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Inaugural Address

Concepts, limits and extension of the Indian Gondwana

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DR VENKATACHALA, Dr Maheshwari, Dr Tiwari, Prof. R. C. Misra, Prof. Ahmad, Shri Tripathi, distinguished professors, geoscientists, ladies and gentlemen, I feel honoured to have been asked by the Organisers to inaugurate the Workshop on *Concepts, limits and extension of the Indian Gondwana* this morning in the beautiful and inspiring premises of Birbal Sahni Institute of Palaeobotany, on the occasion of the birth anniversary of the great man Professor Birbal Sahni, the founder of this leading Institute. A scientist of international repute, a perfect human being, a selfless nationalist, a visionary, soaked in work culture and highest intectualism and an inimitable Guru, as Professor Birbal Sahni was, his name and fundamental contributions in Botany, Palaeobotany and Geology, continue to inspire a large scientific community in the country and abroad. Professor Sahni and Professor Seward, his teacher, remain as immortal as the discipline of Palaeobotany.

It was unique experience for me to have been taught by this great man for 9 hours in three days in my B.Sc. Class. I am conscious that many of the distinguished scientists present here had the privilege of long and close association with Professor Sahni in various pursuits. I certainly envy them. The story of little *Azolla* and the palm, the romance of Saline Series, his infallible contributions to Palaeobotany and Geology of Gondwanaland and scores of other topics constantly impart strength, courage and vision to this Institute to enable it stand up to the founder's and his followers expectations. But then he was not meant to belong to only a few or to be confined. He has always been as inspiring and revered to us in the Geological Survey of India as to this Institute. I am indeed grateful to Dr B. S. Venkatachala, Director, B.S.I.P., and his associates for providing me and my Organisation this opportunity to humbly reiterate our faith and respect for the cause and pursuits for which Professor Birbal Sahni devoted all that he had.

The Indian Gondwana sedimentary basins occupying about 50,000 sq km provide crucial data to the geological and geodynamic history of the Indian Shield. Gondwana geology holds key to coal resources, evolution of plant life and vertebrate fossil fauna in India. Conceptual interests are developing in the possible oil and gas resources in some of these basins. Various organisations, institutes and geoscientists have been generating voluminous interesting data on Gondwana geology, Gondwanaland, continental drift, plate-tectonics, coal resources, etc. Geological Survey of India has been deeply engrossed in Gondwana geology and coal exploration.

A number of interesting researches and ideas have been made in recent years adding to or refining the classical ideas about the Indian Gondwana in peninsular, extra-peninsular part and in marine shelf areas of Indian sub-continent. I would, however, like to touch upon a few salient points of general interest.

DEFINITION OF GONDWANA

Gondwana geology, which had its birth in the Upper Palaeozoic-Mesozoic sedimentary basins of the peninsular Indian Shelf, blossomed into a distinct entity of earth-science with its ramifications of sedimentary, biotic, tectonic, magmatic and

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magnetic records in Southern Hemisphere. Evidently, in its wide usage, the term Gondwana often carried different connotations to stratigraphers, palaeontologists or workers in geotectonics and this has made its definition somewhat flexible. The Gondwana in its classical and stratigraphic sense includes a pile of typical essentially terrestrial rocks with closely associated paralic or shallow marine sediments which exhibit a distinct floral and faunal identity with the homotaxial rocks of southern continents implying similar climatic, geomorphic setting and proximal geographic location and bondage. It has both litho- and bio-stratigraphic attributes and in Indian sub-continent ranges in age from Late Carboniferous to Early Cretaceous.

CONCEPTS AND LIMITS AT GLOBAL LEVEL

The concept of Gondwanaland, invoked to explain the continuities of terrestrial conditions across the southern continents, also sharpened the broad palaeogeographic concepts of the Northern Continent (Laurasia); characterised by distinctive, geological, tectonic, faunal, floral and palaeoclimatic features. The concept of Tethys or inter-continental sea and the Pacific assumed greater necessity to accommodate the global fits. Concurrently, the theory of continental drift and all its attributes became compulsive to explain the Cretaceous-Tertiary seafloor spreading and present redistribution of continental and ocean areas. The Indian sub-continental crustal block thus defined in palaeogeographic terms attained distinctive limits and geotectonic identity in the then existing global frame. The revolutionary impact of expositions on marine geology and geophysical data transformed the theories of global rifts and drifts and the mechanisms into the comprehensive concept of plate tectonics. The Indian Plate is the new attribute, encompassing the Indian Gondwana continental block with its marine and other continental crustal adjuncts, bounded by the mid-oceanic ridges of the Indian Ocean and by the Tethyan sutures on the north and extending in south-east Asia up to East Pacific. The Indian peninsular crustal block is normally considered as a rigid mass put into motion on a smooth conveyor belt activated by the convection cell of the mantle. However, the rigidity concept of the peninsular shield in time and space is viewed with ample sceptism.

Thus the emerging concept of plate tectonics gradually but firmly enlarged the concepts of limits and extent of Indian Gondwana in terms of the small or large crustal blocks, etc. within the definition of the Greater Indian Plate.

In such a mileau, besides taking due note of the terrestrial early Gondwana elements in Tibet, glacio-marine sediments in Burma, Thailand, the Precambrian affinities of Seychelles with west-coast Precambrians, etc. it is important to explore the possibilities of the likely Gondwana elements in the Naga Patkai-Arakan-Andaman-Nicobar belt.

GONDWANALAND FIT

A universally acceptable concept of the Gondwanaland fit vis-a-vis the Indian Segment still evades us. The notable contributions of Professor F. Ahmad in this regard have to be given due thought. The most controversial segment is the eastern Indian margin. According to many models (based on plate tectonic concepts), the eastern coast is juxtaposed against Antarctica, bringing in the East Indian Gondwana rifts in the proximity of Enderby Gondwana rift and radiating ice fields. Considering the coal geology, workers like N.D. Mitra and others have favoured such a fit. Against the view, the fit presented by O'Driscoll (1980) juxtaposes Australia to the East Coast margin, and Antarctica is not shown in the proximity of India. S. K. Acharyya and others have favoured such a fit, using plate tectonic concepts and broad geological and geodynamic considerations. Even though there may be different schools of thoughts, there is need to critically study these issues by way of producing optimal structural, isotopic and palaeomagnetic data on the Indian Gondwana and its Precambrian basement of the East Coast in conjunction with the off-shore deeper probes into the sea bed of Bay of Bengal.

LIMITS OF GONDWANA IN THE INDIAN PLATE

The Precambrian frame of the Indian Plate, as integral part of the Gondwanaland was ingrained in relation to the regional Palaeozoic tectonics of supercontinent. The late Precambrian tectonics is reflected by the upthrust Eastern Ghats against the marginal drying up Late Precambrian-Cambrian basins; and similarly the attenuated Vindhyan Basin shifted northwards away from the bounding up-thrust Aravalli-Satpura compression belt. The block in between the uplifted thrust blocks had engrained in itself a ENE-WSE trending compressional Narmada-Son mega lineament which also had strike slip movement; and orthogonal to it, the NW-SW rift systems abutting against the Eastern Ghats. Early Palaeozoic-Late Precambrian thermal and diastrophic activity is indicated in this block in terms of the younging Fission Track dates in Nellore mica-schist belt, K-Ar dates in crystallines of Tamil Nadu, Gauhati granites, etc. However, there is no established early Palaeozoic sedimentation record preserved in this block. The high palaeolatitudinal position of India in Early Permian synchronised with the initial sedimentation as glacio-marine deposits in the Palar Basin and other NW-SE rifts, etc. It is surmised that across the uplifted Eastern Ghats there must have been probably an epicontinental sea which invaded and intermixed with Permian glacial deposits, not only in Godavari-Palar basins but also in the Mahanadi, Bangladesh and Assam areas. A fit with Australia or Antarctica may constrain such a hypothesis. Perhaps detailed study of boulder of the Permian glacio-marine beds of Palar and other East-Coast basins may throw light on the provenance areas other than the Indian Shield.

The Early Permian of the Damodar Valley and other Gondwana basins perhaps received glacial deposits from the uplifted Aravalli-Satpura-Chhattisgarh-Vindhyan domain. The uplift of blocks adjacent to undulating low lands might have been due to late Palaeozoic tectonics in the Gondwanaland. It is a moot question whether the westward or north westward master slope and drainage of the basins or low land in the Barakar and subsequent times had any linkage with the Rajasthan Permian shelf and its southward extension. More light will be thrown on this issue after the possibility of hidden Gondwana basins below the Deccan Trap is fully explored and appreciated. Interpretation of a DSS Profile across Nepanagar-Ujjain has already indicated presence of a hidden Gondwana Basin in Narmada Valley.

Thick Talchir (total 380 m) sediments underlying the Asselian marine beds in Daltonganj Basin need detailed palynological and microbiotic studies to explore the possibilities of Late Carboniferous sedimentation in this and some other basins.

The eastward extension of the Raniganj Basin, the N-S trending Rajmahal-Purnea-Bangladesh-basinal configuration has some important attributes if viewed in terms of limits and extension. Across Bangladesh, but slightly northwards, the Garo-Hills Gondwana and the recently discovered coal basin of Hallydaygunj in Assam close to the western fringe of Garo Hills show a strong N-S linearity and structural grain, and perhaps thickening of sediments towards Bangladesh. Some of the Permian coal seams of this area have attained coking properties. Most part of Rajmahal-Bangladesh Basin is covered by Upper Gondwana, Rajmahal Traps and Tertiary sediments. These cover rocks, except Quaternary, are not well-developed in Garo Hills. Taking the total frame of Meghalaya-Assam basement and the configurations of Permian basin around Rajmahal, one is tempted to suggest that the Garo-Hallydaygunj basins may represent northward shifted part of the Rajmahal-Purnea-Bangladesh Permian Basin across a N-S trending fault system. It is likely that geothermal gradients in this region had started steepening in Permian times initially and the tectonism during the period may be the precursors of the much younger 90° E structure of the Bay of Bengal.

The northern margin of the Indian Plate and therefore the extent of Indian Gondwana is a subject of controversy. But recent studies in Tibet have shown that the glaciogene sediments and cold water marine fauna of Lower Gondwana affinity are associated with volcanics. Acharyya and some other workers believe that the Indian Gondwana margin extended up to southern margin of Kun Lun fold belt till late Palaeozoic times. The rifting mechanism responsible for the creation of Neo Tethys oceans and microcontinents from the extended and tectonised Indian Plate, also influenced intermixing the Early Permian Gondwana elements with marine sediments and association of alkaline basic and subordinate acidic volcanic compositions. These rock units overlie the Tethyan lower Palaeozoic sediments. Such events were perhaps related to the marine transgressions and accentuation of faulting in the terrestrial Gondwana basins in peninsular India. However, no late Palaeozoic volcanism has so far been noticed in the peninsular set up.

The paralic Gondwana of the Lesser Himalayan belt particularly of Eastern Himalaya shows marine and volcanic associations. Whether these are allochthonous bodies derived from the main Tethyan front or represent deposition in faulted basins in front of the late Palaeozoic uplifts in a southern domain is a subject of varied opinions. However, one has to recognise the revised stratigraphic position of the erstwhile late Palaeozoic-Mesozoic Blaini-Krol-Tal sequence now corresponding to Cambrian-Late Precambrian age. Search for any basal Gondwana sequence deposited over the Tal Formation would be worthwhile.

Could there be other locales of late Palaeozoic volcanism and associated Gondwana and marine sediments in the Indian sub-continent? Perhaps the crustal areas close to some of the Mesozoic rifting having higher heat flows, pulsating crustal features during late Palaeozoic could be considered as favourable locales and thus showing up as forerunner of the Mesozoic rifting.

The upper age limit of the Gondwana coincides with significant changes in basin configuration over a given time, active rifting and the separation of the Indian Plate having attained its independent north to north-eastward motion.

During the Early Cretaceous extensional regime, when the Indian Ocean was being created, the Indian Gondwana Plate possibly got separated from the Antarctica-Australian segment. Considerable geochemical diversity has been noted within the Rajmahal-Sylhet volcanics. Alkali basalts and olivine-theoliites initially occurred as surface materials. The former were produced by melting of enriched metasomatised mantle, whereas, the latter may represent large partial mellts of deeper source (Bakshi *et al.*, 1987). Mahoney *et al.* (1983) and Bakshi *et al.* (1987) postulate these flood-basalts as an effect of the Kerguelen Hotspot which possibly lay below the eastern Indian continent. This is more or less consistent with the reconstruction of Gondwanaland by Norton and Sclater (1979) but require India to be 10° further east.

Contemporaneous mantle derived alkaline-ultramafic intrusives are represented by mica-lamprophyres which occur restricted to Damodar Valley coal basins and also to late Palaeozoic belt from eastern Lesser Himalaya. Recently, lamprophyre-lamproite assemblage have been recorded from Damodar Valley area.

The pericratonic Gondwana basins and shelfs evolved in response to rifting episode occurring along the east and west coasts. Thus the Athgarh, Godavari-Krishna, Palar, Cauvery, Kutch and Saurashtra troughs were formed. Basaltic flow is underlain by Early Cretaceous terrestrial sediments in the eastern shelf off Mahanadi delta.

EVOLVING CONCEPTS OF STRUCTURAL AND SEDIMENTATIONAL CHARACTERISTICS OF INDIVIDUAL BASINS

Isolated basin or a cluster of basins have also been under study especially in relation to the tectono-sedimentary analysis and locales of peat deposition and coalification processes. In general, the Permian sedimentation exhibits an accummulation of 2 km thick column in about 50 million years. This slow rate of sedimentation of less than a millimetre a year does not reflect a highly pulsating basinal condition or a general high relief and fast erosion. However, taking into consideration the erosional processes as reflected in sediment mega cycles it may appear that sedimentation is punctuated by diachronous breaks of unknown duration.

The concept of rift basins in Gondwana has so far not withstood the test of time in the absence of contemporaneous volcanics and intrusives in the basin. The dykes of dolerite and mica-lamprophyres are post-depositional intrusives. Deposition outside the faulted half-graben, graben or proto-rift, has been postulated and post-depositional faulting is supposed to have preserved the fault bound sedimentary column. The test of the concept lies in full understanding of the sedimentary basins which are covered under thick post Upper Gondwana deposits.

Recent basinal studies and synthesis of data have indicated that application of facies variation concept, based on various sediment characteristics, defines the depositional behaviour and locales of different kinds of coals in a rational way.

In recent studies, strike slip movements and compressional deformation of the sediments in the proximity of faults has been observed. Influence of faulting on the sediment facies close by and its thicknesses, has also been observed. Recently, reverse faulting has also been recognised in a central Indian basin.

It is rather difficult to precisely demarcate the time boundaries within the Gondwana Sequence on the basis of mega-flora. However, estheriids and vertebrates have been used to narrow down the range of time planes with some success. Marine intercalations with micro- or mega-fossils, though thin and sparse and not available in all the basins, have been used to refine the time planes. Marine beds in the Barren Measures, with algal remains, etc. have given rise to phosphatic beds.

In order to get a comprehensive tectono-sedimentary and stratigraphic idea of the Gondwana formations, it is desirable to have a concerted multi-disciplinary programme of integrated basin analysis studies. Multi-institutional efforts on palaeomagnetic, isotopic age dating and palynostratigraphic studies on drill core samples of full successions of some representative basins is also necessary.

Geochemical studies on coal basins have provided many clues to refine our understanding on the sedimentological and coalification processes. Conceptually, formation of hydrocarbons is being postulated in appropriate geothermal conditions affecting the vegetal organic matter in Gondwana basins. Detailed geochemical, thermal gradient and coal petrographic studies are likely to throw light on these concepts and limitations thereof.

Coal basins are also not immuned to neotectonic activity, particularly in basins with geothermal waters and well documented seismic records. It may be worthwhile to study this aspect in relation to mining and environmental considerations.

CONCLUDING REMARKS

Gondwana geology is in a way the soul of Indian geology. It provides one of the best documentation for global interaction in geological, geophysical and geodynamic modelling. It is the mainstay for our solid fossil energy resources. Better understanding of the concept, limits and extension of Indian Gondwana would depend upon the Indian geoscientists' efforts in key areas of Gondwana geology in conjunction with the evolution of its basement and events leading to the breakup of the Gondwanaland. Deep crustal geology has to be built up onland and off-shore to find the signatures of Late Precambrian, late Palaeozoic and Cretaceous—Early Tertiary crust-mantle interactions. Attributes of rifting and the kind of processes involved require greater attention.

Gondwana basins and the sedimentary packages pose formidable problems of correlation, precise delineation of time planes and on the whole the process of basin evolution. It is absolutely necessary to formulate achievable short and long range programmes to develop a conjunctive lithologic, palynostratigraphic, isotopic magneto-stratigraphic data base on the complete sedimentary column of representative basins.

Problems of coalification, geochemistry of coals and associated sedimentary and igneous constituents, and development of data on palaeogeothermics and present heat flow studies have to be appropriately appreciated and tackled.

The future role of the Birbal Sahni Institute in contributing to the furtherance of Gondwana geology and geodynamics cannot be over emphasised. Geological Survey of India has been looking forward to multi-disciplinary, bilateral or multi-institutional pragmatic achievable geoscientific programmes aimed at fundamental and applied aspects of Gondwana Geology.

Ladies and Gentlemen, this is the auspicious day when we rededicate ourselves to the ideals and pursuits of Jawaharlal Nehru the moulder of modern India and almost his contemporary Professor Birbal Sahni, a model for Indian scientific pursuits.

Before I close, I extend my best wishes to all the participants and to the Organisers for very useful and successful deliberations in the next few days. I have great pleasure in inaugurating the Workshop.

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Concepts, limits and extension of the Indian Gondwana—an introduction to the theme

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THE term Gondwana—first used by H. B. Medlicott in 1872—was formally published by Ottokar Feistmantel in 1876. He desired that it be accepted in the same sense as the Silurian or the Jurassic systems of Europe. Fox (1931) states "The name Gondwana System was applied to deposits of conglomerates, sandstones, shales and coal-measures of fluviatile and lacustrine origin which occur in the Indian *Peninsula** and whose geological age ranges from middle Carboniferous to upper Jurassic. The fauna and flora of these Gondwana sediments are largely of terrestrial forms and include some fresh water fishes and amphibians". Lexique internationale defines the Gondwana 'System' as typically freshwater or riverine accumulations of conglomerates, sandstones, shales and coal-measures of Upper Carboniferous to Lower Cretaceous age. The base of the system is marked by a tillite or glacial boulder bed. Stratigraphical Lexicon of Gondwana formations of India (Sastry *et al.*, 1977) also ascribes an earliest Permian to Early Cretaceous time connotation to the Gondwana Sequence comprising a thick series of fluviatile and lacustrine sediments with intercalated plants, and to a lesser extent animal fossils. The sediments are notable for remarkable continuity of fossil floras. These contain a succession of fossil floras which are named as the *Glossopteris*, the *Dicroidium* and the *Ptilophyllum* floras. These floras have characteristic elements and in the course of time the mere presence of these floral associations was considered sufficient to term the entombing sediments as the Gondwana, even if they were primarily of marine origin.

CONCEPT

When marine signatures were discovered in the Indian Gondwana as far back as 1921 in the Umaria marine bed (Sinor *in* Fermor, 1922, p. 14) these were considered to be exceptions and were included as marine intercalations in the predominantly fresh water facies. Thus, the concept of 'marine intercalations' in a predominantly "continental sequence" was initiated. Subsequently more marine horizons were discovered at Manendragarh, Daltonganj and Rajhara establishing marine intercalations. More and more palynological evidences are forthcoming to show that marine sediments are not that infrequent as earlier believed to be in the Indian Gondwana.

Leiosphaerids and other acritarchs have been recorded in association with terrestrial spores and pollen in authentic marine sediments of Early Permian age. Such association has now been discovered in the Talchir sediments of Son-Mahanadi, Satpura, Damodar and Pranhita-Godavari grabens, Palar and Rajasthan basins as well as in the north-eastern India, strongly indicating a marine or near shore environment of deposition. In the Karharbari sediments acritarchs have been recorded from Umaria marine bed. Marine signatures in the form of characteristic leiosphaerid association have also been found in the Barakar, the Barren Measures and the Raniganj formations (Venkatachala & Tiwari, 1988).

Gondwana plant-bearing beds associated with primarily marine sediments have been well documented from the east coast basins and in the Kutch Basin. Even the Kota Formation, *sensu stricto*, in the Pranhita-Godavari graben has a doubtful record of a nannofossil (Bhattacharya, 1981). A large number of additional records of Lower Cretaceous marine sediments is now available from my own palynological studies on surface and subsurface sediments of the east coast (Cauvery and Krishna-Godavari basins). The palaeoecological regimes of these sediments may vary from non-marine to paralic

*Italicised by the present author for emphasis.

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and represent a transition zone where continental and marine facies interdigitate. But are these sediments really Gondwana just because they contain a 'Gondwana' palynoflora? Can a similar flora not occur simultaneously in itracratonic and coastal sediments? It is well known that palynofloras contain both *in situ* and *ex situ* fossils and it is the discriminating interpreter who can use this information for a meaningful palaeoecological interpretation. Mere occurrence of terrestrial fossil does not imply a continental deposition.

The Permian plant beds in Kashmir, that contain Gondwana elements if not a typical Gondwana flora, are sandwiched between marine formations. Gondwana type palynoassemblages are on record from the Permian of Kumaon Himalaya (Tiwari *et al.*, 1984) and Arunachal Pradesh (Srivastava & Dutta, 1977). Should these sediments be attributed the Gondwana connotation?

The issue is confusing. We either redefine the term 'Gondwana' or abandon it in favour of usage of international time scale, viz., Permian, Triassic, Cretaceous, etc. Should we restrict the term Gondwana to continental facies *sensu stricto* or enlarge the meaning to include both continental and marine facies? Both alternatives have their own inherent strength and weakness. In the former case exceptions would have to be allowed as for the like of Umaria, Manendragarh, Rajhara and Bap beds and such other stratigraphic sequences, which are intercalations in a primarily continental suite of sediments. And what would be the status of fresh water plant beds of Bhuj and Athgarh formations? And once exceptions are allowed, though they prove the rule, the limit of such exceptions and such other extensions becomes a subjective matter and may even over shadow the rule itself. In the latter case, the term Gondwana would serve no useful purpose because it would primarily be then based on the contained floras. With the alleged discoveries of Gondwana taxa in New Guinea, Tibet, Turkey, etc. the day is not far off when the term Gondwana in stratigraphical sense gets extended to some of these areas. After all, many geoscientists subscribe to the idea that these areas formed parts of Gondwanaland. A part of the Tethyan Sequence of Kumaon Himalaya has already been subtly included in Gondwana (Tiwari *et al.*, 1980, 1984).

It is pertinent to examine the situation in other countries. In the Salt Range, Pakistan, marine rather than continental, paludal and lacustrine sedimentation followed the glacial episode. In South Africa, the Karroo Sequence of sedimentary deposits is also distinctly continental. Some marine intercalations at the top of the Dwyka tillite contain *Eurydesma* and *Connularia* (Dickins, 1961; Rillet, 1963). In South America the situation, however, is remarkably different. Marine intercalations occur in the glacial Tubarao Group of Uruguay and Parana basins (Closs, 1969; Rocha-Campos, 1969). These contain goniatite fossils. Goniatites are also recorded from Lower-Middle Pennsylvanian of Peru, Lower-Middle Permian of Colombia and Middle Pennsylvanian of Chubut. Coal seams and carbonified remains of *Glossopteris* flora also occur in the sequence above and/or below the strata containing marine fossils. In western Australia, thick marine Permian sequences are recorded in major basins such as Carnarvon and Canning basins. The Upper Carboniferous of Hunter Valley has glacial varves diamictites, volcanics, shallow marine conglomerates, sandstones, limestone and tuff.

Thus, it is evident that marine sediments occur in all Gondwana countries. The accepted model of a continental facies for the Gondwana Sequence stands challenged. The mere presence of a flora with Gondwanic affinity does not make a sedimentary sequence the Gondwana *sensu stricto*. Exclusion of Gondwana plant-bearing pericratonic beds creates its own problems. The significance of plant-bearing pericratonic beds in the Himalayan region can not be underestimated. Their association with datable marine sediments makes them assuredly important for dating continental facies with similar plant associations. I expect the workshop to closely scrutinize the concept of the term Gondwana and come out with a solution acceptable to most, if not all. It should also examine if it is any more worthwhile to retain this term. I recommend the following three opposite views for discussions:

(i) Under the head Gondwana deposits, only far flung terraines characterised by some aspect of the Glossopteris Flora are considered legitimate. The term should be restricted essentially to those 'austral' deposits found in both geosynclinal and cratonic expression and initiated by the great glacial event (Caster, 1952);

(ii) Gondwana should include all those continental and shallow marine sequences in the southern continents, whose gross lithologic, biologic and tectonic aspects permit reasonable identification with one another (McElroy, 1969);

(iii) The term Gondwana is now redundant in stratigraphic sense and we should now use International terms such as, Permian, Triassic, Jurassic, Cretaceous, etc.

Under the first two alternatives, it is evident that palaeontological uniformity is the major uniting factor. The other uniting factor is the basal glacial episode that is believed to have initiated the Gondwana Sequence of deposits.

LIMITS OF GONDWANA

Did this glacial episode occur simultaneously all over the southern landmass? King (1958) suggested that glaciation may be of somewhat different ages in different parts. If so, it would mean that Gondwana sedimentation did not cover the same time span everywhere. Further, there may be more than one glacial episode. For example, the glacigene Itarare Group of Parána Basin shows atleast 6, may be up to 10, glacial episodes. Atleast 3 marine beds lie only a few meters above the tills. The Beacon Supergroup of Antarctica equivalent of the Gondwana Sequence is of Devonian to Jurassic age with continental or possible shallow marine sediments. The youngest glacial beds have been palynologically dated as Early Permian (Barret & Kyle, 1975). The age of formations underlying glacial deposits in Australia, according to palaeontological evidences, vary from latest Visean to Early Namurian to as young as Westphalian (Roberts, 1971; Roberts, Hunt & Thomson, 1976). The ammonoid faunas in sediments overlying the glacial formations are of Sakmarian age. Kemp *et al.* (1977) believe that palynofossils from Australian glacial beds indicate a Missourian-Virgilian age. However, on available evidences, we do ascribe a earliest Permian age for the basal Gondwana beds in India.

The Gondwana sedimentation is believed to have extended only up to the Lower Cretaceous. The reasons for fixing the upper boundary of the Gondwana at this level are obscure. If the term Gondwana Sequence is to be restricted to a particular type of sediments deposited in the Gondwanaland, one has to ask and answer an important question—till what time did the Gondwanaland exist? A time connotation is involved. Do we consider India a part of Gondwanaland even after it drifted? Or, it lost its Gondwana affiliation only after its rendezvous with Eurasia? Palaeomagnetic data has been interpreted to establish that the eastern Gondwana separated from western Gondwana in Hauterivian (120 ma). India separated from eastern Gondwana block of Australia and Antarctica by Santonian (80 ma) and became attached to Eurasia in the Late Miocene (10 Ma).

If the limits of the Gondwana are to be considered in the floral context the main floral provincialism, comprising the elements of the *Glossopteris* assemblage, was mostly confined to the Permian, probably extending into the basal Triassic. The Triassic floras of the world, too, show a provincialism though at a reduced scale. *Pleuromeia*, a characteristic lycopsid of German Bunter, that occurs extensively in the Soviet Union, has been reported in the Australian Triassic, so does its spore—*Aratrisporites*. Even the Late Triassic palynological assemblages recorded from Western Australia (Dolby & Balme, 1977) and from the Tiki Formation of the Son Graben (Maheshwari & Kumaran, 1977; Kumaran & Maheshwari, 1980) have a number of typical central European taxa at generic level. The lycopod megaspores recovered from the Tiki Formation (Banerji, Kumaran & Maheshwari, 1979) show a certain resemblance with the Norian-Rhaetian megaspores from Poland. The Late Triassic faunas from Madagascar and India have distinct northern affinities (Battail, Beltan & Dutuit, 1987; Chatterjee, 1987). The provincialism exemplified in the Permian floras is no more evident even in the Late Triassic.

In the Upper Mesozoic (?Jurassic-Cretaceous) the Indian flora seems to have acquired a definite northern aspect and became a part of Vakhrameev's Indo-European palaeofloristic province extending from Europe to Japan via India and South China. Should the upper boundary of Indian Gondwana not be placed at the latest Triassic? After all before the advent of the Gondwana flora, too, the Carboniferous floras were homogeneous, though floral zones are recognizable (Chaloner & Meyen, 1973). Authentic Jurassic palynological assemblages are not known from intracratonic Gondwana. But the Late Jurassic-Early Cretaceous palynological assemblages from Kutch Basin, and the Early Cretaceous assemblages from Cratonic and East Coast basins have a large number of cosmopolitan palynotaxa, e.g., *Cicatricosisporites, Aequitriradites, Crybelosporites, Foraminisporis, Trilobosporites, Densoisporites, Coptospora, Appendicisporites, Coronatispora* to name a few. In view of the cosmopolitan mega- and palyno-flora occurring in Upper Mesozoic of India, when this land segment had already departed from the Gondwanaland, the upper limit of the Gondwana needs major rethinking. Interestingly, at many places on the East Coast, the Lower Cretaceous sediments constitute a continuous succession with the Upper Cretaceous sediments (Sastri *et al.*, 1975; Kumar, 1983; Venkatachala & Sharma, 1984).

EXTENSION

If we decide to retain the term Gondwana and also agree to its upper and lower limits, the question naturally will arise as to the geographical distribution of the Gondwana.

As of today, the Gondwana sedimentation within the prescribed time and ecological limits *sensu* Fox (1931) is believed to have been laid down only on the Gondwanaland. The term Gondwanaland was conceived by Edward Suess in 1885 and readily adapted by subsequent workers for a Palaeozoic supercontinent that is believed to have comprised all the southern continents including India. Atleast, during the entire Permian and most of the Mesozoic India is believed to have been an integral part of this supercontinent. But what were the northern limits of the Indian segment is the question that is confounding the geoscientists today. With the introduction of the concept of individual, dyanamic crustal plates, the controversy is warming up. Now it is no more fashionable to regard the northern boundary of India coincident with the Main Boundary Fault, the Central Crystalline Axis or even the Indus Suture Zone. The concept of 'Greater India' is gaining momentum. What was the extent of 'Greater India'? Some would include the whole of Tibet and take the northern boundary to the Tien Shan Mountains. Others would place it along the Bangon-Nujian. In one of the reconstructions, Iran, Afghanistan, Indo-China, etc. are placed north of India. This question has to be discussed dispassionately and multidisciplinary data need be sifted and interpreted. Can palaeontology help?

Crawford (1974) concluded that the distribution of fossil cladoceran *Daphinopsis* and reptile *Lystrosaurus* in the Early Triassic points to an association of Tibet with Inner Mongolia, India, Antarctica and Australia. Another important evidence in support of Tibet and India association is derived from the discovery of a Glossopteris Flora in southern Tibet (Hsü, 1976). Perhaps distribution of pollen and spores may provide additional evidences. Hence, there is sufficient incentive to probe further in this matter. Most important is to identify coeval continental suites for palaeontological investigation. A real understanding of the Cathaysian and Angaran palynofloras is not only a prerequisite but the nomenclature and taxonomy of palynofossils in these assemblages have to be redefined and translated to Gondwana and Euramerican usages to achieve a meaningful comparison. The taxonomy and nomenclature of plant megafossils should normally not present much problem, but even there the bias to recognize familiar taxa has to be overcome. The bias of the investigator specialising in Indian, Russian, American, Chinese or for the matter of fact, any other floras would decide on the identification of a fossil taxa to either *Glossopteris* or *Pursongia* or *Zamiopteris*. Examples are several. Similarity in external morphology of an isolated plant organ, from different palaeogeographical and palaeo-ecological regimes, does not necessarily mean that they represent the same plant. Search should be made for other related organs to verify and confirm such presence. The ground rule is not to start with preconceived ideas or notions. Attempts should be made to evaluate objective speciation that has occurred in nature rather than introduce our own regional biases. Subjectivity always gives rise to problems in all areas of human activity and it is no exception in Gondwana stratigraphy, palaeontology and palaeobotany.

PALAEOCLIMATE

Glossopteris is an undoubted temperate plant. If similar leaves are discovered in tropical regimes, one has to be doubly sure before assigning such leaves to the *Glossopteris* plant. The climate was frigid during the glacial period. Palynological information shows that in the Talchir it became very cold and dry and ameliorated during Lower Karharbari when the first coals were laid down in a cold and humid climate. In the Upper Karharbari, the climate again deteriorated and became very cold and dry. During the Damuda period it was mostly warm and humid. It is also true because most of our coals in great thickness are deposited in the later Permian. In the Lower Triassic it is interpreted to have become cold and humid though no coals have been laid down (Bharadwaj, 1975).

The question we have to answer is—Can spores and pollen by themselves, in the absence of knowledge about their parent plants, provide reliable climatic inferences? Corroborating evidences are always needed to sponsor an idea or to sustain a hypothesis. There is not enough supporting research which can relate exinal or organisational manifestations in spores and pollen to climate. For example, in the cold temperate Talchir Formation, a radial monosaccate pollen association is dominant. *Per contra* palynological suites in the northern hemisphere containing radial monosaccate *Nuskoisporites*/*Cordaitina* do not represent even a cool phase. Taeniate forms may be taken as representing seasonal fluctuation in Gondwana but in the Late Permian Flowerpot Formation of Oklahoma from where they are also recorded, there is no evidence of seasonal fluctuations. However, if we examine the megafloral assemblages, we observe that as compared to the coal-forming vegetation of the northern hemisphere, the Indian Permian megafloral assemblages contain relatively few kinds of plants, though in innumerable numbers, a condition that postulates a cool or cool-temperate climate throughout. Tropical floras, as we know, contain largely diversified floral assemblages including a large variety of taxa. This, in fact, is the climatic zone in which maximum speciation occurs. The presence of annual rings in the wood and the deciduous nature of the leaves in the Indian Permian also support the contention of a cool temperate climate. That the climate did not get too severe is evident from the fact that some of the trees attained considerable size. The reduction in size of leaves in the basal Triassic and the epidermal features of many of the Triassic leaves point to a climate where availability of moisture was relatively poor. Sedimentological studies also do not seem to support a cold, humid climate for the basal Triassic. Infact, the climate could have been warm, if not arid.

PROBLEMS OF DATING AND ZONATION OF GONDWANA SEQUENCES

One of the major problems in the Indian Gondwana stratigraphy has been the lack of uniformity in the usage of various terms. So far, no reasonable chronostratigraphic classification is available and the time connotations to various lithostratigraphic units have been mostly arbitrary. Most of the sediments being continental, biostratigraphic zonation has of necessity to be based on plant micro- and megafossil records. However, these can not be satisfactorily compared with standard biostratigraphic zones of the northern hemisphere because of the vast difference in floristic composition of the two. Even plant megafossil and microfossil zones in the same basin or in the same lithounit do not interlink. This seems to be due to lack of botanical understanding of relationship between mega- and micro-fossils an area in which extended research is needed. In dispersed spores and pollen it is rather much more difficult to know what morphographic characters are intrinsic to each species and what are incidental. Great emphasis should be laid on the study of *in situ* spores and pollen and the information so derived must be incorporated in delineating species of dispersed palynotaxa. This will enable us, to be rid of the situation where genera and species of southern microfossils are referred to characteristic northern taxa while the megafossil records of the two areas are totally different. However, I do not mean that taxa of palynofossils, or for that matter, those of plant megafossils, should be differentiated on geographical basis. This will be just as bad as differentiating taxa on the basis of geological occurrence. For example, diploxylonoid pollen with a small, circular, dark central body is referred to the genus *Platysaccus* in the Permian and to the genus *Podocarpidites* in the Mesozoic. Plant fossils are to be used for dating the sediments and for phytogeographical inferences and not *vice-versa.*

But all the same, we should be vary of determining ages of sediments on the basis of similarity of taxa based on dispersed organs of plant megafossils. Or, we shall end up with dubitable age assignments. For example, the apparent similarity between the Yorkshire Jurassic floras and the Upper Mesozoic floras of India from Rajmahal, Satpura and East Coast has led to Middle-Late Jurassic age assignments to the Indian sediments. We know now for sure from palynological, foraminiferal and radiometric dates, these sediments were laid down during the Early Cretaceous.

The criterion for dividing the Gondwana Sequence into Lower, Middle and Upper Gondwana also requires a fresh look. If one goes into the views of the recent proponents of the three-fold classification of the Gondwana (Lele, 1964; Saksena, 1974), it is apparent that they were guided by the major floral changes. The Lower, Middle and Upper Gondwana were related to *Glossopteris, Dicroidium* and *Ptilophyllum* floras. While, the chronological value of the plant fossils is unsuspected neither we can justify subdividing lithological unit nor any useful purpose would be served by such a three-fold or even a two-fold division of the Gondwana.

It is much more important to recognise lithological units of the rank of a formation and to delimit their spatial distribution. More often than not same formational names, with few exceptions, are applied to coeval units in different grabens. How far is it reliable and in conformity with the code of stratigraphical nomenclature? Lithological units with similar basic characteristics can not be expected to occur in different grabens or basins unless the tectonic and sedimentological history are comparable. Most of the formations lack reliable type sections, and their upper and lower contacts are not usually apparent. The Karharbari Formation is an example. It was recognised on the basis of contained floras (*Botrychiopsis* and *Buriadia*) but later workers assigned lithological characters to it. But not all agree that Karharbari Formation can be identified lithologically in all the basins from where it has been reported, which makes the status of this formation suspect. It seems to be becoming quite common to change the definition or diagnosis of a recognised formation on the basis of subsurface data. The Kamthi, the Dubrajpur and the Parsora formations are such examples. In the Kamthi Formation, *sensu lato*, are now included carbonaceous Infra-Kamthi; in the Dubrajpur Barakar equivalent beds of Rajmahal and in the Parsora the upper part of the Pali Formation. I expect the workshop to re-examine the necessity of incorporating such changes on the basis of the information which is not available in type or reference sections. Slight carelessness or bias in assigning a palaeontological sample to a formation as well as the identification of a taxon either to one or the other, may drastically change the biozonation and age assignment.

A refinement in age determination of various formations is much needed. To date the Talchir-Barakar, Barren Measures and Raniganj formations as Lower, Middle and Upper Permian seems to be more due to convenience in the same way as the Lower, Middle and Upper Gondwana were dated as Permian, Triassic and Jurassic-Lower Cretaceous. It is made to appear as if the 'Lower Gondwana' formations represent the whole of the Permian System in most of the basins. There is every likelihood that a part of the sequence may be missing.

The floras usually being monotonous successions, absolute age determinations need to be introduced wherever possible to firm up age assignments. If few such dates are made available, ages of associated, overlying and underlying sediments can be calibrated. Intercalated marine fauna and terrestrial tetrapod fauna can also be of help in age determinations. In the Pranhita-Godavari Graben many of the litho-units have datable vertebrates which are associated with plant megafossils. In the Son Graben too, the Tiki Formation has datable fauna in some of the horizons. The significance of plant-bearing beds in the Himalayan region cannot be underestimated. They are specially important for precisely dating continental formations, as they are associated with well dated marine sediments. It is necessary now to tie up all available biostratigraphic evidences to understand and interpret the stratigraphy and ecology in a synergistic approach.

In using the mega- and micro-fossils for correlating and dating Gondwana of different basins and grabens, possibility of localization of certain floras should also be kept in view. For example, the typical Karharbari biozone is developed only in the Giridih Coalfield. Elsewhere it is recognised more on extraneous grounds rather than on the presence of the genera *Botrychiopsis* and *Buriadia*. The *Dicroidium* biozone is developed only in South Rewa Basin; there is no definite evidence of the presence of this genus in any other basin. The plant association of the Nidhpur beds too, is a localised development apparently without any comparative fossil flora elsewhere in India. It can not be satisfactorily used for age correlation unless we insist that the ubiquitous Triassic genus *Dicroidium* is present in this assemblage. In such cases the taxonomic identification of such crucial taxa must always be objective. Does the absence of forked rachides in Nidhpur pteridosperm leaves has any meaning? Is it not possible that these leaves represent precursors of the genus *Dicroidium* which is definitely represented only in the Parsora Formation *sensu stricto*? Does the Nidhpur floral assemblage not answer to the '*Thinnfeldia*' *callipteroides* Oppel-Zone of Australia that spans the Permian-Triassic boundary? It may even represent the unconformity between the Raniganj and Maitur formations in the Raniganj Coalfield.

The significance of spore-pollen assemblages in demarcating the Upper Jurassic/Lower Cretaceous boundary needs be re-examined. Whether the boundary is represented by qualitative or quantitative changes has to be expressly determined. Do the spore-pollen assemblages reflect on the presence of Jurassic in the peninsular Gondwana? And how does the megafossil record reflect on this boundary? These are some of the major questions that need to be answered, particularly with reference to the age of the Rajmahal intertrappean beds as there is a recent report of a Lower Jurassic plant megafossil assemblage in the upper part of the Dubrajpur Formation (Sengupta, 1985). We have a radio-metric date of ± 105 ma for some of the Rajmahal traps. Palynologists are also veering around a Lower Cretaceous age (Maheshwari & Jana, 1983). As a matter of fact, there is overwhelming evidence to support a Lower Cretaceous age to all the Upper Mesozoic plants beds. A detailed investigation of their field relationship with associated marine beds will definitely provide a sequential age to these formations.

In recent years the Australian connection of the Indian Gondwana floras is becoming more apparent. *Dulhuntyispora dulhuntyii*, an endemic western Australian Upper Permian pollen, which is not known from any of the Indian Gondwana palynological assemblages, has now been discovered, albeit in reworked form, in the Oliogocene-Miocene of Assam and Miocene of Tripura. The pollen genus *Marsupipollenites* has also been found in Permian of Arunachal Pradesh, Rajmahal Hills and Son Graben. The Carnian-Norian palynological assemblages from Australia (Dolby & Balme, 1977) and India (Maheshwari & Kumaran, 1978; Kumaran & Maheshwari, 1979) depict great similarities. Such occurrences can be used to work out the India-Australia fit. Reworked palynofossils otherwise too have great significance, as they are indicative of the presence of litho-units that may not be exposed or have been completely eroded. These may also indicate palaeodrainage patterns. The Mesozoic sedimentary sequences of the Kutch Basin contain a large number of reworked radial monosaccate as well as bisaccate striate pollen, but no where in Kutch or Gujarat Permian or even Triassic sediments have been exposed. From where did these reworked pollen originate? Does it reflect on the India-Africa fit? or, it has a bearing on the concept of a Indus sub-plate? Reworked palynofossils may also provide an additional parameter to record hiatuses/unconformities. Reworked Permian pollen are found only in the grabens or associated basins on the East Coast. The significance of this find needs attention.

There is some evidence to show that Permian sedimentation did not cease within the Raniganj Formation but probably continued in the Panchet Group as well. In the basal beds of the Maitur Formation in the Raniganj Coalfield, we observe that the *Glossopteris* species, particularly *G. conspicua* Feistmantel and *G. elongata* Dana and *Schizoneura gondwanensis* Feistmantel continue apparently without introduction of any new element. Palynologically also a definite change is observed only above the Raniganj-Maitur boundary. Whether this change is related to the Permian-Triassic transition needs a thorough study. The distribution of the estheriid fauna should also be utilized for this purpose.

Lastly, but in no way less important, are the plant megafossils and microfossil zonal successions and their relations. Presently we have a great many palynological zonal schemes. Most of the zones are based on relatively unimportant proportional distribution of subjectively identified palynotaxa of generic level which probably may reflect local facies changes. A review and synthesis of these palynological zones is urgent. These should further be correlated with plant megafossil and palynological zones of other areas associated with reliable marine invertebrate faunas. Relationship between palynological zones, faunal zones and chronostratigraphic units will help in bringing about a precision in age control. However, the identification of 'northern' microfossil taxa reported from Indian Gondwana is suspect because we do not know if they migrated from the north or are the result of parallel evolution. Can they be used for age determinations? At least the Permian taeniate pollen seem to be the result of parallel evolution as the plant megafossil record, though much less complete, does not support such a cosmopolitan distribution of gymnospermous taxa during the Permian.

These are only some of the many problems that I have outlined or dared to identify. वादे वादे जायते तत्वः—"*Only deep and continued discussion will bring out the truth*". I am sure we will all muster up courage to face criticism, answer questions on our rationale and also accept newer evidences in the spirit of science and revise old concepts. We will never see the elephant if we view it as a fan, pillar or a snake.

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The facts and fictions of the Gondwana concept

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Wegener did not envisage that Gondwanaland was an independent continent. This concept was introduced earlier but concretised by Du Toit. His Permian ice-cap covered almost the entire supercontinent. Ahmad, however, pointed out that the ice-cap at no stage was exceptionally large. Du Toit was not aware of the glacial deposits in Arabia or Tibet, and his ice-cap would have to be enlarged considerably if it was to form deposits in these areas, particularly the latter, as well. All evidence goes to suggest that Tibet was not separated from India in the Permo-Triassic and the suture zone concept is not valid. These Tibetan glacial deposits carry Glossopteris flora and Stepanoviella and Eurydesma fauna as typical Gondwana forms. The deposits reach up to Kun Lun mountains.

The Himalayan region was separated from the peninsular basin and was part of the southern margin of an epicontinental Tethys. The ice-cap did not reach this area. However, Himalayan diamictites, as also those of Tibet should be older than the peninsular and a Carboniferous age assigned to them by Chinese geologists may be valid.

The Gondwana concept envisaged glacial deposits overlain by freshwater sediments. This seemed to apply to peninsular India, Western Australia, South Africa, etc. But of late marine incursions have been reported from India and South Africa leaving, perhaps, only Antarctica where it could truly be applied today. The ice-cap covered peninsular India and peneplained it, so that after it receded the area was significantly downwarped and this resulted in marine incursions. Umaria's access to sea was obviously to the south-east underneath the ice-cap and hence it could not carry fauna older than that of Manendragarh. Rajhara, too, was perhaps an extension of this sea, although it could have been independent.

Key-words—Gondwanaland, Continental Drift, Plate tectonics, Palaeogeography (India).

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साराँश

गोंडवाना अवधारणा के तथ्य एवं परिकल्पनायें

ऍफ़० अहमद

वेगनर की यह परिकल्पना नहीं थी कि गोंडवानाभूमि एक स्वतंत्र महाद्वीप था। यह अवधारणा पहले प्रस्तावित की गई थी परन्तु दु टॉयट ने इसे ठोस रूप प्रदान किया। उनके अनुसार परमी हिम-आवरण ने प्रायः सम्पूर्ण महाद्वीप को ढक रखा था। अहमद ने भी हालाँकि इंगित किया है कि यह हिम-आवरण काफी विशाल था। दु टॉयट अरब अथवा तिब्बत की हिमानी निक्षेपों से अवगत नहीं था अतः उनके द्वारा प्रस्तावित हिम-आवरण का और भी बड़ा स्वरूप होगा यदि इन क्षेत्रों में इससे निक्षेपों का निर्माण हुआ हो, मुख्यतया बाद वाले क्षेत्र में। सभी प्रमाणों से व्यक्त होता है कि परमी-त्रिसंघी कल्प में तिब्बत भारत से अलग नहीं था तथा सूचर क्षेत्र अवधारणा भी अमान्य है। इन तिब्बती हिमानी निक्षेपों में ग्लॉसॉप्टेरिस वनस्पतिजात तथा स्टीपेनोवियॅल्ला एवं यूरीडेस्मा जीवजात सामान्यतः पाये जाने वाले प्ररूप हैं। ये निक्षेप कुन लुन पर्वत श्रृंखला तक विस्तृत हैं।

हिमालयी क्षेत्र प्रायद्वीपीय द्रोणी से अलग था तथा अधिमहाद्वीपीय टॅथीज़ के दक्षिणी किनारे का एक भाग था। उक्त हिम-आवरण इस क्षेत्र तक नहीं पहुंच सका था। हालाँकि, तिब्बत की भाँति हिमालयी डायामिक्टाइट प्रायद्वीपीय की अपेक्षाकृत पुरातनतर होने चाहियें तथा इनकी चीनी भूविज्ञानीयों द्वारा प्रस्तावित आयु भी सत्य हो सकती है।

गोंडवाना अवधारणा के फलस्वरूप ही हिमानी निक्षेपों की परिकल्पना की गई जिनके ऊपर स्वच्छ-जलीय अवसाद विद्यमान हैं। यह अवधारणा प्रायद्वीपीय भारत, पश्चिमी ऑस्ट्रेलिया, दक्षिण अफ्रीका आदि के लिए लागू होती है। केवल अंटार्कटिका जहां कि यह आज भी इसे यथार्थ रूप में प्रयुक्त किया जा सकता है, को छोड़कर भारत एवं दक्षिण अफ्रीका से अंतिम समुद्री अतिक्रमण अभिलिखित किये गये हैं। सम्पूर्ण प्रायद्वीपीय भारत हिम-आवरण से आवरित था तथा इस आवरण के हटने के पश्चात् यहां समुद्री अतिक्रमण हुआ। उमरिया दक्षिण-पूर्व की ओर हिम-आवरण के नीचे समुद्र से स्पष्ट रूप से जुड़ा हुआ था अतएव इससे उपलब्ध जीवजात मनेन्द्रगढ़ से पुराना नहीं है। रझारा भी सम्भवतया इसी समुद्र की एक शाखा है, हालाँकि यह पृथक हो सकता है।

Concepts, limits and extension of the Indian Gondwana
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TO Wegener (1926) Gondwanaland was, at best, a notional continent, for he does not seem to have recognized it as an independent landmass. Perhaps he used it only because Suess (1885) had accepted the concept introduced earlier in India. Indeed, it was left to Du Toit (1937) to give a concrete shape to this supercontinent, separated from the northern continents by an oceanic Tethys. But the Gondwana 'concept', envisaged side by side, had some unique features—a glacial horizon, at the base, often with a profound unconformity underneath, its flora amazingly uniform over at least five of the present continents, its fauna, too, supposedly endemic, and yet their correlation intriguing even from basin to basin.

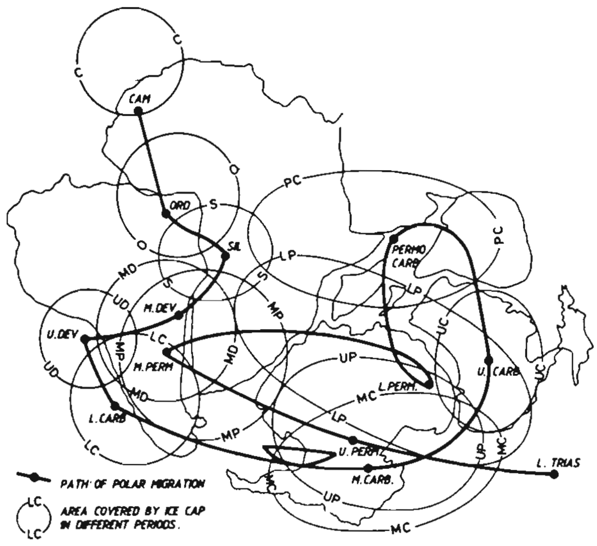
On the other hand this unusual intra-Gondwanaland similarity had led to the concept of continental drift. Vehemently denied by the agressive American school for decades, and then converted almost overnight by the evidence provided by palaeomagnetism and mid-ocean ridges, it soon got wedded instead to plate tectonics. In its defence, the American school is equally agressive once again. Of late, however, Earth expansion is making inroads in the field, for plate tectonics is faced with a number of internal contradictions. Suturing and subduction are two veritable pillars of plate tectonics, and the type area of these, the Indus-Tsangpo Suture, lies within our sphere of interest in the present study. In fact, a storm appears to be gathering around the interpretations of this feature, for it now appears certain that it existed *before* the so-called collision and subduction in the region, and northern Tibet was always a part of the Indian subcontinent, even more so than today for the Himalaya did not intervene at the time.

GONDWANA GLACIATION

Blanford, Blanford and Theobald (1856) reported the discovery of a boulder conglomerate from the Talcher Coalfield in Orissa, that they thought could be of glacial origin. Europe had just then discovered the Pleistocene glaciation in both the hemispheres, and accepted that the Earth had faced a cold spell. But this case of glaciation in the tropics could not be reconciled with the fact that a warm climate was known simultaneously from Europe and America. Western geologists, therefore, did not accept it till the discovery of the striated pavement on the bank of the Penganga by Fedden (1875). It remained intriguing for the ice here had apparently moved *towards* the pole, a feature but locally known from the Pleistocene glaciation anywhere. Although an immense amount of field-work has gone into these glacial deposits in all parts of Gondwanaland in the last over a hundred years, it is a measure of the extreme scepticism of the scientific community that in the sixties of this century the Royal Society was persuaded to depute an experienced geologist to India to confirm that the deposits so considered were really of glacial origin. He came, he saw and he was won over.

Earlier it was thought that the entire area over which glacial deposits exist in the so-called Gondwanaland was at once covered by an ice-cap (Du Toit, 1937) (Text-fig. 1). Such an ice-cap would have been about four times the present Antarctica ice-cap, and could not have existed without a profound lowering of temperature over the globe. And yet there certainly was no ice age at the time. Ahmad (1960), accordingly, suggested that not only the Gondwanaland was then at the South Pole, but it was drifting all the time, and that the ice cap at any single stage was considerably smaller than that envisaged by Du Toit. This migrating pole subjected different areas to glaciation at different times (Text-fig. 2). Ahmad (1960) has used minor differences in floral occurrences in deducing the differences in the ages of ice-caps, yet accepting these data only when these conformed to the palaeogeography of the time. Thus, Glossopteris flora in Kashmir is contained in a succession in the Agglomeratic Slates that carries the Rhacopteris flora at a lower horizon (Sharma *et al.*, 1979). More important, *Gangamopteris* in the Vihi Bed appears without any *Glossopteris*, the latter coming in later, gradually to dominate the flora. Elsewhere, the Agglomeratic Slates carry the Carboniferous *Fenestella* and above it the Permian *Eurydesma-Deltopecten* assemblage. Nakazawa and Kapoor (1979) and Acharyya *et al.* (1979) regard the Vihi Bed as considerably younger than the *Eurydesma-Deltopecten* Bed but it is more likely that these and the Agglomeratic Slate horizons were more or less contemporaneous and simple manifestations of fresh-water and marine environments in the two areas. It may be emphasized, therefore, that although the Agglomeratic Slates are not truly glacial, it is obvious that glaciation had appeared in the Carboniferous, conforming to the age assigned to the fluvioglacial deposits in northern Tibet (Wang Naiwen, Pers. comm., 1984).

In peninsular India, a *Gangamopteris-Noeggerathiopsis* assemblage is characteristic of the Damuda beds, the Talchir and Karharbari horizons carrying *Noeggerathiopsis-Paranocladus* and *Gondwanidium-Buriadia* (Sastry *et al.*, 1979) respectively, i.e., *Gangamopteris* in peninsular India appeared a while *after* the glaciation. It may, thus appear that a truly frigid climate, did not suit it, for in Kashmir, too, it might have been flourishing well



Text-figure 1—Ahmad's map of polar migration.

beyond the margin of the ice-cap. In the Salt Range, too, *Gangamopteris* occurs above the boulder bed, in fact with a thin barren bed intervening.

In the Congo Basin, Africa, *Gangamopteris*, without any *Glossopteris* at all, has been found in great abundance (Veatch, 1935). Thus, the area compared with Kashmir in this regard, both having presumably been along the margin of the Permo-Carboniferous ice-cap. On the contrary, in South Africa *Gangamopteris cyclopteroides* has been reported only from two localities and in both it occurred along with the material filling the joints in the underlying gneisses, that on the surface carry striated pavements. Obviously, *Gangamopteris* had existed well before the glaciation had set-in, was wiped out by the ice-cap cover and failed to reappear after the ice-cap had receded. The age of *Gangamopteris* was, obviously, over and hence none occurs in the overlying Gondwana beds, i.e., the ice-cap had covered the area very near the end of the Permian.

In South America, *Glossopteris* is the predominant genus in the glacial beds, and *Gangamopteris* is present only in one species, the long lived *G. cyclopteroides.* Thus, it would appear that glaciation in South America was younger than that in the Congo Basin, but older than that of South Africa, where even the two sub-species of *G. cyclopteroides* had disappeared by the time glaciation ended, i.e., the event in South America was in the Middle-Upper Permian.

The situation in eastern Australia was entirely different. There had been a strong Carboniferous glaciation, and after only a brief interval, the Permian started with glaciation that lasted till the top of the Permian, with but minor fluctuations. The Permian System comprises a marine formation at the bottom, followed by the Greta Coal Measures. A marine formation follows, with the Newcastle Coal Measures coming at the top. Yet glaciation was present all the time, closing in and receding marginally. The situation in Western Australia, on the other hand, is very similar to that in peninsular India, as, indeed, it should have been, for the two areas were in juxtaposition, and hence there existed an environmental continuation of one into the other. All these features cannot be explained by a large, single ice-cap, and there seems to be no escape from Ahmad's rapidly migrating pole.

The age of the glacial deposits of Herat (Afghanistan) and the three localities in southern Arabia (Helal, 1965; McClure, 1980) cannot be evaluated on these bases, and by analogy, they may be placed in the Permo-Carboniferous, the area having been comarginal to the ice-cap in Kashmir area (Text-fig. 3). Dickins and Shah (1979, p. 400) discuss the fauna from the Haushi Formation of Arabia and equate it with that of the Carnarvon and Canning basins of Western Australia, as also the Bhadaura and Agglomeratic Slates horizons of India. This would be in accord with the age deduced above. The glacial deposits in northern Tibet are generally marine in character, yet typical Gondwana flora is reported locally. Chinese geologists consider the fauna too, as of Gondwana affinities, and yet place the succession in the Carboniferous. The ice, it is believed, moved from south to north and thus all available evidence goes to show that Tibet, in the Carboniferous, was a part of India, and was not separated from the latter by a Tethyan Gulf of oceanic character.

Additional evidence in this regard is provided by the following lines:

1. The presence of a number of Triassic vertebrate forms, e.g., *Lystrosaurus* of typical Gondwana affinities in Sinkiang and Shansi bespeaks unequivocally of the absence of any oceanic basin intervening in the Tibetan area. Significantly, too, no deep sea sedimentary deposits have been discovered in the area to-date.

2. The suturing is believed to have been Eocene-Oligocene, whereas the ophiolites in the Indus Suture Zone belong to two different ages: uppermost Jurassic-lowest Cretaceous and Lower Cretaceous, i.e., the ophiolite emplacements took place some 50 Ma *before* the supposed suturing. This is impossible to explain on the basis of the current hypothesis.

3. In the plate tectonics speculation India should have been in the southern hemisphere when

the ophiolites were emplaced, and yet the Indian plate margin involved has suffered extensive thermal metamorphism.

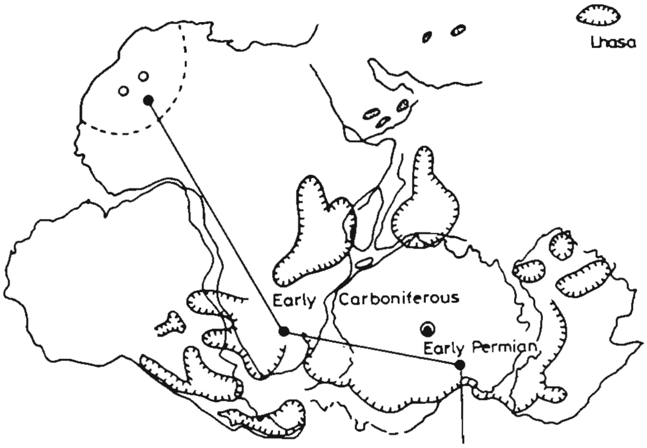
4. The ophiolites carry minerals which indicate their deep seated origin, and not obducted ocean floor. More specifically, it has been shown that the second emplacement must have originated at a temperature of 1105°-1240°C, and a pressure of 27-46 kb, conforming to a depth of 80-140 km (Liang Rixuan & Bai Wanji, 1984). Diamonds and poissanite have been reported from this emplacement and bespeak of origin at high temperature and pressure.

5. Crystal settling in the second emplacement is extensive and has resulted, at almost every exposure, in acidic rocks near the top and ultrabasic at the bottom. This indicates highly molten rock, something impossible to obtain in obducted oceanic rocks.

These lines of evidence leave one in no doubt that India was not separated from Tibet and no wonder, therefore, that the glacial deposits carry Glossopteris flora (Wang Naiwen, 1984, p. 27) and Stepanoviella and Eurydesma fauna (Han Tangling & Wang Naiwen, 1983; Yang Shipu & Fan Yingman, 1981, and others). These lines of evidence are in addition to the faunal and floral similarities from the Cambrian to the Jurassic that Ahmad (1978) pointed out in his Birbal Sahni Memorial Lecture, followed by a palaeogeographic study of the Tethyan region (Ahmad, 1981) and a review (Ahmad, 1982). If these floral and faunal similarities were restudied, there would be scores more of common forms that have come to light since.

What other evidence does any one need to be convinced that India and Tibet have stayed together from at least the Carboniferous to the Triassic and may be from Precambrian to date. All this is concrete evidence that can be checked and rechecked, ranged as it is against plate tectonic speculation of collision, subduction and progressive underthrusting (e.g., Klootwijk, 1987).

Palaeomagnetic evidence has been used extensively to determine the south polar migration (McElhinny, 1973; Vilas & Valencio, 1979; Daly & Pozzi, 1976) and the curves are fairly similar. Text-figure 3 is typical of these and it would be seen that the envisaged polar migration, as pointed out above, could not account for the glacial deposits in Tibet, Afghanistan or Arabia. Obviously the pole migrated rapidly during the period but palaeomagnetism has not been able to record this event. Also, the ice-cap indicated by Du Toit (Text-fig. 1) is too large and since his study Tibet and Arabia have been added to the areas affected without a profound lowering of global temperature. However, Ahmad (1960), has shown (Text-fig. 2) that no earlier ice-cap was as

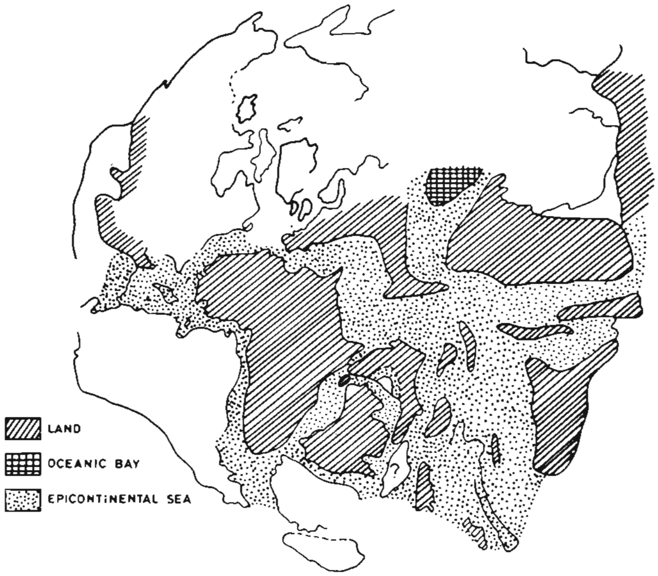


Text-figure 2—Polar migration path after McElhinny (1973). After Crowell (1977) with glacio-marine areas in Arabia, Iran, Afghanistan and Tibet added. Early Permian South Pole after Vilas and Valancio (1977).

large as that envisaged by Du Toit for the Permian and the tropical climate reported from Europe and North America rules out any significant dip in temperature. It is, therefore, obvious that the vast expanse of Gondwana glaciation was the result of a very rapid polar migration in the Carboniferous through Permian. Indeed, there seems to be no escape from it.

PENINSULAR INDIA

The basis of the Gondwana 'concept', if it could be called a concept, was on two pillars, glacial deposits at the base, followed by freshwater deposits, marked by thick coal seams. Indeed, it was thought that glaciation would always peneplane an area and result in coal deposits by reducing the inflow of sediments in the marshes. This, too, was based on observations in peninsular India, where it then appeared to be strictly valid. The entire peninsula having been isostatically downwarped by the weight of the ice cap, with vast areas continuing to be downwarped even after the cap had receded and others rebounding back gradually, sedimentation occurred in isolated downwarping basins. Epeirogenic conditions, thus, varying in mode and magnitude, an ice eroded topography, significantly peneplaned, occasionally devoid of any soil cover, and hence of plant cover, or only partly covered by newly emerging, still struggling, often ill-at-ease, floral forms, a drainage system struggling to get established, and interrupted repeatedly by virtually hundreds of thousands of lakes of all imaginable sizes, fast developing into marshes, conjointly left individualistic imprints in these basins. This line-up was formidable and led, inspite



Text-figure 3—Palaeogeography of the Tethys region (after Ahmad, 1981). The epicontinental sea extended to the Arctic region.

of obvious kinship, to significant differences in the character and thickness of sediments, the entire gamut of environmental factors and hence of contained floral remains, resulting in serious problems in correlations. On the other hand, peneplanation resulted in lack of sediments the streams carried, and with the little they possessed caught in the lakes in the higher reaches, the peat deposited was fairly free of mineral matter and hence of ash in the coal formed in these basins.

This rather confidently advocated 'concept' was upset when K. P. Sinor (1923) discovered a marine horizon within the glacial deposits at Umaria, in central India. This led to a spate of speculations about the direction from which this incursion reached central India. Ahmad (1971) suggested that this inland sea extended south-eastward to connect with the Carnarvon Basin of Western Australia, which was then adjacent. The direction of this marine incursion is still being debated, seeking in the drainage channels that came into being subsequently, whereas these fossils occur in the tillite itself, i.e., they were deposited while the ice-cap existed as the sole source of drainage. Most of this drainage must have been flowing into the Tethys to the north, many emanating from glaciers continuing the ice cover. The recognized drainage certainly came into being subsequently. It may, moreover, be emphasized that peninsular India was then downwarped by the weight of the ice and this must have facilitated the sea incursion. Many of the freshly emerging drainage channels must have been discharging into this ephemeral sea; the drainage system indicated in the Gondwana sediments came in at a later stage and later reversed to form the present drainage.

This south-eastward basin took into account the Manendragarh Basin. Later, however, the Rajhara Bed (Daltonganj Coalfield) was discovered and it appears that a large area in central India was covered by a transgressive sea in the Talchir times. Rajhara's connection to the north is not likely, though not impossible, for the Ganga Valley was not ice covered and hence not downwarped.

The suggestion that these basins are of materially different ages, is most unlikely and such interpretations of faunal remains could lead only to complications. Thus, it has been suggested that the Umaria fauna, carrying linoproductids was older than that of Manendragarh and Rajhara, with eurydesmids (Shah & Sastry, 1975; Dickins & Shah, 1979). Sastry *et al.* (1975) opine categorically that eurydesmids must have lingered on in Umaria, yet it is equally possible that linoproductids had, in fact, appeared earlier in Manendragarh. A considerable difference in the age of Manendragarh and Umaria is inconceivable. And Rajhara, as older than Umaria, makes things more difficult unless it was connected to the Tethys, independently of Umaria, which as suggested above, was not ruled out.

EXTRA-PENINSULA

The Himalayan region was separated from the peninsular basins by an emergent Ganga Basin area whereas the Indus Basin area was submerged as a gulf of the Tethys. A major difference in the two basins is that the Himalayan area was part of the southern coastal region of the Tethys, that continued as an epi-continental sea far to the north. Thus, marine conditions dominated in the region, although it was only littoral and paralic in character. It is also not likely that the ice-cap actually extended to the Himalayan region except, locally and rarely, as long glacial tongues. Similarly, marine glacials, apparently from icebergs belonging to this horizon, reached into northern Tibet right up to the Kun Lun Range, and, as mentioned earlier, are locally associated with Glossopteris flora (Wang Changsheng, 1984; Wang Naiwen, 1984).

Theoretically, the Himalayan diamictites should, as pointed out above, be older than the peninsular India tillites irrespective of whether the pole moved away rapidly, as envisaged by Ahmad (1960) or slowly, as indicated by palaeomagnetic data (e.g., Daly & Pozzi, 1976) for the former area lay along the margin or a little beyond the ice cap in Late Carboniferous. This age is suggested by the occurrence of the Rhacopteris flora below the

Gondwana flora in the Agglomeratic Slates (Sharma, 1976) and the presence of *Fenestella* below the *Eurydesma-Deltopecten* zone in the diamictite horizon, i.e., glaciation had started earlier, truly in the Carboniferous. This is confirmed by the Chinese geologists who, on the basis of the fauna, place the fluvioglacial deposits of the Lhasa Block in northern Tibet in the Carboniferous. The age of the glacial deposits in the peninsular region, it is agreed, is Permian, and Thomas and Dickins (1954) correlate Umaria with the Callytharra Formation in the Carnarvon Basin of Western Australia, and place it in the Sakmarian. For icebergs to deposit 1200 m of diamictites in Tibet the ice-cap must have been in the area for a fairly long time.

Also of significance is the occurrence in the Vihi Bed of vertebrates, *Archegosaurus, Actinodon, Lysipterygium* and others of Lower Permian affinities of Europe. The Vihi Bed carries only *Gangamopteris.* An Artinskian age (Kapoor & Shah, 1979) for it would be unlikely and it cannot but be basal Permian.

The Subansiri fauna is considered to be Uralian by Singh (1975), but Waterhouse *et al.* (1975) lay stress on the presence of *Uraloceras*, and place it in the Sakmarian. *Stepanoviella,* too, is considered to be Sakmarian by Waterhouse (1970) but is known also from the Tibetan glacials, placed in the Upper Carboniferous. Higher up in the same succession in the Subansiri area freshwater beds contain *Glossopteris*, but no *Gangamopteris* is present. The same situation obtains in the Darjeeling area as well, and it may be safe to place the horizon in the Permo-Triassic. Thus, it is possible that a complete Permian succession is present in the area.

The position in the type area of the Blaini and Krol is rather confused, for unlike other areas, no megafossils have been reported from these, whereas the micro-faunal/floral evidence is rather contradictory. However, a rich fauna of bryozoa, bivalves and brachiopods has been reported from the Garhwal Nappe (Bijni & Amri tectonic units) and the age of these boulder slates is placed between Middle Carboniferous and Early Permian, the fauna being comparable with that of the Subansiri area and the Agglomeratic Slates of Kashmir (Acharyya *et al.*, 1979, p. 424; Acharyya & Shah, 1975). But the original source of these allochthonous units is not known, and hence little reliance could be placed on the evidence yielded, even though it seems to fit-in with the views, advanced here, that glaciation had appeared in the Carboniferous.

Other areas of the so-called Tethyan Zone are the Chamba Synclinorium, Malung (Ladakh), Spiti, Nepal and parts of Higher Himalaya. A glacial horizon at the base of the succession is present in several of these areas, and Acharyya *et al.* (1979, p. 427) place these in Late Palaeozoic. To sum up, the position, as it seems to have obtained, is that the Tethys was an epicontinental sea whose southern shore-line existed within the Himalayan belt, and extended in places to Lesser Himalaya, perhaps, at times farther south temporarily. The drainage from Ganga Valley flowed into it, on the one hand and into the westward flowing Damodar on the other, these streams could not have formed any mighty rivers for the width of the intervening land, except in the west, was small and the area peneplaned. Topographic highs in this sea provided land bridges during periods of regression, allowing land plants and vertebrates to migrate from one part to another of Pangaea (Ahmad, 1978). Crawford (1975) was certainly correct when he thought that Tibet and India belonged to the same block, the northern submergent, the southern emergent. In fact, there was yet another emergent area to the north, the Siberian block. Acharyya *et al.* (1975, p. 421), however, suggest that the evidence is "against wide and extensive Tethys between Gondwanaland and Cathaysia/Laurasia", yet they do not specify whether their Tethys was an ocean or a sea nor what they would have considered a " wide and extensive" Tethys. In fact, all evidence goes to suggest that this sea extended from the Himalayan area to the south of the Siberian platform. On the contrary, Kapoor's (1979, p. 443) comment as to how Cathaysian elements "intruded in the Kashmir Gondwana" obviously lacks perspective.

DISCUSSION

The above brief review brings out clearly that in the Permo-Carboniferous times there were two major basins in the Indian subcontinent the Himalayan and the Peninsular. The Himalayan region comprised a littoral, paralic zone of an epicontinental Tethys Sea and there seems to be no doubt that it extended from eastern Pangaea to Western Pangaea, the entire width of the supercontinent, with a peripheral gulf covering most of the Pakistani area with the Bhadaura area on its eastern margin.

The other major basin in peninsular India was formed of a number of interconnected chains of large and small basins of marshy character, separated by gneissic basement, discharging into an epicontinental sea extending initially from Daltonganj to Umaria and beyond to the south-east and later on to the present west coast, somewhere to the south of the Narmada. The Narmada itself played no part in it, for the rift, apparently did not exist, being Tertiary in age.

It has been pointed out earlier that the Permo-Carboniferous glacials extended to northern Tibet.

This would lead to some interesting conclusions: (1) the marine area in the Himalayan region could hardly have escaped this glaciation. Some doubts have, of late, been expressed on this count following the discovery of some Cambro-Ordovician conodonts from a bed till lately correlated with the Talchir beds of peninsular India (Azmi *et al.*, 1981). It would thus appear that in the Himalayan region diamictites are of two different ages, some, perhaps, being Late Precambrian, and thus belonging to the most severe glacial age the Earth has known, the Varangian Glaciation. In the Cambrian the South Pole was actually to the north-west of Africa, and the North Pole somewhere near the present position of Australia actually to the west of the then Tasmania. In the Late Precambrian the pole would, perhaps, have been farther away. Neither of the poles could leave behind glacial deposits in the Himalayan region. Hence there must have been a considerable dip in the temperature resulting in a severe ice age. On the other hand some of these Himalayan glacials, must belong to the Gondwana horizon and they need to be so identified specifically; (2) that, as pointed out above, Tibet was a northward continuation of the so-called Gondwanaland, and the so-called Indus-Tsangpo feature is not a suture, as often suggested, basically on palaeomagnetic evidence. The consensus amongst the Chinese geologists is very strongly in favour of this view, and Zheng Haixiang (1981) was only expressing this when he stated that it is "not entitled to be a suture zone"; and finally (3) it seems that the area from the region of the Lesser Himalaya to Tibet and beyond downwarped more or less quietly except perhaps occasionally becoming geosynclinal in narrow belts, from the Cambrian and may be earlier, and accumulated in parts some 60 to 70 km of sediments. This has misled many a geophysicist to speculate that this was an area of double thickness, with the Indian continental crust having thrust underneath the Tibetan block. This is, otherwise too, inacceptable on several counts. Indeed, it does not seem to be realized that an 8-20 km thick ophiolite wall stands in between the two blocks. It must have come into being, in plate tectonic speculations, at the time of the collision and suturing. To be able to underthrust the Tibetan block the Indian block would have to leap-frog over it and immediately to the north sink underneath the Tibetan plate. The impossibility of this needs no stressing.

One may, then, want to know the character of the Indus-Tsangpo feature. All available evidence goes to suggest that a rift opened in the area in the Triassic and attracted a lot of sediments. The rift continued to deepen and beginning in the Upper Jurassic magmatic emplacement took place, followed by a second phase in Lower Cretaceous. The sediments in the rift were thrown up and formed a melange. Thus, Gopel, Allegre and Xu (1984) agree that it was a propagating ridge, under slow spreading condition. Wang Xibin, Cao Yougong and Zheng Haixiang (1980) conclude that it was a tensional fissure, whereas Chang Chengfa (1980) opines that Late Permian-Triassic rifting which resulted in the Panjal Traps produced the Indus-Tsangpo rift.

On the other hand, accepting continental drift, all the continental areas for the Permian time, are assembled either in a single supercontinent, Pangaea, or into two continents, Gondwanaland and Laurasia, may be into four, with Angaraland and Cathaysia, in addition. A wide triangular bay, interpreted as the oceanic Tethys, appears in most Pangaea reconstructions along its east, tapering down to around the Black Sea. Ahmad (1981, 1982) studied the palaeogeography of the region and concluded that there was no oceanic gulf or bay in the area, and instead the area was covered by an epicontinental sea. Lin Baoyu and Qiu Hongrong (1984, p. 5) reiterate that "based on characteristics of the Palaeozoic biota and sediments, at the time, both flanks of the Yarlung-Zangbo Rivers belong (-ed) to the same ancient plate". Similarly, Owen (1976, p. 250) from his studies of the sea-floor spreading data, concluded that "the evidence for a former Tethyan ocean between Gondwanaland and Laurasia is non existent", and that there is "no need to infer the presence of Tethyan oceanic crust north of India". Crawford (1975) had earlier opined that "India and Tibet were, at least in the Phanerozoic, one huge crustal block, with the southern part emergent, and the northern submerged by the Tethys." Stocklin (1981) agrees with this when he stresses that "the Tethys was essentially not a wide ocean but an epicontinental sea".

Floral and faunal exchanges, down to the level of freshwater invertebrates and insects, were too frequent all through the Proterozoic to admit of an ocean or a gulf, even a narrow one. Fieldwork by Chinese geologists has established, as pointed out earlier, that the fluvio-glacial deposits of the Upper Palaeozoic had their source in south. Also, the Lower Permian vertebrate fauna of Kashmir was of European affinities whereas the Lower Triassic vertebrates of Sinkiang, Shansi and Thailand were related to those of India, Africa and Antarctica. These, it would not be possible to explain unless a wide, unobstructed, continental ligation is accepted latitudinally across the entire Asiatic continent. Carey (1958, 1976) has, on the other hand, pointed out that it is impossible to assemble the continents on the present diameter globe without a wide gaping gore on the eastern margin, and that this gulf disappears if the continents are assembled on a globe of a smaller diameter. Since the palaeontological evidence for continuation in landmass from India to China, right across Tibet is irrefutable, one has to accept that the Earth has, indeed, expanded.

As originally put forward, the Gondwana concept envisaged glacial deposits overlain by freshwater sediments. This was equally important in the peninsular region, as also in eastern Australia and South America. However, marine incursions have since been recorded from vast areas in peninsular India and South Africa leaving very few areas, except, perhaps, Antarctica, that stand up to the original concept. In addition, it is certain that even the so-called Gondwana glaciation was not of the same age everywhere, and, instead, ranged from Upper Carboniferous to Upper Permian. This means a range of more than a geological age—about 50 Ma—a long time by any reckoning. More important is the fact that continental deposits overlying glacial beds—true to Gondwana concept—occur in Siberia (Epshteyn, 1981) and Korea. These areas never belonged to Gondwanaland, and to apply the term to these, certainly outside the classical Gondwanaland, would be a travesty.

In the above brief review of the age of the Gondwana glacial deposits in different parts of the supercontinent an attempt has been made to bring out, without making it a homily, that while evaluating minute or even minor differences in ages of two or more basins palaeontology, by itself, is not infallible and a balanced approach is essential, with the palaeogeography of the area, for any specific age, clearly understood. It is, thus, not sufficient to say that since Umaria contains linoproductids it must be older than Manendragarh with eurydesmids. Such an obviously unlikely suggestion should be provided with an explanation for it needed either an independent connection for Umaria or why an equivalent bed is not present is Manendragarh. This, palaeogeographically, seems to be impossible.

It would be of interest to go into this question in a little detail. Thus, Fox had suggested a connection to the north and Krishnan had ruled it out on the ground that it was across the Vindhyan Range that he wrongly thought existed at the time. Instead, he suggested that the bay opened along the Narmada rift. A little consideration would convince that neither of these was likely. Even though the Vindhyan Range did not exist at the time, a narrow gulf across the then emergent Ganga Basin area, would be rather far-fetched although apparently not impossible. On the other hand, Narmada River and the rift along it apparently did not exist either, being Late Tertiary or even possibly Quaternary in age. Umaria fauna is akin to that of Western Australia and the Subansiri area, and a connection with the south-east, as discussed earlier, was accordingly, more likely.

Similarly, it has been pointed out that palaeomagnetic data, too, are incapable of providing the evidence for minor subdivisions. Thus, all the studies to-date place the Permian South Pole to the south-east of South Africa in about 45°S latitude, whereas the Arabian glacial deposits (Helal, 1965; McClure, 1980) are from around 15°-20°N latitude, i.e., the ice-cap, if this pole position is accepted, must have extended for about 55° of latitude from the pole. If such an ice-cap existed today at the South Pole, it would extend to almost the Tropic of Capricorn across Australia, South Africa and South America. Without a major dip in the temperature, the possibility cannot be envisaged, and in the Permian there certainly was no such frigidity. Significantly, the Pleistocene ice-cap, at its maximum, did not extend that far. Hence an exceptionally large ice-cap could not have existed at any time during the period. The Arabian and Tibetan glacial deposits, thus, cannot be justified with this palaeomagnetically determined South Pole position, nor is the amount of polar migration suggested by this method of any help. One is, accordingly, obliged to accept the fast polar migration suggested by Ahmad (Text-fig. 2) on palaeogeographic grounds, with the Upper Permian pole coinciding with the palaeomagnetic pole assigned for the whole of Permian.

CONCLUSIONS

During the early Gondwana times two marine basins existed in the Indian subcontinent, the Himalayan, along with the Western Indian and the Peninsular. In fact, the reported discovery of Gondwana coal in parts of Sind, suggests that perhaps even parts of the western basin turned, at least locally, into a freshwater basin. However, of the Western Indian Basin little is known, for it lies concealed underneath the Indus Basin—except for the bore-hole discovery of the coal only a very small part along its eastern margin being exposed. The Himalayan Basin was evidently part of an epicontinental Tethys. Glacial sedimentation in the region started in the Carboniferous, with *Fenestella* and *Rhacopteris*, identifying the marine and continental areas respectively.

Peninsular India was largely, perhaps entirely, covered by ice, and hence, sedimentation could only begin in Sakmarian times when the ice-cap had receded towards Africa. Marine incursion existed side by side with the ice-cap, and extending from the south-east and reaching up to Umaria and, perhaps, Rajhara and elsewhere. Palaeontological evidence suggesting that Umaria is older than Manendragarh is, therefore, invalid.

Evidence is incontrovertible that Gondwana glacial sediments reached into northern Tibet. Also, the fauna known from the area from Ordovician through Permian is of Gondwana affinities, and so are the Triassic vertebrates of Shansi, Sinkiang, Korea and Thailand. The Lower Permian vertebrates of Kashmir are of European affinities. These rule out a Tethyan ocean from the region, and the suture zone concept becomes altogether inacceptable. Supporting evidence for this view is incontrovertible. Indeed, Pangaea was then the only landmass on the surface of the globe and the existing continents were parts of it. Floral and faunal migrations, to the extent these happened, would have been impossible even with a narrow ocean intervening. The above analysis has amply demonstrated that whereas for broad generalizations palaeontological and palaeomagnetic studies are valid and acceptable, both these lines of evidence are inadequate when applied to small basins or time scales. Their evidence should, therefore, be tested against palaeogeography.

As originally conceived, the Gondwana concept could hardly be applied anywhere, except very locally, and it would not be legitimate to apply it to parts of successions nor to extra-Gondwanaland areas. It has, nevertheless, served and continues to serve a purpose, for it has been responsible for numerous developments in geology.

If it is accepted that there was no oceanic gulf or bay in the eastern Asian region and if Carey's contention that this gulf can be eliminated only if the continents are assembled on a globe of smaller diameter and not on one of the present size, it seems to follow that the Earth has expanded, to about twice its size since the Permian.

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Lower Gondwana marine incursions : periods and pathways

B. S. Venkatachala & R. S. Tiwari

Venkatachala, B. S. & Tiwari, R. S. (1988). Lower Gondwana marine incursions : periods and pathways. *Palaeobotanist* **36** : 24-29.

Marine nature of sediments in the Talchir Formation and its equivalent horizons is well-established by the occurrence of invertebrate faunas in Umaria, Manendragarh, Daltonganj, Rajhara, Ranjit Pebble Slate, Subansiri and Bap Boulder Bed. Most of these sediments also contain acritarchs, leiosphaerids and other palynofossils of marine origin in association with spores and pollen. The terrestrial palynofossil assemblage attributes an Early Permian age to these sequences. Leiosphaerids in the Karharbari and Barakar formations are, so far, known only in the Son Graben, indicating continuation of marginal marine environments. The discovery of phosphorite in the Barren Measures of Kelo-River, Son Graben and of palynofossils in these sediments confirm marine influence also in the Late Permian. Thus, the so-far accepted model of a predominantly continental facies for the Lower Gondwana stands challenged. It appears that during the Early Permian, almost all the low-lying embryonic basinal depressions experienced marine transgression from an eastern bay. To the west and north-west the network of marine pathways was connected with Arabian Sea and the Salt Range Sea. The evidences for continuation of marine transgression in the Middle and Late Permian of central India further demand a search for such signatures which could establish the remnant pathways to the heart of the peninsula. The marine leiosphaerid group of palynofossils can be purposefully utilized for palaeoenvironmental reconstructions.

Key-words—Lower Gondwana, Marine incursions, Acritarchs, Leiosphaerids, Continental facies (India).

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साराँश

अधरि गोंडवाना समुद्री अतिक्रमण : विभिन्न काल एवं मार्ग

बेंगलूर श्रीनिवासा वेंकटाचाला एवं राम शंकर तिवारी

उमरिया, मनेन्द्रगढ़, डाल्टनगंज, रझारा, रंजीत बालुकाश्म स्लेट, सुबनसिरी एवं बाप गोलाश्म संस्तर में अरीढ़धारी जीवजातों की उपस्थिति से तालचिर शैल-समूह एवं इसके समतुल्य संस्तरों में अवसादों की समुद्री प्रकृति व्यक्त होती है। इनमें से अधिकतर अवसादों में ऍक्रीटार्क, लिओस्फ़ेयरिड तथा बीजाणुओं एवं परागकणों के साहचर्य में समुद्री उद्भव वाले अश्मित परागाणु भी विद्यमान हैं। स्थलीय परागाणु समुच्चय से इन अवसादों की प्रारम्भिक परमी आयु प्रस्तावित होती है। करहरबारी एवं बराकार शैल-समूहों में लिओस्फ़ेयरिड अभी तक केवल सोन द्रोणिका से ही ज्ञात हैं जिससे तटीय समुद्री परिस्थितियां इंगित होती हैं। केलो नदी के बैरन मेज़र्स, सोन द्रोणिका एवं इन अवसादों में अश्मित परागाणुओं के अन्वेषण से अनंतिम परमी कल्प में समुद्री प्रभाव की पुष्टी होती है। अतएव अधरि गोंडवाना हेतु पूर्व प्रभावी फ़ेसीज का अभी तक मान्य मॉडल अब एक प्रश्न बन गया है। ऐसा प्रतीत होता है कि प्रारंभिक परमी कल्प में प्रायः सभी कम गहरे प्राथमिक द्रोणीय दबावों ने पूर्वी खाड़ी से उत्पन्न समुद्री अतिक्रमण का अनुभव किया है। पश्चिम एवं उत्तर-पश्चिम में समुद्री मार्ग अरब सागर एवं साल्ट रेंज से जुड़ा हुआ था। मध्य भारत के मध्य एवं अनंतिम परमी कल्प में समुद्री धँसाव की निरन्तरता के कारण इन पर और अनुसन्धान की आवश्यकता है जिससे प्रायद्वीप के केन्द्र में अवशिष्ट मार्ग स्थापित किया जा सके। पुरावातावरणीय व्याख्याओं में परागाणविकरूपकों के समुद्री लिओस्फ़ेयरिड समूह का महत्वपूर्ण उपयोग किया जा सकता है।

Concepts, limits and extension of the Indian Gondwana
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THE first data input for the recognition of marine signature in the otherwise non-marine package of Gondwana Sequence, was through the discovery of Umaria Marine Bed by Sinor as far back as 1923. He based this find on the occurrence of *Eurydesma* and *Productus*. The *Eurydesma-Productus-Conularia* assemblage has been subsequently found from Manendragarh (Ghosh, 1954), Subansiri (Sahni & Dutta, 1959), Badhaura in western Rajasthan (Mishra *et al*., 1961; Shah, 1963) and Daltonganj (Dutt, 1965) associated with the Talchir Formation which initiated the Gondwana deposition in the peninsular as well as in extra-peninsular regions. Palynological, sedimentological and geochemical data have accrued to supplement records of marine sedimentation during the Permian, necessitating a rethinking on the Gondwana depositional environment. These records, earlier considered with scepticism, as they were few in number, have been authenticated by additional information.

