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Vegetational changes and their climatic implications in coal-bearing Gondwana

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An attempt has been made to decipher the climatic changes during the Lower Gondwana times of India particularly during the coal forming period. The synthesis has been done mainly on the available data of plant characteristics flora and vegetation. It is observed that the climate was essentially temperate during the Lower Gondwana. The climate was very cold during sedimentation of Talchir rocks and it has gradually ameliorated in Karharbari, Barakar, Kulti and Raniganj period with increase in humidity and rain fall; sudden fluctuations of dry and semi-arid conditions were experienced in the deposition of Kulti and Kamthi formations.

Key-words—Palaeoecology, Palaeoclimate, Vegetational changes, Lower Gondwana (India).

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साराँश

कोयला-धारक गोंडवाना में वनस्पतिकीय परिवर्तन तथा इनका जलवायवी तात्पर्य

शैला चन्द्रा एवं अनिल चन्द्रा

भारत के अधरि गोंडवाना काल में विशेषत: कोयला उत्पत्ति के समय हुए जलवायवी परिवर्तनों की व्याख्या करने का प्रयास किया गया है। प्रस्तुत विश्लेषण मुख्यतया लाक्षणिक वनस्पतिजात एवं वनस्पति के उपलब्ध आँकड़ों पर आधारित है। यह प्रेक्षित किया गया है कि अधरि गोंडवाना के समय जलवायु शीतोष्ण थी। तालचिर चट्टानों के अवसादन के समय जलवायु बहुत ही ठंडी थी तथा शनै: शनै: करहरबारी, बराकार, कुल्टी एवं रानीगंज में आर्द्रता एवं वर्षा में वृद्धि के साथ-साथ ठीक होती चली गई; कुल्टी एवं कामथी शैल-समूहों के निक्षेपण के समय शुष्क एवं अर्ध-शुष्क परिस्थितियों में अकस्मात उतार-चढ़ाव भी हुए।

THE record of changes in the earth's climate during the geological ages can be scanned from various lines of evidence. Out of these, the history of plants as revealed by their remains is of particular significance as these cover a vast expanse of earth's history and widest range of ecological environments. Plants have lived at all levels on land, in continental water and upland and in environments of exceeding dryness. Because of these wide ecological adaptation the plants can be used in conjunction with the animals in the interpretation of past climates. Plants are more useful and reliable because many of them have been very sensitive to climatic conditions and invariably to changing climates. The ecological tolerances vary greatly from group to group, often down to the species level. The evidence of fossil plants as it bears upon past climate is for the most part indirect. It is assumed that the plants of the past were more or less similar to their modern relatives in physiologic requirements and hence in their ecological tolerance. It is not always an easy task to assess the climatic relations of an unfamiliar flora

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that too found in the form of incomplete fossil specimens. Ecological reconstructions of ancient and extinct groups of plants is therefore a subject of uncertainties. To some extent the Tertiary and Quaternary climatic elucidations are easier as compared to the Mesozoic and Palaeozoic. The climatic interpretability of Palaeozoic flora is even more difficult and highly theoretical because our modern plant climatic indicators can not be applied for Lower Gondwana plants (Brenchley, 1984; Schopf, 1973; Dorf, 1963, 1969; Schwarzbach, 1963).

Our effort was to visualize the entire available data and postulate the effect of climate on the Lower Gondwana plants in their morphology, anatomy and the evolutionary aspect. For this study one has to depend on the modern climatic factors and their effect on different plant parts. Generally same parameters have been used for fossil plant studies. This has certain drawbacks and if we blindly follow these parameters, our results would be far reaching and hazardous. In any such interpretative study dealing with fragmentary evidences certain limitations are always faced. Modern plant climatic indicators can not be applied for Lower Gondwana plants, e.g., according to present day indicators, the smooth-margined, simple, entire, large leaves with pinnate venation of the *Glossopteris* leaves indicate floral characteristic of tropical climate. Major plant evolutionary events took place in the Carboniferous and Permian and may have resulted from the adaptation of biological strategies of plants. The interpretation of ecology from botanical structures can be very misleading. There is no doubt that the evolution of certain structures may have been turned in response to particular environmental pressures, but it does not mean that plants possessing these structures must always be found in the same environment.

Fossil assemblages give a partial view of flora. An assemblage may contain mixture of plants belonging to quite distinct habitats. Identification and determination of species is often arbitrary. It is extremely difficult to obtain reliable quantitative information on the floristic composition of fossil plants.

Fossilization is a selective process and may not represent the original entire flora. Fossil plant material is often best preserved in acidic or anaerobic condition. If fossil plants are not preserved in situ, their stratigraphical distribution is controlled by transport and depositional processes. In general, fossil plant assemblages are controlled by the interactions of their original ecology with sedimentary process. So we must know the transport history and depositional process as evidenced from the sedimentology.

A modern plant association is a community of definite floristic composition and more or less uniform structure and habitat. This is very much lacking in fossil plant association. The fossil plant association has an objective reality, regardless of effects of differential preservation, collecting bias, etc.

Incomplete data and presumptions based on them can lead us to wrong conclusions. Our knowledge in Lower Permian strata is still very incomplete and imperfectly known and we need to have more information in Talchir, Karharbari, Barakar and Kulti formations. We have no co-ordination between palaeobotanists, palynologists, sedimentologists and palaeontologists. Thus, it is high time that we interact with each other in a better and big way. We must search some parameters which could be useful in determining the climate of the Gondwana period. It is likely that if we search hard we may find out some useful parameters in the venation pattern of the *Glossopteris* plant. At present we have no set parameters of our own. In near future we should be able to tell about the past climate of a particular period say Talchir in a particular basin and not of a particular period or era as a whole, as we are doing today. We should also take into consideration periods of storms, floods, drought and forest fires.

HISTORY

In 1937, in a symposium during the International Geological Congress held in Moscow, Birbal Sahni, D. N. Wadia, M. D. Zalessky, C. S. Fox, A. L. du Toit, A. Krystofovitch, and others discussed the significance of fossil floras in interpretation of Lower Gondwana climate. Kräusel (1961) made some valuable observations about Gondwana climates. In the last two decades the subject was discussed during International Gondwana Symposia held in Argentina (1967), South Africa (1970), India (1977), New Zealand (1980) and Canada (1986). Lele (1976) made a fresh approach to sort out certain plant morphological characteristics and their appearance, dominance, disappearance patterns in time for interpreting palaeoclimate. Bharadwaj (1976), Laskar and Mitra (1976) and Shah (1976) made palaeoclimatic contemplations drawn from diverse studies. Apart from major consideration to fossil plants in this paper, other evidences like pollen-spores, animals, lithology, palaeolatitudes, palaeotemperatures and stratigraphy have also been considered.

TALCHIR

Talchir sedimentation in India commenced with a glacial episode in basal Permian. The Talchir rocks

with their characteristic olive-green colour are readily distinguishable from other Gondwana formations. The rock types include diamictite (tillite), conglomerate, sandstone, laminated varve-like shale, siltstone (rhythmite facies) and locally turbidite deposits. The part of the Talchir Formation overlying the tillites consists of greenish-grey sandstones and fine-grained greenish shales which may be highly indurated varved clays. The green colour is attributed to the presence of iron in the ferrous state and to the absence of a strong oxidising environment when the sediments were deposited.

