Gondwana formations show more or less uniform pattern of distribution of flora in different basins (Surange, 1975; Chandra & Chandra, 1988). Plant megafossils are very useful for deciphering the floral alterations but attempt to define finer biozonations poses certain problems since megafossils are found in restricted facies and that too in outcrops, the subsurface samples having limited scope for such occurrences; so also, quantitative determination can hardly be attempted. During the last three decades, palynological sequence in coal-bearing Lower Gondwana of India has been built up with detailed data-base from various basins, including type areas (Bharadwaj, 1974a, 1974b, 1975; Bharadwaj, Srivastava, Ramanamurthy & Jha, 1984; Chandra & Lele, 1979; Kar, 1973; Lele & Srivastava, 1979; Shukla, 1983; Tiwari, 1974, 1975; Tiwari & Ram-Awatar, 1986, 1987; Tiwari & Singh, 1986; Tiwari, Srivastava, Tripathi & Singh, 1981; Tiwari & Tripathi, 1984; Tripathi, 1986). This has resulted into identification of changing pattern of palynofossils through Permian and the Permo-Triassic boundary, thus providing sufficient basis for climatic determinations.



Text-figure 1—Palaeogeographical situation of India during Permian and Early Triassic time.

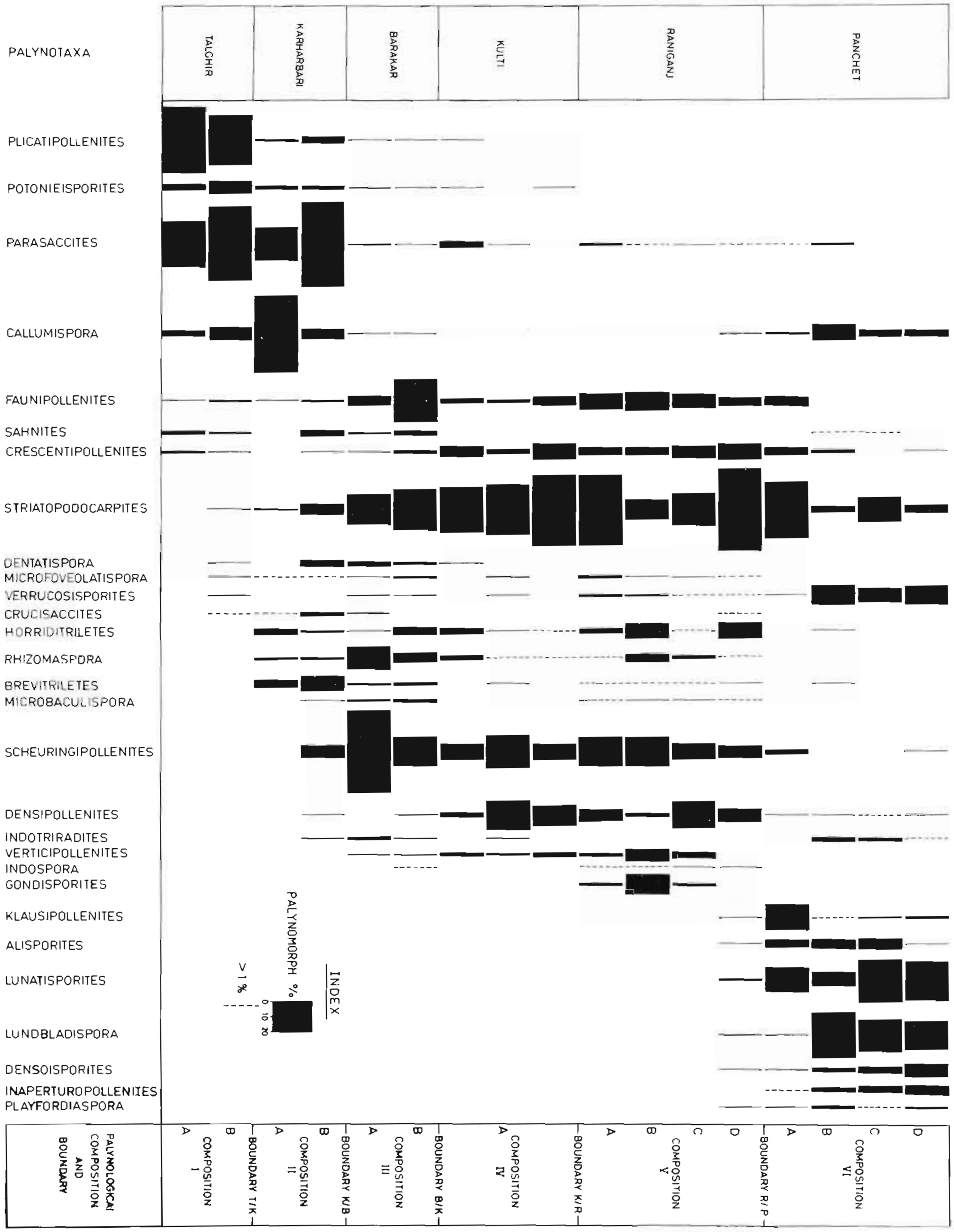
PALYNOLOGICAL SUCCESSION THROUGH LOWER GONDWANA

Detailed palynological investigations of Lower Gondwana formations have established that composite changes exhibit definite course of characters incorporating new elements and eliminating older ones. Thus, the totality of assemblage becomes diagnostic mosaic for each horizon and the gross as well as subtle alterations demarcate the boundary (Text-fig. 2). In the present discussion the palynofloras of Lower Panchet are also incorporated since some of the most significant changes have been recorded at the Permian/Triassic boundary. The present synthesis is based mainly on bore-hole data, and in case of surface samples only those have been considered where information from well-documented sequential samples is available.

Composition I (Talchir Palynoflora)

This palynoflora (Text-fig. 2) is uniformly typified by the dominance of radial monosaccate pollen. Within the Talchir Formation itself, the dominance of generic constituents deciphers the identity of older *Plicatipollenites* rich (Composition IA), and the younger *Parasaccites* rich (Composition IB) zones. The older flora, as such, is less diversified because it shows smaller size-range, the rarity of trilete spores (except *Callumispora*) and sporadic disaccate pollen, while the younger composition has a higher degree of diversity within the radial monosaccate and disaccate taxa.

Talchir/Karharbari boundary—At this level, the appearance of certain typical genera, viz., *Jayantisporites*, a pseudozonate spore, and *Crucisaccites* and *Stellapollenites* radial monosaccate pollen with special organization, is recorded. At this boundary the trilete genus *Callumispora* gets stabilized and also increases in frequency which further amplifies in the Lower Karharbari assemblage.



Text-figure 2—Distribution of significant palynotaxa in terms of percentage frequency through coal-bearing Gondwana.

Composition II (Karharbari Palynoflora)

The palynoflora from Upper Talchir shows a basic continuity with the immediately younger assemblage of Karharbari (Text-fig. 2) with a higher degree of diversity in radial monosaccate pollen. Within this composition, the older assemblage (Composition IIA) reveals the dominance of *Callumispora*. The simple as well as apiculate trilete spores increase in the population. The younger level (Composition IIB) exhibits the recurrence of dominance in radial monosaccate—*Parasaccites* complex, and decline in *Callumispora*.

Karharbari/Barakar boundary— The

palynofloral change at this level is marked by the appearance of a phase of cingulate zonate spores, viz., *Indotriradites* and *Dentatispora*, and varied apiculate taxa. Monosaccate pollen are represented in a very low frequency. A significant diversity in disaccate pollen is observed for the first time at this level.

Composition III (Barakar Palynoflora)

Striate and nonstriate-disaccate pollen are pronounced (Text-fig. 2). The older assemblage (Composition IIIA) is diagnosed by *Scheuringipollenites* (with haploxylonoid construction) abundance while in the younger level (Composition IIIB), the dominance of nonstriate pollen is replaced by the striate pollen genus *Faunipollenites* (haploxylonoid construction). The distribution pattern of trilete spores shows a richness in the lower and middle part which ultimately decreases in the upper part of this assemblage. Thus, the Composition III representing Barakar Formation contains diversified palynofossils with maximum combinations of characters and multiple pathways of evolutionary trends in the organizations.