In the configuration of eastern Gondwanaland, India finds its placement between eastern margin of Africa in the west and Antarctica in the east; Australia being offset towards north-eastern direction with reference to India (Smith *et al*., 1981). The time-span involved in the deposition of Gondwana Sequence in India is conventionally considered as earliest Permian to Early Cretaceous. The latter limit as well as the nomenclature of spatially extended occurrence of these deposits is debatable.

Hercynian orogeny initiated the formation of Gondwana basins in the early Early Permian along the ancient weaker zones, which are presently aligned with the major river courses (Datta & Mitra, 1982). The embryonic basins were narrow as well as shallow in the earliest Permian giving rise to tectonically active grabens (or half grabens) which accumulated large sedimentary piles, including coals, during most of the Permian Period.

MARINE SIGNATURES

The invertebrate fossil fauna characterised by *Eurydesma-Productus-Conularia* assemblage is an unequivocal evidence for interpreting marine environment in the Permian. Palynoassemblages containing alete palynofossils—variously lebelled as leiosphaerids, leiofusids, smooth-walled acritarchs, apiculate-spinate globular bodies, etc.—and land plant spores and pollen are associated with this fauna in several horizons. The leiosphaerid group of palynofossils has thus emerged as an indicator of marine environment. Their close association with the rocks containing marine fauna and phosphoritic nodules provides a high degree of confidence in their utility for environmental determination even for those strata which are devoid of other evidences. The associated spore-pollen assemblages, mostly allochthonous, render age connotation to the whole assemblage because the Talchir, Karharbari, Barakar, Kulti and Raniganj formations have their own distinct index spore-pollen floras.

Recent discovery of phosphoritic beds, along with some evidence of bioturbidites in the Barren Measures of Son Valley is important in extending the marine influence in the Lower Gondwana (Datta, 1986).

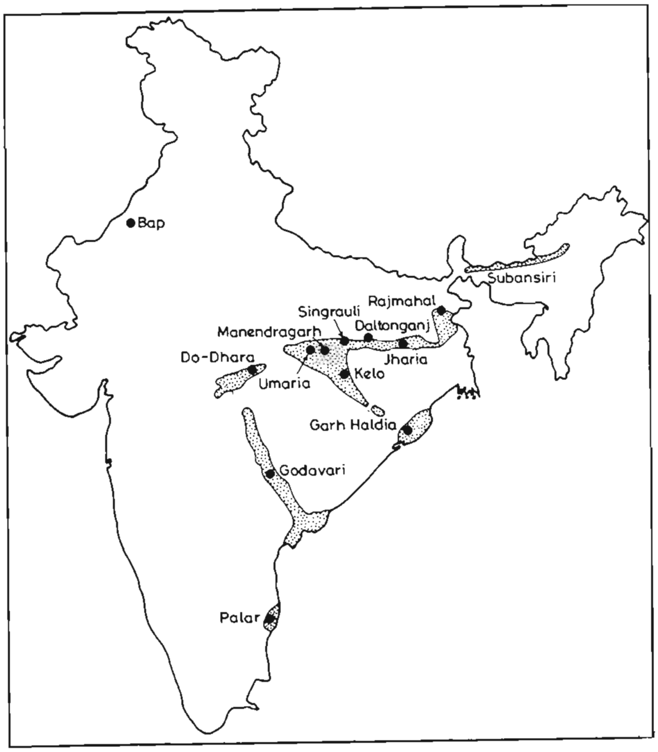
The finding of algal limestones in the Motur Formation of Satpura Basin and concentration of boron and sulphur in Damodar Graben (Datta, 1986) are important geochemical evidences suggestive of marine regimes.

These biological and geochemical marine indicators have to be considered for deciphering marine incursion in the 'Lower Gondwana' sediments.

Talchir Formation— This formation, the lowermost lithostratigraphic unit of Gondwana in India, is well known for its fluvio-glacial nature of deposition with tillite, varves, needle shales and other glacial sedimentary features. Intensive palynological studies during the last three decades in the Gondwana grabens of peninsular India establish the palynofloral suite that distinguishes the Talchir Formation (Tiwari, 1975; Tiwari & Tripathi, 1988, in this Volume). The index fossils of this assemblage are—*Plicatipollenites, Parasaccites, Virkkipollenites, Callumispora* and *Quadrisporites*. These are associated with few striate-disaccate pollen. This flora exemplifies expansion in radial monosaccate pollen.

A careful evaluation of spore-pollen data considered in conjunction with faunal data permits an earliest Permian age assignment to the Talchir Formation. This conclusion is further supported by the absence of typical Carboniferous taxa, such as *Raistrickia, Microreticulatisporites, Cirratriradites, Crassispora, Vestispora, Alatisporites*, etc. and the dominance of radial monosaccate pollen and the significant incidence of *Callumispora*. The subsequent Karharbari palynoflora is, infact, a continuation of the older Talchir palynoflora which fact also substantiates the Permian age assignment (Tiwari & Tripathi, 1988, in this Volume). It is not pertinent to correlate the glacial events occurring in various Gondwana continents as they are not coeval.

Sequel to the record of marine fossils from Umaria and Manendragarh (see Lele & Chandra, 1969, 1972, 1973) several new occurrences have been reported. Leiosphaerid assemblage was not considered as an infallible evidence of marine environment, till Venkatachala and Rawat (1973)



Text-figure 1—Records of leiosphaerids and other acritarchs in the Early Permian.

stated that "the dominance of Leiosphaerids and other acritarchs suggests a marine influence" in the Talchir sediments of Chingleput area, Palar Basin, from where they recorded (along with a *Plicatipollenites*-assemblage) the genera *Leiosphaeridia, Leiofusa* and *Dactylofusa.* They further confirmed the marine connotation of this acritarch assemblage by finding them in the *Eurydesma*-bearing Bap Boulder Bed in Rajasthan (Venkatachala & Rawat, 1984).

Leiosphaerids recorded from the Dodhara area of Satpura Basin (Bharadwaj, Tiwari & Anand-Prakash, 1978) allow an extension of the marine arm from Umaria and Manendragarh into the central part of the Indian Peninsula. Similarly, the presence of leiosphaerids and other such fossils and unidentified vesicles in the Talchir sediments of Jharia Coalfield (Tiwari *et al.*, 1981) and leiosphaerids in the Talchir of Dudhi River Section of Bokaro Coalfield (unpublished data) are records of marine transgression in the Damodar Graben.

Venkatachala and Rawat (1984) recorded an Early Permian palynological assemblage from Bap Formation of Rajasthan which also contains *Leiosphaeridia* in association with a rich marine invertebrate fauna of Permian age (Rao *et al.*, 1977). Rawat and Jain (1985) studied the palynoflora of Talchir sediments from Pranhita-Godavari Graben and identified a monosaccate dominant assemblage along with *Leiosphaeridia.* On this basis, a cold, brackish water or shallow-marine condition was deduced for the Early Permian deposits of this area (Raiverman *et al.*, 1985).

Recently, Tiwari *et al.* (1987) have recorded a Talchir palynoflora in the khaki-green shales which are unconformably overlain by the Athgarh Sandstone, in the south-west Athgarh Basin. This palynoflora, besides *Plicatipollenites,* contains *Leiosphaeridia* and unornamented acritarch-like fossils. Urn-shaped structures, apparently comparable to Chitinozoa, are also recorded. The stratigraphic setting and palynoflora in this sequence are comparable to that of Palar Basin. A monosaccate pollen rich palynoflora containing leiosphaerids has also been discovered from the Talchir sediments in Chuperbhita Coalfield, Rajmahal Basin (Banerjee & D'Rozario, 1987).

These records of marine incursions in Talchir of Palar Basin, Pranhita-Godavari, Satpura, Son-Mahanadi and Damodar grabens, Mahanadi (Athgarh) and Rajasthan basins (Bap Boulder Bed) support the conclusion that an epicontinental, shallow transgressive sea was present all along the tracks of graben-lineaments. The palaeotopographic low in which the Talchir Formation was deposited apparently made way for marine incursions.

In the extra-peninsular region, there are well-established evidences of marine regimes in the Early Permian of Salt Range, Kashmir, and the North-East. Palynological studies have further provided evidences of marine incursions in the Permian sediments of Upper Assam and Arunachal Pradesh (Srivastava & Dutta, 1977; Singh, 1979). Recently, Sharma *et al.* (1986) have reported an Early Permian *Plicatipollenites-Parasaccites* rich pollen assemblage with *Leiosphaeridia* in the subsurface of the Bara Pathar area, Upper Assam. This is yet another record of Early Permian marine sequence in the Assam Basin. Reworked Permian palynofossils in the Tertiary sediments have been extensively recorded.

Karharbari Formation—This formation exhibits comparatively more diversified palynoflora than the Talchir Formation. A varied radial monosaccate and striate-disaccate pollen assemblage distinguishes the Karharbari palynoflora. Marine leiosphaerids are recorded from the Umaria Coalfield in the Son Graben.

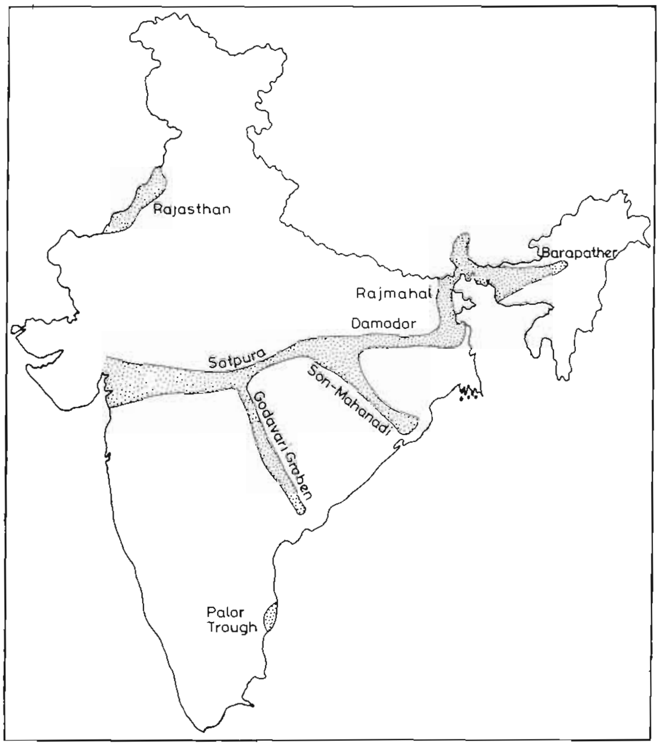
Barakar Formation—Exhaustive Barakar palynofloras are known from all the grabens which are dominated by non-striate disaccate and striate-disaccate pollen and zonate spores. Leiosphaerids indicative of a marine influence are known from Umaria Coalfield (Srivastava & Anand-Prakash, 1984). A diversified acritarch assemblage containing

Leiosphaeridia, Peltacystia, Hindisporis, Circulisporites and *Brazilea* is known from Johilla Coalfield (Anand-Prakash & Srivastava, 1984). The Purewa seam in the Singrauli Coalfield contains a number of smooth-walled as well as ornamented alete palynofossils, such as, *Balmeela, Kagulubeites, Brazilea* and *Peltacystia*, whose affinities are uncertain. They exhibit similar morphologies comparable to the marine acritarch fossils listed earlier (Tiwari, 1969). *Gondisphaeridium* and *Globulaesphaeridium*, recorded from the Barakar sediments of Godavari Basin, also show similar affinities (Tiwari & Moiz, 1971). *Hemisphaerium* recorded from Pench-Kanhan and Pathakhera coalfields of Satpura Basin may also belong to this group (Anand-Prakash, 1972). These fossils show advanced morphologies as compared to *Leiosphaeridium*. A detailed comparative morphological study is needed. However, a marine influence in all these grabens in the Barakar is significant.

Kulti Formation (Barren Measures)—This formation contains a well-diversified striate-disaccate rich palynoflora. *Densipollenites*, an important marker fossil, appears at this stratigraphic level.

Recent discovery of phosphoritic deposits in the Barren Measure sequence on the Kelo River Section of Ib-River Coalfield, Madhya Pradesh by the Coal Division of the Geological Survey of India is significant and indicates a marine influence in this area (Datta, 1986). Maceration of these phosphorite-bearing sediments has yielded a fairly well-preserved Late Permian spore-pollen assemblage in association with *Leiosphaeridia*, confirming the marine influence. The Barren Measures in the type area, i.e., Raniganj Coalfield, has also been reported to contain phosphorite. Palynofossils described as alete spores (Kar, 1968; Tiwari *et al.*, 1981) from the Jharia Coalfield are probably leiosphaerids. A detailed study is underway. Algal limestones are also recorded in the Motur Formation (= Kulti Formation) in the Satpura Basin.

Raniganj Formation—This Upper Permian sequence exemplifies maximum diversification of striate-disaccate pollen. The Raniganj palynoflora is an extension of the Barren Measure flora. An acritarch assemblage composed of *Leiosphaeridia* and allied forms, such as—*Greinervillites, Hemisphaerium, Circulisporites, Singraulipollenites* has been recorded from the Jhingurdah seam in Singrauli Coalfield (Sinha, 1969). This Seam earlier considered as Barakar is now correlated with Raniganj Formation (Tiwari & Srivastava, 1984).



Text-figure 2—Marine incursion and pathways in the Early Permian.

PATHWAYS

The Talchir Formation experienced marine incursions of a much greater spatial extent than earlier considered. Several propositions have been put forward to indicate the paths of marine incursions in the Indian Peninsula during the time of deposition of Talchir Formation. Fox (1931) proposed a pathway from Salt Range reaching up to Umaria, while Krishnan (1968) proposed a westward connection through Narmada Valley. Ahmad (1961) envisaged a connecting channel of central India with the eastern sea-bay. Sastry and Shah (1964) concluded that the Umaria fauna dominated by productids belonged to a warm-water realm, and postulated a linkage with Badhaura and Salt Range areas. *Per contra* the Manendragarh and Sikkim (Khemgaon) faunas with *Eurydesma* are considered cold-water faunas. They proposed two arms of the Tethys reaching up to the heart of the Peninsula. Jhingran (1967) postulated that there could have been a very wide gulf from the north (i.e., Tethys shore) which encompassed all the areas from where marine fauna has been found. Ahmad (1970) visualized an incursion of sea from south-east through Mahanadi Valley during Early Permian. On the basis of palaeocurrent data, he suggested that an outlet must have existed for the Barakar drainage in the area south of the Narmada Valley, now covered by basalt.

Several new evidences have come to light during the last two decades, which suggest a new line of thinking in reconstructing marine pathways. Palynological evidences establish marine Permian occurrences in Palar Basin, Godavari, Son-Mahanadi, Satpura and Damodar grabens in the east and Rajasthan in the west and in north-eastern basins, in addition to the earlier known records in the Salt Range, Pakistan. It is now possible to postulate a net-work of pathways in the Early Permian connecting major depressions which were formed along the weaker zones of lineaments. The gateway of these incursions could have been from the eastern sea-bay for the peninsular area. The general trend of direction of palaeodrainage was south-east north-west, from east coast up to central India and then towards north-east connecting with the Tethys (Casshyap & Tewari, 1984). The preposition of a connection of this net-work with western sea-bay through Narmada lineament still requires support. However, such a situation has been already proposed by Ahmad (1970) who opined that an outlet must have existed for the Barakar drainage in the area south of Narmada Valley, now covered by basalts. It is pertinent at this juncture to emphasize marine influence in the Talchir of Shahpur and Dodhara area in central Satpura Graben on the basis of palynological studies. This evidence enhances the chances of westerly continuation of the pathway postulated here.

Marine occurrences in the Karharbari, Barakar, Barren Measures and Raniganj sequences, as discussed earlier in this paper, need attention. As evidences are still forthcoming, it is premature to put forth any conclusive postulation. However, it is possible that the pathways suggested for the Talchir marine incursion continued into the younger Permian. Marine signatures in the Son Graben are evident in all the Permian formations of this area. This feature in the central part of peninsular India needs consideration and careful study.

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Marine influence in Hutar Coalfield, Bihar

S. Chaudhuri

Chaudhuri, S. (1988). Marine influence in Hutar Coalfield, Bihar. *Palaeobotanist* **36** : 30-36.

Circumstantial evidences based on the proximity of upper part of Talchir and lower part of Karharbari formations in Hutar Coalfield with those of Daltonganj Coalfield having reported evidence of marine bed as well as evidences of wave activity and salinity raise the possibility of some marine influence in Hutar too. A few evaporites in this coalfield indicate dessication though temperature does not seem to have attained a high level. The presence of foraminiferal genera *Tolypammina, Saccammina, Bigenerina* and *Ammobaculites* in addition to *Frondicularia* cf. *cavernula* (Paalzow) in this background strongly argues for a marine influence in the basal part of Karharbari and adjacent Talchir areas. Significance of this has been discussed.

Key-words—Foraminifera, Marine conditions, Talchir Formation, Karharbari Formation, Hutar Coalfield.

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साराँश

बिहार में हुतार कोयला-क्षेत्र में समुद्री प्रभाव

एँस० चौधरी

डॉल्टनगंज कोयला-क्षेत्र की भाँति हुतार कोयला-क्षेत्र में तालचिर के ऊपरी भाग एवं करहरबारी शैल-समूह के निचले भाग की पारस्परिक निकटता पर आधारित प्रमाणों से हुतार में भी कुछ समुद्री प्रभाव की सम्भाव्यता बढ़ गई है। इस कोयला-क्षेत्र में कुछ वाष्पनजों से निर्जलीकरण व्यक्त होता है हालाँकि तापमान अधिक नहीं पहुँच पाया था। **फ्रोन्डिकुलेरिया** सजातीय **केवरनुला** (पालज़ॉ) के साथ-साथ इस क्षेत्र में **टोलीपेम्मीना, सेक्कामीना, बाइजेनेरीना** एवं **ऐंम्मोबेकुलाइटिस** की उपस्थिति से करहरबारी एवं निकटस्थ तालचिर क्षेत्रों के निचले भाग में समुद्री प्रभाव की संभावना और प्रबल हो जाती है। इसी प्रभाव का महत्व सभी दृष्टिकोणों से विवेचित किया गया है।

HUTAR Coalfield in Bihar shows development of Lower and Upper Gondwana sediments (Rizvi, 1972). Lower Gondwana, according to Rizvi (1972), consists of Talchir and Barakar sediments. Ghosh and Basu (1967) and Sastry *et al.* (1977) designate a part of the Barakar sediments of Rizvi, as exposed in Deori Nala, as Karharbari; this nomenclature has been adopted in the present discussion. The environments of the sediments of Talchir and Karharbari formations are normally considered as nonmarine. This contention seems to owe its basis on the presence of coal, some botanical evidences and absence of marine fauna. It is widely known that coal may develop in a variety of environments including marine. The botanical data can provide important clues regarding environment of their site of origin but *in situ* records are insufficient. The availability of any fauna depends in addition to its environment, on preservation and intensity and resolution of search. The presence of marine bed (?s) (in Sastry *et al.*, 1977) in Talchir Formation at Rajhara, Daltonganj Coalfield, about thirty kilometres due north of Hutar (Text-fig. 1a), raises a possibility of marine influence in Hutar Coalfield though fossil evidences are lacking. This issue is examined in the sections exposed in the Deori Nala and some of its

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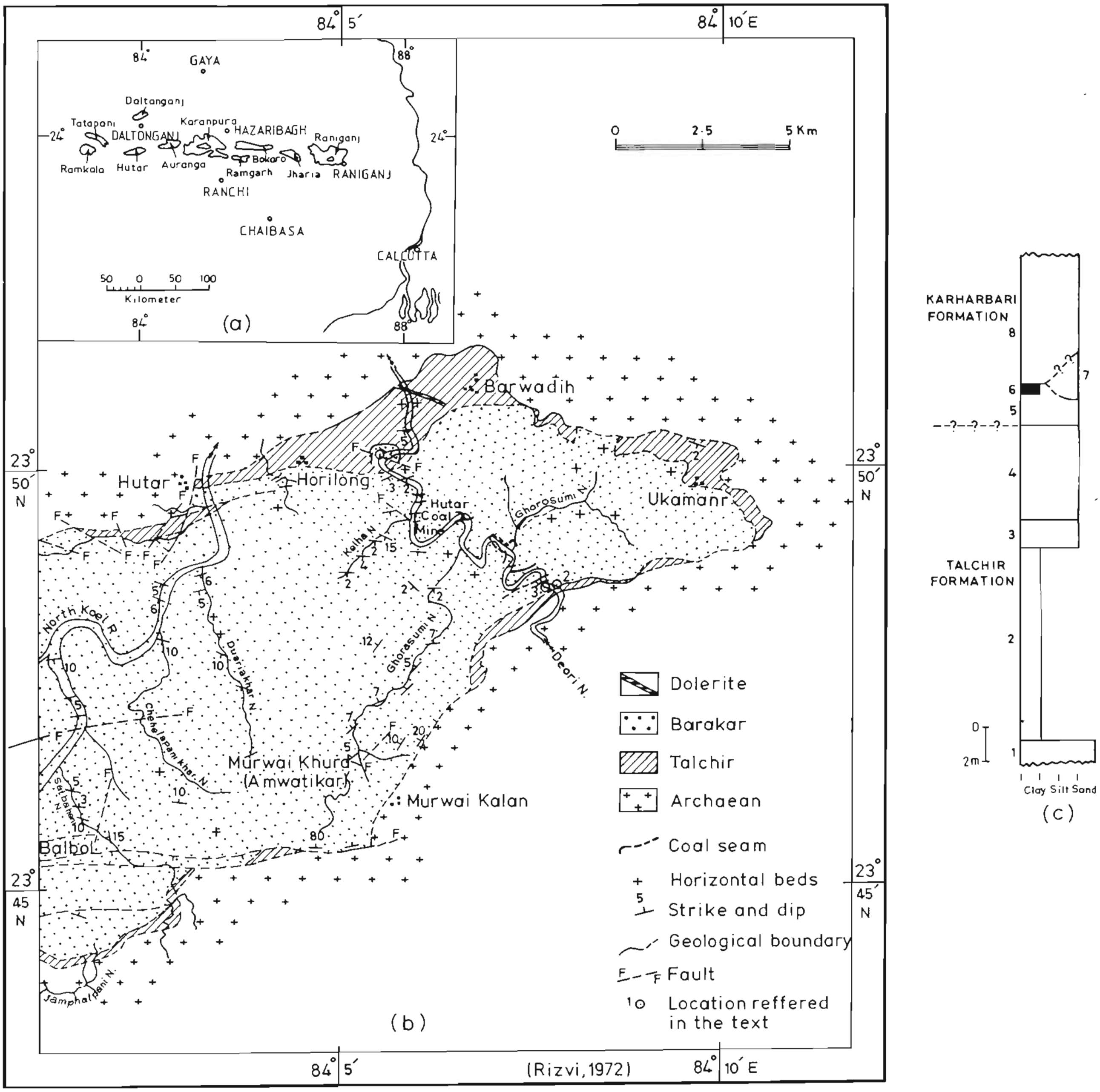

Fig.1.

Text-figure 1—a, Map showing location of Hutar and Daltonganj coalfields; **b,** the geological map of the eastern part of Hutar Coalfield, (from Rizvi, 1972). The Barakar rocks in and around Deori Nala are mentioned as of Karharbari Formation in the text except at location 1 which is considered as of Talchir Formation because of the presence of green shale; and **c,** a vertical column of rocks drawn on the basis of exposures at locations 2 and 3 of Text-fig. 1b and a little upstream. The boundary between Talchir and Karharbari formations is tentatively drawn following Rizvi (1972). The numbers by the side of the column refer to the various litho-units. The unit? which is a wave-rippled sandstone with the authigenic nodule in it occurs at location 3 of Text-fig. 1b. Samples for SEM studies were collected from this unit. Units 1 and 5 contain clastic grains of up to boulder size. Unit 6 is carbonaceous shale with alternations of sand. Unit 3 contains pebbles and unit 2 is greenish with varves.

tributaries in the eastern part of the coalfield (Text-fig. 1b).

In Hutar Coalfield, the Talchir Formation consists of boulder bed, sandstone, siltstone and shale while the Karharbari sediments comprise sandstone, locally with pebbles and coarser grains, siltstone, shale and coal. So far, five coal seams, with a few of local nature, have been recognised and all of them are more or less thin, none being more than two metres or so in thickness.

SEDIMENTARY FEATURES

Wave ripple including wave ripple bedding/lamination is one of the significant sedimentary structures in this area (Pl. 1, figs 1, 2). Recognition of this structure is based on cross sectional profile and internal structures following De Raaf *et al.* (1977). Significantly, Karharbari sediments (Barakar of Rizvi, 1972) of Daltonganj Coalfield also reveal similar structure (Pl. 1, fig. 3). So far, presence of wave ripple has not been reported from the Lower Gondwana sediments of India. Besides, planar and trough cross strata are observed in Hutar.

In the north-western end of Deori Nala (location 1, Text-fig. 1b) the top part of Talchir Formation contains, besides green shale, a very soft white medium to fine sandstone with small wave ripples. In places, the rock is cemented by sparry calcite and it contains some translucent brown microcrystalline textured ellipsoidal phosphate-bearing (confirmed by qualitative chemical analysis) peloid-like masses possibly of faecal origin together with water soluble salts bearing Na^{+}, K^{+}, Ca^{++} and Cl^{-} SO_4^{--} ions. A carbonate, sulphate and halite (halide) association is apparent in this case. Similar salts have also been noted in a red medium sandstone from the lower part of Karharbari Formation exposed in a tributary of Deori Nala near Hutar Colliery. Here occur a few pseudomorphs after gypsum crystals which had poikilitic as well as displacive growth affecting the primary sedimentary structures and hence reflecting an early diagenetic development of the gypsum crystals. Syndepositional origin is also evident from dissolution of some of the upper parts of the crystals of the pseudomorphs at places followed by deposition of the clastic grains.

THE FAUNAL RECORD

So far, no megascopic fossil diagnostic of sedimentary environment has been observed either in Talchir or in Karharbari sediments of the Hutar Coalfield. In view of this, an intense search for microfossils was carried out under SEM even though light microscopic studies did not reveal anything significant. As a first step, a white wave rippled Karharbari sandstone exposed a little above Talchir-Karharbari contact in the south-eastern end of Deori Nala (Text-fig. 1c, unit 7) was chosen. The sample collected from this exposed rock was disintegrated in 10 per cent acetic acid and then examined under SEM. In this sandstone occur some authigenic nodules consisting of a core of pyrite and an outer shell of magnetite (altered) and hematite. Such a nodule reflects a more or less reducing and alkaline or nearly so condition (Garrels & Christ, 1965; Krauskopf, 1979) on a local scale which must have been the result of biogeochemical activity in the sediments where organic debris were abundantly present. In fact, pyrite is known to develop by biogeochemical decay of such debris very early in the history of diagenesis. Magnetite has a similar history being contemporaneous with, to later than pyrite in origin. This is a mineral not commonly formed in (post-Precambrian) sedimentary environment (Ramdohr, 1980; Blatt *et al.*, 1980) though of organic origin (Trudinger *et al.*, 1979; Nealson, 1983).

One of these nodules as well as the grains separated from its host rock when examined under SEM yield some fossils, of which some foraminifera are important. These are identified following Loeblich and Tappan (1964) and/or Brasier (1980) and include the genera *Tolypammina, Bigenerina, Saccammina* and *Ammobaculites* (Pl. 1, figs 4,5,6; Pl. 2, fig. 1). Chaudhuri (1987) reported *Frondicularia* cf. *cavernula* (Paalzow) from the same nodule. The size of the tests is small and diameters are near the lower range, i.e., 10 μm as suggested by Shrock and Twenhofel (1953) and Baksi (1976) for foraminifers. The study of the microfossils has been qualitative. In fact, such SEM studies are extremely time consuming and often difficult because of tiny size, unsatisfactory preservation and problem of

PLATE 1 →

1. Symmetrical cross sectional profile of wave ripple. Location 2 of Text-fig. 1b, Karharbari Formation, Hutar Coalfield.
2. Wave ripple bedding in coarse to medium sand with some flasers. Note form discordance, bidirectional forests (both above the arrow at the lower central part) differently structured lenses some of which are swollen, lateral transition of cross lamination into low angle parallel laminations, irregular, curved lower set-boundaries, weakly developed bundled upbuilding (marked by arrow on the right). Some asymmetry of ripples and dominantly unidirectional forests are also observed. The 25 paise coin serves as scale. Location 3 of Text-fig. 1b and unit 7 of Text-fig. 1c, Karharbari Formation, Hutar Coalfield.
3. Wave ripple with bifurcating crest, Karharbari Formation, Daltonganj Coalfield.
4. *Tolypammina*, in-situ in the nodule. Note the large proloculus (marked by arrow) and irregularly wound second chamber.
5. *Bigenerina*, in-situ in the nodule. The test is biserial in the early part followed by uniserial growth, aperture terminal. It is of agglutinated type and the lower part is broken.
6. *Saccammina* in wave rippled sand. Agglutinated spherical test with an aperture.

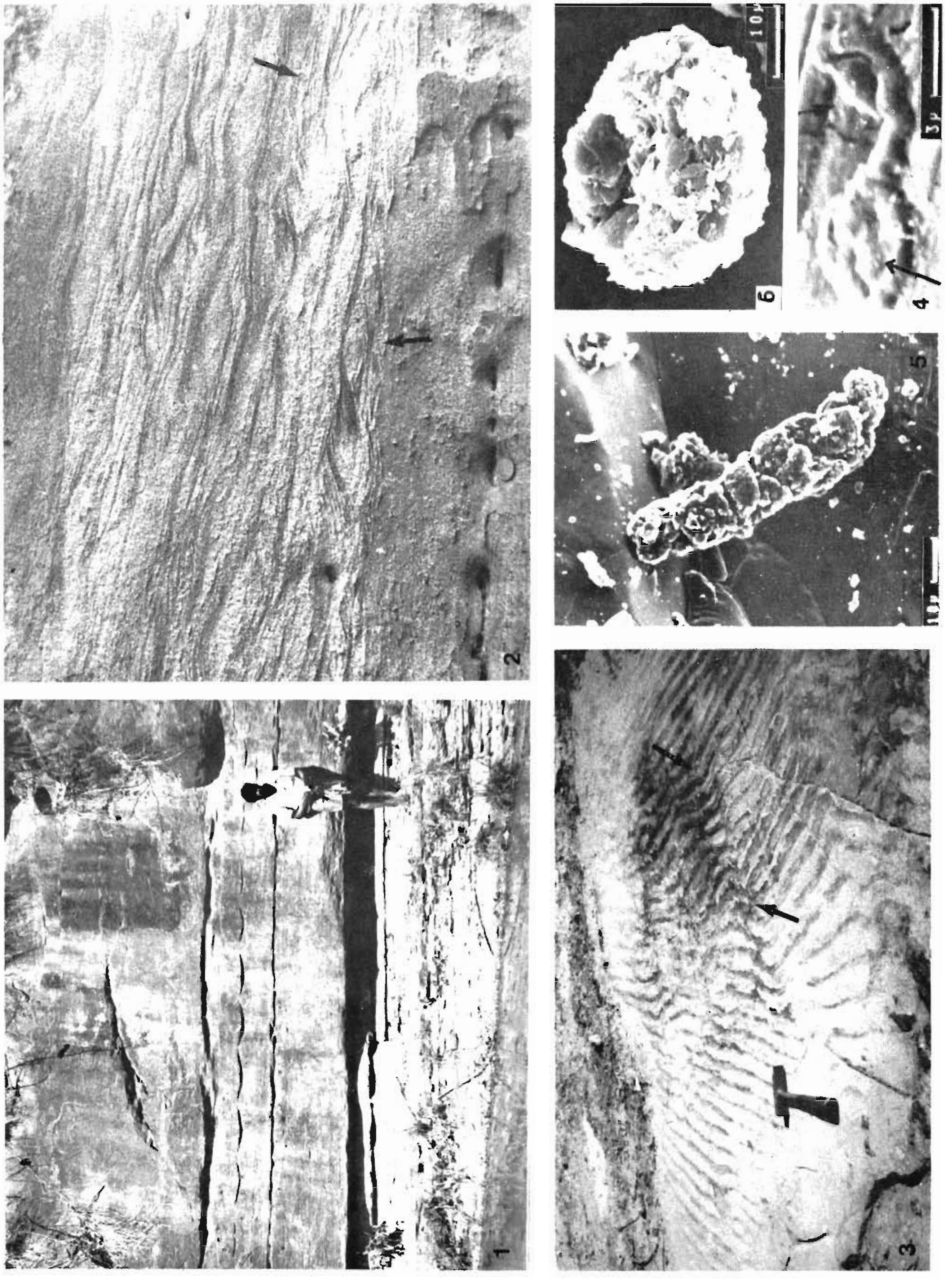

PLATE 1

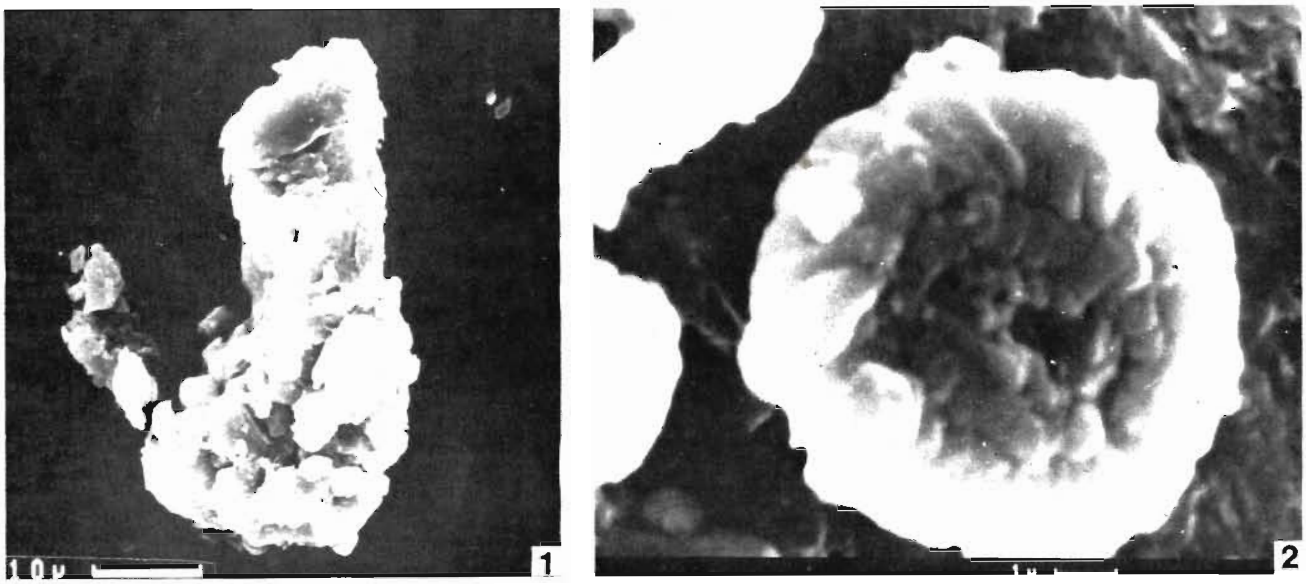

PLATE 2

1. *Ammobaculites*, in wave rippled sand. Agglutinated test with early planispiral coiling followed by uniserial growth, aperture terminal.
2. Coccolith in Talchir Formation of Ramgarh Coalfield.

recognition in *in situ* position where chance of encountering the fauna in a better state is more than if the rock is disintegrated.

THE SEDIMENTARY ENVIRONMENT

The water soluble salts, particularly the gypsum of pseudomorphs, in the beds are probably a result of evaporation during and a little after (diagenetic) sedimentation of clastic grains, e.g., during Talchir Karharbari times. Evaporites form where evaporation exceeds inflow and temperature is not of prime importance (Hardie *et al.*, 1977). Cold polar deserts too can witness development of such minerals. In Hutar, high temperature aridity is not expected during Talchir-Karharbari times due to the well-known glaciation but some dryness is indicated by the abundance of large clasts of mechanically weak and hence locally derived, pyrofusinite (fusain) in some sandstones and shales. Occasional dry zones in peninsular India during Lower Gondwana times were suggested by Datta *et al.* (1977), too. Thus, existence of dry, but not hot (could even be cold), condition facilitating process of desiccation necessary for the development of evaporites, is possible.

Wave action takes place in shallow marine (Johnson, 1981), lacustrine (Collinson, 1981) and even in fluvial environment where its effects and records are in general poor. In fact, wave action may take place in other areas under marine influence also, e.g., in a delta or an estuary. Considering the strong wave action as suggested by the coarse grain size and appreciable amplitude of the wave ripples, one would tend to favour a marine influence rather than that of a lake (Collinson, 1981). Moreover, phosphate and evaporite minerals besides carbonate in Hutar seem to lend support to the idea of marine influence (Johnson, 1981). The sedimentological evidences generally do not indicate the environment with confidence but in present case provided impetus for search of fauna in a terrain which is apparently uninviting. The faunal characteristics are encouraging. The foraminiferal genera, as found in Hutar, point to brackish to marine environment (Loeblich & Tappan 1964). The genus *Tolypammina* is known from the Manendragarh marine bed (Bhatia & Singh, 1959). Fossil records of fresh water foraminifera are rare (Brasier, 1980).

The usefulness of fossils, particularly of microfossils, as indicator of sedimentary environment depends to a great extent on whether they are autochthonous. Autochthony is often difficult to establish by direct evidence. In the present case the microfossils have known ranges (Brasier, 1980) that encompass the Talchir-Karharbari sediments. *F. cavernula* (Paalzow) has distribution in the Early Permian Zechstein (Z_1) rocks of parts of Europe (Pattison, 1981). Moreover, occurrence of the microfossils in the ferruginous sediments of nodules point to their emplacement very early in the history of the rock and in all possibility during deposition of the clastic grains. This is strengthened by the record of wave action and somewhat high palaeosalinity in the host and associated rocks. The possibility of the microfossils getting incorporated into the sediments by post-burial leaking and reworking is very remote. The transportation, which fossils might have undergone, was in all probability not considerable not beyond the domains of marine processes-marine to brackish water areas.

It is now clear that weight of evidences, as offered by the regional setting, palaeohydrodynamics as reflected by the sedimentary structures, palaeosalinity and the faunal content, strongly favours a marine influence in the coalfield.

CONCLUDING REMARKS

Extensive sedimentological studies coupled with improved knowledge on the faunas, mega-, micro- and nanno-, will help decipher various palaeogeomorphic units and associated environmental features in space and time on local as well as on regional scale. There are some indications of ?tidal effect in the form of water level fluctuation, and bidirectionality of flow. The possibility of some of the rocks being as of storm origin is not remote. A coccolith (Pl. 2, fig. 2), though of not precisely known significance, has been found in a wave rippled siltstone below Talchir-Barakar contact in the northern part of Bhera Nala in Ramgarh Coalfield, Bihar (Chaudhuri *et al.*, 1987).

On the basis of the present study the following points emerge:

1. The absence of fauna, marine or not, in many beds is likely to be more apparent than real.
2. The marine influence is not necessarily confined to the already recognised marine beds only.
3. Careful sedimentological studies may help to delineate areas of interest, though not necessarily diagnostically.
4. Cross stratifications of wave and current origin are very often difficult to distinguish between unless extreme care is taken.

The presence of wave ripple beds is not confined to Hutar and Daltonganj only. Preliminary investigations by the author and his associates reveal the presence of this structure in Ramgarh and Manendragarh-Chirimiri areas of Bihar and Madhya Pradesh, respectively. So, hydrodynamic interpretations together with directional aspects of the cross strata should be taken care of appropriately in order to avoid serious consequential implications.

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Karharbari : a formation or biozone

Manju Banerjee

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In the initial identification of the Karharbari sediment in Giridih Coalfield both litho- and bio-characters of the sediments were emphasized. Later, Karharbari has been considered as lithologically distinct unit, a definite palaeontological zone and both combined as a chronostratigraphic unit in between Talchir and Barakar. Karharbari is quite distinct in lithological composition, heavy mineral assemblage and coal seam characteristics. Stratigraphical delineation is not always distinct but from careful observation, Karharbari is identified as 'formation' in some of the basins or considered as basal member of Barakar Formation. Age of Karharbari has been suggested as Upper Sakmarian to Artinskian. The characteristic bioassemblage of Karharbari is more similar to Talchir bioassemblage in mega- and palyno-floral compositional pattern. *Botrychiopsis*, one of the characteristic members of Karharbari bioassemblage and also a dominant member of the Pre-Gondwana Botrychiopsis Flora (Middle Carboniferous-Lower Permian) of South America (Brazil, Argentina) and Australia is not recorded from any other Indian Lower Gondwana horizons so far. Karharbari environmental facies (both climatic and ecological) were initiated during Talchir sedimentation. Terminologies, e.g., Karharbari megafloral assemblage and Karharbari palynofloral assemblage are proposed in the Karharbari biozone. Macroenvironment zone for Talchir-Karharbari and microenvironment zone of Lower Karharbari are recognised considering environment of deposition. Talchir and Karharbari are considered as biostratigraphic zone. The continuation of the marine transgressional phase during Karharbari is suggested from the occurrence of brackish water acritarchs.

Key-words—Biozonation, Karharbari, Gondwana, (India).

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साराँश

करहरबारी : एक शैल-समूह अथवा जैवमंडल

मंजु बैनर्जी

गिरीडीह कोयला-क्षेत्र में करहरबारी अवसादों के प्रारम्भिक अभिनिर्धारण हेतु अवसादों के शैलिकीय एवं जैविक दोनों ही लक्षणों पर बल दिया गया। लेकिन बाद में करहरबारी को शैलिकीय दृष्टि से एक विभिन्न इकाई, एक सुनिश्चित पुरातात्विक मंडल तथा इन दोनों को मिलाकर तालचिर एवं बराकार के मध्य एक कालस्तरिक इकाई के रूप में माना गया। शैलिकीय संरचना, भारी खनिज समुच्चय तथा कोयला-सीम संलक्षणों के कारण बिल्कुल अलग है। इसका स्तरिकीय निरूपण सदैव भिन्न नहीं है परन्तु विशेष प्रेक्षणों के आधार पर कुछ द्रोणीयों में करहरबारी को एक 'शैल-समूह' की भांति अभिनिर्धारित किया गया है अथवा इसे बराकार शैल-समूह का आधारी सदस्य माना गया है। करहरबारी की आयु उपरि सकमारिअन से आर्टिन्सकिअन प्रस्तावित की गई है। गुरु-एवं परागाणविक-वनस्पतिजातीय स्वरूप में करहरबारी का लाक्षणिक जैवसमुच्चय तालचिर जैवसमुच्चय से बहुत मिलता है। **बोट्रीकिऑप्सिस**, जो करहरबारी जैवसमुच्चय के लाक्षणिक सदस्यों में से एक है तथा दक्षिण अमेरिका (ब्राजील, अर्जेन्टीना) एवं ऑस्ट्रेलिया के गोंडवाना-पूर्व बोट्रीकिऑप्सिस वनस्पतिजात (मध्य कार्बनीफ़ेरी-अधरि परमी) का भी एक प्रभावी सदस्य है, अभी तक किसी भी भारतीय अधरि गोंडवाना संस्तरों से अभिलिखित नहीं किया गया है।

करहरबारी वातावरणीय संलक्षणी (जलवायवीय एवं पारिस्थितिक) तालचिर अवसादन के समय शुरू हुई थीं। करहरबारी गुरुवनस्पतिजातीय समुच्चय एवं करहरबारी परागाणुवनस्पतिजातीय समुच्चय नामक शब्द करहरबारी जैवमंडल में प्रस्तावित किये गये हैं। अवसादन के वातावरण की दृष्टि से तालचिर-करहरबारी हेतु गुरुवातावरण मंडल तथा अधरि करहरबारी हेतु सूक्ष्म वातावरण मंडल बनाये गये हैं। तालचिर एवं करहरबारी को एक जैवस्तरिक मंडल के रूप में माना गया है। करहरबारी के समय समुद्री धंसाव की निरंतरता लवणी-जलीय एक्रीटार्कों की उपस्थिति के आधार पर प्रस्तावित की गई है।

Concepts, limits and extension of the Indian Gondwana
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KARHARBARI has remained a controversial unit in the stratigraphic classification of Indian Lower Gondwana since Blanford (1878) suggested separate identity of a typical lithosuccession including coal seams distinct from Talchir and Barakar in the Karharbari Village (lat. 24°14'—24°14' long. 88°16'—86°23') of Giridih Coalfield, Bihar (Map 1). Blanford's observation was strongly supported by Feistmantel (1876, 1879, 1882, 1886) through evidence of a distinct plant fossil assemblage recovered from the typical sediments of Karharbari Village in Giridih Coalfield and also from Hutar, Umaria, Mohpani and Shahpur coalfields. McClelland (1848) mentioned about the distinctness and similarity of the basal coal seams of the field with that of Deoghar, Kurao (Kundit Kuraia) and Itkhuri which lie nearly in the same latitude but did not identify the strata separately. Recognition of this sedimentary sequence as the formal stratigraphic unit 'formation' has been often questioned due to indistinct delineation for geological mapping of the strata in most of the basins although the lithocharacters are very much distinct from underlying Talchir and overlying Barakar sediments.

The bioassemblage recovered from the sediments, however, has significant characteristics and distinctness from other Lower Gondwana assemblages suggesting a definite biostratigraphic zone. Since the strata with this characteristic assemblage have not been deposited uniformly and also with sharp delineation in all the basins the identification of the sedimentary sequence in a higher lithostratigraphic rank has been considered variously.

LITHOCHARACTERS OF KARHARBARI

The lithocharacteristics to identify Karharbari as separate lithostratigraphic unit described by Ghosh and Basu (1969) are: (i) the dominance of reworked Talchir materials in the matrix, (ii) composition of sandstone which is greywacke to sub-greywacke, and (iii) distinctive heavy mineral assemblages.

Pareek (1969) also distinguished Karharbari for the lithocharacteristics of polymictic pebble bed usually containing Talchir pebbles which occur at the base of Karharbari. This rock unit is considered as a prominent unit for separating the strata from Talchir. The observations reveal that the sandstone of Karharbari is mature, soft and yellowish or light grey in colour and characterised by the presence of greenish yellow material similar to that of Talchir; the gritty and pebbly sandstones contain angular pieces and fragments of quartz, feldspar partly or wholly kaolinised. The lowest coal seams of Indian Lower Gondwana are associated with such sandstones. The coal seams are also very much characteristic in the non-laminated and dull nature of coal.

DEPOSITIONAL CHARACTERISTICS

Ghosh and Basu (1969) have strongly suggested that although gradational, careful observations in the field distinguish Karharbari as a mappable unit. The lower contact, i.e., with Talchir is marked by erosional unconformity but the upper contact is not so well-marked only excepting the more or less common occurrence of a pebbly conglomeratic zone at the base of Barakar. In the Son Valley, Karharbari has been deposited conformably over the Umaria marine bed. The stratigraphic position of the Umaria marine bed over Talchir has been suggested as both unconformable (Gee, 1928; Fox, 1931; Ghosh & Basu, 1969) and conformable (Ahmad, 1957). Karharbari sediments are suggested to have been deposited in the glacially denuded valleys encircled by high topographic relief; high gradient streams with high width and depth ratio carried down the course, clastic detritus from the high relief through the characteristically braided channels; unstable tectonic environment has been suggested to be responsible for the lesser thickness of Karharbari coalseams; the sediments were being accumulated in the embryonic basins during Karharbari after deglaciation at the end of Talchir sedimentation (Laskar, 1977).

DISTINCTION OF KARHARBARI FROM BARAKAR

Karharbari Sandstone is greywacke to sub-greywayke and composed of angular to sub-angular fragments. Barakar Sandstone is arkosic, dominated by gritty to pebbly and coarse-grained varieties with rounded to subrounded nature of the fragments.

In heavy mineral composition, Zircon and Rutile are dominant in Karharbari Sandstone and occur as common to rare component of Barakar Sandstone. Whereas Tourmaline is dominant in the Barakar Sandstone but occur in negligible ratio in Karharbari Sandstone.

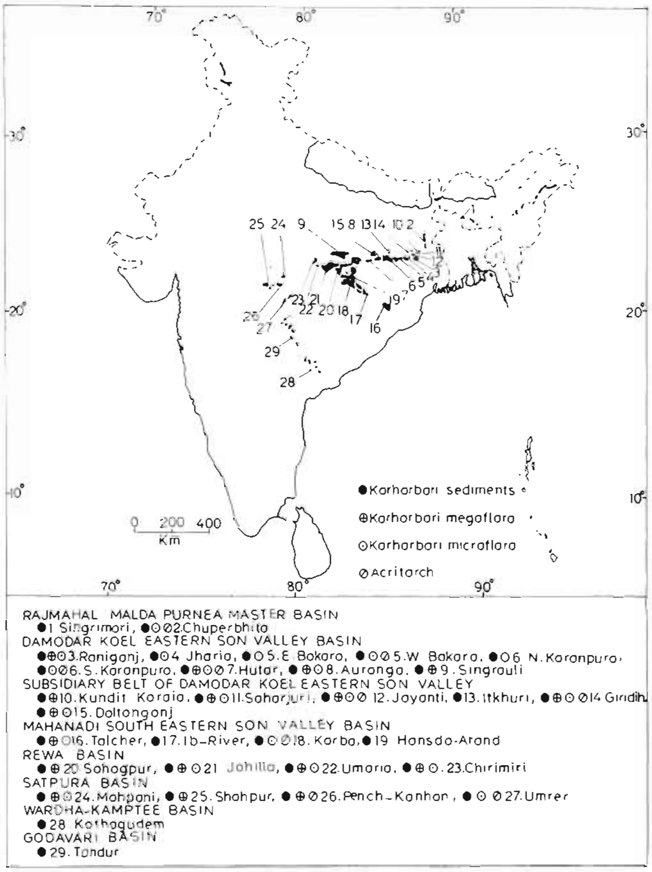
PRESENT STATUS OF KARHARBARI IN LITHOSTRATIGRAPHIC CLASSIFICATION

Definition—Sastry *et al.* (1977a) have defined Karharbari as consisting of grey to brown and mottled carbonaceous sandstones, grit and conglomerates with occasional coalseams of non-banded, dull type and fire clays. The sandstones are with angular to sub-angular quartz and mostly

Table 1—Stratigraphic sequence of Lower Gondwana showing biozone in Karharbari Formation

Geologic Time			KARHARBARI BIOZONE: Megafloral zones, CENO-zone	KARHARBARI BIOZONE: Megafloral zones, ACME Zone	KARHARBARI BIOZONE: Miofloral zones, CENO-Zone	KARHARBARI BIOZONE: Miofloral zones, ACME Zone	BIOSTRATIGRAPHIC CLASSIFICATION: Faunal Zones	BIOSTRATIGRAPHIC CLASSIFICATION: Biozone and Macroenvironment Zone		Damodar Valley		Rajmahal Hills		Koel Valley		Mahanadi Son Valley	Narmada Valley (Upper / Lower)	Wardha-Pranhita Godavari Valley	East coast: Krishna Godavari	Rajasthan
PERMIAN																		V Kamthi Fm Gl	Kamthi Fm	
	UPPER	Tatarian							Damuda Group	Gl Raniganj Fm.		Plant beds (Raniganj Fm)	Damuda Group	Gl. Raniganj Fm		Gl Raniganj Fm	Bijori Fm.	V		
										Kulti Fm.Gl. (Barren Measures) Gl						Gl. Kulti Fm (Barren Measures)	Motur Fm	Motur Fm.		
		Kazanian								Barakar Fm.		Barakar Fm		Gl Barakar Fm.		Gl. Barakar Fm	Barakar Fm	Gl Barakar Fm.		
	LOWER	Artinskian	1) Gangamopteris 2) Noeggerathiopsis 3) Glossopteris 4) Botrychiopsis 5) Buriadia 6) Ottokaria	1) Gangamopteris 2) Noeggerathiopsis 3) Botrychiopsis 4) Buriadia 5) Ottokaria	Callumispora Parasaccites Plicatipollenites	Callumispora		Gangamopteris		Gl. Karharbari		Gl. Karharbari		Gl. Karharbari		Gl. Karharbari Mb	Karharbari Mb.			
								Glossopteris		Fm/Mb A Jharia West Bokaro*		Mb Fm A* Chuperbhita		Mb Fm A* Hutar		A. Korba	A Pench Kanhan			
										S. Karanpura Giridih										
								Neoggerathiopsis								Umaria bed at base Sr Ch ?-disconformity—				
								Parasaccites												
		Sakmarian					Streptorhyncus A. Zone	Plicatipollenites Callumispora	Talchir Fm	Rikba bed at top Gl	Talchir Fm		Talchir Fm	Eu.Gl Rajhara bed near top Ch	Talchir Fm	Gl. near top				
		Asselian					Eurydesma A. Zone	Diverse Acritarch								Eu. Manendragarh bed at base	Talchir Fm.	Talchir Fm		Sr Badhaura
Precambrian Metamorphites																Precambrian Metamorphites				

Stratigraphic classification and faunal records (after Sastry et al. 1977a; Acharyya et al. 1977) Acritarch occurrence is added in the table from reported records and present study
Gl. = Occurrence of Glossopteris; **Eu.** = eurydesma dominated fauna; **Sr.** = Streptorhynchus fauna; **Ch.** = Chitinozoa; **V.** = Continental vertebrate fauna; **A.** = Acritarch; * = Present record. **Mb.** = Member; **Fm.** = Formation.



Map 1—Showing records of Karharbari sediments, megaflora, microflora and acritarch from different coalfields of Indian Lower Gondwana. The coalfields are considered under basins according to Datta *et al.*, 1983 and Mitra and Raja Rao, 1987.

unaltered, fresh feldspar. It overlies unconformably the Talchir Formation in the type area, Karharbari Village, Giridih Coalfield (Ghosh & Basu, 1969) and conformably over Umaria marine bed at Rewa Basin. Karharbari has been defined as formation by Ghosh and Basu (1969), in type area and by different workers in other basins and also as member within basal part of Barakar Formation due to ill-defined lithological distinction (Table 1).

Age—Artinskian to Upper Sakmarian age of Karharbari has been considered from comparative analysis of the faunal assemblages recorded from Marine bed at Umaria which lies conformably below Karharbari. Lower limit has been suggested from the faunal records of Umaria which is correlated with the marine bed of Salt Range and upper limit of Karharbari has been ascertained through extrapolation of evidences of megaplant fossils similar to peninsular Karharbari assemblage recorded from Lower Gondwana Bed at Kashmir which is overlain by the marine Zewan Bed.

BIOASSEMBLAGE OF KARHARBARI SEDIMENTS

Identification of a very typical plant fossil assemblage by Feistmantel (1876, 1879, 1882, 1886) in the carbonaceous shales associated with the Lower Karharbari seams in the Giridih Coalfield (Map 1) strongly suggested a distinct phase of deposition immediately after Talchir glaciation and before the coal-bearing Barakar Formation. Since then plant fossil assemblage has become successful parameter to identify the Karharbari rocks than lithostratigraphic consideration. With the introduction of palynological study, the palynofloral composition of Karharbari sediments has been worked out and found to be very much distinctive and useful in identifying Karharbari rocks. The mega- and palyno-floral evidences explore a typical assemblage from Karharbari sediments.

Zeiller (1902) contributed some additional plant fossils of the strata from the type area. Sen (1953) first tried to apply palynological data for identification and correlation of coalseams and distinguished the Lower Karharbari seams in the type area Giridih Coalfield with dominance of trilete, smooth types of spores (? *Callumispora*) and more monosaccates compared to the disaccate dominance in the younger Bhaddoah seam. Further mega- and palyno-floral records from the type area have been made by Guhasarkar (1956), Maithy (1965a-g, 1966, 1969a, 1977), Srivastava (1973), Maithy and Misra (1984), Bharadwaj (1966), Pant and Nautiyal (1965, 1966, 1967, 1984), Pant and Gupta (1968), Pant and Kidwai (1968), Pant and Singh (1976, 1979), Pant, Nautiyal and Misra (1981), and Maheshwari and Tewari (1986).

Megaplant Assemblage

So far 31 genera and about 100 species of megaplant fossils are recorded from Karharbari

PLATE 1 →

1. *Glossopteris decipiens*, G.S.I. specimen no. 5026. × 4/5.
2. *G. longicaulis*, G.S.I. specimen no. 5086. × Nat. Size.
3. *Noeggerathiopsis hislopi*, G.S.I. specimen no. 5065. × Nat. Size.
4,5. Portion of the big fronds of *Botrychiopsis valida* illustrated by Feistmantel, 1881, pl. VI.
6. *Ottokaria bengalensis*, G.S.I. specimen no. 7288. × Nat. Size.
7. *Rubidgea obovata* Maithy, BSIP specimen no. 32793/604. × Nat. Size.

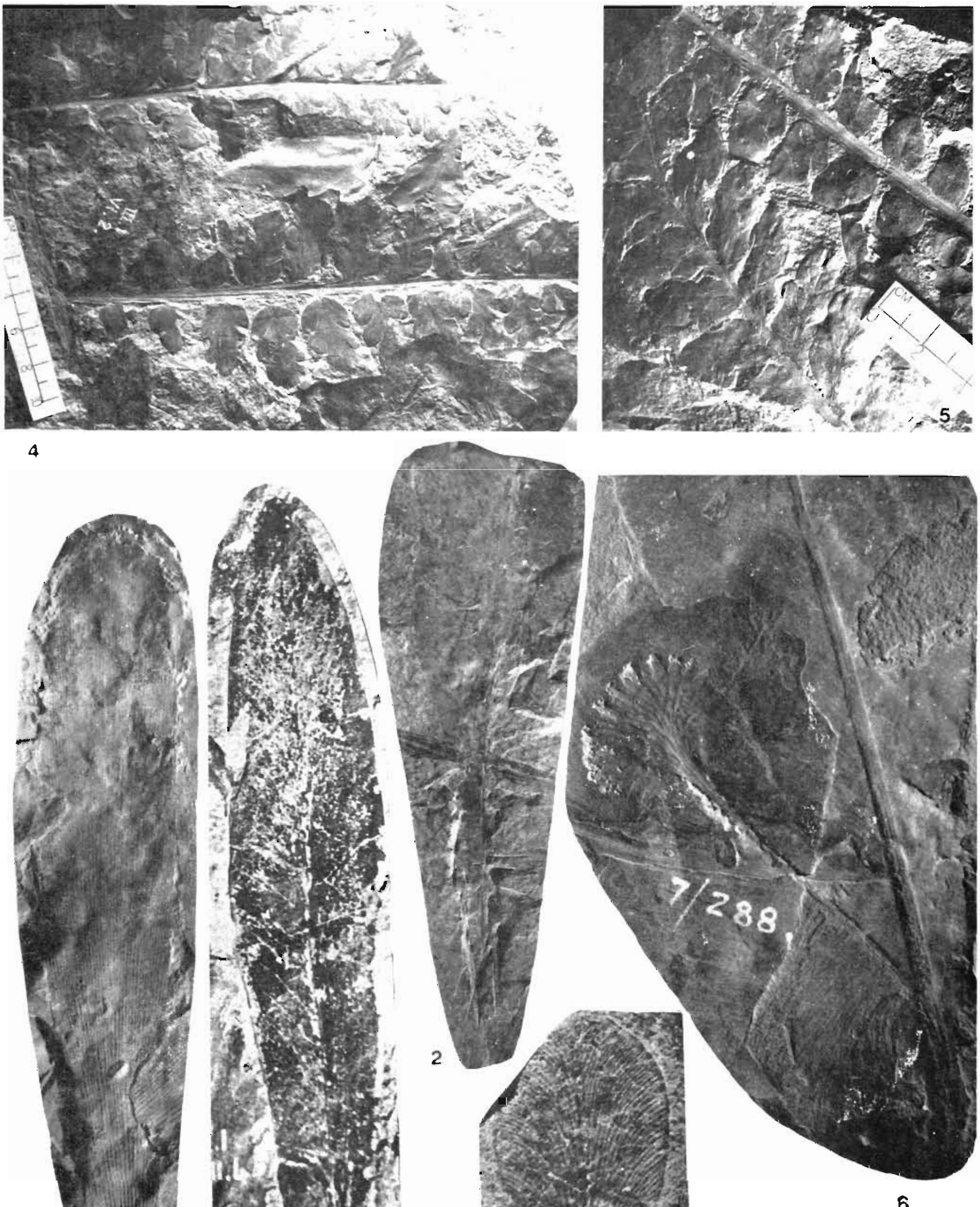


PLATE 1

sediments of different coalfields. The common occurrence of *Glossopteris* identifies the assemblages as Lower Gondwana Glossopteris flora. Most of the species of the genus are with fine venation pattern; medium mesh species are also encountered in moderate frequency. Feistmantel (1879, 1882, 1886) recognised a number of species including some new records, the lectotypes for which have been identified later (Banerjee, 1978). The species are *G. decipiens* (Pl. 1, fig. 1), *G. longicaulis* (Pl. 1, fig. 2), *G. taenioides* (Pl. 2, fig. 1), and *G. communis* (Pl. 2, fig. 2). *G. decipiens, G. indica* and *G. communis* are much frequent in the Karharbari assemblage

Plant assemblages from Karharbari sediments show very common occurrence of the *Gangamopteris* type of leaves. The leaves are apparently without any distinct midvein, but the veins in the middle part of the lamina often concentrate simulating a midrib. The lamina is covered with fine veins forming crowded meshes similar to that of *Glossopteris*. The closer similarity of fine mesh *Glossopteris* species and *Gangamopteris* species will be clearly understood when the ecofacies of the strata with such fossils is explored. About 15 species of *Gangamopteris* are recorded from Karharbari sediments of which *G. cyclopteroides* (Pl. 2, figs 3,4) is the most common which again is a common species of Talchir flora.

Common occurrence of *Noeggerathiopsis* in the assemblages of Karharbari sediments indicates similarity with the Talchir flora. But similar to *Gangamopteris* this genus also exhibits maximum species variation indicating proliferating growth of the group of plants during the deposition. *N. hislopi* (Pl. 1, fig. 3) is the most common species of the assemblages of Karharbari among about 10 to 11 species so far known.

Glossopteris, Gangamopteris and *Noeggerathiopsis* are common genera of both Talchir and Karharbari which either flourish in the younger horizon of Raniganj Formation, viz., *Glossopteris* (Banerjee, 1987) or continue up to the younger horizon of Indian Lower Gondwana, viz., *Gangamopteris* in Raniganj Formation (Banerjee, 1987) or occur sporadically in Barakar and Raniganj formations (Lakhanpal *et al.*, 1970), viz., *Noeggerathiopsis*.

However, the occurrence of *Botrychiopsis* (=*Gondwanidium*—Pl. 1, figs 4,5), *Buriadia* (Pl. 2, fig. 6), *Ottokaria* (Pl. 1, fig. 6), *Euryphyllum* (Pl. 2, fig. 7), *Rubidgea* (Pl. 1, fig. 7) in addition to *Glossopteris, Gangamopteris* and *Noeggerathiopsis* distinguishes the assemblage of Karharbari sediments from the other Lower Gondwana megaplant assemblages. *Buriadia, Ottokaria* although recorded sporadically from younger horizons (Banerjee, 1973, 1978b; Srivastava, 1973), *Botrychiopsis* is recorded from Karharbari sediments only. The less known genera *Euryphyllum, Rubidgea* are also reported from Karharbari only. The Cenozone and Acmezone representatives of megafloral assemblages are enumerated in Table 2. *Botrychiopsis valida* Feistmantel (1879) shows a luxuriant growth of the plant with profuse pinnately branched axis, bearing apparently rounded pinnule of considerable thickness indicating a tree-like habit of the plants. The genus is recorded both from Lower Karharbari and Upper Karharbari (Bandopadhyaya, 1959). Monopodially branched *Buriadia heterophylla* also occurs in the same association of *Botrychiopsis, Gangamopteris* and *Glossopteris* leaves in the type area.

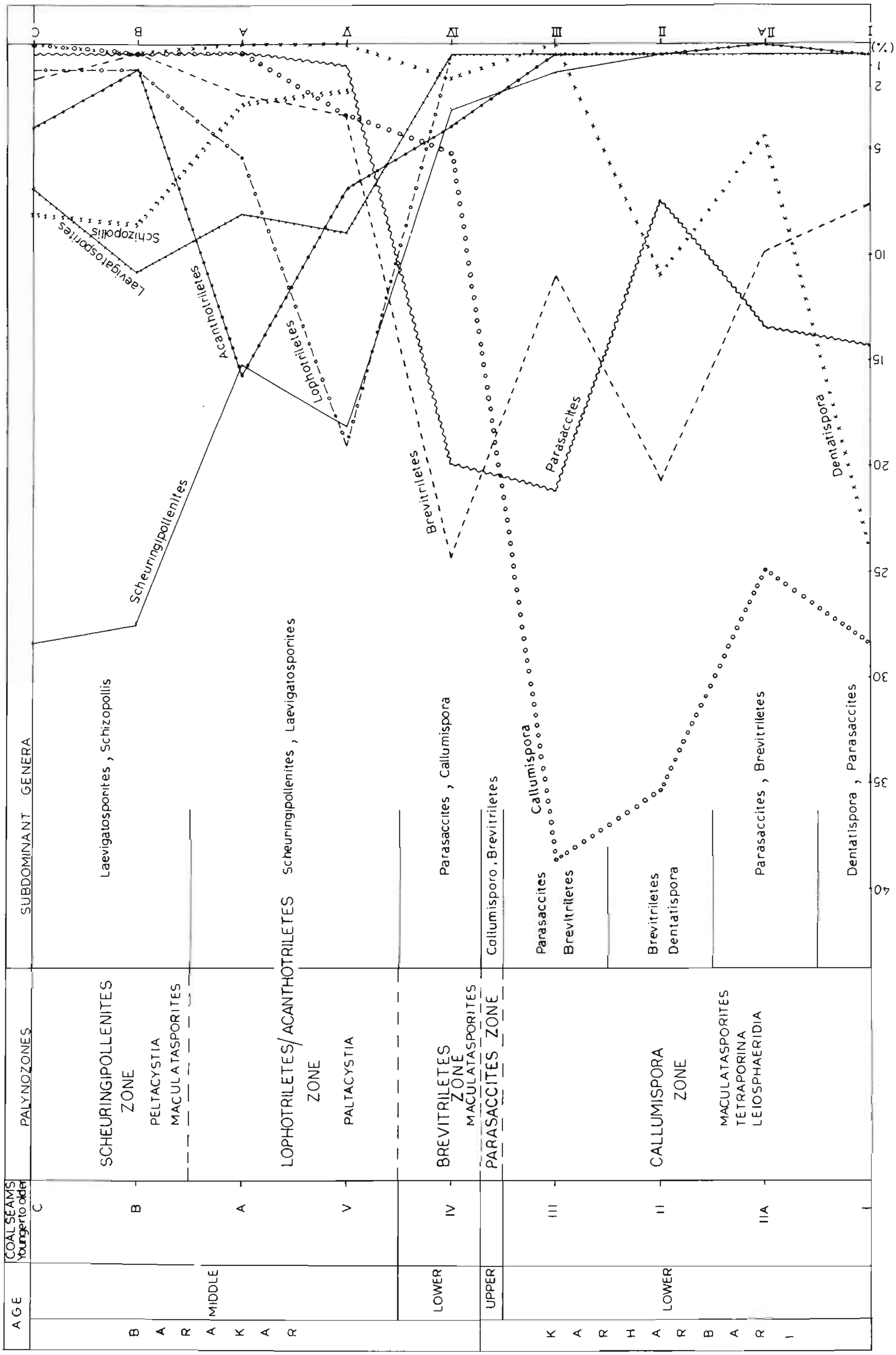
Affinity as well as environmental analysis of the characteristic representatives of Karharbari sediments are not yet known sufficiently. *Glossopteris* and *Gangamopteris* leaves are generally grouped as Glossopteridales or Glossopteridopsida and have been analysed so far considering the climatic factor only; the ecological factor analysis of the species remains still unattended. Critical analysis of the species occurring at the basal coal-bearing strata of Lower Gondwana will reveal the depositional characteristics. *Botrychiopsis* is

Table 2—Megafloral assemblage from Karharbari sediments

GENUS	QUALITATIVE ANALYSIS	RELATIVE ABUNDANCE OF OCCURRENCE
Glossopteris	Mostly fine mesh form and also medium mesh form	Common
Gangamopteris	Diverse	Dominant
Noeggerathiopsis	Diverse	Dominant
Botrychiopsis	Three species	Occur in Karharbari only
Ottokaria	Three species	Dominant
Buriadia	Diverse	Dominant
Euryphyllum	Two species	Occur in this horizon only.
Rubidgea	Three species	Occur in this horizon only
Gymnospermic seed	Diverse	Frequent
Vertebraria	Two species	Frequent
Schizoneura and Equisetaceous stem	Diverse	Frequent
Neomariopteris	Three species	Frequent

KARHARBARI MEGAFLORAL ASSEMBLAGE

CENOZONE	ACMEZONE
Gangamopteris	*Gangamopteris*
Noeggerathiopsis	*Noeggerathiopsis*
Glossopteris	*Botrychiopsis*
Botrychiopsis	*Buriadia*
Buriadia	*Ottokaria*
Ottokaria	



Text-figure 1—Shows the frequency of occurrence of mioflora in the lithosuccession of Lower Gondwana sediments in Hurilong and Hutar colliery blocks of Hutar Coalfield (after Banerjee & Ganguly, 1986; Ganguly & Banerjee, 1986 a, b).

suggested to be a progymnosperm which grew in the periglacial environment (Retallack, 1980; Meyen, 1987). *Buriadia* is the southern hemisphere Permian conifer and resembles the northern hemisphere conifer in the forked leaves but differs in the ovule bearing character (Pant & Nautiyal, 1967). *Noeggerathiopsis* is considered under Noeggerathiopsidales, suggested to be a cordaitalean plant (Pant, 1982). Northern hemisphere cordaitales, however, show characteristics of mangrove plants.

Microfossil Assemblage

Palynoassemblages were recorded from the type area Giridih Coalfield with the Lower Karharbari seams and also of the younger horizons in the type area (Sen, 1953; Maithy, 1965f; Bharadwaj, 1966; Srivastava, 1973). Similar assemblages are recovered from channel, bore-core or traverse samples from a number of coalfields of the different basins (Map 1). The assemblages recorded are also reviewed from time to time (Bharadwaj, 1966, 1971, 1974; Maithy, 1969b; Tiwari, 1974a). About 67 genera and more than 200 species are now on record from Karharbari sediments. Mostly trilete spores and monosaccate pollen grains dominate the assemblages.

Callumispora (=*Punctatisporites*) (Pl. 3, figs 1-2), *Cyclogranisporites* (Pl. 3, fig. 3), *Granulatisporites, Brevitriletes* (Pl. 3, fig. 4), *Microbaculispora* (Pl. 3, fig. 5), *Lophotriletes, Microfoveolatispora* (Pl. 3, fig. 6) are the more common trilete taxa of which *Callumispora* exhibits highest frequency; predominant occurrence of the monosaccate pollen grains, viz., *Parasaccites* (Pl. 3, fig. 7), *Plicatipollenites* (Pl. 3, fig. 8), *Virkkipollenites*, etc. accounts for the climatic condition of glacial influence.

Frequency study of channel and bore-core samples from the type as well as other coalfields has revealed a distinctive microfloral assemblage pattern from Karharbari sediments. Assemblage zone representatives, however, have differential frequency of occurrence in the lower and upper horizons of Karharbari (Text-fig. 1; Table 3). Combination of taxa with same higher frequency of monosaccates in the Upper Karharbari indicates influence of cooler climate and the trilete dominance with *Callumispora* indicates more humid and swampy ecological condition with lesser influence of climate indicator taxa. Climatic variation continued since Talchir up to the end of Karharbari approaching towards the closing phase of glaciation and deglaciation. From the relative frequency of occurrence in stratigraphic sequence of the monosaccate pollen grains in Lower Gondwana, the climatic transformation is apparent. But the dominance of *Callumispora* during *Botrychiopsis* phase of deposition in Karharbari and again during *Dicroidium* phase Triassic sedimentation (Tiwari, 1979) might be due to similar ecological condition.

Affinity of the miofloral taxa of Indian Lower Gondwana is very much conjectural as the spores and pollen have rarely been recorded *in situ* (Banerjee, 1969). The monosaccate pollen grains are assigned to the gymnospermous coniferous plants supposed to be of cool climate habitat. *Callumispora* has been suggested as a gymnosperm pollen grain (Bharadwaj, 1987 during the workshop discussion); the allied taxa *Punctatisporites* of Lower Carboniferous (northern hemisphere) dominance is known to be the prepollen of Pteridosperms (Meyen, 1987).

OTHER SIGNIFICANT BIOTA RECORDED FROM KARHARBARI SEDIMENTS

Megaspores, algae, fungal spores, acritarchs, Tasmanids and microcrystals similar to sponge spicules are recorded along with palynoflora from Karharbari sediments (Map 1; Table 3; Pl. 3, figs 14-18). The frequent occurrence of megaspores indicates the occurrence of luxuriant swampy vegetation and the fungal spores are indicator of humid condition. *Alternaria* sp. has records of fresh and brackish water environment (Jarzen & Elsik, 1986). *Quadrisporites* of the Lower Karharbari, (Shukla, 1983) is regarded as a common form of Talchir (Bharadwaj, 1966). The acritarch and tasmanids recorded in the Karharbari assemblage are now considered as brackish water biota (Tappan, 1980). Microcrystals, although not exactly similar but with some morphological similarity with the sponge spicules have been recorded from Talchir sediments of Daltonganj (Lele & Srivastava, 1974), are recorded from West Bokaro Coalfield along with palynofloral assemblages similar to that of Karharbari and Lower

PLATE 2 →

1. *Glossopteris taenioides*, G.S.I. specimen no. 5490. × Nat. Size.
2. *G. communis*, G.S.I. specimen no. 5267 (slightly reduced).
3. *Gangamopteris cyclopteroides*, G.S.I. specimen no. 5016 × Nat. Size.
4. *G. cyclopteroides*, G.S.I. specimen no. 5464. × Nat. Size.
5. *G. buriadica*, G.S.I. specimen no. 5025. × Nat. Size.
6. *Buriadia heterophylla*, G.S.I. specimen no. 5050. × Nat. Size.
7 *Euryphyllum whittianum*, G.S.I. specimen no. 5036. × Nat. Size.

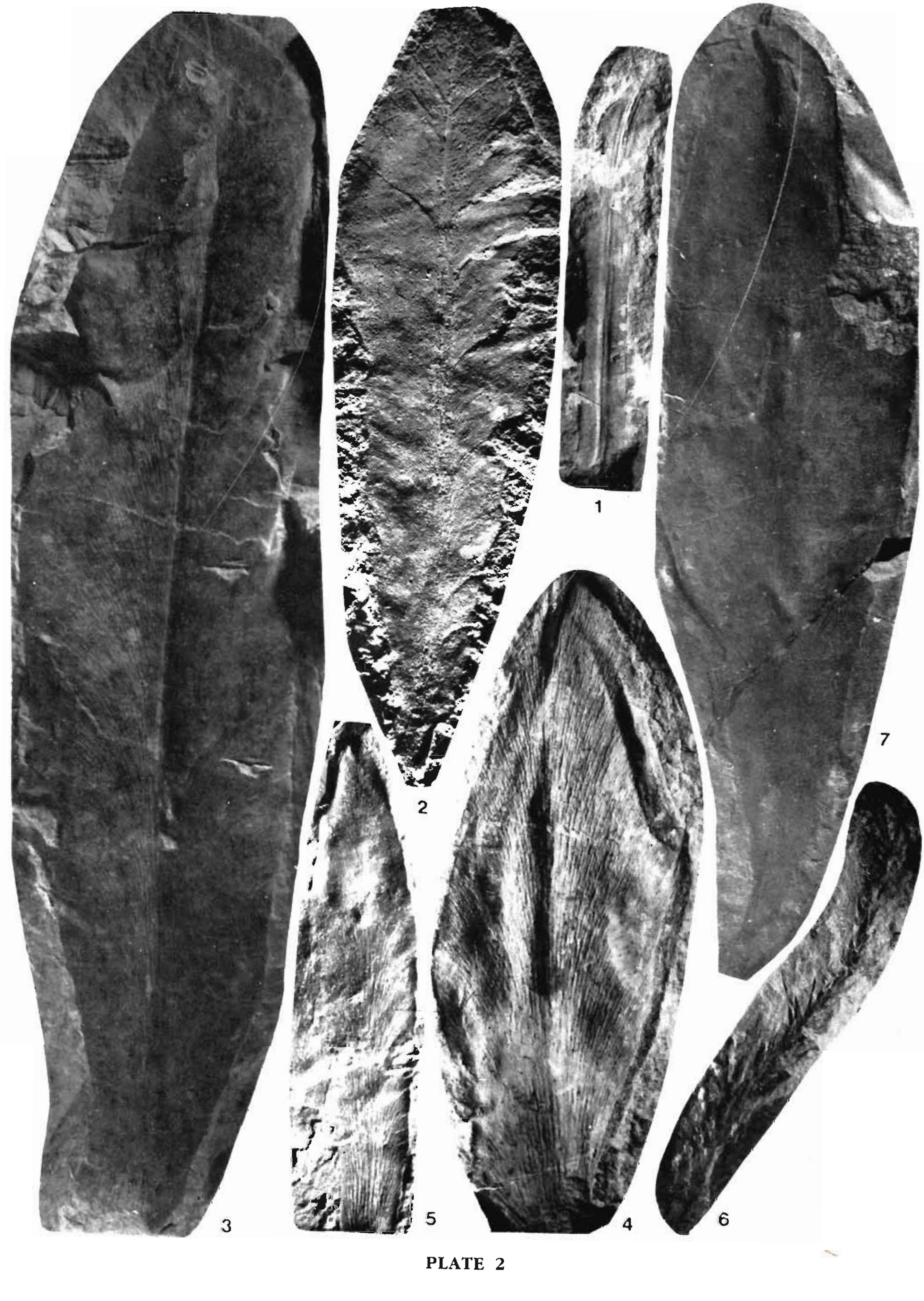


PLATE 2

Table 3—Palynoflora from Karharbari sediments

	GENUS	QUANTITATIVE ANALYSIS
Upper Karharbari	*Parasaccites*	Dominant
	Plicatipollenites	Dominant
	Callumispora	Frequent
	Brevitriletes	Frequent
	Scheuringipollenites	Common
Lower Karharbari	*Callumispora*	Dominant
	Parasaccites	Frequent
	Plicatipollenites	Frequent
	Brevitriletes	Frequent
	Cyclogranisporites	Frequent
	Microbaculispora	Frequent
	Microfoveolatispora	Frequent

Karharbari palynofloral Assemblage
Callumispora-Parasaccites-Plicatipollenites

Other microbiota—Some occur both in Upper and Lower Karharbari

ACRITARCHS	FUNGI
Balmeella	*Alternaria* and others
Brazilea	Other fungal spores
Foveofusa	Micro-crystals cf. sponge spicule
Leiosphaeridea	Megaspores
Maculatasporites	
Pilasporites	
Spongocystia	
Spinose and non-spinose	
Tetraporina	

Barakar and also spinose and non-spinose type of acritarchs (Banerjee & Das, 1983, 1986a,b). This assemblage of biota other than microflora recorded from Karharbari sediments of type and a number of other coalfields is significant enough to consider the environment of deposition during Karharbari sedimentation.

PRESENT STATUS OF KARHARBARI

A distinctive bioassemblage both of megaflora (Table 2) and microflora (Table 3) is revealed by analvsing all the megaplant and spores, pollen records from the Karharbari sediments (Map 1). The assemblages are recognised as Karharbari megafloral assemblage and Karharbari palynofloral assemblage. Besides, a number of acritarch forms are common in the assemblages as the fungal spores (Table 3). All these evidences suggest a typical biozone of Karharbari as follows:

Karharbari Biozone

Gangamopteris-Noeggerathiopsis-Glossopteris-Botrychiopsis-Buriadia-Ottokaria-Callumispora-Parasaccites-Plicatipollenites-diverse, brackish water Acritarchs, fungal spores.

The floristic pattern of Karharbari biozone and relative abundance of the taxa in Talchir, Barakar, Kulti (Barren Measure) and Raniganj formations indicate continuation of a uniformly composite pattern of vegetation that differed in the frequency of occurrences and specific variations of the genera and species according to change of climate and ecofacies (Text-fig. 2). The bioassemblage of Karharbari is more similar to that of Talchir. However, *Botrychiopsis*, one of the characteristic members of Karharbari biozone and also a dominant member of the pre-Gondwana Botrychiopsis flora during Middle Carboniferous-Lower Permian of South America (Brazil, Argentina—Archangelsky, 1986) and Australia (Retallack, 1980) is not encountered in any of the assemblages of other Lower Gondwana horizons of peninsular India except in an assemblage of extrapeninsular Permian deposit (Tewari & Singh, 1980) along with *Glossopteris, Gangamopteris, Lepidodendron* and *Calamites.*

Karharbari and Talchir are considered as the *Gangamopteris-Noeggerathiopsis-Glossopteris-Parasaccites-Plicatipollenites-Callumispora* macro-environment and biostratigraphic zone. The dominance of other taxa within this zone

PLATE 3 →

Some of the microfossils encountered from Karharbari sediments of Hutar, West Bokaro and Chuperbhita coalfields. (figs. 1-16 × 700).

1. *Callumispora tenuis*
2. *Callumispora barakarensis*
3. *Cyclogranisporites gondwanensis*
4. *Brevitriletes levis*
5. *Microbaculispora tentula*
6. *Microfoveolatispora indica*
7. *Parasaccites talchirensis*
8. *Plicatipollenites gondwanensis*
9. *Laevigatosporites flexus*
10. *Jayantisporites pseudozonatus*
11. *Didecitriletes horridus*
12. *Marsupipollenites triradiatus*
13. *Gnetaceaepollenites sinuosus*
14. *Quadrisporites horridus*
15. *Tetraporina* sp.
16. *Maculatasporites indicus*
17. *Alternaria* sp. × 1000
18. Microcrystals cf. sponge spicule. × 250

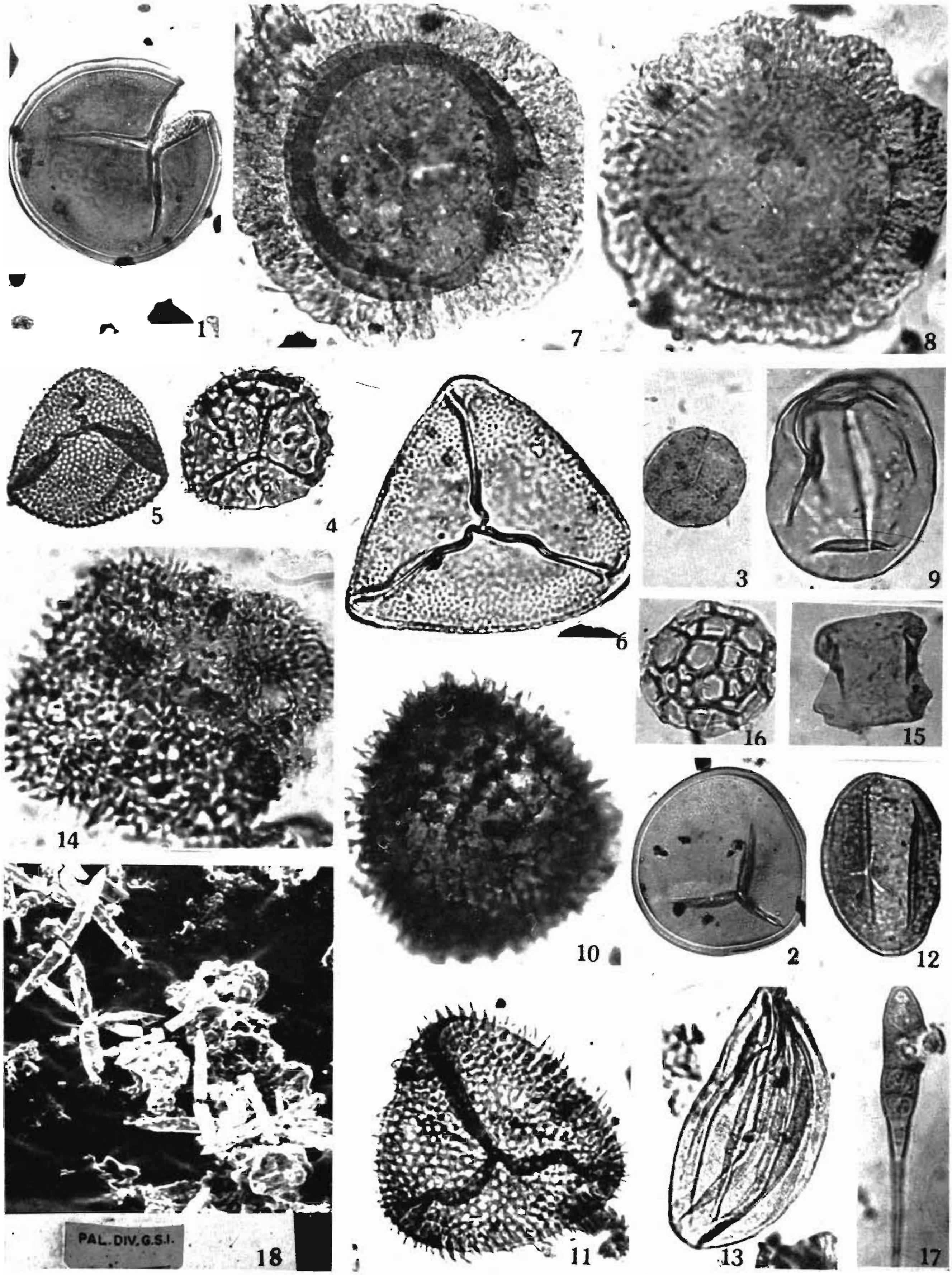
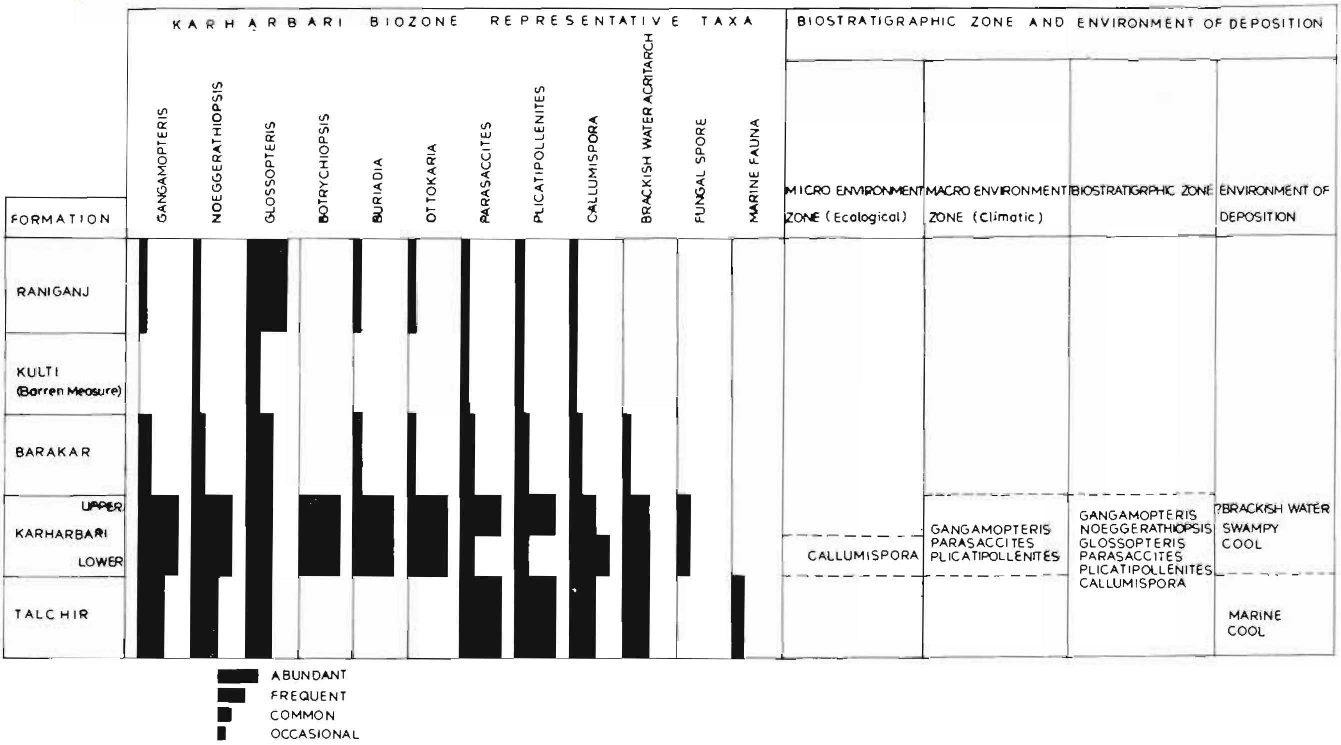


PLATE 3



Text-figure 2—Relative abundance of Karharbari biozone taxa and acritarch in Lower Gondwana horizons and macroenvironment, microenvironment zone.