Megaflora

The Lower Talchir mega- and microflora recorded from sediments close to the tillites (Lele & Karim, 1971; Surange & Lele, 1956; Lele, 1975) includes *Noeggerathiopsis* and *Gangamopteris* and some monosaccate pollen (*Potonieisporites/Plicatipollenites*). *Glossopteris* has not been found during Lower Talchir. Eight species of *Gangamopteris* are reported from the top most Rikba beds (latest Talchir) of North Karanpura Coalfield (Feistmantel, 1879). Chandra and Surange (1979) recognised *Glossopteris talchirensis* from the same area. Some small shoots of *Paranocladus* and *Noeggerathiopsis hislopi* are also known. Winged seeds are more common and frequent. The sandy facies of the Upper Talchir Formation often carry equisetaceous stems.

Surange and Lele (1956) discovered stunted forms of *Gangamopteris* and *Noeggerathiopsis* in 3 m thick needle shales, above the boulder bed in Giridih Coalfield. Feistmantel (1879) discovered *?Schizoneura, Gangamopteris cyclopteroides* and *Noeggerathiopsis* from Deogarh area and *Gangamopteris? angustifolia, Glossopteris* sp. and a few stems from Karanpura Coalfield. Chandra and Srivastava (1982) described *Noeggerathiopsis hislopi* and *Noeggerathiopsis* sp. from Anupur area, and well-preserved *Gangamopteris cyclopteroides, G. intermedia, G. clarkeana* and *G. major* from Chirimiri Coalfield. A newly collected megaflora from Umaria has an altogether new assemblage full of seeds which at places are attached at the tips of axes. Some palmate leaf forms and a few very small pieces of *Noeggerathiopsis* are also seen.

Palynology

Qualitatively there are 46 genera recorded; monosaccate pollen dominate. Tiwari (1975) has suggested three tentative palynozones in the Talchir Formation. Chandra and Lele (1979) have suggested two palynofloral zones in the Talchir Formation of South Rewa Gondwana Basin.

Palaeoclimate

Evidently in the early phase the Talchir flora was very meagre and scanty. In the late Talchir, an appreciable diversity is seen in plant fossils. Towards the end of the Talchir the Glossopteris flora is established. Lele (1976) hypothesized that during the early phase of Talchir deposition, the Indian peninsula was presumably a land surface of high elevation, ice covered and nearly barren of vegetation. Bizzare storms and winds must have swept accross the irregular terrain from the mountainous country which was still covered with unconsolidated till. The glacial sedimentation in several Damodar Valley basins exemplify a cyclic pattern governed by advancing and retreating ice fronts. There were thus interstatial climatic fluctuations within a single cycle and perhaps more than one cycle were present.

Sahni (1939) visualized the existence of a preglacial vegetation and believed that the Talchir plants were lineal descendants of that vegetation. Surange (1966) assumed that Glossopteris Flora co-existed with the glaciers. There is no direct evidence to prove the evolution of the new forms in Talchir.

It is evident that there are three distinct floral phases in the Talchir. The first assemblage (unpublished) found in Umaria is composed of simple axes with seeds at their tips, a few *Noeggerathiopsis* and some equisetalean stems. Devonian flora is not known from India and whatever we know is from other Gondwana countries. It is likely that some of the Devonian forms continued in the Talchir. *Noeggerathiopsis* and *Gangamopteris* plants appeared later in the second floral phase. Lastly *Glossopteris* plant appeared in the third phase (Table 1).

During Early Talchir, the Indian peninsula was mostly covered with thick ice sheets having small crevices. Plants with simplest morphological structures were growing in these crevices. This is supported by plant fossils found in Umaria. These plants were perhaps descendants of the Devonian flora. As the conditions became a little favourable, the same assemblage proliferated and new leaf forms came into being. During the Middle Talchir small stunted *Gangamopteris* and *Noeggerathiopsis* appeared. In the Upper Talchir, we see a few forms of *Glossopteris* with some other veined leaf forms. During these three phases the temperature improved (Waterhouse, 1976), land became more ice free and plant types proliferated. It is irksome to imagine one climatic condition for the whole Indian landmass during Talchir period. The climatic conditions improved in pockets, at places the temperature was freezing and at others it improved and could have

Table 1—Plant characteristics of Lower Gondwana formations

PLANT TYPES	HABIT	LEAF	POLLEN	SEED	VEGETATION
KAMTHI Dominated by Glossopteris (43) subdominated by ferns, equisetales, fertile types many believed to be Glossopteridalean	small, medium and large arboresent trees with huge amount of wood, dominated by tree subdominated by bushy shrubs	leaves small to large, variety of apex and base mostly petiolate, strong, prominent midrib, open mesh and narrow mesh forms in equal proportion, intermediate mesh forms subdominant		seeds winged or unwinged	thick dense forest with big trees, small plants groging underneath, upland vegetation
RANIGANJ Dominated by Glossopteris (42) subdominated by ferns, Equisetales, many new types appeared, fructifications plenty	small, medium and large arboresent trees with lot of secondary wood, herbs, shrubs and big trees well represented	leaves small to large, variety of apex, mostly petiolate, midrib generally strong prominent, veins also prominent, open and narrow mesh forms in equal proportion, thick epidermis with well developed stomatal complex	striate diasaccate with triletes	seeds winged or unwinged	thick, dense forest with small lakes, lowlying river valley, floodplains swampy
BARREN MEASURES Dominated by Glossopteris with lycopods and ferns	mediumly built arborescent trees generally with secondary wood, herbaceous plants also depicted	leaves small and medium sized, midrib solid and prominent, narrow and intermediate mesh forms	striate disaccate		sparse, forest like, semiaquatic, uplands.
BARAKAR Dominated by Glossopteris (12) subdominanted by Equisetaceous genera Phyllotheca, Schizoneura and Lelstotheca, ferns rare, woods represented by three genera, conifer genus Walkomiella, Barakaria, Diphyllopteris also appeared.	strongly built, arborescent plants with secondary wood, herbaceous shruby plants also	leaves medium, large size nonpetiolate mostly, rarely petiolate, midrib, veins prominent, narrow and intermediate mesh forms dominant, open mesh types appeared, epidermis thick well developed stomata	bisaccate dominant, monosaccate subdominant	seeds winged or unwinged	forest dense swampy, low lying river valley, some plants semi- aquatic
KARHARBARI Dominated by Gangamopteris, (17) Noeggerathiopsis (11) subdominant, Glossopteris, fairly represented, Gondwanidium, Buriadia Rubidgea, Euryphyllum Arberia, Ottokaria appear and disappear Equisetales, ferns appreciable.	weakly and mediumly built plants, small amount of wood, generally shrubs and herbs	leaves small and medium sized, mostly devoid of midrib, when present not prominent, faint veins, venation mostly dense, intermediate and open mesh leaf forms appeared	monosaccates dominant	seeds mostly winged	forest like vegetation appeared but not very dense
TALCHIR Dominated by Gangamopteris, Noeggerathiopsis, subdominated by Paranocladus, Glossopteris equisetaceous stems very rare.	very weakly built plants, almost no wood.	leaves small sized, fleshy, apex generally obtuse, devoid of solid midrib, perhaps non petiolate, veins loosely arranged, narrow mesh type of venation.	monosaccates dominant	seeds generally winged	sparse patchy vegetation

been between 5°–10°C. This is also supported by the palaeogeographic position of India during Talchir (Table 2).

COAL MEASURES

In India, most of the important coal deposits occur in fresh water sediments of Permian age that are prominently developed in the Peninsula. The major coalfields of Son, Damodar, Mahanadi, Pench-Kanhan-Tawa (Satpura), Wardha and Godavari Valley basins are broadly aligned along important river valleys. The Damuda sedimentation heralding coal-forming conditions in peninsular India and eastern Himalaya encompasses three coal-bearing formations, viz., the Karharbari, the Barakar and the Raniganj in ascending order. The Kulti or Barren Measures or Ironstone Shale Formation intervenes the Barakar and the Raniganj coal measures.