Barakar/Kulti boundary—At this level the genus *Densipollenites* records an increasing trend and the percentage frequency of trilete cavate spores declines. The genus *Faunipollenites* is low in incidence.

Composition IV (Kulti Palynoflora)

The dominance of striate-disaccate pollen mainly of *Striatopodocarpites* (mostly diploxylonoid construction), similar to the younger level of Composition III, continues to persist in this zone (Text-fig. 2) but the diminishing frequency of trilete spores is noteworthy. The flora, as such is uniform in quality with reference to striate and nonstriate genera of Barakar. The genus *Densipollenites* is abundant (Composition IVA). *Gondisporites, Sahnites, Callumispora* and *Indospora* have not been encountered during quantitative estimation. Thus, the differences from the Barakar and Raniganj palynoflora are existent but subtle.

Kulti/Raniganj boundary—At this level, the palynoflora exhibits subtle qualitative change. The frequency of *Densipollenites* declines. The major change is observed in the fact that several trilete spore genera appear and diversify. Some monolete spore taxa also appear. Thus, in contrast to the Kulti palynoflora, the Raniganj palynoflora is proliferated in forms representing several plant groups and various organizations.

Composition V (Raniganj Palynoflora)

The Raniganj palynoflora (Text-fig. 2) continues to be dominated by the striate-disaccate pollen, mainly *Striatopodocarpites* (mostly diploxylonoid construction). The frequency of trilete spores, such as *Microfoveolatispora, Microbaculispora, Cyclogranisporites* and *Horriditriletes* increases in the middle part of Raniganj Formation and gradually decreases in the upper level. This composition is divisible into four zones. The older one (Composition VA) is marked by the dominance of genus *Striatopodocarpites* while the next level is marked by the genus *Gondisporites* (Composition VB). The genus *Densipollenites* reappears in the younger part (Composition VC) after the increase in *Gondisporites*. The genus *Crescentipollenites* signifies the youngest level (Composition VD). Radial monosaccate pollen also show an increase in their percentage at the last phase of the Raniganj composition.

PLATE 1 →

(All photomicrographs are. × 500 unless otherwise stated)

1. *Lunatisporites* showing taeniae, thin central body, saccus intrareticulation with thick muri.
2. *Parasaccites* showing radial monosaccate construction, thin central body, saccus intrareticulation with thin muri.
3. *Plicatipollenites* showing radial monosaccate construction, dense central body, saccus intratreticulation with thick muri.
4. *Densipollenites* showing dense central body, saccus intrareticulation with thick muri.
5. *Scheuringipollenites* showing haploxylonoid construction, thin central body, saccus intrareticulation with thin muri.
6. *Callumispora* showing thick exine.
7. Portion of saccus of disaccate pollen showing thick muri (arrow). × 1000.
8. Portion of saccus of disaccate pollen showing thin muri (arrow). × 1000.
9. Tetrad of *Lundbladispora*.
10. *Faunipollenites* showing haploxylonoid construction, thin central body, striations, saccus intrareticulation with thin muri.
11. *Striatopodocarpites* showing diploxylonoid construction, thin central body, striations, saccus intrareticulation with thin muri.
12. *Striatites* showing diploxylonoid construction, dense central body, striations, saccus intrareticulation with thick muri imparting a leathery appearance.
13. Portion of *Parasaccites* pollen showing saccus intrareticulation with thick muri (arrow). × 1000.

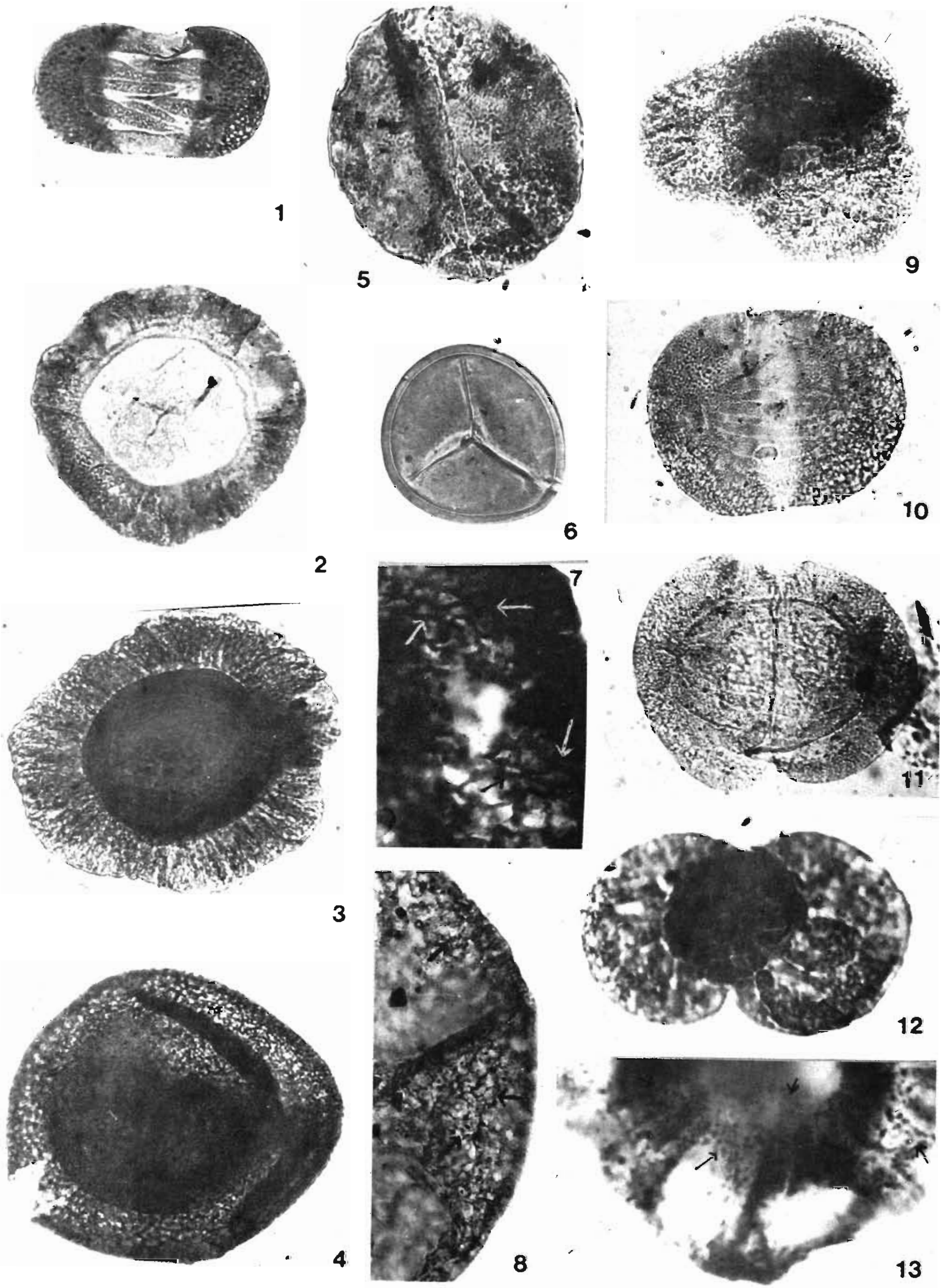
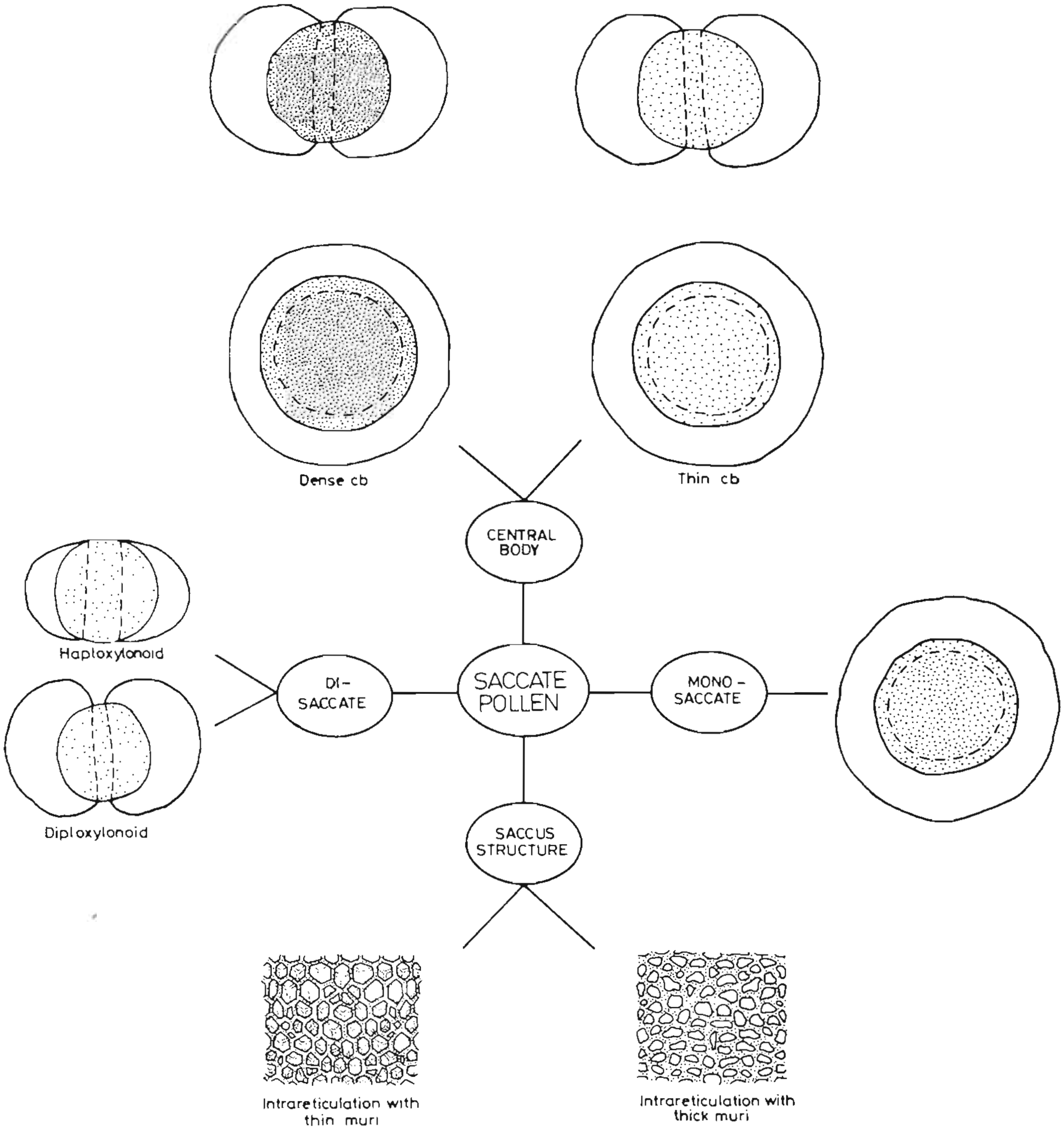