(microenvironment zone) may be considered as subzones of the macroenvironment and biostratigraphic zone.

KARHARBARI BIOASSEMBLAGE REPRESENTATIVES FROM OTHER PARTS OF THE SUBCONTINENT

Salt Range

As early as in 1938, Virkki recorded megafossil assemblage from Salt Range that includes several species of *Glossopteris, Schizoneura, Ottokaria* and *Cordaicarpus*. Later Virkki (1945) described a monosaccate rich palynoassemblage. Kar (1965 *in*: Maithy, 1969b) on the basis of miospore analysis regarded the age of the beds as equivalent to Karharbari.

Kashmir and other extra-peninsular area

Gangamopteris kashmirensis, Cordaites (Noeggerathiopsis hislopi) and *Psygmophyllum (Ginkgophyton)* are recorded from the Nishatbag and Vihi beds of Kashmir (Kapoor, 1979; Singh *et al.*, 1982; Lele & Maithy, 1982). The assemblage does not contain any typical Karharbari form and is more similar to Talchir assemblage of Peninsula. But the faunal record of the marine bed below this *Gangamopteris* bed is similar to that of the Umaria marine bed lying conformably below Karharbari in peninsular Gondwana. Evidently Karharbari affinity of the Kashmir Bed has been suggested.

Mega- and palyno-floral assemblage recorded from the Permian sediments of Uttar Pradesh by Tewari and Singh (1980) and Tiwari *et al.* (1980) is quite interesting. *Gangamopteris, Glossopteris, Botrychiopsis, Lepidodendron, Calamites, Callumispora* combination is very much significant and perhaps will throw light in analysing the introduction of Glossopteris flora in the Lower Gondwana of the subcontinent.

Records of *Callumispora* and other monosaccate pollen grains with acritarch, Chitinozoan assemblage from the Tethyan Sequence is, however, from Upper Permian horizons (Tiwari *et al.*, 1984).

Arunachal Pradesh

Singh (1979) described *Callumispora* rich palynoassemblage from the Bomte Member of Garu Formation in Siang District of Arunachal Pradesh, eastern Himalaya. The assemblage is similar to the Karharbari palynofloral assemblage (Lower Karharbari) of the peninsular basins. The age of the sediments has been suggested as Asselian to Sakmarian from marine faunal evidences (Singh, 1979). Srivastava and Dutta (1978) described Karharbari miofloral assemblage from Siang District. The palynological assemblages of Karharbari from

Arunachal Pradesh also recorded occurrence of diverse acritarch, *Botryococcus*, etc.

CONCLUSION

The observations of Ghosh and Basu (1969) on Karharbari as a definite lithological unit, palaeontological zone and both combined as a chronostratigraphic unit in between Talchir and Barakar is now supported by data in many of the coalfields (Map 1). However, identification of the strata as a mappable unit in the field has not been found as comfortable as it should be. Nevertheless, the lithological, petrological constituents with strong mega- and palyno-floral records distinguish the sedimentary sequence from the rest of the Indian Lower Gondwana Succession. Karharbari deposition occurred during the same macroenvironment phase as Talchirs, in which Lower Karharbari depicts a distinct microenvironment phase. Marine transgression during Karharbari is apparent from the occurrence of brackish water acritarchs in the bioassemblage.

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Kamthi—a new concept

B. C. Pande

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King had described 'Kamthi beds' as the group of rocks disconformably overlapping the Permian coal measures in an otherwise extremely soil covered areas in the Wardha Godavari Graben. Some of the later workers while projecting on the surface the lithics encountered in the sub-surface drilling in the Godavari Valley Coalfield subdivided these beds into lower, middle and upper horizons, by considering them to have gradational contacts, to account for the biota revealed from these litho-units.

A reappraisal of the basic geoscientific data base (geological and geophysical) and the interpretations from the surface and the sub-surface lithics have undisputedly shown that the pattern of Gondwana sedimentation in the Godavari Valley, during the Palaeozoic and Mesozoic periods, has been in an oscillating and continental fluvial regime governed by the basin configuration and palaeodrainage inter-related to their development in time and space.

The palynofossil content unequivocally proves the presence of the Upper Permian lithics lying buried under the Lower Triassic (Kamthi) sediments. The latter having a widespread expanse in the graben, from the northwest to the southeast,•which is believed to be due to the further deepening of the basin floor at the time of their sedimentation.

The possibility of Kamthi constituting the basal part of the enlarged Maleri sequence of the Triassic lithics is very much indicated thereby defining the base of the Triassic in the Godavari Graben. It is, thus, considered undisputed that the Kamthi is nothing more than a concept in the geological history of this part of the Godavari Graben which is defined by its mode of occurrence as governed by the associated tectonism.

Key-words—Stratigraphy, Lithology, Tectonism, Kamthi Formation, Godavari Valley (India).

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साराँश

कामथी—एक नवीन अवधारणा

बी० सी० पान्डे

किंग ने चट्टानों के उस समूह को जो कि वर्धा-गोदावरी द्रोणिका में अत्यधिक मिट्टी से ढ़के क्षेत्रों में परमी युगीन कोयला संस्तरों के ऊपर असमान रूप से विद्यमान था 'कामथी संस्तर' नाम दिया। बाद में कुछ शोध-कर्त्ताओं ने इन संस्तरों को क्रमिक संस्पर्श तथा जीविता के आधार पर अधरि, मध्य एवं उपरि संस्तरों में विभक्त किया। मूलभूत भूवैज्ञानिक एवं भूभौतिकीय आँकड़ों की पुन: समीक्षा से तथा सतही एवं उपसतही शैलों की व्याख्या से यह निस्संदेह व्यक्त हुआ है कि पुराजीवी एवं मध्यजीवी कल्प में गोदावरी घाटी में गोंडवाना अवसादन अस्थिर एवं नदीय काल में हुआ है तथा इसमें द्रोणी के आकार एवं पुराजलप्रणाली की विशेष भूमिका रही है। उपलब्ध परागाणुओं की मात्रा से अधरि त्रिसंघी (कामथी) अवसादों के नीचे दबी उपरि परमी शैलों की उपस्थिति स्पष्ट रूप से सिद्ध हो जाती है। अधरि त्रिसंघी अवसाद इस द्रोणी में उत्तर-पश्चिम से दक्षिण-पूर्व तक बृहत् रूप से विकसित थे और ऐसा अनुमान है कि इनका इतना विस्तार इनके अवसादन के समय घाटी की अधिक गहराई बढ़ जाने के कारण हुआ। इस प्रकार निस्संदेह यह प्रस्तावित किया गया है कि गोदावरी द्रोणिका के इस भाग के भूवैज्ञानिक इतिहास में कामथी एक अवधारणा के अतिरिक्त कुछ अधिक नहीं है जिसमें सहयुक्त विवर्तनिकता की सक्रिय भूमिका रही है।

Concepts, limits and extension of the Indian Gondwana
(Editors : B. S. Venkatachala & Hari K. Maheshwari)
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IN the paper on "Kamthi—a new concept" let it be understood that the matter is not as new as it might appear to be speculating. Yet it carves a new dimension emboldened by the data base evidence and thus lends support to what the originator had perhaps intended when he proposed it.

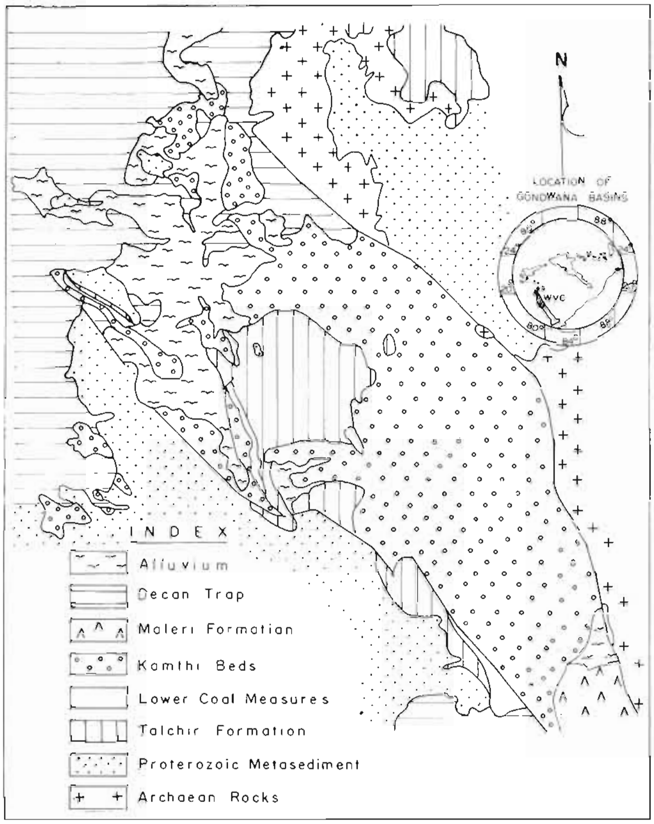
Many controversies have arisen when the available data base has been placed in the geological time frame based on vaguely defined standards. Such a synthesis has often presented an ambiguous picture and one such area is the 'Kamthi' in the stratigraphy of the Godavari Graben.

Though 'Kamthi' may not encompass connotation in a broader perspective yet it does highlight the regional problem which may have a bearing on a much wider plane, particularly when this term is being used increasingly to define the undifferentiated Gondwana lithics in other basins also. It is, therefore, essential to have the proper understanding of the facts which controvert the widely believed conception and it is better to look back to the original description of the Kamthi beds.

King's view—King (1881) described "Kamthi Beds" as the group of rocks which disconformably overlap the Permian coal measures in the Pranhita-Godavari-Graben and assigned them an Upper Permian to Lower Triassic age. These beds were considered peculiar in their geological and structural relationship with the underlying rocks in the litho-sequence. It is in this state that these beds were differentiated from the rocks otherwise known from the Kamptee Coalfield.

Fox's view—Fox (1934) identified a number of coalfields within this master basin based on the scantily scattered exposures of the coal-bearing rocks and named them after the locality where they occurred, viz., Bandar Coalfield, Warora Coalfield, Chanda Coalfield, Tandur Coalfield, etc. The coal in these coalfields was stated to be lying buried under the cover of the younger Kamthi sediments which were found to be water-bearing and any mining planned through a pair of inclines was with heavy cost on the pumping. Furthermore, coal being of inferior quality, it could not attract much attention in the market for the run off mining cost far exceeded prevalent sale price of the coal

Later views—Later workers of GSI (1960-66), while examining the potentiality of this master basin for regional sub-surface exploration by drilling to prove new mine blocks, came to the conclusion that these isolated coal measures, as a matter of fact, continue underneath the younger sediments, both along their strike and along the dip. It is then, that the concept of the existence of the master graben came to be established.



Text-figure 1—Geological map of Wardha Valley Coalfield, Maharashtra.

With the progressive accumulation of the sub-surface data some of which had been sporadically analysed palynologically an attempt was made to project the data base on the otherwise densely covered terrain from the bore-holes.

Consequently, what resulted was the subdivision of the Kamthi into three litho-stratigraphic units, named as the 'Lower (cf. Raniganj) the 'Middle' (cf. Lower Panchet) and the 'Upper' unit, conformably lying one over the other in an ascending order and with gradational contacts between them. This sequence was further believed to be resting over the unit, designated as the "Barren Measures", which overlies the coal-bearing Barakars in the Godavari Sub-basin, again with a gradational contact.

The Godavari Sub-basin constitutes only a part of the larger Pranhita-Godavari Graben and in the other sub-basins 'Kamthi' sediments continued to be believed to be resting with an angular disconformity over the underlying coal measures. In order to conceive it in the way it had been projected the question arises as to when and how such a mode of sedimentation is possible? As is well known, in a gradational contact the beds rest one over the other in an undisturbed sequence in terms of time and space. On the other hand, in an overlap the older beds lie buried under the cover of the younger sediments representing the time transgression.

The controversy, thus, created by the assumption of a gradational contact in the Lower Gondwana lithosequence in a restricted part of the graben as against the disconformable angular overlap widely believed in the remaining part of the graben has necessitated a relook at the facts bringing the contradictions in the basic concept.

It was also essential because charged to locate new shallow blocks for mining by the corporate body of the public sector it had become essential that the subsurface drilling be conducted in the identified areas where coal can be proved at shallower depths. But while executing the operations, based on the assumptions as outlined above, it was found that most often the surface geological maps prepared largely on the soil covered terrains were hardly conducive to match the requirement. While some bore-holes were passing through the basal lithics with no coal, the others were getting closed much above in the sequence without touching the coal seams. It was, therefore, essential that the data base had to be reassessed and processed thoroughly before embarking on any prognostication.

PERMIAN LITHOSTRATIGRAPHY

As a result, it was found that the Permian lithic content comprises :

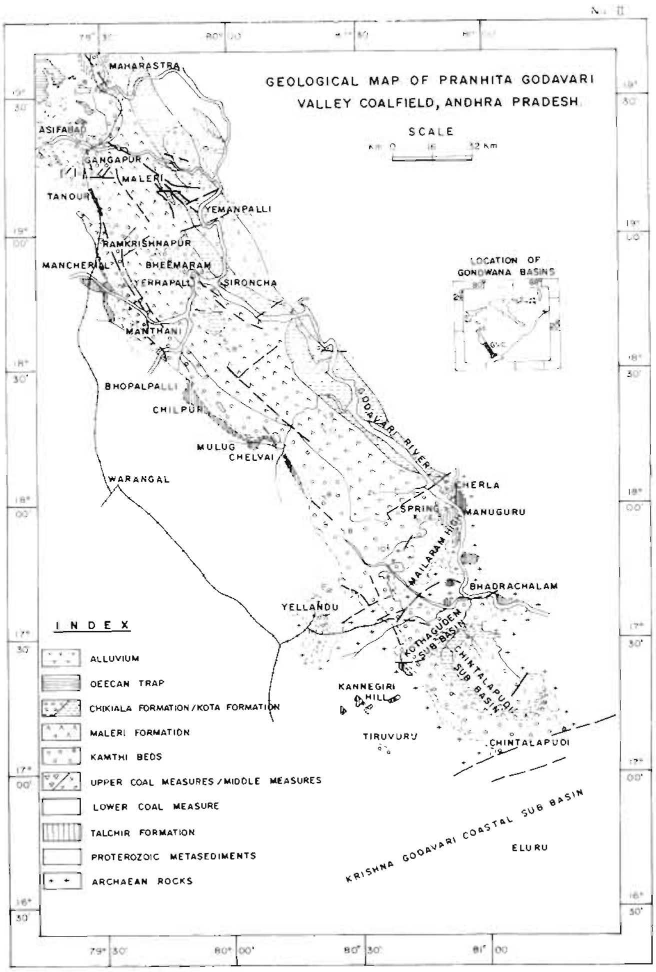
1. Talchir and basal Lower Coal Measure (dipping 18° to 20°), overlapped by younger sediments with dips 8° to 10° on the surface geological outcrop maps (Text-figs 1, 2).

2. Younger Lower Coal Measure beds with coal seam; rock sequence with no thicker coal zone (now designated : Middle Measures) and the Upper Coal Measures (being yet another coal-bearing horizon higher up in the sequence), encountered only in the sub-surface. These do not show in any outcrop except in the river section in the Ramagundem area, where they are exposed due to the 'V' erosion of the younger formation by the rivers Godavari and Maner. The alluvial cover, in a recent survey conducted by NGRI in this area, had been found to be around 120 m (Personal communication).

A close look at the lithic pile encountered in the bore-holes shows :

(a) Lower coal-bearing rocks having two types of facies :

i) Basal facies which is predominantly a coarse grit, 90 to 120 m in thickness, with few shale/carbonaceous shale bands.



Text-figure 2—Geological map of Pranhita-Godavari Valley Coalfield, Andhra Pradesh.

ii) Top facies, 150-250 m thick, with lithics exhibiting fining upward cycle and bearing a number of coal seams.

(b) The sediments of Middle Measures include medium to coarse-grained sandstones interbedded with shales and clays. The pale green colour, so characteristic of them, is generally dominating in the middle part.

(c) The Upper Coal Measures again consist of the two lithofacies :

i) The lower 200 m which includes a 20 m thick coal and shale intermixed seam along with the six other thin coal seam/bands stratified with the medium-grained felspathic sandstone, clays, shale and carbonaceous shale.

ii) The upper 600 m thick stratified sequence of sandstones, shale and clays of variegated colours between grey, white, mauve, pale green and grey, the latter colours pre-dominating higher up in the succession. The argillaceous content, however, is relatively more in proportion in the sequence of the Upper Coal Measures.

Table 1—Palaeogeographic and palaeoclimatic distribution (Mesozoic) in Godavari Graben

Geographic Location	Lower elevation	Lower to medium elevation	Higher elevation	Medium elevation	Coastal
Ecology	Landform Dinosaurs	Aquatic Reptiles	No fauna	Dwarfed fauna (?)	Marine & fresh water (mixed)
Fauna	Dominant	Dominant			
Flora	Evergreen type vegetation	Mediterranean type vegetation	Alpine type vegetation	Coniferous type vegetation	Coastal type vegetation
Palaeoclimate	Humid warm	Warm & cold alternate	Cold	Cold dry	Coastal humid

BIOTA CONTENT

The biota worked out by the Birbal Sahni Institute of Palaeobotany shows :

A. Lower Coal Measure beds have three palynozones (2 to 4) comparable to the Lower and Upper Karharbari and Lower Barakar. The Upper Barakar biota is strikingly missing.

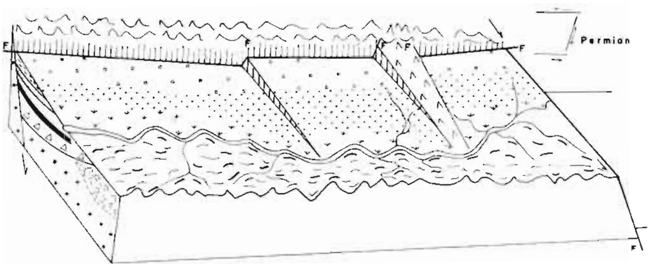
B. Middle Measure biota is correlatable to the floral assemblage of Barren Measures of the type area.

C. In the Upper Coal Measure the basal litho-units show palynoflora of the Lower Raniganj affinity and the upper lithics mark close similarity to the Upper Raniganj and Lower Panchet beds of Raniganj Coalfield.

The youngest palynozone, however, contains some Triassic elements which show proximity of the beds to the Upper Permian and Lower Triassic transition. Any bed disconformably overlying these beds by reason of its superposition, therefore, must have to be younger in age.

The characteristic features noted in the Permian lithic, thus, are :

1. The Basal Barakar has only linear exposures at the fringes.
2. Inliers of the older meta-sediments (Proterozoic) are present at some of the locales along the central axis indicating a basement high.



Text-figure 3—Schematic diagram, Stage 1 : Permian.

3.(a) Coal is found in two horizons with a no thicker coal zone in between them.
(b) Coal in the lower horizon is of economically viable thickness and is comparatively free of the dirt bands than that found in the upper horizons where it is intimately intermixed with the shale.
4. There is evidence to prove that the pari passu deposition of the lithics has been controlled by the periodical activation of the marginal faults and the cross faults.
5.(a) The sedimentation has been in two longitudinal basins separated by a mid-longitudinal ridge remnants of which are still found on the surface peeping through the cover of the younger rocks.
(b) The basin configuration, as revealed by the Bouger anomaly maps of the ONGC, also corroborates the tectonic frame-work of the Permian beds.

KAMTHI BASIN

Kamthi sediments, on the other hand, show a much wider expanse for deposition from the north-west to the south-east. The entire graben is also interconnected by these sediments for they are found at the same horizon in all the coalfields. This, perhaps, is as a result of the activation along the marginal faults controlling the sedimentation which further deepened the depositional floor. As a result, the younger sediments came to rest not only over the earlier laid sediments but also directly over the basement rocks.

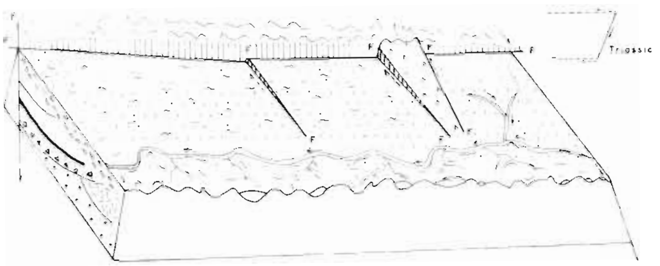
The latter phenomenon is more pronounced along or towards the western margin where undoubtedly it provided an undisturbed uneven palaeo-surface at the time of the sedimentation. The various Lower Gondwana inliers/outliers outside the limits of the coalfields are undisputed examples lending support to such a stipulation.

Table 2—Facies variation in a part of the Gondwana Sequence in Godavari Valley Coalfield

			Kota beds	*Overlying rocks*
			Unconformity	
			Dharmaram	: essentially a sand stone facies
			Maleri	: essentially a clay facies
Upper Gondwana	Upper to Lower Triassic	Maleri Series	Bheemaram	: essentially a sandstone facies
			Yerrapalli	: essentially a clay facies
			Kamthi	: essentially a sandstone facies
			Angular overlap	
			Upper Coal Measures (cf. Raniganj & Lower Panchet)	: essentially sandstone, shale & clay with interbeds of carbonaceous shale and coal towards the base
Lower Gondwana	Upper to Lower Permian	Damuda Series	Middle Coal Measures (cf. Barren Measures)	: essentially sand stone, interbedded with shale, clay and carbonaceous shale
			Lower Coal Measures (cf. Lower Barakar, Upper and Lower Karharbari)	: essentially sandstone and shale inter-stratified with carbonaceous shale and coal-seams
			Talchir	: essentially sandstone, shale and tillites.
			Unconformity	
			Basement of Proterozoic and Azoic rocks	

The dilemma of the geoscientists, of the Directorate of Geology and Mining, Govt. of Maharashtra, of finding coal under the cover of the younger sediments (Kamthi) further westwards to the realm of the Wardha Valley Coalfield, in the hollows of the Deccan Traps, outlines that the basin floor for these sediments was much wider, particularly in the western side, and covered more lands than is presently exposed. The faulting presently seen, marking the western limits of these lithics, is a later date structural disturbance and is possibly pre-Trappean in age.

Further, a thick sequence of clay lithics (over 170 m) has been reported in the bore-hole drilled by the Singareni Collieries Company Limited, and is found to overlie the Lower Coal Measures in the bore-holes drilled in the Dorli Mining Block in the



Text-figure 4—Schematic diagram, Stage 2 : Advent of Triassic (Kamthi).

Goleti coalbelt, Godavari Sub-basin. The coal in the incrop regions has analysed to show it to be oxidised, a position analogous to that found in the present day coal outcrops (Personal communication). It is undoubted, therefore, that this marks the palaeoerosional surface of the coal seam over which the clay sequence has been deposited. The question whether the clay sequence belongs to the Middle Measures (Middle Permian) or still higher up in the sequence, i.e., the clay horizons of the Maleri sequence, is still open.

The sum up, such a wider basinal floor for the deposition in the western side of the graben boundaries reveals that :

i) The palaeo-floor was much wider over which the Kamthi and younger sequence were deposited.

ii) The fault contacts now seen along the western contacts of the Gondwana fields are later date phenomena.

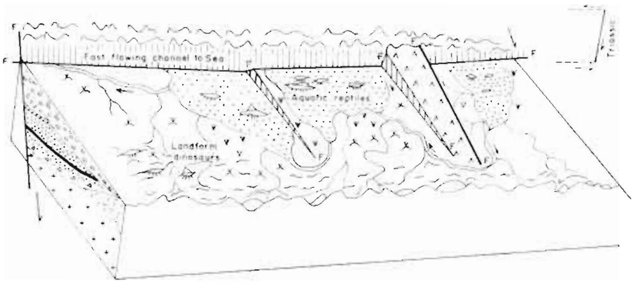
The eastern margin, nonetheless, presents a sharp contact. The Upper Gondwana rocks are abutting against it in the Godavari and Chintalpudi sub-basins, the latter being a recent find by the officers of Geological Survey of India (the Southern Region, Personal Communication).

The geothermal manifestation in the Bugga-Manuguru-Parnshila areas close to the eastern marginal fault and the fact that the epicentre of the 1969 Bhadrachalam earthquake, remnants of which are still noticed in the underground workings of Manuguru underground mine, lay near its vicinity are indications that this fault system may still be an active plane.

The eastern marginal fault plane had greatly contributed to the pari-passu deposition of the Gondwana lithics. It had been periodically activated so as to mould the depositional floor and it is undisputed that it perhaps is still behaving as an active plane.

KAMTHI LITHOLOGY

The Kamthi beds comprise a litho-sequence of medium- to coarse-grained sandstone with low to



Text-figure 5—Schematic diagram, Stage 3 : Mesozoic (post-Kamthi).

scanty matrix. They are whitish to pale brownish in colour but at places exhibit ferruginous/calcareous nature. The grain size varies from medium to coarse and cross-bedding structures are invariably observed. The porosity and permeability is such that invariably at depths they constitute a good acquifer zone for developing the artesian conditions. Two of the GSI bore-wells, which showed a head of over 10 m, have been dedicated to the nation and are maintaining a continuous flow of the water.

The basal beds of these sandstones, however, show remarkable similarity to the underlying Barakar felspathic sandstones possibly due to the latter having provided the immediate provenance for generation of its sediments and often create confusion in the building up of the litho-sequence in the bore-hole. The Kamthi sandstones show inter-stratification of the intraformational pebble beds and the pebble size is generally very small, hardly ranging above 5 cm. These create lots of problems, while negotiating them, in the sub-surface drilling. The sandstones are interbedded with siltstones, shales and clays. The siltstone beds are ferruginated and very hard. The interbeds are intermittent at the base but become more profuse towards the top. The sandstone, being loose and friable, erodes off easily and the terrain is occupied mostly by the soil or the jungle.

The Kamthi facies exhibit in a single cycle of deposition the ferruginated siltstone/claystone at the base which is overlain by the finer clayey clastics, pale brown ferruginous sandstones and is succeeded towards the top by the medium to coarse grained, cross-bedded sandstones, more often ferruginated or calcareous in nature.

The cycle, which shows coarsening upwards, is present in entirety or as a truncated sequence and repeats a number of times until it is overlain by the beds of the Yerrapalli clays (Maleri sequence). At places, particularly in the upper part of this facies sequence, the ferruginated siltstones/claystones are very hard and compact and closely resemble the quartz-arenite rock.

KAMTHI TECTONO-SEDIMENTATION

The fact that the Kamthi sediments have been laid over a wider basin with an angular overlap over the Permian lithics, undoubtedly, indicates relative deepening of the depositional floor due to the greater movement along the eastern marginal fault resulting in the widespread transgression of the depositional waters.

The post-Kamthi sedimentation is an argillo-arenaceous sequence, which dates from Lower/Middle to Upper Triassic, based on the vertebrate fauna. These are believed to be representing continental fluctuating fluvial sediments deposited under the reducing energy regime in the restricted (post-Kamthi) retreating basins during the Early Mesozoic times. Recent findings of these deposits in the Chintalpudi Sub-basin also indicates that they follow the same trend.

Remarkably, there is no record of such beds in the adjoining northern Wardha Valley Coalfield although the palaeo-drainage of the times is believed to be towards north-west. This gap in the data base, therefore, deserves an immediate attention. The tectono-sedimentation outline can be better understood by the cartoons shown in Text-figures 3-5 and Table 1.

DISCUSSION

The Kamthi beds appear to constitute the basal lithics of the argillo-arenaceous Maleri sequence of King (1881). The fact that the Maleri sequence commences with a clay facies (Yerrapalli), which is a deeper but relatively calm water lithic free from the turbulent current action, makes one suspect that the inundated waters earlier must have receded to create such a sedimentological environs for their deposition. Another increase in the water domain must have been responsible for the deposition of the sand facies (Bheemaram) on whose recession the clay (Maleri) were laid down. The top sand facies (Dharmaram) makes yet another inundation of water in the depositional realm.

Now with the inclusion of the Kamthi sequence in this cyclic pattern of inflow and outflow of water one can surmise a tectono-sedimentological condition where the widespread periodic inundation of water is indicated by the sand facies (Kamthi) and the undisturbed argillaceous lithic pile (Yerrapalli), higher up in the sequence, signifies the retreat and stagnation point of these inundating waters.

In keeping with this review of the sedimentation cycle the enlarged Maleri Series now can be assumed to begin with a sand facies and alternate with clay facies until the close of Triassic period (Table 2).

There is strong evidence to consider the Kamthi beds (estimated to be more than 300 m) to constitute the basal part of the enlarged Maleri sequence of the Triassic sequence. The Permo-Triassic boundary in such an event will lie at the angular disconformable plane at the base of the 'Kamthi' beds. Although many questions on sedimentation are yet to be resolved but it is undisputed that the 'Kamthi' cannot by itself constitute an independent 'Formation' on its own merit.

In terms of general geology, however, it is more like a concept in this part of the Indian Gondwana Province as defined by its mode of occurrence and its sedimentation is governed by the associated tectonism.

The main points emanating, thus, are :

(a) Kamthi denotes younger horizon overlapping the Permian lithics and hence cannot be sub-divided, as is being suggested.

(b) Coal is found in two horizons with an included no thicker coal zone in the Permian lithics which lie buried under the initial cover of the Kamthi sediments.

(c) Bouger Anomaly maps of the ONGC show two basinal trends separated by a mid-longitudinal palaeoridge in the master basin.

(d) Eastern marginal fault is still an active plane.

(e) Coal in the eastern longitudinal basin shows higher rank (feebly caking; index below 7) due, perhaps, to the geothermal manifestation.

The questions which, however, still remain unanswered are :

1. Outlet channels to the Narbada sea (?) from the master basin during the Upper Gondwana times when the palaeo-drainage is believed to be towards north-west. It is especially so because there is no record of the presence of these beds in the northern Wardha Valley Coalfield. In this connection, is it not desirable to look for them along the eastern marginal fault, more towards its central part?

2. Presence or absence of Upper Permian lithics under the 'Kamthi' cover in the Wardha Valley Coalfield.

3 The demarcation of the nodal point of separation of the continental fluvial Upper Gondwanas from the coastal Upper Gondwana in the Chintalpudi sub-basin, the cause and reason.

4. The north-western limits of the Pranhita-Godavari master basin. Where do they lie?

A search into these is believed to be much revealing and rewarding.

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Any mission can only succeed if it has the blessings and motivations from the higher management. No word can aptly describe the faith and trust exhibited by Director General, G.S.I., in entrusting the task and for this the author feels elated and expresses his sincere gratitude to him.

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Permian-Triassic boundary in the Peninsula

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ABSTRACT

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The boundary between the Permian and Triassic systems is still a matter of controversy. The traditional view is that the base of the *Otoceras* beds marks the base of the Triassic and hence the top of the Permian. Though the basal Triassic is known, the topmost mariñe Permian is still to be recorded; this gap is not even represented by the non-marine sequence of rocks either in extra-peninsular India or in Salt Range, Pakistan.

In peninsular India, there is an undoubted non-marine (continuous) succession of Upper Permian and Lower Triassic age and no marine beds or intercalations are known. Similarly, from the extra-peninsular India, no terrestrial elements are known from the Upper Permian and Lower Triassic. Hence, the equivalence of the non-marine biozone to that of the marine is not known; only broad generalizations can be made.

The biota known from the non-marine Gondwana Sequence of Upper Permian and Lower Triassic are plants (mega as well miofloral elements), vertebrates and invertebrates, which include estheriids, insects and anthracosids. The vertebrates and invertebrates are known from the Upper Permian but are so few in number, that these can not be taken for discussion on Permian-Triassic boundary problems.

On reviewing the biota in the various peninsular basins, the Damodar Basin is considered significant for the problem of Permian and Triassic boundary. In the Raniganj Coalfield five sections, namely, Tatulakh, Machkunda Jhor, Banspatelli, Nunia Nala and Nunia Khal have been studied extensively.

Summarizing, following points are worth notice:

1. There was a peak development of the Glossopteris Flora in the upper part of the Raniganj Formation. Normally, the peak development takes place just before the extinction. The complete extinction does not rule out the lingering of older forms.
2. The appearance of *Lepidopteris* and the small forms of *Dicroidium* is noted in the basal Panchet.
3. *Glossopteris* though became extinct at the lower altitudes has probably withdrawn to the higher altitudes, the climatic conditions of which was more akin the lower level. *Dicroidium* also was thriving simultaneously at higher altitudes at that time.
4. Higher up in the sequence but in the lower altitudes, *Lystrosaurus* and *Estheriella* appear.
5. The miofloral zonations with respect to Raniganj and Panchet formations particularly with respect to *Lystrosaurus* Zone, *Estheriella* Zone and *Lepidopteris* Zone are to be noted.

In the light of all above considerations, the problem of Permian and Triassic boundary is being reviewed.

Key-words— *Otoceras,* Glossopteris Flora, *Dicroidium,* Permian-Triassic boundary.

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Depositional model and tectonic evolution of Gondwana basins

S. M. Casshyap & R. C. Tewari

Casshyap, S. M. & Tewari, R. C. (1988). Depositional model and tectonic evolution of Gondwana basins. *Palaeobotanist* **36** : 59-66.

The paper analyses sedimentary evolution of Gondwana basins of Indian peninsula based on lithofacies, their association, dispersal and sedimentary characters from lowermost glacial Talchir (basal Permian) through Karharbari, Barakar, Barren Measure, Raniganj to Mahadeva (Middle Triassic). Particular attention is focussed on the role of formative processes and interaction of tectonism and climate on sedimentary evolution and basin configuration.

Key-words—Tectonic evolution, Gondwana, Depositional model, Indian Peninsula.

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साराँश

गोंडवाना द्रोणीयों का निक्षेपणीय प्रतिरूप एवं विवर्तनिक विकास

एस० एम० कश्यप एवं आर० सी० तिवारी

इस शोध-पत्र में करहरबारी, बराकार, बैरन मेज़र्स व रानीगंज नामक चरणों से गुजरते हुए अधरितम् हिमानी तालचिर (आधारी परमी) से महादेवा (मध्य त्रिसंघी) तक शैल-फेसीज़, इनका साहचर्य, विकीरण एवं अवसादीय लक्षणों के आधार पर भारतीय प्रायद्वीप की गोंडवाना द्रोणीयों के अवसादीय विकास का विश्लेषण किया गया है। अवसादीय विकास एवं द्रोणी संरचना पर रचनात्मक प्रक्रियाओं तथा विवर्तनिकता एवं जलवायु की अन्त:क्रिया की भूमिका पर विशेष ध्यान दिया गया है।

PAST fifty years have seen rapid growth of literature on sedimentology of Gondwana Sequence of peninsular India. Depositional facies models have been developed for various formations of peninsular Gondwana basins. Even so our understanding of Gondwana basins is limited with respect to the framework of Gondwana basins, their depositional limits, and geomorphic, tectonic and climatic control on lithofacies dispersal and evolution of Gondwana lithic-fill through time and space.

The paper summarises sedimentary characters and lithofacies dispersal in Gondwana basins of the Peninsula. An attempt is made to analyse sedimentary evolution of Gondwana basins based on lithofacies dispersal from Talchir (basal Permian) to Mahadeva (Middle Triassic), with particular reference to geomorphic, tectonic and climatic setting.

LITHOFACIES DISPERSAL AND DEPOSITIONAL MODELS

Glacigene sedimentation

Gondwana sedimentation in peninsular India was initiated by deposition of glacigene Talchir sediments on uneven Precambrian basement, as

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preserved and available in three major basins of Koel-Damodar, Son-Mahanadi, Pranhita-Godavari and Satpura, and in small isolated basins. Several attempts have been made to interpret depositional environments and palaeogeography of Talchir sediments locally and regionally (Banerjee, 1966; Casshyap & Qidwai, 1974; Casshyap & Tewari, 1982; Casshyap & Srivastava, 1987; Frakes *et al.*, 1975; Ghosh & Mitra, 1975; Dickins & Shah, 1979; Datta *et al.*, 1979).

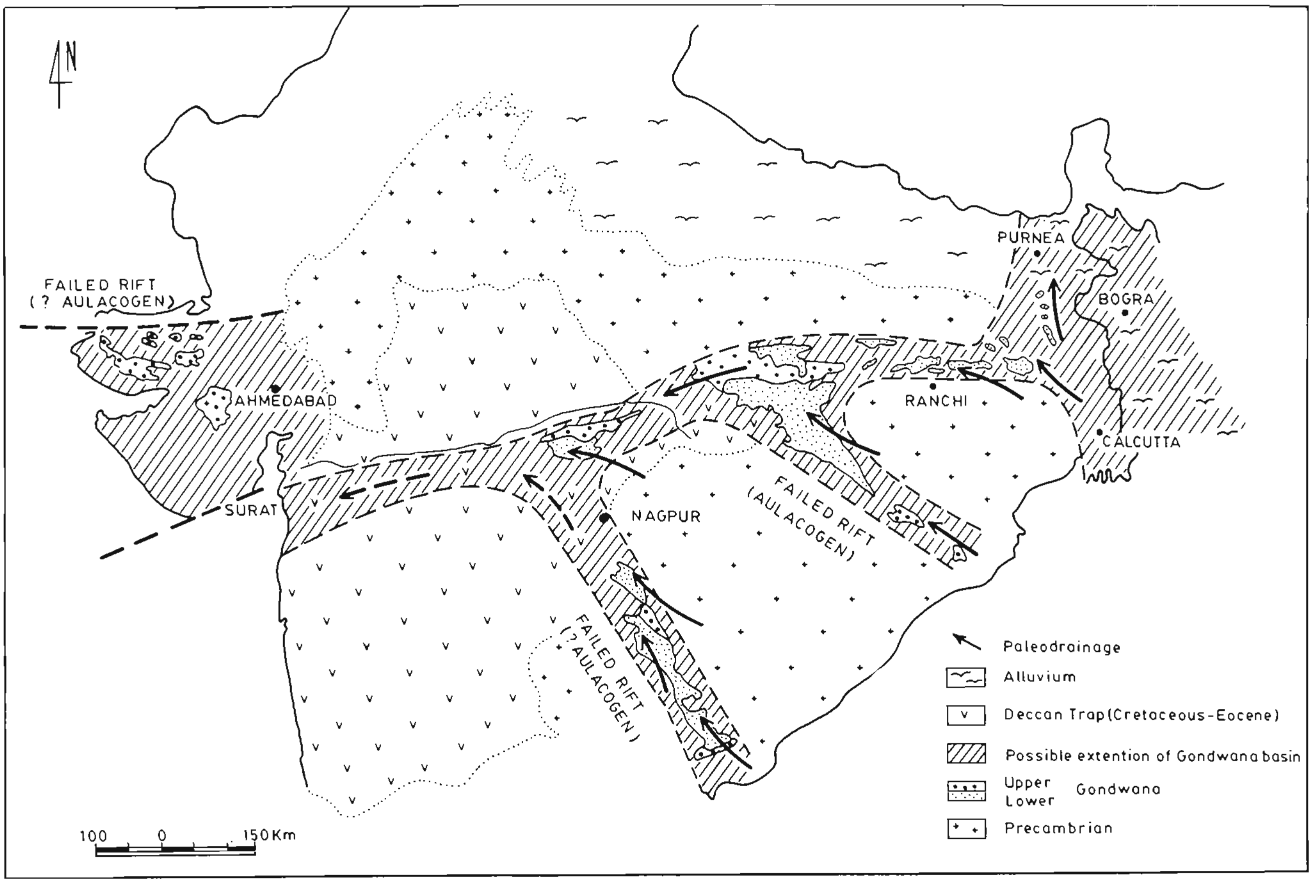
The Talchir sediments lying unconformably on Precambrian basement are marked by uniformly green colour and are composed of typical glacigene facies including tillite, conglomerate, sandstone, rhythmite and laminated shale. The tillite is locally massive but generally stratified, and occurs as thin beds in association with conglomerate, sandstone or shale. The conglomerate facies, as and where developed, commonly in upper part, occurs in channel-like elongate bodies and may be massive, stratified to cross-bedded. Majority of embedded lithoclasts in tillite and conglomerate are derived locally from bordering Precambrian highlands. Some lithoclasts of massive basal tillite are pentagonal in shape and may exhibit striations. Indeed, there is distinct increase in roundness and homogeneity of lithoclasts from tillite up to conglomerate (Tewari, in Press). The coarse clastic facies, by and large, occur in proximal parts near basin margins (Casshyap & Tewari, 1982; Casshyap & Srivastava, 1987). The sandstone facies occurring throughout the sequence in varying abundance is massive to thinly bedded, whereas those of upper part are profusely cross-bedded. The interbedded sequence of fine sandstone/siltstone and shale (rhythmite) is characterised by occasional sole structures, dropstones, ripple marks, and ripple- and flaser bedding. The interbedded facies occurs as thick units associated with channel-fill sandstone both laterally alongside and in downslope direction. Thin limestone beds are also associated with interbedded facies in some places. The laminated shale is the dominant facies of Talchir sediments in the areas away from the basin margin and in downslope direction.

Palaeoice transport based on striated pavement, till fabric and matching of lithoclasts composition reveals inward ice movement from basin margins locally and from south-east to north-west regionally in various Gondwana basins (Casshyap & Qidwai, 1974; Casshyap & Srivastava, 1987; Ahmad *et al.*, 1976). Similar northwesterly palaeo-drainage is deduced from associated outwash conglomerate and sandstone (Casshyap & Tewari, 1982).

The varying facies assemblage of Talchir sequence in different basins does not favour a uniform regional depositional facies model. Besides the limited basal tillite of glacial origin, the Talchir sediments generally favour mixed facies of glacio-fluvial, glacio-lacustrine and/or shallow marine to tidal flat environments. The occurrence of marine invertebrate fauna near Umaria and Manendragarh in central India (*see* Sastri & Shah, 1964) is the only direct evidence of marine influence, but lack of fauna elsewhere is no justification to rule out marine environment altogether. Recently Casshyap and Srivastava (1987) demonstrated that Talchir sedimentation took place in glacial valleys in southern upland terrain and broad open shelf (delta plain?), influenced by tidal channels, in the low lying northern terrain in Son-Mahanadi Basin, and thus raised the possibility of marine influence in several other low lying areas of central and eastern India depending upon the basement configuration of the basin and its location (Srivastava *et al.*, 1988).

Fluvial sedimentation

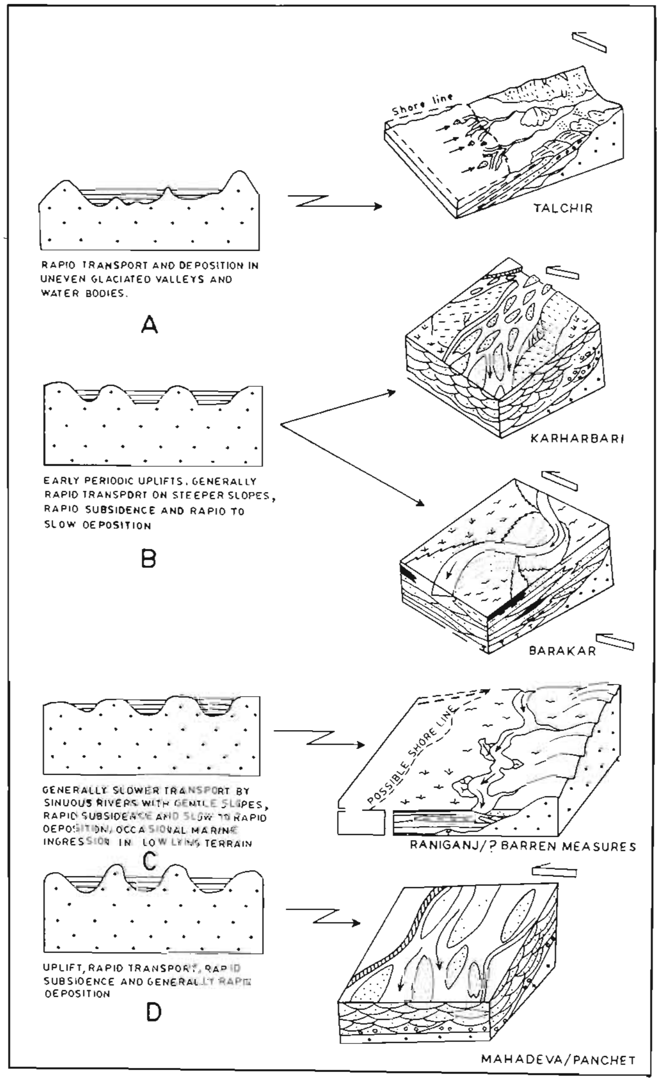
Karharbari Formation — The first phase of fluvial sedimentation is recorded by Karharbari sediments lying gradationally on the glacial outwash deposits. These fluvial sediments, occurring in discontinuous patches with a maximum thickness of about 300 m overlap, lie unconformably on the Precambrian basement, and cite evidence of expansion of the basin at this stage. Palaeohydrological studies from several basins suggest that Karharbari streams were low sinuous (1.12-1.25) with high width/depth ratio (53-68), flowed relatively down the steeper palaeoslope (65 cm/km) from south-east to north-west in most basins (Casshyap & Khan, 1982a; Casshyap & Tewari, 1984). The basal Karharbari is characterised by conglomerate bodies particularly in proximal parts, as in the southern part of Talcher Coalfield of Mahanadi Basin and East Bokaro Coalfield of Damodar Basin. The conglomerates are clast supported, elongate channel like, and massive to cross-bedded resembling longitudinal braid bars of medial alluvial fans. The recurrence of conglomerate in the upper Karharbari in southern part of Talcher Coalfield may be attributed to a minor tectonic uplift in the source land to the south-east. The conglomerate facies rapidly merge into multistorey and multilateral coalescing channel bodies of pebbly and gritty to coarse and medium sandstone, similar to the facies characterising distal alluvial fans. The bulk of the succeeding Karharbari consists of fining upward asymmetrical cycles in which the lower sandstone member exceeds the upper shale and coal (Casshyap & Khan, 1982b; Tewari & Casshyap, 1983). The sandstone facies characterised by cosets



Text-figure 1—Map of peninsular India showing the distribution of Lower Gondwana basins and their possible original limits and areal extension underneath the younger traps along Narmada lineament in west and Ganga alluvium in northern Bihar and Bengal in the north.

of planar and trough cross beds has been attributed to longitudinal and transverse braid bars (Casshyap & Tewari, 1984). Thin bodies of shale capping channel sandstone represent vertical accretion during shifting and abandoning of channel. The Karharbari coals are evidently thin, laterally impersistent and show frequent splitting, typical of restricted peat swamps developed in the abondoned channels and distal crevasse splays of braid plain. A statistical analysis of lithologic variables reveals close association of channel sandstone and coal justifying the development of coal swamps in abandoned channels (Casshyap *et al.*, in Press).

Barakar Formation — Following the deposition of gravelly and sandy Karharbari, unified Gondwana basins further expanded areally to accommodate thick (880 m) and extensive Barakar sediments as is evident by overlapping of the Barakar sediments on to the underlying basement in several parts. The channel patterns of Gondwana streams demonstrate a progressive metamorphosis in their sinuosity from Karharbari through lower to upper Barakar. The Barakar streams were relatively sinuous (1.45-2.05) with low width/depth ratio (21-42). The palaeoslope remained unchanged during Barakar time trending more or less southeast-northwest and was more gentle (52 cm/km) than that of the underlying Karharbari. The resultant Barakar sediments, throughout, are made up of recurring fining upward symmetrical cycles of coarse to medium sandstone, interbedded fine sandstone/siltstone and shale, and coal (Casshyap, 1970; Casshyap & Khan, 1982b; Casshyap & Tewari, 1984; Tewari & Casshyap, 1983). The Barakar sandstone is commonly channel-shaped in lower part to tabular sheet-like in upper part showing abundant cosets of planar and trough cross beds; it has been attributed largely to channel shifting and lateral accretion of point bar. Associated thick persistent beds of thinly bedded fine sandstone/shale and carbonaceous shale correspond to levee deposits. Indeed, the fine clastic facies show a progressive increase in thickness and bulk volume from Karharbari through lower to upper Barakar. The Barakar coals are thick, laterally continuous and are associated with channel-fill sandstone and fine clastic levee deposits. Extensive



Text-figure 2—Generalised schematic representation of palaeoprofile, topographic and tectonic setting, and patterns of Gondwana sedimentation from glacigene Talchir to fluviatile Mahadeva formations. Note the proximity of shore line to account for periodic ingression.

occurrence of coal seams in Barakar has been attributed to protected peat swamps developed in distal flood plains and protected lakes of meandering streams (Casshyap, 1970; Casshyap & Tewari, 1984). The progressive decline in channel sandstone and increase of fine clastics through time from Karharbari up to Barakar and down the palaeoslope in each basin is suggestive of progressive maturity of source land owing to prolonged erosion due to amelioration of climate and without pulses of uplift, and increase in channel sinuosity through space and time, as sedimentation progressed.

Barren Measure—Brown to reddish, dominantly clastic sequence of Barren Measure (800 m) which overlies the Barakar gradationally, but otherwise barren of coal, is more widespread in coalfields of Koel-Damodar Basin than in Son-Mahanadi and other basins. The Barren Measure is composed essentially of channel-like coarse to medium cross-bedded sandstone interbedded with siltstone, grey to red micaceous shale. The channel sandstone and fine clastic facies have been attributed to deposits of point bars and overbank levees of meandering streams which flowed dominantly upon pre-existing palaeoslope from southeast to northwest. Local discovery of phosphorite from Barren Measure of Ib-River Basin of southeastern Madhya Pradesh by the Geological Survey of India (communication by N. D. Mitra, 1987) is indeed interesting and calls for proper reconstruction and shifting of shore line during the course of fluviatile Gondwana sedimentation.

Raniganj Formation—As Gondwana basins grew in size through time, the Raniganj sediments were deposited gradationally above Barren Measure. These sediments are more widely developed in Koel-Damodar Basin with maximum thickness of 1,035 m than in other Gondwana basins. The Raniganj is likewise, represented by fining upward cycles of coarse to medium sandstone, interbedded fine sandstone/shale and coal (Casshyap & Kumar, 1987). Thin lenses of pebbly sandstone are locally recorded from the southern part of North Karanpura Basin. Raniganj sandstone is channel- to tabular-shaped, showing abundant planar and trough cross beds. Associated thinly interbedded fine sandstone/shale occur as thick and laterally persistent units exhibiting parallel lamination, ripple cross lamination, and rib-and-furrow structure. Coal occurs as thin to moderately thick seams, laterally persistent for several tens of kilometers interbedded with fine clastic facies. The reported occurrence of Jhingurdah coal seam as thick as 160 m from Raniganj sediments of Singrauli Coalfield of Son Basin is an exception. Facies models based on facies assemblage, sedimentary structures and their inter-relationship and consistency in palaeo-drainage directed toward northwest and west suggest unified nature of Damodar basins during Upper Permian Raniganj time (Casshyap & Kumar, 1987). Palaeohydrologic study reveals deposition of Raniganj sediments largely by meandering and locally by braided streams in the lower part. Indeed, the sinuous pattern of Raniganj streams shows a marginal increase in channel sinuosity in the downcurrent direction in Damodar Basin from east to west.

Triassic Gondwana—The Triassic Gondwana sediments collectively referred to as Mahadeva or classified as Panchet/Lugu/Kamtini/and Maleri in various basins, are markedly different from the underlying Raniganj sediments. These Upper Gondwana sediments with a maximum estimated thickness of 1,000 m constitute thickly forested high grounds as and where they occur in Raniganj, Bokaro, North Karanpura and adjoining coalfields of Koel-Damodar Basin, southern and northern parts of Son-Mahanadi Basin and Pranhita-Godavari and Satpura basins. Indeed, the Triassic sedimentation covered most of the peninsular basins, and their absence from certain critical areas such as the Jharia Coalfield of Damodar Basin and central part of Son-Mahanadi Basin can only be explained by post-Triassic tectonic uplift and subsequent erosion of Upper Gondwana sediments (Casshyap & Tewari, 1984, p. 122).

Generally speaking, the Triassic Gondwana sediments abound in pebbly coarse to medium sandstone. Sandstone bodies are thick (4-7 m), channel-like, showing abundant cosets of planar and trough cross-bedding. The associated interbeds of shale are grey, micaceous to red in colour; they are thin (2 m) in lower part of Mahadeva sequence of Rewa-Son Basin and thick (3-4 m) in upper part, and in westerly downcurrent direction. Overall lithofacies association and sedimentary characters of Mahadeva sediments are suggestive of their deposition by westerly and southwesterly flowing system of bed load braided streams; the channel pattern became moderately sinuous in the downcurrent direction in the west (Tewari, in preparation).

TECTONIC SETTING

The origin of intracratonic basins in the peninsular shield during Late Palaeozoic time and their prolonged subsidence to produce thick pile of classical Gondwana Sequence is a fundamental problem of global tectonics which is seriously engaging the attention of modern sedimentologists. Pranhita-Godavari-Satpura and Son-Mahanadi basins, oriented transversely to the present day east coast are, undoubtedly, linear basins elongating southeast-northwest in the direction of palaeoslope (Text-fig. 1). These basins may have coincided with ancient crustal lineaments and represent reactivated Permian grabens or, more precisely, failed rifts. Their lithofacies dispersal and palaeodrainage and subsequent reversal by and large demonstrate the character of aulacogens. The Koel-Damodar Basin now represented by a large number of disconnected coalfields of Bihar and Bengal, including those of Rajmahal to the north seems to have been considerably truncated and modified as a consequence of large scale post-Gondwana faulting and erosion (Casshyap, 1977). This basin was possibly areally much more extensive, interrupted locally by Precambrian highlands. Tectonically, this basin may represent a regional sag in the crust or half graben, but not a typical linear rift as visualised by Fox (1934) and others.

The problem of origin of Gondwana basins of the Peninsula remains an open question until sufficient surface and subsurface evidences are obtained in support of their tectonic setting.

BASIN EVOLUTION AND PALAEOGEOGRAPHY

Text-figure 2 a-d illustrates systematic evolution of peninsular Gondwana basins through time from Talchir up to Mahadeva.

Talchir glacial basins

Indeed, there is not enough evidence to support the early concept (Fox, 1934; Pascoe, 1959) that the Late Palaeozoic glaciers occurred as continental sheet in the Indian Peninsula, which occupied an estimated palaeolatitude of the order of about 50°S and 60°S during Late Palaeozoic (Runnegar, 1979). The available evidence, at most, favours mild glaciation in peninsular India similar to the temperate valley glaciers (Casshyap & Srivastava, 1987) (Text-fig. 2a).

It is more likely that Talchir glaciers were derived from ice-caps occupying the highlands in the proximity of various basins (Frakes *et al.*, 1975; Casshyap & Srivastava, 1987). The bulk of glacial sedimentation in each basin was brought about during the retreat of glacial lobes. Thin and impersistent massive tillite may correspond to deposits laid down directly on the basement. These basal tillites outcrop commonly in the proximity of highlands near the margin or within the basin wherever they occur. The stratified tillites are, however, more common; they are thin, laterally more persistent than massive basal tillite and occur at different horizons in the Talchir sequence. These tillites are evidently attributed to reworking by meltwater/subglacial water soon after they were deposited by glaciers or dropped as large chunks (icebergs) by floating ice in the underlying body of water in different parts of basin. Indeed, the stratified tillites are occasionally associated with stratified to cross-stratified channel-like bodies of conglomerate and coarse pebbly sandstone as reported from different basins (Casshyap & Tewari, 1982; Casshyap & Srivastava, 1987).

The rapid gradation of lithofacies from margin towards inner part of basin, particularly conspicuous in Son-Mahanadi Basin especially in Talcher, Korba and Manendragarh areas, is apparently not so remarkable in Koel-Damodar and other basins. Rapid dispersal of lithofacies in marginal parts is genetically significant and has been attributed primarily to the pre-existing basement profile of the basins (Casshyap & Srivastava, 1987). The pre-Talchir basement profile in Son-Mahanadi Basin was much too uneven owing to the occurrence of the older granitoid uplands, providing a net-work of interconnected valleys and sub-basins. Apparently, the basement profile was not so in the case of Koel-Damodar as is evident from lack of granitoid inliers through the Talchir terrain. It is therefore reiterated that basement profile was the dominant factor in controlling patterns of Talchir sedimentation in each basin.

The meltwater streams from receding ice-caps evidently brought down and deposited the bulk of Talchir sediments in the overlooking basin laterally and longitudinally down the slope. The evidence from lithofacies arrangement, texture and structure, by and large, favour intermixing of environments from time to time and at any given place including fluvial, lacustrine and shallow marine tidal to eustary. Of these, the lacustrine and/or shallow marine tidal flats/estuary seem to be more widespread than generally believed and reported. Surely, the marine Talchir can not remain restricted to a few outcrops where invertebrate fossils have been reported. The overall lithofacies association, general paucity of largescale trough cross stratification, occasional occurrence of flat bedding, wave ripples and wave ripple bedding, flaser bedding calcareous nodules and calcareous shale, and overall preponderance of green colour are some of the features indicating periodic intermixing of lacustrine and shallow marine tidal flats through most part of the Talchir sequence.

The fluvial influence became more prominent in upper part owing to amelioration of climate and increase in meltwater streams as indicated by interbedding of profusely cross-bedded channel sandstone locally associated with carbonaceous shale, and occurrence of dark grey rather than green shale. The palaeodrainage initiated by receding glaciers remained unchanged as the fluvial streams became dominant towards the end of Talchir sedimentation. It is here suggested that the marine influence and shore line receded locally and regionally gradually with the retreat and termination of Talchir ice lobes and consequent regional uplift.

Post-glacial fluviatile basins

At the end of glacigene sedimentation, and with the advent of well-defined fluvial system, the Gondwana basins expanded areally and became more or less unified into three linear basins of Koel-Damodar, Son-Mahanadi and Pranhita-Godavari and Satpura (Text-fig. 1). These linear basins became the site of fluvial sedimentation which continued more or less uninterruptedly for about 70 Ma to produce some 4,000 m thick pile of sediments represented by Karharbari, Barakar, Barren Measure, Raniganj and Mahadeva in different basins.

The fluvial system of streams transported and deposited essentially quartzose gravels and coarse sand. These basal clastics known as the Karharbari Formation abound in conglomerate/pebbly sandstone, and coarse to medium sandstone with thin interbeds of shale and coal. The mature, monomictic clast supported conglomerate may well be indicative of early periodic uplifts at the onset of Karharbari sedimentation. Steeper slopes on account of periodic uplifts became the site for braided and anastomosed Karharbari streams to transport abundant bed load. Associated distal fan facies represented by pebbly coarse arkose to subarkose is indicative of rapid deposition and rapid subsidence (Text-fig. 2b). Rapid subsidence and frequent shifting of braided channels should have prevented development of thick peat swamps to produce only thin, impersistent and splitted coal seams such as those which characterise the Karharbari Formation. The occurrence of a distinct and well-developed (~ 40 m) conglomeratic horizon in the uppermost Karharbari in Talcher and IB-River coalfields of Mahanadi Basin is suggestive of yet another episode of tectonic uplift at the end of Karharbari sedimentation.

As sedimentation progressed, the topography of source land located to southeast of each basin, progressively became mature. The Gondwana streams, consequently, underwent progressive metamorphosis in channel from braided, moderately sinuous to meandering to deposit the lower, middle and upper Barakar sediments, respectively. At this stage the expanded basins areally became unified into longitudinal alluvial plains, apparently bigger in size than their present limits (Text-fig. 1). The sinuous to meandering Barakar rivers loaded with abundant mixed- and suspended load flowed on gentle palaeoslope from southeast to northwest. The resultant sediments are characterised by a progressive increase in the fine clastic facies through time from lower to upper Barakar and along the length of the basin in downcurrent direction. The lithofacies composition and their dispersal, abundance of fine clastics and absence of conglomerate horizons, and immature to submature sandstone are indicative of rapid to slow deposition and rapid subsidence of Lower Permian Barakar sediments (Text-fig. 2b). Overall, the Barakar sediments lack evidence of pronounced tectonic uplifts and are suggestive of continued amelioration of climate which matured the topography of source land more than the underlying Karharbari.

The bulk of overlying Barren Measure and Raniganj sediments were deposited largely by meandering streams flowing on a distinctly gentle palaeoslope directed towards northwest and west. These meandering streams deposited greater amount of suspended sediments than the underlying Barakar. Petrographically, the Raniganj sandstones are subarkosic to arkosic arenites and texturally immature to submature. It is suggested that the bulk of Upper Permian sediments may represent slow to rapid deposition and rapid subsidence. Owing to near flat topography and proximity of shore line in the north, it is possible there may have been marine ingressions in the low lying terrain during Barren Measure and Raniganj sedimentation, occasionally, in response to pulses of rapid subsidence (Text-fig. 2c).

Evidence from lithofacies of Triassic Gondwana rocks suggests a fresh episode of tectonic uplift and readjustment of palaeoslope at the onset of Upper Gondwana sedimentation. The Triassic Gondwana sediments record a sudden increase in coarse clastic including pebble beds (Text-fig. 2d) and decline in bulk fine clastics as compared to the underlying Permian sediments. Further, the northwesterly palaeodrainage so well established in the Upper Permian was slightly readjusted towards west and southwest, in response to tectonic uplift. The coarse clastic sediments of Pachmarhi, and Mahadeva resembling those of the Early Permian Karharbari were deposited largely by braided streams which became moderately sinuous in the downcurrent direction. The occurrence of red bed facies may call for semi-arid climate during Triassic times.

CONCLUDING REMARKS

About 140 Ma prior to the rifting of Indian Plate, the Gondwana sedimentation in the Peninsula was brought about in linear intracratonic basins during the retreat of ice lobes at the beginning of Permian Period (Asselian). The primitive Gondwana basins which were confined to narrow-to-broad glacial valleys grew in size with the onset of fluviatile sedimentation at the termination of Talchir ice age in Early Permian. The basins expanded areally through time as sedimentation progressed through Middle and Upper Permian up to Triassic. The northwesterly to northerly palaeodrainage established at the onset of glacial outwash remained more or less unchanged throughout the Permian, and shifted slightly towards west and west-southwest during Late Permian to Middle Triassic, respectively, particularly in the central tract along the Narmada lineament.

It is suggested that the progressive maturity of source land topography due to prolonged amelioration of climate from glacial, cold, warm to semi-arid exerted greater control on Gondwana sedimentation than basinal and extrabasinal tectonics. However, periodic tectonic uplifts were operative during crustal rebound in Early Permian following the retreat of Talchir ice lobes and again in Early Triassic as is evident by the occurrence of conglomeratic and pebble bed horizons, and the preponderance of coarse arkosic to subarkosic sandstones. Lack of corroborative rock records implies that end of Triassic witnessed a period of non-deposition in the intracratonic basins throughout the Peninsula, although transgressive Jurassic Sea had inundated parts of western margin of Indian Shield in Kutch and western Rajasthan, beyond realm of Gondwana basins. Deltaic to paralic and shallow marine sedimentation continued during the Cretaceous Period selectively in cratonic embayments along Narmada lineament in west and in localised coastal (?) troughs (basins) of Gujarat and along the east coast, as also in southern parts of the pre-existing Gondwana troughs, following the reversal of palaeoslope to the south and creation of the east coast and the sea after separation of India from Antarctica. The palaeoslope so established some 140 Ma ago in Early Cretaceous time has remained practically unchanged till present time.

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Depositional history of the basal Barakar beds—a study from Ramgarh Coalfield, Hazaribagh District, Bihar

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Bhattacharya, A. (1988). Depositional history of the basal Barakar beds—a study from Ramgarh Coalfield, Hazaribagh District, Bihar. *Palaeobotanist* **36** : 67-73.

The rock record of the basal Barakar Formation of the Ramgarh Coalfield, Hazaribagh District, Bihar has been interpreted as an ancient example of the sandur deposit, i.e., a glacial outwash plain deposit having two distinct units as—(a) channel facies divisible with riffles and pools, and (b) interchannel bar facies. Each of the facies of the environment in its stratigraphic set up, lithological attributes, sedimentary structural assemblage and palaeocurrent pattern correspond to one in the model.

The lenticular and sheet-like gravelly and pebbly sandstones with crude and sharp parallel stratifications, graded beds and scour- and fill structures characterise the bar facies whereas, coarse arkosic sandstones with ripple and megaripple bedding, lenticular to planar cross-beds, and buried megaripple trains characterise the riffles of the channel facies. Gravel lenses at regular intervals have been related to the transverse ribs of the riffle facies. The lenticular sandy shales, siltstones and carbonaceous shales within coarse sandstones have been interpreted to be the pools of the channel facies. Palaeocurrent direction within the basal Barakar beds swings between NW to NNW.

The basal Barakar beds, at the bottommost part maintain a gravel: sand ratio to the order of 40 : 60; the proportion of sand, however, increases upwards. The gravelly and pebbly sandstone are highly indurated with fresh feldspars in all cases. The gravels are rounded to well rounded with high sphericity values.

Depositional features exhibit an uninterrupted pattern of sedimentation from the glacial Talchir Formation, through the sandur basal Barakar beds to the true fluvial Middle and Upper Barakar beds till the end of the Ironstone Shale Formation. The sandur sedimentation model with channel and bar facies as identified from the basal Barakar beds of Ramgarh Basin has also been presented in a block diagram.

Key-words—Stratigraphy, Sedimentation, Depositional history, Ramgarh Coalfield, Barakar (India).

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साराँश

आधारी बराकार संस्तरों का निक्षेपणीय इतिहास–हजारी बाग़ जनपद (बिहार) में रामगढ़ कोयला-क्षेत्र का अध्ययन

अशोक कुमार भट्टाचार्य

हज़ारी बाग़ जनपद (बिहार) में रामगढ़ कोयला-क्षेत्र की आधारी बराकार शैल-समूह की चट्टानों के अभिलेख की व्याख्या सेन्दुर निक्षेप के एक प्राचीन उदाहरण के रूप में की गई है। इसमें (अ) कुंड प्रखातिकाओं में विभक्तनीय संलक्षणी प्रणाल, तथा (आ) भित्ति अन्तर-प्रणाल संलक्षणी नामक दो विभिन्न इकाईयाँ हैं। वातावरण का प्रत्येक प्रणाल स्तरविन्यास, शैलविन्यास, अवसादीय समुच्चय तथा पुराप्रवृत्ति के ढंग में आपस में अनुरूप हैं। स्पष्ट समानान्तर स्तरणों, क्रमिक संस्तरों एवं निर्घर्षपूर्ण संरचनाओं से युक्त मसूराकार एवं चादर के समान बजरीली तथा गुटिकामय बालुपत्थर दंड-संलक्षणी के लक्षण हैं जबकि ऊर्मिका एवं गुरुऊर्मिका वाली संस्तरों से युक्त मोटी आर्कोजी बजरी, मसूराकार और समतल क्रॉस संस्तर तथा अंतर्हित गुरुऊर्मिका श्रृंखला प्रणाल संलक्षणीयों की प्रखातिकाओं के लाक्षणिक गुण हैं। निश्चित अंतराल पर बजरीमय-लैंसों को प्रखातिका संलक्षणीयों के अनुप्रस्थ भाग से सम्बद्ध किया गया है। मसूराकार बलुई शैलों, पाँशुप्रस्तरों एवं मोटे बालुपत्थरों में विद्यमान कार्बनी शैलों की व्याख्या प्रणाल संलक्षणीयों के कुंडों के रूप में की गई है। आधारी बराकार संस्तरों में पुराप्रवृत्ति की दिशा उत्तर-पश्चिम से उत्तर-उत्तर-पश्चिम के बीच प्रेक्षित की गई है। आधारी बराकार संस्तरों की निचली तली में बजरी एवं बालु 40 : 60 के अनुपात में मिलते हैं, हालाँकि बालु की मात्रा ऊपर की ओर बढ़ जाती है। बजरीमय एवं गुटिकामय बालुपत्थर साफ़ फेल्डस्पार

Concepts, limits and extension of the Indian Gondwana
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की उपस्थिति के कारण अत्यधिक कठोर हो गये हैं। इनमें विद्यमान बजरी गोलाकार है। निक्षेपणीय संलक्षणों से हिमानी तालचिर शैल-समूह के अवसादन का अखंडित स्वरूप प्रदर्शित होता है। यह अवसादन आयरनस्टोन शैल शैल-समूह की समाप्ति तक सेन्दुर आधारी बराकार से यथार्थ नदीय, मध्य एवं उपरि बराकार तक हुआ था। प्रणाल एवं दंड संलक्षणी सहित सेन्दुर अवसादन का नमूना भी जैसा कि रामगढ़ द्रोणी के आधारी बराकार संस्तरों से अभिनिर्धारित किया गया है, एक त्रिआयामी-चित्र के रूप में प्रस्तुत किया गया है।

THE sedimentary sequence of the Ramgarh Coalfield, Bihar belongs to the Gondwana Supergroup of the Koel-Damodar Valley. The basin was first discovered by D. H. Williams around 1848 and was subsequently studied by Ball (1867), Fox (1934), Ghosh (1950), Mehta and Joshi (1962), Sen (1967) and Rao *et al.* (1969).

The Gondwana Sequence covers a total 60 sq km area and occurs as an outlier of the Karanpura and Bokaro coalfields (Text-fig. 1). From the east to the west of the semi-triangular basin, three Lower Gondwana formations, viz., the Talchir, the Barakar and the Ironstone Shales grade from one to the other without any noticeable break in sedimentation. Of the three formations, both Talchir and Ironstone Shale have patchy and localized occurrences whereas, the Barakar Formation occupies the major part of the basin. The Barakar Formation, in almost all Gondwana basins, is marked by a sedimentary sequence having a general rhythmic alternation of two contrasted lithofacies which include— (a) poorly sorted coarse white arkose, interbedded with siltstone and conglomerate; and (b) well-stratified sheets of shales, siltstone and coal. The former association is related to a channel facies whereas, the latter to interchannel flood facies (Banerjee, 1963; Sengupta, 1970).

Many workers have recognised three distinct units, viz., Basal or Lower, Middle and Upper within the Barakar Formation. The basal Barakar beds have often been confused with the Karharbari Formation so far as their sedimentological characters are concerned. The basal Barakar beds or in some cases the rocks of Karharbari Formation have been supposed to be a channel or braided stream deposit (Casshyap, 1979) and piedmont alluvial plain deposit in intermontane valleys (Rao *et al.*, 1969).

Lithological and structural features of the basal Barakar beds as studied from Ramgarh Coalfield, however, suggest their generation from a sandur deposit, i.e., a glacial outwash plain deposit having many channels and interchannel bar facies in close interlacing network. Such a depositional environment for the basal Barakar beds has been suggested for the first time from the Indian Gondwana. The present paper attempts to enumerate the evidences that lead to the understanding of such a depositional environment for the basal Barakar beds of the Ramgarh Basin and their relationship with the underlying Talchir Formation and immediately overlying the Middle and Upper units of the Barakar Formation.

THE BASIN

The Ramgarh Coalfield situated between 23°35′N to 23°42′N and 85°30′E to 85°45′E, in eastern India is a more or less triangular east-west trending sedimentary basin (Text-fig. 1) of the intracratonic type. The sedimentaries belong to the Lower Gondwana group and are divided into three formations, Talchir, Barakar, and Ironstone Shale. The greatest width is 14 km in the eastern part which tapers out to the west for an east-west extension of about 20 km, with a west-central zone of constriction of the basin where the width comes to be 1.5 km.

The basin is surrounded by the Chhotanagpur Archaean metamorphites on all sides and downfaulted within them along the southern boundary. Except for a few shallow synformal and antiformal flexures the Barakar beds are generally within 30° dip. A number of oblique faults have also been reported (Mehta & Joshi, 1962).

The basin is dissected in the central part by the westerly flowing Damodar River and in the eastern part by the northerly flowing Vera River. Exposures of Gondwana rocks can be well-studied from these river sections, road and railway cuttings and on the excavation faces of the Rajrappa Colliery. The Gondwana rocks have a general dip towards west, north-west and south-west with an amount ranging mostly between 10° and 30°.

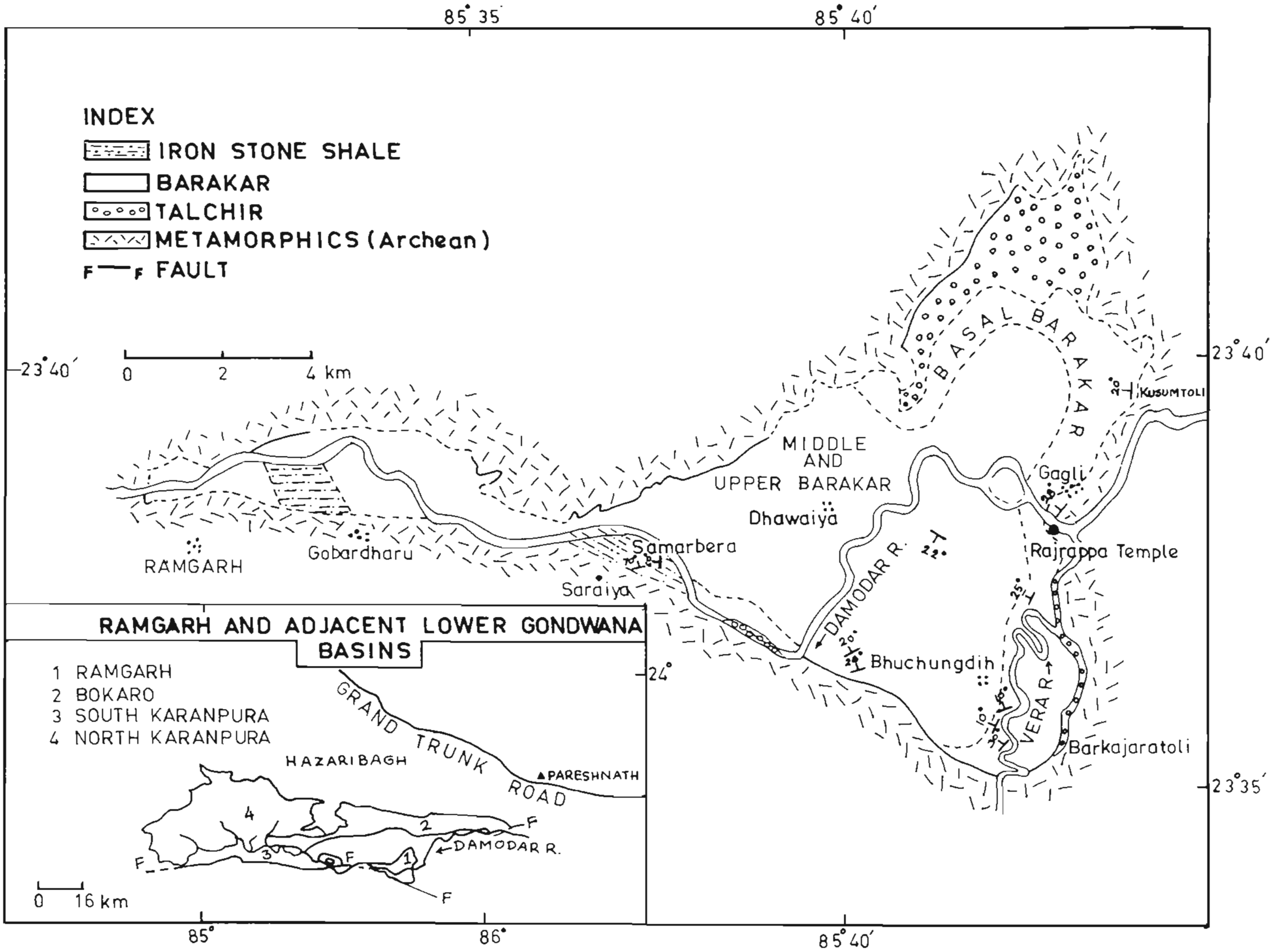
The general stratigraphy of the basin may be summarised as in Table 1.

CLASSICAL SANDUR SEDIMENTATION MODEL

The 'sandur' deposit or glacial outwash plain deposit is a braided glaciofluvial deposit having two morphological units, each characterised by an association of sediments and sedimentary structures. The units are— (a) 'channels' which can be subdivided into— (i) 'pool' having fine silty and shaly facies with parallel stratifications, and (ii) 'riffle' of gravelly sand and pebbly sandstones with ripple- and megaripple bedding, cross-bedding, etc. Transverse ribs contribute a bed form typical of riffle portion (McDonald & Banerjee, 1971); and (b)

			FORMATION	LITHOLOGY
Lower Gondwana	Up Carboniferous to Permian	Damuda	Ironstone Shale	Highly indurated pink to reddish brown fine sandstones, silstones and shales. Small nodules of siderites and occasional streaks of carbonaceous matter.
			.... Conformable	
			Barakar	— Upper : Intercalated fine cross-bedded sandstones and shales with thick coal seams
				— Middle . Medium to fine cross-bedded sandstones, gritty sandstones with workable coal seams.
				— Basal : Coarse pebbly sandstones and thin intercalated shales, poorly sorted gravelly sandstones with thin local coal seams and sandy shales.
			.... Conformable	
		Talchir	Talchir	Varved shale, green and khaki shale, Talchir Boulder Bed.
			.... Unconformity	
			Archaean	Granite gneiss, mica schists, quartzites, amphibolites, vein gneisses.

Table 1



Text-figure 1—The geological map of the Ramgarh Coalfield. Inset shows relation with adjacent basins. Geological map modified after Mehta and Joshi, 1962.

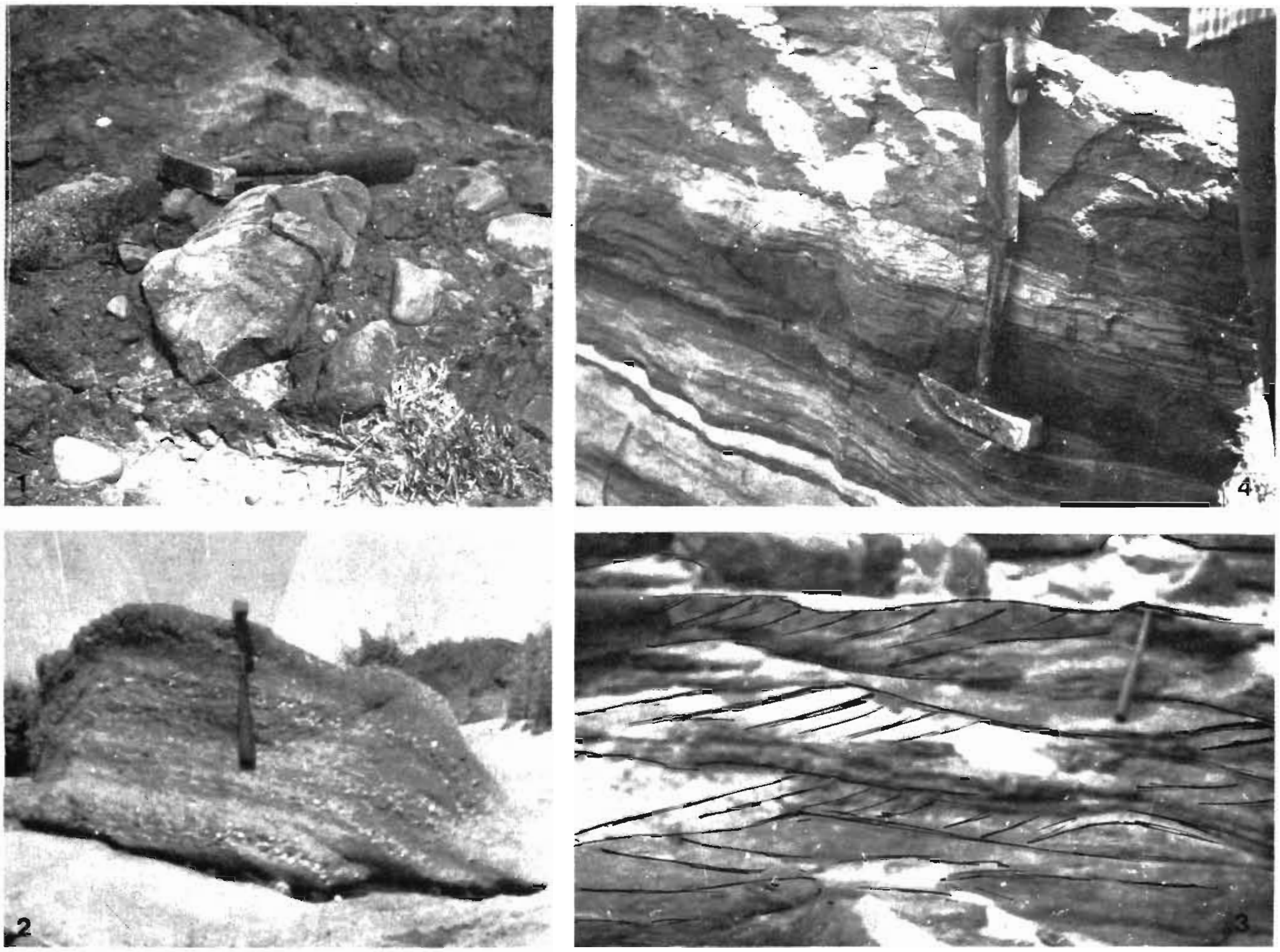


PLATE 1

1. An exposure of Talchir Boulder Bed around Sariya.
2. Graded bedding in basal Barakar beds.
3. Megaripple bedding in basal Barakar beds, hammer is 40 cm in length.
4. Ripple bedding in basal Barakar beds.

interchannel 'bars' characterised by relatively finer, poorly sorted coarse sandstones and pebbly sandstones having parallel bedding. Both channel and bar facies, however, are characterised by scour- and fill-structures (Reineck & Singh, 1980, p. 203).

THE BASAL BARAKAR BEDS

On the eastern part of the Ramgarh Coalfield the basal Barakar beds form a distinct 50 to 100 m thick lithounit having two distinctive facies and are well exposed on the Vera River Bed. These basal beds lie conformably over the Talchir Boulder Bed (Pl. 1, fig. 1) or over Talchir green or khaki shales with gradational contact. The boulders of the Boulder Bed are often faceted, iron-shaped to irregular bodies and range in size up to 5 m. Near Saraiya, on the southern bank of Damodar River, the boulders show a crude orientation of their long axes. Compositionally the Boulder Bed is polymictic being composed of boulders of quartzites, granite gneisses, migmatites, amphibolites and vein quartz derived from Archean basement.

LITHOLOGY

The basal Barakar beds show two broad contrasted facies which alternate both in vertical and lateral senses. The sedimentary bodies are lenticular to sheet-like in geometric shapes as seen in sections. Lithologically, the beds are medium to poorly sorted gravelly sandstones or coarse pebbly sandstones. Graded bedding with grain size variations from gravel to fine sand occurring from bottom to top in

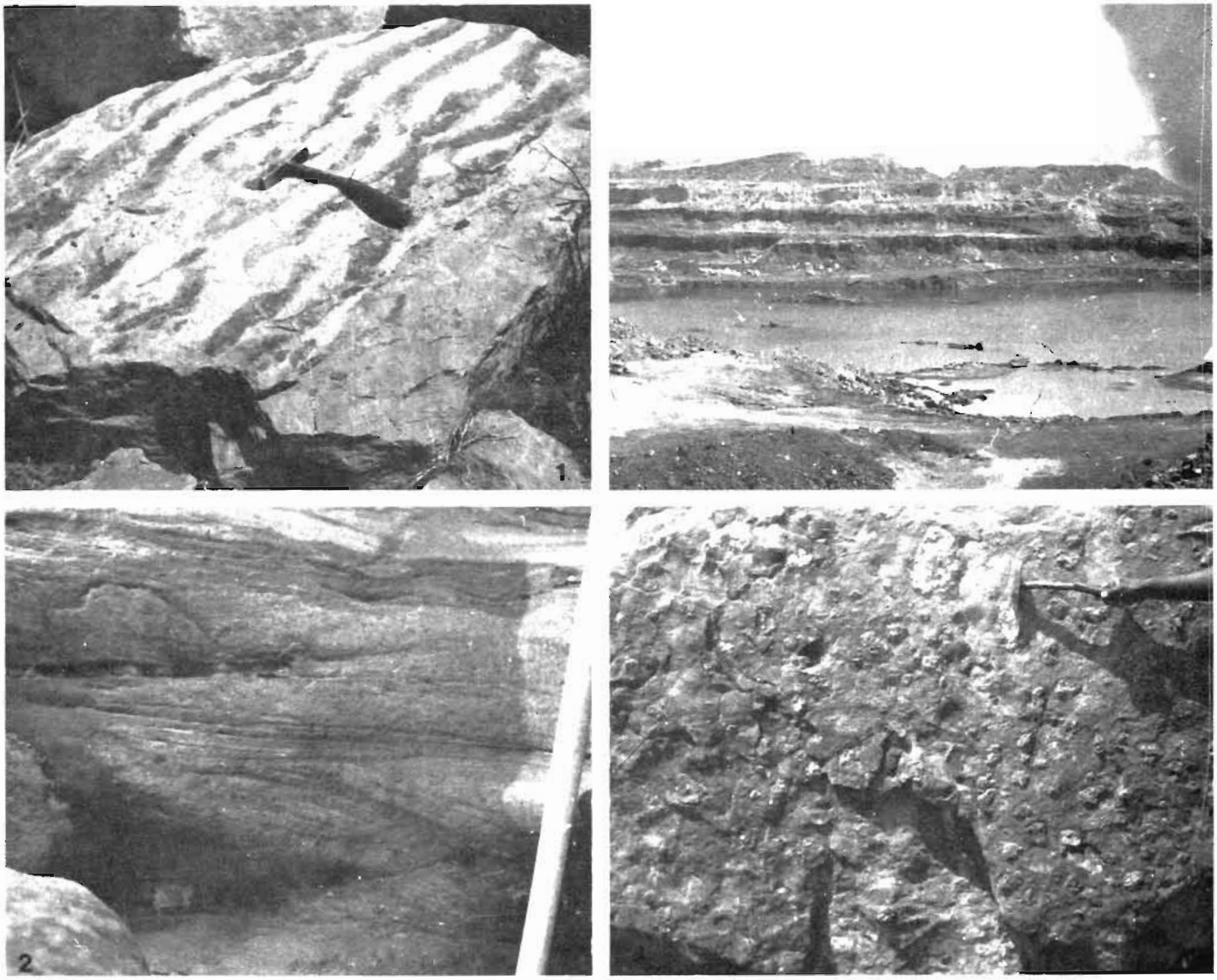


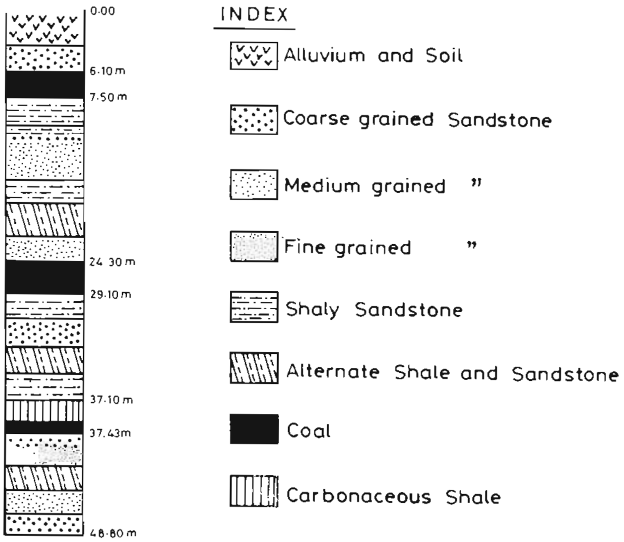
PLATE 2

1. Wavy ripple marks on the surface of the basal Barakar beds
2. Scour-and fill structure in the basal Barakar beds
3. Three different coal seams in alternations in the sandstones and shales as exposed in a mining face.
4. Pyrite nodules in sandstones

individual sedimentation unit (Pl. 1, fig. 2) is well-registered in many cases. This coarse gravelly and pebbly sandstone facies may be related to the bar facies of glacial outwash plains.