KARHARBARI

Karharbari, the basal most formation of the Damuda Group, was not considered as a persistent unit and was not demarcated in the different coal basins including the type area—Giridih Coalfield. Feistmantel (1879) recognised it as the upper limit of Talchir Formation. Saise (1894) included it as a basal unit of the Barakar Coal Measures. The discovery of Umaria marine bed intervening the Talchir and Karharbari formations has proved to be the deciding factor for its inclusion in Damuda Group (Gee, 1928). It is considered as a distinct biozone and well-defined stratigraphic entity (Ghosh & Basu, 1967; Ghosh *et al.*, 1969). The formation consists of grey to brown and mottled carbonaceous sandstones, grits and conglomerates with occasional coal seams and fire clays.

The distribution pattern of Karharbari Formation suggests that the Karharbari basins were more or less moulded on the geometry of the Talchir depositories. Extensive developments of Karharbari Coal Measures have been recorded in Giridih, Talchir, Korba, Hasdo-Arand, Sohagpur, Lakhanpur, Johilla, Umaria and Hutar basins which were extensively glaciated and hence formed ideal locales for Karharbari sedimentation (Laskar *et al.*, 1976).

Megaflora

Plant fossils from this formation have been investigated by Feistmantel (1879), Zeiller (1902), Seward and Sahni (1920), Lele and Maithy (1964), Maithy (1966, 1970), Kulkarni (1971), Srivastava (1977), and Chandra and Srivastava (1982). The Karharbari flora is best developed in the Giridih Coalfield and comprises *Schizoneura* (2 spp.), *Phyllotheca* (2 spp.), *Gondwanidium* (2 spp.), *Neomariopteris* (1 sp.), *Gangamopteris* (17 spp.), *Noeggerathiopsis* (11 spp.), *Euryphyllum* (2 spp.), *Rubidgea* (2 spp.), *Buriadia* (1 sp.), *Arberia* (2 spp.), *Ottokaria* (1 sp.), *Cordaicarpus* (2 spp.), *Samaropsis* (6 spp.), *Ginkgophyton, Palmatophyllites* and *Dolianitia* (each with one sp.). Pant and Singh (1968) added five species of *Gangamopteris* and instituted a new seed genus *Maheshwariella* from Giridih and Kurasia coalfields. There are stray records of fossil plants from Jayanti, North Karanpura, Raniganj, Johilla, Chirimiri, Umaria, Mohpani, Hutar and Daltonganj coalfields.

Gangamopteris and *Noeggerathiopsis* both reach their acme in this formation. The assemblage has been formally named as *Gondwanidium-Buriadia* Assemblage Zone by Shah *et al.* (1971). The genera *Rubidgea, Euryphyllum, Gondwanidium (Botrychiopsis), Buriadia, Arberia* and *Ottokaria* make their appearance and are considered to be the index fossils for this formation.

The *Gangamopteris* leaves, which are as long as 35 cm and as wide as 8.5 cm, show a marked general increase in size. The overall size of the plants was small and not as strongly built as one finds in the Barakar and Raniganj formations (Table 1). Majority of plants were midribless, small built, shrubby with almost no secondary growth. We find some Equisetales like *Phyllotheca* and *Schizoneura* to suggest that they were growing near small ponds or river banks. Plenty of winged seeds and pollen in Karharbari suggest that they were wind dispersed. Plants could therefore spread themselves far and wide as is evidenced by the fossil occurrence of Karharbari plants in a large number of basins stretching from the Damodar Valley in the east to the Singrauli Basin in the central part of India. It can safely be concluded that almost all the Talchir plants continued in the Karharbari. Many new forms, equisetalean and fern groups made their appearance.

Palynology

The Karharbari mioflora is also best known from the Giridih Coalfield (Srivastava, 1973). This flora is also known from equivalent strata of North Karanpura, South Karanpura, Korba, Jayanti, Mohpani, Auranga, West Bokaro and Raniganj coalfields and Umrer Quarry in Maharashtra. The monosaccate pollen characterising Talchir Formation continue to dominate in the Lower Karharbari assemblage. The assemblage of Lower Karharbari is dominated by *Callumispora* complex and subdominated by *Parasaccites* complex as

evidenced by the carbonaceous shale and coal strata in the Giridih Coalfield. Similar assemblages have also been reported from the equivalent sections of Korba and North Karanpura coalfields and surface exposures of Jayanti and Raniganj coalfields.

Palaeoclimate

It appears that in the Karharbari Formation unfavourable climatic conditions of the Talchir ameliorated favouring proliferation of flora. Lele (1976) opined that the glaciers had nearly disappeared from the ground by the Karharbari. The climate became very hospitable for plant growth as evidenced by the plant and coal types of Giridih. It can safely be deduced that by Lower Karharbari the land was completely free of ice and temperature became much high. The resultant was better plant growth for peat formation. By the Upper Karharbari there was again a dry cold spell which did not favour plant growth for coal formation.

In Lower Karharbari, climate was humid and cold but warmer than the underlying Talchir. By the Upper Karharbari there was return of dry phase climate which hampered growth of thick vegetation and therefore less accumulation of peat. This is evidenced by the poorer quality of coal and less fossils. In general, it can be determined that the Karharbari climate was cold with humid and dry spells (Table 2).

Substantial deposits of Karharbari coal also suggest proliferation of vegetation in coal basins. The Karharbari coals are fusain rich as compared to the durain rich coals of the later Damuda basins. We visualize that the Karharbari vegetation developed with ample sunlight, strong winds and enough rainfall. It can be inferred that in the Lower Karharbari diverse plants gave rise to substantial coal deposits as is evidenced by fossils from Giridih Coalfield.

BARAKAR

The Barakar Formation is characterised by coarse- to medium-grained cross-bedded and massive felspathic sandstones, pebble beds, carbonaceous shales, fire clays and coal seams (Fox, 1931; Laskar *et al.*, 1976). The Barakar sandstones are generally coarser than those of the underlying Karharbari and the overlying Barren Measures. These are grey, white to yellow or brownish, gritty or pebbly sandstones. Interbeded with the sandstones are siltstones and shales (occasionally carbonaceous), fire clays and coal seams. The Barakar River Section of the Raniganj Coalfield represents the type area of this formation, although the unit is better developed in the adjacent Jharia Coalfield. The Barakar Formation is economically very important as it contains the maximum number of good quality coal seams and also has maximum thickness amongst all the coal-bearing formations. The Barakar is the principal repository of bituminous coal and also important for fire clays. In the Damodar Valley coalfields, the ratio of coal to non-coal horizons varies from 1 : 5 to 1 : 10 which is much less in other fields. Total number of seams is variable in different coalfields. In Jharia Coalfield, 25 seams are developed where in seam number XI to XVIII and a part of X seam are quality prime coking coal.

Megaflora

The megafloral assemblage of the Barakar is characterised by the dominance of the genus *Glossopteris* and the absence of *Gangamopteris* and *Noeggerathiopsis*. *Gangamopteris* may be present in the Lower Barakar in some coal basins (they may represent the Karharbari) but it is absent in a large number of coalfields of true Barakar age (Table 1). *Glossopteris* is represented by as many as 12 species. Equisetaceous genera are represented by *Phyllotheca* (5 spp.), *Schizoneura* (1 sp.) and *Lelstotheca* (1 sp.). The fern-like plants are represented by *Neomariopteris* (2 spp.), *Pecopteris* (1 sp.) and *Alethopteris*. The conifers are represented by only one species of *Walkomiella*. Number of woods are also known from the Barakar Formation. They are *Araucarioxylon* (4 spp.), *Damudoxylon* (2 spp.) and *Polysolenoxylon* (3 spp.) (Maheshwari, 1972).