PLATE 1



Text-figure 3—Showing varied morphographic characters of saccate pollen grains considered for the present study.

Raniganj/Panchet boundary— Marked qualitative change is recorded in the palynological compositions at this level by the appearance of certain palynotaxa, viz., *Lundbladispora, Densoisporites, Playfordiaspora, Goubinispora, Klausipollenites* and *Lunatisporites*, well within the Raniganj below the lithological boundary. Concurrently, reverse situation has been noted with regard to the typical Raniganj forms, viz., *Densipollenites, Crescentipollenites*, which decline considerably and subsequently disappear.

Composition VI (Lower Panchet Palynoflora)

The taxa which appear at the R/P Boundary stabilize in Panchet (Text-fig. 2). Cavate-cingulate spores and a new genus of disaccate taeniate pollen, *Lunatisporites*, occur in different combinations of percentage frequency and consequently four main groups within Early Triassic can be identified. At the advent of Panchet, palynoflora is abounding in *Klausipollenites* (Composition VIA) and *Striatopodocarpites*. Next in sequence appears the *Callumispora* and *Verrucosisporites* combination (Composition VIB). *Lunatisporites* signifies the third zone (Composition VIC), and the last zone is marked by cingulate, cavate forms—*Lundbladispora* and *Densoisporites* (Composition VID). It is interesting to note that the genus *Callumispora* (characteristic of Composition I and II of Talchir and Karharbari formations) reappears in early phase of the Panchet assemblage in appreciable frequency.

PALYNOLOGY AND PALAEOCLIMATE

Methods for palaeoclimatic interpretations are mainly based on indicators and analogy (Lamb 1961, 1972). By analogy of the present day indicators, the palaeoclimate of a particular period can be inferred by signatures available in the strata. The parameters for such interpretations are:

(1) Sediment-types pointer to climate, e.g., carbonates, evaporites, red beds, tillites and other environmental indicators, (2) flora (megaflora & palynoflora) and fauna, (3) temperature determinations from oxygen isotope ratios, (4) palaeowind directions, and (5) direction of flow of ice-sheets in the past.

Above mentioned parameters have limitations for palaeoclimatic inferences as individually they do not provide full range of climatic variables. An integrated approach of all the available parameters can effectively resolve the workable palaeoclimatic reconstruction. However, the environmentally significant fossils provide a good deal of information regarding temperature and moisture. Among fossils, animal evidence has greater applicability in marine sediments while plant fossils are important in the terrestrial sediments.

For interpreting palaeoclimate on the basis of palynological data, several questions need be answered. What makes the necessity of a dense central body? Why at a particular level the sacci are more leathery? Does the regular incidences of haploxylonoid and diploxylonoid population reflect climate? Studies on living pollen grains have revealed that various morphographic characters, viz., saccus construction, nature of exine, the mechanism of mother-cell safety, etc., are sensitive to climate (Ueno, 1958, 1979; Guinet, 1987; Hebda & Lott, 1987). The manifestation of exinal sculpture and structure, saccus construction and harmomagathic features are considered as important characters, because they contribute devices which save the mother cell from adverse climatic conditions. Therefore, it is necessary to assess various morphographic features of dispersed spores and pollen which could ultimately be utilized for climatic determinations.

EVALUATION OF MORPHOGRAPHIC CHARACTERS VIS-A-VIS CLIMATE

Fossil spores and pollen exhibit various morphographic characters with specific configuration and structures, each with a precise function. These morphographic features transcend taxonomic delimitations of dispersed spores and pollen. The behaviour pattern of significant morphographic events are evaluated for their sensitivity to climate. For the sake of descriptive account the genera *Callumispora* and *Densipollenites* have been treated as 'characters'.