The gravelly sandstone beds are well stratified to crudely stratified and exhibit rapid alternation of well sorted and moderately sorted cross-bedded arkosic sandstone of the riffle facies of the channels. Small lenses (length within 1 m and thickness 10 cm) of gravels at more or less regular intervals in lateral and vertical sequences may reflect sectional manifestations of the gravelly 'transverse ribs' of the riffle portions of channels of the outwash plains (McDonald & Banerjee, 1971). At the bottommost part of the beds the gravel: sand ratio is of the order of 40 : 60; the proportion of sand, however, increases towards the upper part of the basal beds.

In contrast to the gravelly and pebbly sandstone facies, sandy silts, silty shales and fissile carbonaceous shales have very local occurrences. These bodies are elongated lenticular both in plan and section and merge laterally into gravelly and coarse sandstones. This finer facies may be related to the pool facies of the channels. The carbonaceous shales contain impressions of *Vertebraria*, *Glossopteris* and *Gangamopteris* (?) in abundance



Text-figure 2—Representative sedimentary sequence of the Barakar Formation of the Ramgarh Coalfield as obtained from bore-hole data.

and in all cases are sandwitched between underlying 1 to 5 m thick lenticular coal seams and overlying lenticular gravelly sandstones.

Unlike the Middle and Upper Barakar beds, the basal beds, sometimes are devoid of any definite cyclic pattern of sedimentation as marked by alternation of sand, shale and coal facies. The Barakar beds are better sorted and relatively finer sized than that of underlying Talchir Boulder Bed but poorer in sorting and coarser sized than the succeeding Middle and Upper Barakar beds.

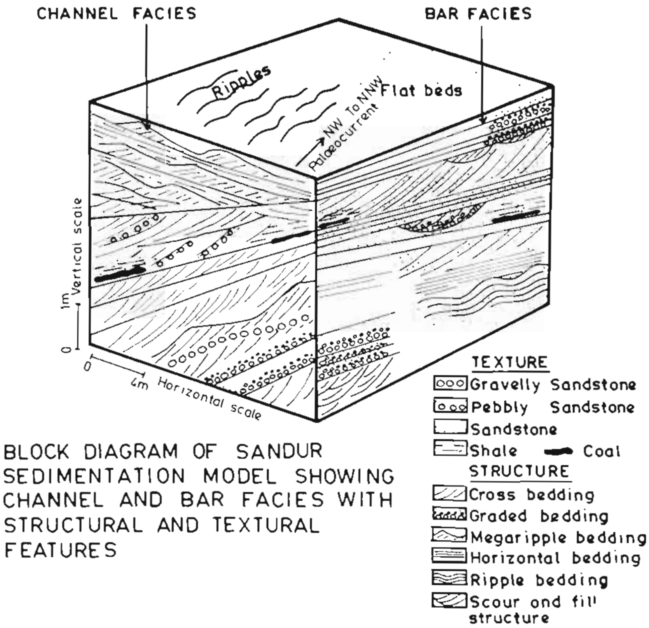
The pebbly and gravelly sandstones of the basal beds are very indurated with the presence of fresh feldspars in all cases. The gravels are found to be well rounded (av. roundness 0.8) with high sphericity (sphericity between 0.7 and 0.9); size ranges between 0.5 to 3 cm with the commonest size around 1.5 cm. Compositionally the gravels are of quartz, feldspar, quartzite, granite and gneisses and are supposed to be derived from underlying formations.

SEDIMENTARY STRUCTURES

The gravelly and pebbly sandstones, representative of the bar facies are crudely or sharply parallel-stratified and grade both laterally and vertically to profusely cross-bedded coarse pebbly sandstones to coarse sandstones of the channel facies. The bedding thickness ranges between 15 cm and 2 m. The cross-bedded units are mostly of trough-lenticular type with planar erosional bounding surfaces. In many cases, megaripple beddings (Pl. 1, fig. 3) with wavelength ranging between 1 and 4 m and height between 30 cm and 1 m register non-erosional upper bounding surfaces. Cosets of trough-lenticular cross-beds and composite sets composed of alternation of tabular and lenticular sets can be seen in 5 to 10 m vertical sections exposed on Vera River banks. These cross-bedded units often with alignment of pebbles along foreset laminae are supposed to be resultant from megaripple migration along with subsidence. The megaripples can be inferred to be generated in the upper part of the lower flow regime of the outwash plain channels.

Isolated buried megaripples without any evidence of erosion of crestal profiles are noticed in many sections. Ripple-bedded sandstones (Pl. 1, fig. 4) sometimes alternate with megaripple bedding in sections. Scour and fill structures (Pl. 2, fig. 2) with poorly sorted gravel lags at the base of the scours are most common structures of both channel and bar facies of the sandur deposits. Rao *et al.* (1969) also noticed occurrences of excellent channel sand grading to silt in the Ramgarh Basin. Small wavy ripples marks (Pl. 2, fig. 1) having wavelengths less than 30 cm and height around 2 cm are present in few places as surface beds forms.

Palaeocurrent measurements in the field were done from foresets of cross-beds, foresets of ripple bedding and trends of ripple trains in plan. The overall palaeocurrent direction swings between NW to NNW.



Text-figure 3—Block diagram to represent the sandur sedimentation model showing channel and bar facies as identified from the basal Barakar beds of Ramgarh Coalfield.

Text-figure 3 illustrates a block diagram to represent the sandur sedimentation model with channel and bar facies as identified from the basal Barakar beds of Ramgarh Coalfield.

MIDDLE TO UPPER BARAKARS AND IRONSTONE SHALES

The basal Barakar beds grade further west of the basin to Middle and Upper Barakar beds that truely represent a cyclic pattern of sedimentation with medium to fine sandstones, shales and coal seams (Pl. 2, fig. 3). All gradations exist between sandstones to siltstones and shales. Shales are mostly associated with coal-bearing portions. Lenticular cross-stratifications of medium to small scale are very common. Apart from cross-laminations, convolute laminations and load casts are also present occasionally. A representative sedimentary sequence of the Middle and Upper Barakar beds of the Ramgarh Coalfield as obtained from bore-hole data is shown in Text-figure 2.

Such a cyclic sedimentation may be related to fluvial cycle caused by shift in the channel alignment and environmental boundaries simultaneous with subsidence (Banerjee, 1978, fig. 8). A fining upward fluvial cycle of a different type related to annual flood cycle over river point bars and flood basins has been described by Allen (1965), Visher (1965) and Casshyap (1970).

In rare cases, Middle Barakar fine sandy beds contain nodules of pyrites having 2 to 10 cm diameter (Pl. 2, fig. 4). These pyritiferous sandstones might reflect an euxinic environment of their formation perhaps in certain arrested pools of the river flood plains.

The Ironstone Shale Formation is well-bedded and cross-bedded fine sandstones, siltstones and shales having a general pink to pinkish red colour. They are of local occurrences and seen to maintain a graded contact with the Barakar Formation.

CONCLUSION

The basal Barakar beds of the Ramgarh Coalfield with their textural and structural attributes and facies relations indicate deposition on gently sloping glacial outwash plain cut through by many channels, i.e., in a sandur environment.

The sandur deposits have two distinct facies—(i) channel facies with riffles and pools, and (ii) inter-channel bar facies having gradational contacts in both lateral and vertical senses. The basal beds register deposits of both the facies as has been illustrated with textural and structural parameters, geometric shape of sand bodies and geomorphic-geologic framework of sedimentation. The gravelly and pebbly sandstones with crude or sharp parallel stratifications, graded beds and scour and fill structures characterise the bar facies whereas, coarse sandstones with ripple and megaripple bedding, lenticular and planar cross-bedding, buried megaripple trains, scour and fill structures and gravel lenses characterise the riffles of the channel facies. The lenticular sandy shales and siltstones within coarse pebbly sandstones may be related to the pools of the channel facies.

Such a depositional environment has been supposed to have graded uninterruptedly from true glacial Talchir deposits and has led to the true fluvial model sedimentation commencing from the Middle Barakar upwards.

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Vegetational changes and their climatic implications in coal-bearing Gondwana

Shaila Chandra & Anil Chandra

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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 विशेषतः 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 शनैः शनैः 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, flood-plains 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, triletes & monoletes.	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° Centigrade	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 proliferate, 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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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).

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साराँश

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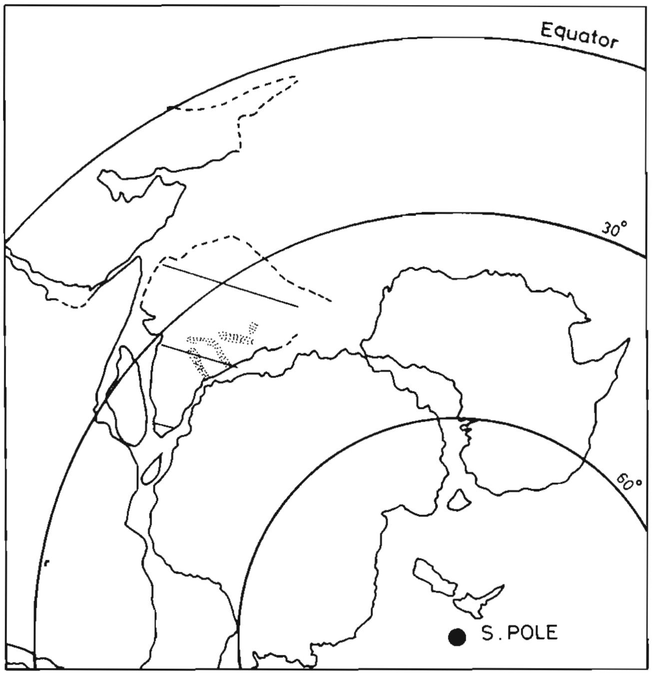
Lower Gondwana coal deposits of India lie between 25°-16°N latitude in a triangular pattern distributed along main river valleys, viz., Damodar, Son-Mahanadi, Satpura and Pranhita-Godavari. The generalised stratigraphic sequence in Lower Gondwana is as follows:

	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.

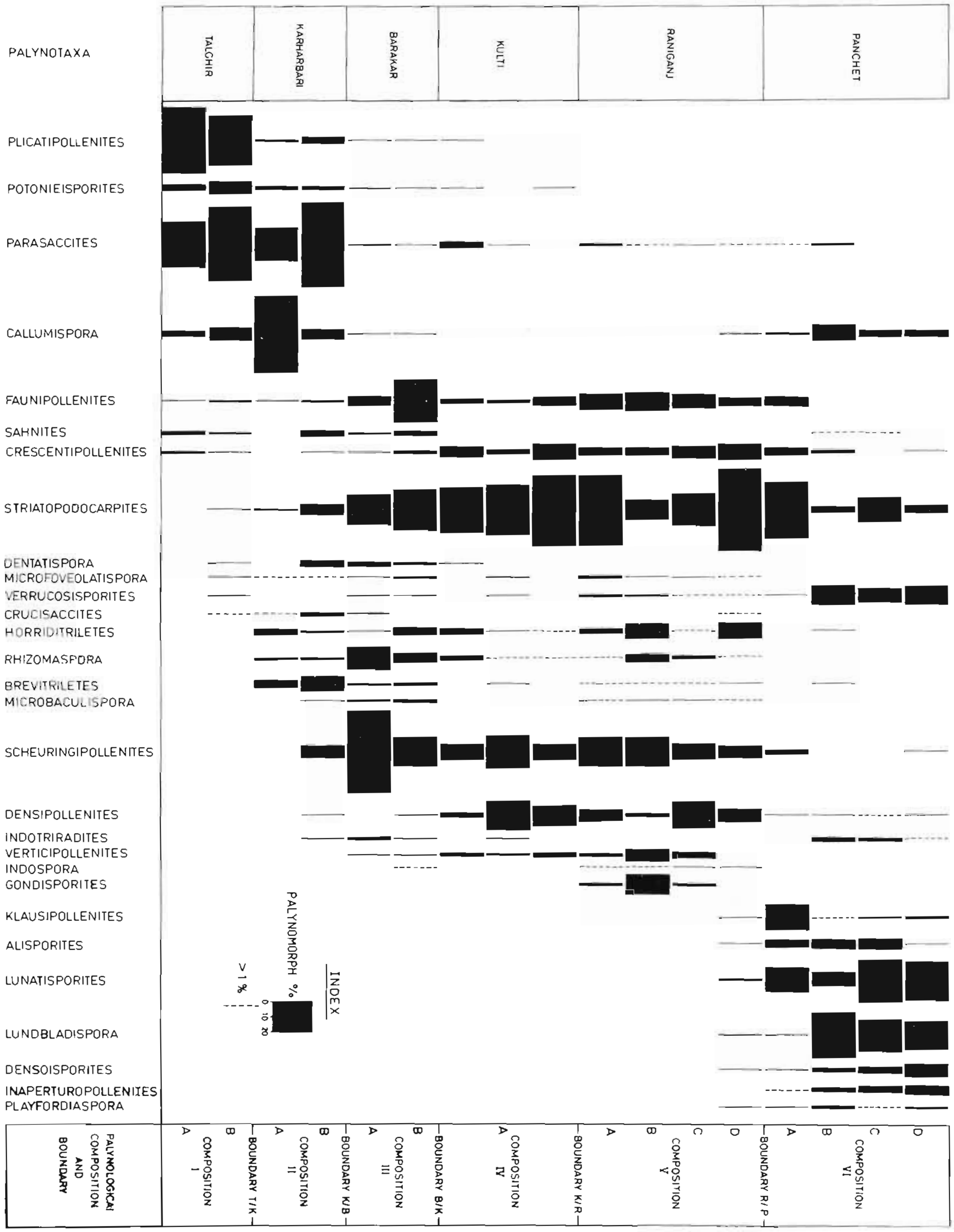
PALYNOLOGICAL SUCCESSION THROUGH LOWER GONDWANA

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.

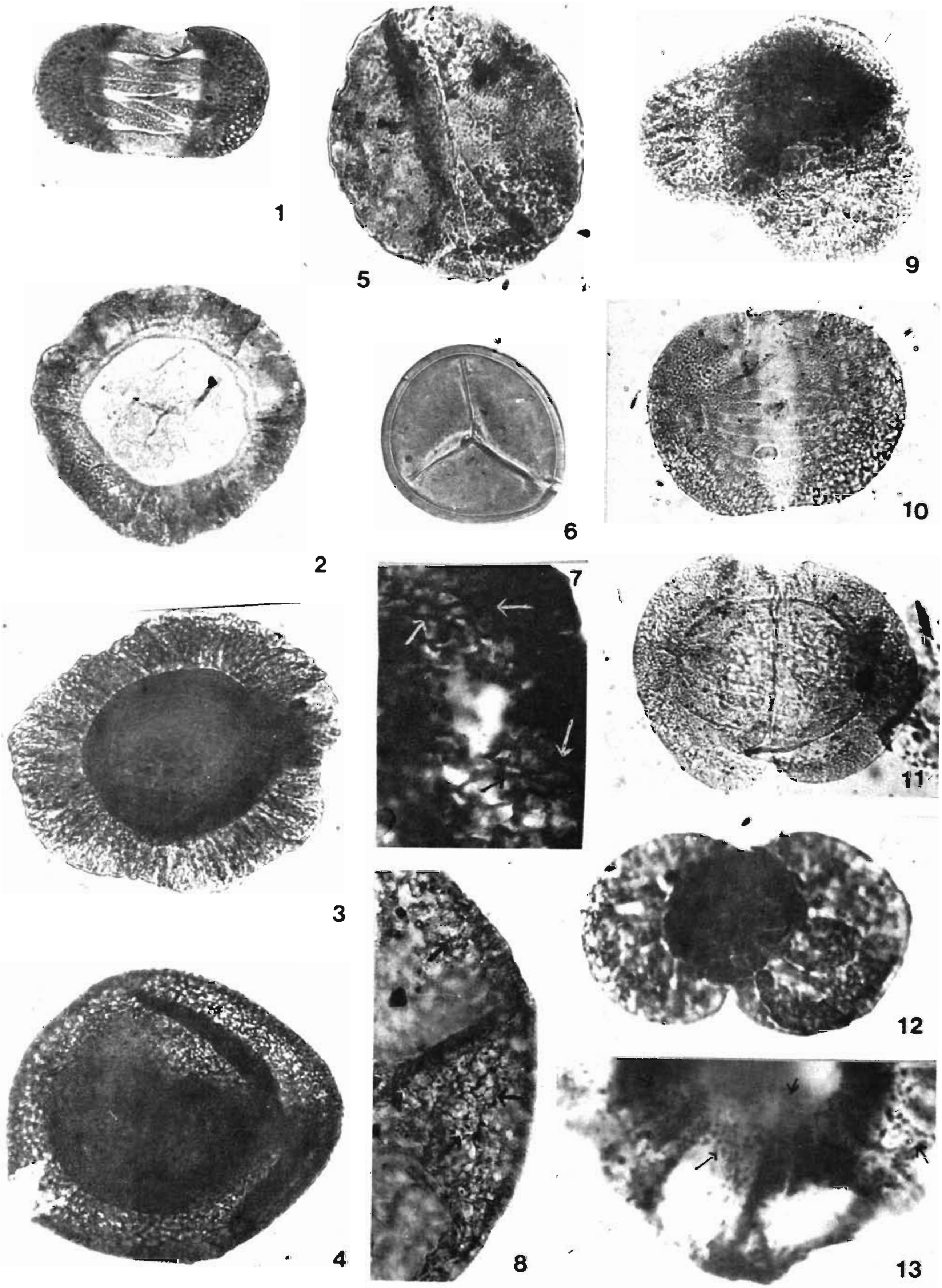
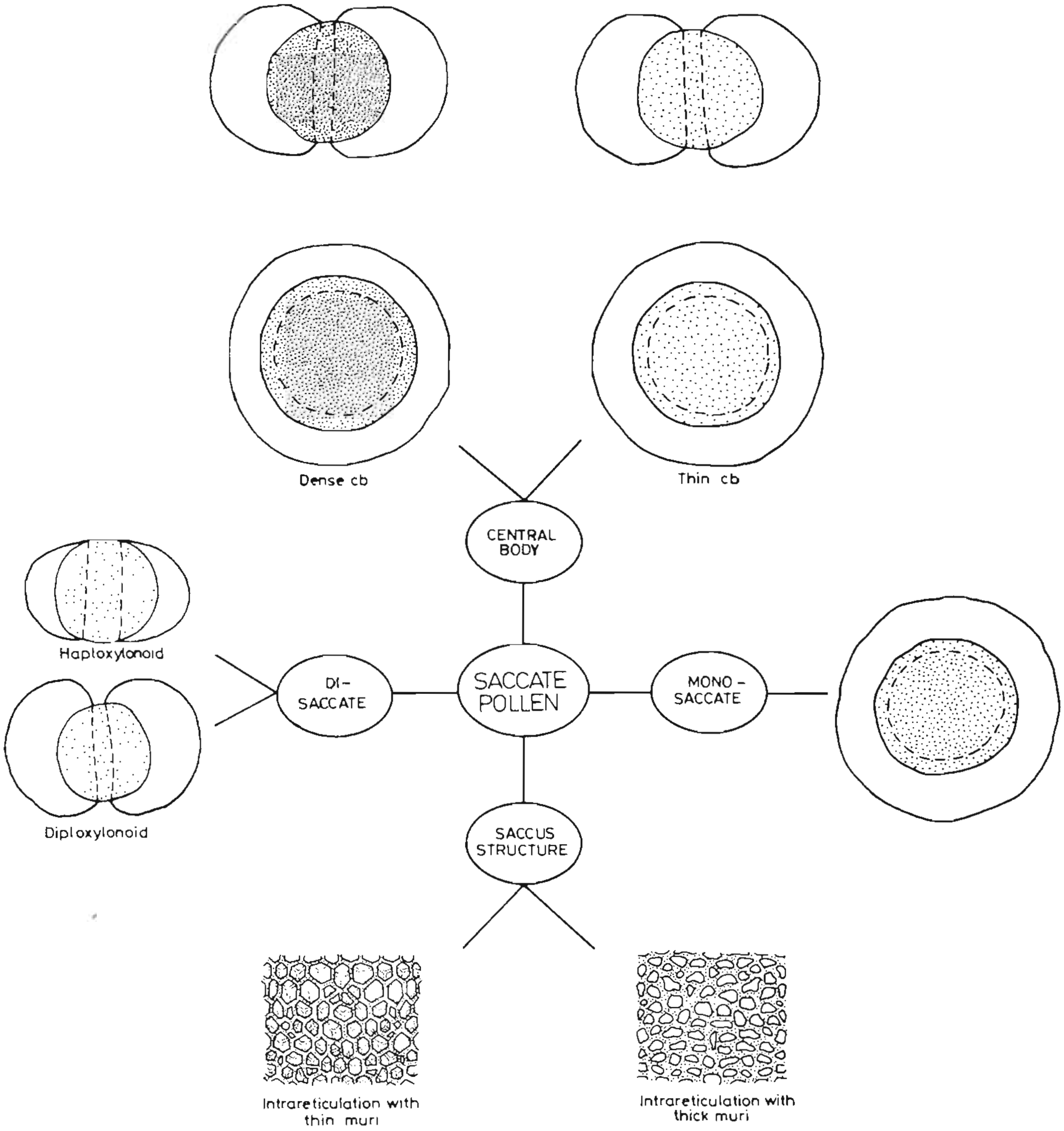


PLATE 1



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'.

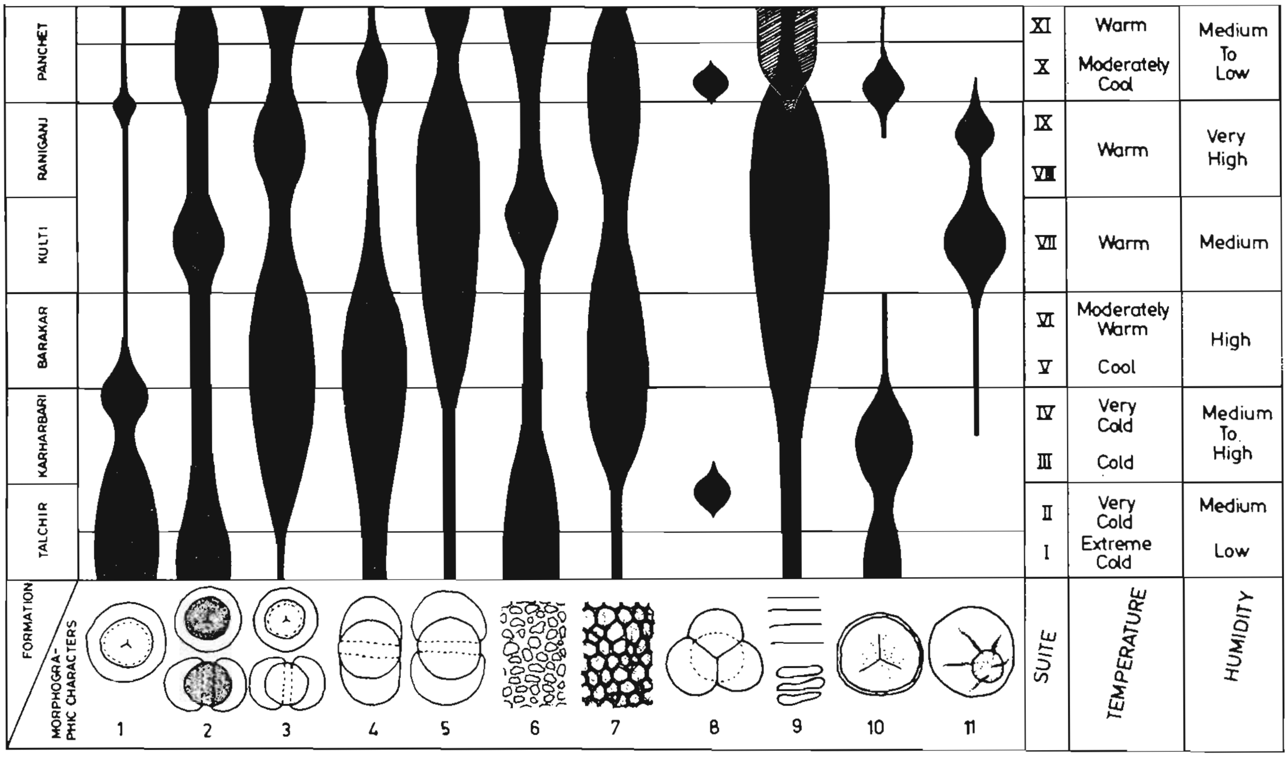
1. Central body— It is the central part of the saccate pollen grain containing the cytoplasmic contents and nucleus which gives rise to microgametophyte after division. In fossil pollen the central body (represented by nexine & sexine), shows variation in the density of its wall on the basis of which 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

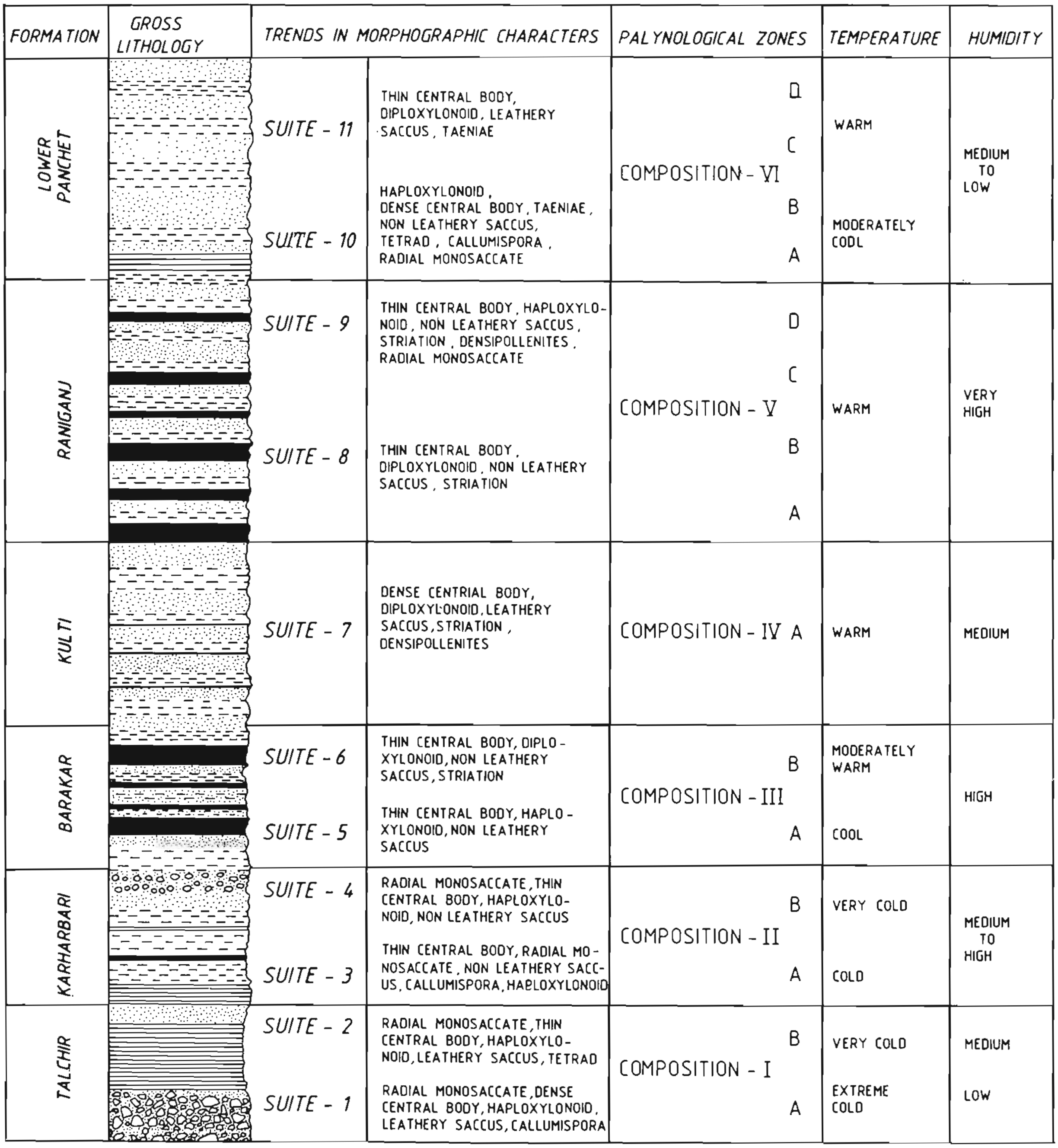
Palynology vis-a-vis other parameters

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.

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Megaspore biostratigraphy of the Gondwana

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Maheshwari, Hari K. & Tewari, Rajni (1988). Megaspore biostratigraphy of the Gondwana. *Palaeobotanist*, **36** : 102-105.

Dispersed megaspores are known from almost all the Gondwana horizons though they are comparatively rare. Approximately, 36 genera and 110 species are known from the Gondwana sediments. The number of genera and species is almost equally divided between Permian and Mesozoic Gondwana. Most of the formations except Talchir, Barren Measures and Upper Tiki have marker megaspore taxa at generic level. The above mentioned three formations have marker taxa only at species level. At the present state of our knowledge megaspores are found useful only for broader zonation. As far as age determination is concerned, the megaspores, as compared to other palynofossils, indicate younger ages.

Key-words—Megaspores, Biostratigraphy, Morphotaxonomy, Gondwana (India).

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सारांश

गोंडवाना का गुरुबीजाणु जैवस्तरविन्यास

हरिकृष्ण माहेश्वरी एवं रजनी तिवारी

विकीरित गुरुबीजाणु प्रायः सभी गोंडवाना संस्तरों से विदित हैं यद्यपि अपेक्षाकृत ये कम मिलते हैं। गोंडवाना अवसादों से इनकी लगभग 36 प्रजातियाँ एवं 110 जातियाँ ज्ञात हैं। परमी एवं मध्यजीवी गोंडवाना में इन प्रजातियों एवं जातियों की संख्या लगभग बराबर है। तालचिर, बेरन मेज़र्स एवं उपरि टिकी के अतिरिक्त अधिकतर शैल-समूहों में चिन्ह्क गुरुबीजाणु प्रजाति-स्तर पर विद्यमान हैं। वर्तमान ज्ञान के आधार पर गुरुबीजाणु केवल मोटे तौर पर मंडलन करने में उपयुक्त सिद्ध हुए हैं और जहाँ तक आयु निर्धारण का सम्बन्ध है गुरुबीजाणु अन्य परागाणविकरूपकों की तुलना में अल्पायु इंगित करते हैं।

EXTANT land plants can be divided into two categories on the basis of the spores they produce. Some plants produce almost uniform sized spores. Other plants produce two types of spores, micro- and mega-, which give rise to male and female gametophytes, respectively. In fossil condition where nature of gametophytes produced by the spores is not known, micro- and mega-spores are differentiated on the basis of their respective sizes. The cutoff point between the two has variously been put at 150 μm (Harris, 1961), 200 μm (Zerndt, 1934) and 300 μm (Schopf, 1938). Generally, spores larger than 200 μm in size are considered as megaspores.

Megaspores are known from almost all the horizons, late Devonian upwards. However, their quantitative occurrence, as compared to that of microspores, being rather rare, not much information is available regarding their morphological variation and distribution in time and space.

Megaspores in the Gondwana sediments were first isolated by Carruthers (1869) from the Brazilian

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coal beds though he thought them to be sporangia. Zeiller (1895) recognized their true nature as megaspores. One of the first reports of the occurrence of megaspores in the Indian Gondwana is by Mehta (1943) from the Singrauli Coalfield. Sitholey (1943) reported megaspores from the Triassic of Salt Range, now in Pakistan. The first detailed account of megaspores from the Permian Gondwana of India was published by Surange, Singh and Srivastava (1953) which was partly revised by Srivastava (1954). Dev (1961) and Singh, Srivastava and Roy (1964) published on megaspores from Early Cretaceous 'Gondwana'.

Chart 1 : Distribution of Megaspore species in Indian Gondwana Formations

NAME OF (A) TAXA ↓ / HORIZON (B) →	TALCHIR (1)	KARHARBARI (2)	BARAKAR (3)	BARREN MEASURES (4)	RANIGANJ (5)	MAITUR (6)	LOWER TIKI (7)	UPPER TIKI (8)	JABALPUR (9)	BHUJ (10)
Duosporites dijkstrae	×									
Banksisporites indicus	×	×	×							
Duosporites congoensis	×	×	×	×						
Talchirella nitens	×	×	×	×	×					
Ancorisporites venkatachalae		×								
Barakarella prakashii		×								
Barakarella shuklae		×								
Duosporites tiwarii		×								
Jhariatriletes filiformis		×								
Shahdolia chaloneri		×								
Surangeaesporites karharbariensis		×								
Banksisporites utkalensis		×	×							
Barakarella pantii		×	×							
Bokarosporites rotundus		×	×							
Duosporites multipunctatus		×	×							
Talchirella trivedii		×	×							
Talchirella flavata		×	×	×						
Biharisporites spinosus		×	×	×	×					
Ancorisporites binaensis			×							
Banksisporites dijkstrae			×							
Banksisporites endosporitiferus			×							
Barakarella churuliaensis			×							
Biharisporites arcuatus			×							
Biharisporites distinctus			×							
Bokarosporites psilatus			×							
Canaliculites triangulatus			×							
Cystosporites indicus			×							
Duosporites irregularis			×							
Jhariatriletes binaensis			×							
Jhariatriletes comatus			×							
Jhariatriletes densus			×							
Lagenicula gondwanensis			×							
Mamillaespora grandis			×							
Mamillaespora superba			×							
Manumisporites distinctus			×							
Manumisporites høegii			×							
Pilatriletes mirzapurensis			×							
Ramispinatispora indica			×							
Ramispinatispora nautiyalii			×							
Singraulispora indica			×							
Singraulispora insignis			×							
Jhariatriletes damudicus			×	×						
Jhariatriletes srivastavae			×	×						
Panticella waltonii			×	×		×				
Duosporites katrinalaensis				×						
Singhisporites baculatus				×						
Jhariatriletes baculosus				×	×					
Singhisporites radialis				×	×					
Noniasporites harrisii					×					
Surangeaesporites raniganjensis					×					
Talchirella densicorpa					×					

Chart-1 : Contd.

A ↓ B →	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Banksisporites gondwanensis						×				
Banksisporites granulosus						×				
Banksisporites minuticorpus						×				
Banksisporites panchetensis						×				
Biharisporites maiturensis						×				
Maiturisporites distinctus						×				
Maiturisporites indicus						×				
Maiturisporites spinotriletus						×				
Panticella bharadwajii						×				
Pantiella bosei						×				
Talchirella dubia						×				
Talchirella sinuata						×				
Banksisporites major							×			
Banksisporites triassicus							×			
Grambastisporites nidhpurensis							×			
Lagenicula spinosa							×			
Mamillaespora sidhiensis							×			
Trikonia emarginata							×			
Banksisporites dettmannae								×		
Banksisporites gondwanensis								×		
Banksisporites pinguis								×		
Banksisporites tenuis								×		
Banksisporites sparsus								×		
Bokarosporites janarensis								×		
Erlansonisporites singhii								×		
Erlansonisporites triassicus								×		
Banksisporites sinuosus								×		
Hughesisporites variabilis								×		
Verrutriletes distinctus								×		
Verrutriletes minuticorpus								×		
Verrutriletes obscurus								×		
Horstisporites areolatus								×		×
Saccarisporites lurzeri									×	
Minerisporites mineri									×	×
Auriculozonospora reticulata										×
Bacutriletes cutchensis										×
Bacutriletes dijkstrae										×
Bacutriletes srivastavae										×
Bacutriletes kachchensis										×
Dijkstraisporites filiformis										×
Dijkstraisporites grantii										×
Dijkstraisporites triangulatus										×
Erlansonisporites cf. erlansonii										×
Erlansonisporites indicus										×
Horstisporites biswasii										×
Hughesisporites rajnathii										×
Hughesisporites singhii										×
Minerisporites auriculatus										×
Minerisporites cutchensis										×
Minerisporites dharesiensis										×
Minerisporites mesosporeoides										×
Minerisporites reticulatus										×
Paxillitriletes battenii										×
Paxillitriletes cutchensis										×
Umiaspora bosei										×
Valvisisporites minor										×
Verrutriletes royii										×
Verrutriletes stoliczkae										×
Verrutriletes triangulatus										×

After, Høeg, Bose and Manum (1955) proved the importance of the nature of the mesosporium (inner body) in morphotaxonomy of Gondwana megaspores from Zaïre, Pant and Srivastava (1961, 1964) improvised the technique and methodology and applied it to the morphotaxonomy of

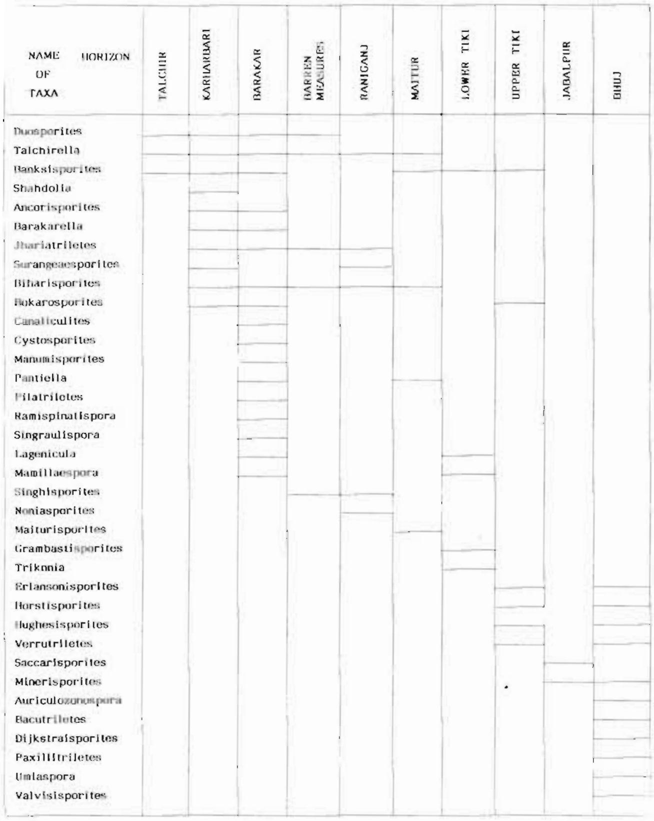

Chart 2—Distribution of megaspore genera in the Indian Gondwana formations.

megaspores from Permian Gondwana of India. Later workers have followed almost the same approach.

Megaspores are now known from: Early Permian Talchir Formation (Lele & Chandra, 1974); Early Permian Karharbari (basal Barakar) Formation (Bharadwaj & Tiwari, 1970; Pant & Mishra, 1986); Early Permian Barakar Formation (Bharadwaj & Tiwari, 1970; Lele & Srivastava, 1983; Pant & Mishra, 1986); Late Permian Barren Measures Formation (Kar, 1968; Bharadwaj & Tiwari, 1970); Late Permian Raniganj Formation (Bharadwaj & Tiwari, 1970; Agashe, 1979; Jha & Srivastava, 1984; Maheshwari & Bajpai, 1984); ?Triassic Lower Tiki Formation (Pant & Basu, 1979); Early Triassic Maitur Formation (Maheshwari & Banerji, 1975); Late Triassic Upper Tiki Formation (Banerji, Kumaran & Maheshwari, 1978); Early Cretaceous Jabalpur Formation (Dev, 1961); Early Cretaceous Bhuj Formation (Singh, Srivastava & Roy, 1964; Banerji, Jana & Maheshwari, 1984). References to more publications are given in bibliography.

DISCUSSION

Though, a number of workers have contributed to the study of Gondwana megaspores, yet not enough data has been generated to use megaspores for finer stratigraphic zonation and correlation. There are approximately 52 genera and 139 species of Gondwana megaspores out of which some 36 genera and 110 species are known from the Indian Gondwana.

Occurrences of fossil megaspore species in different formations of the Indian Gondwana (*sensu lato*) are plotted in Chart 1. Distribution of megaspores at generic level is summarised in Chart 2. From these distribution charts it is evident that though the megaspores are comparatively infrequent, yet their distribution pattern is such that broad megaspore biostratigraphic zones can be demarcated. As majority of megaspore species are of necessity based on a specimen or two, the incidence of variation within a species is not known. Even then, it seems that majority of them have a restricted distribution and can be, individually or collectively, used for zonation and correlation. Due to paucity of information such zonation has to be provisional. When more data is available a regional zonation scheme may be drawn.

From the distribution pattern it is evident that the megaspore taxa are endemic up to Lower Tiki (or Upper Pali of authors, i.e., the Nidhpuri beds) of probable latest Permian age. Upper Tiki (Tiki ormation *sensu stricto*, Late Triassic) onwards cosmopolitan genera start appearing, e.g. *Erlansonisporites, Horstisporites, Minerisporites*, etc. evidently representing beginning of a connection between Laurasia and Gondwana.

Two cenozones are identifiable, viz.,

A. *Talchirella-Banksisporites* Assemblage Zone (Talchir to Lower Tiki/Upper Pali).
B. *Erlansonisporites—Verrutriletes* Assemblage Zone (Tiki to Bhuj).

Following assemblage subzones are recognised:

A1. *Talchirella nitens—Duosporites dijkstrae* Assemblage Subzone (Talchir).
A2. *Talchirella trivedii—Ancorisporites venkatachalae* Assemblage Subzone (Karharbari/basal Barakar).
A3. *Talchirella trivedii—Ancorisporites binaensis* Assemblage Subzone (Barakar).
A4. *Talchirella densicorpa—Noniasporites harrisii* Assemblage Subzone (Raniganj).
A5. *Talchirella dubia—Banksisporites panchetensis* Assemblage Subzone (Maitur).
A6. *Banksisporites major—Lagenicula spinosa* Assemblage Subzone (Lower Tiki/Upper Pali).
B1. *Erlansonisporites triassicus—Verrutriletes distinctus* Assemblage Subzone (Upper Tiki/Tiki *sensu stricto*).
B2. *Dijkstraisporites—Paxillitriletes—Minerisporites* Assemblage Subzone (Bhuj-Jabalpur).

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The origin, rise and decline of Glossopteris Flora : with notes on its palaeogeographical northern boundary and age

D. D. Pant

Pant, D. D. (1988). The origin, rise and decline of Glossopteris Flora : with notes on its palaeogeographical northern boundary and age. *Palaeobotanist* **36** : 106-117.

In Africa impressions of two leaves of *Gangamopteris* were found lying below the glacial conglomerate and in Australia *Gangamopteris* and *Schizoneura* were found interbedded with the glacial beds at Bacchus Marsh. Microfossils, including pollen grains like those of the Glossopteris Flora, have been reported from the tillites, particularly from the Bacchus Marsh tillite. Similar microfossils have also been reported from the beds of the Talcher stage lying immediately above the glacial beds. All these fossils indicate that they were the pioneers of the Glossopteris Flora which may have come into existence in unglaciated and protected locations of Gondwanaland during the Ice Age itself. The early elements of the Glossopteris Flora thus seem to have lived in a cold temperate climate alongside glaciers. The flora of this stage was relatively poor but as the climate warmed up the forests became richer and their plants more diversified. However, this flora was living in a climate where a cold winter alternated with a warm summer and it abounded in deciduous plants. The climax of the Gondwana vegetation was reached during the Raniganj stage when a much warmer and more humid climate supported a rich forest vegetation again abounding in deciduous trees. Thereafter, there was a sudden change of vegetation during the Triassic when the plants of the Glossopteris Flora yielded place to new elements of the Dicroidium Flora.

The disappearance of the Rhacopteris-Lepidodendropsis Flora with the onset of the glaciation during the Carboniferous-Permian times is easily understood but the sudden appearance of an entirely new Glossopteris Flora after, or even during the glaciation itself, and its almost simultaneous spread in all parts of Gondwanaland raise difficult questions about its origin and phylogeny. Besides dealing with the answers to these questions, the author discusses the factors and implications of the gradual decline of the Glossopteris Flora and the rise of the Dicroidium Flora during the Triassic. The estimates of the geological age and palaeogeographical limits of the Glossopteris Flora are also scrutinized in the light of recent work.

Key-words—Gondwanaland, Glossopteris Flora, Dicroidium Flora, Palaeogeography, Glaciation.

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साराँश

ग्लॉसॉप्टेरिस वनस्पतिजात की उत्पत्ति, विकास एवं ह्रास : इसकी पुराभौगोलिक सीमा तथा आयु पर टिप्पणियाँ

दिव्य दर्शन पन्त

अफ्रीका में हिमानी संगुटिकाश्म के नीचे **गंगामॉप्टेरिस** की दो पत्तियों की छापें पाई गई तथा ऑस्ट्रेलिया में बैक्कस मार्श की हिमानी संस्तरों में **गंगामॉप्टेरिस** एवं **शाइज़ोन्यूरा** अन्तःसंस्तरित अवस्था में उपलब्ध हुए। ग्लॉसॉप्टेरिस वनस्पतिजात के परागकणों सहित टिलाइटों, विशेषतः बैक्कस मार्श टिलाइट से सूक्ष्मपादपाश्म अभिलिखित किये गये हैं। इसी प्रकार के सूक्ष्मपादपाश्म हिमानी संस्तरों के ठीक ऊपर विद्यमान तालचिर चरण की संस्तरों से भी अभिलिखित किये गये हैं। ये सभी पादपाश्म व्यक्त करते हैं कि ये ग्लॉसॉप्टेरिस वनस्पतिजात के पथ-प्रदर्शक थे जो कि हिमयुग में गोंडवानाभूमि के अहिमनदित एवं संरक्षित स्थानों में विद्यमान रहे हैं। इस प्रकार ऐसा प्रतीत होता है कि ग्लॉसॉप्टेरिस वनस्पतिजात के प्रारम्भिक अवयव हिमनदी के साथ-साथ ठंडी शीतोष्ण जलवायु में विद्यमान रहे हैं। इस चरण का वनस्पतिजात अपेक्षाकृत क्षीण था परन्तु जैसे ही जलवायु में ऊष्णता आई वनों में इन पौधों की बाहुल्यता हो गई। यद्यपि, यह वनस्पतिजात उस जलवायु में विद्यमान था जहां ठंडी शीत ऋतु के बाद गर्म गर्मी की ऋतु आती थी। यह वनस्पतिजात पर्णपाती

Concepts, limits and extension of the Indian Gondwana
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पौधों के रूप में विकसित था। गोंडवाना काल की वनस्पति रानीगंज चरण में अपनी चरम सीमा पर पहुंची जबकि और अधिक गर्म एवं अधिक नम जलवायु ने सघन वनों की वनस्पति का संपालन किया इन्हीं वनों में ये पर्णपाती वृक्ष भी विद्यमान थे। इसके पश्चात् त्रिसंघी कल्प में वनस्पति में एक अचानक परिवर्तन आया जबकि ग्लॉसॉप्टेरिस वनस्पतिजात के पौधों ने डाइक्रोइडियम वनस्पतिजात के नये अवयवों को स्थान दिया।

कार्बनीफेरी-परमी काल में हिमनदन के प्रादुर्भाव के साथ-साथ रैकॉप्टेरिस-लेपिडोडेन्ड्रॉप्सिस वनस्पतिजात की विलुप्ति का कारण सहज ही जाना जा सकता है परन्तु हिमनदन के समय भी अथवा इसके पश्चात एक सम्पूर्ण नये ग्लॉसॉप्टेरिस वनस्पतिजात के प्रादुर्भाव तथा गोंडवानाभूमि के सभी भागों में इसके प्राय: एक साथ विस्तार से इसकी उत्पत्ति एवं इसके जातिवृत्त के विषय में कठिन प्रश्न सामने उभर कर आये हैं। इन प्रश्नों के उत्तरों के अतिरिक्त लेखक ने ग्लॉसॉप्टेरिस वनस्पतिजात के शनैः शनैः विलुप्तीकरण के कारकों तथा अनुमानों तथा त्रिसंघी काल में डाइक्रोइडियम वनस्पतिजात के उद्भव का विवेचन किया है। ग्लॉसॉप्टेरिस वनस्पतिजात की भूवैज्ञानिक आयु एवं पुराभौगोलिक सीमाओं का भी सम्भाव्य उल्लेख किया गया है।

DIGGING down into the sediments of geological time one finds that up to the Lower Carboniferous, the world's land-mass formed a single continent which Wegener hypothetically called Pangaea (all lands) and this was surrounded by a universal sea Panthalasa (all seas). Evidence of this comes from our inability to recognise any clearly defined regional floras in this land-mass after the first invasion of land by plants in the Upper Silurian right up to the Lower Carboniferous. The last uniform flora which occupied Pangaea during the early Lower Carboniferous is called the Rhacopteris-Lepidodendropsis Flora. There is, however, some evidence to show that in the Middle Carboniferous the Angara area may have already separated from Euramerica and the flora of that area became different.

As we ascend into the Upper Carboniferous strata we find that our world has undergone a great divide into a northern continental mass called Laurasia, a name derived from Laurentia, the old name for North America and Asia and this was separated by a median Tethys Sea from a southern land mass named Gondwanaland, by Suess, after the Gond tribe of central India. Remnants of this fission persist up to date. During this period Laurasia was having a warm, humid and swampy climate like that of present day tropics and it allowed the growth of the evergreen forests of the Pecopteris Flora. Abundant air spaces in the roots and stems of the flora indicate the existence of swamps and the absence of growth rings in the secondary xylem of the trees suggest the prevalence of a uniform climate all the year round. The remains of the forests of this rich flora are preserved in the form of coal seams of Europe and North America. In the flora of the northern landmass of this time we can also distinguish two other regional floras, the Angaridium Flora of Angarida and the Gigantopteris Flora of Cathaysia. Between the Angaridium Flora and the Pecopteris Flora of Europe was an ecotone which Meyen (1987) calls Sub-Angarida.

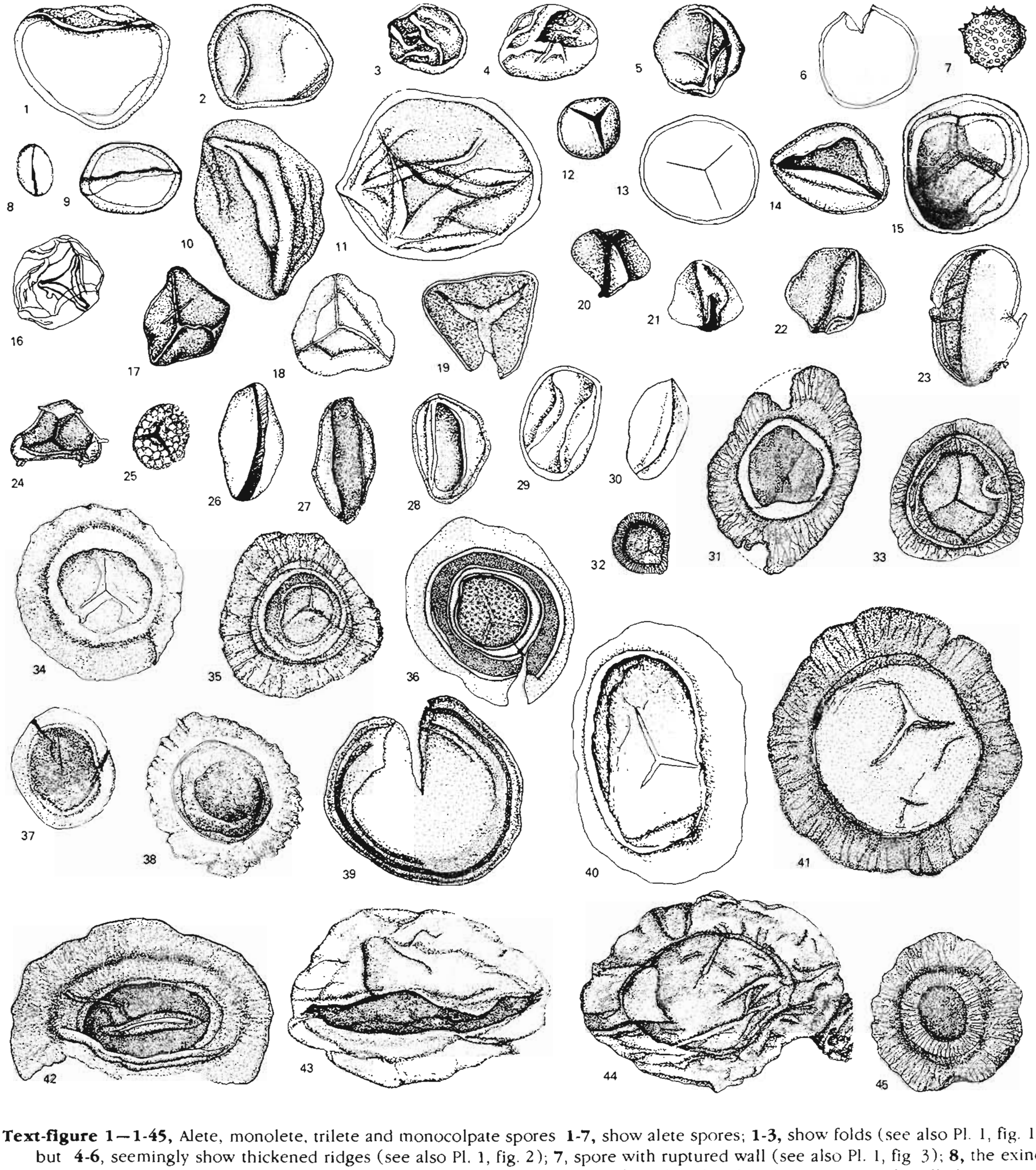
THE GREAT GONDWANA GLACIATION

In contrast, all parts of Gondwanaland were in the grip of a widespread glaciation which is believed to have begun in the Upper Carboniferous times. In some parts the glaciation may have persisted up to the Lower Permian. According to some authorities this was the greatest Ice Age that the world has ever witnessed. Remains of this glaciation are preserved in the form of a characteristic basal scratched boulder bed overlain by glacial conglomerates in all parts of Gondwanaland. The glacial remains were first discovered at Talcher in India and hence all homotaxial beds of this kind can be called by the name Talchir Boulder Bed and tillites. They have been subsequently discovered in Africa, Australia and South America, etc. where names like Dwyka tillite (Africa), Bacchus Marsh tillite (Australia), etc. are locally applied to them. Even in the Indian subcontinent glacial beds, homotaxial with the Talchir Boulder Bed and tillites are found in Kashmir and Kumaun Himalayas, Umaria (Madhya Pradesh) and Salt Range (Pakistan), etc.

The occurrence of varves in some Australian glacial deposits of this period (Sussmilch, 1923) indicates that even in the icy climate of Gondwanaland there was an alternation of colder winters and relatively mild summers. However, the vast stretches of ice bound Gondwanaland of this time seem to have been largely bereft of vegetation and the beds are generally lacking in fossils of any kind.

EARLIEST MEGAFOSSILS OF GLOSSOPTERIS FLORA

The only exceptional reports of megafossils in beds of this ice age are from Africa and Australia. In South Africa Leslie (1921) and du Toit (1924) found leaves of *Gangamopteris* actually lying below the glacial conglomerate in the Dwyka tillite at Vereeniging (*see* Pl. 3, figs 2, 3) and Strydenberg, respectively. In Australia, Sussmilch (1923) found *Gangamopteris* as well as *Schizoneura* interstratified with the glacial beds at Bacchus Marsh in Victoria. No megafossils have so far been reported from any tillite in India but Virkki (1938) found well preserved *Gangamopteris, Schizoneura, Glossopteris* and remains of other typical members of the Glossopteris Flora 25 feet above the Talchir Boulder Bed in Salt Range (Virkki, 1938 and Ph.D. Thesis,



Text-figure 1—1-45, Alete, monolete, trilete and monocolpate spores **1-7,** show alete spores; **1-3,** show folds (see also Pl. 1, fig. 1) but **4-6,** seemingly show thickened ridges (see also Pl. 1, fig. 2); **7,** spore with ruptured wall (see also Pl. 1, fig 3); **8,** the exine of spore shows minute spines (see also Pl. 1, fig. 4); **9-11,** monolete spores (see also Pl. 1, fig. 7); **12-19,** smooth-walled spores are of *Leiotriletes* type (see also Pl.1, figs 8-11); **18,** shows a spore with a peripheral flange around a trianguloid body (see also Pl. 1, fig. 16); **20-23,** spores are trilobate; **20-22,** *Brachytrilistrium* Naum.-type (see also Pl. 1, fig. 12); **23,** *Dolichotrilistrium* Naum.-type Trilete spores; **24, 25;** *Lophotriletes* type (see also Pl. 1, fig. 14); **26-30,** monocolpate spores are of *Ginkgocycadophytus* type (see also Pl. 1, fig. 15); **31-45,** show monosaccates of *Endosporites, Nuskoisporites, Potonieisporites* and allied types; **31-38,** spores are trilete: others are alete; **42,** spore shows a linear slit with thickening around the aperture (see also Pl. 1, figs 18-23, 25-29). All figs. × 370.

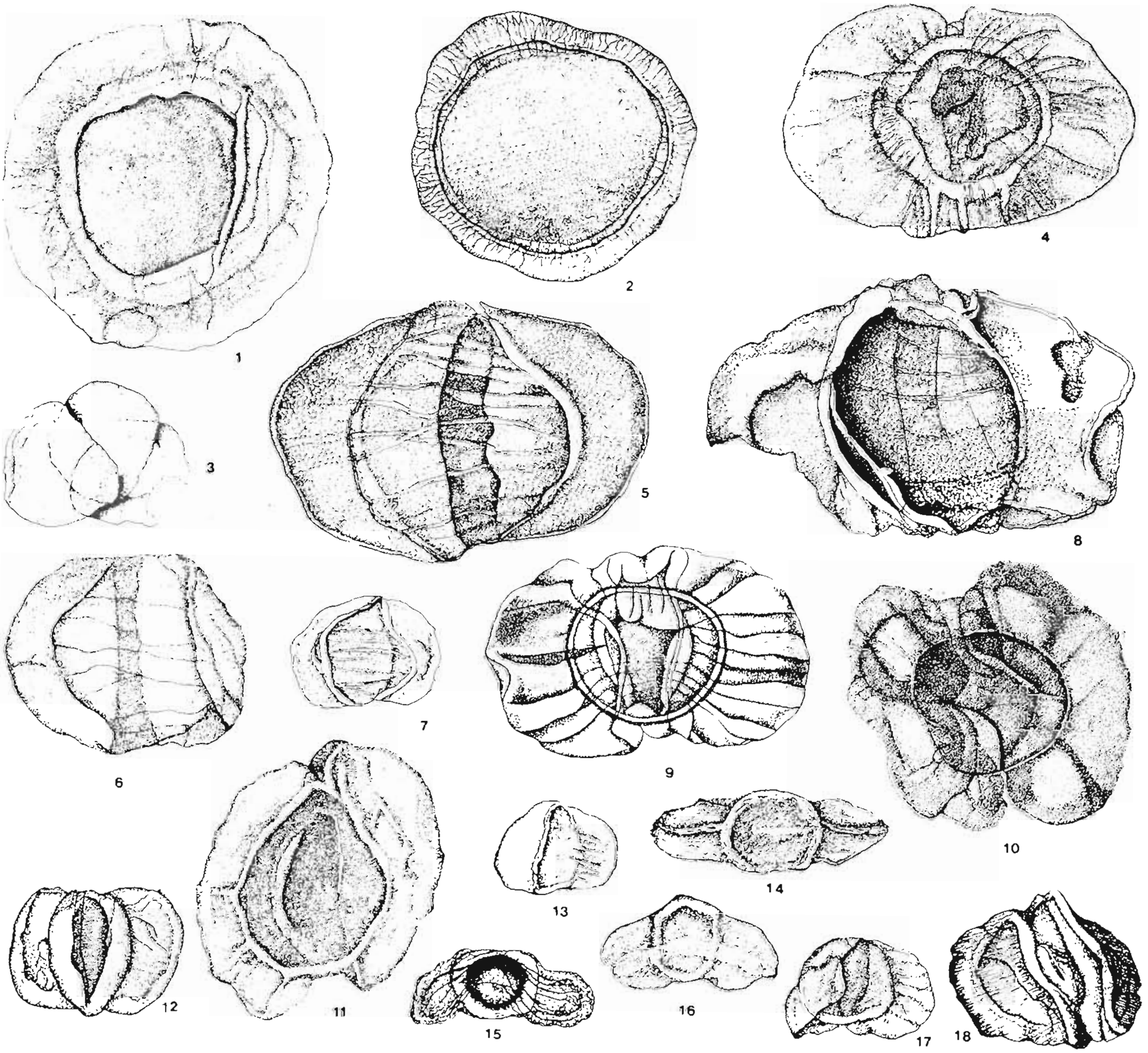
Lucknow University *see* also Pl. 3, fig. 1). Earlier Jowett (1925) had reported plant remains lying directly over the glacial boulder bed in Karanpura Coalfield. Subsequently Surange and Lele (1956) also found a few megafossils only a few feet above the basal boulder bed. Lele (1966) assembled all the available data about the occurrence of megafossils in ten Indian localities of Talchir series and pointed out that *Gangamopteris* alone is found in all the ten localities while *Noeggerathiopsis* occurs in six and seeds of *Samaropsis* and *Cordaicarpus* occur in four but *Glossopteris* is found only in the upper strata of the Talchir in two localities. The early occurrence of *Gangamopteris* in India agrees with its early occurrence in South Africa and Australia as mentioned above.

EARLIEST MIOSPORES OF GLOSSOPTERIDS

Besides the above megafossils, Virkki (1939, 1946) and Pant (1942, 1943, 1949, 1955) and Pant and Mehra (1963) reported a large variety of miospores and other microfossils from Bacchus Marsh tillite. An extensive search for miospores in material of Lower Gondwana tillites was taken up by the present author in 1941 when the late Professor Birbal Sahni gave him rock samples from Talchir in India, Dwyka at Vereeniging and Strydenberg in South Africa and Bacchus Marsh in Australia and formulated the problem for his investigation in a rough sketch a fascimile of which is reproduced in Plate 3, figure 1. The author's investigation of a rock sample from Coimadai Creek, Bacchus Marsh bearing the number "Off BM 1926, 965" which was obtained from Mr W. N. Edwards, Keeper of the Geology Department, British Museum (Nat. Hist.), London proved quite rich not only in the gross content of microfossils but also in their variety. Roughly about 1,200 miospores and a single megaspore were mounted on slides after macerating a rock piece which was hardly about 2 cm^3 in volume. Statistical counts of miospores of different varieties show that 41 per cent of their total number are monosaccates with radially symmetrical circular, oval or trianguloid outlines and a uniformly wide saccus around a central corpus. In addition 1 per cent monosaccates are bilaterally symmetrical with a saccus which is wider on two sides. The central corpus of some monosaccates is alete but in others it bears a trilete. The monosaccates are followed in descending order of frequencies by striate or non striate-disaccates 8 per cent, asaccate triletes 8 per cent; asaccate monoletes 6.5 per cent, trilobate triletes 6.5 per cent, monocolpates 5 per cent and the remaining about 24 per cent include a majority of aletes or other odd sporomorphs and about 3 to 4 per cent indeterminates. Some of these miospores have been reported already by Pant (1949, 1955) and Pant and Mehra (1963). The various kinds of miospores found in the tillite are illustrated in text-figures 1 and 2. A careful comparison of these with the figures and photographs of Lower Gondwana sporomorphs published by Virkki (1937, 1945), Balme and Hennelly (1955, 1956a, 1956b), Pierart (1959), Potonié and Lele (1960), Bharadwaj (1962), Bharadwaj and Tiwari (1964a, 1964b), Bharadwaj and Salujha (1964, 1965a, 1965b), Bharadwaj *et al.* (1965), Bharadwaj and Srivastava (1969), Bharadwaj *et al.* (1978) and others shows that practically all of them are referable to the same sporomorphs or closely similar ones. The high frequency of radial monosaccates in the mioflora and also the percentages of the different kinds of miospores in the tillite present an overall aspect which is closely comparable with that of the miofloras reported from the beds of Talchir and Karharbari stages which lie immediately above the glacial tillites in India (*see* Bharadwaj, 1974).

CONTEMPORANEOUS EXISTENCE OF ICE AND EARLY GLOSSOPTERIDS

As mentioned above the occurrence of *Gangamopteris* and a few other members of the Glossopteris Flora, interbedded with the glacial tillites and also occurring at the base of the tillites in Australia and South Africa, as well as the occurrence of the same kind of miospores in beds, which lie immediately above the tillites in India and other parts of Gondwanaland suggest that the Gondwana Ice Age and the earliest members of the Glossopteris Flora appeared almost simultaneously. Therefore, we can safely conclude that the pioneers of the Glossopteris Flora had come into existence during the Gondwana Ice Age. Seward (1933) compared the situation in ice bound Gondwanaland with that of present day Greenland and New Zealand. He pointed out that the present flora of Greenland has nearly 400 species of vascular plants growing in protected and unglaciated parts while in New Zealand one can see tropical looking "tree ferns cast shadows on the ice below them". A confirmation of these ideas comes from the miospores which have been reported from the Bacchus Marsh tillite. Such pollen grains from neighbouring vegetation seem to have been blown over the ice of Gondwana glaciers and later when the ice melted, they were deposited in the tillites. Pollen grains of surrounding vegetation become deposited in the same manner over the ice of modern glaciers, e.g., in Central Europe where Vareschi (1942) recovered them by melting the ice.



Text-figure 2—1-18, Monosaccate and disaccate spores; **1, 2,** spores show monosaccates of *Nuskoisporites*-type with a wide and a narrow saccus, respectively (see also Pl 2, figs 1,2); **3,** shows three adherent identical spores of *Nuskoisporites*-type possibly from the same tetrad, **4,9,** a new type of disaccate sporomorph, *Rugasaccites marshensis* gen et sp. nov. where the two sacci are seemingly joined by narrow connections in front and/or rear and they have distinct radiating folds, the corpus is non-striate (see also Pl 2, fig 7), **5-8,** spores are *Alisporites*-or of *Striatites*-type (see also Pl. 2, fig. 11-13); **10-18,** show *Pityosporites* type of spores of various sizes squashed in different aspects All figs × 370

PLATE 1

→

1-6 Smooth walled alete spores 1, 2 × 425, 3-6 × 380

7. Two monolete spores. × 425

8-11. *Leiotriletes*-type of spores, all × 380.

12 *Brachytrilistrium*-type of spore. × 380.

13. *Periplecotriletes*-type of spore. × 380.

14 *Lophotriletes*-type of spore. × 380.

15. *Ginkgocycadophytus*-type of spore. × 790

16. *Hymenozonotriletes*-type of spore. × 380

17-23. Trilete monosaccate spores of *Endosporites*-type all × 380.

24. Alete reticulate spore × 380.

25-29. *Nuskoisporites*-type of alete monosaccate spores. × 380.

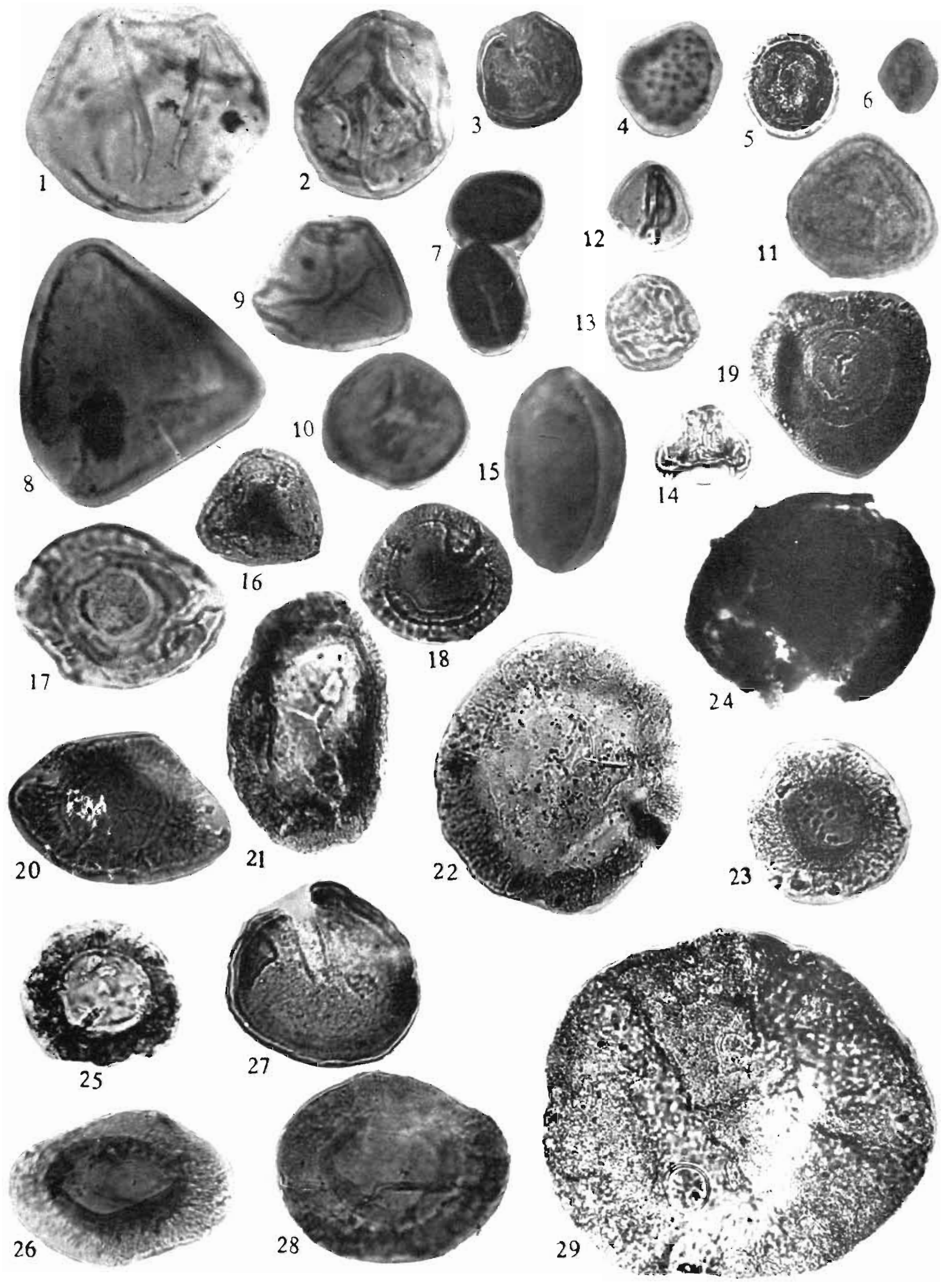


PLATE 1

ANCESTRAL STOCK AND ORIGIN OF GLOSSOPTERIS FLORA

The sudden appearance of an entirely new flora leaves us guessing about its ancestral stock and about the manner of its origin. No pre-Gondwana plants of the area are closely comparable with the pioneers or even the later elements of the Glossopteris Flora. There is also no possibility of the glossopterids having invaded Gondwanaland from any other territory because nothing like its elements was existing in any previous or contemporaneous floras. The origin of the Glossopteris Flora with its predominantly simple leaved gymnosperms is therefore entirely unknown. In this connection Seward (1922, 1924) suggested that the onset of catastrophic climatic changes in the geological history of the earth like the sudden chilling of Gondwanaland during the Carbo-Permian glaciation or the sudden rise of temperatures during widespread volcanic upheavals during some periods, etc. may have been responsible for large scale extinctions of old forms and the abrupt appearance of new forms. Sahni (1937, 1939) suggested that since it had become well known that radiations, chemicals, sudden heating and chilling, etc. can induce mutations, the Gondwana glaciation may have been itself responsible for the disappearance of the previous vegetation and the appearance of the Glossopteris Flora. Such mutations must have been induced on a large scale in pre-existing plants in a widespread area so that the flora spread rapidly all over Gondwanaland. At present this is the only plausible explanation known to us about the origin of the Glossopteris Flora.

RISE AND ULTIMATE CLIMAX OF GLOSSOPTERIS FLORA

With glaciers all around, the climate of Gondwanaland during the Talchir and Early Karharbari stages must have been of the cold temperate type with very cold winters. In this cold climate a few deciduous trees of *Gangamopteris* and *Noeggerathiopsis* were growing but *Glossopteris* was rare and appeared later. Some herbaceous forms like *Schizoneura* were also present.

Subsequently, during the deposition of the sediments of the Damuda Series with its three stages, viz., Barakar, Ironstone Shales and Raniganj, as the temperatures rose and glaciers receded, the forests of Gondwanaland became richer. Even at this time, the prevalent trees of the Glossopteris flora were deciduous but a few evergreen conifers also existed. Winters were still quite cold or dry and the secondary wood of tree trunks had marked seasonal rings. Ice had now melted away and Gondwanaland had developed a warm and humid temperature climate where ferns, sphenopsids and lycopsids formed the undergrowth in the shade of trees or along water courses in the forests.

The climax of this flora was reached during the last Raniganj Stage when the forests developed a greater variety of glossopterid, genera like *Gangamopteris, Glossopteris, Rhabdotaenia, Euryphyllum, Palaeovittaria, Belemnopteris, Sagittophyllum, Pteronilssonia* besides *Noeggerathiopsis* and some conifers, etc. There is now a far greater variety of species. Many of these gymnosperms were large leaved deciduous forest trees.

The litter of abscissed leaves and fallen plant parts and seeds on the forest floor must have provided shelter and food to many animals like those which live in present day warm temperate forests but so far only a few remains of cockroach wings have been observed in India (Pant & Das, 1987) and Africa (Rayner & Coventry, 1985). There is need for intensive search for animal remains among the fossils of the Glossopteris Flora.

DECLINE OF GLOSSOPTERIS FLORA

Unlike the abrupt rise of the Glossopteris Flora, its decline was gradual. Many of its elements lingered on in the Triassic Dicroidium Flora (*see* Pant & Pant, 1987). The climate of the area seems to have become drier and warmer as the spread of the flora and reptiles also indicate. Once again mutational changes may have been responsible for

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PLATE 2 →

1-3. Alete spores of *Nuscoisporites*-type 1, 2 × 380, 32. × 560.
4,5. Monosaccate spores with slits having thickened sides. Both × 380.
6,11-13 *Striatites* spores. Spore in 13 is a more magnified view of spore in 12, 6, 12 × 380, 11 × 487, 13 × 585.
7. *Rugasaccites marshensis* gen et sp. nov. Type specimen. × 380.
8-10. Large disaccate spores of *Alisporites* and *Pityosporites*, all. × 380.
14,15. Spores of *Sahnites*, both. × 380.
16,17. Spores of *Pityosporites*-type seen in a side and a top view, both. × 380.

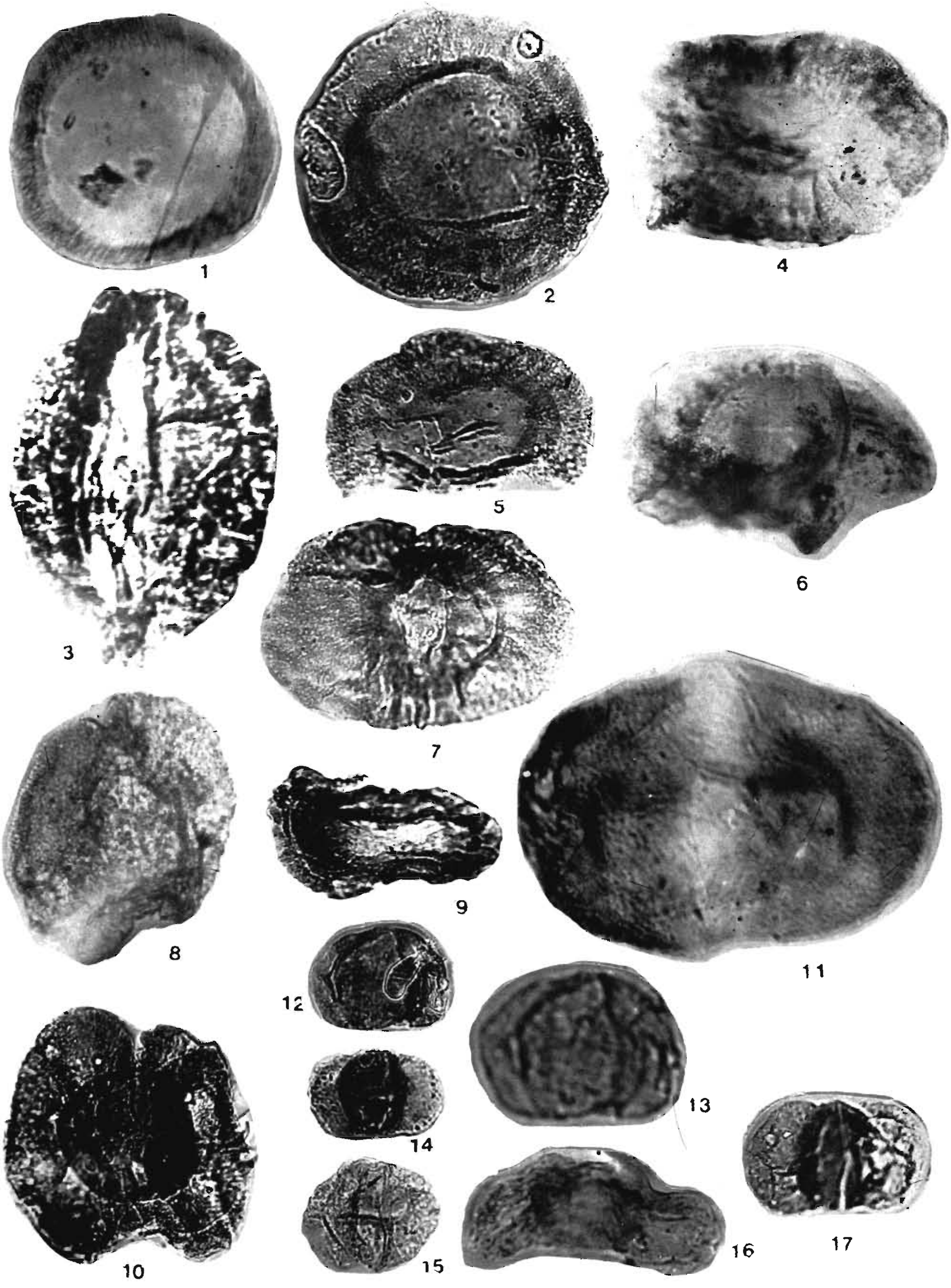

PLATE 2

the coming in of new elements but other new forms may have migrated from other parts. Some old forms adapted themselves for the changed conditions and continued their existence with dwindled strength of numbers.

PALAEOGEOGRAPHICAL NORTHERN BOUNDARY OF GONDWANALAND

The northern limit of Gondwanaland towards the north of India has lately become quite uncertain. Earlier *Glossopteris* and *Gangamopteris* containing beds were reported only up to the Himalayan region in Kashmir, Kumaun and Darjeeling areas which were believed to mark the southern shore of the Tethys sea and the palaeogeographical northern boundary of Gondwanaland. However, lately the boundary has been suggested to have been lying far towards the north of the Himalaya, after Yin and Guo (1976) and Hsü (1976) reported a rich Glossopteris Flora of an early stage of the Late Permian in the northern slope of Qomolangma Feng (Mount Everest Area) in southern Xizang (Tibet) and Crawford (1974) emphasized the occurrence of the cladoceran *Daphiopsis* and the reptile *Lystrosaurus* in Lower Triassic of Tibet. According to Termier and Termier (1981) *Lystrosaurus* occurs simultaneously in Tarim Basin, India, South Africa and Antarctica and Crawford has used this for postulating his hypothesis of Greater Gondwanaland which extended up to the Tarim basin.

The finds of mixed Cathaysian and Gondwana elements in the Mamal Bed in Kashmir and the occurrence of *Glossopteris* in Hazro in Anatolia up to Soviet far east complicate the boundary problem of Gondwanaland and it could indicate the existence of an ecotone in the north of Gondwanaland.

AGE OF THE GONDWANA GLACIATION AND GLOSSOPTERIS FLORA

Although it is generally agreed that the Gondwana glaciation started sometime in the latter part of the Palaeozoic, it is not settled whether it started in the Carboniferous or the Permian times so that it is often called the Carbo-Permian glaciation. Along with the age of the glaciation, the age of the Glossopteris Flora has also been discussed by geologists and palaeobotanists and there is hardly any unanimity in the matter.

In 1875, Blanford (*in*: Oldham, 1893) had suggested that the Talchir Boulder Bed of India was contemporaneous with the Permian glacial beds of England. Feistmantel and Vredenberg (*see* Schuchert, 1929) believed that it was of Permian or Early Triassic age. It was at one time even correlated with beds which are regarded to be Jurassic. Warth (1887, 1888 as quoted by Virkki, 1945) and Waagen (as quoted by Schuchert, 1929) held that the glaciation took place in the Carboniferous. In later years Seward (1924, 1929), Sahni (1926, 1938), du Toit (1926, 1927), David (1932), Thomas (1929), Walton (1929) and others have suggested that although the glaciation did not begin simultaneously in all parts of Gondwanaland, it began as early as the Upper Carboniferous, while Schuchert (1929, 1936), Teichert (1941, 1943, 1943a, 1943b) and others hold that the glaciation began in the Permian and according to Schuchert in "early Middle Permian". Geological evidence supporting the views of the various authors is partly palaeobotanical and partly palaeozoological as mentioned below:

Palaeobotanical evidence—It comes from the occurrence of mixed floras containing typical European and Cathayasian Carboniferous plants in Lower Gondwana beds. The occurrence of these mixed floras according to Thomas (1929) indicates a Carboniferous age not only for the underlying glacial beds but also for the origin of the closely associated Glossopteris Flora. In the Irwin River District of Australia Teichert (1941) mentions the occurrence of *Bothrodendron*, *Sphenophyllum* and *Lepidodendron* intermixed with *Glossopteris*, *Gangamopteris* and other typical members of the Glossopteris Flora in the Coal Measure Series which overlie the tillite. Seward and Sahni (1920) thought that *Bothrodendron* was also present in India. Seward (1908) believed that it also occurred in South Africa and Seward and Leslie (1908) reported it from Vereeniging in association with *Lepidodendron* and *Sigillaria*. In the Wankie flora of South Africa, Walton (1929) found *Glossopteris* and

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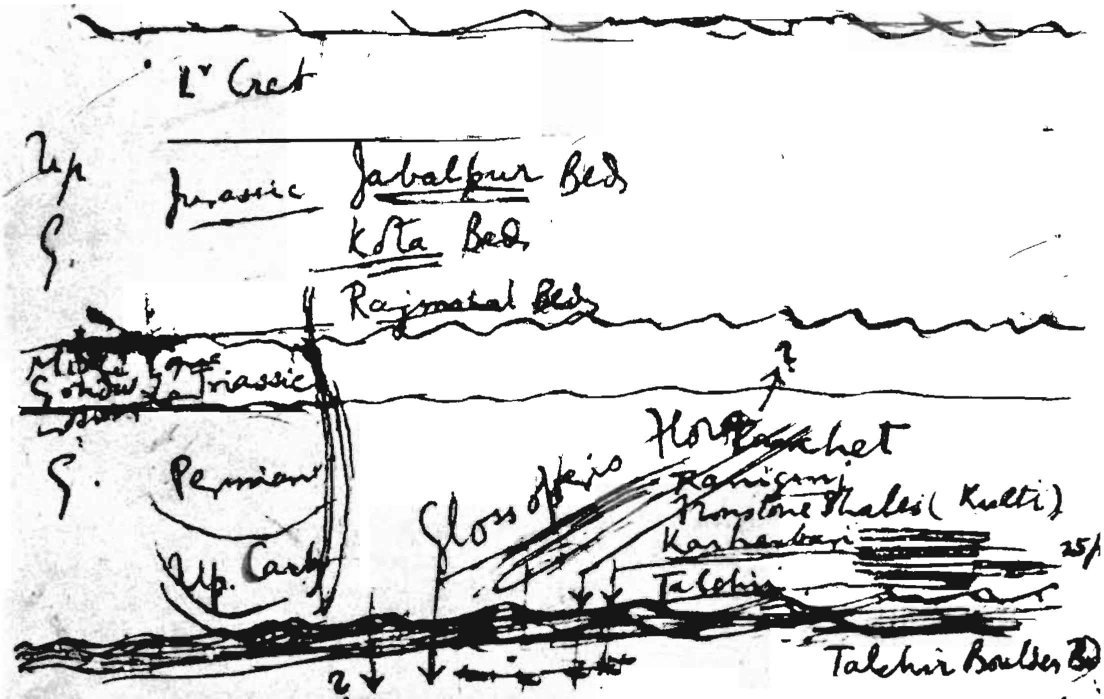
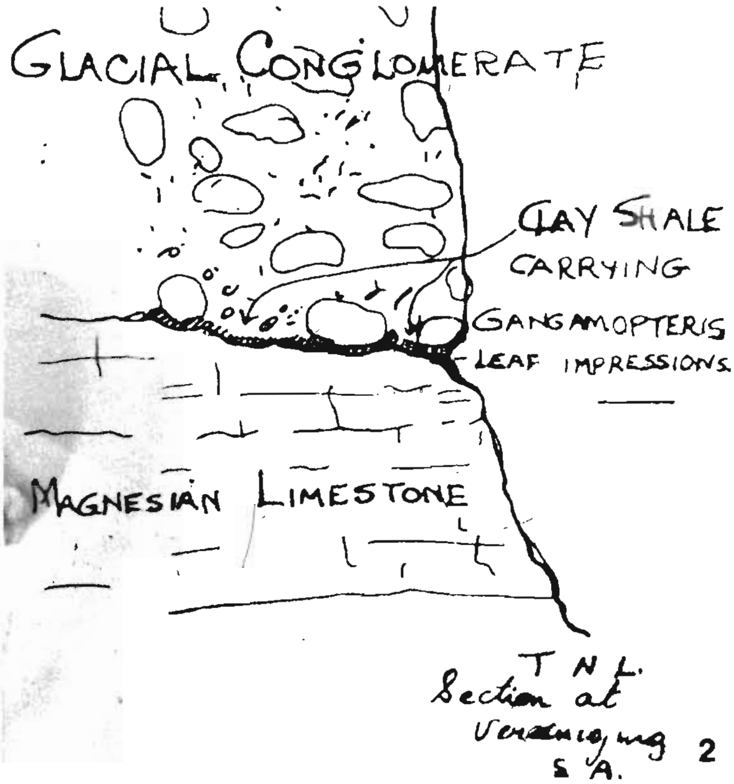
PLATE 3 →

1. Sahni's rough sketch showing the Talchir Boulder Bed and tillite at the base and Triassic (Panchet) beds at the top both with question (?) marks to indicate the problematic downward and upward extensions of the Glossopteris Flora.
2. T. N. Leslie's sketch of Dwyke tillite beds at Vereeniging, South Africa showing position of layer containing *Gangamopteris* impressions.
3. One of Leslie's hand-specimens of *Gangamopteris* obtained from the layer indicated in fig. 3. × 1.