Lele, Swaroop and Singh (1966), Kulkarni (1971) and Srivastava (1977) reported Barakar plants from Singrauli, South Karanpura and Auranga coalfields, respectively. A few new types, viz., *Neomariopteris barakarensis, Ottokaria biharensis* and *Diphyllopteris* were added later. Apart from the above mentioned plants, we have records of plants with doubtful affinities. They are *Barakaria, Rhipidopsis, Pseudoctenis* and *Angiopteridium*.

Palynology

The known assemblages of this formation comprise more than 50 genera. The Barakar can be defined as Lower, Middle and Upper on the basis of palynological studies. The Lower Barakar is recognised as *Parasaccites*, zonate, and cingulate zone. The Middle as *Podocarpites* along with *Scheuringipollenites/Vesicaspora* zone. It has been possible to attempt further finer zones (Tiwari, 1975; Lele & Srivastava, 1979).

Table 2—Palaeoclimates of Lower Gondwana formations

AGE / ECOLOGICAL FACTORS		PLANT COVER	PALYNOLOGY	ANIMALS	PALAEO-GEOGRAPHY	PALAEO TEMP	LITHOLOGY / SEDIMENTOLOGY / COAL TYPES	PALAEOCLIMATE
KAMTHI		As in Raniganj	Not known	Invertebrate	70° TO 40° South latitude.	22°-23° Centigrade.	Red, grey, argillaceous siltstone & conglomerates with interstratified red shales, frequently ironstained, intersected by hard ferruginous band of dark brown colour.	As in Raniganj, but with dry and semi-arid spells.
RANIGANJ		Lush green thick forest (dominated by deciduous trees) with Arthrophytes, Pteridophytes and Glossopteridales	Striate, disaccate, trilates & monolates.	Invertebrate & vertebrate.	70° TO 40° South latitude.	22°-23° Centigrade.	Thick, massive cross bedded to laminated, fine to medium grained siltstones, shales & coal seams	Warm, humid, temperate with intermittent rain falls, low land.
BARREN MEASURES		Sparse vegetation with lycopods and Glossopteridales.	Striate disaccates dominate Densipollenites (2-5%) Striate disaccates dominate, Densipollanites (12-40%) Striate disaccates dominate Densipollenites (1%) a few trilete	Some vertebrate & invertebrates.	70° TO 40° South latitude.	21°-30° Centigrade.	Thick micaceous shales with ferruginous bands and medium to coarse grained sandstone	Warm, humid, temperate with dry, hot and wet humid spells
BARAKAR	*UPPER*	Broadnet forms of Glossopteris appear.	Podocarpites with Scheuringipollenites, Vesicaspora.	Invertebrates	70° TO 40° South latitude	14°-28° Centi grade	Well developed laminations and fairly good cleaning characteritics	Warm, humid, temperate, abundant rain fall, hot and cold season.
	MIDDLE	Gangamopteris disappears closed net Glossopteris dominate, rest as in lower Barakar.	Non-striate Scheuringipollenites, Ibisporites				Well developed laminations orthohydrous, variable phosphorous content better cleaning characteristics.	Warmer, Humid, temperate, abundant rain fall, hot and cold season.
	LOWER	Stray Gangamopteris, variety of equisetales & ferns, Glossopteris with shrubby, small to large trees, woods with secondary growth, seeds winged	Parasaccites zonate, cingulate forms				Orthohyhrous fairly developed laminations, erratic variation of phosphorous contents, difficult cleaning characteristics	Warm, temperate, humid, hot, cold season.
KARHARBARI	*UPPER*	Sparse vegetation, same plants as in lower Karharbari continued	Triletes dominate, monosaccate sub dominate	Marine invertebrate	70° to 40° South Latitude	9°-25° Centigrade	Carbonaceous sandstone, grits and conglomerates.	Cold, dry and strong winds
	LOWER	Gangamopteris, Noeggerathiopsis, midrib less closed veined forms dominate, shrubs & small trees, new forms appear, thick vegetation, terrestrial, no secondary growth.	Monosaccates dominate with large number of triletes.			15°-26° Centigrade	Grey to brown mottled carbonaceous sandstone, grits and conglomerates with coal seams and fire clays	Cold, humid, completely free of ice, strong winds, ample sunlight, & rainfall, irregular tectonic activity, small pond and lakes appear.
TALCHIR	*UPPER*	Closenet Glossopteris appears, Gangamopteris and Noeggerathiopsis proliferrate, Paranocladus, appeared, small herbaceous plants in small patches.	Monosaccate acritarchs rich	Marine invertebrates.	70° to 40° South Latitude	9°-22° Centigrade	Greenish sandstone	Deglaciated, cold, strong winds
	MIDDLE	Gangamopteris, Noeggerathiopsis, small herbaceous plants growing in small ice free patches.	Monosaccate				Greenish grey fine grained sand stone and shale.	Freezing cold, strong winds
	LOWER	Small minute herbaceous plants in glacial crevices	Monosaccate				Tillites	Very cold, frigid glaciated strong winds.

Palaeoclimate

This is an important period containing maximum development of coal. The most important prerequisite for the formation of coal swamps is dense vegetation and abundant rainfall which should exceed potential evaporation. The quality and the characteristics of Lower Barakar coals indicate that the vegetal matter must have been deposited in somewhat deeper waters. The conditions of sedimentation were such that the sorting of the mineral matter from the vegetal matter was not possible. Therefore the mineral matter is found intergrown with the coal substance.

Basu (1964) observed that during Middle Barakar the vegetal matter might have possibly deposited in deeper waters where considerable degree of sorting of vegetal and mineral matters have occurred. The Upper Barakar coals contain good to medium quality coals and variable phosphorous content. The depositional conditions of Upper Barakar coals appear to be same as that of Middle Barakar (Basu, 1964). In the end, considering all the available data, it can be concluded that the climate during the Barakar was warm temperate with appreciable amount of humidity. There were intermittent spells of hot and cold seasons associated with abundant rainfall. Similar contentions were also drawn by Laskar and Mitra (1976), Shah (1976) and Lele (1976) on the basis of various other parameters. High palaeolatitude position of India during this period also supports this result.

KULTI (BARREN MEASURES)

The thick strata devoid of any workable coal seams, occurring between the Barakar and Raniganj formations of Jharia Coalfield were named as Barren Measures by Fox (1931). This formation is lithologically and biostratigraphically correlated to the Kulti Formation of Raniganj Coalfield. In Satpura, Kamptee belt of central India and the Motur Formation which intervenes the Barakar Coal Measures and the Bijori Formation containing thin lenticles of coal has been correlated with the Barren Measures.