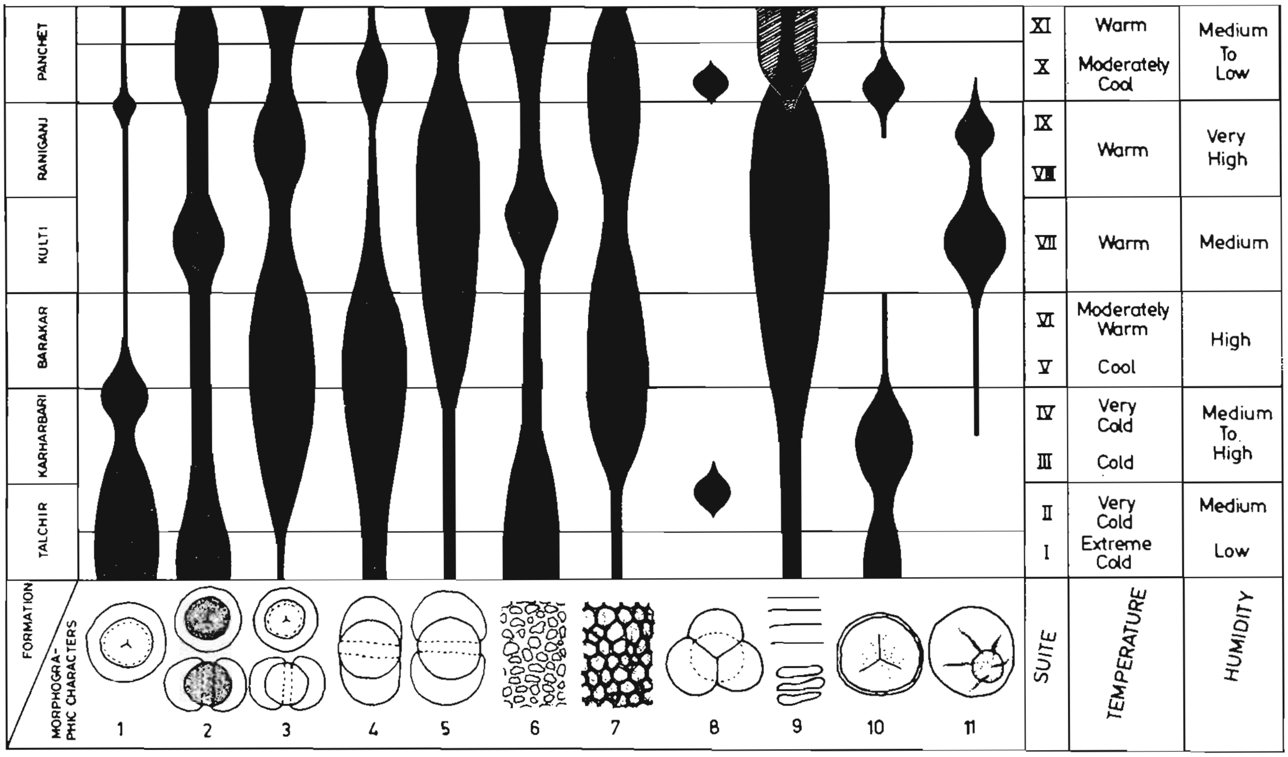
1. Central body— It is the central part of the saccate pollen grain containing the cytoplasmic contents and nucleus which gives rise to microgametophyte after division. In fossil pollen the central body (represented by nexine & sexine), shows variation in the density of its wall on the basis of which character two basic types can be identified, viz., thin body and dense body (Text-fig. 3; Pl. 1, figs 1,2,5,10,11). The extra thickness of the central body is considered here to be a device to protect the delicate cell-contents in response to extreme climatic conditions. Normal, thin body-wall, on the other hand, could indicate amelioration of intensive situation. When the relative abundance of these characters is plotted (Text-fig. 4), it is revealed that pollen with dense central body are dominant in Lower Talchir assemblage. Such pollen also exhibit an upward trend in Upper Karharbari, Kulti, Upper Raniganj and early part of Lower Panchet palynofloras. In remaining horizons, the incidences of dense body show decreasing trend, while the representation of thin-bodied pollen is inversely proportional to the thick-bodied pollen. These trends have a corroborative linkage with other morphographic characters selected here and also with other parameters for climatic assessments.

2. Saccus— The mode and extent of sexine with relation to nexine gives rise to two basic categories in the saccate pollen, the monosaccate and the disaccate.

a. Radial monosaccate construction— This organization (Text-fig. 3; Pl. 1, figs 2, 3) helps in floating of the pollen during dispersal. It also provides protection to the nexine by covering it at most of the subequatorial region and at the same time keeps the germinal area free for quicker sprouting. The distribution pattern of radial monosaccate pollen (Text-fig. 4) shows its peak throughout the Talchir. They decrease in Lower Karharbari but show an increasing tendency in the Upper Karharbari. Their abundance suddenly decreases to be sporadic in the Barakar, Kulti and Raniganj assemblages. However, a fair recurrence of radial monosaccate pollen is noticed in Upper Raniganj palynoflora and across the Raniganj/Panchet boundary.

b. Disaccate construction— Within the disaccate group, two forms are identified, e.g., haploxylonoid and diploxylonoid (Text-fig. 3, Pl. 1, figs 5,10,11,12).

Although the function of saccus has been suggested to be an aid for floating, the



Text-figure 4—Trends in the distribution of morphographic characters, considered to be important from Talchir to Lower Panchet, in terms of relative abundance. **1**, Radial monosaccate; **2**, Dense central body; **3**, Thin central body; **4**, Haploxylonoid construction; **5**, Diploxylonoid construction; **6**, Leathery saccus; **7**, Non-leathery saccus; **8**, Tetrad of spores; **9**, Solid black striations and oblique lines: Taeniae; **10**, *Callumispora*; and **11**, *Densipollenites*

harmomagathic importance (i.e., protection of the germinal aperture from desiccation in adverse condition) attached to it is very crucial. The shapes of the sacci are also considered to be climate sensitive. According to Ueno (1958, 1979) species with haploxylonoid sacci (*Pinus pumila* and *Pinus koraiensis*) grow in cool temperate and subpolar or subalpine zone while species having diploxylonoid sacci (*Pinus thunbergia* and *Pinus densiflora*) flourish in temperate zone. Evidently, the relative abundance of these two types is temperature controlled.

An analysis of distribution of these two types of organizations reveals that the haploxylonoid condition mostly dominates over diploxylonoid in Lower Permian and Lower Triassic (Text-fig. 4). An increase in diploxylonoid type is noticed in Upper Permian. In later part of Lower Panchet the diploxylonoid reappears as prominent group.

3. Saccus infrastructure—The saccus of Permian gymnospermous pollen is filled with alveolae in contrast to the hollow nature of saccus-cavity in living conifers (e.g., Pinaceae). This filled nature is termed as pseudosaccate (Sheurging, 1974; Tiwari, 1981). The alveolate construction, generally described as infrareticulate structure, results from the arrangement of endosexinal elements in a network-like pattern consisting of anastomosing ridges or muri enclosing irregular spaces, the alveolae. The size of alveolae varies from less than a micron to ten micron and the muri show considerable range in thickness (0.5 to 3 μm). Obviously, various combinations of sizes and muri thicknesses of alveolae give rise to varied saccus structure. Besides, infrapunctate structure with leathery, thick appearance of sexine has also been recorded in Gondwana pollen. The compact, thick, leathery-looking sacci (Text-fig. 3) can be identified as one trend in saccus (Pl. 1, figs 7, 13) which is differentiated from the one with thin muri, and fine to medium-sized reticulate structure (Pl. 1, fig. 8), i.e., non-leathery. The protosaccate construction in Permian and Triassic pollen has a definite meaning in course of evolution of saccus as well as in the experimentation to devise a protection mechanism for the microgametophyte. The protosaccus would have provided better safety to the nexine than the true saccus with hollow cavity. The role of leathery and non-leathery types, thus, becomes evident with reference to the changing climatic conditions from extreme to amicable situation.

Keeping these two lines of morphography in view, the distribution of pollen (Text-fig. 4) reveals a maximum abundance of leathery nature in Talchir palynoflora; it declines gradually, replaced by saccus with thin muri and fine reticulation (non-leathery), till the end of Late Permian. Once again, in Early Triassic palynoflora an increasing tendency in thickness of the muri resulting into leathery appearance has been recorded.

4. *Striations and taeniae* — The striations are linear grooves present on the central body of the pollen grain (Pl. 1, figs 10, 11, 12) whereas the taeniae are the irregular ribbon-shaped stripes disposed on the proximal face of the central body leaving thin, irregularly wide areas between them (Pl. 1, fig. 1). Although the precise function of these characters are not known, it has been suggested (Tiwari, 1982) that they are related with the functions of water accumulation, harmomagathy, or emergency germinal exits. It is further opined here that these characters seem to be related with seasonal mild fluctuations and have functioned normally during a small span of favourable conditions. The abundance of taeniate forms indicates more severe fluctuations than those experienced during the time when striate pollen dominated the scene.

It has been demonstrated that in Permian the striations show definite trend of evolution in their complexity. In older assemblages, mainly simple horizontal striations are present. Progressively the branched nature with vertical partitions and reticuloid pattern come in prominence. The taeniae are last to proliferate in the Early Triassic assemblage (Vijaya, 1988). This qualitative complexity and abundance slowly increase (Text-fig. 4) from Talchir to Karharbari; in Barakar, Kulti and Raniganj it is on its peak but a decline is recorded at the Permian-Triassic boundary (Vijaya, 1988) resulting into the oblivion of the character itself in Mesozoic. The maximum diversification in striation types is evidently associated with maximum luxuriant vegetation which produced coal. Obviously, a warmer humid climate at this level of time must have favoured their proliferation.