Lr Cret
Jurassic
Jabalpur Beds
Kota Beds
Rajmahal Beds
Triassic
Permian
Up. Carb
Glossopteris Flora
Raniganj
Ironstone Shales (Kulti)
Talchir Boulder Bd

1


GLACIAL CONGLOMERATE
CLAY SHALE
CARRYING
GANGAMOPTERIS
LEAF IMPRESSIONS
MAGNESIAN LIMESTONE
T N L.
Section at
S. A.

2

3

PLATE 3

other Lower Gondwana plant remains mixed with *Pecopteris* and other typical European Carboniferous plants. In South America, too, du Toit and others discovered *Rhacopteris szajnochai* and *Cardiocarpus polymorphus* between glacial beds and *Asterocalamites, Sigillaria, Lepidodendron larcinus, Psaronius* with *Glossopteris, Gangamopteris* and *Noeggerathiopsis* and according to du Toit (1937) this indicated an Upper Carboniferous age for the glaciation. However, the reports of the above mixed elements require to be re-examined in the light of recent knowledge since most of the reports of European Carboniferous elements are based on surface impressions of sterile parts and some of them have, and others may prove to belong to homoplastic Gondwana forms which were different from European Carboniferous elements, although they were externally similar (*see* Edwards, 1952; Chaloner & Lacey, 1973; Lacey, 1975; Xingxue, 1986).

The miofloras reported from the Lower Gondwana tillites and beds immediately overlying them are dominated by radial monosaccates which first appeared in the Lower Carboniferous but the presence of disaccates, which are first reported in the Upper Carboniferous and continue upwards, may only rule out a Lower Carboniferous age. However, the agewise vertical distribution of characteristic miospores has to be confirmed on a world-wide scale before the miospores reported from the tillites and overlying Lower Gondwana beds can be used for age determination.

Palaeozoological evidence—In the Indian subcontinent, according to Reed (1932), the occurrence of *Eurydesma* and other marine fossils in a horizon lying above the boulder bed in Salt Range (Pakistan) indicates an "Upper Carboniferous age rather than Lower Permian" for the horizon. Accordingly, this author points out that the boulder bed lying immediately below that bed could not be younger. In Kashmir, the *Gangamopteris* beds (Noetling, 1902 as mentioned by Hayden, 1908) which lie above the trap are overlain by the Zewan Stage which is equivalent toFenestella shales of Spiti. Therefore, according to Reed the *Gangamopteris* bed could not be younger than Upper Carboniferous. Reed also believes that the marine fossils (discovered by Sinor, 1923) overlying the Talchir tillite in Umaria in central India also favour a similar conclusion.

In South Africa du Toit and Thomas regard the occurrence of *Eurydesma, Pygocephalus* and the fish *Palaeoniscus* in the Dwyka shales above the Dwyka tillite to suggest a Carboniferous age for these beds.

In South America marine fossils collected from two horizons over the glacial matrix in Brazil and Argentina (du Toit, 1927—appendix by Reed) indicate, according to Reed, a Carboniferous and possibly Lower Middle Carboniferous age for the Gondwana glaciation and the GlossopterisFlora.

In Australia, the fauna of the *Eurydesma* and *Conularia* horizons of New South Wales and the occurrence of *Paralegoceras jacksonii* in the Lower Marine beds below the Irwin Coal Measures in Western Australia, according to Thomas (1929), indicate an Upper Carboniferous age for the beds and the glacial beds below could not be younger. Other workers in Australia, e.g., Teichert (1941) suggests that the glaciation in that area started sometime in the beginning of Permian (Sakmarian) or at a time only slightly preceding the Permian.

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Palynological correlation of Lower Gondwana coal seams

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Correlation of coal seams which is a universally accepted terse geological problem, has been enunciated in all its aspects. The physical and chemical characteristics which are unpredictably variable in coal seams have been evaluated *vis-a-vis* their palynological characteristics which are almost constant qualitatively. These are suggested to be used for typification of each coal seam or its lithological equivalent so as to trace its lateral extension through correlation of the bits and parts occurring in various sectors of the coalfield. As examples of palynotypification, two, recently studied two coal seams from Talcher Coalfield, have been illustrated. One of them is the basal seam in a bore-hole designated as Seam I and interpreted geologically to be of Karharbari Formation. Palynologically it is characterised by the association of *Indotriradites* and *Dentatispora*. The other one is an out-crop seam, so far undetermined geologically. It contains preponderance of *Callumispora*, a spore genus which signifies Karharbari Formation. These coal seams, where so ever their lateral continuations extend, can be identified on the basis of the palynological contents qualitatively and to some extent also quantitatively.

The short-comings and limitations of palynological methodology in the effort to achieve correlation of coal seams have been discussed and ways and means to mitigate the same suggested.

Key-words—Palynology, Correlation, Coal-seams, Karharbari Formation, Lower Gondwana (India).

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साराँश

अधरि गोंडवाना की कोयला-सीमों का परागाणविक सहसम्बन्ध

दिनेश चन्द्र भारद्वाज

एक सर्वमान्य स्पष्ट भूवैज्ञानिक समस्या—कोयला-सीमों के सहसम्बन्ध, का विवेचन सभी पहलुओं को ध्यान में रख कर किया गया है। भौतिक एवं रासायनिक संलक्षणों का, जो कोयला-सीमों में विभिन्नता प्रदर्शित करते हैं, तथा परागाणविक लक्षणों का तुलनात्मक मूल्यांकन किया गया है। प्रायः परागाणविक लक्षण गुणात्मक दृष्टि से स्थिर रहते हैं। अतः प्रत्येक कोयला-सीम अथवा इसके समतुल्य शैलों की प्रारूपता निर्धारित करने में इनका उपयोग प्रस्तावित है ताकि कोयला-क्षेत्र के विभिन्न क्षेत्रों में सहसम्बन्ध के माध्यम से इसका पार्श्व विस्तार खोजा जा सके। परागाणविक प्रारूपता के दो उदाहरणों के रूप में कोयला-सीमों का नवीनतम अध्ययन प्रस्तुत किया गया है। इनमें से एक वेध-छिद्र की आधारी सीम है। यह प्रथम सीम करहरबारी शैल-समूह की है तथा परागाणविक दृष्टि से **इन्डोट्राइरेडाइटिस डेन्टाटिस्पोरा** के साहचर्य से अभिलक्षणित है। दूसरी एक दृश्यांश सीम है जिसका अभी तक भूवैज्ञानिक अभिनिर्धारण नहीं किया जा सका है। इस सीम में **केल्यूमिस्पोरा** की प्रधानता करहरबारी शैल-समूह को इंगित करती है। इन कोयला-सीमों के पार्श्व विस्तार का परागाणुओं के गुणात्मक स्वरूप तथा कुछ हद तक परिमाण के आधार पर भी अभिनिर्धारण किया जा सकता है। कोयला-सीमों के सहसम्बन्धन में प्रयास करने हेतु परागाणविक विधि की सीमाओं एवं कमीयों का विवेचन किया गया है तथा प्रस्तुत समस्या के निराकरण हेतु कुछ उपाय आदि सुझाए गये हैं।

COAL SEAMS correlation has always been a difficult problem for geologists. All the parameters more commonly used in coal prospecting are handicapped by some inconsistency or the other. The thickness of coal seams often varies from place to place and so do the physical and chemical characteristics. Even the so valued coal quality varies, depending upon the extent of metamorphosis the peat undergoes due

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to varied overburden at different locations. A seam of pure coal might become shaly coal or even a carbonaceous shale in various parts of its lateral extent. Thus, crux of this problem is the inability to typify a coal seam which may hold good through out its lateral extent in the coalfield and on the basis of which the seam may be identified all over the area. However, the organic matter contained in the seam and its continuation, being residue of the vegetation growing in or around the basin of deposition, is expected to have been more or less similar all over its extent. This organic residue contains numerous hardy components such as the spores, pollen grains, cuticles and tracheids which are unalterable in their external features or morphography during fossilization. These provide a reliable means of typification for each coal seam irrespective of other differences. Among them, the most varied and distinctive are the spores and pollen grains of the various plant groups. These groups represent evolutionary tendencies acquired by the plant kingdom through geological time. Each of these tendencies is characterised by individualistic reproductive biology including the morphography of the spores and pollen grains, which makes them easily identifiable and classifiable. Thus, spores and pollen grains contained in the fossilized organic debris or coal representing the original vegetation growing in a region at any point of time, provide it a genetic identity. This identity of each coal seam can be traced all over the coalfield through palyno-analysis of samples, i.e., the representation of spores and pollen grains in each sample can be estimated qualitatively and quantitatively.

The principles, as enunciated above, make the problem of coal seams correlation appear very easy. However, in practice it is not so. Inspite of supposed genetic constancy of the palynological contents, the samples from contiguous bore-holes may not compare palynologically and thus, pose problems in correlation—Why?

VARIABLE FACTOR

The theoretically uniform palynological contents of any sediment, may minorly not be so in nature especially in the quantitative representation of spores and pollen grains in the processed samples. This may be due to differential:

1. over representation of some spore kinds due to presence of sporangia, pollen sacs or pollenia in a sample;
2. destruction of some spore kinds due to infiltration or over action of acidic or alkaline medium in the sediments or macerates respectively, thus causing absence of some and consequent over-representation of others in correlatable samples;
3. sedimentary segregation of spores, pollen grains and other micro-remains depending upon the speed and turbulence of the carrying medium resulting into gravitational separation;
4. acumen of palynologists in identifying a spore, pollen grain or its part which may lead to differing results in quantitative estimation.

Realizing the need for reducing the interplay of the above mentioned inconsistencies in interpretation of correlation, varied measures have been practised in palynostratigraphical studies. Differential over-representation is easily over come by preparation of thoroughly mixed samples so as to be representative of the whole or the specific parts of a coal seam.Fortunately, even in finely powdered (70 mesh) sample, small spores and pollen grains remain undamaged. Hence, representative coal samples used for analyses in coal survey laboratories are equally suitable for small spore analysis.

Differential spore destruction due to infiltration of coal deposits by calcareous solutions is known and cannot be mitigated. However, any destruction due to over treatment with acids and alkalies during maceration, is avoided through vigilance and care. Moreover, all abnormal macerations are normally rejected and the process repeated.

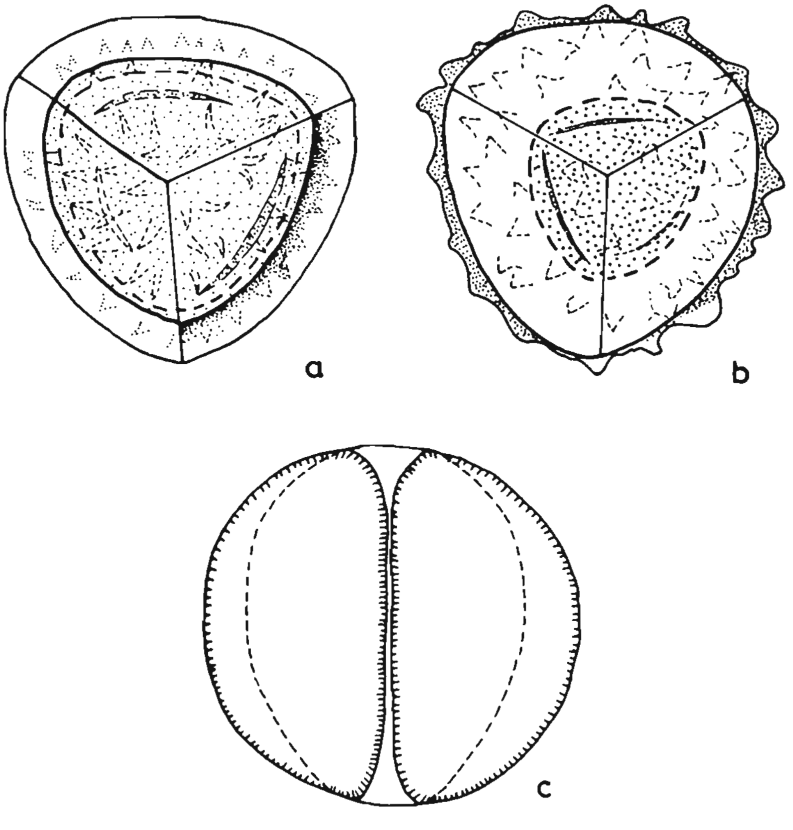
Gravity segregation of spores resulting into unusual representations of certain spore kinds is more theoretical than factual.Further, even if it is sizeable, there is no method of correcting it.

Lastly, to avoid play of the subjective, personality factor, similarity of training, use of broader-based, genealogically coherent taxa as units for quantitative estimation, and interchange of analyses between workers are the remedial measures available.

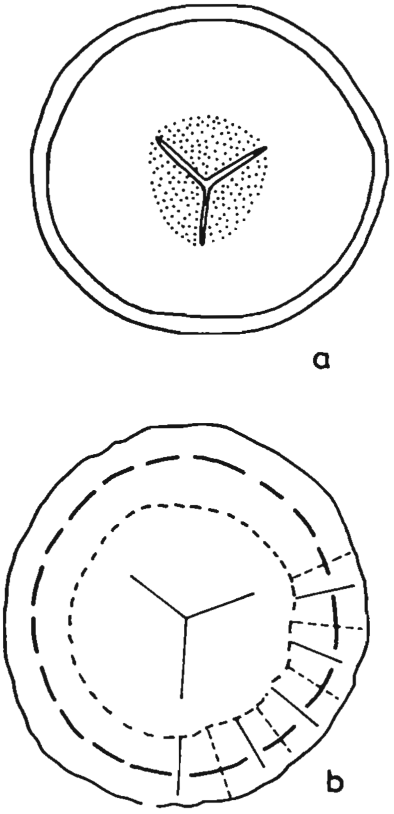
Inconsistency in the lithological nature of coal seams causes difficulties. Hence, to mitigate the lithological variations, all hopeful lithologies besides coal should also be sampled and studied.

CONSTANT FACTOR

While quantitative representation of taxa is minorly variable, the qualitative presence of taxa in each seam is considered constant. Among the gamut of taxa present in the seam a few, even if rare, might be strikingly characteristic and chrono-stratigraphically restricted. Some may be so singly or in association with some others, to make themselves distinctive for that seam. As examples of the same, I report here two cases from our current investigations of Lower Gondwana coalfields from Orissa.



Text-figure 1—Semi-diagrammatic sketches of A, *Indotriradites*, B, *Dentatispora*, and C, *Scheuringipollenites*.



Text-figure 2—Semi-diagrammatic sketches of A, *Callumispora* and B, *Radial monosaccate*.

Table 1—Suprageneric and generic quantitative representation in two coal seams of Talcher Coalfield

CHAMPARI NALA		SEAM-I, DMTU-026 (216.10 m)	
Callumispora	56%	Smooth Triletes +	
Smooth Triletes	9%	Monoletes	15%
Ornamented Triletes	18%	*Indotriradites*	60%
Zonate Triletes	1%	*Dentatispora*	3%
Nonstriate Disaccates	4%	Nonstriate Disaccates	17%
Radial Monosaccates	11%		
Striate Asaccates	1%	Radial Monosaccates	5%
	100		100

In the sample from Seam I of bore-hole DMTU-26 at 269.50 m level in Talcher Coalfield, a characteristic association of *Indotriradites, Dentatispora* and *Scheuringipollenites* (Text-fig. 1) has been found. The same association has been earlier found (Bharadwaj & Tiwari, 1964) in basal Barakar horizon of Ghordeva Sector in Korba Coalfield. This qualitative as well as quantitative association (Table 1) should now be considered to typify Seam I in Talcher Coalfield. In all the bore-holes in its neighbourhood, any coal seam which contains similar palyno-composition can be identified as Seam I very easily. With this datum fixed, it would be possible to characterise the preceding and the succeeding strata also.

The second sample is from a seam outcrop in Champari Nala of Talcher Coalfield. It contains an association of *Callumispora* and radial monosaccates (Text-fig. 2) and some ornamented small triletes. This assemblage compares closely with that of Lower Karharbari of Korba Coalfield (Bharadwaj & Srivastava, 1973) and should identify the lateral continuations of Lower Karharbari sediments in the Talcher Coalfield. I believe that the Champari Nala seam is the first palynologically authenticated record of a Karharbari seam in Talcher Coalfield.

The palynological characteristics of both these samples are distinctive singly because each represents a separate zone but to establish the diagnostic palynocombination, the whole sequence lying above and below needs to be qualitatively and quantitatively palyno-analysed. Hence, the first step to be taken in the palynological study of any coalfield is the detailed, generic level palynoanalysis of at least one (Table 2) closely sampled (including all lithologies), regional or deep bore-hole, containing the whole of coaliferous sequence, from

Table 2—Percent frequency chart of Sporae dispersae in bore-hole no. BOR/MA/043

(All levels are typified by different combinations of genera with % represented in bold figures).

Sample No.	Depth (M)	Lithology	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
125	14.94	Carb. Shale	—	2.0	0.5	**5.5**	—	0.5	—	1.5	—	—	1.0	1.5	—	—	1.0	**8.0**	3.0	5.0	2.0	21.5
133	20.50	Sandy Shale	0.5	1.0	—	1.5	2.0	—	—	1.5	3.0	—	—	1.0	1.0	—	—	5.5	—	2.5	1.0	**31.5**
136	25.00	Coal	—	—	—	—	0.5	—	—	—	—	—	0.5	—	0.5	—	—	8.0	1.0	2.0	1.0	22.0
142	42.90	Coal	0.5	3.0	—	**7.0**	3.5	0.5	1.0	1.0	**7.5**	—	1.5	0.5	1.0	—	—	5.0	—	5.0	1.5	**28.0**
145	45.25	Coal	—	1.5	—	3.0	1.5	—	—	1.0	2.5	—	0.5	**4.5**	—	—	0.5	2.0	1.0	3.0	3.5	**28.0**
152	50.35	Alternating shale and sandstone	—	0.5	—	1.0	0.5	—	—	0.5	0.5	—	—	0.5	—	—	—	4.0	—	1.0	1.0	28.0
158	73.29	Shaly SST.	1.0	1.5	—	1.5	1.5	—	—	0.5	1.0	—	—	0.5	—	0.5	1.0	**13.0**	1.0	4.0	**8.0**	16.0
167	94.40	Coaly shale	—	0.5	—	1.5	—	—	—	—	—	—	—	—	—	1.0	0.5	5.5	3.5	**6.5**	**7.5**	24.0
173	100.45	Coal	—	1.5	—	1.0	0.5	—	—	—	1.0	0.5	—	1.0	—	—	—	7.5	—	**7.5**	5.5	20.5
177	109.94	Shale	—	2.5	—	3.0	4.0	1.0	0.5	1.0	2.0	—	1.5	1.0	2.0	—	—	3.0	2.0	**3.0**	5.0	18.5
182	115.40	Shaly SST.	—	1.0	—	1.5	2.5	0.5	—	—	—	—	1.0	—	—	1.0	0.5	4.5	2.0	5.5	2.0	20.5
	120.77	Metamorphic																				
	126.00	Bore-hole closed																				

Contd.

21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Total
3.0	0.5	2.5	1.0	—	3.0	—	26.0	—	1.0	6.0	1.0	2.0	—	0.5	0.5	—	—	—	100
1.0	—	1.0	—	1.0	—	—	**32.5**	1.5	3.0	7.0	—	—	—	—	0.5	0.5	—	—	100
1.0	1.5	**7.0**	1.5	—	2.0	—	**32.5**	2.0	—	12.0	1.0	2.0	—	—	0.5	—	1.5	—	100
—	0.5	0.5	—	—	—	—	26.5	—	1.5	3.0	—	1.5	—	—	—	—	—	—	100
—	2.5	1.5	—	—	1.0	—	**28.0**	—	3.5	10.5	—	—	—	0.5	—	—	—	—	100
—	**5.0**	1.5	0.5	—	3.0	—	**31.5**	1.0	3.0	11.5	2.0	2.0	—	—	0.5	—	1.0	—	100
2.0	1.5	0.5	0.5	—	3.0	1.0	17.0	2.0	3.0	12.0	1.0	4.0	—	1.5	0.5	0.5	—	—	100
1.5	—	—	—	—	**3.5**	—	26.5	1.5	3.5	7.5	—	3.5	—	1.0	—	—	—	1.0	100
5.0	—	—	—	0.5	3.0	—	24.5	—	4.0	8.5	2.0	4.0	0.5	—	0.5	0.5	0.5	—	100
3.0	0.5	—	0.5	1.0	2.0	**3.0**	24.5	1.0	**4.0**	5.5	—	5.0	—	—	—	—	—	—	100
3.0	3.5	0.5	—	—	3.0	**4.5**	20.5	1.0	3.0	9.0	2.0	**5.5**	0.5	1.0	0.5	—	—	—	100

1, *Acanthotriletes*; **2**, *Apiculatisporis*; **3**, *Cyclobaculisporites*; **4**, *Cyclogranisporites*; **5**, *Horriditriletes*; **6**, *Imparitriletes*; **7**, *Lacinitriletes*; **8**, *Leiotriletes*; **9**, *Lophotriletes*; **10**, *Microbaculispora*; **11**, *Microfoveolatispora*; **12**, *Latosporites*; **13**, *Thymospora*; **14**, *Parasaccites*; **15**, *Plicatipollenites*; **16**, *Cuneatisporites*; **17**, *Labiisporites*; **18**, *Ibisporites*; **19**, *Platysaccus*; **20**, *Scheuringipollenites*; **21**, *Vesicaspora*; **22**, *Striamonosaccites*; **23**, *Striasulcites*; **24**, *Tiwariasporis*; **25**, *Striapollenites*; **26**, *Crescentipollenites*; **27**, *Distriatites*; **28**, *Faunipollenites*; **29**, *Lahirites*; **30**, *Striatites*; **31**, *Striatopodocarpites*; **32**, *Verticipollenites*; **33**, *Rhizomaspora*; **34**, *Maculatasporites*; **35**, *Densipollenites*; **36**, *Ginkgocycadophytus*; **37**, *Schizopollis*; **38**, *Weylandites*; **39**, *Praecolpatite*.

each sector. This study would typify each coal seam on the basis of quantitatively significant association of atleast two genera, besides revealing the trend of palynological changes in geological time from the base to the top of depositional sequence. The palyno-analyses of other bore-cores can be referred to this standard profile and lateral correlations suggested. Such an information would help the geologist incharge in final interpretation of coal seams correlation, fault throws and coal potential.

SEAM SPLIT

The problem of seam split often creates difficulties in coal seams correlation. Palynologically a coal seam should be qualitatively and quantitatively constant at one location. Hence, between contiguous bore-boles a seam, even if split, can be identified through palynological comparison. In cases of seams which are thicker than 3 m, it is preferable to sample it in two or more parts so that the differences if any, occurring due to extended duration of deposition, may be revealed and taken into account for interpretation.

CONCLUSIONS

Although comprehensive palynological studies on correlation of coal seams in Lower Gondwana coals (Bharadwaj *et al.*, 1964, 1965, 1966, 1968, 1969a, 1969b, 1970, 1971) have been carried out in the past to understand and evolve the know-how for this difficult problem, certain aspects still need further studies for enhanced refinement and precision. Nevertheless, we may conclude about the stratigraphical value of various palynological units as follows:

Units	*Stratigraphy*
Geneologically coherent supra-generic units in quantitative combination	Zones
Morphographically coherent generic units in qualitative combination	Subzones
Generic units in quantitative combination	Stratum correlation

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Palynology of Kamthi Formation in Godavari Graben

Suresh C. Srivastava & Neerja Jha

Srivastava, Suresh C. & Jha, Neerja (1988). Palynology of Kamthi Formation in Godavari Graben. *Palaeobotanist* **36** : 123-132.

Five palynological assemblages have been recognised in the Kamthi Formation of Godavari Graben. The assemblages are characterised by overall abundance of striate-disaccate pollen. The associated palynofossils, however, distinguish the palynoassemblages at various levels of the formation. The Lower Member containing coal seams shows unequivocal resemblance with the Raniganj palynoflora of Damodar Valley and Son-Mahanadi coalfields. Distinct change in lithology at the beginning of the Middle Member is marked by the appearance of *Parasaccites* rich assemblage simulating a cooling phase akin to that observed during the Talchir period. The younger sediments of the Middle Member contain *Corisaccites-Guttulapollenites* Assemblage and *Densipollenites* Assemblage in order of succession representing the uppermost Permian palynoflora in Godavari Graben. The youngest assemblage also indicates a close proximity to the Permian-Triassic transition, thus making the Kamthi Formation a time transgressive unit.

Key-words—Palynology, Kamthi Formation, Raniganj Formation, Permian/Triassic Boundary, Godavari Graben (India).

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साराँश

गोदावरी द्रोणिका में कामथी शैल-समूह का परागाणविक अध्ययन

सुरेश चन्द्र श्रीवास्तव एवं नीरजा झा

गोदावरी द्रोणिका के कामथी शैल-समूह में पाँच परागाणविक समुच्चय बनाये गये हैं। ये समुच्चय रेखीय-द्विकोष्ठीय परागकणों की बाहुल्यता से अभिलक्षणित हैं। सहयुक्त अश्मित परागकण शैल-समूह के विभिन्न स्तरों पर विद्यमान परागाणविक समुच्चयों को विभाजित करते हैं। कोयला-सीमों से युक्त अधरि सदस्य सोन-महानदी कोयला-क्षेत्रों एवं दामोदर घाटी के रानीगंज परागाणुवनस्पतिजात से स्पष्ट समानता व्यक्त करता है। मध्य सदस्य के प्रारंभ में शैल-विन्यास में सुव्यक्त परिवर्तन **पैरासेक्काइटिस** से प्रभावी समुच्चय की उपस्थिति का द्योतक है जो कि तालचिर काल में प्रेक्षित शीतलन अवस्था से हर प्रकार से मिलता है। मध्य सदस्य के अल्पायु वाले अवसादों में **कोरिसेक्काइटिस-गुट्टुलापोलिनाइटिस** समुच्चय तथा **डेन्सीपोलिनाइटिस** समुच्चय आरोही क्रम में विद्यमान हैं जिससे गोदावरी द्रोणिका में उपरितम् परमी युगीन वनस्पतिजात की उपस्थिति इंगित होती है। अल्पतम् आयु वाली समुच्चय भी परमी-त्रिसंधी परिवर्तन से घनिष्ठता इंगित करती है जिससे कि कामथी शैल-समूह का स्वरूप एक उत्क्रमी इकाई के रूप में सामने उभर कर आता है।

SEDIMENTS overlying the Barakar Formation and underlying the Maleri Formation in the Godavari Graben were earlier included within the Kamthi ormation (King, 1881). After the identification of Barren-Measures Formation in Bheemaram area (Sengupta, 1970) and Ramagundam area (Ramanamurty, 1979), the strata occurring between the Barren-Measures and Maleri Formation are referred to the Kamthi Formation (*sensu* Ramanamurty, 1985).

KamthiFormation is spread over a vast tract of Godavari Graben (Map 1) and exhibits significant lateral and vertical variation in lithofacies. The formation attains maximum thickness around

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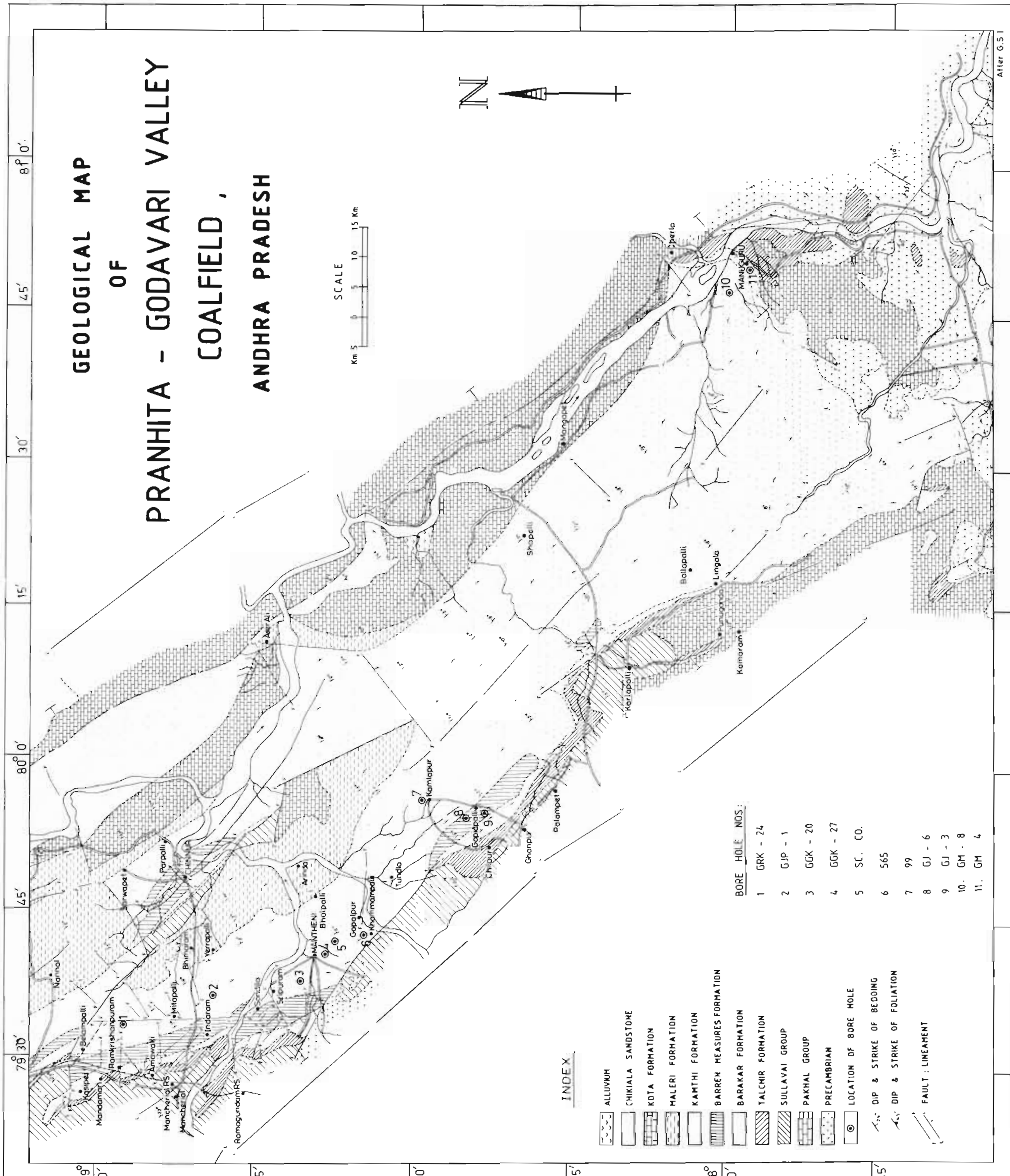


Map 1—Geological map of Pranhita-Godavari Graben, Andhra Pradesh.

Ramagundam and Mantheni areas. It has been divided into: (i) the Lower Member, consisting of greyish white, medium-grained, calcareous sandstones and a few coal seams; (ii) the Middle Member, marked by alternating sequence of medium-grained grey white sandstones, shales and variegated clays; and (iii) the Upper Member, comprising coarse-grained arenaceous facies incorporating coarse-grained ferruginous sandstones and brick-red siltstones. This member forms important topographic features in the Godavari Graben. The contact between the underlying Barren Measures and Lower Member of KamthiFormation is gradational and so also is the case between Lower and Middle members. The Middle Member is totally devoid of coal seams and the sandstone and shales bear a greenish tint and underlies the Upper Member with an unconformity.

The samples investigated have been obtained from following areas (Map 1).

1. Ramkrishnapuram	—B. H. no. GRK-24
2. Jaipuram	—B. H. no. GJP-1
3. Mantheni	—S. C. Co. bore hole
4. Khammampalli	—B. H. no. 565
5. Bhopalpalli	—B. H. no. GJ-6
6. Kamalpur	—B. H. no. 99
7. Manuguru	—B. H. nos. GM-4 and GM-8

In addition, data from following three bore-holes have been incorporated (Bharadwaj *et al.*, 1987).

1. B. H. no. GGK-20	Ramagundam-Mantheni area
2. B. H. no. GGK-27	
3. B. H. no. GJ-3	Chelpur area

PALYNOLOGICAL ASSEMBLAGES

The palynological investigations have led to recognition of five assemblages based on their morphographic characters and also quantitative representation. The distribution of various palynotaxa within the Kamthi Formation has been shown in Text-figure 1.

Assemblage 1

Faunipollenites-Striatopodocarpites Assemblage—This assemblage is characterised by dominance of striate-disaccate pollen chiefly represented by *Faunipollenites* and *Striatopodocarpites. Scheuringipollenites*, a nonstriate-disaccate, is a subdominant element. The presence of some other striate-disaccate genera is significant, viz., *Verticipollenites, Lahirites, Hindipollenites, Crescentipollenites, Distriatites*, etc. Taeniate pollen *Lunatisporites,, Hamiapollenites, Corisaccites, Lueckisporites* occur in rare amounts and their behaviour is inconsistent. Nonstriate-disaccate pollen *Alisporites, Falcisporites, Vitreisporites* and *Chordasporites* also behave like taeniate-disaccate pollen grains. The percentage of trilete spores is comparatively low but the occurrence is fairly consistent. They are represented by *Horriditriletes, Brevitriletes, Verrucosisporites,, Gondisporites*, etc.

The *Faunipollenites-Striatopodocarpites* Assemblage is lithologically associated with the Lower Member and has been recorded in bore-holes GRK-24, GGK-20, GGK-27, GJ-3, GJ-6, GM-4 and GM-8 (Text-fig. 2).

Assemblage 2

Faunipollenites-Striasulcites Assemblage—The dominance of striate-disaccate pollen remains similar as in the preceding assemblage. However, *Scheuringipollenites* gives way to the genus *Striasulcites* which is restricted to the present assemblage only. Further, *Densipollenites* also appears simultaneously but remains low in percentage. *Falcisporites, Vitreisporites, Vesicaspora*, etc. remain impersistent. Though the percentage of trilete spores declines, yet the occurrence of *Gondisporites, Polypodiidites, Osmundacidites*, etc. is significant.

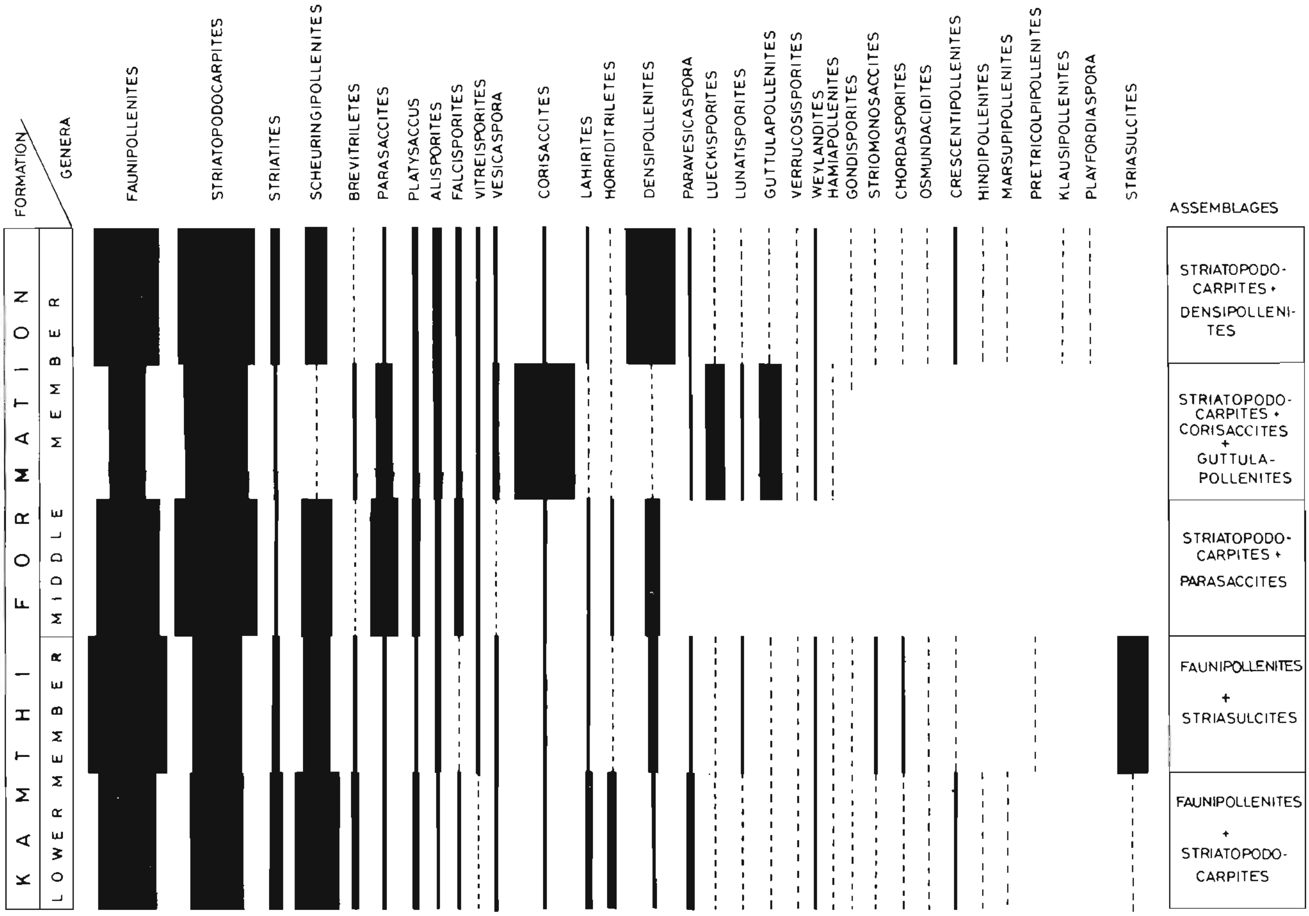
The *Faunipollenites-Striasulcites* Assemblage is well-developed in bore-hole GGK-27 between 580-385 m which marks the lower part of the Middle Member (Text-fig. 2), in bore-hole 565 between 202.25-203.75 m in carbonaceous clayey shale, in bore-hole GM-4 at 170 m in a grey clay overlying a coal band and in bore-hole GM-8 at 95-84 m.

Assemblage 3

Striatopodocarpites-Parasaccites Assemblage—In bore-hole GJ-6 (210-20 m) *Striatopodocarpites* maintains overall dominance and is followed by *Faunipollenites* (Text-fig. 2). *Parasaccites* assumes subdominance, next to the striate-disaccate pollen grains. *Densipollenites, Corisaccites* and *Guttulapollenites* occur in low percentages. The other taeniate disaccate genera are not as well represented. The trilete spores are rare. *Falcisporites, Vitreisporites*, etc. occur only sporadically. This assemblage is associated with sandy black shale, grey black shale and green sandstones and thus, occurs at the end of the coal-bearing sequence.

Assemblage 4

Striatopodocarpites - Corisaccites - Guttulapollenites Assemblage—The dominance of striate-disaccate pollen continues unabatedly in younger sediments (Middle Member). *Densipollenites* tends to increase comparatively but remains low.



Text-figure 1—Succession of various palynological assemblages in Godavari Grabven.

Corisaccites and *Guttulapollenites* together increase to subdominance, the former being more in number. *Lueckisporites* is also represented in significant percentages. *Lunatisporites, Falcisporites, Vitreisporites* appear regularly but in low percentages. In bore-hole GJP-1 (Text-fig. 2) *Corisaccites* reaches its maximum at 276 m and is associated with *Guttulapollenites* and *Parasaccites.* Towards north, in bore-hole GRK-24, this assemblage continues between 121-4-127.00 m. In bore-hole GGK-27, *Corisaccites* occurs between 334-241 m but is in low amounts while *Guttulapollenites* is almost absent. In other areas this assemblage is very poorly represented.

Assemblage 5

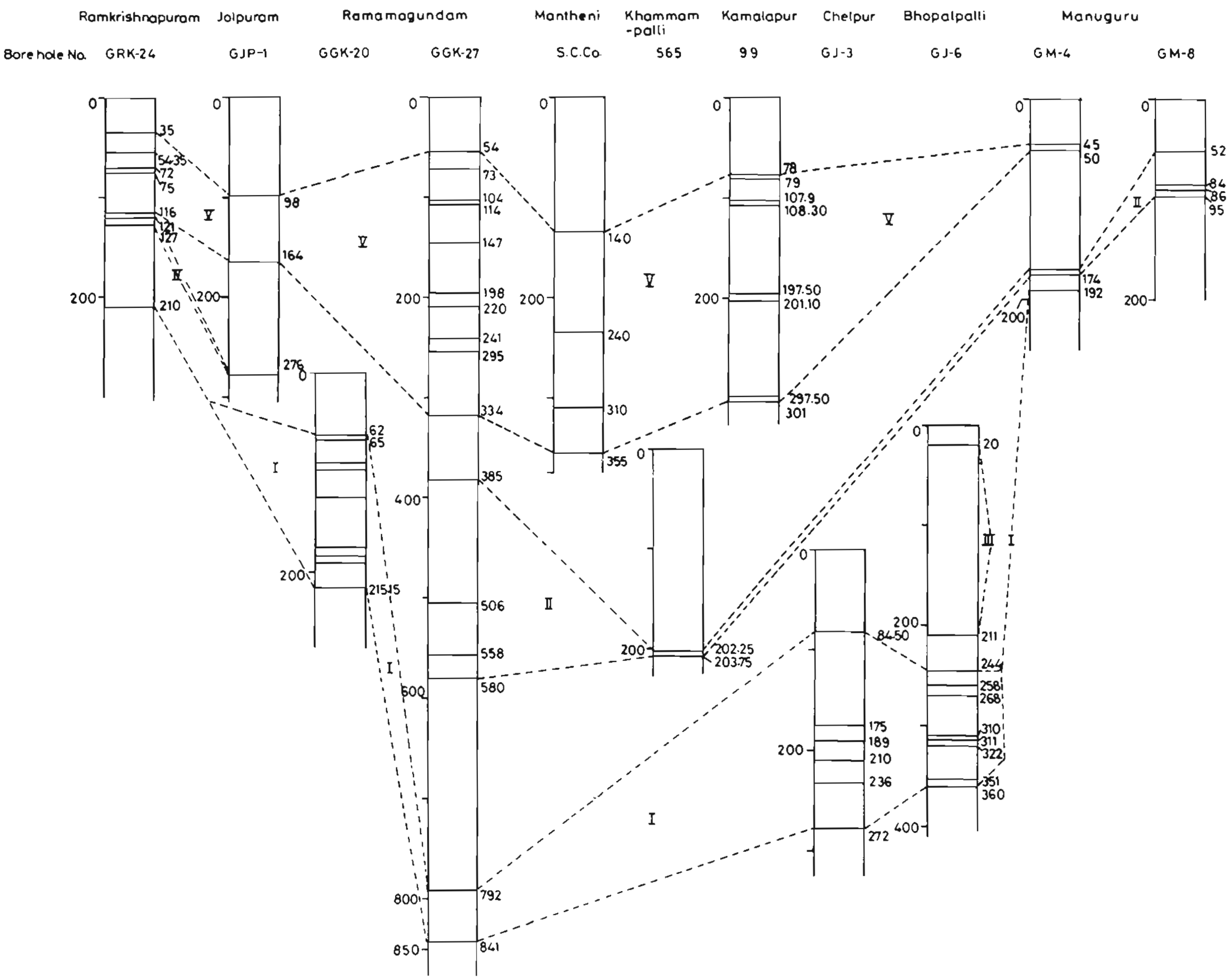
Striatopodocarpites-Densipollenites Assemblage—This assemblage is fairly well-represented in almost all the areas investigated. The sediments overlying the *Striatopodocarpites-Corisaccites-Guttulapollenites* Assemblage are characterised by a significant rise in the representation of the genus *Densipollenites.*

This assemblage succeeds *Striatopodocarpites-Corisaccites* Assemblage in bore-hole GRK-24 (116-35.95 m) and bore-hole GJP-1 (164.98 m). *Weylandites* shows a rising trend in bore-hole GRK-24. In bore-hole GGK-27 (222-54 m) *Densipollenites* records a perfect epibole and reaches overall dominance between 198-147 m. In other areas also *Densipollenites* has been observed to be closely associated with striate-disaccate pollen.

COMPARISON

A number of palynofloras described from other Lower Gondwana coalfields of India resemble one level or the other in the Kamthi Formation of Godavari Graben and their related stratigraphic comparability has also been summarised in Table 1.

Assemblage 1 closely compares with the palynological succession in Raniganj Formation of Damodar Valley (Bharadwaj & Tiwari, 1977; Bharadwaj, Tiwari & Anand-Prakash, 1979). The overall dominance of striate-disaccate genera continues throughout the entire succession.



Text-figure 2—Palynological correlation of assemblages in different bore-holes of Godavari Graben. V *Striatopodocarpites* + *Densipollenites*; IV *Striatopodocarpites* + *Corisaccites* + *Guttulapollenites*; III *Striatopodocarpites* + *Parasaccites*; II *Faunipollenites* + *Striasulcites*; I *Faunipollenites* + *Striatopodocarpites*.

However, *Indospora* and *Spinosporites* present, though in rare amounts, in Raniganj sediments of Damodar Valley have not been observed so far in the Kamthi sediments.

The palynoflora of the Jhingurdah Seam in Singrauli Coalfield (Tiwari & Srivastava, 1984) also compares closely in view of preponderance of striate-disaccate pollen grains. The trilete spores are, however, more frequent in Jhingurdah Seam which also has *Indospora* and *Kendosporites*.

The palynoflora of Raniganj Formation in Auranga Coalfield (Lele & Srivastava, 1979) has a preponderance of striate-disaccate pollen grains, but the percentage of trilete spores is relatively more. urther, *Mahudapollenites* and *Mammialetes* are absent in Assemblage 1.

An assemblage comparable to *Faunipollenites-Striasulcites* Assemblage is not known from any other basin except for the *Striasulcites* rich assemblage from Koel River Section in Hutar Coalfield (Shukla, 1983) which also has *Potonieisporites*, *Scheuringipollenites* and *Faunipollenites*. *Potonieisporites* is not present in this palynoassemblage of Godavari Graben. In addition, the genera *Gondisporites, Polypodiidites, Osmundacidites, Corisaccites, Guttulapollenites, Alisporites, Vitreisporites, Falcisporites, Weylandites* that occur regularly though in low percentages are absent in Hutar palynoassemblage.

Striatopodocarpites-Parasaccites Assemblage is also being first recorded from the Godavari Graben. In the Raniganj Formation of Damodar Valley, *Parasaccites* is present in *Striatopodocarpites-Densipollenites* Assemblage (Bore-hole RAD-5; Tiwari & Singh, 1983) but the percentage of this genus remains low.

Striatopodocarpites-Corisaccites Assemblage is comparable with a similar assemblage reported from

Table 1—Stratigraphic relationship of different palynoassemblages in Permian basins of India

	Areas / Assemblages	RANIGANJ COALFIELD: South of Damodar River	RANIGANJ COALFIELD: North of Damodar River	RANIGANJ COALFIELD: Ondal Area	North Karanpura Coalfield	Rajmahal Basin	SON VALLEY: Singrauli Coalfield	SON VALLEY: Gopad River	Auranga Coalfield
STRIATOPODOCARPITES	*Densipollenites*	Bharadwaj *et al.* (1979) Machhkanda Jhor Section Section A—Grey Shale *Striatopodocarpites Densipollenites*	Bharadwaj *et al.* (1979) Nonia Nala Section—Grey Shale, Laminated Shale, Carbonaceous Shale Nonia Khal Section-Carbonaceous Shale Banerji & Maheshwari (1975) Nonia Nala Section-Grey Shale *Striatopodocarpites + Densipollenites*			Tiwari & Tripathi (1984) Lower part of Dubrajpur Formation		Maheshwari (1977) Carbonaceous Shale-*Striatopodocarpites + Densipollenites*	
	Corisaccites Guttulapollenites								
FAUNIPOLLENITES	*Parasaccites*								
	Striasulcites								
	Striatopodocarpites	Bharadwaj *et al.* (1979) Machhkanda Jhor Section A—Carbonaceous Shale, Coal Section B—Carbonaceous Shale, Khaki Shāle *Striatopodocarpites+ Faunipollenites*	Bharadwaj *et al.* (1979) Nonia Nala Section-Carbonaceous Shale, Coal *Striatopodocarpites Faunipollenites*	Kar (1970) B.H. RE9-Carbonaceous Shale, Lower Assemblage B.H.RN9-Carbonaceous Shale *Faunipollenites Striatopodocarpites*	Bharadwaj *et al.* (1979) Horam Sibadih Section-Carbonaceous Shale *Striatopodocarpites + Faunipollenites*		Tiwari & Srivastava (1984) Jhingurdah Seam *Faunipollenites Striatopodocarpites*		Lele & Srivastava (1979) Sukri River-Carbonaceous shale-*Faunipollenites + Brevitriletes*

Contd.

Table 1 (*Contd.*)

Lesser Himalaya	Tethyan Himalaya	Satpura Basin	GODAVARI GRABEN (Present investigation)						
			Ramkrishanpuram	Ramagundam	Chelpur	Bhopalpalli	Kamalapur	Khammampalli	Manuguru
Tiwari & Kumar (1986) Amkhal Formation *Striatopodocarpites* + *Densipollenites*	Tiwari *et al.* (1984) Malla Johar, Kuling Shale *Striatopodocarpites* + *Densipollenites*	Bharadwaj *et al.* (1978) Bijori Formation *Striatopodocarpites* + *Densipollenites*	*Striatopodocarpites* + *Densipollenites*	*Striatopodocarpites* + *Densipollenites*		*Striatopodocarpites* + *Densipollenites*	*Striatopodocarpites* + *Densipollenites*		*Striatopodocarpites* + *Densipollenites*
		Striatopodocarpites + *Guttulapollenites* + *Corisaccites*	*Striatopodocarpites* + *Corisaccites* + *Guttulapollenites*	*Striatopodocarpites* + *Corisaccites* + *Guttulapollenites*					
						Striatopodocarpites + *Parasaccites*			
				Faunipollenites + *Striasulcites*				*Faunipollenites* + *Striatopodocarpites* + *Striasulcites*	*Faunipollenites* + *Striasulcites*
			Faunipollenites Striatopodocarpites	*Faunipollenites Striatopodocarpites*	*Faunipollenites Striatopodocarpites*	*Faunipollenites* + *Striatopodocarpites*			*Faunipollenites* + *Striatopodocarpites*

Table 2—Stratigraphic status of Kamthi Formation in Godavari Graben

AGE	DAMODAR VALLEY G.S.I. (1977)	GODAVARI GRABEN King (1881)	Sengupta (1970)	Kutty et. al. (1987)	G.S.I. (1882)	Raiverman et al. (1985)
TRIASSIC	PANCHET	UPPER GONDWANA	UPPER GONDWANA	UPPER GONDWANA	UPPER GONDWANA	UPPER GONDWANA
TRIASSIC	PANCHET	KAMTHI	KAMTHI UPPER MEMBER	KAMTHI UPPER MEMBER	KAMTHI UPPER MEMBER	KUDUREPALLI / CHINTALPUDI
PERMIAN	RANIGANJ	KAMTHI	KAMTHI MIDDLE MEMBER, LOWER MEMBER	KAMTHI MIDDLE MEMBER, LOWER MEMBER	KAMTHI UPPER MEMBER	MANER
PERMIAN	RANIGANJ	KAMTHI	IRON STONE SHALES	INFRA KAMTHI LITHOZONE - 4	KAMTHI MIDDLE MEMBER	KHANAPUR
PERMIAN	RANIGANJ	KAMTHI	BARAKAR	INFRA KAMTHI LITHOZONE - 3	KAMTHI MIDDLE MEMBER	JAIPURAM
PERMIAN	RANIGANJ	KAMTHI	BARAKAR	INFRA KAMTHI LITHOZONE - 2	KAMTHI LOWER MEMBER	POTAMADUGU / BALHARSHAH
PERMIAN	BARREN MEASURES	KAMTHI	BARAKAR	INFRA KAMTHI LITHOZONE - 1	BARREN MEASURES	BELLAMPALLI
PERMIAN	BARAKAR	BARAKAR	BARAKAR	BARAKAR	BARAKAR	BARAKAR
PERMIAN	TALCHIR	TALCHIR	TALCHIR	TALCHIR	TALCHIR	TALCHIR

the Bijori (Sukhtawa) Formation in Satpura Basin (Bharadwaj *et al.*, 1978). *Corisaccites-Guttulapollenites* occupy a third place in the order of dominance in Satpura Basin but in Godavari Graben this pollen-complex assumes overall dominance.

Striatopodocarpites, Densipollenites Assemblage is fairly well distributed in Damodar Valley, Singrauli and Auranga coalfields and Satpura Basin. In Damodar Valley this assemblage is present in the Late Permian (Tiwari & Singh, 1983) and continues up to the base of the Lower Triassic. In Satpura Basin, *Densipollenites* rises to dominance near the top of the Bijori Formation succeeding the *Corisaccites* rich assemblage (Bharadwaj *et al.*, 1978).

The striate-disaccate rich assemblage associated with *Densipollenites* from Gopad River Section (Maheshwari, 1967) resembles Assemblage 5. The palynoassemblages described from the lower part of the Dubrajpur Formation in Rajmahal Basin (Tiwari & Tripathi, 1984), the Kuling Shale in the Malla Johar area, Kumaon Himalaya (Tiwari *et al.*, 1984), and the Amkhal Formation in the Lesser Himalaya of Tehri Garhwal District (Tiwari & Kumar, 1986) contain a large number of taxa found in *Striatopodocarpites-Densipollenites* Assemblage and thus bear a qualitative resemblance.

DISCUSSION

Raiverman, Rao and Pal (1985) have reviewed the entire geological succession in Pranhita-Godavari Graben and have provided a new classification on the basis of photogeological techniques and detailed geological field mapping. They have raised the status of Kamthi to a group and divided it into five formations. Their correlation with earlier classification schemes is shown in Table 2. Kutty *et al.* (1988) have restricted the limits of the Kamthi Formation as equivalent to the Upper Member of the Kamthi Formation only. However, in the present investigation the classification in vogue by the Geological Survey of India (Raja Rao, 1982) has been followed. The non-coal-bearing predominantly arenaceous sequence of Barren Measures conformably grades into the coal-bearing Lower Kamthi Member. However, the palynological assemblage changes from the *Densipollenites* rich assemblage of Barren Measures to *Faunipollenites-Striatopodocarpites* rich assemblage with near absence of *Densipollenites* of Lower Kamthi Member. The appearance of *Gondisporites, Falcisporites, Vitreisporites, Corisaccites, Lunatisporites, Weylandites*, etc. though in rare amounts, nevertheless indicates a younger affinity being characteristic of the Raniganj and Panchet assemblages in Damodar Valley. Thus, the palynoflora of the lower part of the Raniganj Formation appears almost coeval with that of the Lower Member of Kamthi Formation. The *Faunipollenites-Striasulcites* Assemblage is associated with coal seams in Manuguru area, but in Ramagundam area it is recorded above the coal-bearing horizon in the beginning of Middle Member.

The sediments between 792-580 m in bore-hole GRK-27, which include the transition from Lower to Middle Member, have not yielded pollen and spores hence it is difficult to comment on the exact stratigraphic status of *Striasulcites* but from the present evidences it appears that the *Striasulcites* assemblage reached its peak at the end of coal-forming phase. The sedimentation of the Lower Member appears to have commenced in a prevailing fluvial environment in relatively deep and narrow to straight sinuous channels. A warm and humid climate seems to have provided a luxurient growth of gymnosperms and pteridophyte which have contributed largely to the coal formation.

The incoming of *Parasaccites* at the base of the Middle Member coupled with the greenish sandstone and shales is significant as it marks the culmination of coal-forming phase. *Parasaccites* is known to have been associated with glacial and cold climate in the Lower Gondwana Sequence and hence a similar cooling though short-lived is envisaged to have been the cause of culmination of coal forming process in the Godavari Graben. *Densipollenites* commencing after the *Parasaccites* phase, continued up to the middle part of the Middle Member which is comparable with the coal-less Barren Measures, denoting a comparative aridity in the climate.

The *Striatopodocarpites-Densipollenites* Assemblage continues up to the top of the Raniganj Formation (Upper Permian) and is succeeded by the cavate-cingulate-taeniate rich assemblage of the Panchet Formation (Lower Triassic, Tiwari & Singh, 1983). In the Godavari Graben epibolic development of *Striatopodocarpites-Densipollenites* Assemblage is noticed within the lower 334 m of the Middle Member in Ramagundam area. The decline of *Densipollenites* is recorded at the top of the sequence indicating a close proximity towards the Lower Triassic boundary. There is every likelihood that the Permian-Triassic boundary lies within the upper part of the Middle Member. Lithologically also the sandstones and shales of this Member are distinct from the underlying Lower Member being greenish in colour and devoid of coal. Some pale-green clays, apparently looking like Talchir needle shales (King, 1881) are exposed around Sitampet. Similar shales are also exposed near Rangaipalli and Jillapalli villages in shallow wells. These khaki green shales which are apparently younger than the Middle Member of Ramagundam-Mantheni area may infact prove to be equivalent to the Panchet Formation.

Evidences indicate that the Lower Member containing coal seams is equivalent to the lower part of the Raniganj Formation of Damodar Valley while the lower part of the Middle Member corresponds to the upper part of the Raniganj Formation and the Bijori Formation in Satpura Basin. The Lower Triassic equivalent palynoflora is expected within the upper part of the unexplored Middle Member. In other words, the Kamthi Formation is time-transgressive palynologically, ranging in age from Upper Permian to ?Triassic.

CONCLUSION

Five palynological assemblages can be recognised in the Kamthi Formation of the Godavari Graben. Assemblage 1 from the Lower Member shows a uniform similarity with Raniganj palynoassemblage of Damodar and Son-Mahanadi grabens. This assemblage is associated with the coal-bearing sediments of the Raniganj Formation. The lithological changes at the base of Middle Member are associated with the appearance of *Striatopodocarpites-Parasaccites* rich assemblage (Assemblage 3). These changes together document an intensive cooling phase, though restricted, simulating the one observed during Talchir Formation. The younger palynological assemblages (Assemblages 4 and 5) are more closer to the palynological succession observed in Satpura Basin and Salt Range, Pakistan. *Densipollenites* rich assemblage in Godavari Graben declines within the Middle Kamthi Member and a larger part of the sequence yet remains to be explored palynologically. The Permian-Triassic boundary is expected within the Middle Kamthi Member.

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Palynological dating of Supra-Barakar formations in Son Valley Graben

Ram-Awatar

Ram-Awatar (1988). Palynological dating of Supra-Barakar formations in Son Valley Graben. *Palaeobotanist* **36** : 133-137.

The Pali Formation was so far considered to be barren of coal. Recently a one meter thick coal seam has been reported in the Middle Pali in the subsurface. Palynological analysis of this coal-bearing stratum has revealed the presence of palynotaxa, viz., *Densipollenites, Faunipollenites, Striatopodocarpites, Striatites* and *Scheuringipollenites*. Strata supposed to be younger to Pali in the outcrop have yielded the genera—*Gondisporites, Densipollenites* and *Striatopodocarpites*. It shows that these beds are of Late Permian age. At the same time, some taxa, like *Lundbladispora, Playfordiaspora, Guttulapollenites, Satsangisaccites* and *Nidipollenites* are also present in this assemblage giving it an younger aspect, i.e., Early Triassic. It is, therefore, suggested that these sediments were deposited during Permian/Triassic time probably closer to Early Triassic.

Key-words—Palynology, Supra-Barakar, Son Valley, Early Triassic (India).

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सारॉंश

सोन घाटी द्रोणिका में बराकर-उपरिशायी शैल-समूहों का परागाणविक कालनिर्धारण

राम-अवतार

पाली शैल-समूह अभी तक कोयले से विहीन समझा जाता था। अभी हाल में मध्य पाली में एक उपसतह में एक मीटर मोटी कोयले की सीम मिली है जिसके परागाणविक विश्लेषण से **डेन्सीपोलिनाइटिस, फ़ॉनीपोलिनाइटिस, स्ट्रआटोपोडोकार्पाइटिस, स्ट्रआटाइटिस** एवं **श्यौरिंगीपोलिनाइटिस्** नामक वर्गकों की उपस्थिति व्यक्त हुई है। इस दृश्यॉंश से पाली से अल्पायु के स्तरों में **गोन्डिस्पोराइटिस, डेन्सीपोलिनाइटिस** एवं **स्ट्रआटोपोडोकार्पाइटिस** नामक प्रजातियाँ उपलब्ध हुई हैं। इससे यह व्यक्त होता है कि ये संस्तरें अंतिम परमी की हैं। साथ ही साथ इस समुच्चय में **लुन्ब्लाडिस्पोरा, प्लेफ़ोर्डियास्पोरा, गुट्टुलापोलिनाइटिस, सत्संगीसेक्काइटिस** एवं **निदिपोलिनाइटिस** नामक कुछ अन्य वर्गक भी मिले हैं जिससे इसकी प्रारम्भिक त्रिसंघी आयु इंगित होती है। अतएव यह प्रस्तावित किया गया है कि ये अवसाद परमी/त्रिसंघी काल में, सम्भवतया प्रारम्भिक त्रिसंघी में निक्षेपित हुए थे।

THE age of Pali and Parsora formations in the Son Graben has been a debatable matter since long. On the basis of floral and faunal assemblage, the Pali Formation has been dated as Late Permian to Early Triassic (Feistmantel, 1882; Chaterjee & Roy Chowdhury, 1974). Similarly, the age of Parsora Formation in the Johilla Coalfield has been considered to be Late Permian to Early Jurassic (Feistmantel, 1882; Cotter, 1917; Seward, 1932; Fox, 1931; Lele, 1964; Shah *et al.*, 1971).

The occurrence of spore and pollen assemblages in the Pali (in bore-core), and the overlying strata (in outcrop)—earlier considered as Parsora Formation—in Johilla Coalfield is significant. Palynological assemblages from the Middle Pali Formation in bore-core JHL-27A and from outcrops pertaining to the youngest Pali Formation, earlier mapped as Parsora (Tiwari & Ram-Awatar, 1986, 1987), have given important clues for the age of these beds.

Concepts, limits and extension of the Indian Gondwana
(Editors . B. S. Venkatachala & Hari K. Maheshwari)
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Lately, a number of bore-holes have been drilled by the Geological Survey of India in this region. Based on the subsurface data, it has been proved that Pali Formation (total thickness 1,500 m) is divisible into three lithological units, viz., Upper, Middle and Lower Pali.

The Parsora Formation, overlying the Pali Formation, has been variously named in the past, such as, Mahadevas (Hughes, 1881), Transitional bed (Feistmantel, 1882), Supra-Barakar (Hughes, 1884), Parsora Bed (Cotter, 1917), Parsora Group (Sahni & Rao, 1956) and Parsora Stage (Lele, 1964).

The Parsora rocks are characterised by coarse-grained sandstone, violet claystone, sandy claystone; mudstones are mottle in shades of violet, lilac and red, which vary in thickness from a few centimeter to as much as 7 meters. The sandstone are well-bedded and highly crossed-stratified.

PALYNOLOGICAL ASSEMBLAGE

Palynological assemblage from Pali—Palynology of bore-hole JHL-27A has been reported by Tiwari and Ram-Awatar (1986, pp. 252, 255).

Palynological Assemblage from outcrop—Earlier this area was mapped under Parsora Formation. Tiwari and Ram-Awatar (1987, p. 106) have recorded the pollen and spores which it is now believed that these taxa are not from Parsora Bed but from the Upper Pali. Important taxa are illustrated on plates 1 and 2.

Age of assemblage

From histogram 1 in Tiwari and Ram-Awatar (1986), it appears that in palynological Assemblage-A (Pali Formation), the striate-disaccate, i.e., *Faunipollenites, Striatopodocarpites, Lahirites* and *Striatites* are dominant elements, alongwith non-striate disaccates. Therefore, the Pali Assemblage broadly compares with that of Raniganj Formation (Bharadwaj & Tiwari, 1977). The Late Permian age for this bed is further supported by the presence of indicator taxa illustrated on Plate 1.

The palynological Assemblage-B, recovered from the out-crop samples exposed between Dargaon and Salaia villages contains a variety of palynofossils. The dominating elements are *Densipollenites, Gondisporites, Striatopodocarpites, Faunipollenites, Crescentipollenites* which qualify these beds to be of Late Raniganj age (Bharadwaj, Tiwari & Anand-Prakash, 1979). In addition to the above taxa, the genera like *Lundbladispora, Falcisporites, Navalesporites, Guttulapollenites, Alisporites, Nidipollenites* and *Satsangisaccites* are also present which are definite indicators of still younger aspect, i.e., Early Triassic, for the bed. Therefore, the affinity with Late Permian on one hand and early phase of Triassic on other is evident, which makes it clear that it has a Permo/Triassic transitionary aspect (Maheshwari & Banerji, 1975; Bharadwaj & Tiwari, 1977; Rana & Tiwari, 1980).

CONCLUSION

The palynoflora found in the subsurface, i.e., Pali Formation, is closely comparable to that of Raniganj Formation. The beds exposed in the north, beyond in the Johilla River Section on the Railway Bridge (Sample no. C7 & C7/1; Tiwari & Ram-Awatar, 1987, map 1) contain a palynoflora which has Permo-Triassic transitionary aspect. These outcrop beds were earlier grouped in the Parsora Formation (Jhingran, 1980), but recent field studies have revealed that the Pali Formation has been repeated near Dargaon Village along Johilla River (Dr N. D. Mitra, pers. Comm. 1988). The lithological characteristics of the samples investigated for palynological studies also suggest their affinity with the Pali Formation, because they are black

PLATE 1

→

All photomicrographs are enlarged Ca × 500 unless otherwise mentioned; Leitz Microscope no. 636107.

1. *Distriatites bilateralis* Bharadwaj, 1962
2. *Scheuringipollenites barakarensis* Tiwari, 1973
3. *Brachysaccus* sp. Mädler, 1964
4. *Parasaccites distinctus* Tiwari, 1965
5. *Callumispora paliensis* Tiwari & Ram-Awatar (in press)
6. *Microbaculispora tentula* Tiwari, 1965
7. *Brevitriletes communis* Bharadwaj & Srivastava emend. Tiwari & Singh, 1981
8. *Microfoveolatispora trisina* (Balme & Hennelly) Bharadwaj, 1962
9. *Faunipollenites varius* Bharadwaj, 1962
10. *Striatites subtilis* Bharadwaj & Salujha, 1964
11. *Ginkgocycadophytus novus* Srivastava, 1970
12. *Lunatisporites pellucidus* Maheshwari & Banerji, 1975
13. *Crescentipollenites fuscus* (Bharadwaj) Bharadwaj, Tiwari & Kar, 1974
14. *Laevigatosporites colliensis* (Balme & Hennelly) emended Venkatachala & Kar, 1968
15. *Osmundacidites senectus* Balme, 1963
16. *Sahnites gondwanensis* Pant emended. Tiwari & Singh, 1984
17. *Rhizomaspora indica* Tiwari, 1965
18. *Densipollenites indicus* Bharadwaj, 1962
19. *Parasaccites korbaensis* Bharadwaj & Tiwari, 1964

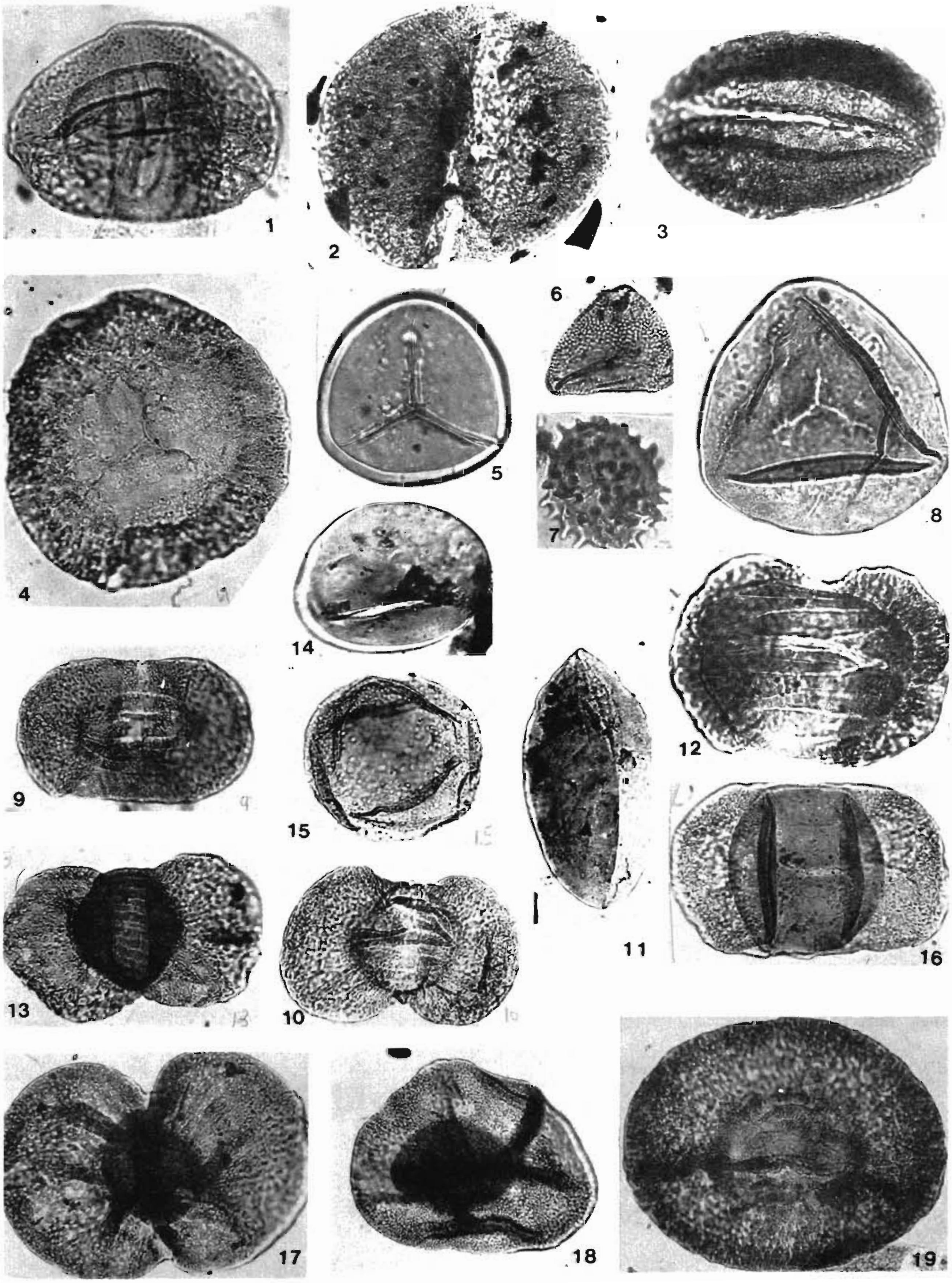

PLATE 1

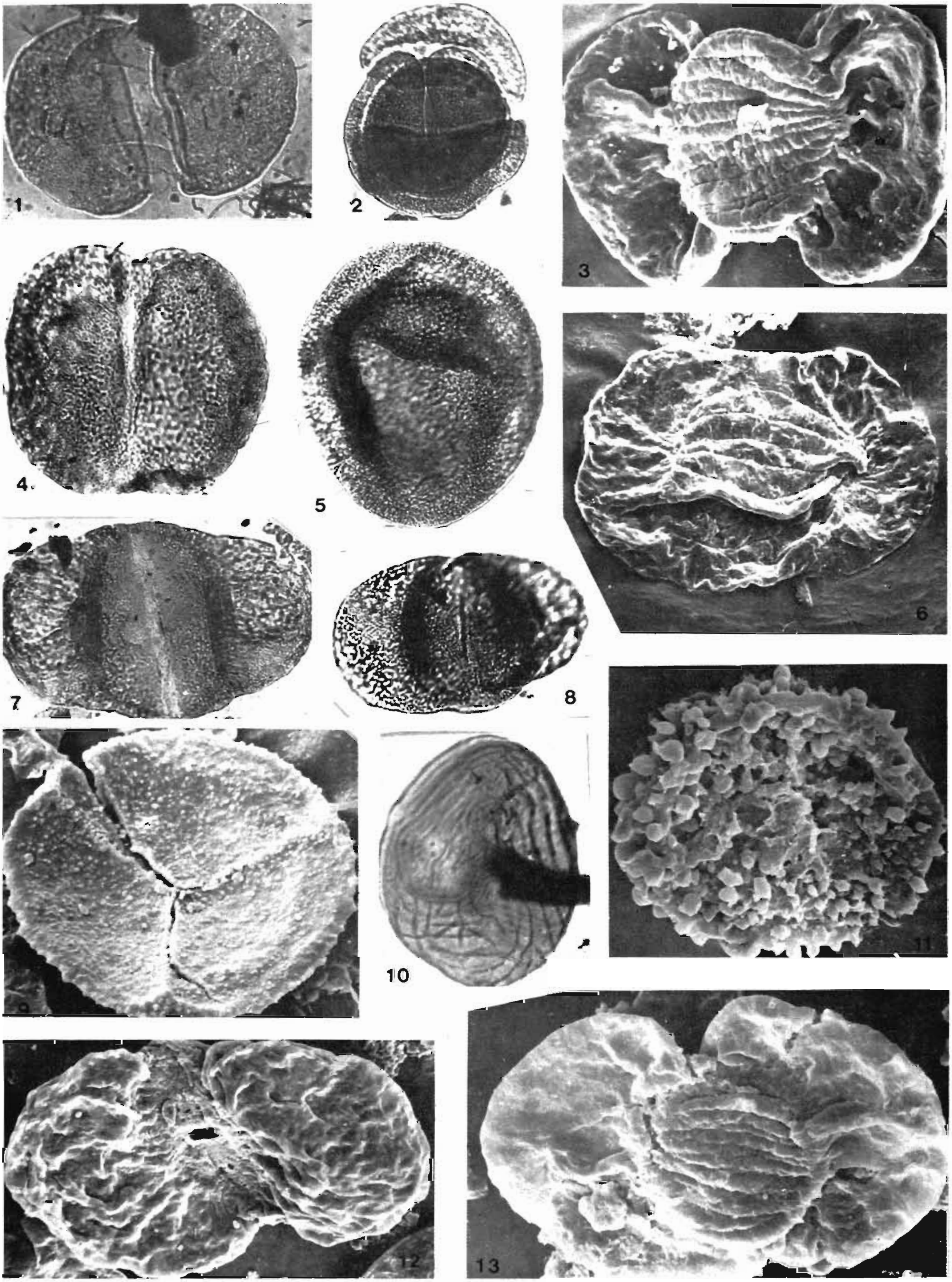

PLATE 2

micaceous shale, and not violet, red ferruginous, coarse-grained sandstone typical of Parsora. The spores and pollen found in these outcrops also support their affinity with Pali Assemblage, although a younger aspect is evident.

This implies that the Pali Formation could be equated with the Barren Measures in the lower part, the Raniganj in the middle part and the Raniganj/Panchet in the upper part. The so-called Parsora in the Johilla River Section, near Dargaon and Salaia across the rail bridge in the north, has an affinity with Pali and represents a Permo/Triassic transitional flora. However, more detailed study of this succession as well as that of typical Parsora is required for precise dating.

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PLATE 2

All photomicrographs are enlarged Ca × 500 unless otherwise mentioned

1. *Lunatisporites* sp. Maheshwari & Banerji, 1975
2. *Lueckisporites* Potonié & Klaus, 1963
3. *Lahirites rarus* Bharadwaj & Salujha, 1965
4. *Scheuringipollenites barakarensis* (Tiwari) Tiwari, 1973
5. *Densipollenites magnicorpus* Tiwari & Rana, 1981
6. *Faunipollenites varius* Bharadwaj, 1962
7. *Satsangisaccites nidpurensis* Bharadwaj & Srivastava, 1969
8. *Falcisporites stabilis* Balme, 1970
9. *Lundbladispora brevicula* Balme, 1963
10. *Weylandites indicus* Bharadwaj & Srivastava, 1969
11. *Osmundacidites senectus* Balme, 1963
12. *Nidipollenites monoletus* Bharadwaj & Srivastava, 1969
13. *Striatites* sp. Bharadwaj, 1962

The Palaeobotanist **36** : 138-142, 1987.

Lower Barakar flora of Raniganj Coalfield and insect/plant relationship

A. K. Srivastava

Srivastava, A. K. (1988). Lower Barakar flora of Raniganj Coalfield and insect/plant relationship. *Palaeobotanist*, **36** : 138-142.

The Lower Barakar flora of Raniganj Coalfield shows close affinity with the Karharbari flora. The venation pattern of different leaf genera and its evolutionary trends are discussed. Insect wings, insect affected leaf and stem specimens are recorded. On the available evidences, insect/plant relationship during the early phase of Glossopteris Flora is discussed.

Key-words—Megafossils, *Glossopteris*, Insect/plant relationship, Lower Barakar (India).

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साराँश

रानीगंज कोयला-क्षेत्र का अधरि बराकार वनस्पतिजात तथा कीट/पादप सम्बन्ध

अश्विनी कुमार श्रीवास्तव

रानीगंज कोयला-क्षेत्र का अधरि बराकार वनस्पतिजात करहरबारी वनस्पतिजात से घनिष्ठ सजातीयता व्यक्त करता है। कीटों के पंख, कीटों द्वारा नष्ट पत्ती एवं तने के प्रादर्श अभिलिखित किये गये हैं। उपलब्ध प्रमाणों के आधार पर ग्लॉसॉप्टेरिस वनस्पतिजात की प्रारम्भिक अवस्था में कीट/पादप सम्बन्धों की विवेचना की गई है।

BARAKAR Formation consisting of eight coal seams is well-developed in the Raniganj Coalfield and covers an area of about 110 sq km. The present study deals with the plant fossil assemblages of the Lower Barakar coal seams I to IV, locally known as Pusai, Kalimati, Salanpur A, Salanpur B, Gourandih, Gopinathpur and Kasta seams. Plant fossils of the Barakar Formation of Raniganj Coalfield have earlier been investigated by Bandyopadhyay (1959), Chandra and Srivastava (1981), Srivastava and Rigby (1983), Maheshwari and Srivastava (1986) and Srivastava (1987). The specimens were collected from Sangramgarh, Dalmia, Palasthali, Gourandih, Raja, Nirsa, New Bagma, Gopinathpur, Lakhimata, Rajpura, Chapapur, Bajna and Khudia collieries.

Plant fossils are mostly preserved as impressions, however, thin carbonified crust is present on some of the specimens. On chemical treatment the crust gets fragmented and does not show cellular details. Therefore, the study is based entirely on the external morphological features. All the figured specimens are deposited with the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

PLANT FOSSIL ASSEMBLAGES

Many genera and species of Equisetales, Filicales, Glossopteridales, Cordaitales and isolated

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seeds and sporangia have been identified. The records include the following:

Equisetales—Lelstotheca robusta (Feistmantel) Maheshwari, *L. striata* Maheshwari & Srivastava, *Trizygia speciosa* Royle, *Phyllotheca indica* Bunbury and a phyllothecan strobilus showing branched sporangiophore, attached near the node of axis (from Dalmia, Sangramgarh & Palasthali collieries).

Filicales—Neomariopteris polymorpha (Feistmantel) Maithy, *N. hughesii* (Zeiller) Maithy and a new sterile frond showing large size pinnules with auriculate base and pecopteroid types of vein (from Palasthali & Gourandih collieries).

Glossopteridales—This group is the dominant constituent of the assemblage and is frequently represented in almost all the collieries.

Rubidgea obovata Maithy, *Euryphyllum whittianum* Feistmantel, *Gangamopteris cyclopteroides* Feistmantel, *G. intermedia* Maithy, *G. major* Feistmantel, *Glossopteris indica* Schimper, *G. communis* Feistmantel, *G. stenoneura* Feistmantel, *G. nimishea* Chandra & Surange, *G. angustifolia* Brongniart, *G. fusa* Kulkarni, *G. browniana* Brongniart, *G. intermittens* Feistmantel, *G. emarginata* Maheshwari & Prakash, *G. barakarensis* Kulkarni, *G. stricta* Bunbury, *G. churiensis* Srivastava, *G. damudica* Feistmantel, *G. decipiens* Feistmantel, *G. longicaulis* Feistmantel, *G. angusta* Pant & Gupta, *G. giridihensis* Pant & Gupta, *Palaeovittaria kurzii* Feistmantel, *Gondwanophyllites dissectus* Srivastava, *Scutum* sp., *Lidgettonia* and a new type of leaf with persistent midrib and dichotomizing secondary veins.

Cordaitales—Noeggerathiopsis hislopii (Bunbury) Feistmantel, *N. minor* Chandra & Srivastava and *Cordaites* sp. (from Gopinathpur, Lakhimata, Rajpura, Raja, Chapapur & Bajna collieries).

Earlier it has been considered by many authors (Seward, 1917; Seward & Sahni, 1920; Meyen, 1969, 1972; Maheshwari & Meyen, 1975; Rigby, Maheshwari & Schopf, 1980) that Gondwana *Noeggerathiopsis* is similar to the northern genus *Cordaites* in external morphology. However, Pant and Verma (1964) and Maithy (1965) favoured retention of both the genera. Rigby (1984) placed all cuticular forms of *Noeggerathiopsis* under a new genus, *Pantophyllum* and has referred the non-cuticular forms to *Cordaites*. I have observed that in external morphological features also the leaves of *Cardaites* and *Noeggerathiopsis* are distinguishable and in the present assemblage both the forms are frequently represented, especially in Raja Colliery. The leaves of *Cordaites* are strap-shaped and show parallel running interstitial fibres in between thick veins, whereas such veins are entirely absent in the leaves of *Noeggerathiopsis*. The presence of *Cordaites*-like leaves in Glossopteris Flora is interesting.

Incertae Sedis—Isolated seeds, e.g., *Samaropsis* sp., *Cordaicarpus* sp., *Cornucarpus* sp. and *Arberiella* type of sporangia (from Raja, Rajpura & Lakhimata collieries).

FLORAL COMPARISON

In general the Lower Barakar assemblage is dominated by *Glossopteris* and *Noeggerathiopsis* complex. Genera, *Gangamopteris, Euryphyllum, Rubidgea* and *Palaeovittaria* are significantly represented. Most of the species of *Glossopteris*, e.g., *G. intermittens, G. churiensis, G. angusta, G. communis, G. fusa, G. giridihensis, G. nimishea* and *G. longicaulis* show parallel running strands in the median region of the leaf, instead of a solid midrib. *G. decipiens* shows an evanescent midrib.

The dominance of *Noeggerathiopsis* and Karharbari species of *Glossopteris* (Chandra & Surange, 1979) together with the presence of *Rubidgea, Euryphyllum* (exclusively reported from Karharbari Flora) and *Gangamopteris* suggests the floral affinity with the Karharbari flora. However, the presence of *Palaeovittaria* is significant because so far it is known only from the Raniganj Formation of the Raniganj Coalfield

EVOLUTIONARY SIGNIFICANCE

A critical analysis of the venation pattern of leaves suggests that there is a gradual transition from midrib-less form to midrib-form in two categories of leaves.

In non-reticulate type of leaves, the appearance of midrib has taken place from *Rubidgea* to new form of leaves with an intermediate form, *Palaeovittaria*, where the midrib is only up to 1/2 or 2/3 of the leaf lamina.

In reticulately veined leaves the midrib apeared at different levels, in different species. In *Gangamopteris cyclopteroides* the median region is occupied by inter-connecting parallel running veins. In some species of *Glossopteris*, the median region is occupied by only parallel running strands but without any inter-connection. Finally a consolidation of these strands results into the solid midrib of *Glossopteris*, e.g., in *G. stricta, G. angustifolia, G. browniana, G. indica*, etc.

INSECT/PLANT RELATIONSHIP

Definite and well-preserved complete and incomplete insect wings have been discovered in

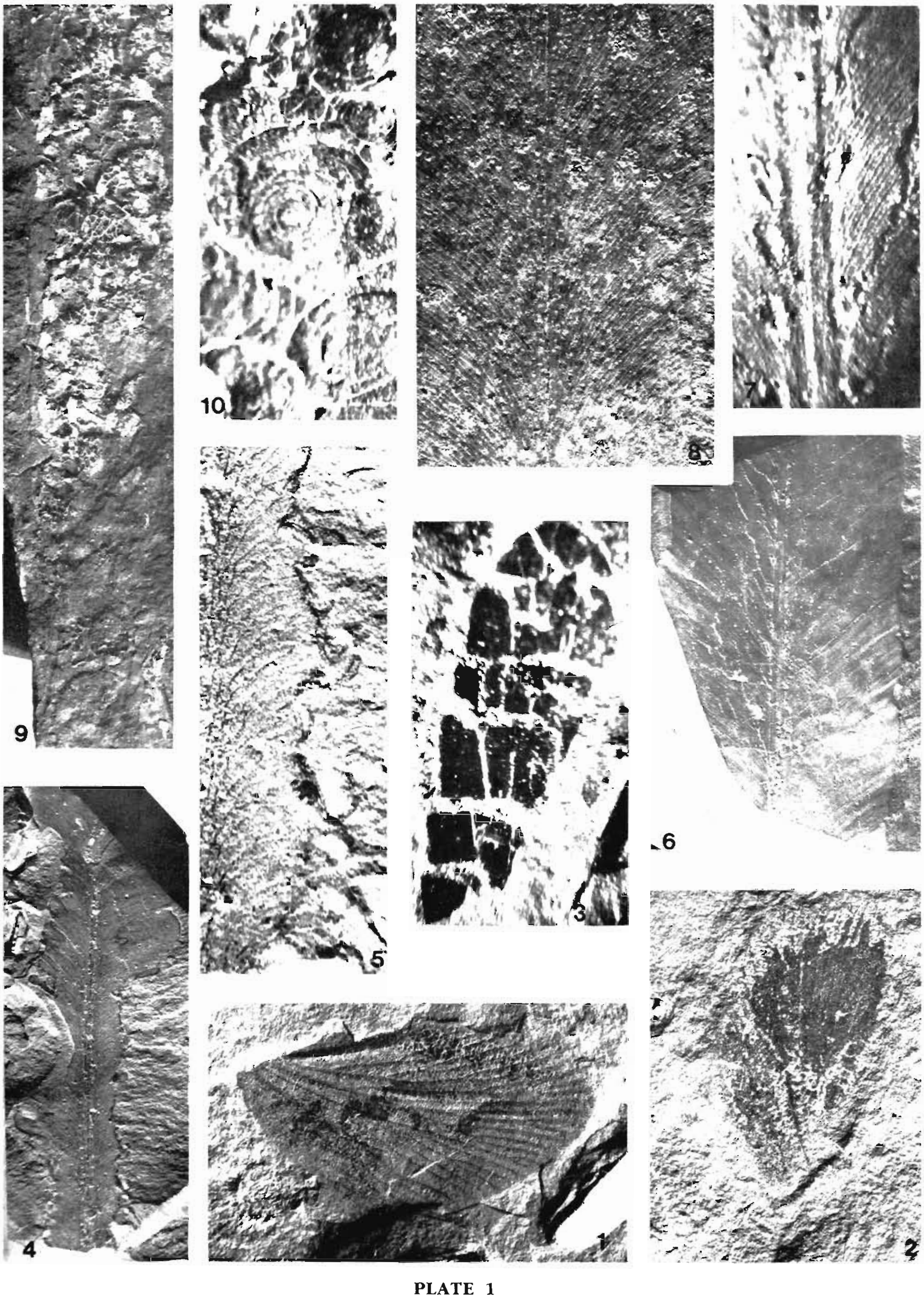

PLATE 1

association with plant fossils. The wings are comparable to the wings of ancient cockroaches belonging to Archimylacridae of Blattoidea Group of insects. Homopteraen insect wings have also been recovered from the assemblage (Pl. 1, figs 1-3).

It has also been observed that the leaf lamina of many specimens is characteristically damaged or distorted. Nibbling, rolling or distortion of leaf lamina have been regarded possibly due to insect activity (Plumstead, 1963; Van Amerom, 1966; Van Amerom & Boersma, 1971; Scott & Taylor, 1983; Scott & Paterson, 1984). Structures similar with the trailing and burrows habit of insect have also been studied (Pl. 1, figs 4, 5).