In Damodar Valley, it is represented by thick micaceous shales, shales with ferruginous bands and medium- to coarse-grained sandstones. Thick carbonaceous shale with ferruginous bands is the typical lithology of Barren Measures. In North Karanpura Coalfield it is predominantly shaly in the eastern part but arenaceous in the western part (Roy Chowdhury & Ghosh, 1972). Roy Chowdhury (1973) observed lithofacial changes in the Motur sediments in the Pench-Kanhan-Tawa Valley. In east, siltstones with parting lineation and red clays constitute the dominant lithology in the eastern side, i.e., Pench Valley, while in Kanhan Valley, coarse-grained sandstones form the bulk of the clastic fill. It was inferred that the Kanhan Valley area was the locale of deposition from a network of meandering channels, while in the Pench Valley back swamp and top stratum deposits were laid down. The critical factor for the formation of the red beds was the maintenance of oxidising conditions after burial. In the flood-plain sediments, the oxidising conditions enabled the iron hydroxide to "age" into hematite (Roy Chowdhury, 1973).

Megaflora

Floral records from Barren Measures are meagre and whatever we know is either from Jharia or Raniganj coalfields. Feistmantel (1881) described *Glossopteris damudica, G. musaefolia, G. communis (G. raniganjensis)* and *G. ?stenoneura* from Kulti, Raniganj Coalfield. Kar (1968) described a lycopod *Cyclodendron leslii*, equisetalean stems, *Neomariopteris, Glossopteris damudica, G. communis, G. conspicua* and *G. retifera* from Jharia Coalfield. Doubtful records of *Rhabdotaenia, Gangamopteris* and *Noeggerathiopsis* are also known from this locality. Re-examination of these specimens is required for correct identification.

Palynology

Palynological studies in contrast have uncovered a rich assemblage. Further efforts to search plant fossils from other localities would be worth while. The flora may not be as poor as is known today. Palynological investigations were carried out in the type area Jharia, North Karanpura, Brahmani Valley and Auranga coalfields (Kar, 1973; Bharadwaj, 1975; Srivastava & Maheshwari, 1979; Lele & Srivastava, 1979). The assemblages are dominated by striate-disaccates with *Densipollenites* and a few triletes. Three zones have been recognised on the basis of variable percentage of *Densipollenites.*

Palaeoclimate

Megafloral and palynological studies of the Kulti Formation give contrary pictures. Fossil floras from the underlying Barakar and overlying Raniganj formations are luxuriant both in quantity as well as in quality. Moreover Barakar plant types are well represented in Raniganj. Paucity of Kulti plants can be explained in two ways, either the climate was not

conducive for plant growth or the conditions were not suitable for their preservation during fossilization. A rich palynoassemblage also indicates luxuriant vegetation in Kulti period. Adversity of climate also can not explain the occurrence of lycopod *Cyclodendron*. Certain reasons may be attributed for this paucity of flora.

a. Vegetation might have withdrawn temporarily due to adverse conditions (Surange, 1966).

b. The vegetation receded to uplands during Barren Measures and invaded the swamps again during Raniganj with the return of hospitable conditions.

c. Environment of the swamps, lagoons and lakes of that period might have been detrimental to the preservation of plant organic matter.

d. The association of red bed facies can be ascribed to the local oxidising conditions.

It is generally believed that Kulti climate was arid. Under the present state of evidences warm, humid and temperate climate prevailed during Kulti period with dry and humid spells. Kulti climate in general was favourable for plant growth but unfavourable for their preservation. Similar observations were made by Ranga Rao *et al.* (1981) on the Siwalik assemblage. The Siwalik assemblage as a whole is impoverished both quantitatively and qualitatively as compared to the Tertiary sediments of other Indian sedimentary basins. Absence of spore-pollen in these rocks was attributed by them to their destruction due to oxidation at the place of origin, during transportation and also at the burial place. Absence of workable coal, paucity of flora and presence of ferruginous bands in Kulti lead us to believe the destruction of vegetation due to oxidation.

RANIGANJ

The Raniganj Formation is composed chiefly of thick massive, cross-bedded to laminated fine- to medium-grained sandstones with interbeded siltstones, shales and coal seams (Cotter, 1917; Fox, 1931; Gee, 1932). The coal seams generally show higher vitrinite content indicating rapid subsidence of the peat swamps and formation of coal under anaerobic conditions. Damodar River and Nonia Nala—a tributary of the former represent the best exposed section of this formation.

The Raniganj Formation is mainly developed in Damodar Valley coalfields and is a major coal-bearing horizon. This formation is correlated with the Bijori Formation of Satpura region, the Kamthi Formation in the Wardha Valley, the Hingir Formation in Mahanadi and Brahmini valleys and the Chintalpudi sandstones of Godavari Valley.

Megaflora

Plant fossils in Raniganj are best developed and well-preserved. Maximum number of genera and species of plants are known. The lycopods are absent but the pteridophytic remains are well represented. The reproductive structures of Equisetales and Sphenophyllales are not known but in recent years fertile pinnae with spores are found in the Filicales. Equisetalean genera are *Phyllotheca* (2 spp.), *Raniganjia, Schizoneura* and *Trizygia* each with one species. Fern genera are *Neomariopteris* (3 spp.), *Dichotomopteris* (1 sp.), *Dizeugotheca* (2 spp.), *Asansolia, Trithecopteris, Damudopteris* and *Leleopteris*, each with one species.

The Gymnosperms are dominant and *Glossopteris* attained its zenith in this formation. It is represented by more than 40 species. *Gangamopteris* is totally absent although *Gangamopteris*-like leaves have been reported (Bajpai, 1985). The other gymnosperm leaf genera are *Palaeovittaria* (2 spp.), *Rhabdotaenia* (3 spp.) and *Belemnopteris* (3 spp.). Supposedly cycadalean genera are *Pteronilssonia, Pseudoctenis* and *Senia*, each with one species. Doubtfully placed ginkgoalean genus *Rhipidopsis* is represented by one species. Recently, conifer-like shoots are instituted under a new genus *Searsolia*. Detached seed genera *Samaropsis* (1 sp.) *Stephanostoma* (1 sp.), and *Polytheca* (1 sp.) are also known from this formation.

Fructifications have been discovered from the Raniganj Formation (Chandra & Surange, 1976, 1977). They are generally found in detached conditions but in some rare instances they have also been found attached to the parent leaf. The fructifications in general show succulent and fleshy nature and the male fructifications generally bore biwinged pollen. The male fructifications are *Eretmonia* and *Kendostrobus* each with one species. The fleshy female fructifications are *Venustostrobus, Jambadostrobus, Plumsteadiostrobus* and *Dictyopteridium* each with one species. The other types of female fructifications like *Partha, Denkania* so frequently found in the Kamthi Formation are totally absent from the Raniganj Formation.

A number of petrified woods like *Dadoxylon, Kaokoxylon* and *Trigonomyelon* have been recorded from this formation. The woods in general show secondary growth, seasonal rings, air spaces, secretory cells and canals in pith. Resinous structures, primary xylem and phloem are rarely preserved. Much of the contributions to the Raniganj flora has been made in the type area Raniganj Coalfield mainly by Feistmantel (1881), Pant and his associates (1968, 1974), Maheshwari (1965) and Chandra and Surange (1976, 1977).

Palynology

In general, assemblages show quantitative increase in trilete and monolete spores. The monosaccate genus *Densipollenites* invariably found in Kulti is not consistently represented. The Lower Raniganj Assemblage is dominated by striate-disaccates and sub-dominated by triletes and monoletes, whereas *Densipollenites* is scantily represented. The Middle and the Upper Raniganj are defined by the relative percentage of striate-disaccates and triletes.

Restoration of Raniganj plants makes a lush green thick vegetation with various habits and habitats. The arthrophytes *Sphenophyllum* and *Lelstotheca* were small delicate plants and often trailing on some larger plants. Their preference to grow in semiaquatic conditions suggests that there were marshy places surrounding the ponds and lakes. Quite often these plants show a selective preponderance in silty or argillaceous shales and fine sandstones which probably indicate a mud-flat-like habitat for the plants. *Schizoneura* and *Phyllotheca* also grew to considerable height in selective marshy places. The stems and leaves were succulent in nature, carrying out photosynthetic activities, as they were generally green in colour.