5. *Tetrad* — On dissolution of the cementing material a tetrad (Pl. 1, fig. 9) gives rise to four isolated spores or pollen. The non-dispersal of four entities appears to have a climatic indication. The release of four isolated units depends upon the production of certain enzymes which act only for a very short time, failing which the isolation of individual spores does not take place (Heslop-Harrison, 1971). It is envisaged that at a given period of time, if the temperature behaves erratically, the enzyme action may fail resulting enormous production of tetrads. The presence of a large number of tetrads in palynoflora may thus reflect the changing conditions of temperature or humidity, or both (Tiwari & Meena, 1988).

In Lower Gondwana, the tetrads are more frequent in Upper Talchir (Lele & Makada, 1972) and in Lower Panchet palynofloras (Tiwari & Meena, 1988). In the remaining horizons these tetrads are rarely recorded (Text-fig. 4).

6. *Callumispora* — This is a trilete-bearing, psilate spore having structured thick exine (up to 7 μm) which mostly shows layering in optical section (Pl. 1, fig. 6). Such an extra density and layering of the spore-coat appear to have been developed as an adaptation to protect the cell content from desiccation during the adverse conditions. The psilate nature of exine has been compensated by the complex layering in the exine itself.

The relative abundance of this taxon shows a definite trend (Text-fig. 4). Its presence in fair amount is marked in the Lower Talchir palynoflora. It increases in Upper Talchir and attains its maximum in the Lower Karharbari. In rest of the formations, its frequency declines. However, once again in Upper Raniganj this genus reappears to a significance and becomes fairly prominent in the Lower Panchet palynoflora.

7. *Densipollenites* — This pollen has an enveloping monosaccus which encloses the central body from all sides (Pl. 1, fig. 4). This construction is again a line of evolution amongst the monosaccate organization providing complete protection to the central body. *Densipollenites* is best suited for adverse climatic conditions, or situations involving major change because its saccus is usually of a leathery type. It attains its peak in the middle part of Kulti, and subsequently declines in Raniganj (Text-fig. 4). However, a marked increase is recorded in the later part of the Upper Raniganj but finally it disappears in the younger horizons.

CHANGING COMPOSITION OF MORPHOGRAPHIC CHARACTERS

The combination of characters in a given palynoflora is diagnostic for that period, and it has been considered for climatic interpretation. Eleven such combinations, termed as 'Suites' have been identified and climatic inferences have been derived from these suites.

Suite-1

1. Radial monosaccates
2. Dense central body
3. Haploxylonoid construction
4. Leathery saccus
5. *Callumispora*

This combination is typical for Lower Talchir assemblage and suggests extremely cold condition with low humidity.

Suite-2

1. Radial monosaccate
2. Thin central body
3. Haploxylonoid construction
4. Leathery saccus
5. Tetrads

This suite recorded in Upper Talchir palynoflora indicates amelioration of the climate. High frequency of tetrads indicates change in temperature. It is inferred that the climate was relatively warmer than that of earliest Talchir with an increase in humidity.

Suite-3

1. Thin central body
2. Radial monosaccate
3. Haploxylonoid construction
4. Non-leathery saccus
5. *Callumispora*

This suite, represented in the Lower Karharbari, suggests a relatively favourable climate—cold with medium to high humidity. The thinning of central body and non-leathery nature of saccus evidence for such a condition.

Suite-4

1. Radial monosaccate
2. Thin central body
3. Haploxylonoid construction
4. Non-leathery saccus

The Upper Karharbari palynoflora possesses this suite indicating a very cold situation with medium to high humidity but not the extreme cold and dry climate as of Lower Talchir.

Suite-5

1. Thin central body
2. Haploxylonoid construction
3. Non-leathery saccus

The above combination represents the Lower Barakar assemblage. It suggests a . favourable climate—cool with high humidity. *Callumispora*, radial monosaccates, thick body and leathery saccus disappear suggesting thereby amelioration of condition.

Suite-6

1. Thin central body
2. Diploxylonoid construction
3. Non-leathery saccus
4. Striation diversity

This Upper Barakar Suite suggests better climate than that experienced during Suite-5, i.e., moderately warm with high humidity. Seasonal changes are also inferred on the basis of abundance as well as complexity of the striations.

Suite-7

1. Dense central body
2. Diploxylonoid construction
3. Leathery saccus
4. Striation diversity
5. *Densipollenites*

These characters have been found to be prominent in Kulti palynoflora. They indicate a relatively adverse condition than Suites 5 and 6, i.e., warm with low to medium humidity.

Suite-8

1. Thin central body
2. Diploxylonoid construction
3. Non-leathery saccus
4. Striation diversity

These characters support warm climate with very high humidity, experiencing seasonal fluctuations. Such a combination has been identified in the Lower Raniganj and lower part of Upper Raniganj assemblages.

Suite-9

1. Thin central body
2. Haploxylonoid construction
3. Non-leathery saccus
4. Striation diversity
5. *Densipollenites*
6. Radial monosaccates

This suite represents the upper most Raniganj palynoflora. It exhibits similarities with Suite-8, experiencing more or less similar climate. However, the addition of characters like radial monosaccates, haploxylonoid construction, indicates a change in climate. Thus, at the closing phase of the Permian the climate cooled down and humidity was reduced but the climate could not have been extreme.

Suite-10

1. Dense central body
2. Haploxylonoid construction
3. Non-leathery saccus
4. Tetrads
5. Radial monosaccates
6. *Callumispora*

This combination, characterizing the Lower Panchet palynoflora, shows the recurrence of certain characters of Suite-1 to Suite-3 and indicates a moderately cool climate with low humidity. The trend of downward temperature initiated in the uppermost part of Raniganj, is expressed significantly in Lower Panchet but it continues only for a short span of time.

Suite-11

1. Thin central body

2. Diploxylonoid construction
3. Leathery saccus
4. Taeniate complex

This suite found in the later part of Lower Panchet assemblage indicates warming of climate with medium to low humidity. Seasonal fluctuations are interpreted on the basis of complexity and abundance of taeniae. The fluctuations might have been more pronounced than those experienced during Barakar, Kulti and Raniganj time.

Remarks—As is clear from the foregoing account, palynological findings do not give indication of aridity in any of the suites. Cooling effect is revealed at the Upper Karharbari, closing of Raniganj and at the advent of the Panchet. Gradual increase in the numerical abundance of striations and taeniae associated with the complexity reflect the seasonal fluctuations from Upper Barakar up to Lower Panchet. The fluctuations during Panchet are interpreted to be more pronounced than those in Lower Gondwana.