One of the leaves shows two rows of minute (0.1 to 0.5 mm), ovoid structure along the midrib. Similar structures have also been observed in groups or bunches scattered over the surface of leaf. The structural features and organizational pattern are comparable with the eggs of herbivorous insects like caterpillar, beetles, aphids, leaf hoppers, bugs and their allies (Metcalf & Flint, 1928; Ross, 1956) (Pl. 1, figs 6, 7).

Disfigurement of lamina with minute irregular-shaped (less than 0.1 mm) outgrowths has also been noticed. In modern forest, many insects, e.g., plant lice, moths, flies and mites injure the plants and such injury results into an abnormal growth of plant tissue and this insect activity causes similar structures known as the gall (Metcalf & Flint, 1928; Comstock, 1948; Ross, 1956; Mani, 1982) (*see* Pl. 1, fig. 8).

Some stem specimens show circular, helicoidal irregularly distributed, filamentous structures (2-10 mm in diameter). Chemical treatment of cellulose acetate pulls reveals nonseptate filaments without any structural details. Boring and tunneling activities of some modern insects, e.g., leaf hoppers, aphids and scale insect result in the formation of such features (Ross, 1956; Wigglesworth, 1964; Mani, 1982) (*see* Pl. 1, figs 9, 10).

The discovery of insect wings in association with plant megafossils demonstrates that the insects, more particularly arthropods, might have played an important role in pollination and dispersal of the glossopterid plants.

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PLATE 1

1-3. Insect wings showing the venation pattern. Fig. 1 shows the coastal, radial, median, cubital and anal veins. Specimen nos. BSIP 36147, 36227 and 36228. × 4.

4. *Glossopteris* leaf showing distorted and damaged part of lamina. specimen no. BSIP 36229. × 1.

5. Leaf lamina enlarged to show the pattern of distortion and nibbling. Specimen no. BSIP 36229. × 3.

6. *Glossopteris* leaf showing two rows of minute ovoid-shaped structures along the midrib. Specimen no. BSIP 36230. × 1.

7. Enlarged portion of leaf showing regular distribution of ovoid structures along the midrib. Specimen no. BSIP 36230. × 8.

8. Part of *Glossopteris* leaf showing disfigurement of lamina and irregular shaped outgrowth over the surface. Specimen no. BSIP 36231, × 2.

9. Probable insect damaged stem showing helicoidal-shaped structures, distributed all over the surface. Specimen no. BSIP 36232. × 1.5.

10. Stem surface enlarged to show the distribution and organizational pattern of helicoidal structures. Specimen no. BSIP 36232. × 8.

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Estheriid zonation in the Gondwana

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Ghosh, S. C., Datta, Ashim, Nandi, A. & Mukhopadhyay, S. (1988). Estheriid zonation in the Gondwana. *Palaeobotanist*, **36** : 143-153.

Estheriid fauna of the Indian Gondwana is represented by 18 genera of fossil conchostraca. On the basis of recent discoveries of leaiid estheriids from the Lower Gondwana formations four new biozones are added to the previously established horizons. Nine estheriid biozones are now established for the entire Gondwana sequence of India. Lacuna, however, still exist in some of the formations. The biozones proposed are helpful for basinal correlation. There are some excellent index fossils to distinguish the Late Permian and Early Triassic Gondwana sediments and emplace precisely the boundary between them. With the record of Leaiid estheriids emerging from the Indian subcontinent, for the first time, all the five continents of the Gondwanaland can be tied up, solving a long existing problem in understanding the migratory route of the fauna. Indian fauna bears many of the common elements of the Gondwana estheriids of other continents from Late Permian to Jurassic periods. Estheriellids are confined to india (Early Triassic), Africa (Late Triassic) and South America (Jurassic-Cretaceous) only. The Indian species of *Estheriella* bear closer affinity to those of Europe (Bundenstein, Germany). It suggests dispersal of the bioprogram through land connections between the two super-continents during the Early Triassic.

Key-words—Estheriids, Leaiids, Esteriellids, Bioprogram, Gondwana stratigraphy, Continental Drift.

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साराँश

गोंडवाना में ऍस्थेरॉयड मंडलन

ऍस० सी० घोष, आशिम दत्ता, ए० नन्दी एवं ऍस० मुखोपाध्याय

भारतीय गोंडवाना का ऍस्थेरॉयड जीवजात अश्मित कॉन्कोस्ट्रेका की 18 प्रजातियों से अभिलक्षणित है। अधरि गोंडवाना शैल-समूहों से उपलब्ध लिऑयड ऍस्थेरॉयडों के अन्वेषण के आधार पर पहले से स्थापित संस्तरों में चार नये जैवमंडल और सम्मिलित किये गये हैं। भारत के सम्पूर्ण गोंडवाना अनुक्रम हेतु अब कुल मिलाकर नौ ऍस्थेरॉयड जैवमंडल स्थापित किये गये हैं। यद्यपि कुछ शैल-समूहों में अभी भी शोध-कार्य होना है। प्रस्तावित जैवमंडल द्रोणीय सहसम्बन्धन में सहायक हैं। कुछ ऐसे विशेष सूचक जीवाश्म हैं जो अनंतिम परमी एवं प्रारम्भिक त्रिसंघी गोंडवाना अवसादों में विभेद प्रदर्शित करते हैं तथा इनके बीच में एक स्पष्ट सीमा भी इंगित करते हैं। भारतीय उपमहाद्वीप से उपलब्ध लिऑयड ऍस्थेरॉयडों के अभिलेखों के आधार पर गोंडवानाभूमि के सभी पाँचों महाद्वीपों में देशान्तरगामी जीवजात के मार्ग की चिरकालीन समस्या को सुलझाया जा सकता है। अनंतिम परमी से जूराई कल्प तक अन्य महाद्वीपों की तरह भारतीय जीवजात में गोंडवाना ऍस्थेरॉयडों के बहुत से सामान्य अवयव मिलते हैं। ऍस्थेरियेल्लिड केवल भारत (प्रारम्भिक त्रिसंघी), अफ्रीका (अनंतिम त्रिसंघी) एवं दक्षिण अमेरिका (जूराई-क्रीटेशी) में ही मिलते हैं। **ऍस्थेरियेल्ला** की भारतीय जातियाँ यूरोपीय जातियों से घनिष्ठ सजातीयता व्यक्त करती हैं। इससे प्रारम्भिक त्रिसंघी कल्प में इन दो महाद्वीपों के मध्य भूमि-संयोजन के माध्यम से जीवजात का एक स्थान से दूसरे स्थान तक प्रवासन व्यक्त होता है।

FOSSIL conchostracans, commonly known as Estheriids, are one of the branchiopod Crustaceans belonging to the Phylum Arthropoda. They are essentially fresh to brackish water dwellers, but generally found in the ephemeral pools of seasonal nature (Tasch, 1969). They can stand the pH volume between 7 and 9 and are intolerant to salinity (Tasch, 1963). For these inherent characteristics, the

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estheriids are unable to cross oceanic barrier and prefer land routes for their migration.

These fresh to brackish water invertebrate fossils are reported from most of the Gondwana formations of India. Previous finds (Jones, 1862; Feistmantel, 1877) were restricted to Mesozoic Gondwana (Ghosh, 1982b). Recent finds of Permian estheriids by Geological Survey of India have augmented information on Gondwana estheriids. Leaiid, the Permian estheriid has been reported for the first time from the Pali Formation of Sohagpur Basin, Madhya Pradesh (Datta, 1987). Subsequently, several finds from Talchir, Barakar and Raniganj formations have been recorded. Though the estheriid occurrences are geographically scattered when stratigraphically arranged they indicate several definite biozones (Text-fig. 1) which can be useful for correlation within a basin (Ghosh *et al.*, 1980). Some of the biozones can be utilized for interbasinal correlation (Ghosh, 1982c).

Fossil conchostrocans are found to occur in both the northern and southern continents. The faunal assemblage of Indian Gondwana are more akin to those of other members of Gondwanaland. Indian Gondwana fauna also show some affinities to those of northern continent. An attempt has been made to describe the data accrued till date on Indian Gondwana estheriids, their distribution in different basins (Table 1a, b), the estheriid biozones (Text-fig. 1) and to discuss briefly the global comparison of the fauna with special reference to Gondwanaland continents.

ESTHERIID BIOZONES

Advent of estheriids in Indian subcontinent is evidenced by *Estheria* sp. (cf. *striata* Muenst) Diener, 1915 (=?*Cyzicus (Euestheria)* sp.) from Carboniferous Po-Series (Horizon G, Lipak River Section, Spiti) in the Himalaya. Moreover, from the Museum specimen of Speckled Sandstone, Salt Range, a fragmentary estheriid has been noticed. These evidences suggest the appearance of fossil conchostraca from the north-west of India in the geological history of fossil conchostraca. Subsequently a part of the Pangean fauna became the main stock from which later taxa developed and dispersed during Gondwana sedimentation.

Leaiids are reported from all other Gondwana continents, mostly from the Upper Permian strata (Tasch, 1970). It is a well distributed fauna of America and Europe during Carboniferous-Permian age (Raymond, 1946; Kobayashi, 1953). Absence of any leaiid record from Indian subcontinent had posed a difficult problem to the palaeontologists supporting distribution of this terrestrial fauna through land routes (Tasch, 1987). A definite Leaiid horizon of Upper Permian age has now been located (Datta, 1987) which is correlatable with other continents (Novojilov, 1956).

The biozones proposed as per the major genera and characteristic taxa found are reproduced in Text-figure 1 and described separately as follows:

Leaiid Biozone I

The geologically oldest record of fossil conchostraca from the Indian Gondwana is from the Talchir green needle-shale above the basal boulder bed in Saharjuri Basin, Bihar. The fragmentary nature of the valves though do not permit proper identification up to generic level, but the presence of two (Pl. 1, fig. 1; Pl. 3, fig. 7) radial ribs originating from the umbonal region confirm its affinity to family Leaiidae assigning a Late Palaeozoic age to the strata. Associated biota include insect remains and a few fish scales. This horizon needs re-examination in Saharjuri Basin and in other basins as well, as leaiid species depending on the characters of the radial ribs can assign a precise age (Novojilov, 1956). Lower age limit of Talchir Formation can thus be determined.

Leaiid Biozone II

Remains of fossil conchostraca were noticed by Dr S. Chandra, (J. N. Univ., New Delhi) in a bore-hole core in Jharia Coalfield. The compact Barakar carbonaceous shale on closer examination was found to contain fragments of a Leaiid and an Estheriinid shell (Pl. 1, fig. 2) confirming continuation of fauna within the Barakar Formation. Associated biota comprise anthracocid non-marine bivalves.

There is no record of fossil conchostraca from the Barren-Measures and/or its equivalent formations. Thus, a gap has been provided at the corresponding strata (Text-fig. 1) in the biozone column.

Hemicycloeaia-Monoleaia Biozone

The upper greenish-grey shale member of Raniganj Formation intersected in a bore-hole in Andal area, eastern Raniganj Coalfield yielded *Monoleaia* sp., a Leaiid with one posteriorly directed radial rib (Pl. 1, fig. 3A). Some fragments of *Cyzicus* (?) were also found associated with them. This biozone is, however, found to be better developed in Sohagpur Basin, further to the west.

A 0.20 m thick red mudstone band found at the base of Richai Hill in the western periphery of

Sohagpur Basin, has yielded one of the richest assemblage of Leaiid estheriids. The bed underlies a pebbly sandstone, white and lavender clay horizon (=Parsora Formation in the adjacent Johilla Coalfield in the west). The horizon is tentatively placed at the top of Middle Pali (=uppermost member of Raniganj Formation) Formation. Scanty exposures do not permit to assign a definite stratigraphic position to this bed. However, the fossil assemblage, described below, indicates Upper Permian age:

a. *Leaia* (*Hemicycloleaia*) sp. abundant (Pl. 1, figs 5, 7)
b. *Leaia* (*Leaia*) sp. scarce (Pl. 1, fig. 4).
c. *Cycloleaia* sp. frequent (Pl. 1, fig. 6)
d. *Rostroleaia* sp. rare (Pl. 1, fig. 8)
e. *Monoleaia* sp. frequent (Pl. 1, fig. 3B).

Associated biota include insect wing, fish scale and fronds of *Glossopteris*, seeds and root burrows. Further detailed study of the fauna is being carried out.

The *Leaia* (*Hemicycloleaia*) dominated biozone during the Late Permian all over the world strongly suggests it to be a Pangean fauna (Chang *et al.*, 1976; Shen Yanbin, 1984). India played a major role in Late Permian palaeogeographic set up for the dispersal of *L.* (*Hemicycloleaia*) from Australia, through Antarctica to India and possibly to south-east China (Table 3a).

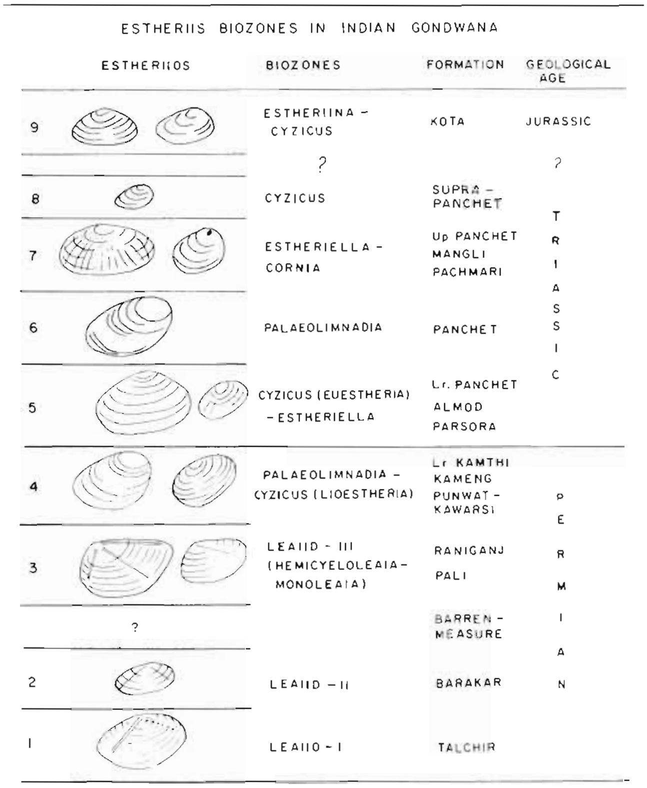
Palaeolimnadia-Cyzicus (Lioestheria) Biozone

The uppermost Permian biozone within the Damuda Group is developed in Raniganj, Ib River and Wardha basins and the Gondwana of Kameng District, Arunachal Pradesh.

A red shale unit belonging to the upper part of Middle Kamthi Formation of Ib River Coalfield, Orissa (S. Mukhopadhyay) has yielded a horizon containing high concentration of estheriids identified as *Palaeolimnadia* sp. (Pl. 1, fig. 10). Another associated larger form *?Pseudoasmussiata* is still under examination. This horizon possibly marks the uppermost biozone within the Permian Gondwana (=Raniganj Formation).

This horizon in Ib River Coalfield is specially noteworthy in containing trail marks of estheriids on the bedding plane (Pl. 3, fig. 5) indicating the beds being the site of dwelling of the fauna. Associated biota include fragments of *Glossopteris*.

The horizon is probably correlatable with the Upper Raniganj *Cyzicus* sp. subzone met with in the bore-hole RNM-3 in Andal area at a depth of about 30 m below the Raniganj-Panchet conformable boundary and about 10 m above the youngest coal seam (R-X) of Raniganj Formation (Ghosh *et al.*, 1987). There is a record of *Cyzicus* (*Lioestheria*) sp.



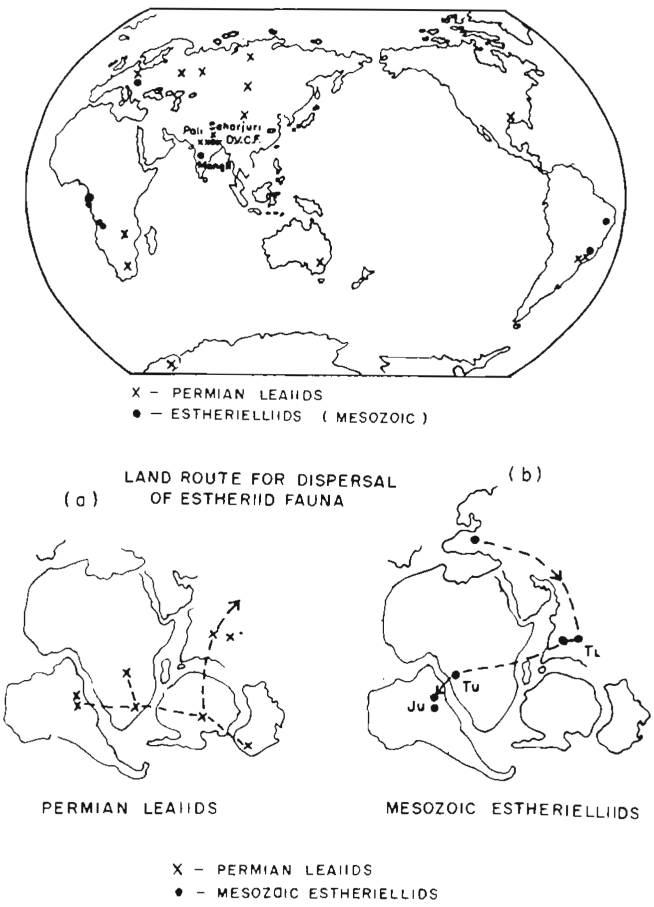
Text-figure 1—Estheriids biozones in Indian Gondwana.

from Punwat-Kawarsi area, Maharashtra in Wardha Basin which possibly belongs to this biozone (Pl. 1, fig. 9). The fauna obtained from eastern Himalaya (Acharyya *et al.*, 1975) also correlatable with this biozone (Pl. 1, fig. 11) alongwith *Estheriina* (pers. comm. : P. P. Satsangi).

Cyzicus (Euestheria)-Estheriella Biozone

The advent of Triassic marks the culmination of leaiids and appearance of estheriellids while other taxa continue (Text-fig. 2). Plant fossils associated with these horizons also corroborate this subdivision. *Glossopteris* is often found to occur with the underlying biozone while *Dicroidium* is associated with this basal Triassic biozone. The biozone is developed in Damodar Valley, Satpura and Johilla basins.

At the base of the Panchet Formation a very well-defined conchostracan zone mainly comprising *Cyzicus* is met with in Raniganj Coalfield (Pl. 2, fig. 9) both in outcrop (Banspetali *nala*, Nunia *nala*, Kanyapur *nala* and other outcrops) and in the bore-holes in Andal area. However, in bore-hole RNM-3 a fragment of *Estheriella* sp. was also found. This horizon marks the basal Panchet Formation and is found in North Karanpura and East Bokaro coalfields and occurs about 20 m above the Raniganj-Panchet boundary. Association of *Estheriella* sp. assigns an



Text-figure 2—Distribution of Leaiids and Estheriellids.

Early Triassic age to this horizon. This horizon extends even beyond the realm of Damodar Valley basins and is met with in Parsora Formation (Pl. 2, fig. 1) in Johilla Coalfield (A. Nandi), and Almod Bed in Satpura Basin where *Cornia* occurs alongwith the *Cyzicus* (*Euestheria*) (Pl. 2, fig. 3). Associated conchostracan genera are *Cycloestheroides* and *Pseudoasmussiata* (Text-fig. 2).

Though the genus *Estheriella* is of singular occurrence in Andal area it has been included in naming the biozone due to its significance as an index fossil for Lower Triassic.

Palaeolimnadia Biozone

This horizon occurs about 50 to 70 m above Panchet-Raniganj boundary and is well developed in Damodar Valley basins. *Cornia* appears in Panchet Formation for the first time in this horizon in Raniganj Coalfield. In North Karanpura Coalfield *Lystrosaurus* fauna occurs alongwith this biozone about 70 m above the Raniganj-Panchet boundary (Chakraborty & Ghosh, 1973).

Estheriella-Cornia Biozone

The biozone is best developed at the top of Panchet Formation, i.e. about 250 m above Raniganj-Panchet boundary in Dhardharwa *nala*, East Bokaro Coalfield, Bihar. There are several species of *Estheriella* of which *E. sastryii* Ghosh 1983 is dominant (Pl. 2, fig. 11; Pl. 3, fig. 8). *E. taschi* (Ghosh & Shah, 1977) has been assigned to a new genus *Cornutestheriella* (Tasch, 1987). The other dominant genus is *Cornia* (Pl. 2, fig. 7) which is represented by several species (Novojilov, 1970). This same horizon, though without *Estheriella*, is also met with in Andal group of bore-holes at a level of about 200 m above the basal *Cyzicus-Estheriella* biozone. Vertexiid group represented by *Cornia, Gabenestheria* and *Vertexia* (Ghosh, 1980) occurs in this horizon in Andal bore-hole (Pl. 3, figs 1, 2). The biozone is again very well-developed in Mangli Bed, Wardha Basin (Ghosh, 1983). *Cyzicus* is found in large numbers besides the captioned *Estheriella* (Pl. 2, fig. 10) and *Cornia* (Pl. 2, fig. 6). The Pachmari Formation in the type area contains this biozone represented by fragmentary-*Cornia* (Pl. 2, fig. 5) and *Cyzicus* (courtsey Dr S. Chanda).

Cyzicus (Euestheria) Biozone

The only estheriid biozone encountered within the Supra-Panchet sediments comprises mainly

PLATE 1 →

1. Leaiid conchostraca, Talchir Formation, Saharjuri Coalfield, Bihar. Umbonal part broken, nodose posterior rib prominent. Magnification × 22, SEM photo.
2. Leaiid conchostraca, Barakar Formation, Jharia Coalfield, Bihar (Bore-hole core sample, courtsey Dr S. Chanda). × 15.

3A. *Monoleaia* sp., Raniganj Formation, Raniganj Coalfield, SEM photo. × 20.

3B. (?)*Monoleaia* sp., Pali Formation, Sohagpur Coalfield. × 12.

4. *Leaia (Leaia)* sp., Pali Formation, Sohagpur Coalfield, SEM photo. × 22.
5. *Leaia (Hemicycloleaia)* sp., Pali Formation, Sohagpur Basin. × 12.
6. *Cycloleaia* sp., Pali Formation, Sohagpur Basin. × 12.
7. *Leaia (Hemicycloleaia)* sp., Pali Formation, Sohagpur Basin. × 12.
8. *Rostroleaia* sp., Pali Formation, Sohagpur Basin. × 15.
9. *Cyzicus (Lioestheria)* sp., Kawarsi area, Wardha Basin. × 10.
10. *Palaeolimnadia* sp., Kamthi Formation, Ib River. × 10.
11. *Cyzicus (Lioestheria)* sp., Kameng Gondwana (courtsey Shri P. P. Satsangi). × 15.

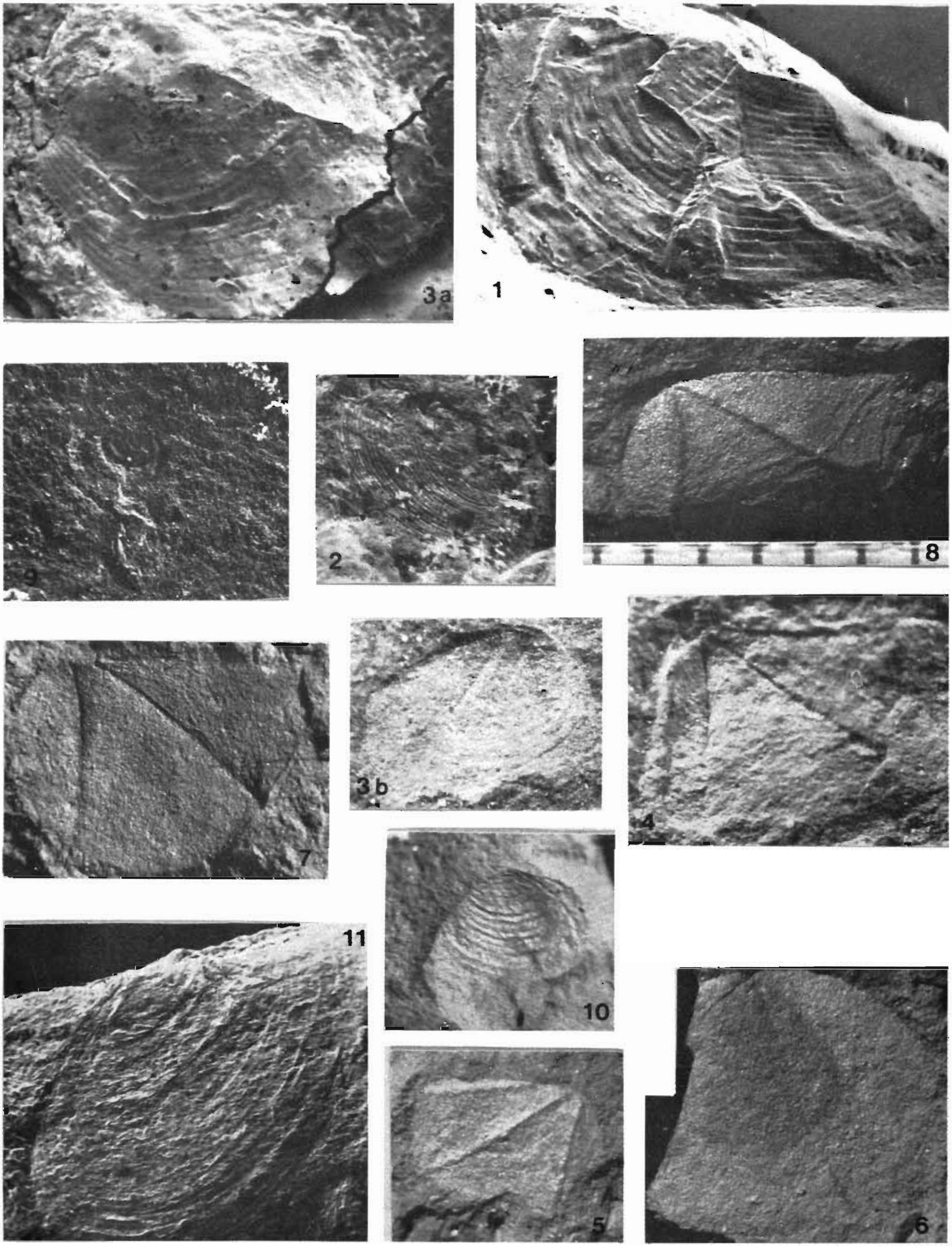
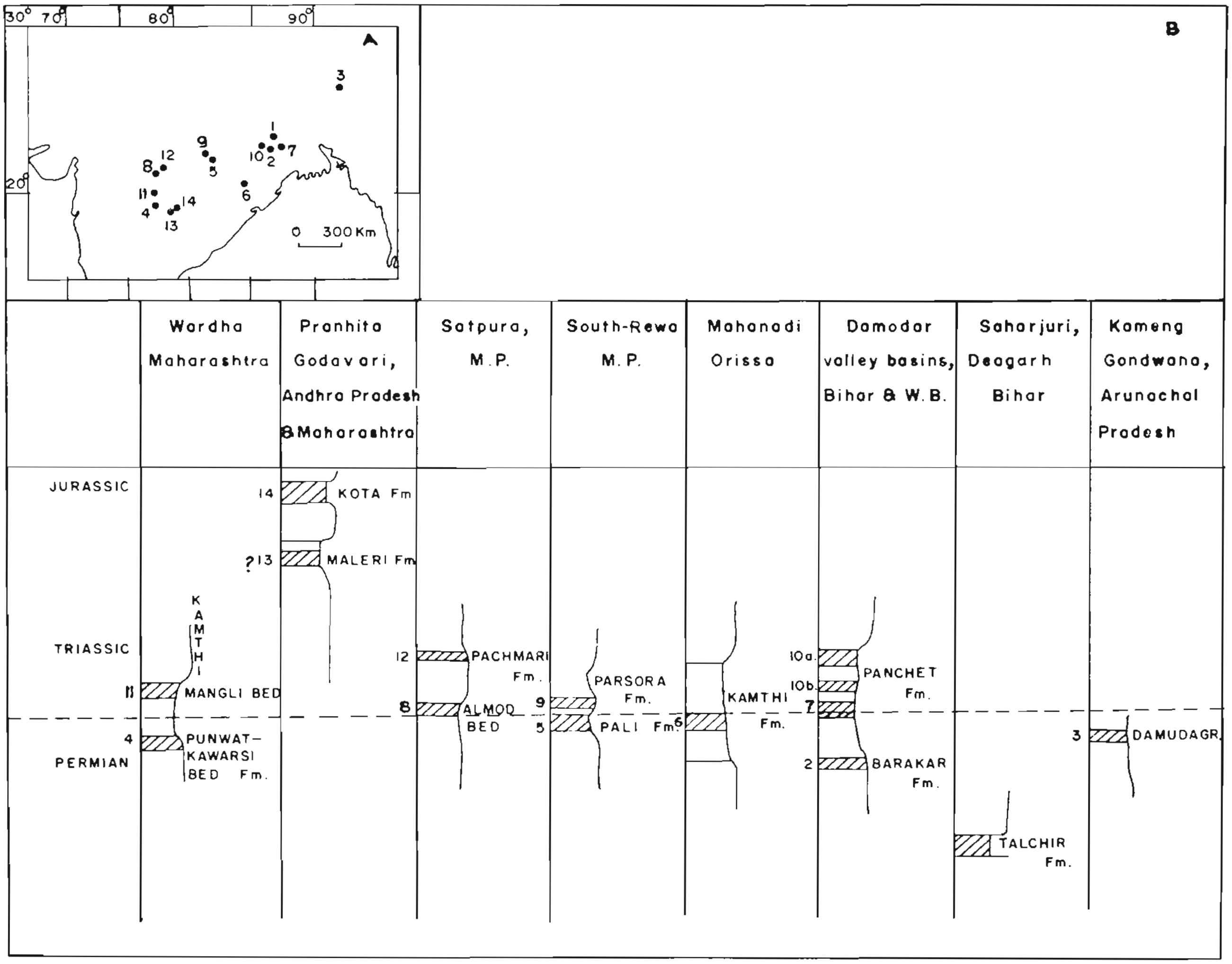


PLATE 1

Table 1—Lithostratigraphic sequence showing distribution of estheriid-biozones in Indian Gondwana



Cyzicus (*Euestheria*) sp. It is about 50 cm thick and occurs about 50 m above the base of Lugu Hill in East Bokaro Coalfield (Ghosh & Shah, 1977).

It may be noted that there are several subzones comprising *Cyzicus* and *Palaeolimnadia* in the Panchet Formation (Tasch, 1973) in Damodar Valley basins. These are helpful for intrabasinal correlation.

Estheriina-Cyzicus Biozone

There is a large gap in estheriid biozone within the rocks above the Supra-Panchet and the Kota Formation. This biozone is very well developed in Kota Formation, Pranhita-Godavari Basin. The fauna comprises *Estheriina, Cyzicus, Pseudoasmussiata*

PLATE 2 →

1. *Cyzicus (Euestheria)* sp., Parsora Formation, Johilla Coalfield. × 10.
2. *Cyzicus (Euestheria)* sp., Supra-Panchet Formation, Lugu Hill. × 12.
3. *Cyzicus* sp., Almod Bed, Satpura Basin (scale given). × 25.
4. *Palaeolimnadia* sp., Panchet Formation, Raniganj Coalfield. × 12.
5. *Cornia* sp., Pachmari Formation, Satpura Basin (courtsey Dr S. Chanda). × 25.
6. *Cornia* sp., Mangli Bed. × 10.
7. *Cornia panchetella* Tasch 1987, Panchet Formation, East Bokaro Coalfield. × 10.
8. *Pseudoasmussiata* (?) sp., Panchet Formation, Raniganj Coalfield. × 18.
9. *Cyzicus* sp., Panchet Formation, Raniganj Coalfield. × 8.
10. *Estheriella* sp., Mangli Bed. × 25.
11. *Estheriella sastryii* Ghosh, Panchet Formation, East Bokaro Coalfield. × 20.

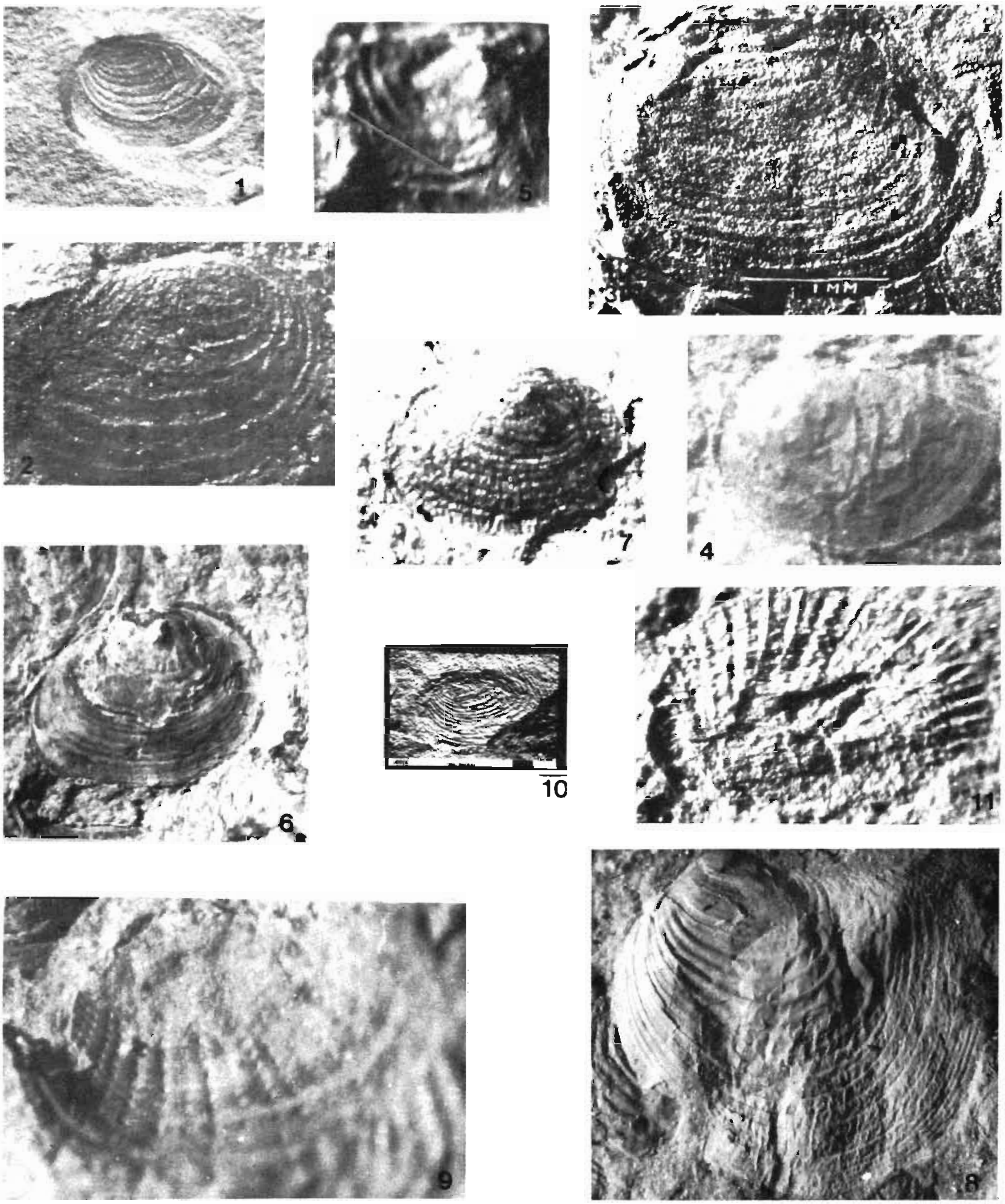
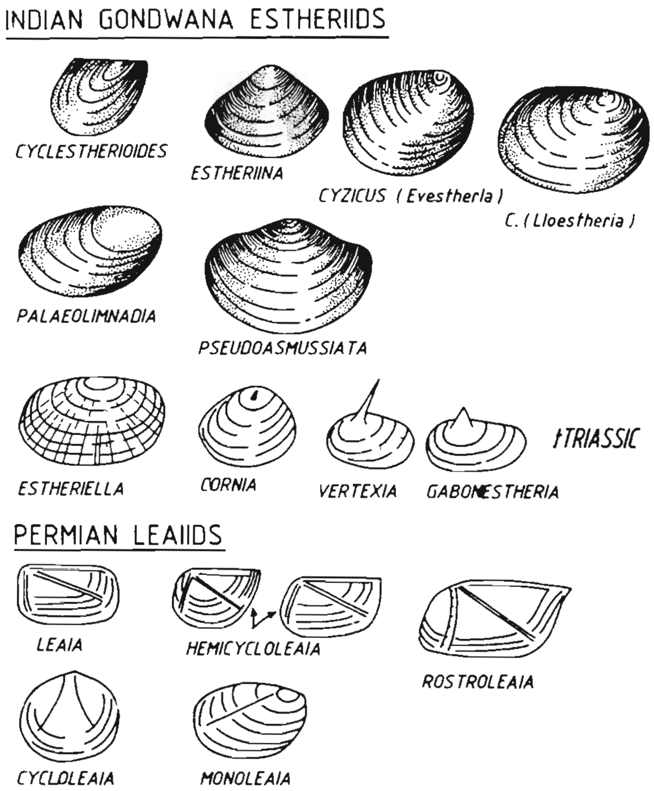


PLATE 2



Text-figure 3—Indian Gondwana Estheriids and Permian Leaiids

and *Palaeolimnadia* (Pl. 3, figs 3, 4). This Early Jurassic biozone is very well traceable for tens of kilometers in the basin and there are about 6 to 7 subzones (Tasch *et al.*, 1973). There is no equivalent bed outside the basin.

FAUNAL ANALYSIS

Discovery of leaiids from the Talchir, Barakar and Pali formations now establishes the fact that during the Permian time wide dispersal of the fauna occurred amongst all the Gondwana continents. The leaiids alongwith some *Cyzicus* and *Estheriina* define the Lower Gondwana conchostracan population. Further search and detailed identification up to species level is required for refining the biozones.

The basal Panchet member is dominated by *Cyzicus (Euestheria) minuta* and permits interbasinal correlation. The overlying *Cornia panchetella* Tasch 1987 and *Estheriella sastryii* Ghosh 1983 again offer another interbasinally correlatable horizon. *Palaeolimnadia* and *Gabonestheria* occur alongwith *Vertexia* in the same horizon. The Lower Jurassic Kota Bed with *Cyzicus (Lioestheria) kotahensis, Pseudoasmussiata, Palaeolimnadia* and *Estheriina* is of unique occurrence in India.

The major and characteristic genera are figured in Text-figure 1 to show main taxonomic features while their distribution through different Gondwana formations is explained in Table 2.

Cyzicus and *Palaeolimnadia* dominate the Indian population. Radially ribbed forms like *Leaia* and *Estheriella* indicating specific age offer an excellent opportunity for and emplacement of Permian-Triassic boundary (Table 3). Detailed distribution of Indian etheriids fauna, bed-wise, is listed as under:

I. Permian

A) Talchir Formation, Saharjuri Basin
?Leaia sp.
B) Barakar Formation, Jharia Coalfield
Leaia sp.
Estheriina sp.
C) Pali Formation, Sohagpur Basin
Leaia (Leaia) sp.
L. (Hemicycloleaia) sp.
Cycloleaia sp.
Rostroleaia sp.
Monoleaia sp.
D) Kamthi Formation, Ib River Coalfield
Palaeolimnadia sp.
Cyzicus sp.
E) Punwat - Kawarsi area, Kamthi Formation, Wardha Basin
Cyzicus sp.
C. (Lioestheria) sp.
F) Raniganj Coalfield (Andal area)
Monoleaia sp.
Cyzicus sp.

PLATE 3 →

1. *Vertexia* sp., Panchet Formation, Bore-hole RNM 4 (depth 106 m), Raniganj Coalfield, SEM photo. × 85.
2. *Gabonestheria* sp. Panchet Formation, Bore-hole RNM 4 (depth 106 m), Raniganj Coalfield, SEM photo. × 30.
3. *Estheriina* sp., Kota Formation, Pranhita-Godavari Basin. × 10.
4. *Pseudoasmussiata* sp. × 30.
5. Burrow trails and tracks on bedding plane of red shale, Kamthi Formation. Ib River Coalfield.
6. Hopper crystals of Halite on carapace of *Cornia* (Bore-hole RNM 4), Panchet Formation, Raniganj Coalfield. × 10,000, SEM photo.
7. Carapace ultrastructure between growth lines of Talchir Leaiid, SEM-photo. × 155.
8. Shell ultrastructure between growth lines of *Estheriella* sp., SEM photo. × 135.

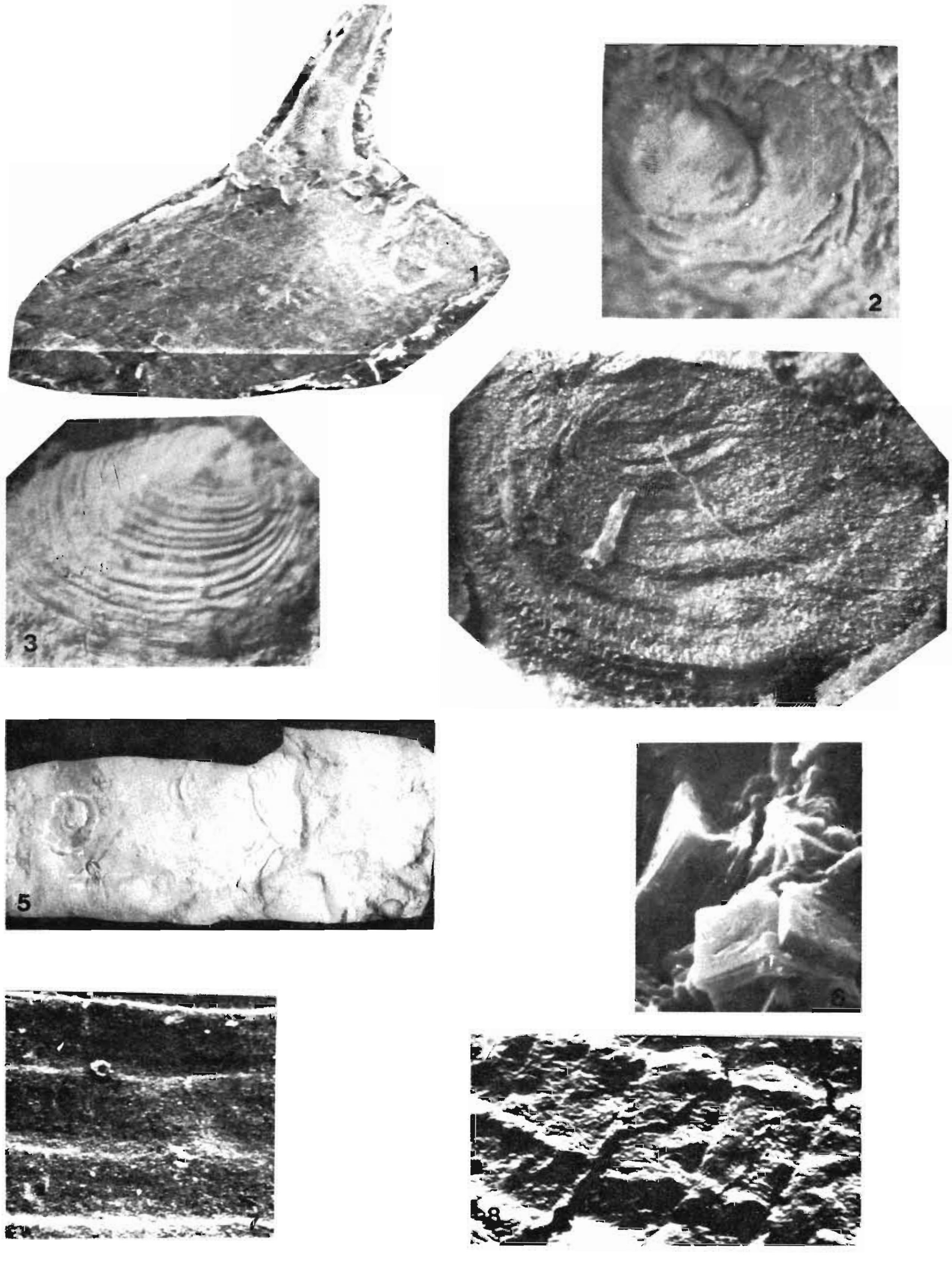
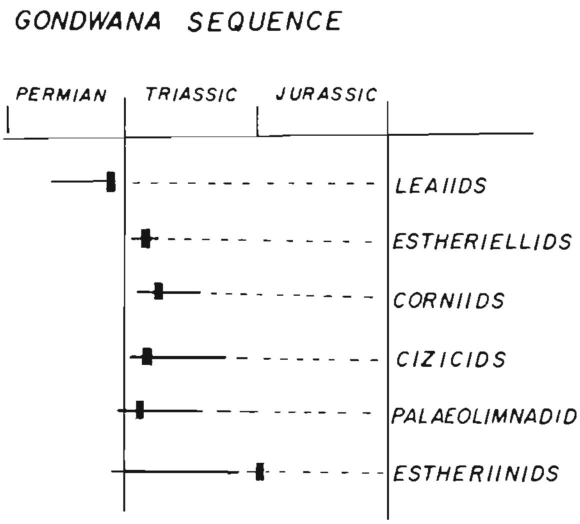


PLATE 3

Table 2—Distribution of major estheriid families of Indian Gondwana with acme of development.



G) Kameng Gondwana, Arunachal Pradesh
Estheriina sp.
Cyzicus (Lioestheria) sp.

II. Triassic

A) Panchet Formation, Raniganj Coalfield
Cyzicus (Euestheria) bengalensis Tasch 1987
Cycloestheroides (Sphaeroestheria) sp. Tasch 1987
Pseudoasmussiata bengalensis sp. Tasch 1987
Cyzicus (Lioestheria) miculis Tasch 1987
Cyzicus (Euestheria) raniganjensis Tasch 1987
C. (E.). mangaliensis Jones 1862
Cornia panchetella Tasch 1987
Cycloestheroides (Cycloestheroides) machkendaensis Tasch 1987
Cyzicus (Euestheria) dualis Tasch 1987
Palaeolimnadia sp.
Estheriella sp.
Gabonestheria sp.
Cornia sp.
Vertexia sp.
Cyzicus (Euestheria) sp.

B) North Karanpura Coalfield
Palaeolimnadia sp.
Cyzicus (Euestheria) sp.

C) East Bokaro Coalfield
Estheriella sastryi Ghosh 1983
Estheriella sp.
Cornutestheriella taschi Tasch 1987, Ghosh & Shah 1977
Cyzicus (Lioestheria) bokaroensis Tasch 1987
Palaeolimnadia sp.
Cornia sp. cf. *C. bengalensis* Tasch 1987

D) Parsora Formation, Johilla Coalfield
Cyzicus (Euestheria) sp.

E) Almod Bed, Satpura
Cyzicus (Euestheria) sp.
Cornia sp.

F) Pachmari Formation, Satpura Basin
Cornia sp.
Cyzicus (Euestheria) sp.

G) Mangli Bed, Wardha Basin
Cyzicus (Euestheria) mangaliensis Jones 1862
Pseudoasmussiata indicycloestheria Tasch 1987
Cornia panchetella Tasch 1987
Estheriella sp.

III. Jurassic

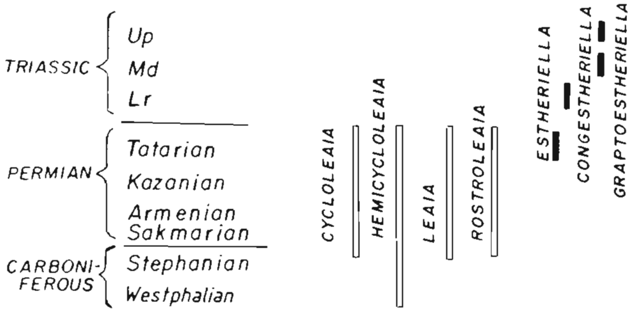
Kota Formation, Pranhita-Godavari Basin
Cyzicus (Lioestheria) kotahensis Jones 1862
C. (L.) sp.
C. (Euestheria) crustabundis Tasch 1987
Pseudeasmussiata andhrapradeshia Tasch 1987
Palaeolimnadia (Grandilimnadia) sp.
Estheriina (Nudusia) adilabadensis Tasch 1987
E. (N.) indijurassic Tasch 1987
E. (N.) bullata Tasch 1987
Estheriina (Estheriina) pranhitaensis Tasch 1987

GONDWANALAND EXTENSION

With the new Leaiid records from the Indian Gondwana Sequence a major lacuna has been filled up. The group originally evolved in China (Chang *et al.*, 1976) and subsequently dispersed to all the available land masses through land routes. During Gondwana sedimentation it appeared in Australia and by Late Permian it spread to Antarctica, Africa, South America and through India probably to China (Shen Yanbin, 1984) (Text-fig. 3a).

The earliest record of Early Triassic *Estheriella* is from the Panchet Formation, India where from it dispersed to Africa (Upper Triassic) and South America (Jurassic) during the Mesozoic Period (Tasch, 1980). Similarity of Indian fauna with that of Bundenstein estheriellids (Weiss, 1875) suggests, direct land-route between India and Western Europe

Table 3—Distribution of ribbed estheriids through geological ages.



during Early Triassic Period (Text-fig. 3b.) *Cyclestheroides* and *Pseudoasmussiata* are found in Indian, African and South American Triassic Gondwana deposits as the continental contiguity offered non-marine dispersal routes.

Gobonestheriids and corniids recorded from the Triassic sequences of India (Andal, Raniganj), Africa (Lesotho) and South America (Brazil), indicate spread of the bioprograms for these taxa due to proximity of continents (Gondwanaland).

Similarity between the Kota estheriids and those of Antarctic Nunatak assemblage, alongwith the insect fauna, suggests divergence from the same parent stock specially for estheriinids.

Palaeoecology played major role in evolutionary changes (Ghosh, 1980, 1982a). Proliferation of vertexiids in the Panchet Formation in Andal area, eastern Raniganj Coalfield is noted in bore-holes. Pseudomorphs of halite and gypsum are found closely associated in the sediment as well as inside the fossils (Pl. 3, fig. 26). Desiccation leading to hypersalinity possibly led to endemic forms with variety of umbonal spines (Ghosh, 1984). Such information associated with the conchostracan fauna will be of immense importance for better understanding of Gondwana palaeogeography.

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Stratigraphic position and age of plant bearing Nidpur beds

Shyam C. Srivastava

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The Gopad River Section near Nidpur has yielded a rich and diversified flora showing the dominance of *Dicroidium* associated with the culmination of non-striate bisaccate pollen. Gymnosperms are the main components of this fossil assemblage. *Dicroidium* a widely disseminated taxon in the Gondwanaland has restricted stratigraphical range. It has been considered to be an infallible indicator of Triassic time. Furthermore, the consistency of usual association of *Pteruchus* with *Dicroidium* also supports a Triassic age for Nidpur beds. Confirmatory evidence of Triassic age is also provided by frequent occurrence of *Alisporites indicus* correlated with the variable pollen (*Alisporites*-complex) of *Pteruchus*. The dominant pollen *Satsangisaccites* distinguishes Nidpur assemblage from other palynofloras whereas *Nidipollenites* has now been reported from other Triassic palynofloras of the Indian subcontinent. A stratigraphic position of Nidpur beds between that of Panchet and Parsora formations is advocated; extensive review of data supports a Middle Triassic age.

Key-words—Stratigraphy, *Dicroidium*, Nidpur beds, Middle Triassic (India).

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साराँश

निदपुर के अश्मित पादप-धारक संस्तरों की स्तरिकीय स्थिति एवं आयु

श्याम चन्द्र श्रीवास्तव

निदपुर के समीप गोपद नदी खंड से अरेखीय द्विकोष्ठीय परागकणों की बाहुल्यता तथा **डाइक्रोइडियम्** की प्रचुरता से युक्त एक घना वनस्पतिजात उपलब्ध हुआ है। इस समुच्चय में अनावृतबीजीयों का प्रभुत्व है। गोंडवानाभूमि में दूर-दूर तक विस्तृत **डाइक्रोइडियम** स्तरिकीय सीमाओं में ही सीमित है। यह पौधा त्रिसंघी कल्प का अमोघ सूचक माना गया है। इसके अतिरिक्त **टेरूकस** एवं **डाइक्रोइडियम** के साहचर्य से निदपुर संस्तरों की त्रिसंघी आयु की पुष्टी होती है। **टेरूकस** के परागकणों (**ऐलिस्पोराइटिस**-सम्मिश्र) की विविधता तथा **ऐलिस्पोराइटिस इंडिकस** की बाहुल्यता भी त्रिसंघी आयु के प्रमाण जुटाते हैं। **सत्संगीसेक्काइटिस** परागकणों की बाहुल्यता के कारण निदपुर समुच्चय अन्य परागाणविक समुच्चयों से भिन्न है जबकि **निदिपोलिनाइटिस** अब भारतीय उपमहाद्वीप के अन्य त्रिसंघी कालीन परागाणविक वनस्पतिजातों से भी अभिलिखित किया गया है। पंचेत एवं परसौरा शैल-समूहों के मध्य में निदपुर संस्तरों की स्तरिकीय स्थिति की विवेचना की गई है। उपलब्ध आँकड़ों की समीक्षा से निदपुर संस्तरों की मध्य त्रिसंघी आयु की पुष्टी होती है।

THE plant-bearing Nidpur beds, discovered by Satsangi (1964), lie about two and a half kms from north-west corner of village Nidpur on the left bank downstream of Gopad River (24°7′ : 81°54′) in a 7.5 m thick section. In much of the Gopad River region, Raniganj Formation (Upper Permian) is exposed (Hughes, 1881) but rocks ascribed to Panchet Formation are also exposed in Gopad River Section in the southern part of Singrauli Coalfield (Raja Rao, 1983).

The Nidpur plant beds occur nearly in the central part of South Rewa Basin in a small fault bounded outcrop (Srivastava, 1974a, text-fig. 1; Raja Rao, 1983). The lithological succession comprises

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carbonaceous sandy shales of dark and light grey colour with micaflakes superposed by an unfossiliferous massive sandstone consisting of micaceous ferruginous fine to coarse-grained sandstone and light yellow shale (Bharadwaj & Srivastava, 1969). Relationship of the plant-beds with the concealed older formation is not known.

FOSSIL FLORA

The Nidpur plant-beds contain an extremely diverse and rich flora represented by compressions of foliage, detached fertile organs, scale-leaves and seeds, etc. Palynofossils have also been recovered from carbonaceous shale. Systematic palaeofloristic studies by Srivastava (1969, 1971, 1974a, 1974b, 1974c, 1975a, 1975b, 1976, 1977, 1979, 1984a, 1984b, 1984c), Chandra and Satsangi (1965), Bharadwaj and Srivastava (1969), Bose and Srivastava (1970, 1971, 1972, 1973a, 1973b), Srivastava and Maheshwari (1973), Pant and Basu (1973, 1977, 1978, 1979a, 1979b, 1981) and Pant and Pant (1987) have shown the representation of major taxonomic groups in the flora. These are: Phycophyta, Bryophyta, Pteridophyta, Glossopteridophyta, Pteridospermophyta, Cycadophyta, Ginkgophyta and Coniferophyta.

Megaflora

Plant taxa recognized are: *Algacites oogonifera* Pant & Basu, *Hepaticites nidpurensis* Pant & Basu, *H. riccardioides* Pant & Basu, *H. metzeroides* Walton, *H. foliata* Pant & Basu, *Glossopteris senii* Srivastava, *G. papillosa* Srivastava, *G. nidpurensis* Srivastava, *Glossopteris* sp. cf. *G. linearis* Bunbury, *G. nilssonioides* Pant & Pant, *G. sidhiensis* Pant & Pant, *Glossopteris* spp., *Rhabdotaenia* sp., *Lepidopteris indica* Bose & Srivastava, *Bosea indica* Srivastava, *Rugatheca nidpurensis* Pant & Basu, *Dicroidium nidpurensis* Bose & Srivastava, *D. papillosum* Bose & Srivastava, *D. gopadensis* Bose & Srivastava, *Pteruchus nidpurensis* Srivastava, *P. indicus* Pant & Basu, *P. thomasii* Pant & Basu, *P. gopadensis* Pant & Basu, *Marhwaseaphyllum hastatum* Srivastava, *Rewaphyllum nidpurensis* Srivastava, *R. argentinicum* (Archangelsky) Srivastava, *Taeniopteris glandulata* Srivastava, *Nidistrobus harrisianus* Bose & Srivastava, *Nidpuria problematica* Pant & Basu, *Lelestrobus pennatus* Srivastava, *Gopadia coriacea* Srivastava, *G. papillata* Srivastava, *Glottolepis rugosa* Bose & Srivastava, *G. glabrosa* Srivastava, *G. tuberculata* Srivastava, *G. sidhiensis* Srivastava, *G. ovata* Srivastava, *Equitatilepis elongatus* Pant & Basu, *Satsangia campanulata* Srivastava & Maheshwari, *Conites* sp., *Chakrea papillata* Srivastava, *Rugaspermum insigne* Pant & Basu, *R. media* Pant & Basu, *R. obscura* Pant & Basu. Megaspores, namely, *Grambastisporites, Srivastavaesporites, Trikonia, Mamillaespora* and *Nidhitriletes* show lycopsid alliance.

Banerji *et al.* (1976) have described plant impressions from adjacent sediments. These comprise *Glossopteris gopadensis, G.* sp. cf. *G. senii, G. taeniopteroides, Dicroidium* spp., *Taeniopteris* sp. cf. *T. glandulata*, scales and seeds. This assemblage is very similar to the one described from the carbonaceous beds. However, in this bed *Dicroidium* is not that frequent as in the carbonaceous beds and therefore, authors have opined that the former could be slightly older deposit. I strongly feel that the frequency of *Dicroidium* in impression bed is more or less the same. As regards the differentiation between compression and impression beds at Nidpur, that could be ascribed due to varying sedimentological milieu prevailing at Gopad River Section; relatively high energy sandy shales permitted preservation of impressions while low energy fluvial flat with intermittent restricted circulation resulted in deposition of carbonaceous shales with excellent compressions.

The Nidpur outcrop has an overwhelming presence of *Dicroidium*. a taxon considered to be an infallible indicator of a Triassic age. The consistent association of *Pteruchus* and *Dicroidium* documents a Triassic age for Nidpur deposits. *Dicroidium* did not survive with any degree of certainty beyond Rhaetic and that becomes quite apparent from floral assemblage of Parsora Formation, the upper limit of the Triassic in South Rewa Gondwana Basin.

Dicroidium appeared on the Gondwana Triassic scene with characteristic pinnate organization and often a forked rachis whereas in Permian floral regime no such plants were present, on the contrary, glossopterids have simple entire, smooth margined leaves. In Nidpur, *Dicroidium* fronds fairly large, usually bipinnate or pinnate bearing thick cuticles, are generally met, a feature frequent in early-Middle Triassic leaves. Forked rachides have not been found by me because it is not easy to find a main rachis forked as the fronds are large and commonly got broken (Archangelsky, 1968). From Nidpur, Professor D. D. Pant of Allahabad University, Allahabad, has got a big *Dicroidium* frond accompanied with several others, revealing forked primary rachis (Pers. comm.).

Besides, the scrutiny of *Dicroidium* spp. from all over Gondwanaland has shown that the percentage-frequency of bipinnate-pinnate leaves is higher than those of forked *Dicroidium* fronds (Retallack, 1977).

Moreover, the concerted view and intensive work of Townrow (1957), Bonetti (1966), Archangelsky (1968), Bose and Srivastava (1971) and Retallack (1977) have definitively elaborated the genus *Dicroidium* so that it could incorporate the allied varied leafy forms. Therefore, Maheshwari's (1976) comments regarding the identity of Nidpur dicroidia, evidently has got no relevance in taxonomic consequences in Dicroidium Flora. On the other hand, other floral associates, more especially, the fertile structures have also to be taken into consideration before one points out taxon's identity. Interestingly, Maheshwari (1976) has placed Nidpur beds in lithostratigraphical sequence (Table 1) ranging from upper part of Lower Triassic-Middle Triassic. In view of the facts, the questioning of Venkatachala (1986) regarding the Nidpur dicroidia being the typical ones, is not considered valid.

Further, to equate the genus *Dicroidium* with those of *Buriadia* and *Botrychiopsis* (Venkatachala, 1986) is not at all tenable because the later two genera are neither widely distributed in the entire Gondwanaland nor they span throughout the Permian period. Therefore, they may not be taken as criterion for distinguishing a major sub-division.

Beside the taxa cited above, another significant constituent is *Lepidopteris* (though certain species such as *L. ottonis* and *L. martinsii* are known in Permian, see Vakhrameev *et al.*, 1978) which frequently occurs in Nidpur and because of its wide distribution in Triassic sediments of southern and northern hemisphere; having its dominance (inclusive of its fertile organs) in Triassic period, much reliance could be placed upon its presence too, as an indicator of age.

Palynoflora

Chandra and Satsangi (1965) first recorded the palynofloral assemblage from *Dicroidium*-bearing Nidpur Shale. Bharadwaj and Srivastava (1969) established taxonomically for the first time the broad Triassic miofloral frame work from Nidpur. Further, it would be worth to mention over here that these two palynofloras are from the same stratigraphic level of a condensed sequence and not the different expressions of the same assemblage as has been pointed out by Roychowdhury *et al.* (1975).

The palynoflora shows the preponderance of non-striate bisaccate pollen which constitute more than 50 per cent of the assemblage (Bharadwaj, 1970) and are presumed to be derived from *Dicroidium* (Anderson & Anderson, 1970; Roychowdhury *et al.*, 1975). Other pollen such as striate forms are little in quantity while costate and colpate ones are less frequent. Trilete spores are rare. Among the non-striate bisaccate grains, viz., *Satsangisaccites, Alisporites* and *Nidipollenites* occur in enormous number. The other important constituents, viz, *Weylandites* and *Praecolpatites* are also fairly represented in palynofloral assemblage. Trilete forms, although present, are quantitatively insignificant. *Satsangisaccites* distinguishes the Nidpur palynoflora from other miofloral assemblages.

The association of some pollen genera, namely, *Klausipollenites* and *Chordasporites* along with *Alisporites indicus* within a sporangium has been interpreted to represent ontogenetic stages of the same taxon (Srivastava, 1974c) because a relatively consistent sequential pattern is evident in *Alisporites* complex. *Alisporites indicus* which is of corystospermaceous origin, and extremely abundant in Middle-Upper Triassic units, could be treated as to be of potential stratigraphic significance. *Nidipollenites* was first recorded from Nidpur but now its occurrence has been noted in other Triassic assemblages of the Indian sub-continent such as Janar Nala, Upper Pali Formation of South Rewa Basin. Certain other newly evolved palynofossils such as *Weylandites* and *Praecolpatites* also occur in the flora. The striate bisaccate forms, viz., *Striatites, Lunatisporites, Striatopodocarpites, Faunipollenites,* etc. are represented in small quantities in Nidpur in comparison to Raniganj and Panchet mioflora. Of the typical elements of the Panchet mioflora, there is total absence of *Verrucosisporites, Decisporis* and *Playfordiaspora*, however, *Lunatisporites* by its occurrence in Nidpur assemblage, is long ranging. The conspicuous absence of *Playfordiaspora* particularly in Nidpur, is quite interesting because its range has been noted up to Norian (Tiki Formation). Thus on the basis of palynological succession, it may be inferred that the Panchet mioflora presents an older aspect than Nidpur mioflora and represents a transition between the two well-diversified miofloras of Raniganj and Nidpur; also it demonstrates that Nidpur is younger than Panchet Formation, thus supporting the megafloristic evidence in affixing the age of Nidpur beds.

STRATIGRAPHIC POSITION AND AGE

The floral contents of Nidpur have played pivotal role in determining the age and stratigraphic position of these beds in the Gondwana System of India.

Satsangi (1964) deduced that *Dicroidium*-bearing beds of Gopad River Section are certainly not older than Panchet. Further, in the presence of variety of *Dicroidium* spp., Nidpur beds come closer to Parsora because of which author attributed the beds to be of younger aspect within the Panchet. Srivastava (1969), Bharadwaj and Srivastava (1969), Bose and Srivastava (1970), Srivastava (1971), Bose and Srivastava (1971, 1972) also envisaged Triassic age for Nidpur beds.

Bose (1974) considered Nidpur beds to be youngest amongst the Lower Triassic beds because of the absence of filicinean remains. Srivastava (1974a) concluded that the fossil assemblage is closer to Middle Triassic floras of the southern hemisphere and therefore younger than the Panchet Stage. Roychowdhury *et al.* (1975, table 13.2) supported this view and placed Nidpur beds at the base of Tiki Formation (Anisian). Mitra *et al.* (1979) too, have favoured Nidpur floral remains ranging in age from Upper Scythian-Lower Anisian. But because of the occurrence of this floral deposits in the vicinity of Raniganj Formation in nearby Singrauli Coalfield, authors have remarked that Raniganj-Panchet model loses its perfection in Damodar Valley and places Raniganj straddling across the so-called Permo-Triassic boundary. However, this hypothesis could not have weight owing to the recent finds of Raja Rao (1983) which show the occurrence of Panchet Formation in Latazharia, Harauri nalas and Gopad River Section. And with this report it is quite apparent that there is distinctive differentiation between the two formations (i.e., Raniganj & Panchet) and so, the question does not arise of Raniganj Formation extending beyond Permian. However, Raja Rao (1983) has placed Nidpur beds under Panchet Formation and also fully agrees with Srivastava's (1979) conclusion regarding Nidpur's stratigraphic position between Panchet and Parsora formations.

Biostratigraphically, Retallack (1977) recognized four zones based upon lineage of *Dicroidium*-leaves and considered Nidpur a transitional assemblage of Early Triassic and so, included floral assemblage in upper part of *Thinnfeldia callipteroides* Zone.

A Triassic age was ascribed to Nidpur outcrop (Chandra & Satsangi, 1965) because of the presence of enormous number of bi-winged gymnosperm pollen. Bharadwaj and Srivastava (1969) considered these beds to be of younger Lower Triassic (Panchet Stage) due to dominance of nonstriated-saccate and richness of *Dicroidium*.

Trivedi and Misra (1970) described a spore-pollen assemblage dominated by striate-bisaccate pollen from sediments near Nidpur and considered this deposit to be of Triassic age. But Srivastava (1974b) placed this palynoflora in Permian because of the total lack of *Dicroidium* leaves and other notable palaeofloral elements of *Dicroidium*-beds of Nidpur. Roychowdhury *et al.* (1975) were also of the same view and ruled out the possibility that two miofloras (Bharadwaj & Srivastava, 1969; Trivedi & Misra, 1970) are different expressions of same. Later, Banerji and Maheshwari (1974, 1975) and Pant and Pant (1987) also supported Srivastava's (1974) view for the age of the miofloral assemblage.

After this definitive Triassic palynofloral investigation of Nidpur, Panchet palynoflora could readily be differentiated from Nidpur palynoflora, because the palynofloral assemblage from Nidpur is characterized by virtual non-existence of triletes and preponderance of various kinds of gymnospermous pollen grains (Bharadwaj, 1970). The author placed Nidpur assemblage in Upper Panchet and pointed out that the palynoflora from Nidpur is fairly distinct from Lower Panchet and Upper Raniganj stages. This miofloral demarcation contradicts the view of Balme (1969) that Dicroidium Flora did not become firmly established until late Lower Triassic. However, Balme (1970) while dealing with palynology of Permian and Triassic strata in Salt Range, Pakistan, assigned late Early Triassic age to Nidpur beds because of the profuse occurrence of costate form *Weylandites*. But abruptly in the conclusion and comparative account of various Permian-Triassic assemblages he considered Nidpur palynoassemblage to be Late Permian.

Also Anderson and Anderson (1970) reviewed closely the palynoflora from Nidpur and considered it comparable with that from Lower Panchet (Chart 19; and in 1980, fig. 3), that is, from *Faunipollenites* (=*Protohaploxypinus reticulatus*) Zone in the lower most Narrabeen Group of Sydney Basin, Australia (dated as Late Permian, Helby, 1973; Balme & Helby, 1973). However, in Nidpur as the frequency of *Faunipollenites* is quite low and quantitatively insignificant, its comparison with lowermost Narrabeen Group does not appear to be justified.

Srivastava (1974b) while reviewing Triassic miofloristics of India, assigned Nidpur beds within Panchet Stage. Maheshwari (1974a, 1974b) expressed similar view for the placement of Nidpur beds with the rocks of Panchet Group. Banerji and Maheshwari (1974), Maheshwari and Banerji (1975) and Banerji and Maheshwari (1975) differentiated Nidpur palynoflora from miofloral assemblages of Maitur Formation and because of the paucity of striate bisaccate grains opined that Nidpur beds are definitely younger than Panchet Group. Bharadwaj and Tiwari (1977) while studying Permian-Triassic transition in Raniganj Coalfield, have also opined Nidpur mioflora to be younger than that of Panchet.

But Venkatachala (1978) contemplated Nidpur palynoassemblage to be a continuation of Raniganj palynoflora. However, the systematic analysis has shown, within reason, that the transition from Permian to Triassic was a gradual one with a number of palynomorphs persisting relatively unchanged into the Triassic. Striated-bisaccate form is one such example. Although these forms are represented in small quantities, yet they reflect a wider range for the plant taxa which might have borne them. These forms continued from Raniganj through Panchet where their frequency was quite high, into Nidpur. Thus, Nidpur flora was composed of residual Palaeozoic taxa in association with characteristic forms of Triassic and newer types evolved. This gradual appearance of new elements reflects towards the advancing and developing nature of vegetation.

However, now it is quite apparent that the non-striate bisaccate grains attained potential value during Triassic and corroborate megafloristic evidence and show that gymnosperms were the main constituents of Nidpur vegetation except for occasional intrusion of Late Permian plant *Glossopteris* and re-emergence of some lower plant group. Now since the chief palynofossils of Nidpur that is *Nidipollenites, Satsangisaccites, Weylandites, Praecolpatites, Platysaccus queenslandii, Alisporites indicus* and *Aumancisporites* have attained stratigraphic significance, henceforth, to ascribe an Upper Permian age to Nidpur beds without presenting any reason is not justified.

Further, Maheshwari and Kumaran (1979), Kumaran and Maheshwari (1980) while dealing with the sporae-dispersae of Son River Section (Giar) and Janar Nala Section (Harai) have expressed their view that the time gap between Pali and Tiki Formation (=Anisian-Early Carnian) is probably represented by Nidpur beds which have been taken as representing the lower part of Tiki Formation (Roychowdhury *et al.*, 1975). They also brought Janar Nala (Harai) palynoflora much closer to Nidpur palynoflora by showing dominance of *Satsangisaccites* in both the assemblages because the later is distinguished by its occurrence in the assemblage and rest other palynomorphs of Nidpur are represented in Janar Nala in varying composition. But *Weylandites*, a striate-colpate taxon which is fairly frequent in Nidpur is conspicuously absent in Janar Nala assemblage.

Upon the palynologic zonation Sundaram *et al.* (1979) have grouped Nidpur beds under Middle Triassic (Table 2). They supported Roychowdhury *et al.* (1975) and have ruled out the possibility of Nidpur being younger than Middle Triassic. But from palynological stand point, Tiwari and Rana (1980) by equating *Goubinispora* with that of *Trochosporites* (*Trochosporites* sp. reported from Nidpur by Bharadwaj & Srivastava, 1969) showed the occurrence of this miospore genus in Nidpur palynoflora as well in bore-hole of East Raniganj. They also pointed out that *Goubinispora* represents a declining phase at Nidpur whereas in Middle Triassic palynofloral assemblage recovered from bore-hole, the palynotaxon was quite prolific. With this observation they dated Nidpur at younger level than Anisian, i.e., Carnian (early Late Triassic) and further reasoned out that Nidpur mioflora reveals no continuity with late-Early Triassic assemblage.

Sarbadhikari (1974, 1979) maintained the view that Nidpur belongs to Lower Panchet, to the *Glossopteris-Dicroidium* transitional Zone because its lithology does not match with the parent horizon (Panchet) where carbonaceous bands are practically unknown. Therefore, the author safely concluded that Nidpur *Dicroidium* since are preserved in carbonaceous shale might well be in uppermost Permian and thus was sceptical for the post-Raniganj status for Nidpur and consequently, correlated Nidpur *Dicroidium* with the occurrence of *Dicroidium* in the lowermost Narrabeen-strata of Australia.

However, findings of carbonaceous matter in Triassic sediments of Nidpur is not all new because similar floral assemblages preserved in carbonaceous shale have been reported from Triassic deposits of Gondwana countries. Further, Nidpur flora is full of *Dicroidium* leaves associated with its fertile organs and documents a wide spread in Upper Scythian-Anisian-Ladinian units. At Nidpur *Glossopteris* is in dwindling stage because the species met are reduced in number, size and shape and are in a very fragmentary state. Thus the continuity of *Glossopteris* in low frequency at Nidpur points out that the genus is long ranging and thereby loses its stratigraphical significance.

This could be further proven by another line of evidence like palaeoclimatic conditions which reveal that the relatively better Triassic floral assemblages occur in late Early to Middle Triassic (Late Scythian-Anisian-Ladinian) because of Permian climatic conditions which must have lingered on into the Triassic; similar conditions must have been prevailing in Nidpur (Lele, 1976) for the luxuriant growth of plants.

CONCLUDING REMARKS

Mega- and palyno- floral data from Nidpur are complementary and largely compatible. The synthesis of available data and comparative account with other Triassic floras known from India and other Gondwana continents reflect that in its qualitative or quantitative composition, Nidpur fossil flora does not fully agree either with the floral assemblage of Panchet Formation dominated by

Glossopteris or with the Upper Tiki and Parsora formations exhibiting Late Mesozoic plants *Pterophyllum, Elatocladus, Pagiophyllum* and *Desmiophyllum.* However, Nidpur palaeofloral assemblage differs substantially in richness of *Dicroidium* and pollen genera, chiefly *Nidipollenites, Satsangisaccites, Alisporites* and *Weylandites* as compared to other Triassic formations of India. But these genera so characteristic of Nidpur are also well represented in Middle-Upper Triassic floras of Gondwana countries.

Unequivocally, with the balanced floristic picture provided by megaplant studies, stratigraphic position of Nidpur beds between that of Panchet and Parsora Formation is favoured and a Middle Triassic age (=Anisian-Ladinian) is supported.

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Floristic zones in the Mesozoic formations and their relative age

Sukh-Dev

Sukh-Dev (1988). Floristic zones in the Mesozoic formations and their relative age. *Palaeobotanist* **36** : 161-167.

Through a comprehensive analytical study of the Indian Mesozoic flora and synthesis of the available data 12 assemblage zones and a floral succession are established. These assemblage zones also extend into the Early Cretaceous flora in the neighbouring countries: Pakistan, Nepal, Bhutan and Sri Lanka. The Gondwana Triassic elements and the European Jurassic-Cretaceous elements in the flora are highlighted. The inter-relationship of the Mesozoic floras of Gondwanaland, European and Asian countries is examined. The relative age of the biozones is worked out on the basis of plant megafossils, palynology, palaeontology, stratigraphy and radiometry. It is suggested that the concept of Gondwana be replaced by chronostratigraphic terms, viz., Triassic, Jurassic and Cretaceous for the Indian Mesozoic sediments.

Key-words—Floristics, Biostratigraphy, Phytogeography, Mesozoic (India).

साराँश

मध्यजीवी शैल-समूहों में वनस्पतिजातीय मंडल तथा इनकी आयु

सुख-देव

भारतीय मध्यजीवी वनस्पतिजात के गहन विश्लेषणात्मक अध्ययन तथा उपलब्ध आँकड़ों के संश्लेषण से 12 समुच्चय मंडल एवं एक वनस्पतिजातीय अनुक्रम स्थापित किये गये हैं। ये समुच्चय मंडल पड़ोसी देशों—पाकिस्तान, नेपाल, भूटान एवं श्रीलंका—के प्रारंभिक क्रीटेशी वनस्पतिजातों में भी विस्तृत हैं। उपलब्ध वनस्पतिजात में गोंडवाना त्रिसंघी अवयवों एवं यूरोपीय जूराई-क्रीटेशी अवयवों पर भी प्रकाश डाला गया है। गोंडवानाभूमि, यूरोपीय एवं एशियाई देशों के मध्यजीवी वनस्पतिजातों की अन्तरबन्धुता का अध्ययन किया गया है। गुरु-पादपाश्मों, परागाणविक अध्ययन, पुरातात्विक अध्ययन, स्तरिकी एवं रेडियोमितीय कालनिर्धारण के आधार पर जैवमंडलों की आयु भी प्रस्तावित की गई है। यह प्रस्तावित किया गया है कि भारतीय मध्यजीवी अवसादों के लिए गोंडवाना अवधारणा को कालानुक्रमिक शब्दों अर्थात् त्रिसंघी, जूराई एवं क्रीटेशी से प्रस्थापित किया जाना चाहिये।

SINCE the initiation of study of the Indian Mesozoic flora in the middle of the 19th Century plant megafossils have been systematically described and illustrated from Early Triassic to Early Cretaceous sediments. These plants represent algae, bryophytes, pteridophytes (Isoetaceae, Equisetaceae, Marattiaceae, Osmundaceae, Matoniaceae, Weichseliaceae, Dipteridaceae, Aspidiaceae, Cyatheaceae, Dicksoniaceae, Dennstaedtiaceae, Gleicheniaceae, Schizaeaceae and Azollaceae), pteridosperms, glossopterids, cycadophytes, ginkgophytes, Caytoniales, Pentoxyleae and conifers. From time to time biozonation of the Mesozoic sediments based on plant megafossils has been attempted (Shah *et al.*, 1971) but with limited success. Here a synergistic analysis of Indian Mesozoic floral assemblages has been attempted to clearly demarcate the floristic zones and their relative age.

Anomalies regarding the age and position of various formations are resolved to a great extent. The Bhuj, Gangapur, Jabalpur, Rajmahal and East

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Coast sediments, hitherto considered Jurassic on the evidence of megaflora, are assigned an Early Cretaceous age on the basis of palynology, palaeontology and radiometric dating (Biswas, 1977; Venkatachala & Kar, 1970; Bose *et al.*, 1982; Mc Dougall & McElhinny, 1970; Agarwal & Rama, 1976; Arkell, 1956; Bose & Dev, 1959; Singh, 1966). The presence of *Weichselia* and *Onychiopsis* plants in the Bansa sediments indicating an Early Cretaceous age is confirmed.

FLORISTIC ZONES AND THEIR AGE

1. *Lepidopteris-Dicroidium-Glossopteris* Assemblage Zone

The Panchet Group assemblage is characterized by the appearance of the genera *Lepidopteris* and *Dicroidium*. The other elements of the assemblage are *Trizygia, Schizoneura, Cladophlebis, Neomariopteris, Cyclopteris, Sphenopteris, Glossopteris, Vertebraria, Taeniopteris, Macrotaeniopteris, Podozamites, Pseudoctenis, ?Pterophyllum, Noeggerathiopsis, Samaropsis*, etc. In this assemblage *Glossopteris* is represented by about 5 species. Species of *Lepidopteris* and *Dicroidium* increase in number in the upper part of the group.

Age—Early Triassic

Occurrence :

—Raniganj Coalfield (Banerji & Bose, 1977).
—Auranga Coalfield (Bose & Banerji, 1976).
—Ramkola-Tatapani Coalfield (Bose *et al.*, 1977).
—Daigaon Formation, Madhya Pradesh (Lele, 1969).

2. *Gopadia-Glottolepis-Dicroidium* Assemblage Zone

The Triassic rocks on the west bank of Gopad River near Nidpur Village (24°7'N : 81°54'E) comprise mainly of carbonaceous shales with micaflakes and micaceous fine grained sandstones. Plant fossils from these beds were first reported by Satsangi (1964). Subsequently an interesting rich flora preserved as compressions has been described by various workers. This plant assemblage is dominated by leaves of *Dicroidium*. *Glossopteris* is less common, represented by smaller and narrower forms. Scale-leaf *Glottolepis* and *Taeniopteris* are quite common. The other elements are *Algacites, Hepaticites, Sphagnophyllites, Rhabdotaenia, Lepidopteris, Bosea, Pteruchus, Marhwaseaphyllum, Rewaphyllum, Nidia, Sidhiphyllites, Nidistrobus, Nidpuria, Lelestrobus, Conites, Gopadia, Satsangia, Chakrea, Rugatheca, Rugaspermum*, etc. (for references see Srivastava, 1988, this Volume).

Age—Middle Triassic.

Remarks—The plant assemblage from Nidpur represents a more evolved flora than that of the Panchet. The palynoflora also corroborates the magaflora (Bharadwaj & Srivastava, 1969) in having dominance of nonstriate-bisaccate pollen grains.

3. *Pagiophyllum-Elatocladus-Dicroidium* Assemblage Zone

In the plant assemblage of Tiki Formation (named after the village Tiki (23°56'N : 81°22'E) the genus *Dicroidium* is commonly met with. This assemblage is marked by the appearance of new elements like *Pagiophyllum, Elatocladus, Yabeiella, Xylopteris, Sphenobaiera* and *Baiera*. Other elements are *Lepidopteris* and *Desmiophyllum* (Pal, 1984b).

Age—Late Triassic.

Remarks—In the plant assemblage recovered from near Giar from Son River Section the genera *Elatocladus* and *Pagiophyllum* are commonly found, whereas these are absent in the Harai plant assemblage obtained from Janar River Section. The Giar Assemblage seems to be younger than that from Harai. In the Tiki Formation are also found *Mesembrioxylon malerianum* woods, vertebrates and unionid *Tikkia* (Shah *et al.*, 1971).

4. *Marattiopsis-Pterophyllum-Dicroidium* Assemblage Zone

This assemblage comes from the Parsora Formation, named after the village Parsora (23°26' N : 81°06' E) in Shahdol District, Madhya Pradesh. It is characterized by the appearance of the genera *Marattiopsis, Danaeopsis* and *Parsorophyllum*. The genus *Dicroidium* is fairly well-represented. The other constituents are *Pterophyllum, Ginkgoites* and *Desmiophyllum*, etc. (Lele, 1956, 1962a-b, 1969).

Age—Late Triassic.

Remarks—The Parsora Formation overlies Tiki Formation as observed in Bamandev Hill Section (Sahni & Rao, 1956).

5. *Brachyphyllum-Pagiophyllum-Desmiophyllum* Assemblage Zone

The plant assemblage of Hartala Formation developed near Hartala Village (23°49'29" N : 81°15'11" E), Shahdol District, Madhya Pradesh comprises *Brachyphyllum, Pagiophyllum* and *Desmiophyllum*.

Age—Early Jurassic.

Remarks—The Hartala Formation overlies the Tiki Formation. The plant fossils are preserved in white or pinkish white shales (Pal, 1984a). So far, the Triassic genera *Lepidopteris* and *Dicroidium* are not known in the Hartala Formation. *Pagiophyllum* is most common. The genus *Brachyphyllum* is not found in Tiki and Parsora formations. On the basis of plant fossils and lithology of sediments the Hartala Formation is considered as Early Jurassic.

6. *Hausmannia-Ptilophyllum-Araucarioxylon* Assemblage Zone

The floral assemblage of the Kota Formation named after the village Kota (18°55′N : 80°02′ E) on the east bank of the river Pranhita, is rich in conifer woods comprising *Araucarioxylon, Podocarpoxylon, Cupressinoxylon* and *Taxaceoxylon*. Among them Ginkgoalean wood, *Ginkgoxylon* is also present. The other constituents of the flora are represented by impressions of *Equisetites, Cladophlebis, Hausmannia, Sphenopteris, Otozamites, Ptilophyllum, Elatocladus, Brachyphyllum* and *Pagiophyllum*.

The significance of presence of Rajmahal woods *Araucarioxylon santalense, Podocarpoxylon rajmahalense* and *Taxaceoxylon* cf. *T. rajmahalense* in the Kota flora can not be fully assessed at present.

Age—Middle Jurassic (or slightly younger).

Remarks—The Kota Formation is characterised by limestone band, grits of light brown colour with red clay bands and sandstones. Carbonaceous clays are also present. It underlies Early Cretaceous Gangapur Formation. The age of the Kota Formation is considered Liassic on fish evidence, but on discovery of Ostracod the age is extended to Early Middle Jurassic (Govindan, 1975). Palaeobotanical data, particularly the fossil woods show clear affinity with the Rajmahal flora (Rajanikanth & Sukh-Dev, in Press). In view of the present palaeobotanical findings more work is called for on the Kota Formation for knowing its real position.

7. *Pachypteris-Cladophlebis daradensis* Assemblage Zone

The Jhuran Formation in Kutch Basin has yielded an assemblage of plant fossils consisting of *Cladophlebis daradensis, Pachypteris indica, P. specifica, Pagiophyllum chawadensis* and *Cladophlebis* species. At present the flora of the Jhuran Formation is not sufficiently known for dating purpose.

Age—Late Jurassic (Tithonian).

8. *Dictyozamites-Pterophyllum-Anomozamites* Assemblage Zone

The Chaugan sediments of Jabalpur Formation in Madhya Pradesh exposed from Morand River to Imjhiri show dominance of cycadophytes over pteridophytes and conifers. The cycadophytes are constituted by *Ptilophyllum, Pterophyllum, Dictyozamites, Anomozamites, Ctenis* and Taeniopteris.

The pteridophytes are represented by *Equisetites Gleichenites, Hausmannia Cladophlebis*, pteridosperms by *Pachypteris*; ginkgophytes by *Ginkgo* and conifers *Araucaria, Pagiophyllum, Brachyphyllum, Elatocladus, Moranocladus* and *Araucarites* (Bose & Banerji, 1981; Bose & Zeba-Bano, 1978; Sukh-Dev & Zeba-Bano, 1980, 1981b; Zeba-Bano 1979).

Age—Early Cretaceous.

Occurrence:

—Chaugan Reserve Forest, Madhya Pradesh (Crookshank, 1936).

—Bhuj Formation—Assemblage 1, Kutch (Bose & Banerji, 1984).

—Pariwar Formation, Rajasthan (Bose *et al.*, 1982).

—Sarnu Hill Formation, Rajasthan (Baksi & Naskar, 1981; Banerji & Pal, 1986).

—Dubrajpur Formation (Upper beds); Rajmahal Formation—Assemblage 1, Bihar (lower 3 intertrappean beds between lava flows 1-4) (Bose & Sah, 1968; Sharma, 1969, 1971, 1975; Zeba-Bano *et al.*, 1979).

—Sivaganga Formation, Tamil Nadu (Maheshwari, 1986; Sukh-Dev & Rajanikanth, in Press);

—Kagbeni beds, Thakkhola Valley, Nepal (Barale *et al.*, 1978).

—Taltung Formation, Palpa District (Kimura *et al.*, 1985).

—Tabbowa beds, Sri Lanka (Sitholey, 1944).

Remarks—The Chaugan sediments lie unconformably over Triassic Denwa and Bagra sediments and are overlain unconformably by the Deccan Traps or the Lametas (Crookshank, 1936). The plant assemblage of the Chaugan sediments is essentially similar to Assemblage 1 of Rajmahal Formation, the lower traps of which are dated 100-105 million years (reliable minimum age, McDougall & McElhinny, 1970). Considering that this is the minimum age limit, it is not inconsistent with the present conclusion in as much as the age may be older than 105 Ma. McDougall and McElhinny (1970, p. 374) have admitted the possibility of the Early Cretaceous age for these traps. Further, no angiosperm is obtained so far from the floras of these intertrappean sediments nor from the similar floras as mentioned above in other parts of the country under the assemblage no. 8. Therefore lack of angiosperm also indicates that these floras are older than 105 Ma, i.e., Albian. Moreover, this assemblage no. 8 is also older than the succeeding assemblages nos. 9 and 10 which also lack angiosperms.