Fern plants also favour shady places and were perhaps growing under giant plants of *Glossopteris*. Some of the fern plants were delicately built as evidenced by slender rachis and dainty pinnules. A few of them might have been robust and sturdy as is evidenced by big pinnules with prominent veins attached to wide and rigid rachis which is often winged. Some of these ferns possessed open branching system. Inspite of these evidences, it is difficult to say whether the tree ferns were growing in Raniganj. Most of the ferns bore marattiaceous sporangia. Such ferns generally favour warm and humid environment as revealed by present day plants.

The *Glossopteris* plant might have been represented by small to big trees. Some of the species could be shrubs of good height. The leaves were generally large, with a solid, more or less persistent midrib. Few species had strong petiole (Table 1). The venation pattern of the *Glossopteris* diversified in Raniganj with narrow, open and intermediate mesh types. The open mesh type is also indicative of warm to humid conditions. Leaf epidermis is generally thick with well-developed stomatal complex. The subsidiary or epidermal cells commonly have papillae. The epidermal character of any genus indicates mesophytic conditions. Fossil woods are gymnospermous, pycnoxylic with prominently developed growth rings.

Palaeoclimate

The flora of carbonaceous facies of the Raniganj and Jharia coalfields indicates lush green forest-like vegetation particularly in favourable lowlands. In general, during Raniganj times, the presence of warm, humid but temperate climate with intermittent rainfalls is indicated. The calcareous nature of the Raniganj Formation is likely to be a product of warm humid climate (Laskar & Mitra, 1976). The coal seams show vitrinite contents and indicate rapid subsidence of the peat swamps and formation of coal under anaerobic condition (Table 2).

KAMTHI

The Kamthi Formation is characterised by red and grey argillaceous sandstones and conglomerates with interstratified red shale. The sandstones vary greatly in colour and character. The fine-grained micaceous varieties are white with blotches and irregular streaks of red. Fine massive and homogeneous mudstone, yellow in fresh sections but becoming red when exposed, is a characteristic litho-unit. These pass into red shales.

In the type area the Kamthi Formation overlies the Barakar unconformably. In the Pranhita-Godavari Valley, around Bheemaram, the Kamthi is placed between the Ironstone Shale and Yerapalli Formation (Sen Gupta, 1970). Towards extreme south, Kamthi as Chintalpudi Sandstone is unconformably overlain by the coast Upper Gondwana.

Megaflora

The floral assemblages are broadly similar to that of the Raniganj Formation. Typical Kamthi flora from the type area was published by Bunbury (1861). *Glossopteris* species show close similarity with Raniganj species, although some are typical of Kamthi. The overall size of leaves is quite large and both open and close venation types are found. The *Glossopteris* species include *G. leptoneura, G. stricta, G. musaefolia, G. damudica, G. angustifolia* and *G. indica*. The other plant types are *Phyllotheca* (1 sp.), *Schizoneura* (1 sp.), *Neomariopteris, Vertebraria* and three species of *Taeniopteris*. Bunbury (1861) also reported some plants which we consider as doubtful or as wrongly identified, viz., *Filicites, Noeggerathiopsis hislopi, ?Knorria, Yuccites (=Dictyopteridium)* rhizome of a fern and some stems with ridges and furrows.

Feistmantel (1880) identified some plants from Isapur, south-east of Chandrapur. They are

Glossopteris indica, G. browniana, G. cf. *musaefolia.* From Chawart, he described *Actinopteris* sp. along with a lot of seeds identified as *Cycadinocarpus* by Hughes. From Kawarsa, Feistmantel recorded *Phyllotheca indica, Schizoneura, Glossopteris indica* and *G. browniana.* From Anur, 3 km south-east of Antargaon *Phyllotheca indica, Schizoneura* sp., doubtful *Zeugophyllites elongatus, G. browniana* and *G. leptoneura* are recorded.

In 1880, Oldham (Feistmantel, 1881) described plant fossils from Kamthi, viz., *Polytheca indica, Vertebraria indica, G. communis, G. damudica, G. browniana, G. stricta, G. musaefolia, G. leptoneura, Gangamopteris hughesi, Angiopteridium* cf. *maclellandi, Macrotaeniopteris danaeoides, M. feddeni* and *Neoggerathiopsis hislopi.* Feistmantel (1881) reported plants from Wardha-Godavari Valley, viz., *?Alethopteris* sp., *Macrotaeniopteris danaeoides, M. feddeni, Angiopteridium* cf. *A. maclellandi, Glossopteris communis, G. stricta, G. musaefolia, G. indica, G. damudica, G. angustifolia, G. leptoneura, Gangamopteris hughesi, Noeggerathiopsis hislopi, Anthrophyopsis* and *Rhipidopsis densinervis.*

Attempts to search for fossils in this formation resulted in only two localities. Chandra and Prasad (1981) described two assemblages from Bazargaon and Kanhargaon localities in Chandrapur District of Maharashtra. They described fossil impressions along with many petrified gymnosperms from Kanhargaon. The fossils are *Neomariopteris hughesi, Trizygia speciosa, Schizoneura gondwanensis,* equisetalean stems, *Glossopteris musaefolia, G. stricta, G. leptoneura, G. mohudaensis, G. indica, G. raniganjensis, G. bosei, G. angustifolia, G. lanceolatus, G. tenuifolia, G. densinervis, G. venustus,* three *Glossopteris* species and *Vertebraria.* The gymnospermous woods are *Dadoxylon chandrapurensis, D. maharashtraensis, D. parenchymosum, Trigonomyelon kamthiensis, Kaokoxylon pseudotrimedullaris, Taxopitys indica, T. surangei, Australoxylon kanhargaoense, A. longicellularis, Zalesskioxylon lepekhinae, Z. simplexum, Prototaxoxylon uniseriale, P. maithyi* and *Baieroxylon multiseriale.* These fossil woods in general exhibit gymnospermous characters like secondary growth with seasonal growth rings and bordered pits on the walls. Chandra and Prasad (1981) have reported from Bazargaon *Schizoneura gondwanensis, Glossopteris musaefolia, G. mohudaensis* and *Dictyopteridium sporiferum.* In recent years a rich assemblage of fossil plants has been recovered from the Kamthi Formation in Hinjrida Ghati of Dhenkanal District, Orissa (Chandra & Rigby, 1981, 1983). The flora comprises lycopod—*Cyclodendron leslii,* articulates—*Trizygia speciosa, Phyllotheca indica, Raniganjia bengalensis, R. etheridgei, Schizoneura gondwanensis, Lelstotheca robusta, Sphenophyllum crenulatum, S. churulianum* and *S. utkalensis,* ferns—*Dizeugotheca phegopteroides, Neomariopteris hughesi, M. polymorpha, M. khanii, Pantopteris gracillus, Damudopteris bengalensis* and *Asansolia* cf. *phegopteroides,* cycads—*Pseudoctenis balli* and *Senia reticulata,* male fructifications—*Eretmonia utkalensis, E. hinjridaensis, E. ovata, Glossotheca utkalensis, G. orissiana* and *G. immanis,* female fructifications—*Dictyopteridium sporiferum, Indocarpus elongatus, Cistella ovata, Scutum sahnii, S. elongatum, S. indicum, Partha indica, P. spathulata* and *Utkalia dichotoma* (Surange & Chandra, 1978, Chandra, 1984) and the genus *Glossopteris* represented by 41 species. The *Glossopteris* species here exhibit various types of venation—narrow, open and intermediate types and show maximum closeness to the Raniganj flora (Singh & Chandra, 1987).