CLIMATE DURING LOWER GONDWANA

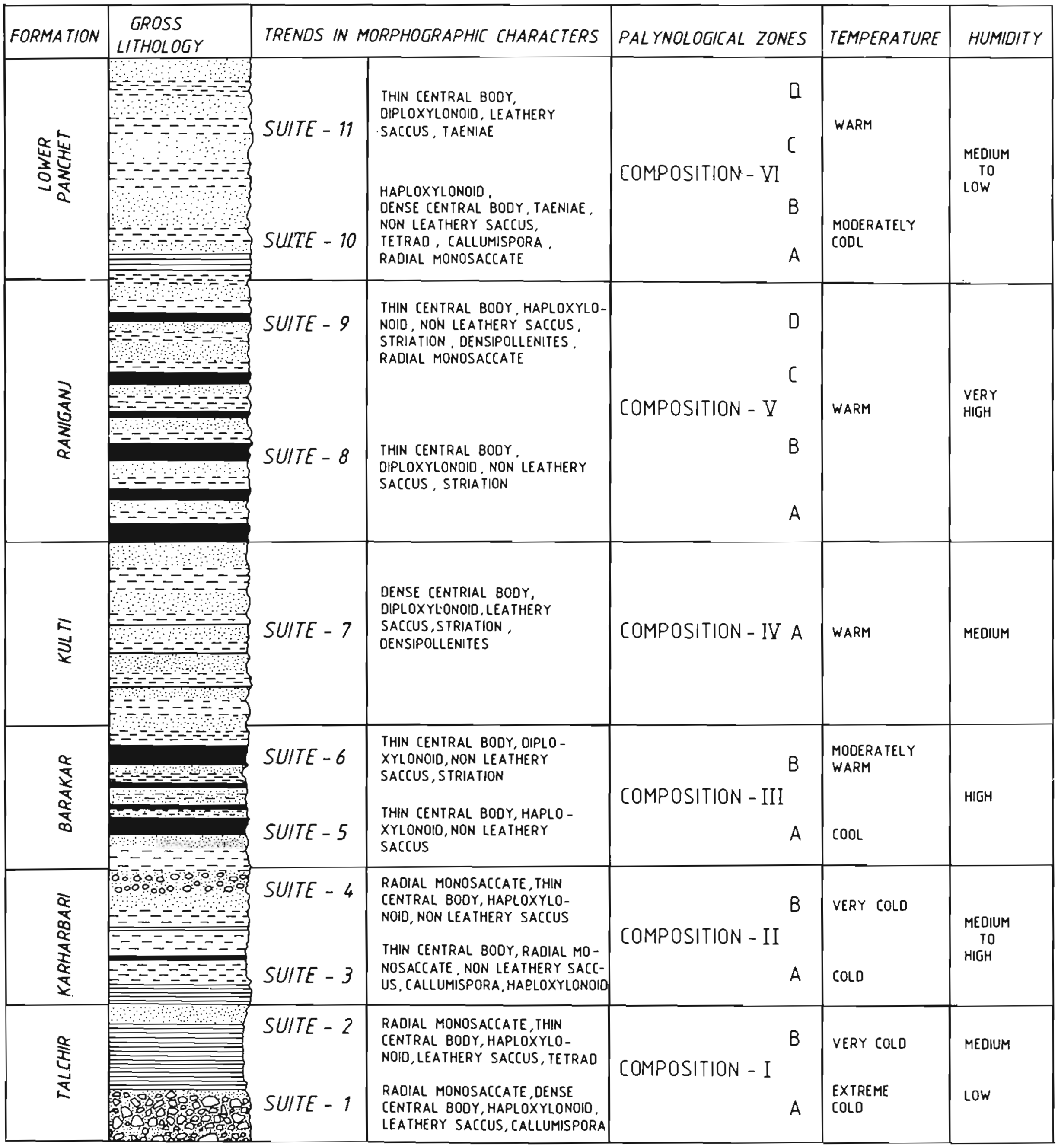
Palynology vis-a-vis other parameters

The generalised panorama of the climate of a particular area in a given time is deduced mainly on the basis of fauna and flora of that region. Palaeoclimatic inferences are strengthened if substantiated by other evidences, such as, lithology, sedimentology, palaeogeography and palaeolatitudinal position of the landmass, etc. Therefore, presently for the interpretation of palaeoclimate which was experienced during the time when coal-bearing Gondwana were deposited, the palaeopalynological results are interpolated with other parameters also (Text-fig. 5). It is now established that the palaeogeographical position of India during Permian time was mainly in the temperate zone between 20°-45°S latitude, the coal-bearing horizons in particular. This basic configuration of continents makes the backdrop of interpretation of other data.

At the base of the Gondwana the morphographic characters of palynomorphs indicating an extreme climate with low humidity are dominating in Suite-1. The overwhelming dominance of *Plicatipollenites-Parasaccites* complex with less diversification of other forms (Composition IA) in the lower part of Talchir is associated with the Talchir glacigene sediments—tillite, striated pavements, varves; thus inferentially, it is supported that the extreme cold climate existed in the earliest Permian. In the later part of Talchir, association of morphographic characters of Suite-2 which is still related with the *Parasaccites-Plicatipollenites* palynoflora, however, with a better degree of qualitative diversity, (Composition IB), reveals amelioration of the climate, from frigid to a very cold condition with medium humidity. These inferences are further supplemented by mineralogical studies of Talchir sediments. They have higher content of fresh feldspar in the older part suggesting a less cooler phase during the younger period (Singh, 1976). Similar conclusions are also drawn by Suttner and Dutta (1986) on the basis of mineralogical analysis who inferred a cold semi-arid climate during Talchir. The Talchir flora predominantly contains leaves of *Gangamopteris* having no midrib, a character interpreted to indicate cold climate (Lele, 1976). The initial studies of oxygen isotope of Indian Gondwana sediments (Dutta & Suttner, 1986) also support a cold, semi-arid climate for Talchir. However, further work on oxygen isotope may provide finer zonations.

The combination of morphographic characters in Suite-3 related with Composition IIA infers to ameliorated cold climate with high humidity which is favourable for luxuriant growth of vegetation. This is also supported by the presence of thick coal seams in Karharbari. The association of characters in Suite-4 suggests a recurrence of very cold phase with medium to high humidity. It is associated with *Parasaccites* and *Callumispora* (Composition IIB) prominence. It has been postulated that a second glacial advance might have produced such a cooling phase (Bharadwaj, 1974). Recent report of a boulder bed in Korba Coalfield akin to tillite, at the top of Karharbari Formation (Mitra, 1988 in this Volume) strengthens the conclusions derived here on the basis of morphography of spores and pollen.

The morphographic characters representing Suite-5 are associated with the dominance of *Scheuringipollenites* (Composition IIIA); they point towards a favourable and cool climate in the begining which gradually warms up and becomes moderately warm as revealed by Suite-6 with dominant *Faunipollenites* (Composition IIIB). Also, high humidity throughout the Barakar is indicated. On the basis of proliferation of striations, it is proposed that from Barakar onwards some seasonal fluctuations in temperature and humidity are experienced. The indication of high humidity is also substantiated by the presence of thick coal strata and abundant pteridophytic spores in Barakar. However, the sedimentological studies indicate a different picture, inferring a warm temperate to subtropical climate in the lower part and tropical humid climate in the upper part (Singh, 1976). Likewise, megafloristically also a warm to hot temperate climate was concluded (Lele, 1976; Chandra & Chandra, 1988) on the basis of leaves with distinct



Text-figure 5—Synthesis of lithological and palynological compositions to evaluate palaeoclimate.

midrib as well as diversification of flora. However, on the basis of present studies it is suggested here that a cooler climate in the older part and moderately warm in the upper part with high humidity was prevailing in Barakar. This view supports the recent study by Suttner and Dutta (1986) who inferred a temperate, humid climate on the basis of mineralogical studies. Similarly, Dutta and Suttner (1986) have opined for a temperate humid climate during Barakar, based on oxygen isotope analysis also.

In Suite-7 the richness of *Densipollenites* (Composition IV) in Kulti (Barren Measures) reveals different conditions than the Barakar. It appears to have experienced warm climate with medium to low humidity. The composition and complexity of palynoflora of Kulti Formation explicitly projects a continuity of a uniform palynoflora from Upper Barakar to Raniganj. The diversification in palynomorphs does not support views for a dry arid climate during Kulti depositional period (Bharadwaj, 1975; Kar, 1976; Lele, 1976; Chandra & Chandra,

1988) Mineralogical and lithological studies have shown that the dominance of red facies and absence of coal seams in Kulti Formation is a result of environment of deposition rather than the climate (Singh, 1976). The similarity of heavy mineral composition of Barakar and Kulti sediments (Kar *et al.*, 1964) warrants similar climate, tropical to subtropical humid, during Barakar and Kulti. According to Singh (1976) the red colouration is due to presence of siderite which has high concentration of iron (as carbonate) which develops in lakes. This siderite after oxidation develops red colour. Besides, the siderite also indicates high bacterial activity which is optimum in warm and humid climate (Shah, 1976), which might be responsible for the absence of carbonaceous matter in Kulti. These inferences are in accordance with present findings for warm and humid climate during deposition of Kulti sediments.