9. *Allocladus-Brachyphyllum-Pagiophyllum* Assemblage Zone

The plant assemblage recovered from the sediments exposed on the Sher River near the village Sehora (22°52′ N : 79°21′ E), Narsinghpur District, Madhya Pradesh shows richness of conifers, less cycadophytes and pteridophytes. In this assemblage *Onychiopsis, Doratophyllum, Allocladus* and *Satpuria* are new entrants. This assemblage includes flora of closeby areas of Hard River near Hasnapur and Jabalpur as well. This assemblage has rich representation of *Pachypteris, Ptilophyllum, Allocladus, Brachyphyllum* and *Pagiophyllum* (Sukh-Dev & Zeba-Bano, 1978, 1979, 1081a,b).

Age—Early Cretaceous

Occurrence :

—Jabalpur Formation, Sehora on Sher River, Narsinghpur District, Madhya Pradesh.

—Bhuj Formation—Assemblage 2, Kutch (Bose & Banerji, 1984) (Trambau, Sukhpur, Dharesi)

—Gangapur Formation—Assemblage 1, Andhra Pradesh (Bose *et al.*, 1982; Sukh-Dev & Rajanikanth, 1988).

—Rajmahal Formation—Assemblage 2, Bihar (Nipania flora, between lava flows 4-5) (Mittre, 1957-1958a-b).

—Golapalli, Raghavapuram, Budavada and Vemavaram formations, Andhra Pradesh (Feistmantel, 1877, 1879; Baksi, 1964, 1968; Sastri *et al.*, 1977).

—Sriperumbudur Formation, Tamil Nadu (Feistmantel, 1877, 1879; Baksi, 1964, 1968; Sastry *et al.*, 1977).

—Sakesar beds, Salt Range, Punjab, Pakistan (Sahni & Sitholey, 1945).

—Lingshi Group—Bhutan (Ganesan & Bose, 1982).

Remarks—In this assemblage genus *Onychiopsis* is an important taxon as it was of world-wide distribution during the Early Cretaceous time. A caution is to be exercised in assigning Wealden age on the basis of *Onychiopsis* as it occurs in the Middle Jurassic in Israel (Lorch, 1967), Late Jurassic in Madagascar (Appert, 1973), Middle Jurassic to Early Cretaceous in Japan (Kimura & Aiba, 1986) and Late Cretaceous (Cenomanian, Velenovsky, 1888) in Czechoslovakia. Regarding the age of the present assemblage the Bhuj Formation (Ukra Member) is dated 112 ± 15 million years (Srivastava & Rajagopalan, 1985) which covers this assemblage. On the basis of foraminifera Raghavapuram Formation is considered Barremian, similar to Vemavaram and Sriperumbudur formations (Sastry *et al.*, 1977).

10. *Weichselia-Onychiopsis-Gleichenia* Assemblage Zone

The sediments around the village Bansa (23°36′45″ N : 80°39′20″ E) of Jabalpur Formation in Shahdol District, Madhya Pradesh are marked by richness of pteridophytes and conifers, reduction of cycadophytes and pteridosperms. This plant assemblage is characterized by frequent occurrence of *Weichselia, Onychiopsis, Phlebopteris, Hausmannia, Cycadopteris* and proliferation of *Gleichenia, Araucaria, Allocladus, Brachyphyllum* and *Pagiophyllum* (Bose & Dev, 1960, 1972; Sukh-Dev, 1970; Sukh-Dev & Bose, 1974; Sukh-Dev & Zeba-Bano, 1977).

Age—Early Cretaceous (Aptian-Albian)

Occurrence :

—Jabalpur Formation, Bansa, Shahdol District, Madhya Pradesh.

—Dhrangadhra Formation (Borkar & Chiplonkar, 1973; Kumaran *et al.*, 1983).

—Gardeshwar Formation (Bose *et al.*, 1983).

—Himmatnagar Formation (Banerji *et al.*, 1983).

—Gangapur Formation—Assemblage 2, Andhra Pradesh (Sukh-Dev & Rajanikanth, 1988).

—Athgarh Formation, Orissa (Patra, 1973, 1980).

—Tirupati Formation, Andhra Pradesh.

—Pavalur Formation, Andhra Pradesh.

—Satyavedu Formation, Tamil Nadu.

Remarks—Genus *Weichselia* is an important Early Cretceous plant. In Europe, this genus occurs from Neocomian to Albian. The *Weichselia*-bearing floras are known mostly from Early Cretaceous, then tropical-subtropical regions as southern Europe, Moscow Basin, western Siberia Depression, Chuskhakul Hills, southern Primorye, North America, Peru, Middle East, China, India and Japan (Vakhrameev, 1964; Sukh-Dev, 1970; Kimura & Aiba, 1985). In India *Weichselia* is known from Bansa (Madhya Pradesh), Himmatnagar and Songad (Gujarat).

The Pavalur, Satyavedu and Tirupati formations are considered Aptian on the faunal evidence and their stratigraphical position (Sastry *et al.*, 1977).

11. *Azolla* Assemblage Zone

The Lameta Group developed near the village Dongargaon in Chandrapur District, Maharashtra has yielded a couple of fertile organs of *Azolla* and some other plant remains.

Age—Late Cretaceous (Maastrichtian).

Remarks—From the Lameta clays near the village Dongargaon in Maharashtra fertile organs of *Azolla* and some fragmentary plant remains have been recovered. The clay samples were collected by Dr S. L. Jain. Spores of *Azolla* (*A. cretacea*) are reported from the Maastrichtian subsurface samples in Cauvery Basin (Venkatachala & Sharma, 1982). *Azolla* is also known from the Deccan Intertrappeans (Sahni, 1941; Trivedi & Verma, 1971). The trap samples overlying the fauna and plant-bearing beds are dated 66.2 ± 3.9 million years (Besse *et al.*, 1985). Thus the age of these Lameta sediments is Maastrichtian. Vertebrates including fish, turtles and dinosaurs have been reported from these sediments indicating a probable continental facies (Berman & Jain, 1982). The presence of *Azolla* plants in the clay beds indicates a fresh-water lacustrine environment.

12. *Raphaelia-Piazopteris-Acrostichopteris* Assemblage Zone

The plant assemblage from Fukche, Ladakh in Kashmir is constituted by *Raphaelia, Piazopteris, Acrostichopteris, Taeniopteris, Nilssonia, Cycadites, Pterophyllum, Anomozamites, Ptilophyllum* and few other plants (Bose *et al.*, 1983).

Age—Middle-Late Jurassic.

Remarks—The plant assemblage does not resemble any one known from India, Pakistan, Nepal, Bhutan or Sri Lanka. It rather resembles Eurasian flora. Therefore it is treated here separately from the mainstream Indian floras.

DISCUSSION

A study of Indian Mesozoic plant assemblages clearly demonstrates that the Indian Mesozoic flora owes its origin to two stocks; namely the Gondwana Stock and the Eurasia Stock. Most of the elements of the flora are of the Gondwana Stock that flourished in central, western and eastern parts of India and extended into Pakistan, Nepal, Bhutan and Sri Lanka. Contemporary flora of Ladakh (Middle-Late Jurassic) also flourished on the southern edge of Eurasia.

The development of the Mesozoic flora from the Gondwana Stock has been gradual as is evidenced by the rise, climax and fall of *Dicroidium* and its associates. The *Glossopteris* and its associates also disappeared from the scene in Late Triassic. At this time the floral elements in the Indian Triassic, viz., *Marattiopsis, Danaeopsis, Cladophlebis, Sphenopteris, Taeniopteris, Macrotaeniopteris, Pseudoctenis, Pterophyllum, Ginkgoites, Desmiophyllum, Baiera, Pagiophyllum, Elatocladus*, etc. (Assemblages 1, 2, 3 and 4) rapidly underwent the process of diversification and amplification and gained prominence in the Jurassic-Early Cretaceous times (Interestingly, these Triassic elements were also world-wide in distribution, though their representations varied). As the Indian Plate moved from southward towards North and came in close proximity of the European flora, a distinct Indo-European Palaeofloristic Province emerged, extending from Europe via India, South China, Far East to Japan during Jurassic to Early Cretaceous. At that time the European elements like *Thinnfeldia, Cycadopteris, Weichselia*, etc. entered the Gondwana flora of India, through the European, Middle East and closeby African lands and later possibly from Far East on coming closer to these countries. Many plants or plant groups common to both the regions as mentioned above during the Triassic Period developed possibly by homoplasy and later by intermingling of their floras. This Indo-European Palaeofloristic Province had predominant development of Marattiaceae, Osmundaceae, Gleicheniaceae, Matoniaceae, Dipteridaceae, numerous Cycadales, Bennettitales, conifers with scale-like leaves and some ginkgophytes. The exclusive elements of the European flora were members of the family Pinaceae, and that of the Indian flora were members of Podocarpaceae and Pentoxyleae (Pentoxyleae were also present in Australia and New Zealand), whereas Araucariaceae, Taxaceae and possibly Cupressaceae were common to both the floras. Palaeogeographically this flora flourished in the tropical to subtropical climate. The xeric characters of the plants are indicated by the presence of small dissected leaves, thick cuticle, leathery texture of leaves with sunken stomata, hairs and papillae. The dry conditions are also exhibited by the presence of red beds in the Indo-European Palaeofloristic Province. Thus the Jurassic-Early Cretaceous flora of India contains a mixture of European as well as Gondwana elements. Precise determination of the Gondwanic and European elements in the mixed floras poses a big problem as identifications in several cases are doubtful and the floras are not adequately known. Therefore it is necessary to study the mixed floras in depth, keeping in mind the palaeogeographic position of the plates affecting global migration of floras before a tangible conclusion can be drawn on the Gondwanic and non-Gondwanic elements in the Indian flora.

By the end of Early Cretaceous the complexion of the Indo-European Palaeofloristic Province distinctly changed. A large majority of the elements of this flora suddenly vanished and paved a way for the rise and spread of the angiosperms. The Late Cretaceous flora of India then assumed a new dimension, leading to the development of the modern flora. It is interesting to note that this flora has continued to maintain its Indo-European heritage till today, i.e., it has the following families still growing in India: Lycopodiaceae, Selaginellaceae, Isoetaceae, Equisetaceae, Marattiaceae, Osmundaceae, Matoniaceae, Dipteridaceae, Gleicheniaceae, Aspidaceae, Cyatheaceae, Dicksoniaceae, Dennstaedtiaceae, Schizaeaceae and Azollaceae among pteridophytes: Cycadaceae (*Cycas*) among cycadophytes; Podocarpaceae (*Podocarpus*) and Cupressaceae (*Cupressus* and *Juniperus*) among conifers; and Taxaceae (*Taxus*) among taxads.

A restudy of the Indian Mesozoic flora clearly shows that it has been recovered from the continental, marine and transitional strata of the so-called 'Gondwana'. This prompts me to review the original definition of the 'Gondwana' according to which these sediments were laid under continental conditions (fluvitiale/lacustrine). Subsequently several marine intercalations have also been included in the Gondwana System expanding its original concept to a degree of its being untenable. Therefore, it is concluded that the term 'Gondwana' be replaced by the chronostratigraphic units, viz., Triassic, Jurassic, and Cretaceous for the Indian Gondwanic sediments.

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Upper Jurassic—Lower Cretaceous spore-pollen assemblages in the peninsular India

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Singh, H. P. & Venkatachala, B. S. (1988). Upper Jurassic-Lower Cretaceous spore-pollen assemblages in the peninsular India. *Palaeobotanist* **36** : 168-176.

The Upper Jurassic-Lower Cretaceous spore-pollen assemblages recovered from the 'Upper Gondwana' sediments in the western, central, southern and eastern parts of the country have been reviewed. Palaeontological geological, tectonic and environmental evidences have been used for reinterpretation of palynological data. Stratigraphically important palynotaxa have been identified. The occurrence of continental Jurassic assemblages has not been considered authentic. The usage of term 'Gondwana' for continental as well as paralic sediments has been questioned. Distribution of some significant Gondwanic elements has been highlighted.

Key-words—Palynology, Stratigraphy, Upper Gondwana, Upper Jurassic, Lower Cretaceous, Peninsular India.

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साराँश

प्रायद्वीपीय भारत में उपरि जूराई-अधरि क्रीटेशी परागकण-बीजाणु समुच्चय

हरिपाल सिंह एवं बेंगलूर श्रीनिवासा वेंकटाचाला

देश के पश्चिमी, मध्य, दक्षिणी एवं पूर्वी भागों में उपरि गोंडवाना अवसादों से उपलब्ध उपरि जूराई-अधरि क्रीटेशी बीजाणु-परागकण समुच्चयों का पुनरीक्षण किया गया है। पुरातात्विक, भूवैज्ञानिक, विवर्तनिक एवं वातावरणीय प्रमाणों का उपयोग परागाणविक आँकड़ों की पुर्नव्याख्या करने में किया गया है। स्तरिक दृष्टि से महत्वपूर्ण परागाणुवर्गक अभिनिर्धारित किये गये हैं। अलवणीय जूराई समुच्चयों की उपस्थिति प्रामाणिक नहीं मानी गई है। अलवणीय एवं तलांचली अवसादों के लिए 'गोंडवाना' शब्द के प्रयोग पर प्रश्न लगाया गया है। इसके अतिरिक्त कुछ विशिष्ट गोंडवानी अवयवों के वितरण पर प्रकाश डाला गया है।

THE Upper Mesozoic rocks are well-developed in the peninsular India and are exposed in the western, central and eastern parts of the country. They are normally termed as 'Upper Gondwana'. These sediments were laid under varied environments of deposition (marine, estuarine, continental and intertrappean). In the western part of India, Upper Mesozoic sediments depict continental as well as estuarine facies (Kutch, Kathiawar and Jaisalmer basins) whereas in the central and eastern parts of the country deposits of mainly continental facies were laid (Satpura, South Rewa basins and Pranhita-Godavari Graben).

The Rajmahal Basin (Bihar) witnessed intermittent igneous activity resulting in the deposition of several lava flows. Intertrappean sequences hold a treasure of fossilised vegetation. The isolated patches of Upper Mesozoic sediments are also exposed along the east coast in Mahanadi, Cauvery, Krishna-Godavari and Palar basins.

Palynological information is known from most of the Upper Jurassic-Lower Cretaceous sediments.

Concepts, limits and extension of the Indian Gondwana
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Palynotaxa, in general, are easily identifiable as they possess distinctive morphological characteristics. Since most of the Upper Jurassic-Lower Cretaceous assemblages are grossly similar in composition, diverse opinions have been expressed in regard to age assignments of the 'Gondwana' sequence. The problem of dating known palynoassemblages is rendered difficult as many of them are not defined with respect to stratigraphic columns, thus their position in the Jurassic-Cretaceous sequence cannot be firmly established. In order to resolve some of these problems, the published palynological data have been comprehensively reassessed. Palaeontological, geological, tectonic and environmental evidences have been used as corroborative factors in deciphering stratigraphic position. Several stratigraphically important fern palynotaxa have been identified and used as workable parameters in distinguishing the Upper Jurassic-Lower Cretaceous assemblages. The occurrence of inland Jurassic continental sediments has been questioned. It has been observed that palynoassemblages of east coast of India and Western Australia are closely comparable. It has also been suggested to restrict the use of the term 'Gondwana' to a geographical context rather than to a stratigraphical one.

The status of Upper Jurassic-Lower Cretaceous spore-pollen assemblages recorded from the 'Upper Gondwana' sediments well-developed in the western, central, southern and eastern parts of the country, are reviewed. Emphasis has been laid to determine the qualitative changes occurring in the composition of the assemblages across the boundary, however, imperceptible they may appear to be numerically. It has been essential to follow this approach as the Early Cretaceous assemblages mostly exhibit a continuum of the Upper Jurassic palynoflora. Palynotaxa like *Araucariacites, Callialasporites* and *Podocarpidites* tend to dominate the assemblages across the boundary.

The Neocomian strata are distinguished by the presence of (incoming) cryptogamic spores, viz., *Cicatricosisporites, Impardecispora, Aequitriradites, Crybelosporites, Cooksonites, Foraminisporis, Contignisporites, Densoisporites, Haradisporites, Lametatriletes, Coptospora, Appendicisporites, Boseisporites, Coronatispora* and by the dominance of some gymnospermous pollen like *Microcachryidites* and *Podosporites*. The other Late Jurassic fossils continue into the Neocomian.

The appearance of *Weichselia* and *Onychiopsis* was considered as infallible megafloral evidences to date the Lower Cretaceous sediments (discussed by Sukh-Dev, 1988, this Volume). The report of ammonite fauna (Spath, 1933) from the east coast 'Gondwana' and its further study by Arkell (1956) who dated them as Early Cretaceous expressed serious doubt on the occurrence of Jurassic in the east coast of India. Since then, this problem has continued to attract attention of stratigraphers (The problems involved with marine intercalations or marine strata in the east coast are further discussed by Venkatachala and Rajanikanth, 1988, this Volume). Distribution and role of the Upper Mesozoic palynological assemblages recovered from the marine/non-marine and surface/subsurface material in deciphering environment of deposition and the time of deposition in different basins/grabens of the country need be reassessed to resolve 'The Upper Gondwana' problem in the country.

KUTCH BASIN

The Upper Jurassic-Lower Cretaceous assemblages have been studied from the Kutch Basin by Singh *et al.* (1964), Venkatachala (1967, 1969a, 1969b, 1970), Venkatachala and Kar (1967, 1968a, 1968b, 1970, 1972), Venkatachala *et al.* (1969a, 1969b, 1969c), Venkatachala and Rawat (1972), Rawat (1969, 1976) and Koshal (1975). Dependable palynological information on Upper Jurassic-Lower Cretaceous boundary has been provided by Venkatachala and Kar (1970) from the Jhuran/Bhuj formations in the Kutch Basin.

Biswas (1971) has recognized four lithological units in the Kutch mainland of which the assemblages reported from the Jhuran Formation (= Katrol Formation, Kimmeridgian—Valanginian) and Bhuj Formation (= Umia Formation, Valanginian-Aptian) have been reviewed to determine compositional changes in the palynofloras. Palynological succession of the Jhuran and Bhuj formations has been worked out by Venkatachala and Kar (1970). They have instituted three palynozones of which palynozone-1 encompasses the Jhuran Formation whereas palynozones 2 and 3 represent the Bhuj Formation. The transitional palynozone 2 is considered Berriasian in age and demarcates the boundary between the Jhuran and Bhuj formations. However, Sah (1983) considers that the Upper Jurassic-Lower Cretaceous boundary may lie within the palynozone 1 of the Jhuran Formation and suggests redefinition of the sequence between the Jhuran and Bhuj formations. Singh (1974) opines that the contact between the Jhuran and Bhuj formations is unconformable (Rajnath, 1952), therefore, the palynofloral break occurs near or after the Aptian. Jai Krishna (1983) has carried out extensive work in the Kutch area and disagrees with the contention of Rajnath (1952). This supports the palynological conclusion of Venkatachala and Kar (1970).

Palynozone 1 of the Jhuran Formation is characterised by the restricted occurrence of *Katrolaites* and comparatively less diversity of cryptogamic spores. *Callialasporites, Alisporites, Podocarpidites, Platysaccus, Microcachryidites, Podosporites* and *Classopollis* are well-represented. *Cicatricosisporites australiensis* makes its first appearance in the transitional Palynozone 2 and is considered to demarcate the Jurassic-Lower Cretaceous boundary. The presence of this palynofossil has been used to distinguish the Lower Cretaceous assemblages from the Upper Jurassic ones (Srivastava, 1978). Some of the other stratigraphically important constituents of this zone are: *Cyathidites cutchensis, C. pseudopunctatus, C. grandis, Concavisporites indicus, Murospora punctata, Aequitriradites verrucosus, Coptospora, Trilobosporites, Platysaccus indicus* and *Schizosporis* spp. It is dominated by the genus *Impardecispora* and *Araucariacites.* Palynozone 3 shows further amplification and diversification of the cryptogamic spores with distinctive morphology. There is no marked diversification in the gymnospermous pollen assemblage. The Upper Jurassic gymnospermous pollen represented by *Araucariacites, Callialasporites, Podocarpidites, Classopollis, Cycadopites, Microcachryidites* and others transit into the Lower Cretaceous assemblages and are represented in different proportions. Some of the important cryptogamic palynofossils of the Palynozone 3 are: *Gleicheniidites senonicus, Appendicisporites* sp., *Baculatisporites comaumensis, Neoraistrickia verrucata, Pilosisporites notensis, Foveosporites canalis, Trilobosporites hannonicus, Sestrosporites pseudoalveolatus, Coronatispora perforata, C. telata* and *Foraminisporis* sp. *Araucariacites* is well-represented (by 20-70 per cent).

Appendicisporites appears in the Walkamota Section and *Ephedripites* is observed in the overlying Dayapar assemblage. The Jhuran Formation Palynozone 1 is dated as Upper Tithonian in age and is designated as the *Impardecispora* assemblage and contains *Araucariacites* and *Callialasporites* which are also dominant. It is considered to range in age from Berriasian to Hauterivian. Palynozone 3 is designated as *Appendicisporites* assemblage and is considered Aptian in age. *Ephedripites* occurs in the Dayapar sediments which overlie the Walkamota Section. It is indicative of post-Aptian age. Palynozone 3 also contains phytoplankton which suggest a marine influence. Singh (1974) believes that the palynofloral change observed by Venkatachala and Kar (1970) in Palynozone 3 occurs around Albian. However, this observation is not supported by palynological and other evidences.

The spore-pollen assemblages described from the Bhuj beds represented at Ghuneri and Trambau (Singh *et al.*, 1964) do not contain *Appendicisporites* and as such they are comparable to the lower part of the Palynozone 3. They are considered Berriasian-Hauterivian in age.

Kar (1972) reported that the Upper Jurassic Jhuran Formation contains 21 genera and 50 species whereas the Lower Cretaceous Bhuj Formation has 46 genera and 70 species. He indicated that the Lower Cretaceous assemblages are characterized by the presence of distinct genera like *Coptospora, Cooksonites* and *Aequitriradites* and divided the Lower Cretaceous assemblages into two zones. The Lower Zone is represented by *Bhujiasporites, Concavissimisporites* and *Impardecispora.* The Upper Zone has *Staplinisporites, Densoisporites, Polycingulatisporites* and *Cingulatisporites.* Critical evaluation of these zones shows that they broadly fall within the age limits of palynozones 2 and 3.

SAURASHTRA BASIN

The Dhrangadhra palynoassemblages (Varma & Rawat, 1964; Venkatachala & Rawat, 1970) are Lower Cretaceous in age. The presence of *Appendicisporites* and *Impardecispora* in the Dhrangadhra assemblage dates it to Aptian. This conclusion is comparable with the information known from Palynozone 3 of Kutch. Singh (1974) believes that the lower part of the Dhrangadhra Formation may belong to Upper Jurassic which is not tenable on the basis of available palynological data.

JAISALMER BASIN

The Upper Jurassic-Lower Cretaceous sediments of Jaisalmer Basin are represented by the Bedesir Formation and Parihar sandstones. Palynological reports on the Upper Jurassic-Lower Cretaceous assemblages are scarce. However, Banerjee (1972) worked out Khara Tal Well no. 1 for its palynofossil contents. Palynological assemblage representative of strata encompassing depth levels between 1492.02-1719.03 m contains such characteristic palynotaxa as *Cicatricosisporites, Appendicisporites, Pilosisporites* and *Trilobosporites* rendering it comparable with the *Appendicisporites* assemblage of Bhuj (Aptian). Palynological study of the subsurface sediment of Manhera Tibba structure, Jaisalmer (Lukose, 1974) shows that the Goru Formation assemblage is probably Aptian-Lower Albian in age. Broadly it is comparable to the *Coptospora cauveriana* Zone but also contains some floral elements like

Clavatipollenites and *Triporoletes* (= *Rouseisporites*), the identification of which needs confirmation. Since palynofossils are not illustrated in the paper reassessment is not possible.

SATPURA BASIN

The Sehora assemblage from the Jabalpur Formation was described by Dev (1962). He recorded several palynofossils that are known from the Upper Mesozoic rocks of Australia. The assemblage also contains reworked Permian striated-bisaccate pollen. The assemblage was considered by him as younger than that recorded from the Rajmahal Formation. The Jabalpur Formation assemblage (Singh, 1966) was studied from the same sediments exposed along the Sher River near Sehora and Harad River near Hathnapur. Several palynotaxa characteristic of Lower Cretaceous age were recorded. The characteristic palynofossils that help for Lower Cretaceous age assignment are: *Cicatricosisporites, Triporoletes (= Rouseisporites), Coptospora, Crybelosporites, Contignisporites, Aequitriradites, Densoisporites* and *Cooksonites.* Gymnospermous pollen are represented by *Callialasporites, Araucariacites, Platysaccus, Podocarpidites, Podosporites, Vitreisporites, Classopollis* and *Cycadopites.* Kumar (1973) carried out detailed taxonomic study on the material supplied by Singh (1966) describing several taxa which provided additional data favouring a Lower Cretaceous age assignment. However, on the basis of quantitative analysis of the same assemblage, Bharadwaj *et al.* (1972) assigned an Upper Jurassic age. This controversy has been discussed in detail by Rao and Venkatachala (1971) and Singh (1972, 1974) who reassign them to Berriasian-Aptian age. The *in situ* spores of *Weichselia reticulata* (Stokes et Webb.) Fontaine have been studied by Alvin (1971). They are closely comparable to the specimens included under the genus *Lametatriletes* which has consistently been reported from Sehora, Hathnapur and Lameta Ghat assemblages. *Weichselia reticulata* has a world-wide occurrence in the Lower Cretaceous. The presence of *Lametatriletes* spp. signals the occurrence of *Weichselia* in the sediments of Jabalpur Formation though the megafossil genus has not been as yet discovered.

SOUTH REWA BASIN

The Bansa Formation assemblage (Maheshwari, 1974) shows the abundance of *Araucariacites* (23-58%) and *Callialasporites* (19-34%). The other gymnospermous elements are represented by *Properinopollenites, Alisporites, Podocarpidites* and *Cycadopites* which are frequent in occurrence. The distribution of *Microcachryidites* and fern spores in the assemblage is reported to be infrequent. However, the presence of *Coniatisporites, Impardecispora apiverrucata, Lametatriletes, Densoisporites mesozoicus, Metamonoletes* and *Crassimonoletes* (Singh *et al.*, 1964) shows its closer affinity with the Berriasian-Hauterivian assemblages of Kutch. Palynological composition of the Berriasian-Aptian assemblages recorded from the South Rewa and Satpura basins (Dev, 1962; Singh, 1966; Bharadwaj *et al.*, 1972; Kumar, 1973; Bharadwaj & Kumar, 1974a, b; Maheshwari, 1974) are closely comparable to the Bhuj Formation Palynozones 2 and 3 as well as to the Trambau and Ghuneri assemblages (Singh *et al.*, 1964). It is possible that the Jurassic sequence in this area has either been eroded or represents a non-depositional phase.

RAJMAHAL BASIN

The Rajmahal Formation assemblages (Rao, 1943; Mittre, 1954; Sah & Jain, 1965) hitherto considered Bajocian to Oxfordian are comparable to the Jabalpur assemblages and hence are considered Lower Cretaceous in age. These assemblages contain *Impardecispora purverulenta, Foraminisporis assymetricus* and *Cicatricosisporites australiensis* which have been used to date the Lower Cretaceous. The presence of *Foraminisporis asymmetricus* indicates that these assemblages could range from Barremian to basal Aptian. The Mandro Well Section assemblage (Maheshwari & Jana, 1983) is also stated to be of Lower Cretaceous as it contains *Aequitriradites* and *Cooksonites.* There are several thick basaltic flows in the Rajmahal Basin which are intermittently intercalated with 11 Intertrappean beds (Ramaswamy, 1952-53). The lower five Intertrappean beds contain plant remains. Cycadophytic remains dominate the second and third Intertrappean beds whereas the fourth one contains dominance of conifers (*Nipania*). Singh, G. (1974) considers that the Rajmahal sediments might represent a big time interval and the upper flows might be of Lower Cretaceous age. The Rajmahal traps have been dated radiometrically as Lower Cretaceous (McDougall & McElhinny, 1970).

Palynoassemblage zones A-F (Tiwari *et al.*, 1984) have been recognised from the subsurface sequence of the NE Rajmahal Basin. These contain Dubrajpur Formation and Intertrappean beds. The zones have been dated as late Lower Triassic (Zone A-C), Late Jurassic (Zone D) and Early Cretaceous (Zone E-F). A re-examination of the palynological composition of the assemblage zones D-F affirms the presence of Early Cretaceous palynofossils like *Aequitriradites, Coptospora, Cooksonites, Impardecispora, Cicatricosisporites, Triporoletes (= Rouseisporites), Densoisporites* and *Neoraistrickia truncata*. The stratigraphic importance of the occurrence of these fossils in the assemblage Zones D-F is significant. There appears to be a time gap suggesting an unconformity between assemblages C and D.

PRANHITA-GODAVARI GRABEN

The Gangapur Formation unconformably overlies the Kota Formation in the Pranhita-Godavari Graben. Palynological assemblages of the Gangapur Formation are assigned Neocomian-Aptian age. The assemblages have been extensively studied by Rao *et al.* (1979). Ramanujam and Rao (1979), Rao and Ramanujam (1979), Ramanujam and Rao (1980), Maheshwari (in Bose, Kutty & Maheshwari, 1982) and Ramakrishna and Ramanujam (1987). A distinctive assemblage (Ramakrishna & Ramanujam, 1987) is described from the outcrops in the Adilabad District. Some of its important constituents are *Cicatricosisporites australiensis, C. hughesii, Aequitriradites spinulosus, Cooksonites minor* and *Microcachryidites antarcticus* associated with gymnospermic saccate and non-saccate pollen. This assemblage is closely comparable to those recovered from Anksapur, Rallapet and Wankalam (Ramanujam & Rao, 1979; Rao *et al.*, 1983; Bose, Kutty & Maheshwari, 1982). No angiospermic pollen grains have been found. The usual Neocomian-Aptian palynofossils belonging to the cryptogams constitute the important aspect of the above assemblage (stratigraphic implication of these assemblages has been discussed by Venkatachala & Rajanikanth, 1988, this Volume).

MAHANADI BASIN

The Mahanadi Basin is mostly concealed by the Holocene deposits. However, the Athgarh Formation is exposed near the western margin of the basin, southwest of Cuttack, which has been considered late Mesozoic in age. This formation contains several plant megafossils (Jain, 1968; Patra, 1973, 1980). The megafloral assemblage indicates an Early Cretaceous age for this formation.

Maheshwari (1975) described a palynoassemblage from the Sidheshwar Hill and Jagannath Prasad quarry containing the Lower Cretaceous palynofossils: *Impardecispora* sp. and *Podosporites tripakshii*. Jana and Tiwari (1986) reinvestigated this assemblage and assigned an Upper Jurassic age and considered it homotaxial with the Rajmahal Assemblage zones D-F (Tiwari *et al.*, 1984) and Jabalpur Assemblage (Kumar, 1973). These assemblages, i.e., Jabalpur and zones D-F of Rajmahal have been reassessed and dated Early Cretaceous in age. The Athgarh assemblage also contains *Lametatriletes indicus* (cf. spores of *Weichselia reticulata*), *Boseisporites praeclarus, Monolites indicus* and *Onychiopsis* (Patra, 1973) which further confirm an Early Cretaceous assignment.

CAUVERY BASIN

The Upper Mesozoic sediments (continental, paralic to marine) are exposed as detached patches in the Cauvery Basin. The Sivaganga beds overlie the Archaean complex and are overlain by the Dalmiapuram Formation which is dated Aptian-Early Albian on both palynological and faunal evidences (Bhatia & Jain, 1969; Rao & Venkatachala, 1971; Venkatachala & Jain, 1969; Venkatachala *et al.*, 1972). Several palynologists have studied surface and subsurface material from the Cauvery Basin, viz., Banerjee and Misra (1968), Jain and Subbaraman (1969), Venkatachala (1973), Venkatachala and Sharma (1974a, 1974b) and Maheshwari (1986). Four palynological zones have been recognised in the Jurassic-Cretaceous subsurface sequence—*Callialasporites segmentatus* Zone containing an impoverished assemblage which was earlier assigned an Upper Jurassic (Tithonian) age, is reassigned a Lower Cretaceous age (Berriasian) because of the presence of *Cicatricosisporites australiensis*. The succeeding *Microcachryidites antarcticus* Zone (Neocomian) contains characteristic palynofossils, viz., *Microcachryidites, Cooksonites* and *Aequitriradites*. This zone has been identified in several subsurface sequences. Most of the Lower Cretaceous elements continue to occur in the succeeding *Coptospora cauveriana* Zone (Aptian-Lower Albian). However, the first appearance of *Coptospora* and *Polypodiaceoisporites* and others gives a distinctive character to this zone. The first appearance of *Appendicisporites* is noteworthy (see Venkatachala, 1974 for a detailed discussion). *Ephedripites* is present at the top of the zone. The Dalmiapuram Grey Shale assemblages (Rao & Venkatachala, 1971; Jain & Subbaraman, 1969; Jain & Taugourdeau-Lantz, 1973; Venkatachala & Kumar, 1980) are contemporaneous with the *Coptospora cauveriana* Zone. These have been recovered from several subsurface sequences in the basin. Jain and Taugourdeau-Lantz (1973) assign an Early Albian age to the Dalmiapuram Formation.

KRISHNA-GODAVARI BASIN

The Godavari Depression contains Golapalli Sandstone, Raghavapuram Shale and Tirupati Sandstone in an ascending order whereas Budavada Sandstone, Vemavaram Shale and Pavalur Sandstone are exposed in the Krishna Depression. These units have been considered time equivalents and representing facies variations (Venkatachala & Sinha, 1986). Palynological assemblages have been studied by Ramanujam (1957), Kar and Sah (1970), Rao and Venkatachala (1971) and Sharma *et al.* (1977). These assemblages have been assigned Neocomian-Aptian age. A marked palynofloral similarity has been observed in the assemblages recovered from the Krishna Depression, Bapatla-Velupcharla Ridge and West Godavari Depression (Sharma *et al.*, 1977). This information made it possible to establish a homotaxial nature of sediments encountered in the subsurface sequence in the two depressions of the Krishna-Godavari Basin (Raghavapuram/Vemavaram shales). In a comprehensive study of stratigraphy, age and palaeoecology of 'Upper Gondwana' equivalents of the Krishna-Godavari Basin (Venkatachala & Sinha, 1986) major environmental regimes varying from non-marine in the west to shallow marine in the east through transitional swampy environment have been delineated on the basis of palynofossils.

Some of the important constituents of this assemblage are *Appendicisporites sellingii, Cicatricosisporites ludbrookii, C. hughesii, Impardecispora apiverrucata, Crybelosporites velatus, Cooksonites variabilis, Aequitriradites spinulosus* and *Microcachryidites antarcticus.* Detailed account of Neocomian-Aptian palynoassemblages containing phytoplankton from the subsurface of Godavari and Krishna depressions have been rendered by Sharma *et al.* (1970), Venkatachala (1977) and Venkatachala and Sinha (1986). Neocomian-Aptian palynoassemblages (Venkatachala, 1977) recovered from the shallow wells drilled in the West Godavari Depression as well as Krishna Depression demonstrate the presence of phytoplankton in addition to some of the following characteristic palynofossils: *Bhujiasporites, Cicatricosisporites australiensis, C. ludbrookii, C. hughesii, Trilites verrucosus, Plicifera senonicus, Impardecispora purverulenta, Crybelosporites stylosus, Densoisporites velatus, Appendicisporites sellingii, Coronatispora* sp., *Cooksonites variabilis, Microcachryidites antarcticus* and *Podosporites tripakshii.*

Sastri *et al.* (1963), Bhalla (1969) and Bakshi (1966) date the Raghavapuram shales as Early Cretaceous on the basis of faunal assemblages. In fact, the entire sequence of exposed Upper Mesozoic rocks in the "East-coast Gondwana" is assigned Lower Cretaceous age (Mitra *et al.*, 1971).

PALAR BASIN

The Sriperumbudur beds are poorly exposed in the Palar Basin and overlie the Talchir Formation unconformably. They contain splintery grey and greenish shales and have interbedded sandstone and limestone. Scattered outcrops of the Satyavedu beds overlap the Sriperumbudur beds transgressively.

Spore-pollen/phytoplankton assemblages distinctly of Neocomian-Aptian age recovered from the Kancheepuram area have been described by Ramanujam and Srisailam (1974), Ramanujam and Varma (1977), Venkatachala (1977) and Ramanujam *et al.* (1980).

The Kattavakkam bore-hole assemblage (Ramanujam & Srisailam, 1974) was dated as Late Jurassic which was earlier assigned Early Cretaceous age (ONGC unpublished reports). The presence of *Impardecispora apiverrucata, Cicatricosisporites australiensis* and *Concavisporites cutchensis* makes it cogent to reaffirm Lower Cretaceous age.

The other Early Cretaceous palynoassemblages contain the following important markers: *Impardecispora apiverrucata, Neoraistrickia truncata, Cicatricosisporites australiensis, Aequitriradites spinulosus, A. verrucosus, Cooksonites variabilis, Coptospora* sp., *Foraminisporis, Crybelosporites* sp. and *Microcachryidites antarcticus.* Murthy and Sastri (1962) have dated the Sriperumbudur beds on the basis of foraminiferal evidence as Lower Cretaceous. Sastri and Mamgain (1971) also dated the Upper Gondwana sediments of the Krishna-Godavari Basin and correlated them with the Sriperumbudur and Satyavedu beds.

CONCLUDING REMARKS

The Upper Jurassic-Lower Cretaceous boundary may be placed at the top of the Jhuran Formation in the Kutch Basin on the basis of palynological data. The Upper Jurassic assemblage of Kutch (Jhuran Formation) is characterized by the restricted presence of *Katrolaites* and comparatively less diversity of cryptogamic spores. The transitional zone is distinct by the advent of *Cicatricosisporites australiensis.* Its first appearance is usually considered to distinguish the Lower Cretaceous. This zone also depicts the dominance of *Impardecispora* and *Araucariacites.* The Neocomian-Aptian assemblages, in general, show further amplification and diversification of cryptogamic spores with distinctive morphology, viz., *Appendicisporites, Aequitriradites, Impardecispora, Foraminisporis, Lametatriletes* and several others. These forms are not encountered in the Upper Jurassic assemblages.

The base of the Lower Cretaceous sediments is marked by the appearance of a new set of cryptogamic spores which possess distinctive morphology though they remain low in number. Their stratigraphical importance in delineating the Upper Jurassic-Lower Cretaceous boundary has proved to be beyond doubt. Quantitative changes in the composition of the palynofloras, particularly of gymnospermous pollen (such as *Classopollis, Callialasporites* and others) seem to represent different depositional environments. Such changes, however, striking they may appear to be, are certainly of less stratigraphic importance.

The Jurassic-Cretaceous transitional strata usually exhibit a great diversity of spores and high percentage of bisaccate pollen of gymnosperms. This distinct change in the composition of the palynofloras near the Jurassic-Cretaceous boundary is a world wide phenomenon. The appearance of cryptogamic spores like *Cicatricosisporites* and *Impardecispora/ Trilobosporites* at or near the J-C boundary is almost universal. *Appendicisporites* is restricted to the Cretaceous strata only. *Aequitriradites, Pilosisporites, Cooksonites, Coptospora, Crybelosporites* and *Foraminisporis* assume greater stratigraphic importance.

It seems possible to generalize that *Microcachryidites* and *Podosporites* are typical elements of the Jurassic-Cretaceous Gondwanic assemblages distributed in Australia, New Zealand, India, South Africa, Madagascar and southern South America.

Determination of precise contemporaneity of some palynoassemblages discussed here is difficult as the data are not related to stratigraphic columns.

Satpura, South Rewa, Rajmahal and East Coast basins contain only Lower Cretaceous palynoassemblages ranging in age from Berriasian to Aptian. It appears that either the Jurassic sediments were eroded in this area or represent a non-depositional phase.

Kutch and Rajasthan basins seem to have witnessed shallow marine sedimentation during the pre-Cretaceous Period (faunal and phytoplankton evidence) whereas in the eastern sector it started during the Lower Cretaceous in response to the rifting activity.

Detailed comparisons of the Upper Mesozoic palynoassemblages particularly of Neocomian age from India and Australia led Sastri *et al.* (1981) to believe that the east coast of India and west coast of Australia were juxtaposed. It is possible to draw conclusion that the continental deposits of the Rajmahal Basin (Neocomian) may represent an extended part of the Great Artesian Basin of Australia.

The term 'Gondwana' was proposed to include inland continental sediments. The marine sediments of Kutch and others with the continental sequence in the peninsular India were later included as marine intercalations. The term 'Gondwana' in the present context thus appears to be continuously expanded to include paralic as well as marine sequences. It is necessary to review and restrict the use of the term 'Gondwana' to a geographical context rather than to a stratigraphic one.

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Palynozonation of Jhuran and Bhuj formations in Kutch Basin

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Maheshwari, Hari K. & Jana, B. N. (1988). Palynozonation of Jhuran and Bhuj formations in Kutch Basin. *Palaeobotanist* **36** : 177-182.

The palynological assemblages of Jhuran and Bhuj formations of Kutch Basin have many genera in common. *Araucariacites*-complex is the dominating group of palynofossils. The assemblage of Bhuj Formation differs from that of Jhuran Formation in variety of trilete genera and in the frequent occurrence of hilate group (viz., *Aequitriradites, Cooksonites, Coptospora, Triporoletes*, etc.). The occurrence of hilate group in the assemblages from Jhuran Formation is almost nil. In all, four palynological zones have been recognized, one palynological zone is in Jhuran Formation and the other three zones are in Bhuj Formation. On the basis of palynological data it seems that the Jurassic-Cretaceous boundary lies somewhere in the Upper Member of Jhuran Formation.

Key-words—Palynozonation, *Araucariacites*-complex, Bhuj Formation, Jhuran Formation, Kutch Basin (India).

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साराँश

कच्छ द्रोणी में झुरन एवं भुज शैल-समूहों का परागाणविक मंडलन

हरिकृष्ण माहेश्वरी एवं बृजेन्द्र नाथ जाना

कच्छ द्रोणी में झुरन एवं भुज शैल-समूहों के परागाणविक समुच्चयों से उपलब्ध बहुत सी प्रजातियाँ सामान्य हैं। **अॅराकेरिआसाइटिस**-सम्मिश्र परागाणविक-रूपकों का प्रभावी समूह है। भुज शैल-समूह का समुच्चय त्रिअरीय प्रजातियों की विभिन्नता एवं हाइलेट समूह (**ऍक्वीट्राइरेडाइटिस, कुक्सोनाइटिस, कोप्टोस्पोरा, ट्राईपोरोलिटीस**, आदि) की प्रचुर उपस्थिति के कारण भिन्नता प्रदर्शित करता है। झुरन शैल-समूह से उपलब्ध समुच्चयों में हाइलेट समूह की उपस्थिति प्रायः नगण्य है। कुल मिलाकर चार परागाणविक मंडल बनाये गये हैं जिनमें एक मंडल झुरन शैल-समूह में है तथा शेष अन्य तीन भुज शैल-समूह में हैं। परागाणविक ऑकड़ों के आधार पर ऐसा प्रतीत होता है कि जुराई-क्रीटेशी सीमा झुरन शैल-समूह के उपरि सदस्य में विद्यमान है।

IN Kutch Basin the Mesozoic sedimentaries, ranging in age from Bathonian to Aptian, extend in an east-west direction along the whole length of Kutch Mainland. The sediments are also exposed in the islands in the Rann located to the north of mainland. The Mesozoic rocks have been variously classified by different workers, but the classification that seems to be accepted most is by Biswas (1971). He has divided the Mesozoic rocks of Kutch Mainland into four formations, viz., Jhurio, Jumara, Jhuran and Bhuj, in order of superposition.

Palynological investigations of Mesozoic sediments of the Kutch Basin were initiated by Singh, Srivastava and Roy (1964). Later on, more data were made available through the works of Mathur and Mathur (1965), Venkatachala (1967, 1969a, 1969b), Venkatachala and Kar (1967, 1968a, 1968b, 1970, 1972), Venkatachala, Kar and Raza (1969a,

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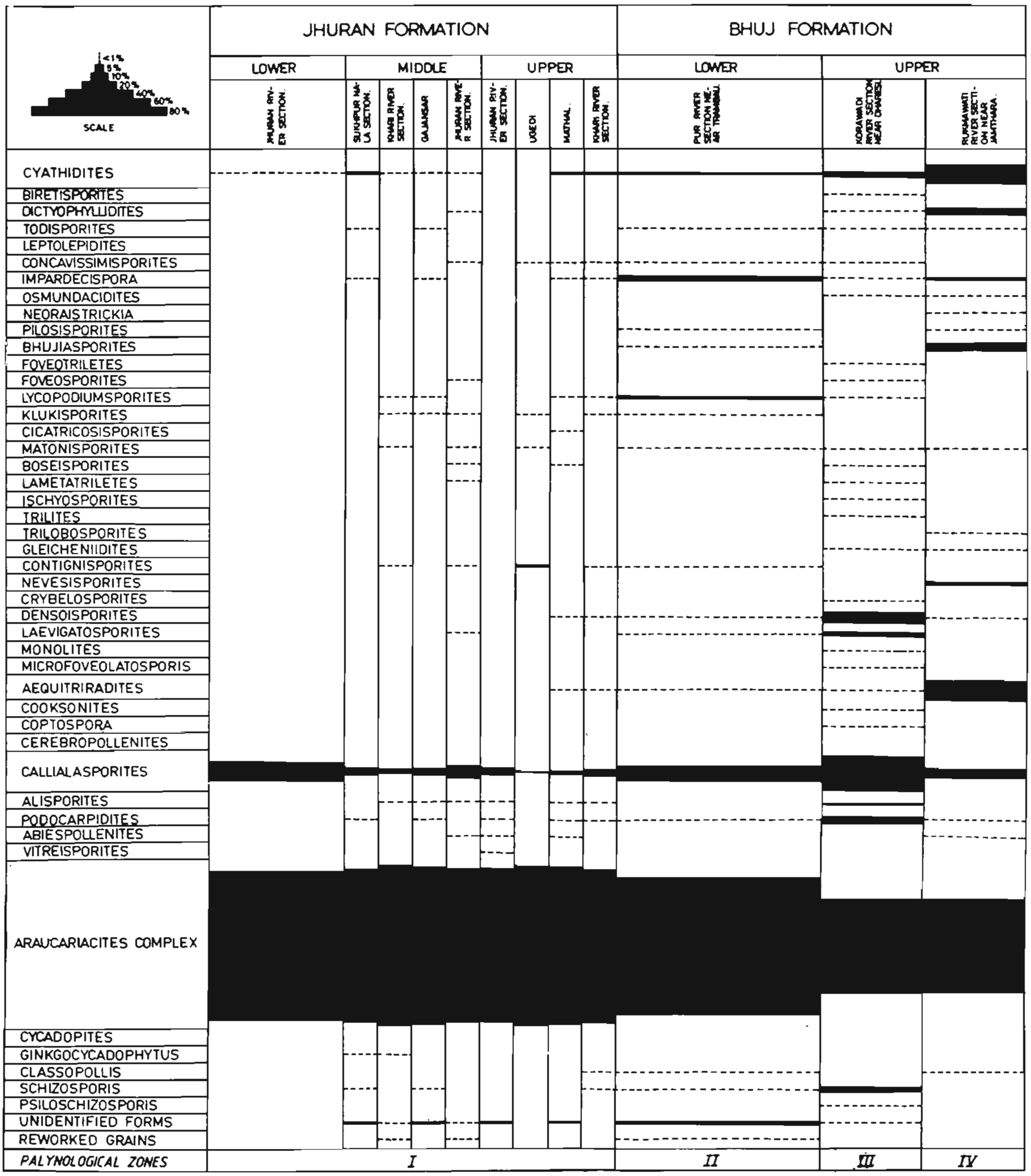

Text-figure 1—Showing percentage frequency of various miospore genera and palynological zones in Jhuran and Bhuj formations.

1969b, 1969c), Mathur *et al.* (1970), Mathur (1980), etc. Koshal (1975, 1983) reported palynological assemblages from subsurface samples of Banni and Nirona wells.

The palynological data incorporated in this paper have been obtained from surface sediments collected during last ten years from Kutch Mainland. Out of four lithounits, the basal two. i.e. Jhurio and Jumara formations did not yield any worthwhile palynofossils except for nannofossils in the Jumara. The Jhuran and the Bhuj formations have yielded a rich palynological assemblage comprising spores, pollen and dinoflagellates. Nannoplankton have also been recovered from few Jhuran samples. Here we deal only with spore-pollen assemblages.

PALYNOLOGICAL DATA

The Jhuran Formation has been divided into four formal members, i.e., lower, middle, upper and

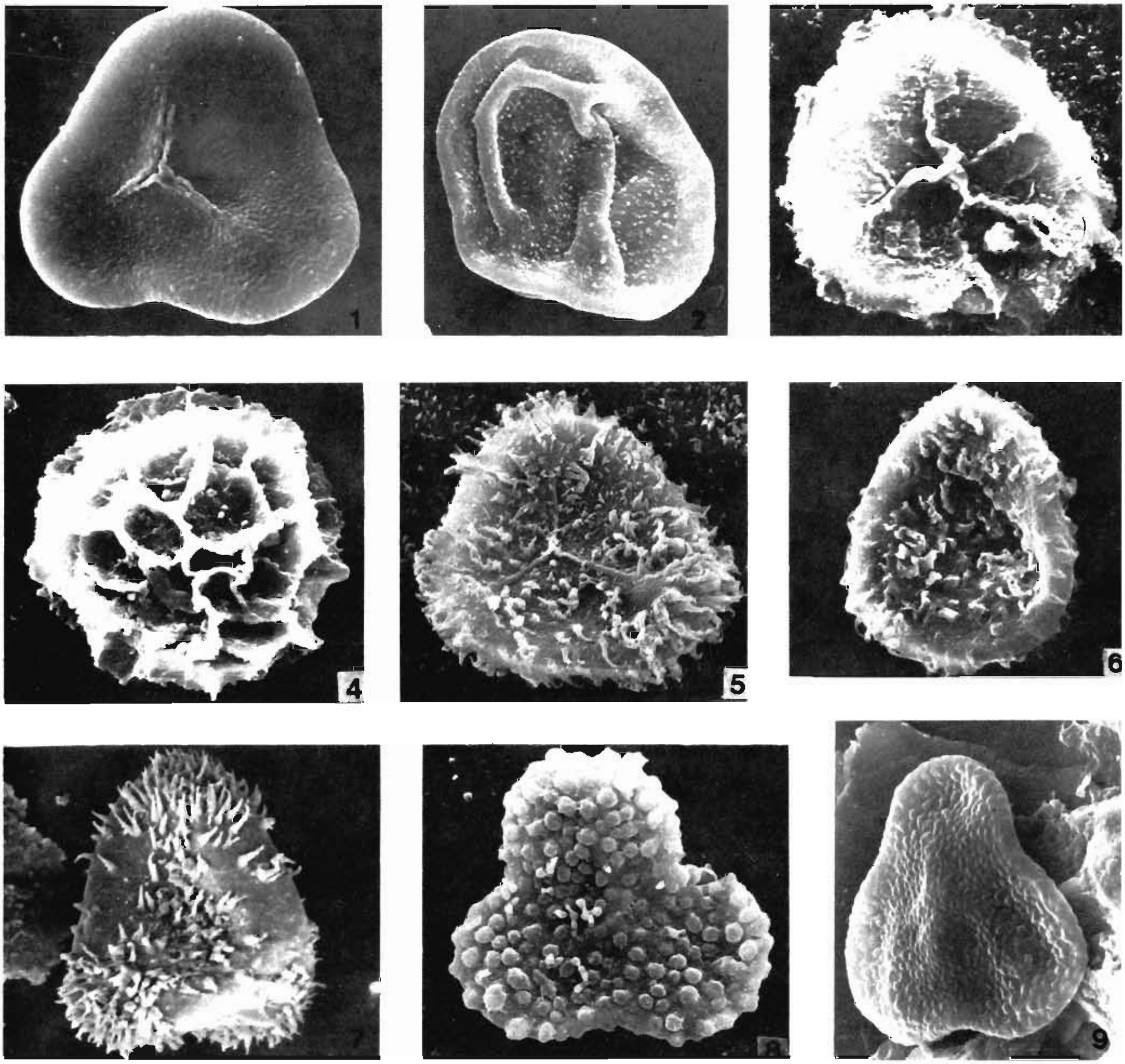

PLATE 1

Photomicrographs of important spore and pollen taxa from Jhuran and Bhuj formations.

1. *Cyathidites ghuneriensis* Singh, Srivastava & Roy. × 600.
2. *Todisporites major* Couper. × 600.

3,4. *Lycopodiumsporites trambauensis* Singh, Srivastava & Roy, **3.** Proximal view. × 600; **4.** Distal view. × 500.

5,6. *Bhujiasporites* sp. proximal and distal view. × 600.

7. *Pilosisporites* sp. × 600.
8. *Impardecispora* × 600.
9. *Concavissimisporites verrucosus* (Delcourt & Sprumont) Delcourt, Dettmann & Hughes. × 600.

Katesar members. All members except Katesar are fossiliferous.

The palynological assemblage representing Lower Member of Jhuran Formation, recovered from Jhuran River Section near Jawaharnagar, is very poor in spore-pollen content. Trilete spores represented by the genera like *Cyathidites, Todisporites, Biretisporites* and *Lycopodiumsporites* are less than 1 per cent of the assemblage. In quantitative estimation, dominance of conifer pollen (i.e.

Araucariacites-complex) is noticed; this group constitutes 88.75 per cent of the total assemblage. *Callialasporites* is 10.75 per cent (Text-fig. 1).

The palynological assemblage of Middle Member has been recovered from Sukhpur Nala, Khari River, Gajansar and Jhuran River sections. In this assemblage the trilete spores are relatively more than in the Lower Member. The assemblage comprises *Cyathidites, Biretisporites, Todisporites, Dictyophyllidites, Leptolepidites, Impardecispora, Concavissimisporites, Foveosporites, Foveotriletes, Lycopodiumsporites, Klukisporites, Matonisporites, Lametatriletes, Contignisporites, Laevigatosporites, Callialasporites, Alisporites, Podocarpidites, Abiespollenites, Vitreisporites, Araucariacites*-complex, *Classopollis, Cycadopites, Ginkgocycadophytus, Schizosporis*, etc. Here too, the *Araucariacites*-complex is the dominant group of palynofossils and constitutes 91.4 to 95.67 per cent of the total assemblage. *Callialasporites* is 3.05 to 4.69 per cent of the assemblage. Quantitative representation of individual trilete spore genera is less than 1 per cent except for *Cyathidites* which is up to 2 per cent in some of the samples. The palynological assemblage from the Jhuran River Section has the highest number of spore-pollen genera.

The Upper Member of Jhuran Formation is exposed in Jhuran River near Jawaharnagar, Ugedi well, Chawad River near Mathal and Khari River near cremation ground. The palynological assemblage is more or less similar to that of the Middle Member in having only a few trilete spores but the genera like *Densoisporites, Cicatricosisporites* and *Aequitriradites* make their first appearance here. The *Araucariacites*-complex constitutes 91.5 to 95 per cent of the total assemblage. *Callialasporites* is only 1.5 to 4.4 per cent of the total. The trilete genera are less than 1 per cent except for *Cyathidites* and *Contignisporites*.

The Bhuj Formation overlies the Jhuran Formation and is underlain by the Deccan Trap flows. It has been divided into two members, lower and upper.

Palynological assemblages recovered from the Bhuj sediments are very rich and well-diversified. The representative assemblage of Lower Member has been recovered from Pur River Section near Trambau. This assemblage comprises: *Deltoidospora, Cyathidites, Todisporites, Dictyophyllidites, Osmundacidites, Concavissimisporites, Impardecispora, Baculatisporites, Baculareticulosporis, Pilosisporites, Bhujiasporites, Klukisporites, Lycopodiumsporites, Boseisporites, Matonisporites, Contignisporites, Murospora, Densoisporites, Laevigatosporites, Monolites, Aequitriradites, Callialasporites, Podocarpidites, Alisporites, Abiespollenites, Classopollis, Araucariacites*-complex, *Schizosporis*, etc. The *Araucariacites*-complex is the dominant group of palynofossils constituting 82 per cent of the total assemblage. The genus *Callialasporites* is 9 per cent. The commonly encountered trilete genera are *Cyathidites, Impardecispora, Lycopodiumsporites* and *Bhujiasporites*. Almost all trilete spore genera are less than 1 per cent except for *Cyathidites* (1.7%), *Impardecispora* (4.25%) and *Lycopodiumsporites* (2.5%).

The palynological assemblages of the Upper Member exposed in Korawadi River Section near Dharesi and Rukmawati River Section near Jamthara is compositionally rich and contains genera like *Deltoidospora, Cyathidites, Biretisporites, Dictyophyllidites, Todisporites, Concavissimisporites, Osmundacidites, Impardecispora, Lycopodiacidites, Foveotriletes, Foveosporites, Lycopodiumsporites, Matonisporites, Boseisporites, Lametatriletes, Ischyosporites, Trilites, Gleicheniidites, Crybelosporites, Densoisporites, Laevigatosporites, Monolites, Microfoveolatosporis, Aequitriradites, Cooksonites, Coptospora, Cerebropollenites, Callialasporites, Alisporites, Platysaccus, Podocarpidites, Araucariacites*-complex, *Psiloschizosporis*, etc. The *Araucariacites*-complex shows an appreciable fall and constitutes only 54 per cent of the total assemblage. The Dharesi assemblage shows a certain increase in *Callialasporites* (up to 19.7%) and *Densoisporites* (7.1%). There is a remarkable variation in the genus *Densoisporites* in Dharesi Assemblage. A number of hilate forms such as *Aequitriradites, Cooksonites, Coptospora* and *Triporoletes* are also represented.

In the palynological assemblage of Rukmawati River Section there is a sudden rise of certain trilete and hilate genera. Some of the characteristic forms of this assemblage are *Cyathidites* (11.66%), *Deltoidospora* (1.08%), *Dictyophyllidites* (3.92%), *Impardecispora* (15%), *Pilosisporites* (0.25%), *Nevesisporites* (1.5%), *Bhujiasporites* (3%), *Trilobosporites* (0.5%), *Aequitriradites* (10.75%), *Callialasporites* (4.5%), *Araucariacites*-complex (53.5%), *Schizosporis* (3%), etc. As a whole the palynofossil assemblage of Rukmawati River Section is different from other known palynofossil assemblages of the Kutch Basin.

PALYNOLOGICAL ZONATION

It is evident from the above that the poorest assemblage has been found in the Lower Member of Jhuran Formation. In the Middle Member there is a qualitative as well as quantitative rise of trilete

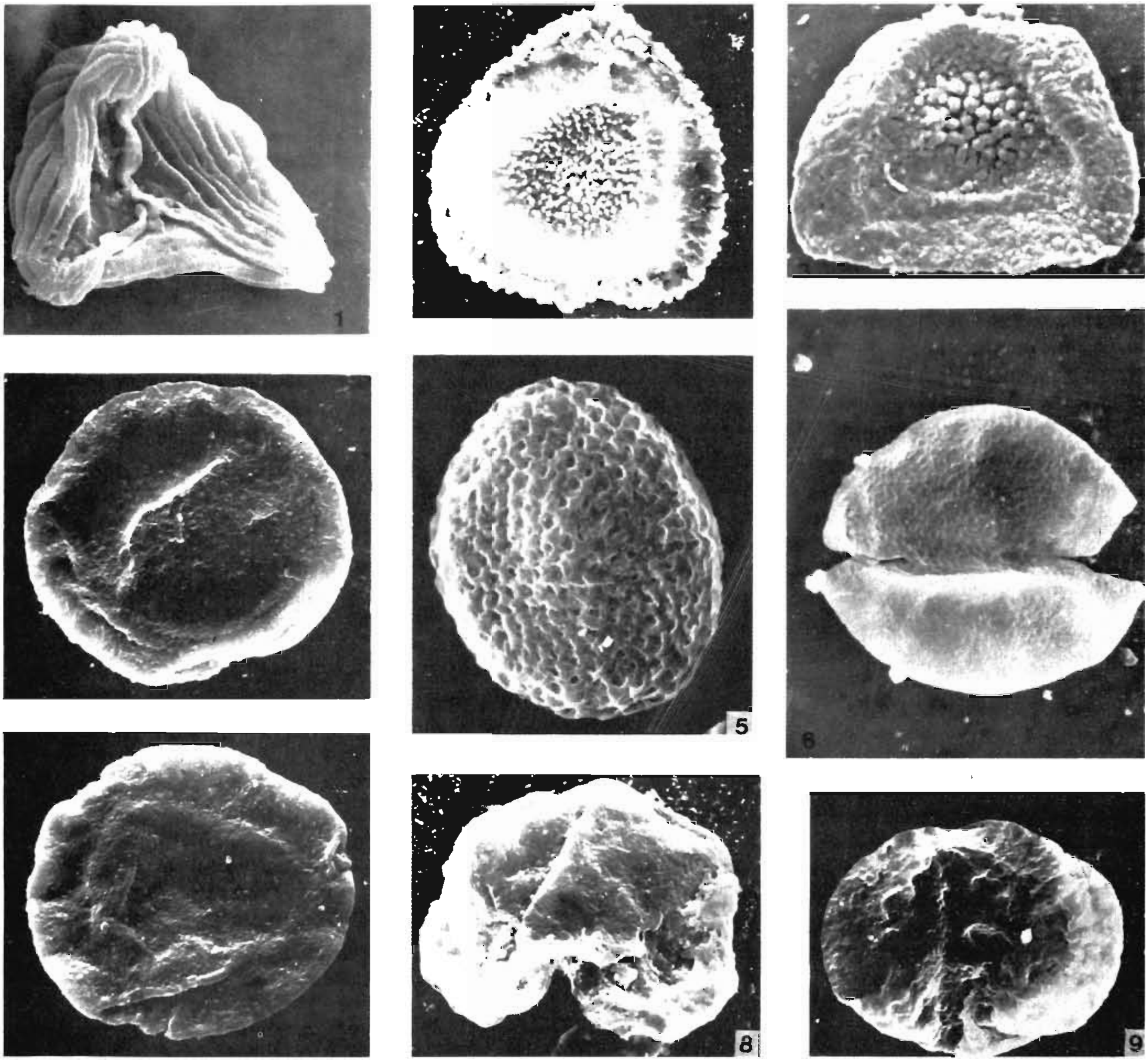

PLATE 2

1. *Cicatricosisporites australiensis* (Cookson) Potonié. × 700.
2. *Aequitriradites* sp. × 800.
3. *Cooksonites* sp. × 800.
4. *Callialasporites* sp. × 600.
5. *Schizosporis reticulatus* Cookson & Dettmann. × 450.
6. *Schizosporis* sp. × 500.
7. *Callialasporites dampieri* (Balme) Dev. × 600.
8. *Abiespollenites* sp. × 600.
9. *Alisporites grandis* (Cookson) Dettmann. × 700.

genera. In both the members, the dominant palynofossil is the *Araucariacites*-complex. The representation of *Callialasporites* declines in the Middle Member. In the Upper Member the induction of certain trilete and hilate genera enriches the assemblage. The first appearance of certain stratigraphically important genera such as *Cicatricosisporites, Aequitriradites*, etc. heralded the initiation of Lower Cretaceous Epoch. So, the Jurassic/Cretaceous time boundary lies somewhere in the Upper Member of Jhuran Formation. The palynological assemblage of Jhuran Formation constitutes the *Palynozone I.* This zone also has frequent representation of dinoflagellate cysts and scanty occurrences of nannofossils.

The palynological assemblages of the Bhuj Formation are distinguishable from that of Jhuran Formation by the variety and abundance of spores and pollen and almost total absence of marine elements. The trilete group, which forms only 0.2 to 3.36 per cent in Jhuran Formation, constitutes 10.3 to 26.4 per cent in the Bhuj Formation. The oldest one, i.e. *Palynozone II* from the Bhuj sediments near Trambau, shows the common occurrence of trilete spore genera *Impardecispora, Bhujiasporites* and *Lycopodiumsporites*, etc. *Palynozone III* is characterised by the richness of flora and the high representation of *Densoisporites* (up to 7.1%). *Palynozone IV* is characterized by the sudden rise in quantitative representation of trilete and hilate forms. It is only in *Palynozone IV* that the subdominant genus is other than *Callialasporites.* In this zone the genera *Cyathidites* and *Aequitriradites* contribute 11.66 and 10.75 per cent, respectively. Palynozones III and IV are represented in Korawadi and Rukmawati sections, respectively.

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Stratigraphic implication of 'Late Gondwana' floras in the East Coast

B. S. Venkatachala & A. Rajanikanth

Venkatachala, B. S. & Rajanikanth, A. (1988). Stratigraphic implication of 'Late Gondwana' floras in the East Coast. *Palaeobotanist* **36** : 183-196.

The Cauvery, Palar, Krishna-Godavari and Mahanadi basins in the East Coast of India include coeval, paralic, lagoonal and deltaic Mesozoic ('Late Gondwana') deposits distributed in detached outcrops. The 'Ptilophyllum Flora' characterising these sediments was earlier considered Jurassic in age. Considerable floristic and stratigraphic data have accrued necessitating a relook on earlier age assignments and stratigraphic placements. Biostratigraphic evidences considered *in toto* suggest an Early Cretaceous age to the flora found in these sediments. Sedimentation of these sediments is attributed to rifting of Indian Plate coupled with a reactivation phase. It is recommended that the term 'Gondwana' should either be recircumscribed to include marine coastal sediments or discontinued in favour of usage of chronostratigraphic terminology.

Key-words—Stratigraphy, 'Late Gondwana' Flora, East Coast, Early Cretaceous (India).

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साराँश

पूर्व तट में 'अनंतिम गोंडवाना' वनस्पतिजातों का स्तरिक महत्त्व

बेंगलूर श्रीनिवासा वेंकटाचाला एवं अन्नमराजु रजनीकान्थ

भारत के पूर्व तट में कावेरी, पलार, कृष्णा-गोदावरी एवं महानदी द्रोणीयों में तटांचली, समकालीन, लैगूनी एवं डेल्टीय मध्यजीवी ('अनंतिम गोंडवाना') निक्षेप विद्यमान हैं जो कि अलग-अलग दृश्यांशों में वितरित हैं। इन अवसादों को अभिलक्षणित करने वाले 'टाइलोफ़िल्लम् वनस्पतिजात' की आयु पहले जूराई मानी गयी थी। परन्तु पर्याप्त उपलब्ध वनस्पतिजातीय एवं स्तरिकीय आँकड़ों के कारण अब इनकी आयु एवं इनके स्तरिक स्थान पुनः विचारणीय हैं। समस्त जैवस्तरिकीय प्रमाणों से इन अवसादों में उपलब्ध वनस्पतिजात की प्रारम्भिक क्रीटेशी आयु इंगित होती है। इन अवसादों के अवसादन से भारतीय प्लेट का विस्थापन इंगित होता है। यह भी प्रस्तावित किया गया है कि 'गोंडवाना' नामक शब्द समुद्री तटीय अवसादों के लिए परिसीमित अथवा कालानुक्रमिक शब्दों के लिए प्रयुक्त नहीं किया जाना चाहिये।

FLUVIAL-LACUSTRINE successions ranging in age from Upper Palaeozoic to Jurassic in the peninsular India were termed "Gondwana" by Medlicott in 1872. The term appeared in print only in 1876 (Feistmantel, 1876). These are characterised by conglomerates, sandstones, shales and coal measures (Fox 1931). The upper limit of the 'Gondwana' Sequence and the nomenclature of spatially extended occurrence of these deposits in the East Coast of India is debatable. Thin marine beds discovered along the East Coast were considered as marine intercalations in the 'Late Gondwana'. These deposits include coeval, paralic, lagoonal Mesozoic sediments distributed in detached outcrops parallel to the shoreline. An analogy between the east coast sedimentary basins

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and those on the west coast of Australia has been observed by Sastry *et al.* (1974) on the basis of faunal and palynological comparisons.

The 'Ptilophyllum Flora' characterises the east coast sediments and has been traditionally considered Jurassic in age. Considerable floristic and stratigraphic data has accumulated, which necessitates a reassessment of earlier age assignments and stratigraphic placements. Additional records of Lower Cretaceous marine sediments have been reported from shallow, structural and deep wells drilled by the ONGC (Sastry *et al.*, 1974, 1975, 1981; Rao & Venkatachala, 1971; Venkatachala & Sinha, 1986). An objective analysis of this data demonstrates that the quantitative differentiation and age assignments based on megaflora are not tenable for east coast sediments.

The east coast 'Late Gondwana' sediments are distributed in Cauvery, Palar, Krishna-Godavari and Mahanadi basins. The ecological regimes of these sediments vary from nonmarine to paralic through marginal marine environments (Murthy & Sastry, 1961, 1962; Sastry & Mamgain, 1971; Venkatachala & Sinha, 1986). These represent a transition zone where continental and marine facies interdigitate. Palynological evidences suggest an environmental realm consisting of 'upland flora' characterised by allochthonous saccate gymnosperm pollen; autochthonous swampy environments marked by non-saccate palynoassemblage and phytoplankton denoting marine environments in Early Cretaceous sequence of the Krishna-Godavari Basin (Venkatachala & Sinha, 1986). This is also true with regard to the other basins under discussion (Venkatachala, 1977). Consequent to this observation the noticeable differences in the floral composition (Ferns/Cycadophytes/Conifers) of different basins have to be reassessed to understand the depositional environment and stratigraphic implications. A comparative analysis of mega- and palynofloral records from the sediments confirms an Early Cretaceous age. An overview and assessment of east coast 'Late Gondwana' floras help understand geological and climatic factors involved.

CAUVERY BASIN

Sivaganga Formation

'Late Gondwana' deposits occur near and around Uttatur, Terani, Naicolam, Karai, Rayani, Kattipuliyar and Sivaganga areas. The Sivaganga Formation, which is considered to be the southern most 'Late Gondwana' unit, comprises coarse pebbly and gritty sandstones. The subsurface facies equivalents comprise paralic shales and argillaceous sandstones. This formation underlies the well-known marine Upper Cretaceous fossiliferous sequences. Some thin beds within this formation contain plant fossils, arenaceous foraminifera and ostracods.

Megaflora—Megaflora has been studied by Feistmantel (1879), Gopal, Jacob and Jacob (1957), Chowdhury (1958), Mamgain, Sastry and Subbaraman (1973), Ayyaswami and Gururaja (1977), Jeyasingh and Sudhersan (1985) and Maheshwari (1986). Cycadophytes constitute the dominant group followed by conifers and ferns. The flora is characterised by *Marattiopsis, Taeniopteris, Thinnfeldia, Anomozamites, Ptilophyllum, Otozamites, Dictyozamites; Elatocladus, Brachyphyllum, Ginkgoites* and *Araucarites* (Table 1). The megafloral assemblage has been variously dated as Middle-Upper Jurassic (Feistmantel, 1879; Gopal, Jacob & Jacob, 1957; Bose, 1966). Studies by Ayyaswami and Gururaja (1977) and Maheshwari (1986) suggest an Early Cretaceous affinity.

Blanford (1862) remarked that the Uttatur plant beds appeared both on stratigraphical and lithological grounds "....to be not very widely separated in time from Cretaceous rocks immediately overlying them". Later, Chowdhury (1958) suggested that "...the plant beds are homotaxial with the Jabalpur—Tirupati group" These suggestions veer round a Lower Cretaceous age assignment.

Palynoflora—Palynology of subsurface sediments are known through the studies of Rao and Venkatachala (1971), Venkatachala *et al.* (1972) and Venkatachala (1973, 1974). Maheshwari (1986) also recorded some palynotaxa. The *Microcachryidites antarcticus* Zone (Neocomian) is recognised in the Karaikal, Karaikudi, Nagapattinam, Tirutturaipundi and Vridhachalam areas. This palynoflora comprises distinct markers such as *Cooksonites, Neoraistrickia, Aequitriradites, Polycingulatisporites, Impardecispora, Staplinisporites, Ischyosporites, Crybelosporites, Klukisporites* and *Contignisporites* (Table 2). Palynological evidences recorded in the subsurface of the Sivaganga area, as evidenced by a study of subsurface sequence met within the Karaikudi well, confirm marine influence during the Early Cretaceous.

Fauna—Mamgain, Sastry and Subbaraman (1973) recorded ammonites such as *Gymnoplites* cf. *simplex* Spath, *Pascoites* cf. *crassus* Spath and ?*Inoceramus* sp. from the Terani beds. Venkatachala (1977) lists *Ammodiscus cretaceous, Ammobaculites humei, Spiroplectammina* sp., *Haplophragmoides sluzari* and *Bathysiphon taurinensis.* Arenaceous foraminifera like *Ammobaculites, Ammodiscus, Bathysiphon, Haplophragmoides* and *Trachammina*

Table 1—Distribution of megaflora

Taxa	*Cauvery*	*Palar*		*Krishna-Godavari*		*Mahanadi*
	Sivaganga	*Sriperumbudur*	*Satyavedu*	*Krishna Depression*	*Godavari Depression*	*Athgarh*
	1	2a	2b	3a	3b	4
PTERIDOPHYTES						
Cladophlebis	sp.		sp.	sp.	sp.	sp.
C. indica	+	+	+	+	-	+
C. srivastavae	+	-	-	-	-	+
C. reversa	+	-	-	-	-	-
C. whitbyensis	-	+	-	+	+	+
C. denticulata	-	-	-	-	-	+
Sphenopteris	sp.	-	-	-	sp.	sp.
S. tiruchirapalliense	+	-	-	-	-	-
Onychiopsis paradoxus	-	-	-	-	-	+
Coniopteris	-	-	-	-	-	sp.
Rhizomopteris	sp.	-	-	-	-	-
R. balli	-	-	-	-	-	+
Marattiopsis macrocarpus	+	-	-	-	-	+
Phlebopteris athgarhensis	-	-	-	-	-	+
P. polypodioides	-	-	-	-	-	+
Gleichenia	-	-	-	-	-	sp.
G. gleichenoides	-	-	-	-	-	+
G. nordenskioldii	-	-	-	-	-	+
Hausmannia	-	-	-	-	-	sp.
Eboracia	-	-	-	-	-	sp.
Equisetites	sp.	-	sp.	-	-	sp.
PTERIDOSPERMS						
Cycadopteris	-	-	-	-	-	sp.
Pachypteris	-	-	-	-	-	sp.
P. ellorensis	-	-	-	+	-	-
Thinnfeldia	-	sp.	-	sp.	-	sp.
T. indica	+	-	-	-	-	-
T. subtrigona	-	-	-	-	+	-
T. feistmantelii	-	-	-	-	+	-
CYCADOPHYTES						
Taeniopteris	sp.	-	sp.	-	-	-
T. spatulata	+	+	+	+	+	+
T. ovata	+	-	-	-	-	-
T. lata	+	-	-	-	-	-
T. mcClellandii	-	+	-	+	+	-
T. ensis	-	-	-	+	-	-
Anomozamites	sp.	-	sp.	-	sp.	-
A. haburensis	+	-	-	-	-	-
A. lindleyanus	-	+	-	-	-	-
A. fissa	+	-	-	-	-	+
Pterophyllum	sp.	sp.	-	sp.	sp.	-
P. footeanum	-	+	-	-	+	-
P. morrisiana	+	-	-	+	-	-
P. carterianum	-	-	-	+	-	-
P. kingianum	-	-	-	+	-	-
P. distans	-	-	-	+	-	-
Ptilophyllum	sp.	-	-	sp.	sp.	-
P. acutifolium	+	+	+	+	+	+
P. cutchense	+	+	-	+	+	+
P. rarinervis	+	-	-	+	-	-
P. tenerrimum	-	-	-	+	-	-
Dictyozamites	-	sp.	sp.	-	-	-
D. indica	+	-	-	+	+	-
D. falcatus	+	-	-	+	+	-
D. feistmantelii	+	-	-	-	+	-

Contd.

D. sahnii	-	-	-	-	+	-
Otozamites	-	-	-	-	sp.	sp.
O. angustatus	+	-	-	-	-	-
O. rarinervis	+	+	-	+	+	-
O. exhislopii	-	-	-	-	+	-
O. vemavaramensis	-	-	-	-	+	-
O. gondwanaensis	-	-	-	-	+	-
Cycadites	-	-	-	-	sp.	-
Cycadolepis	-	-	-	sp.	sp.	sp.
Williamsonia	-	-	-	sp.	-	-
W. blanfordii	-	-	-	+	-	-
W. gigas	-	-	-	+	-	-
Pseudoctenis	sp.	-	-	-	-	-
P. footeana	+	-	-	-	+	-
Bucklandia	-	-	-	sp.	-	-
CONIFERALES						
Elatocladus	-	-	-	-	sp.	sp.
E. plana	+	+	-	+	+	-
E. tenerrima	+	+	-	+	-	-
E. conferta	+	+	-	+	-	+
Pagiophyllum	sp.	-	-	-	sp.	sp.
P. marwarensis	+	-	-	-	-	-
P. peregrinum	-	+	-	+	+	-
Brachyphyllum	sp.	-	sp.	-	-	sp.
B. regularis	+	-	-	-	-	-
B. rhombicum	-	+	-	+	-	-
B. rajmahalensis	-	+	-	-	-	-
B. feistmantelii	-	-	-	+	+	-
Araucarites	-	-	-	-	-	sp.
A. cutchensis	+	+	-	-	+	+
A. minutus	+	+	-	-	-	+
A. macropterus	-	+	-	+	-	cf.
Podozamites lanceolatus	+	-	-	+	-	+
Desmiophyllum	sp.	-	-	-	sp.	-
Conites	-	-	-	sp.	sp.	-
C. sessiles	-	+	-	-	+	-
C. sripermaturensis	-	+	-	-	-	-
C. verticillatus	-	+	-	-	-	-
Torreyites constricta	-	-	-	-	+	-
Araucarioxylon rajmahalense	-	+	-	-	-	-
A. agathioides	-	-	-	+	-	-
Podocarpoxylon parthasarathyi	-	+	-	-	-	-
P. tirumangalense	-	+	-	-	-	-
Cupressinoxylon coromandelinum	-	+	-	-	-	-
C. alternans	-	-	-	+	-	-
GINKGOALES						
Ginkgoites	sp.	sp.	-	sp.	-	-
G. rajmahalensis	cf.	-	-	-	-	-
G. crassipes	-	+	-	+	+	-
G. feistmantelii	-	-	-	+	-	-
Baiera	-	-	-	-	-	sp.

(+) Present; (-) Absent; (sp.) Species not attributed; (cf.) Comparable form

were recorded by Banerji and Sastry (1979). Banerji (1982) reported some arenaceous foraminifera from the Sivaganga Formation which include *Lituola* sp., *Miliammina* sp., *Pelosina* sp., *Polychasmina* sp., *Pseudoreophax* sp., *Saccamina* sp. and *Textularia* sp. These evidences ascribe an Early Cretaceous age.

Dalmiapuram Formation

This formation succeeds Sivaganga Formation and comprises a sequence of marine limestones with intervening shales containing ammonoids, foraminifera, ostracods and palynofossils (Banerji, 1972; Bhatia & Jain, 1969; Jain, 1968; Jain, 1977; Venkatachala, 1972). Plant megaflora is not known.

Palynoflora—The palynoflora is known through the studies of Jain and Subbaraman (1969), Rao and Venkatachala (1971), Venkatachala *et al.*, 1972; Jain and Taugourdeau Lantz (1973) and Jain (1977). Rich and diversified phytoplankton known from this

Table 2—Distribution of palynoflora

Taxa	*Cauvery*	*Palar*	*Krishna-Godavari*	*Mahanadi*
Cyathidites australis	+	+	+	+
C. minor	+	+	+	+
C. punctatus	–	–	+	–
C. pseudopunctatus	–	–	+	–
C. cutchensis	–	–	+	–
C. trilobatus	–	–	+	–
C. jurassicus	–	–	+	–
C. asper	–	–	cf.	–
C. cancavus	–	–	–	+
Deltoidospora	Sp.	–	Sp.	Sp.
D. baltiiminor	+	–	–	–
D. rhytisma	+	–	–	–
D. juncta	–	+	–	–
D. diaplana	–	+	–	–
Stereisporites antiquasporites	+	+	+	–
Biretisporites	sp.	sp.	+	–
B. spectabilis	+	+	+	–
B. potoniaiae	–	+	cf.	–
Concavisporites	sp.	–	–	–
C. juriensis	+	–	–	–
C. cutchensis	–	+	–	–
Leptolepidites	sp.	–	sp.	–
L. major	–	–	–	–
L. verrucatus	–	+	–	–
Triletes	–	–	–	sp.
T. verrucosus	+	+	+	–
T. tuberculiformis	+	+	–	–
T. orikkaiense	–	+	–	–
T. grandiverrucosus	–	–	+	–
T. rugosus	–	–	+	–
Osmundacidites	sp.	–	–	–
O. singhii	–	+	–	–
O. wellmanii	–	+	+	+
Baculatisporites comaumensis	+	+	–	–
B. claveoides	–	+	–	–
B. baculatus	–	+	+	–
Concavissimisporites	sp.	–	sp.	–
C. veriverrucatus	–	+	–	–
C. crassatus	–	–	–	+
Impardecispora	–	–	–	sp.
I. purverulentus	+	–	+	–
I. apiverrucata	–	+	–	+
I. trioreticulosus	–	+	+	–
I. marylandensis	–	+	–	–
I. tribotrys	–	–	+	–
Neoraistrickia	sp.	–	–	sp.
N. truncatus	+	+	+	–
Ceratosporites	sp.	sp.	–	–
C. acutus	+	–	+	–
C. equalis	+	+	+	–
C. couliensis	–	+	–	–
Foveotriletes	sp.	–	–	–
F. crassipunctatus	–	–	+	–
Lycopodiumsporites eminulus	+	+	+	–
L. austroclavatidites	+	+	+	+
L. reticulumsporities	+	–	–	–
L. sp. cf. *trambauensis*	–	+	–	–
L. reticulum	–	–	+	–
L. regulatus	–	–	+	–
L. crassireticulatus	–	–	+	–
L. circolumeus	–	–	+	–
Lycopodiacidites	sp.	–	–	–

Contd.

Klukisporites	sp.	-	-	-
K. scaberis	+	-	+	-
K. faveolatus	-	+	-	-
K. areolatus	-	+	-	+
K. pseudoreticulatus	-	-	-	+
Staplinisporites caminus	+	+	+	-
Converrucosisporites	sp.	sp.	-	-
Laevigatosporites	sp.	-	-	sp.
Corrugatisporites	sp.	-	-	-
Lygodiites laevigatus	+	-	-	-
Pilosisporites	sp.	sp.	-	-
Cicatricosisporites	sp.	-	-	-
C. hughesii	+	-	+	-
C. metrioides	-	+	-	-
C. ludbrookei	+	+	-	-
C. australiensis	+	+	+	-
C. hallei	-	+	-	-
C. augustus	-	+	-	-
C. gonidontos	-	+	-	-
C. apicaulis	-	+	-	-
C. mohriodes	-	+	-	-
Matonisporites	sp.	sp.	sp.	-
M. phlebopteroides	-	+	-	-
M. crassiangulatus	-	+	-	+
M. discoidalis	-	+	-	-
M. cooksonae	-	+	-	-
M. sahnii	-	+	-	-
Ischyosporites crateris	+	+	+	+
I. punctatus	-	+	-	-
Gleichenidites	sp.	sp.	sp.	-
G. senonicus	-	+	+	-
G. circinidites	-	+	-	+
Clavifera	sp.	sp.	-	-
Appendicisporites	-	sp.	-	-
A. sp. cf. *A. tricornitatus*	+	-	-	-
A. sp. cf. *A. irregularis*	+	-	-	-
A. verrucosa	-	+	-	-
A. sellingii	-	-	+	-
Taurocusporites	sp.	-	-	-
T. segmentatus	-	+	-	-
Plicifera	sp.	-	-	-
P. minutus	-	+	-	-
P. senonicus	-	-	+	-
Cingulatisporites	sp.	-	-	-
Coptospora	sp.	sp.	-	-
C. cauveriana	+	+	-	-
C. kutchensis	-	+	-	-
Contignisporites	sp.	sp.	-	-
C. glebulentus	+	+	+	+
C. multimuratus	+	+	+	-
C. cooksonii	+	+	+	-
C. fornicatus	+	-	+	+
C. crenatus	-	+	-	-
C. dorsostriatus	-	+	-	-
C. problematicus	-	+	-	-
Kraeuselisporites linearis	+	+	+	-
Psilospora	sp.	-	-	-
Polycingulatisporites roduncus	+	+	+	-
Crybelosporites stylosus	+	-	+	-
C. punctatus	-	+	-	-
Densosporites	-	sp.	·	·
D. velatus	+	-	+	-
D. indicus	-	-	-	+
Monoletes	-	sp.	-	-
M. indicus	-	+	-	+
M. grandis	+	-	-	-

Contd.

M. intragranulatus	–	+	–	–
Thymospora	sp.	–	sp.	–
Cooksonites	sp.	sp.	–	–
C. variabilis	–	+	+	–
Aequitriradites	–	sp.	–	–
A. spinulosus	+	+	+	–
Polypodiisporites	sp.	–	sp.	–
Callialasporites trilobatus	+	+	+	+
C. lenticularis	+	–	–	–
C. triletes	+	+	+	+
C. segmentatus	+	+	+	+
C. dempieri	+	+	+	+
C. monoalasporus	+	–	+	–
C. kattavakuamense	–	+	–	–
C. reticulatus	–	+	–	–
C. discoidalis	–	+	–	+
C. punctatus	–	+	–	–
C. lucidus	–	–	+	+
C. doeringii	–	–	–	+
C. enigmatus	–	–	–	+
Cornamessifera	sp.	–	–	–
Coronatispora	sp.	sp.	–	–
C. perforata	–	+	–	–
Sestrosporites	sp.	–	–	–
S. pseudoalveolatus	–	+	–	sp.
Auritulinasporites	sp.	–	–	–
Tripartina	sp.	–	–	–
Undulatisporites pannuceus	–	+	–	–
Dictyophyllidites	–	–	–	sp.
D. venkatachalae	–	+	–	–
D. harrisii	–	–	–	+
Todisporites rotundiformis	–	+	–	–
T crassus	–	+	–	–
T. minor	–	+	–	+
Echinatisporis varispinosus	–	+	–	–
E. vembanii	–	+	–	–
Foveosporites	–	sp.	–	–
F. canalis	–	+	–	–
F. subtriangularis	–	+	–	–
Dictyosporites complex	–	+	–	–
Callispora faveolata	–	+	–	–
C. potoniei	–	+	–	–
Ornamentifera	–	–	–	sp.
O. echninata	–	+	–	–
O. granulosa	–	–	+	–
Murospora sp. cf. *mesozoica*	–	+	–	–
M. florida	–	–	+	–
Verrucosisporites	–	–	–	sp.
V. rotundus	–	+	–	–
Foraminisporis cf. *dailyi*	–	+	–	–
Distalanulisporites verrucatus	–	+	–	–
Crassimonoletes	–	–	–	sp.
C. surangei	–	+	–	–
Metamonolites baradensis	–	+	–	–
Bhujiasporites	–	–	sp.	–
Conbacculatisporites densibaculatus	–	–	+	–
Boseisporites	–	–	sp.	–
B. praeclarus	–	–	–	+
Vitreisporites	sp.	–	–	sp.
V. pallidus	+	+	+	+
Lametatriletes indicus	–	–	–	+
Dettmannites	–	–	–	sp.
Reticulatisporites pudens	–	–	–	+
Alisporites	sp.	–	–	sp.
A. grandis	+	+	–	+

Contd.