Thus, it is evident that the Kamthi flora is also as diversified as the Raniganj flora. Five palynological zones have been recognised in the Kamthi Formation of Godavari Graben (Srivastava & Jha, 1988).

The vegetation comprises arthrophytes, Filicales and gymnosperms. The arthrophytes were perhaps growing in small patches around pond or lake side. Some of the ferns might have been tree ferns as indicated by large sized pinnae and pinnules with sturdy venation of some of the ferns of Handapa. Some of the *Glossopteris* plants were of considerable height towering up to 40-60 feet. This is evidenced by huge tree trunks with seasonal growth rings. Some of the *Glossopteris* plants possessed large leaves providing shade to several plants growing underneath. All these fossil floral assemblages are associated with variegated sediments. This perhaps represents upland vegetation and explains the scarcity of coal in Kamthi inspite of lush green thick vegetation.

Palaeoclimate

The Kamthi Formation is generally considered as equivalent to Raniganj Coal Measures. The plant types are also similar except few. Variety of plant types, huge sized leaves and seasonal growth rings in tree trunks indicate favourable climate for plant growth, i.e., warm and humid. The bisaccate pollen and winged seeds indicate that the dispersal and dissemination were carried out by strong winds. Abundant leaf depositions, as found in Handapa Bed, point to seasonality. The red bed facies of the

ferruginous sandstones also marks seasonal dry spells and semi-arid conditions once in a year. This could be one of the reasons for non-formation of coal in Kamthi.

CONCLUDING REMARKS

The Lower Gondwana sequence commences with deglaciation, a scanty vegetation and no coal. It is followed by a long coal phase entombing a rich and diversified vegetation. A non-coal phase is repeated with records of a sparse vegetation again followed by a coal phase with a luxuriant vegetation. Plant played an important role in the formation of coal. Peat which eventually gives rise to coal can be formed in any climate where plants grow. Accumulation of vegetal matter when exceeds dissipation form into peat. The condition is usually dependent on moisture relations rather than temperature. In fact, any group of plant in any geological time and in any climatic condition can give rise to coal.

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REFERENCES

Bajpai, U. 1985. A gangamopterid leaf from Raniganj Formation. *Geophytology* **15** : 60-63.

Basu, T. N. 1964. On the inter-correlation of Gondwana coalfields of India. *Metals Minerals Rev.* : 5-31.

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

Bharadwaj, D. C. 1976. Palaeogeography of India during Gondwana times and its bearing on the climate. *Geophytology* **6** : 153-161.

Brenchley, P. J. 1984. Fossils and climate. *Geol. Jour.* (*Specl. issue*) **11**.

Bunbury, C. J. F. 1861. Notes on a collection of fossil plants from Nagpur, central India. *Q. Jl geol. Soc. Lond.* **17** : 325-346.

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

Chandra, Anil & Srivastava, A. K. 1982. Plant fossils from the Talchir and coal-bearing formations of South Rewa Gondwana Basin, India and their biostratigraphical significance. *Palaeobotanist* **30** : 143-167.

Chandra, S. 1984. *Utkalia dichotoma* gen. et sp. nov.—a fossil fructification from the Kamthi Formation of Orissa, India. *Palaeobotanist* **31** : 208-212.

Chandra, S. & Prasad, M. N. V. 1981. Fossil plants from the Kamthi Formation of Maharashtra and their biostratigraphic significance. *Palaeobotanist* **28-29** : 99-121.

Chandra, S. & Rigby, J. F. 1981. Lycopsid, sphenopsid and cyacadaceous remains from the Lower Gondwana of Handappa, Orissa. *Geophytology* **11** : 214-219.

Chandra, S. & Rigby, J. F. 1983. The Filicales from the Lower Gondwanas of Handappa, Orissa. *Palaeobotanist* **31** : 143-147.

Chandra, S. & Surange, K. R. 1976. Cuticular studies of the reproductive organs of *Glossopteris*. Part-1, *Dictyopteridium feistmanteli* sp. nov. attached on *Glossopteris tenuinervis*. *Palaeontographica* **156B** : 87-102.

Chandra, S. & Surange, K. R. 1977. Cuticular studies of the reproductive organs of *Glossopteris*. Part-2. *Cistella* gen. et sp. nov. attached on *Glossopteris taeniodes* Feistmantel. *Palaeobotanist* **23** : 161-174.

Chandra, S. & Surange, K. R. 1977. Cuticular studies of the reproductive organs of *Glossopteris*. Part-3 *Jambadostrobus* and *Venustostrobus* borne on *Glossopteris* leaves. *Palaeontographica* **164B** : 127-152.

Chandra, S. & Surange, K. R. 1979. *Revision of the Indian species of Glossopteris*, Monograph no. 2. Birbal Sahni Institute of Palaeobotany, Lucknow.

Cotter, G. de P. 1917. A revised classification of the Gondwana System. *Rec. geol. Surv. India* **9** : 27-114.

Dorf, E. 1963. The use of fossil plants in paleoclimatic interpretations in problems in paleoclimatology. *Proc. NATO palaeoclimat. Conf., Newcastle upon Tyne* : 13-48.

Dorf, E. 1969. Palaeobotanical evidences of Mesozoic and Cenozoic and climatic changes. *Proc. North Am. Palaeont. Conv.*, Part D : 323-346.

Feistmantel, O. 1879. The fossil flora of the Lower Gondwana-1. The flora of the Talchir-Karharbari beds. *Mem. geol. Surv. India Palaeont. indica*, ser. 12, **3** : 1-64.

Feistmantel, O. 1880. The fossil flora of the Lower Gondwana-1. The flora of the Damuda and Panchet divisions. *Mem. geol. Surv. India Palaeont. indica*, ser. 12, **3** : 1-77.

Feistmantel, O. 1881. The fossil floras of the Gondwana System. The flora of the Damuda-Panchet Division. *Mem. geol. Surv. India palaeont. indica*, ser. 12, **3** : 78-149.

Fox, C. S. 1931. The Gondwana System and related formations. *Mem. geol. Surv. India* **58** : 1-241.

Gee, E. R. 1928. The geology of the Umaria Coalfield, Rewah State, central India. *Rec. geol. Surv. India* **60**.

Gee, E. R. 1932. The geology and coal resources of the Raniganj Coalfield. *Mem. geol. Surv. India* **61**.

Ghosh, P. K. & Basu, A. 1967. Stratigraphic position of the Karharbari in the Lower Gondwanas of India. *in* : *Gondwana Stratigraphy*, Unesco, Paris, pp. 107-117.

Ghosh, P. K., Deekshitulu, M. N. & Murthy, B. R. N. 1969. The Karharbari in the Gondwana of peninsular India. *Proc. 22nd int. geol. Cong., New Delhi*, pt. **9** : 169-180.

Kar, R. K. 1968. Studies in the Glossopteris flora of India—36. Plant fossils from the Barren Measures Succession of Jharia Coalfield, Bihar, India. *Palaeobotanist* **6** : 243-248.

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

Kräusel, R. 1961. The palaeobotanical evidence of climate. *in: Descriptive palaeoclimatology*, Intersci, Publ., New York, pp. 227-254.

Kulkarni, S. 1971. *Glossopteris* and *Gangamopteris* species from South Karanpura Coalfield. *Palaeobotanist* **18** : 297-304.