The morphographic characters in Suite-8 and Suite-9, representing the Palynological Composition V, indicate warm climate with very high humidity throughout the span of Raniganj Formation. This conclusion corroborates the presence of thick coal deposits in Raniganj Formation. In the latter part, however, the palynology suggests a change, that is, lowering of temperature and decrease in the humidity. The faunal records also reveals a temperate climate (Shah, 1976). Similar inferences are also drawn megafloristically having dominance of species of *Glossopteris* with open meshes in leaves (Lele, 1976) and richest megaflora in kind and number (Chandra & Chandra, 1988). The mineralogical studies also reveal a warm humid climate (Singh, 1976) Recently, on the basis of oxygen isotope and mineralogical studies, Suttner and Dutta (1986) and Dutta and Suttner (1986) have given a generalised picture of climate. They have inferred a gradual change from cool and humid climate in Barakar towards warm, semi-arid from Raniganj to Panchet. The climate inferred by them during Raniganj is in accordance with present findings.

The climate indicator pollen spore characters in Suite-10 suggest a relative cooling at the beginning of Panchet deposits. This suite represents older part of Palynological Composition VI, where radial monosaccate pollen and *Callumispora* increase significantly. Thus, reflection of some conditions similar to Composition I and II representing Talchir and Karharbari palynofloras, respectively, are noted in Lower Panchet. A cool and medium to low humid climate thus may be inferred. Bharadwaj (1975) had proposed a third glacial phase at this level. However, physical evidences for such an event are not on record in India, although in Lower Panchet the presence of olive green shales and fresh feldspar, typical for Talchir, may infer cooling of the climate. Recently Suttner and Dutta (1986, p. 355, fig. 12) on the basis of mineralogical as well as oxygen isotope studies have inferred that the cool and humid climate of Barakar gradually changed towards warm and semi-arid up to Panchet. However, it is noticed here that their figures clearly reveal the pattern of curve at Upper Raniganj and Lower Panchet to be similar to that of the Talchir. It indicates recurrence of Talchir-like climate, i.e., cooling and lowering of humidity during Upper Raniganj and Lower Panchet which substantiates present inferences. The present authors have recorded a typical Early Triassic palynoflora having rich *Lundbladispora* together with *Callumispora, Verrucosisporites* and *Playfordiaspora* in clay sediments from Weuda area, Sri Lanka (Per. obs. 1986). These rhythmites directly overlie the typical boulder bed and their glacial nature is substantially supported by the sedimentological studies (Dahanayake & Dasanayake, 1981). This evidences that there had been a glacial event in the Early Triassic time in Sri Lanka. It might not have been much extensive so as to reach the heart of Indian continent but it had a push of cooling effect all over the Peninsula. The influence of glaciation during Lower Panchet, therefore, cannot be disregarded.

Suite-11 representing the younger part of Composition VI having *Lunatisporites* in abundance reveals warming up of the climate with seasonal fluctuations. The faunal evidences—abundance of *Lystrosaurus, Proterosuchus* and amphibians, also support a warm and humid climate rather than extreme conditions of aridity (Shah, 1976). Rich palynological population, its kind and morphographic features, evaluated in this discussion, do not support any arid condition in later part of Lower Panchet; rather a warm and less humid situation might have existed during that period. Seasonal fluctuations are also interpreted on the basis of smaller estherid found in Panchet (Shah, 1976; Ghosh *et al.*, 1988). The mineralogical studies had suggested that red colour of sediments in Panchet is due to the presence of siderite and thus it is facies controlled (Singh, 1976). According to Singh (1976) these sediments were deposited in a subtropical climate with prolonged seasonal fluctuations and, as such, there is no evidence of aeolian sand deposits which could reveal a dry and arid climate. These conclusions are in accordance with present palynological proposition for a warm and slightly humid climate with pronounced seasonal fluctuations during Panchet. The inferences drawn from megafloral basis suggesting widespread aridity with irregular rainfall and scanty water source

(Lele, 1976) do not corroborate with the presently drawn conclusions. The apparent disparity in the richness of palynoflora and impoverised megaflora in fossil state is probably due to nonpreservation of the megafossils. This condition might be attributed to the depositional environment rather than climate.

The palynological proposition, in general, deciphers a warm with medium to low humid climate for Panchet. It does not support for an arid or semiarid climate, as suggested earlier by Pascoe (1958), Wadia (1961) and Tripathi and Satsangi (1963). The seasonal fluctuations are also inferred here on the basis of abundance of taeniae and their maximum complexity. These fluctuations probably have been severe than those experienced during Late Permian time, when striations (rather than taeniae) were in proliferation.

CONCLUSIONS

On the basis of present study following conclusions are drawn:

1. Six compositions of palynoassemblages are identified on the basis of major change-overs at various levels from Talchir to Panchet (Permian to Early Triassic) in Indian Gondwana sediments.

	Lundbladispora-Densoisporites Zone (D)
	Lunatisporites-Verrucosisporites Zone (C)
Composition VI	*Verrucosisporites-Callumispora* Zone (B)
	Striatopodocarpites-Klausipollenites Zone (A)
RANIGANJ/PANCHET BOUNDARY	
Composition V	*Striatopodocarpites-Crescentipollenites* Zone (D)
	Striatopodocarpites-Densipollenites Zone (C)
	Striatopodocarpites-Gondisporites Zone (B)
	Striatopodocarpites-Faunipollenites Zone (A)
KULTI/RANIGANJ BOUNDARY	
Composition IV	*Densipollenites-Striatopodocarpites* Zone A
BARAKAR/KULTI BOUNDARY	
Composition III	*Faunipollenites-Scheuringipollenites* Zone (B)
	Scheuringipollenites-Faunipollenites Zone (A)
KARHARBARI/BARAKAR BOUNDARY	
Composition II	*Parasaccites-Callumispora* Zone (B)
	Callumispora-Parasaccites Zone (A)
TALCHIR/KARHARBARI BOUNDARY	
Composition I	*Parasaccites-Plicatipollenites* Zone (B)
	Plicatipollenites-Parasaccites Zone (A)

2. In the Lower Gondwana palynofloras 11 morphographic characters have been identified to infer climatic conditions.
   i. Dense central body—low humidity
   ii. Thin central body—high humidity
   iii. Radial monosaccate—cold phase
   iv. Haploxylonoid construction—cool phase
   v. Diploxylonoid construction—warm phase
   vi. Leathery saccus structure—less humidity
   vii. Non-leathery saccus structure—medium to high humidity
   viii. striations and taeniae→seasonal fluctuations
   ix. Tetrad of spore—sudden change of temperature
   x. *Callumispora*—cool phase, low to medium humidity
   xi. *Densipollenites*—warm phase, low to medium humidity
3. The cumulative abundance of assorted characters fall in well-marked trends from Talchir to Lower Panchet and 11 Suites for combination of these morphographic characters could be identified.
4. The palynological composition as well as morphographic characters in Talchir, Upper Karharbari and Lower Panchet indicate glaciation or cooling effects due to glacial advances.
5. Cold conditions with medium to high humidity was prevailing during Lower Karharbari and moderately warm with high humidity during Barakar. The climate was warm with low to medium humidity at the time when sediments of Kulti Formation were deposited. Raniganj experienced warm and high humid climate. In late Early Panchet the climate was warm with low to medium humidity.
6. Palynologically, arid conditions are not indicated at any level during Lower Gondwana.
7. Signatures of seasonal fluctuations are recorded from later part of Early Permian. These fluctuations became more pronounced in Panchet.

REFERENCES

Bharadwaj, D. C. 1974a. Palaeobotany of Talchir and Karharbari formations and Lower Gondwana glaciation. *in* : Surange, K. R. *et al.* (eds)—*Aspects and appraisal of Indian palaeobotany.* Birbal Sahni Institute of Palaeobotany, Lucknow, pp. 369-385.

Bharadwaj, D. C. 1974b. Palynological subdivisions of Damuda Series. *in* : Surange, K. R. *et al.* (eds)—*Aspects and appraisal of Indian palaeobotany.* Birbal Sahni Institute of Palaeobotany, Lucknow, pp. 392-396.

Bharadwaj, D. C. 1975. Palynology in biostratigraphy and palaeoecology of Indian Lower Gondwana formations. *Palaeobotanist* **22** : 150-157.