Laskar, B. & Mitra, N. D. 1976. Palaeoclimatic vicissitudes in India during Lower Gondwana sedimentation. *Geophytology* **6** : 162-169.

Laskar, B., Mitra, N. D. & De, A. K. 1976. Lower Gondwana basins of peninsular India—their sedimentation and history. *Workshop in exploration of coal*, C.M.P.D.I.

Lele, K. M. 1966. Quest for the early traces and subsequent development of Glossopteris flora in the Talchir Stage. *in* : *Symposium on floristics and stratigraphy of Gondwanaland*, Birbal Sahni Institute of Palaeobotany, Lucknow, pp. 85-97.

Lele, K. M. 1975. Studies in the Talchir flora of India-10. Early and Late Talchir miofloras from the West Bokaro Coalfield, Bihar. *Palaeobotanist* **22** : 219-235.

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

Lele, K. M. 1976. Late Palaeozoic and Triassic floras of India and their relation to the floras of the northern and southern hemisphere. *Palaeobotanist* **23** : 89-115.

Lele, K. M. & Karim, R. 1971. Studies in the Talchir flora of India-6. Palynology of the Talchir Boulder Bed in Jayanti Coalfield, Bihar. *Palaeobotanist* **19** : 52-69.

Lele, K. M. & Maithy, P. K. 1964. Studies in the Glossopteris flora of India-15. Revision of the epidermal structure of *Noeggerathiopsis* Feistmantel. *Palaeobotanist* **12** : 7-17.

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)* **3** : 152-164, Birbal Sahni Institute of Palaeobotany, Lucknow.

Lele, K. M., Swarup, P. & Singh, J. N. 1966. Occurrence of plant fossils in the Lower Gondwana succession of Singrauli Coalfield, Uttar Pradesh. *J. palaeont. Soc. India* **11** : 8-17.

Maheshwari, H. K. 1965. Studies in the Glossopteris Flora of India-22. On some species of the genus *Glossopteris* from the Raniganj Stage of the Raniganj Coalfield, Bengal. *Palaeobotanist* **13** : 144-147.

Maheshwari, H. K. 1972. Permian wood from Antarctica and revision of some Lower Gondwana wood taxa. *Palaeontographica* **138B** : 1-43.

Maithy, P. K. 1966. Studies in the Glossopteris Flora of India-33. Fossil plants and miospores from the coal bearing beds of the Umaria coalfield with some remarks on the age of the beds. *Palaeobotanist* **14** : 52-60.

Maithy, P. K. 1970. Studies in the Glossopteris Flora of India-39. On some new plant fossils from the Karharbari beds, Giridih Coalfield, India. *Palaeobotanist* **18** : 167-172.

Pant, D. D. & Gupta, K. L. 1968. Cuticular structure of some Indian Lower Gondwana species of *Glossopteris* Brongniart. part-1. *Palaeontographica* **124B** : 102-121.

Pant, D. D. & Khare, P. K. 1984. *Damudopteris* gen. nov. a new genus of ferns from the Lower Gondwana of the Raniganj Coalfield, India. *Proc. R. Soc. Lond.* **B186** : 121-135.

Pant, D. D. & Singh, K. B. 1968. On the genus *Gangamopteris* McCoy. *Palaeontographica* **124B** : 83-101.

Pant, D. D. & Singh, R. S. 1974. On the stem attachment of *Glossopteris* and *Gangamopteris* leaves. Part-2. Structural features. *Palaeontographica* **147B** : 42-73.

Ranga Rao, A., Khan, N. N., Venkatachala, B. S. & Sastri, V. V. 1981. Neogene Quaternary boundary and the Siwalik. *in* : Sastry, M. V. A., Kurien, T. K., Dutta, A. K. & Biswas, S. (eds)—*Proc. Field Conference Neogene-Quaternary Boundary, India*, G.S.I. Calcutta. 1979 pp. 131-142.

Roy Chowdhury, M. K. 1973. Short notes on the structures and sedimentation of Motur and Pachmari formations in the Pench Kanhan and Tawa Valley Coalfield, M. P. *Proc. 60th Indian Sci. Cong.* : 177-178.

Roy Chowdhury, M. K. & Ghosh, P. K. 1972. Environmental pattern and mode of deposition of the Barren Measures in the North Karanpura Coalfield, Bihar. *Rec. geol. Surv. India* **99** : 109-120.

Sahni, B. 1939. The relation of the Glossopteris Flora with the Gondwana glaciations. *Proc. Indian Acad. Sci.* **9** : 1-6.

Saise, W. 1894. Note on the Singareni Coalfield, Hyderabad, Deccan. *Rec. geol. Surv. India* **27** : 49-70.

Schopf, J. M. 1973. Coal climate and global tectonics. *in* : *Implications of continental drift to the earth sciences* **1** : 609-622.

Schwarzbach, M. 1963. *Climates of the past: an introduction to palaeoclimatology.*

Sen Gupta, S. 1970. Gondwana sedimentation around Bhimaram, Pranhita-Godavari Valley, India. *J. sedim. Petrol.* **40** : 140-170.

Seward, A. C. & Sahni, B. 1920. Indian Gondwana plants: a revision. *Mem. geol. Surv. India Palaeont. indica*, n. ser., **7** : 1-41.

Shah, S. C., Singh, G. & Sastry, M. V. A. 1971. Biostratigraphic classification of Indian Gondwanas. *First Gondwana Symp., Annals Geol. Dept. A.M.U.* **5-6** : 306-326.

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

Singh, K. J. & Chandra, S. 1987. Some new species of *Glossopteris* from Kamthi Formation of Handapa, Orissa. *Geophytology* **17** : 39-55.

Srivastava, A. K. 1977a. Palaeobotanical evidence for the presence of Karharbari Stage in the Auranga Coalfield, Bihar: megaflora. *Palaeobotanist* **23** : 206-219.

Srivastava, S. C. 1973. Palynostratigraphy of the Giridih Coalfield. *Geophytology* **3** : 184-194.

Srivastava, S. C. & Jha, N. 1988. Palynology of Kamthi Formation in Gondwana Graben. *Palaeobotanist* **36**.

Srivastava, S. C. & Maheshwari, H. K. 1979. Palynostratigraphy of Damuda Group in the Brahmini Coalfield, Rajmahal Hills. *Geophytology* **4** : 35-45.

Srivastava, A. K. 1977b. Studies in the Glossopteris Flora of India 42. Barakar plant megafossils and miospores from Auranga Coalfield, Bihar. *Palaeobotanist* **24** : 50-69.

Surange, K. R. 1966. Distribution of Glossopteris Flora in the Lower Gondwana formation of India. *in* : *Symposium on floristics and stratigraphy of Gondwanaland,* Birbal Sahni Institute of Palaeobotany, Lucknow, pp. 55-68.

Surange, K. R. & Chandra, S. 1978. Morphology and affinities of *Glossopteris Palaeobotanist* **25** : 509-524.

Surange, K. R. & Lele, K. M. 1956. Studies in the Glossopteris Flora of India-3. Plant fossils from the Talchir Needle Shale from Giridih Coalfield. *Palaeobotanist* **4** : 153-157.

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

Waterhouse, J. B. 1976. World correlation for Permian marine faunas. *Univ. Qld Paps.* **7** : 232-250.

Zeiller, R. 1902. Observation sur quelques plantes fossiles des Lower Gondwanas. *Mem. geol. Surv. India Palaeont. indica.* n. ser. 2 : 1-40.