Bharadwaj, D. C., Srivastava, S. C., Ramanamurthy, B. V. & Jha, N. 1984. Kamthi Formation—a palynological appraisal. *Geophytology* **14** : 246-247.

Chandra, A. & Lele, K. M. 1979. Talchir mioflora from South Rewa Gondwana Basin, India and their biostratigraphical significance. *Proc. IV int. palynol. Conf., Lucknow (1976-77)* **2** : 117-151. Birbal Sahni Institute of Palaeobotany, Lucknow.

Chandra, S. & Chandra, A. 1988. Vegetational changes and their climatic implications in coal-bearing Gondwana. *in*: Venkatachala, B. S. & Maheshwari, H. K. (eds)— *Concepts, limits and extension of Indian Gondwana, Palaeobotanist* **36** : 000-000.

Dahanayake, J. & Dasanayake, D. M. S. N. 1981. Glacial sediments from Weuda, Sri Lanka. *Sedim. Geol.* **30** : 1-14.

Dutta, P. K. & Suttner, L. J. 1986. Alluvial sandstone composition and palaeoclimate. II. Authigenic mineralogy. *J. Sedim. Petrol* **56** : 346-358.

Ghosh, S. C., Datta, A., Nandi, A. & Mukhopadhyaya, S. K. 1988. Estheriid zonation in the Gondwana. *in*: Venkatachala, B. S. & Maheshwari, H. K. (eds)—*Concepts, limits and extension of Indian Gondwana Palaeobotanist* **36** : 000-000.

Guinet, P. 1987. Geographic patterns of the main pollen characters in genus *Acacia* (Leguminosae), with particular reference to subgenus Phyllodineae. *in* : Blackmore, S. & Ferguson, I. K. (eds)—*Pollen and spores: form and function*, Linnean Soc., London, pp. 297-311.

Hebda, R. J. & Lott, J. N. A. 1973. Effects of different temperatures and humidities during growth on pollen morphology, an SEM study. *Pollen Spores* **15** : 563-571.

Heslop-Harrison, J. 1971.*Pollen development and physiology.* Butterworth & Co. Ltd., London.

Kar, P., Banerjee, A. K., Banerjee, S. P. & Jhala, S. V. 1964. Heavy mineral assemblages and their significance in Lower Gondwana sediments of West Bokaro Coalfield. *Proc. 22nd int. geol. Congr., New Delhi* **9** : 290-302.

Kar, R. K. 1973. Palynological delimitation of the Lower Gondwana in the North Karanpura sedimentary basin, India. *Palaeobotanist* **20** : 300-317.

Kar, R. K. 1976. Miofloristic evidences for climatic vicissitudes in India during Gondwana. *Geophytology* **6** : 230-244.

Lamb, H. H. 1961. Fundamental of climate. *in* : Nairn, A. E. M. (Ed.)—*Descriptive palaeoclimatology.* Interscience Publ., New York.

Lamb, H. H. 1972. *Climate: present, past and future.* **1** : Mathuen & Co. Ltd., London.

Lele, K. M. 1976. Palaeoclimatic implications of Gondwana floras. *Geophytology* **6** : 207-229.

Lele, K. M. & Makada, R. 1972. Studies in the Talchir flora of India—7. Palynology of the Talchir Formation in the Jayanti Coalfield, Bihar. *Geophytology* **2** : 41-73.

Lele, K. M. & Srivastava, A. K. 1979. Lower Gondwana (Karharbari to Raniganj Stage) miofloral assemblages from the Auranga Coalfield and their stratigraphical significance. *Proc. IV int. palynol. Conf., Lucknow (1976-77)* **2** : 152-164. Birbal Sahni Institute of Palaeobotany, Lucknow.

Mitra, N. D. 1988. Evolutionary history of Gondwanic Plate margin of India. *in*: Venkatachala, B. S. & Maheshwari, H. K. (eds)—*Concepts, limits and extension of the Indian Gondwana. Palaeobotanist* **36.**

Pascoe, 1958. *A manual of the geology of India and Burma,* **2** : 2nd edn., Govt. of India Press, Calcutta.

Scheuring, B. W. 1974. "Protosaccate" Structuren, ein weitverbeitetes Pollen-merkmal zur frühen und mittleren Gymnospermenzeit. *Geol. Palaeont. Mitt. Innsbruck.* **4**(2) : 1-30.

Shah, S. C. 1976. Climates during Gondwana Era in peninsular India: faunal evidences. *Geophytology* **6** : 186-206.

Shukla, M. 1983. Lithostratigraphy and palynostratigraphy of the Lower Gondwana formations in the Hutar Coalfield, Palamau District, Bihar, India. *Palaeobotanist* **31** : 176-190.

Singh, I. B. 1976. Mineralogical evidence for climatic vicissitudes in India during Gondwana times. *Geophytology* **6** : 174-185.

Smith, A. G., Hurley, A. M. & Briden, J. C. 1981. *Phanerozoic palaeocontinental World maps.* Cambridge Univ. Press, Cambridge.

Surange, K. R. 1975. Indian Lower Gondwana floras: a review. *in* : Campbell, K. S. W. (Ed.)—*Gondwana geology.* Australian natn. Univ. Press, Canberra, pp. 135-147.

Suttner, L. J. & Dutta, P. K. 1986. Alluvial sandstone composition and palaeoclimate, I. Frame work mineralogy. *J. Sedim. Petrol.* **56** : 329-345.

Tiwari, R. S. 1974. Inter-relationship of palynofloras in the Barakar Stage (Lower Gondwana), India. *Geophytology* **4** : 111-129.

Tiwari, R. S. 1975. Palynological composition of the basal Gondwana in India. *Bull. Soc. Belg.* **84** : 11-17.

Tiwari, R. S. 1981. Protosaccate condition in Gondwana disaccate pollen. *Geophytology* **11** : 266-267.

Tiwari, R. S. 1982. Nature of striations and taeniae in Gondwana saccate pollen. *Geophytology* **12** : 125-127.

Tiwari, R. S. & Meena, K. L. 1988. Abundance of tetrads in Sporae dispersae from Early Triassic sediments of India, and their relations with change of climate. *Palaeobotanist* (in Press).

Tiwari, R. S. & Ram-Awatar 1986. Late Permian palynofossils from the Pali Formation, South Rewa Basin, Madhya Pradesh. *Bull. geol. Min. metall. Soc. India* **54** : 250-255.

Tiwari, R. S. & Ram-Awatar 1987. A palynological assemblage from Parsora Formation, Johilla Coalfield, South Rewa Gondwana Basin, Madhya Pradesh. *Geophytology* **17** : 104-109.

Tiwari, R. S. & Singh, Vijaya 1986. Palynological evidences for Permo-Triassic boundary in Raniganj Coalfield, Damodar Basin, India. *Bull. geol. Min. metall. Soc. India* **54** : 256-264.

Tiwari, R. S., Srivastava, S. C., Tripathi, A. & Singh, V. 1981. Palynostratigraphy of Lower Gondwana sediments in Jharia Coalfield, Bihar. *Geophytology* **11** : 220-237.

Tiwari, R. S. & Tripathi, A. 1984. A report of Raniganj mioflora from sediments of Dubrajpur Formation in Brahmani Coalfield, Rajmahal Basin. *Geophytology* **14** : 244-245.

Tripathi, A. 1986. Upper Permian palynofossils from the Rajmahal Basin. *Bull. geol. Min. metall. Soc. India* **54** : 265-271.

Tripathi, C. & Satsangi, P. P. 1963. Lystrosaurus fauna of the Panchet Series of the Raniganj Coalfield. *Mem. geol. Surv. India Palaeont. indica* **37** : 1-53.

Ueno, J. 1958. Some palynological observations of Pinaceae. *Jl Inst. Polytech. Osaka City Univ.* **9** : 163-186.

Ueno, J. 1979. *Pinus* and pollen analysis II. *Palaeolimnology Lake Biwa & Japanese Pleistocene* **7** : 348-357.

Vijaya, 1988. Evolutionary pattern of striations in Indian Gondwana palynofossils. (MS).

Wadia, D. N. 1961. *Geology of India.* Macmillan, London.