A. ovalis	–	+	–	+
A. rotundus	–	+	–	–
A. ellipticus	–	–	+	–
Podocarpidites ellipticus	+	+	–	+
P. multesimus	+	–	+	–
P. major	–	+	–	–
P. minisculus	–	+	–	–
P. grandis	–	–	+	–
P. crisiliteximus	–	–	+	–
P. typicus	–	–	+	–
P. magnus	–	–	–	+
P. novus	–	–	–	+
Microcacbryidites	sp.	–	–	–
M. antarcticus	+	+	+	+
Podosporites tripakshii	+	+	+	+
P. raoi	–	–	+	–
Classopollis	sp.	sp.	–	–
C. classoides	+	+	+	+
C. obidonensis	–	+	–	–
C. torosus	–	–	+	–
C. indicus	–	–	–	+
Cedripites nudis	+	+	–	+
C. cretaceous	–	+	–	–
Parvisaccites	sp.	–	–	–
Ginkgocycadophytes	–	–	–	sp.
G. asymmetricus	–	–	+	–
G. detritus	–	–	+	–
G. nitidus	+	+	–	–
G. srivastavae	–	–	+	–
Araucariacites	sp.	–	–	–
A. australis	+	+	+	+
A. ghuneriensis	–	–	–	+
Spheripollenites scabratus	+	+	+	–
S. psilatus	+	–	–	–
Phyllocladidites	–	–	sp.	–
Ramanujamiaspora reticulata	–	–	+	–
Leschikiasporis rudis	–	–	+	–
Singhiapollis triletes	–	–	+	–
S. rudis	–	–	+	–
Indusiisporites microsaccatus	–	–	+	–
Inaperturopollenites	–	–	–	sp.
Araucariapollenites	–	–	–	sp.
Platysaccus densus	–	+	–	–
Phyllocladites inchoatus	–	+	–	–
Dacrycarpites australiensis	–	+	–	–
Laricoidites commiensis	–	+	–	–
L. indicus	–	+	+	–
Granuloperculatipollis	–	sp.	–	–
G. subcircularis	–	–	+	–
G. triletus	–	–	+	–
G. flavatus	–	–	+	–
Schizosporis regulatus	–	+	–	–
Properinopollenites monoalasporus	–	–	–	+
Seboripollenites	–	–	–	+
Abiespollenites	–	–	–	+
Cycadopites couperii	–	+	–	+
C. gracilis	–	+	–	–
C. sakrigaliensis	–	+	–	–

(+) Present; (–) Absent; (sp.) Species not attributed; (cf.) Comparable form.

formation suggest an Early Albian age (Jain, 1977). The palynoflora is assigned to *Coptospora cauveriana* Zone of Aptian—Early Albian age (Venkatachala *et al.*, 1972). It is characterised by *Ceratosporites, Coptospora, Cooksonites, Aequitriradites, Staplinisporites, Foveotriletes, Sestrosporites, Krauselisporites, Foveosporites, Baculatisporites, Klukisporites, Ischyosporites, Trilites, Impardecispora, Polypodiaceoisporites, Appendecisporites, Pilosisporites, Polycingulati-*

sporites, Contignisporites, Crybelosporites, Podosporites and *Classopollis* (Table 2). The occurrence of *Classopollis* and corroded nature of spore and pollen suggest long transportation of palynofossils before deposition. A marine depositional environment is ascribed on the basis of phytoplankton and foraminifera. Foraminiferal evidences suggest that the depositional environment was marine and the depositional site was probably away from the main continental landmass.

Fauna—Rich foraminiferal assemblages recovered from this unit help recognise different biozones like *Lenticulina macrodisca* Zone and *Hedbergella planispira* Zone (Banerji, 1972). They ascribe Aptian—Early Albian and Early Albian age (Jain, 1968; Bhatia & Jain, 1969; Banerji, 1972). Significant fauna include *Lytoceras, Puzosia, Pascoeites, Engonoceras* (ammonoids) and *Lenticulina, Trestix, Gavelinella, Vagunilina, Nodosaria, Gavellinopsis* and *Glandolina* (foraminifers) (Jaikrishna, 1983). Trace fossil *Chondrites* Sternberg was also recorded (Chiplonkar & Tapaswi, 1975).

PALAR BASIN

Sriperumbudur beds

These are characterised by arenaceous and argillaceous rock units comprising splintery green shale, clays and sandstones with ironstone intercalations and unconformably overlaying either the Precambrian basement or Permian boulder beds and green shales. The beds contain marine intercalations (Murthy & Sastri, 1961). Their lithologic suites and fossil fauna are suggestive of deposition under shallow and brackish conditions, probably close to the shoreline (Sastry *et al.*, 1974).

Megaflora—The megaflora comprises species of *Cladophlebis, Dictyozamites, Taeniopteris, Pterophyllum, Otozamites, Ptilophyllum, Elatocladus, Brachyphyllum, Araucarites, Conites, Ginkgoites* and some conifer woods (Feistmantel, 1879; Seward & Sahni, 1920; Sahni, 1928, 1931; Suryanarayana, 1954, 1955). The floral assemblage in general is dominated by conifers followed by cycadophytes and ferns. Pteridosperms and Ginkgoales are poorly represented (Table 2). Foote (1868) compared Sriperumbudur megaflora with that of Rajmahal. A Jurassic affinity to this flora was also suggested (Feistmantel, 1879).

Palynoflora—Palynoflora is known both from surface and subsurface (Ramanujam & Srisailam, 1974; Ramanujam & Varma, 1977, 1981; Venkatachala, 1977; Varma & Ramanujam, 1984). The characteristic fossils include *Aequitriradites, Coptospora, Cooksonites, Foraminisporis, Staplinisporites, Sestrosporites, Ornamentifera, Klukisporites, Impardecispora, Cicatricosisporites, Appendicisporites, Contignisporites, Undulatisporites, Coronatispora, Polycingulatisporites, Taurocusporites, Crybelosporites, Murospora* and *Microcachrydites* (Table 2). Sriperumbudur palynoflora shows significant resemblance with the Early Cretaceous palynoflora from Cauvery and Krishna-Godavari basins.

Fauna—Murthy and Sastry (1961) recorded an Early Cretaceous fauna consisting of ammonite *Pascoites crassus* and foraminifera—*Pelosina complaneta, Haplophragmoides concava, H. footei, H. indicus, Bathysiphon* cf. *taurinensis, Ammodiscus cretaceous, Lituotuba* sp. and *Spiroplectammina indica*.

Satyavedu beds

These overlie the Sriperumbudur beds and are characterised by grits, sandstones and conglomerates. Fragmentary plant fossils are recorded which include *Equisetites, Cladophlebis, Taeniopteris, Nilssonia, Ptilophyllum, Dictyozamites, Elatocladus* and *Brachyphyllum* (Murthy & Ahmed, 1971; Sastry *et al.*, 1977). Faunal and palynological records are wanting. These beds are often correlated with Tirupati and Pavalur beds of Krishna-Godavari Basin.

KRISHNA-GODAVARI BASIN

'Late Gondwana' sediments in this basin are mainly exposed near the western fringes of the Krishna and West Godavari depressions. These unconformably overlie either the Precambrian basement or Permian sediments. These sediments contain few plant and animal fossils. Data derived through surface and subsurface sediments from wells drilled by ONGC suggest that the tripartite classification in the outcrop is not tenable in the subsurface and the respective units are probably lithofacial variants of major argillaceous sequence (Venkatachala & Sinha, 1986).

Krishna Depression

This includes three lithologic units, viz., Budavada Sandstone, Vemavaram Shale and Pavalur Sandstone. The Budavada Sandstone comprises sandstones on the surface and mostly shales in the subsurface. These contain both plant and marine invertebrate fossils. Plant megaflora mainly comprises *Taeniopteris, Otozamites, Dictyozamites, Ptilophyllum* and some conifer woods (Sastry *et al.*, 1977). Marine fossils include ammonites *Pascoeites budavadensis, Gymnoplites simplex* and associated foraminifera, bryozoans, lamellibranchs, gastropods and brachypods (Sastry *et al.*, 1977). These indicate an Early Cretaceous age (Spath, 1933; Sahni, 1960; Bhalla, 1969). Wells drilled on the outcrops of Budavada unit near Nutalapadu and Inkollu yielded shale sections similar to other equivalent units within the basin (Venkatachala & Sinha, 1986). This unit is often correlated with Gollapalli unit in West Godavari depression and Athgarh Sandstone in Mahanadi Basin.

The Vemavaram Shale comprises light grey shales. The subsurface sediments in Uppugunduru well comprise sandstones and silty shales. The plant fossils include *Cladophlebis, Thinnfeldia, Taeniopteris, Ptilophyllum, Otozamites, Elatocladus, Brachyphyllum* and *Araucarites* (Feistmantel, 1879; Seward & Sahni, 1920; Sahni, 1928; Suryanarayana, 1954; Rao, 1959; Bose & Jain, 1967; Jain, 1968; Bose, 1974; Bose & Bano, 1978). This assemblage, dominated by cycadophytes followed by conifers and pteridophytes, has been compared with the Sriperumbudur flora and was considered as Jurassic in age (Feistmantel, 1879). Palynoflora was studied by Ramanujam (1957) and Kar and Sah (1970) and a reassessment suggests an Early Cretaceous age. Animal remains from Vemavaram Shale were identified by Spath (1933) and consist of ammonites, brachipods, lamellibranchs, fish scales and mammalian ribs. The evidences considered *in toto* confirm Early Cretaceous age assignment.

The Pavalur Sandstone conformably overlies the Vemavaram Shale and is composed of sandstones and has been correlated with Tirupati Sandstone in the West Godavari depression. Fossil records are wanting.

West Godavari Depression

'Late Gondwana' sediments are once again represented by three units, viz., Gollapalli Sandstone, Raghavapuram Shale and Tirupati Sandstone. The Gollapalli Sandstone unconformably overlies the Chintalpudi Sandstone and underlies unconformably the Raghavapuram Shale. It comprises sandstones, grits and conglomerates with thin clay intercalations containing plant fossils and arenaceous foraminifera. Some of the important plant fossils include *Gleichenia, Marattiopsis, Pachypteris, Ptilophyllum, Dictyozamites, Taeniopteris, Pterophyllum, Williamsonia, Elatocladus* and *Araucarites* (Table 1) (King, 1880; Feistmantel, 1877a; Sahni, 1928; Sarma, 1957; Baksi, 1964; Mahabale & Satyanarayana, 1979). While discussing the tectonics, sedimentation and marine transgression in this sub-basin, Baksi (1977) inferred a marginal marine to fluvial environment to Gollapalli Sandstone.

The Raghavapuram Shale is characterised by white and buff shales, sandstones, variegated and purplish arenaceous shales. Due to lack of fissility in these rocks the term shale has been replaced by mudstone (Baksi, 1967a).

Megaflora chiefly comprises *Cladophlebis, Taeniopteris, Williamsonia, Ptilophyllum, Otozamites, Dictyozamites, Ginkgoites, Brachyphyllum, Elatocladus* and *Araucarites* (Table 1) (Feistmantel, 1879; Seward & Sahni, 1920; Sahni, 1931; Baksi, 1967a, 1967b). This assemblage was considered Jurassic (Feistmantel, 1879).

Arenaceous foraminifera dominated by *Ammobaculites* associated with *Haplophragmoides* suggest an Early Cretaceous age (Baksi, 1966; Sastry *et al.*, 1963; Bhalla, 1969a, 1972). Other fossils include fish scales and molluscs.

The Tirupati Sandstone comprises clayey, friable and lateritised sandstones. In the subsurface it consists of shales and sandstones. These contain fragmentary plant remains and marine invertebrate fossils like *Holocoleras, Trigonia ventioxa, T. smeei, Pseudomonotis, Limia pecten, Belemnite* and considered to be of Aptian age (Sastry *et al.*, 1977).

Palynological studies from the subsurface sequences from different wells drilled throughout the basin indicate Neocomian-Aptian age (Sastry *et al.*, 1977; Venkatachala & Sinha, 1986). Palynoassemblages encountered in the Krishna-Godavari Basin are enumerated in Table 2. The important fossils include *Staplinisporites, Contignisporites, Triletes, Impardecispora, Crybelosporites, Appendicisporites, Aequitriradites* and *Microcachryidites.*

It may be concluded that the tripartite classification of the exposed 'Late Gondwana' sediments in the Krishna-Godavari Basin is not tenable as the three lithological units identified in the outcrops give place to major argillaceous sequence in the near subsurface and indicate an Early Cretaceous age (Venkatachala & Sinha, 1986). Both palynological and faunal evidences support this age assignment. The major palaeoecological regimes deduced from these evidences indicate nonmarine-paralic through swampy environments.

MAHANADI BASIN

Athgarh Sandstone of 'Late Gondwana' affinity, exposed near the western margin of the basin, consists mainly of white to grey, hard sandstones with intercalations of lenticular greyish-white to pinkish clays and carbonaceous shales bearing plant megafossils.

Megaflora—Some important taxa include *Marattiopsis, Gleichenia, Phlebopteris, Cladophlebis, Eboracia, Hausmannia, Cycadopteris, Onychiopsis, Anomozamites, Ptilophyllum, Araucarites* and *Brachyphyllum* (Table 1) (Feistmantel, 1877b; Adyalkar & Rao, 1963; Jain, 1968; Pandya & Patra, 1968; Patra, 1973, 1980; Patra & Patnaik, 1974). Predominance of pteridophytes helps to compare this with other known Early Cretaceous assemblages of western and central India.

Palynoflora—Presence of important palynotaxa *Ischyosporites, Impardecispora, Klukisporites, Sestrosporites* and *Contignisporites* allows an Early Cretaceous age assignment (Table 2) (Maheshwari, 1975; Jana & Tiwari, 1987).

DISCUSSION

'Late Gondwana' plant beds associated with primarily marine sediments have been well-documented from the east coast basins. A critical reassessment of the 'Late Gondwana' flora in the east coast suggests that floral differentiation and variations in several basins and sub-basins can be attributed to ecological parameters and preservational factors. These floras are homotaxial, though, minor variations are evident. Fallible evidences like presence or absence of Wealden ferns may not hold good for age assignment. The discrepancy between palynological evidences supported by faunal records on one hand and megaflora on the other is due to incompleteness of evidence. Biostratigraphic evidences should be considered *in toto*.

East coast Early Cretaceous sediments embody significant plant fossils such as *Onychiopsis paradoxus, Hausmannia* sp., *Pagiophyllum marwarensis* and *Brachyphyllum regularis*. These plant fossils are also known from some of the Early Cretaceous sequences of central and western India. Predominance of pteridophytes characterises Athgarh megaflora. Likewise equivalent sediments in other basins of east coast also contain more or less similar floral components. Relative dominance of one group of plants over the other in different basins can be ascribed to different ecological niches which are conducive to preservation of megafossils. Available evidences strongly indicate that floral differentiation observed is due to lack of understanding and incompleteness of data rather than their actual absence. Similarly mere occurrence of terrestrial fossils does not imply a continental deposition. This has to be supplemented with data from other disciplines.

An evaluation of palynoflora from the four east coast sedimentary basins suports an Early Cretaceous age assignment. This flora is represented by upland, near basinal as well as marginal floral components. Cosmopolitan palynotaxa such as *Cicatricosisporites, Aequitriradites, Foraminisporis, Crybelosporites, Trilobosporites, Densoisporites, Coptospora* and *Coronatispora* are mostly known from these basins. Distinct palynological zones of the Early Cretaceous subsurface sequence in the Cauvery Basin, viz., *Microcachryidites antarcticus* Zone, *Coptospora cauveriana* Zone and *Triporoletes reticulatus* Zone (in parts) show a characteristic vertical range. These palynofloras containing spore pollen as well as phytoplankton assemblages are Neocomian and Aptian—Early Albian in age (Venkatachala *et al.*, 1972).

Distinct Early Cretaceous palynofossil suites in the Palar Basin from Conjeevaram, Kattavakam, Avadi and Orikkai areas are recognised through the presence of *Contignisporites, Impardecispora, Sestrosporites, Ornamentifera, Klukisporites, Coptospora, Aequitriradites* and *Cooksonites*.

Neocomian—Aptian palynofossil suites (Sharma *et al.*, 1977; Venkatachala & Sinha, 1986) in the subsurface sediments of the Krishna-Godavari Basin are closely comparable to those of the *Crybelosporites stylosus* and the *Dictyotosporites speciosus* zones (Dettmann & Playford, 1969) in Australia. Some of the common palynotaxa include *Crybelosporites stylosus, Murospora florida, Aequitriradites hispidus, Cyclosporites hughesii, Contignisporites cooksoniae, Kraeuselisporites linearis, Biretisporites spectabilis, Dictyotosporites speciosus, Cooksonites variabilis, Foraminisporis asymmetricus, Cicatricosisporites australiensis* and *C. ludbrookii*.

Palynoassemblages recorded from the 'Late Gondwana' sediments of the Mahanadi Basin also contain important Early Cretaceous palynotaxa such as *Impardecispora, Klukisporites, Ischyosporites, Sestrosporites* and *Contignisporites*.

Well documented Early Cretaceous palynofloral assemblages (Neocomian-Aptian) of Kutch and Jabalpur are closely comparable with east coast palynoflora.

As early as 1871, Waagen remarked that cephalopod evidences suggest an Early Cretaceous (Neocomian) age to the marine deposits found in the east coast. Striking similarity of the arenaceous foraminifera of the basins on the east coast of India with those of Australia was also suggested (Sastry *et al.*, 1974, 1981).

Sedimentation of the 'Late Gondwana' on the east coast is attributed to rifting of the Indian Plate during Early Cretaceous (Datta *et al.*, 1983). Both Lower and Upper Cretaceous marine sediments along the east coast were deposited by one and the same marine transgression. An absence of Jurassic sedimentation is possible taking into consideration major reactivation phase coupled with rifting history of 'Gondwana'.

Environment of sedimentation in the east coast is paralic. These sequences consist mainly of sandstones and shales laid down under shallow marine environments. Marine and non-marine 'Late Gondwana' units are contemporary and interdigitate. Similar flora and fauna can be observed in intracratonic and coastal sediments.

The presence of marine fossils and terrestrial plant remains rather suggests that the deposition probably took place in a tranquil, open marine basin near to the shore line. The occurrence of 'Late Gondwana' sediments along the east coast indicates similar depositional mileau. Occurrence of both autochthonous and allochthonous floral components and phytoplankton indicates an ecosystem consisting of non-marine to paralic through swampy environments. Abundance of ferns, cycadophytes and conifers in these floral assemblages also supports this conclusion.

Thus, it is necessary to consider the entire set of stratigraphic, tectonic, palynologic, palaeontologic and environmental evidences to understand the stratigraphic implication of the east coast 'Late Gondwana' flora. Megafossil evidences need be tied up with others for a meaningful interpretation. The occurrence of marine intercalations, earlier considered sporadic, is more a rule than an exception. In view of this, stratigraphic usage of the term 'Gondwana' needs to be reviewed. The term could be recircumscribed to include marine sequences or discontinued to be used.

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The Palaeobotanist **36** : 197-200, 1987.

Some new genera of Triassic seeds

S. R. Manik

Manik, S. R. (1988). Some new genera of Triassic seeds. *Palaeobotanist* **36** : 197-200.

Cuticular studies of compressed seeds from the Triassic sediments of Nidpur, Sidhi District, Madhya Pradesh have revealed the presence of five new genera, viz., *Savitrispermum, Nidispermum, Rotundaspermum, Pyriformispermum* and *Pantiaspermum*. The seeds exhibit affinities with Pteridospermales and Cycadales.

Key-words—Megafossil, Pteridospermales, Cycadales, Seeds, Triassic (India).

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साराँश

त्रिसंघी युगीन बीजों की कुछ नई प्रजातियाँ

सुरेन्द्र राघोबा माणिक

सिधी जनपद (मध्य प्रदेश) में निदपुर के त्रिसंघी युगीन अवसादों से उपलब्ध बीजों के उपचर्मीय अध्ययन से **सावित्रीस्पर्मम्**, **निदिस्पर्मम्**, **रोटन्डास्पर्मम्**, **पाइरिफ़ॉर्मिस्पर्मम्** एवं **पन्तियास्पर्मम्** नामक पाँच नई प्रजातियों की उपस्थिति व्यक्त हुई है। ये सभी बीज टेरिडोस्पर्मेल्स एवं साइकेडेल्स से सजातीयता इंगित करते हैं।

A NUMBER of seeds have been recovered from the bulk maceration of a carbonaceous shale from the Triassic Sequence exposed near Nidpur, Sidhi District, Madhya Pradesh. The seeds show well-preserved cuticle. On the basis of differences in the cuticular features of various seed membranes, five new genera have been established.

SYSTEMATICS

Savitrispermum gen. nov.

Pl. 1, figs 1, 2

Diagnosis—Seed oval; micropylar end curved, having crateriform opening; chalazal end rounded, pollen chamber well-defined; surface smooth, cuticle thin; outer integument consisting of rectangular cells, cell-walls straight; nucellar membrane tough, cells polygonal having slightly undulating cell-walls; megaspore membrane exhibiting no cellular details.

Type species—*Savitrispermum crateriformis.*

Holotype—Slide no. BSIP 9727.

Derivatio nominis—After Late Mrs Savitri Sahni.

Discussion—In its curved micropyle the taxon closely compares with seeds of *Umkomasia* Thomas 1933, a branched fructification. *Amphorispermum* Harris 1932 from Greenland resembles in general shape and size but differs in the presence of "spotted layer".

Nidispermum gen. nov.

Pl. 1, figs 3, 4

Diagnosis—Seed oval; micropylar end obtusely pointed; chalazal end broadly oval; cuticle thick;

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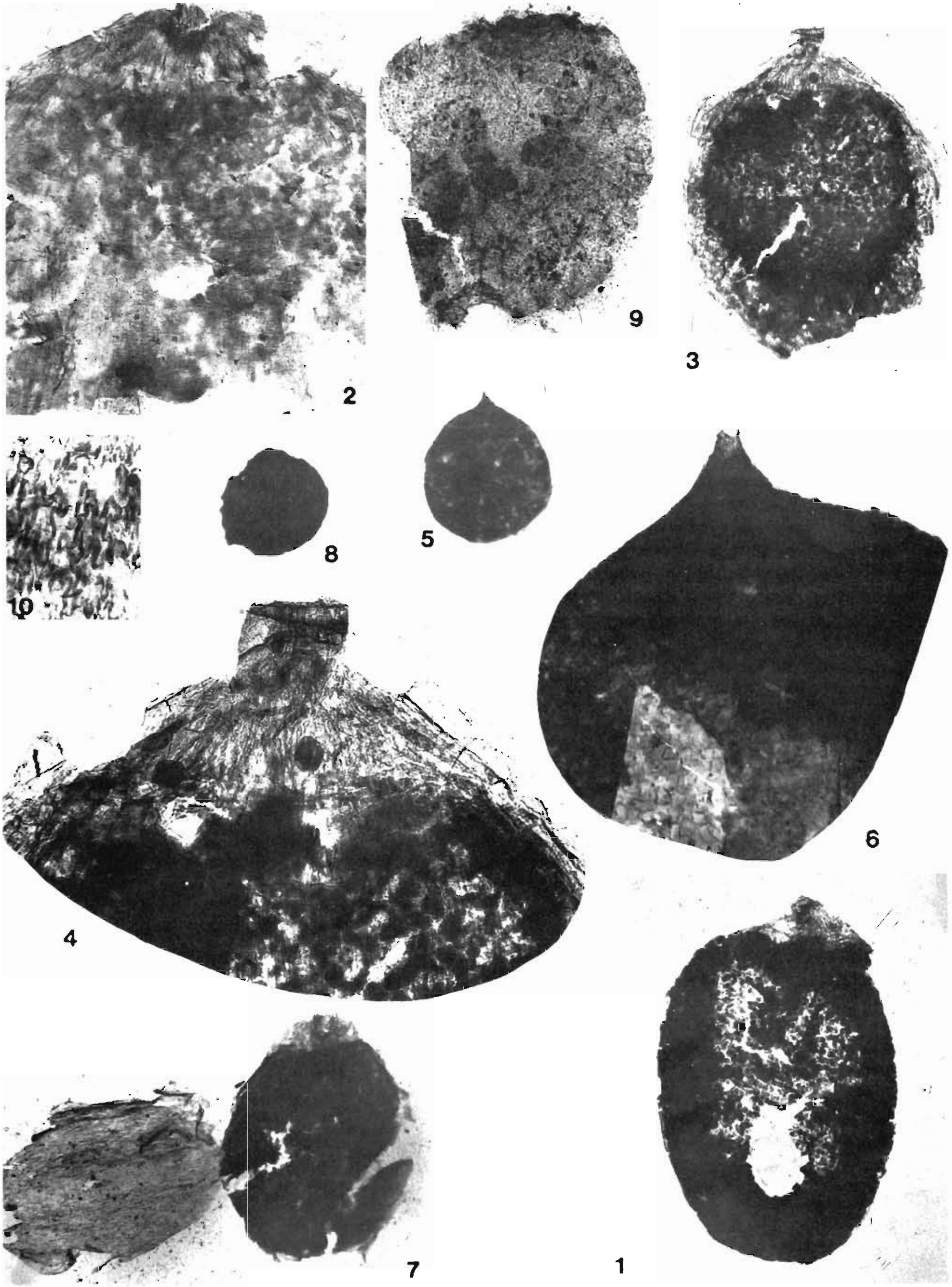

PLATE 1

outer integument tough, smooth or papillate, cells polygonal, straight-walled, nucellar membrane composed of polygonal cells, cells longer than broad; pollen-chamber distinct, pollen-grains present.

Type species—Nidispermum glabrosum.

Holotype—Slide no. BSIP 9729.

Discussion—Nidispermum, while resembling *Savitrispermum* in general shape and size, differs in the absence of a curved micropyle. In its characteristic epidermal structure, *Nidispermum* shows similarity with *Dicroidium nidpurensis* Bose & Srivastava, 1971.

Rotundaspermum gen. nov.

Pl. 1, figs 5, 6

Diagnosis—Seed more or less rounded with mucronate micropylar end; cuticle thick; outer integument consisting of polygonal cells with straight lateral- and end-walls; nucellar membrane made up of irregular polygonal cells showing cell-walls with fine undulations.

Type species—Rotundaspermum mucronatum.

Holotype—Slide no. BSIP 9730.

Discussion—Rotundaspermum mucronatum is distinguished from other seed genera by the presence of mucronate micropylar end.

Pyriformispermum gen. nov.

Pl. 1, fig. 7

Diagnosis—Seed pyriform; micropylar end obtusely pointed, chalazal end broadly oval; cuticle moderately thick; outer integument showing longitudinally elongated cells with smooth surface, cell-walls straight; inner integument delicate, adhering to nucellar membrane; nucellar cuticle thick, cells polygonal; megaspore membrane ill-defined.

Type Species—Pyriformispermum elongatum.

Holotype—Slide no. BSIP 9731.

Discussion—Genus *Pyriformispermum* is distinguished by its pear-shaped character.

Pantiaspermum gen. nov.

Pl. 1, figs 8-10

Diagnosis—Seed broadly oval to elliptical; micropylar and chalazal ends somewhat rounded; cuticle thick; outer integument robust, bearing thickly-developed papillae, scattered all over the surface obscuring cell outlines; nucellar cuticle thick, cells polygonal or at times irregular; megaspore membrane dark brown in colour with indistinct cellular structure.

Type species—Pantiaspermum cristatum.

Holotype—Slide no. BSIP 9732.

Derivatio nominis—After Professor D. D. Pant.

Discussion—In the presence of typical papillae *Pantiaspermum* differs from other seed genera.

ACKNOWLEDGEMENTS

The author is grateful to Dr B. S. Venkatachala for his encouragement and keen interest during the progress of this work. Thanks are also extended to Dr Shyam C. Srivastava for confirming the identifications and critically going through the manuscript.

←

PLATE 1

(All type slides are deposited with repository of Birbal Sahni Institute of Palaeobotany, Lucknow)

Savitrispermum crateriformis gen. et sp. nov.

1. Whole mount of seed showing curved micropyle and nucellus; Holotype slide no. BSIP 9727. × 25.
2. Outer integument of seed with differentiated pollen chamber, Slide no. BSIP 9728. × 50.

Nidispermum glabrosum gen. et sp. nov.

3. A carbonized seed after alkali treatment showing integument being separated. Holotype, slide no. BSIP 9729. × 25.
4. Micropylar end of seed showing micropylar hole and details of pollen chamber associated with a part of nucellus. Slide no. BSIP 9729. × 80.

Rotundaspermum mucronatum gen. et sp. nov.

5. A seed immersed in glycerine showing mucronate micropylar end. Holotype slide no. BSIP 9730. × 10.
6. Micropylar region of seed showing details of micropylar end and nucellus. Slide no. BSIP 9730. × 50.

Pyriformispermum elongatum gen. et sp. nov.

7. Whole mount of seed showing complete outer integument of one face alongwith micropylar opening and pollen chamber, Holotype slide no. BSIP 9731. × 25.

Pantiaspermum cristatum gen. et sp. nov.

8. Seed immersed in glycerine. Holotype slide no. BSIP 9732. × 10.
9. A complete outer investment of seed, with distinct micropylar opening, Slide no. BSIP 9732. × 25.
10. Epidermal details of the outer cuticle with strongly developed papillae, Slide no. BSIP 9733. × 150.

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The Palaeobotanist **36** : 201-204, 1987.

First record of the genus *Culcitites* Appert from India and its significance

Jayasri Banerji

Banerji, Jayasri (1988). First record of the genus *Culcitites* Appert from India and its significance. *Palaeobotanist* **36** : 201-204.

The genus *Culcitites* Appert has been recorded from the Dubrajpur Formation exposed at Khatangi Hill, Bihar. The genus is characterised by bipinnate fronds, deltoid-rhomboidal sterile pinnules and sphenopteroid venation. Fertile pinnules are comparatively small and possess an acroscopic marginal sorus terminating on vein ending, indusium being pouch-like in shape.

Key-words—Megafossils, *Culcitites*, Dicksoniaceae, Dubrajpur Formation, ?Late Jurassic (India).

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साराँश

भारत से कल्सिटाइटिस अँपर्ट प्रजाति का प्रथम अभिलेख तथा इसका महत्व

जयश्री बैनर्जी

बिहार की खातंगी पहाड़ियों में विगोपित दुबराजपुर शैल-समूह से **कल्सिटाइटिस** अँपर्ट प्रजाति अभिलिखित की गई है। यह प्रजाति द्विपिच्छाकार प्रपर्णों, त्रिकोणाकार-चतुष्कोणी बन्ध्य पिच्छिकाओं तथा स्फीनॉप्टेरॉयडी शिराविन्यास से अभिलक्षणित है। अबन्ध्य पिच्छिकायें अपेक्षाकृत छोटी तथा शिराओं के अन्तिम सिरे पर अग्रोन्मुख उपांत बीजाणुधानीपुंज से युक्त हैं और इनमें सोरसछद थैलाकार है।

THE genus *Culcitites* was instituted by Appert (1973) due to its close resemblance with the extant genus *Culcita* (*Balantium*). The genus *Culcita* was placed by Bower (1926) in sub-family Dicksonieae of Dicksoniaceae, whereas, Holttum and Sen (1961) placed *Culcita* together with *Thyrsopteris* in sub-family Thyrsopteroidoideae of Cyatheaceae. However, Harris (1961) included *Thyrsopteris* and *Coniopteris* in sub-family Thyrsopterideae of Dicksoniaceae. Appert (1973) placed *Culcitites* in sub-family Thyrsopterideae of Dicksoniaceae.

Known fossil representatives of Dicksoniaceae from India are *Coniopteris* Brongniart and *Dicksonia* L' Heritier. *Coniopteris* differs by its cup-shaped indusium of stalked sorus and sterile pinnae with basiscopic aphlaebi, whereas *Dicksonia* differs from *Culcitites* mainly by pecopteroid venation of pinnules and bilipped indusium.

Specimens of *Culcitites* reported here were collected from the *Ptilophyllum* bearing beds (Dubrajpur Formation) of Khatangi Hill (24° 30′ 16″ N by 87° 27′ 20″ E), Rajmahal Hills, Bihar. They are preserved as impressions on light grey shales. The stratigraphic section and map have recently been

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Text-figure 1—*Culcitites madagascariensis* Appert, fertile frond showing abaxial indusium and venation of pinnules, Specimen no. BSIP 36218-A, × 4.

published by Sen-Gupta (1984).

Family—DICKSONIACEAE

Genus—*Culcitites* Appert 1973

Culcitites madagascariensis Appert

Pl. 1, figs 1-7; Text-fig. 1

1965 *?Thinnfeldia* sp., Sah, p. 219, pl. 1, fig. 3.
1965 *Microphyllopteris* sp., Sah, p. 219, pl. 1, fig. 5.

Description (Size of the leaf unknown, for description purpose assumed to be bipinnate)—Fronds atleast bipinnate, sterile and fertile pinnules more or less similar, asymmetrical. Sterile pinnae mostly found detached, in juvenile fronds pinnae found attached to pinna rachis. Pinnae alternate to subopposite, emerging at an angle of 40°-60°, usually about 5 mm apart, linear-lanceolate in shape, largest available pinna 5 cm long and 1.6 cm broad, size gradually decreasing towards distal end. Pinnae and pinnules proximally alternate, distally becoming sub-opposite. Pinnules arising at an angle of 50°-60°, deltoid to rhomboidal in shape, imparipinnate, larger at the middle region, typically 3.5-9 mm long, 2.5-6 mm wide, acroscopic basal margin constricted, basiscopic margin decurrent, lateral margin entire to variously lobed, mostly first acroscopic lobe deeply dissected than the others. Venation sphenopteroid, mid-vein arising from ultimate rachis slightly more towards basiscopic side of basal margin, laterals mostly twice forked.

Fertile pinnules generally comparatively small, deltoid, margin entire, 2-3 mm long, 1.5-2 mm broad, basal pinnules rhomboidal with lobed to wavy margin. Each pinnule bearing a marginal indusiate sorus on its acroscopic half, indusium horizontally placed, pouch-like in shape, usually 2 mm long and 1.5 mm broad, adaxial indusium seems to be continuation of lamina. Details of receptacle and sporangium unknown.

Collection—Specimen nos. BSIP 36217, 36218 A, B, 36219A, B and 36220.

Remarks—The specimens exactly match with *Culcitites madagascariensis* described by Appert (1973) from the Upper Jurassic of Manamana Massif, South West Madagascar. However, text-figure 35 of Appert shows two sori at the base of a pinnule which seem to be a developmental feature showing the stage of maturity of the fronds.

In having a single marginal sorus *C. madagascariensis* compares with *Dicksonia kendalli* described by Harris (1961) from Jurassic of Yorkshire which differs by comparatively small pinnules and oval to reniform sori. *Dicksonia speciosa* Sharma 1975 differs by its inverted sori and the venation pattern of the pinnules.

Occurrence of two lipped indusium of the sori first appeared in Jurassic members of Dicksoniaceae

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PLATE 1 →

1. *Culcitites madagascariensis* Appert, fertile frond showing acroscopic indusiate sori, specimen no. BSIP 36218-A, × 1.
2. Counterpart of the above specimen, Specimen no. BSIP 36218-B, × 1
3. A part of sterile pinna showing shape and venation of pinnules, Specimen no. BSIP 36219-A, × 2.
4. Enlargement of fig. 1 showing venation and pouch-shaped indusium, × 8.
5. Detached sterile pinnae showing variations in size and shape of pinnules, Specimen no. BSIP 36219-A, × 1.
6. Fertile frond showing morphological variation of the pinnules, Specimen no. BSIP 36218-A, × 4.
7. Counterpart of the above specimen, Specimen no. BSIP 36218-B, × 4.

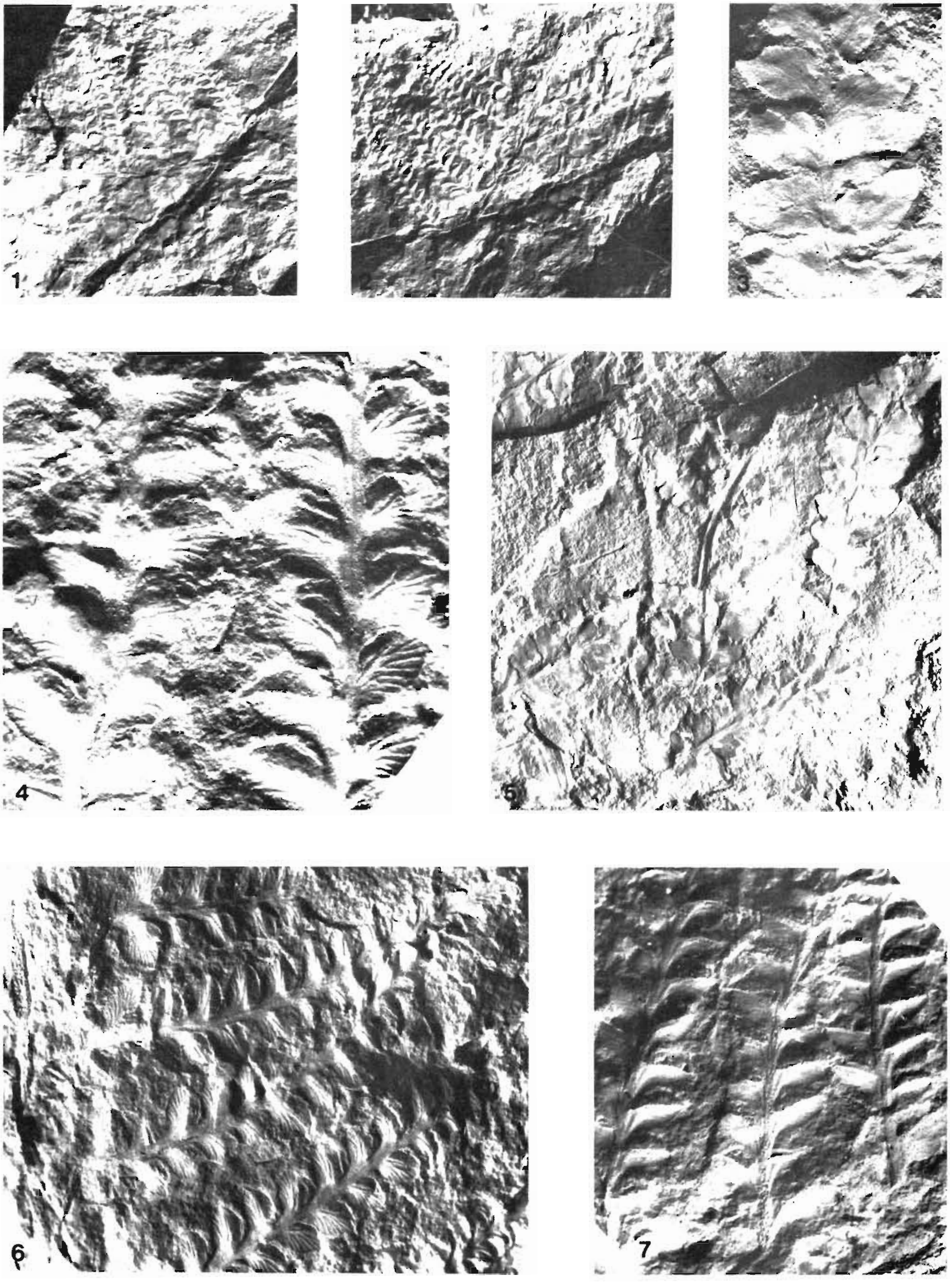

PLATE 1

and perhaps evolved from a primitive marginal sorus. According to Harris (1961) the genus *Coniopteris* either has a cup-shaped indusium or a flattened lobed one. On the contrary, Krassilov (1978) suggested a two-lipped indusium in most species of *Coniopteris*. The genus *Culcitites* is more akin to the extant genus *Culcita* in having two-lipped indusium which forms pouch-like indusial chamber. Retention of this ancestral character, i.e. two-lipped marginal indusium in the early stage of development of cup-shaped indusium in *Thyrsopteris*, as suggested by Bower (1926), provides a clue to its phyletic relationship with the genera *Culcitites* and *Coniopteris*. Appert (1973) also suggested relationship of some fossil and recent members of Dicksoniaceae with the monotypic extant genus *Thyrsopteris*.

Sah (1965) assigned a ? Lower Jurassic age to the *Ptilophyllum* bearing beds of Khatangi Hill. Sah and Shah (1974) suggested a Lower-Middle Jurassic age. The genus *Culcitites* is, so far, known only from the Upper Jurassic of Madagascar. This bed may be contemporaneous to the Late Jurassic/Early Cretaceous subsurface palynozone D-E of Dubrajpur Formation (Tiwari *et al.*, 1983).

As all the extant species of the genus *Culcita* are presently distributed in tropical-subtropical region only, it is probable that a similar climate prevailed in Rajmahal area during Late Jurassic.

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The Palaeobotanist **36** : 205-206, 1987.

Geographic distribution of the genus *Cycadopteris* during the Upper Gondwana

Neeru Pandya

Pandya, Neeru (1987). Geographic distribution of the genus *Cycadopteris* during the Upper Gondwana. *Palaeobotanist* **36** : 205-206.

A leaf of the genus *Cycadopteris* Zigno is reported for the first time from the Athgarh Formation, Orissa. The distribution of the genus *Cycadopteris* in India during the Upper Gondwana is discussed.

Key-words—Megafossil, *Cycadopteris*, Corystospermaceae, Athgarh Formation, Upper Gondwana (India).

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सारांश

उपरि गोंडवाना में साइकेडॉप्टेरिस प्रजाति का भौगोलिक वितरण

नीरू पाँडया

उड़ीसा में अथगढ़ शैल-समूह से **साइकेडॉप्टेरिस** जिग्नो प्रजाति की एक अश्मित पत्ती पहली बार अभिलिखित की गई है। भारत में उपरि गोंडवाना काल में **साइकेडॉप्टेरिस** प्रजाति का वितरण भी विवेचित किया गया है।

ONLY a few species of the genus *Cycadopteris* Zigno are known from the Upper Gondwana (Bose, 1957, 1958; Bose & Dev, 1958). Recently a small leaf of *Cycadopteris* was collected from the Athgarh Formation and is described in this paper.

DESCRIPTION

Family—Corystospermaceae

Genus—*Cycadopteris* Zigno

Cycadopteris sp.

Pl. 1, figs 1-3

Description—Pinna incomplete, 3.4 cm long and 0.5 cm wide. Rachis less than 1 mm broad. Pinnules broadly- ovate, with rounded apex and slightly decurrent base, alternate, rather sparse, attached at an angle of 60°-90°, 2-3 mm long and 1.5-2 mm broad, margin thickened. Midrib broad, persisting up to apex and dividing the lamina longitudinally into broader basiscopic half and narrow acroscopic half. Secondary veins prominent, arising at an acute angle and forking once or twice.

Collection—Specimen no. BSIP 68/3132; Talbast, Cuttack District, Orissa; Athgarh Formation, Early Cretaceous.

Remarks—*Cycadopteris* sp. resembles *C. pulcherrima* (Bose & Dev, 1958) in shape and size of pinnules. In *C. brauniana* (Bose & Dev, 1958) and the present specimen the basiscopic half of pinnules is larger than the acroscopic half. However, the pinnules in *Cycadopteris* sp. are comparatively distant, small and lack phytolemma. *Cycadopteris* sp. is also somewhat comparable to the smaller pinnules of *C. zeilleri* Antevs 1915 in shape, size and arrangement of pinnules; however, the former species lacks cuticular details.

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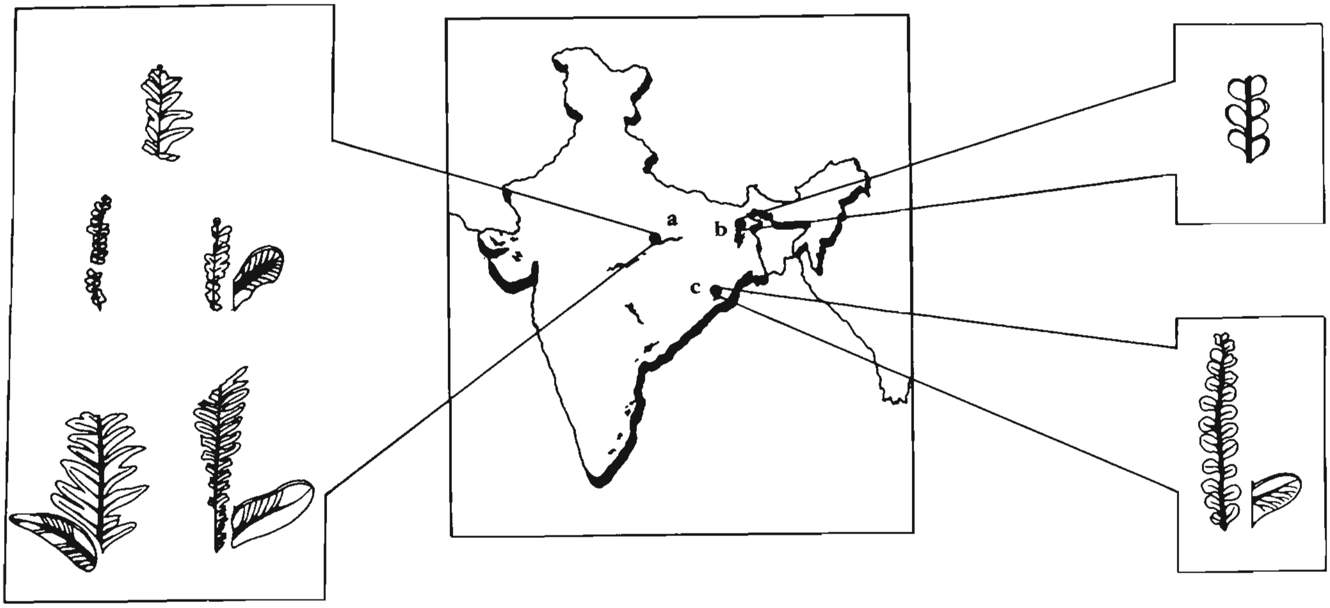
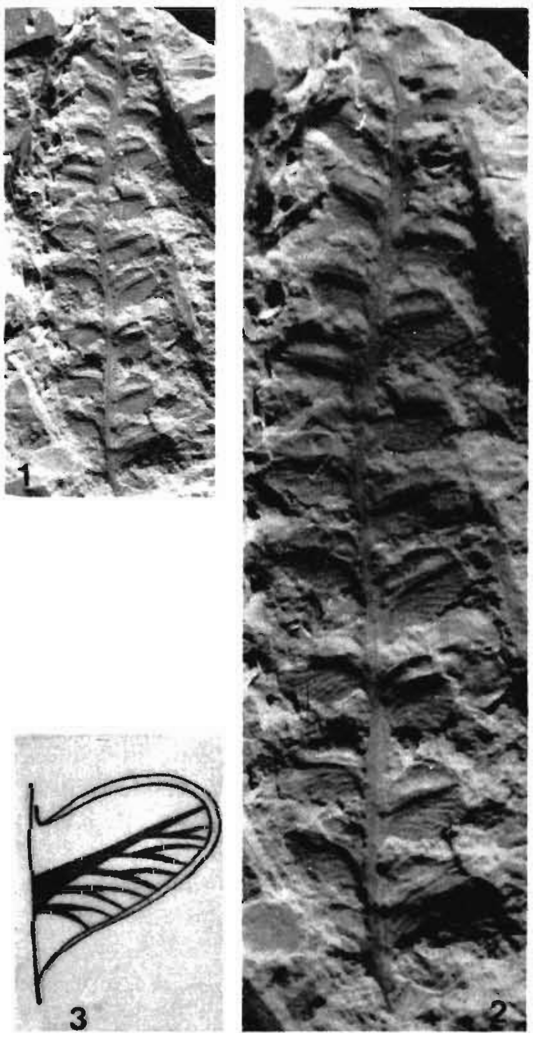


Text-figure 1—Distribution of the genus *Cycadopteris* during the Upper Gondwana in India; **a,** Bansa-Patparha, Jabalpur Formation, Madhya Pradesh; **b,** Chunakhal, Rajmahal Formation, Bihar; and **c,** Talbast, Athgarh Formation, Orissa.



The genus *Cycadopteris* is characterized by thick leathery leaves, turned-margin, generally flange over midrib, sunken stomata and sometimes papillae over the leaves which are xeromorphic characters. The present specimen though preserved as impression has small and thick leaves suggesting a rather dry environment for the Athgarh Formation.

Distribution—The genus *Cycadopteris* was so far known from Early Cretaceous of Bansa and Patparha, (Jabalpur Formation), Madhya Pradesh and Chunakhal (Rajmahal Formation), Bihar. Its occurrence in the Athgarh Formation is significant as this occurrence extends its geographic distribution from Madhya Pradesh and Bihar to Orissa during the Early Cretaceous Period (Text-fig. 1).

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←

PLATE 1

1. *Cycadopteris* sp., Specimen no. BSIP 68/3132, x 2.
2. Above specimen magnified, x 6.
3. A pinnule based on the above specimen showing venation, x approx. 8.

The Palaeobotanist **36** : 207-209, 1987.

Study of amino acids in petrified plants from the Rajmahal Hills

B. D. Sharma & R. Harsh

Sharma, B. D. & Harsh, R. (1988). Study of amino acids in petrified plants from the Rajmahal Hills. *Palaeobotanist* **36** : 207-209.

Chemistry of fossil plants collected from the Rajmahal Hills, Bihar (India) is studied. Amino acids extracted from the petrified woods, rachides and fructifications are identified with the help of paper chromatography. Implication of the chemical study of fossil plants in relation to taxonomy and evolution is discussed.

Key-words—Palaeochemistry, Amino acids, Petrified fossils, Rajmahal Hills (India).

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सारॉंश

राजमहल पहाड़ियों से प्राप्त अश्मीभूत पौधों में अमीनो-अम्लों का अध्ययन

बी० डी० शर्मा एवं आर० हर्ष

राजमहल पहाड़ियों से एकत्र अश्मित पौधों का रासायनिक अध्ययन किया गया है। कागज-वर्ण-लेखी विधि द्वारा अश्मीभूत काष्ठों, फलनों एवं रेकाइड़ों से निकर्षित अमीनो अम्लों का अभिनिर्धारण किया गया है। वर्गिकी एवं विकास को ध्यान में रखते हुए अश्मित पौधों के रासायनिक महत्व का भी विवेचन किया गया है।

CHEMICAL analysis of fossil plants and associated sediments is currently providing biochemical information to palaeobotanists for relating different groups of extinct plants and in the formulation of phylogenetic classifications. Many compounds previously considered so mobile as to prevent their preservation in ancient sediments, may infact be found in fossil material (Dilcher *et al.*, 1970; Niklas, 1982; Niklas & Chaloner, 1976; Niklas & Giannasi, 1977; Hohn & Meinschein, 1976; Wehmiller *et al.*, 1976). Chemicals recovered, e.g., amino acids, flavonoids, lignin, fatty acids. etc. from the fossil samples have helped in establishing relationship among the genera and species of the extinct plants. Amino acids have been recovered from fossil samples of animals and sedimentary rocks (Bada *et al.*, 1973; Dungworth, 1976).

In the Rajmahal Hills, petrified fossils are found either embedded in ferruginous rocks as at Amarjola or in the form of hard silicified cherts as at Sonajori, Nipania, Chilgujari and Hiranduba localities. Amino acids have been extracted from some of the petrified materials and identified tentatively with the help of paper chromatography.

MATERIAL AND METHODS

Petrified *Bucklandia* stems, *Ptilophyllum* rachides, *Williamsonia* (seed-bearing) naked receptacles, *Pentoxylon* stems and *Coniferocaulon* stems were collected from the well-known ferruginous rock of Amarjola, while decorticated, silicified woods were obtained from Sonajori. The specimens were washed several times with distilled

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water and then cooked in a furnace at 200°C for 24 hours to kill all micro-organisms present on the material. After repeated washing with distilled water, dried. The material was crushed into small pieces using separate pestal/mortar for each sample. Extractions were made through soxhlet in 80 per cent alcohol for 48 hours. The solutions were evaporated and to the dried extracts was added 5 ml of 20 per cent alcohol and centrifuged for 10 minutes. The supernatant of each sample was kept in properly labelled Corning glass tubes in a freezer.

Amino acids were recovered through paper chromatography using the method of Hanes *et al.* (1961). The solvent used for chromatography was prepared by mixing butanol, glacial acetic acid and water in the ratio of 5 : 1 : 4 respectively. Different concentrations of extracts, i.e., 50λ, 100λ, 150λ, 200λ and 300λ were spotted on Whatman no. 1 chromatographic paper. 150λ and 200λ concentrations gave satisfactory results. The spots were put at proper distances and 'run' into chromatographic chamber at room temperature (35°C) for approximately 6 hours. The chromatogram was dried and sprayed with a mixture of 200 mg ninhydrin dissolved in 100 ml of acetone, again dried and kept in an oven at 80°C for 10 minutes for colour development. Distinct spots of different colours appeared representing various amino acids present in the samples. Amino acids were identified tentatively on the basis of R_f values.

OBSERVATIONS

Five to nine amino acids appeared in six samples used for the present investigation. Maximum number of amino acids appeared in *Coniferocaulon* stem, while minimum in the naked receptacles of seed-bearing *Williamsonia*. In all, on the basis of R_f value, 17 amino acids could be identified; a number of others remain unknown. The chromatograms show the amino acids in each sample as under:

Bucklandia Stem

L-Arginine
DL-Serine
DL-Alanine
L-Tyrosine
unknown
unknown
unknown

Ptilophyllum rachis

L-Cystine
unknown
DL-Serine
L-Glutamic acid
unknown
L-Cystine hydrochloride
unknown

Williamsonia naked receptacle
unknown

DL-3, 4 Dihydroxyphenylealanine
unknown
DL-Methionine
unknown

Pentoxylon stem

L-Cystine
DL-Aspartic acid
L-Glutamic acid
unknown
L-Cystine hydrochloride
L-Leucine

Coniferocaulon stem
unknown

L-Ornithine monochloride
unknown
DL-Serine
L-Glutamic acid
unknown
unknown
unknown
L-Leucine

Decorticated silicified coniferous wood (from Sonajori)

L-Histidine monochloride
unknown
DL-Threonine
DL-2-Aminobutyric acid
L-Tyrosine
DL-Valine
DL-nor-leucine

A comparison of the known 17 amino acids in the six samples (Table 1) shows that none is common in all the samples. Related organs of a bennettitalean plant, i.e., *Bucklandia* stem, *Ptilophyllum* leaf and *Williamsonia* fructification (Sahni, 1932) possess different amino acids. Similarly the two conifers, selected for the present purpose (samples 5 and 6) do not possess any common amino acid. While taxonomically separated plants preserve some common amino acids, e.g., L-cystine, L-Glutamic acid, and L-Cystine hydrochloride are present in *Ptilophyllum* rachis and

Table 1—Amino acids identified in six samples of petrified plants collected from the Rajmahal Hills, India

	1	2	3	4	5	6
3.55 L-Cystine		+		+		
9.77 L-Ornithine-monochloride					+	
12-L Histidine monochloride						+
13.9 L-Arginine	+					
17.7 DL-Aspartic acid				+		
20.44 DL-serine	+	+			+	
24.44 L-Glutamic acid		+		+	+	
26.00 DL-3-4 Dihydroxy-phenylealanine			+			
27.3 DL-Alanine	+					
30.8 DL-Threonine						+
39.1 DL-2-Aminobutyric acid						+
40.88 L-Cystinehydrochloride		+		+		
46.2 L-Tyrosine	+					+
50 DL-Methionine			+			
55 DL-Valine						+
67.11 L-Leucine				+	+	
70 DL-nor-Leucine						+

1. *Bucklandia* stem, 2. *Ptilophyllum* rachis, 3. *Williamsonia* naked receptacle, 4. *Pentoxylon* stem, 5. *Coniferocaulon* stem, 6. Decorticated silicified coniferous wood.

Pentoxylon stem. Similarly, L-Glutamic acid, and L-Leucine are present in both *Pentoxylon* and *Coniferocaulon*. Present study is a preliminary investigation and needs further work to draw any conclusion regarding the utility of palaeochemistry in taxonomy and phylogeny of extinct plants. However, such a study certainly advances the frontiers of our knowledge about the fossil plants and associated sediments.

There is no effect of kind of preservation in the presence of amino acids. Except the sixth sample (decorticated silicified coniferous wood) from Sonajori, all others have been collected from Amarjola and are preserved in an identical manner. But they possess different amino acids. Amino acids are also very well preserved in the hard silicified wood from Sonajori.

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The Palaeobotanist **36** : 210-213, 1987.

Epiphyllous fungi from the Gondwana

Usha Bajpai & Hari K. Maheshwari

Bajpai, Usha & Maheshwari, Hari K. (1988). Epiphyllous fungi from the Gondwana. *Palaeobotanist* **36** : 210-213.

Epiphyllous fungi belonging to Ascomycetes and Deuteromycetes are recorded. Microthyriaceous germlings have been found on the lower cuticle of a *Glossopteris* species from the basal Barakar sediments of Saharjuri Outlier. Microthyriaceous stromata have been found on the lower cuticle of *Thinnfeldia indica* Feistmantel and a leaf apparently of *Ctenozamites* type, both from Early Cretaceous of Cauvery Basin. Mycelia sterilia have also been recorded on the lower cuticle of *Thinnfeldia indica*. On the basis of the occurrences of Microthyriaceae, a tropical to subtropical climate is deduced for the Early Cretaceous Period of India.

Key-words—Fungi, Epiphyllous, Ascomycetes, Deuteromycetes, Gondwana (India).

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सारॉंश

गोंडवाना से अधिपर्णी कवक

ऊषा बाजपेयी एवं हरिकृष्ण माहेश्वरी

ऍस्कोमाइसिटीज़ एवं ड्यूटेरोमाइसिटीज़ नामक वर्गों से सम्बद्ध अधिपर्णी कवक अभिलिखित किये गये हैं। सहरजुरी पुरान्तःशायी के आधारी बराकार अवसादों से उपलब्ध एक ग्लॉसॉप्टेरिस जाति के निचले उपचर्म से माइक्रोथाइरियेसीय नूतनोद्भिद् प्राप्त हुए हैं। **थिन्नफ़ेल्डिआ इन्डिका** फ़ाइस्टमॅन्टॅल तथा **टीनोज़माइटिस**-प्ररूप की एक पत्ती के अधरि उपचर्म से माइक्रोथाइरियेसीय अवर्णिकायें प्राप्त हुई हैं, ये दोनों ही प्रारम्भिक कावेरी द्रोणी से एकत्रित किये गये थे। **थिन्नफ़ेल्डिआ इन्डिका** के अधरि उपचर्म से बन्ध्य कवकजाल भी अभिलिखित किये गये हैं। माइक्रोथाइरियेसी की उपस्थिति के आधार पर भारत के प्रारम्भिक क्रीटेशी कल्प हेतु उष्णकटिबन्धीय से उपोष्णकटिबन्धीय जलवायु प्रस्तावित की गई है।

THE fungi have a long history and are known from Precambrian to present day, but it is one group of organisms that is comparatively little known in fossil condition. Much of knowledge about fossil fungi is derived from palynological preparations. Reports of occurrence of bacteria, fungi or other microbes on the fossil leaf cuticles are scarce, mostly having been reported on the Tertiary leaves.

In India, fungi are known mostly from the post-Gondwana sediments (Venkatachala & Kar, 1969; Jain & Gupta, 1971, and others) except for some stray reports of fungal spores in petrological sections of Permian coal. Banerji and Misra (1968) have reported a microthyriaceous fungus in the subsurface Upper Cretaceous sediments of southern India. Recently microthyriaceous stromata have also been recorded from the basal Cretaceous sediments (Pant, Srivastava & Pant, 1983; Bose & Banerji, 1984). Here we record some more epiphyllous fungi that were observed after processing carbonified leaves for recovery of cuticles. These belong to the Microthyriaceae and Fungi Imperfecti. We have not

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gone into detailed taxonomy as information available is too little for any meaningful identification.

Two types of microthyriaceous stromata, one type of microthyriaceous germlings, and some hyphae of uncertain affinity have been illustrated. The fungi have been found in two horizons, viz., (i) on dispersed cuticle of a *Glossopteris* species from the shale of basal Barakar Formation, Chitra Patrika Mine, Early Permian, Saharjuri Outlier, Deogarh Coalfield, Bihar and (ii) cuticles of *Thinnfeldia indica* and *?Ctenozamites* from a tube well near Naicolam, Sivaganga Formation, Early Cretaceous, Tiruchirapalli District, Tamil Nadu.

DESCRIPTION

Ascomycetes

The Microthyriaceae, which are epiphyllous fungi, are characterised by strongly flattened, somewhat rounded, shield-shaped ascocarp or ascostroma with a centrum. The stromata vary in size. The margin of the stromata may be entire to fimbriate. The cells of the stromata usually have an ostiole through which the ascospores may be released. In some cases the ostiole is absent (Stevens, 1925). Vegetative mycelium is not known in few genera. All but a few are leaf parasites. They are largely tropical but a number of genera occur in temperate zones, too (Bessey, 1950; Alexopolous & Mims, 1979).

Type-1 (Pl. 1, fig. 1)—? Germlings, 36-248 μm in diameter, discoid, flattened. Margin entire. Cells not decipherable individually, only radiating undulations seen. Ostiole not seen.

These structures are found on the cuticle of a *Glossopteris* leaf from the Lower Permian of Chitra Mine area, Deogarh Coalfield (Bajpai, 1988).

Type-2 (Pl. 1, fig. 2)—Stromata 44-268 μm in diameter, more or less circular, margin fimbriate. Stromata consist of radiating rows of cells. Cells 4-6 μm wide and 4-8 μm long. This fungus has been found on the lower cuticle of *Thinnfeldia indica* (Maheshwari, 1986).

Single-celled ascospores, young stages of stroma and mature stromata are seen on the cuticle. However, the pore or ostiole is not seen on the cross wall of the cells. It is presumed that the stromata lack ostioles.

Type-3 (Pl. 1, fig. 3)—Stromata 200-350 μm in diameter, discoid, strongly flattened. Margin fimbriate to entire at places. Cells are more or less rectangular, compactly arranged, 4-6 μm wide and 3-5 μm in length. Ostiole not seen. Developmental stages are not seen though a number of stromata has been observed on the lower cuticle of a leaf apparently similar to that of *Ctenozamites*. These stromata resemble the one figured by Bose and Banerji (1984, pl. 48, fig. 3).

DEUTEROMYCETES

The Deuteromycetes or Fungi Imperfecti include those fungi which apparently lack a sexual phase. These fungi only have septate hyphae and reproduce by means of conidia. The fungi of this group are known from Devonian to the present time (Dilcher, 1965).

One type each of sclerotia and branched hyphae have been observed on the leaf of *Thinnfeldia indica* Feistmantel. These sclerotia and hyphae belong to Mycelia Sterilia as defined in Bernett's (1960) key to the genera of Fungi Imperfecti.

Type-4 (Pl. 1, fig. 4)—The fossil sclerotia are dark and seem to be thickened somatic structures of interwoven mycelial threads, with long and septate hyphae formed under unfavourable conditions.

The sclerotia measure 80-150 μm in diameter. Hyphal cells are 3-5 μm wide and 20-40 μm long. Branching of hyphae is not seen but in living fungi branched septate hyphae are produced under favourable conditions. The sclerotia may be compared with those of modern *Papulaspora* Preuss.

Type-5 (Pl. 1, figs 5, 6)—The septate branched hyphae are without asexual fruiting bodies and spores. Hyphae are straight or curved, branched oppositely to suboppositely or alternately. Hyphal cells are 8-12 μm wide and 16-60 μm long. The mycelium resembles that of modern *Rhizoctonia* DC.

REMARKS

The fungi grow on living and dead plants under favourable conditions and in the presence of required enzymes. They play an important role in the biodegradation of plant litter due to their ability to utilize cellulose. The enzymes produced by fungal hyphae digest the tissue, partially degrading the tissues and thus providing material for further fungal growth. After decomposition by fungi, the resulting organic matter is attacked by bacteria (Venkatachala, 1981, 1984). The bacteria that are involved to any significant extent in decomposition of plant litter belong to the order Pseudomonadales, Eubacteriales, Actinomycetales and Myxobacteriales. The fungi and bacteria undoubtedly control early stages of diagenesis of the organic matter (Teichmüller & Teichmüller, 1967). Not much, however, is known concerning their occurrence and distribution on fossil plant material.

In the Gondwana, bacterial degradation of organic matter has been illustrated by Bajpai and

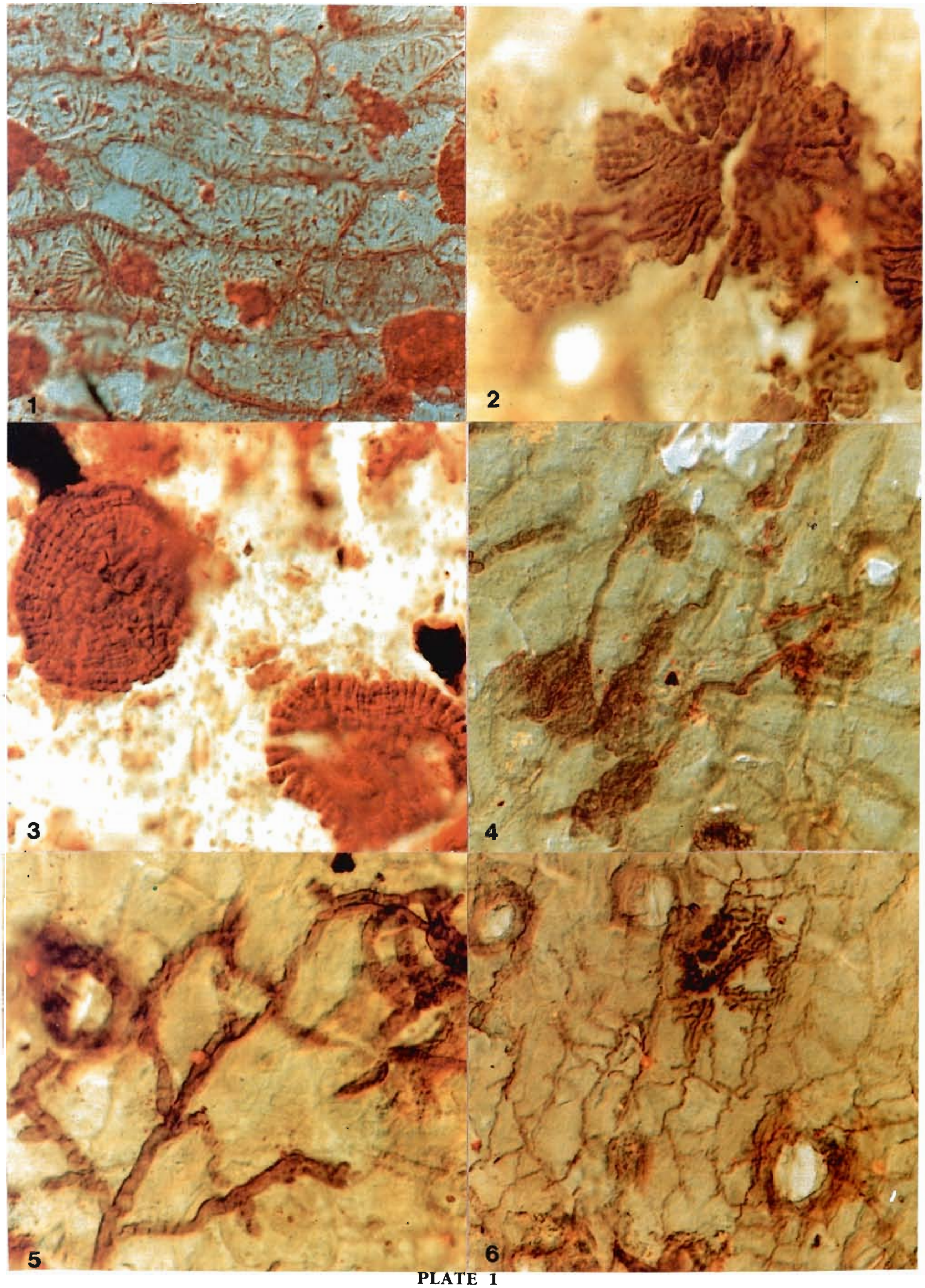

PLATE 1

Maheshwari (1986) on megaspores from the Permian of Zaire. Fungal hyphae are also present on these megaspores. Presently we record fungal infestation on Gondwana leaves. However, it is yet not clear if these fungi grew on the living plant or on the leaves in the litter. As the cuticle on which such microbiota grew is not sufficiently well-preserved, often the lateral walls are lost, it is presumed that the fungus played a role in degradation of the epidermis. Modern microthyriaceae are generally parasitic. fungi imperfecti occur everywhere, producing conidia as readily on decaying plant organs as on living ones (Wolf & Wolf, 1947).

The fossil and extant forms of Microthyriaceae infest both angiosperms and gymnosperms (Dilcher, 1965) but were not known from sediments older than Early Cretaceous. Present report takes back the ancestry of this family possibly to Early Permian. The occurrence of Microthyriaceae in the Bansa, Trambau and Naicolam beds shows that a tropical to subtropical climate prevailed when the Lower Cretaceous sediments of India were being deposited.

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←

PLATE 1

1. Microthyriaceous germlings on the cuticle of a *Glossopteris* leaf. x *ca* 400.
2. Radiate, circular stromata with fimbriate margin on the cuticle of *Thinnfeldia indica.* x *ca* 400.
3. Discoid stromata, without an ostiole on the cuticle of ?*Ctenozamites* sp. x *ca* 400.
4. Sclerotia with long septate hyphae on the cuticle of *Thinnfeldia indica.* x *ca* 250.

5,6. Fungal hyphae on *Thinnfeldia indica.* x *ca* 400, *ca* 250.

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Gondwana Sequence of the northern Pranhita-Godavari Valley : its stratigraphy and vertebrate faunas

T. S. Kutty, S. L. Jain & T. Roy Chowdhury

Kutty, T. S., Jain, S. L. & Roy Chowdhury, T (1988). Gondwana Sequence of the northern Pranhita-Godavari Valley : its stratigraphy and vertebrate faunas. *Palaeobotanist* **36** : 214-229.

The Gondwana Sequence in the northern part of the Pranhita-Godavari Valley consists of four formations of the Lower Gondwana and seven formations of the Upper Gondwana. The gross lithological characters and mappability are considered as the major criteria for delineating the formations. The name Kamthi Formation which has been used by different authors in different senses, is here used in the sense of Sengupta (1970). The rocks between the Barakar and this Kamthi are divided into four lithozones for limitations of mappability. Although some of these lithozones have earlier been designated as formations, at present not sufficient information is available to justify this. Only two breaks, both within the Upper Gondwana, are found to be present; there is no recognisable break between the Lower and the Upper Gondwana. A summary of this succession is presented in tabular form taking into account the works of earlier authors. The alternative views that are radically different from the one presented here are also discussed briefly. The usefulness of plant megafossils and fossil vertebrates in understanding the stratigraphy is discussed briefly and their role in determining the possible geological ages of some of the formations is mentioned.

The vertebrate fauna from a number of formations is listed. At least seven formations are fossiliferous as far as vertebrates are concerned. Of these, two belonging to the Triassic and one belonging to the Jurassic are quite well-documented. The other four are less well-known, but serve as very useful time markers. All these vertebrate-bearing formations can be correlated with co-eval rocks elsewhere in the world. The difficulty of correlating continental deposits is realised and keeping this in view a tentative correlation is presented.

Key-words—Stratigraphy, Pranhita-Godavari Valley, Vertebrate fauna, Gondwana Sequence.

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साराँश

उत्तरी प्रणहिता-गोदावरी घाटी का गोंडवाना अनुक्रम : इसका स्तरविन्यास एवं रीढ़धारी जीवजात

टी० ऍस० कुट्टी, ऍस० ऍल० जैन एवं टी० रॉय चौधरी

प्रणहिता-गोदावरी घाटी के उत्तरी भाग में गोंडवाना अनुक्रम में अधरि गोंडवाना के चार तथा उपरि गोंडवाना के सात शैल-समूह विद्यमान हैं। समस्त शैलिकीय संलक्षणों आदि का शैल-समूहों के परिसीमन में प्रयोग किया गया है। 'कामथी शैल-समूह', जो कि विभिन्न शोध-कर्त्ताओं ने विभिन्न रूप से प्रयोग किया है, शब्द को इस शोध-पत्र में केवल सेनगुप्त (1970) के अनुसार ही प्रयोग किया गया है। बराकार एवं कामथी के मध्य स्थित चट्टानों को मानचित्र परिसीमन हेतु चार शैल-मंडलों में विभक्त किया गया है। यद्यपि इन शैल-मंडलों में से कुछ को शैल-समूहों के रूप में नामांकित किया गया था परन्तु पर्याप्त जानकारी के अभाव में ऐसा करना संभव नहीं है। उपरि गोंडवाना में ही दो दरारें प्रेक्षित की गई हैं; परन्तु अधरि एवं उपरि गोंडवाना में इस प्रकार का कोई अपभ्रंश नहीं मिलता। इस अनुक्रम पर अब तक किये गये शोध-कार्य को एक सारणी के रूप में प्रस्तुत किया गया है। एक दूसरे से भिन्न मतों को भी संक्षिप्त रूप में प्रस्तुत किया गया है। स्तरविन्यास को जानने हेतु गुरुपादपाश्मों एवं अश्मित रीढ़धारीयों का महत्त्व भी विवेचित किया गया है। कुछ शैल-समूहों की सम्भाव्य भूवैज्ञानिक आयु सुनिश्चित करने में इनकी भूमिका का भी उल्लेख किया गया है।

अनेक शैल-समूहों से उपलब्ध रीढ़धारी जीवजात एक तालिका के रूप में प्रस्तुत किया गया है। जहां तक रीढ़धारीयों का प्रश्न है कम से कम ऐसी सात शैल-समूह जीवाश्ममय हैं जिनमें से दो त्रिसंघी कल्प की तथा एक जूराई कल्प की शैल-समूहों का विस्तृत विवेचन किया गया है। अन्य चार इतनी सुविदित नहीं हैं परन्तु आयु निर्धारण में इनका महत्वपूर्ण योगदान है। इन सभी रीढ़धारी शैल-समूहों का विश्व की अन्य समकालीन चट्टानों से सहसम्बन्धन किया जा सकता है। महाद्वीपीय निक्षेपों के सहसम्बन्धन में आने वाली कठिनाइयों को प्रस्तुत किया गया है तथा इसी दृष्टिकोण को ध्यान में रखते हुए अस्थायी सहसम्बन्धन प्रदर्शित किया गया है।

Concepts, limits and extension of the Indian Gondwana
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Publisher : Birbal Sahni Institute of Palaeobotany, Lucknow

THE Pranhita-Godavari Valley (PG Valley) contains not only one of the largest Gondwana basins of India but also gives the most complete succession of Gondwana rocks. The basin forms a part of a series of NW-SE trending Gondwana basins that form the southern arm of the subtriangular Main Gondwana Province of the peninsular India (Robinson, 1970).

The oldest Gondwana rocks of the PG Valley rest mostly on the Pakhal and Sullavai supergroups while the younger part of the succession is cut-off by a great boundary fault running more or less parallel to the strike of these rocks which brings them against the same Proterozoic rocks. At the north-western end of the valley the Gondwana sediments are partly covered by the Deccan Traps and partly followed by the Wardha Valley Gondwana, though separated by a prominent fault. In the south and southeast these rocks are partly represented by the marine and lagoonal Gondwana sediments of the Coromandel Coast and overlain by the recent alluvial deposits of Godavari and Krishna deltas.

The present area has been chosen to serve as a standard for the entire valley because this part has the most complete succession of the Gondwana rocks and has been a happy hunting ground for geologists and palaeontologists for over a century and a half. A geological map of the area bounded by Peddavagu in the north and Godavari River in the south is also presented to explain the stratigraphic interpretation put forward in this paper (Map 1).

STRATIGRAPHY

Geological accounts on the PG Valley started appearing from the second quarter of the last century (Voysey, 1833 (*in* King, 1881), occurrence of sandstones and hot springs; Walker, 1841, search for coal and discovery of fossils; Hislop, 1864, discovery of fossils; Oldham, 1859, occurrence of fossils and Gondwana rocks; Jones, 1863, occurrence of ***Estheria***; Blanford, 1871, occurrence of coal seams; Hughes, 1877, geological account of the area adjacent to the Wardha Valley Coalfield; Egerton, 1878, description of ganoid fishes; Feistmantel, 1879, description of 'Kota Flora'). It was left to King (1881) to give the first detailed account of the geology of the PG Valley that included a stratigraphic description supported by a geological map of the valley. He subdivided the Gondwana rocks into Lower and Upper divisions; each of which was in turn subdivided into stratigraphic units, generally speaking, in consonance with the Gondwana stratigraphic successions found elsewhere in peninsular India. The Lower Gondwana contained three units—Talchir, Barakar and Kamthi while the Upper Gondwana were also subdivided into three units—Maleri, Kota and Chikiala. It may be mentioned here that all the stratigraphic units recognised by King (1881) were thought to show unconformable relationship with the underlying and overlying units respectively.

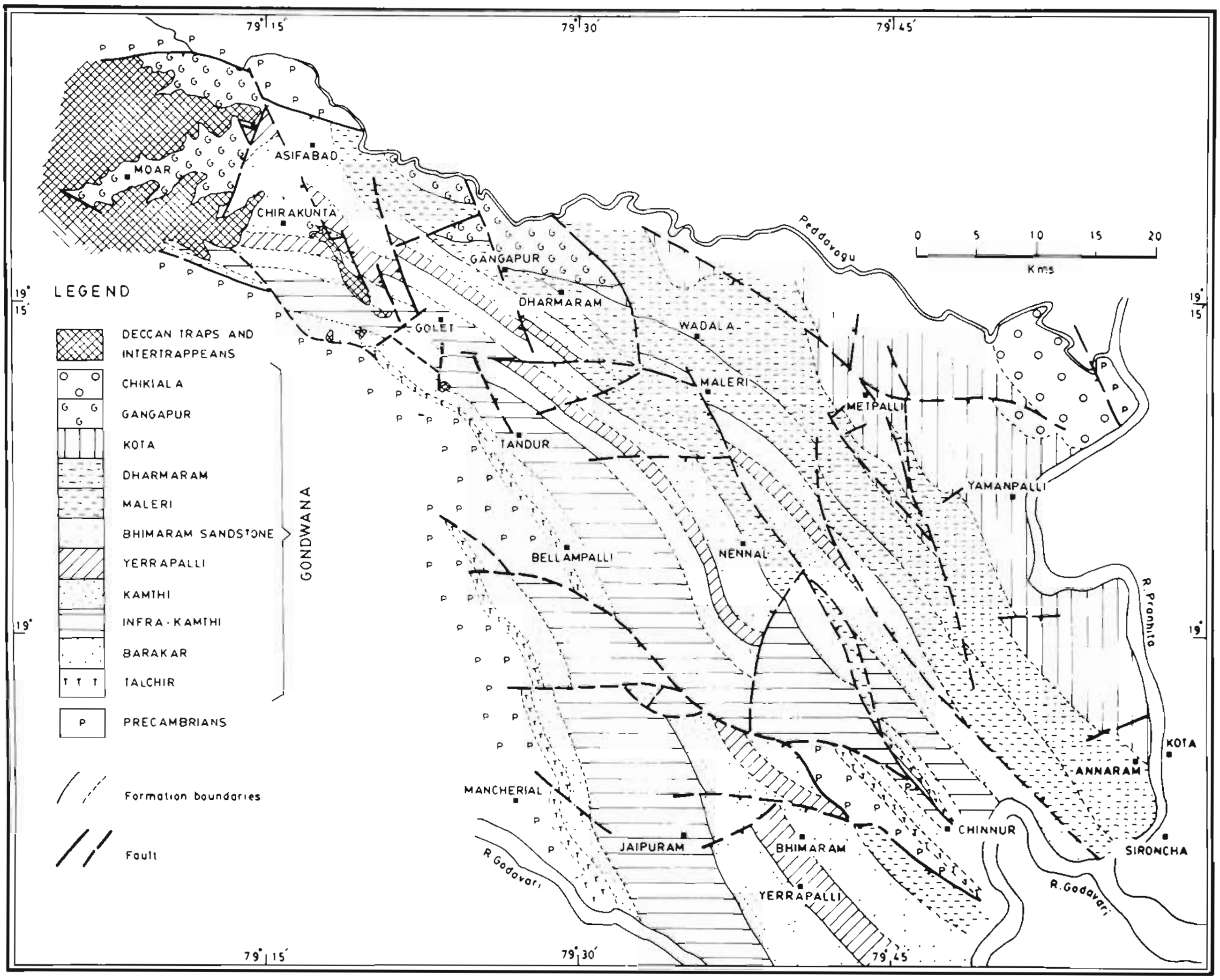
Heron (1949) published a geological map of the area, in which the stress was perhaps more on the Precambrians. He observed that the western boundary of the Gondwana south of Sirpur and its western continuation into the Jangaon Valley (that is the northern boundary in this part of the outcrop) were faulted boundaries. A consequence of this observation was the removal of some of the evidence on which King concluded that the lower boundaries of his Barakar and Kamthi were marked by unconformities.

Coal exploration work continued right through this period, the emphasis had been on their exploitation and on studies related to resource availability. Perhaps as a consequence, in spite of the potential possibilities, these studies did not lead to a better description of the Barakar nor to a publication of a more accurate and detailed map.

A clearer picture of the Maleri fauna emerged through the works of Lydekker (1885), Huene (1940) and Colbert (1958). This fauna comprised a metoposaurid amphibian, a rhynchosaur *Paradapedon* (*Hyperodapedon*), a phytosaur *Parasuchus*, perhaps three more forms of phytosaurs, an armoured pseudosuchian and some early dinosaurs. It afforded a ready correlation with similar faunas from Europe and North America of Late Triassic age.

The apparent stunted progress during the above period was due, to a great extent, to the practical difficulties in understanding the true geology of the area. It reflects the broad resemblances that are seen among the lithologies of different formations and therefore the problems in recognising the formations, the compounding of these problems because of the difficulties in recognising the many faults that exist but leave little trace on these lithologies, and at the same time, the need to understand and map the succession in much more detail to surmount the above problems.

During last 25 odd years, the Indian Statistical Institute under the leadership of Dr Pamela Lamplugh Robinson, University College, London, the Geological Survey of India (GSI) and the Oil and Natural Gas Commission (ONGC) have carried out independent work in this area which have resulted in a revised stratigraphic column and a geological map. There are thus three different versions of the geology of this area under consideration. The work of the GSI (Rao, 1982) and the present work are in some sense complementary, but the version of the



Map 1—Geological map of the Gondwanas of the northern Pranhita-Godavari Valley between Pedda Vagu and the Godavari River (incorporating data from Chatterjee, C. 1967; Kutty, T. S., 1969; Sengupta, S., 1970; Rudra, D. K., 1982; Rao, C. S. R., 1982; Bandyopadhyay, S. & Rudra, D. K., 1985; and Sengupta, D., under preparation). The regional dip of the beds is generally about 10°-15° to NNE or NE; Gangapur and the Chikiala have lower dips, sometimes subhorizontal; the Deccan Traps are practically horizontal.

ONGC (Raivarman *et al.*, 1985) is vastly different. For this reason, in the following section the revisions of Raivarman *et al.* (1985) have not been incorporated, but are discussed separately in a subsequent section.

It is necessary to point out that many stratigraphic names have been used by different authors in different senses. In the discussions that follow it may often be necessary to use a name in the sense as used by a specific author. In such cases the reference is explicitly stated unless the implication is obvious. Unqualified references generally imply their current revised sense as given in Table 1.

Talchir Formation

The Talchir Formation is the oldest of the Gondwana formations of the area. It rests unconformably on an eroded surface of Precambrian rocks. It is believed to represent sediments laid down under a glacial or glacio-fluvial regime.

The Talchir Formation crops out as a narrow strip, broken at places by faults and never attaining any great thickness, along the western margin of the basin. A good section near Mancherial exhibits tillites at the base (Sullavai Supergroup) consisting of polymictic clasts of granite, quartzite and limestone set in a fabric of mixed grain size. The tillites grade upward into a succession of greenish shales and siltstones. The siltstones are succeeded by another unit of structureless tillites which, in turn, are overlain by fine-to medium-grained cross-bedded sandstones. This area thus records recurrence of tillites (*see* Rao, 1982).

Table 1—Revised Gondwana Sequence of the northern Pranhita-Godavari Valley

FORMATION	MAIN LITHOLOGIES	IMPORTANT FOSSILS	AGE
DECCAN TRAPS			LATE CRETACEOUS & EARLY TERTIARY
Chikiala	Highly ferruginous sandstones and conglomerates	?	?
Gangapur	Coarse gritty sandstones; greywhite to pinkish mudstones with interbedded ferruginous sandstones and concretions	*Gleichenia, Pagiophyllum Ptilophyllum, Elatocladus*	Early Cretaceous
Kota	Sandstones, siltstones and clays with a characteristic limestone band	Holostean fishes Sauropods, Pterosaurs Early mammals	Early Jurassic
Dharmaram	Coarse sandstones and red clays	Prosauropods (small & large)	late Late Triassic
Maleri	Red clays, fine to medium sandstones and lime-pellet rocks	Metoposaurs Phytosaurs Rhynchosaurs Aetosaurs	early Late Triassic
Bhimaram Sandstone	Medium to coarse and fine sandstones, ferruginous in the lower part and calcareous in the upper part; some red clays	Labyrinthodont Dicynodont	? (late Middle) (Triassic
Yerrapalli	Mainly red and violet clays with sandstones and lime-pellet rocks	Stahleckeriid & Kannemeyeriid dicynodonts	early Middle Triassic
Kamthi	Ferruginous non-feldspathic or slightly feldspathic sandstones and purplish siltstones	Dicynodont from basal beds	late Late Permian to Early Triassic
Infra Kamthi	4 lithozones; zone 2 is carbonaceous; zones 3 and 4 with red mudstones, latter also has limonitic shales	Endothiodont Cistecephalid (from lithozone 3)	Late Permian and ? very late Early Permian
Barakar	Feldspathic sandstones, carbonaceous shales and coal	Glossopteris flora	late Early Permian
Talchir	Tillites, greenish shales and sandstones		early Early Permian
PRECAMBRIANS		(PROTEROZOIC)	

Barakar and Kamthi of King

The succession above the Talchir and up to the top of the Kamthi of King has been interpreted by different authors in different ways. King's Barakar consists essentially of the coal-bearing group of rocks that overlie the Talchir. More or less the same definition seems to have been adopted by Rao (1982) and Ramanamurty (1985). They recognised a second carbonaceous sequence higher up, and called the intervening beds the Barren Measures, restricting the name Kamthi to the remaining part of this succession. Sengupta (1966, 1970) observed that the sandstones and associated siltstones in the upper part of King's Kamthi were lithologically distinct and distinguishable from the succession below, and therefore restricted the name Kamthi to this upper part only. Though Sengupta's study covered only a relatively small area, the mapping of Chatterjee (1967) and our own observations confirm that the Kamthi, in this revised sense, remains essentially distinct throughout the area under consideration here. Though lateral variations are present, its identity is maintained. In view of the essential similarities of the sandstones of the succession above the Talchir and up to his Kamthi, Sengupta included this entire succession in his Barakar, except for some shales, which he called the Ironstone Shales, that occurred impersistently between them.

We have accepted here the definition of Barakar as used by King (1881) and as also by Rao (1982). We shall use the name Kamthi here in the sense of Sengupta (1970), as its lithological distinctness will

Table 2—Lithostratigraphic interpretations of the Lower Gondwanas of northern Pranhita-Godavari Valley

<table>
<tr><th>King
(1881)</th><th colspan="2">Sengupta
(1970)</th><th colspan="2">Raja Rao
(1982)</th><th colspan="2">This Paper</th><th colspan="2">Lithological characteristics</th></tr>
<tr><td rowspan="7">KAMTHI</td><td rowspan="2">KAMTHI</td><td>Upper Member</td><td rowspan="5">KAMTHI</td><td rowspan="3">Upper Member</td><td rowspan="3">KAMTHI</td><td>Upper Member</td><td rowspan="3">Ferruginous non-feldspathic sandstones &</td><td>abundant pebbles, few siltstone clasts</td></tr>
<tr><td>Middle Member</td><td>Middle Member</td><td>abundant siltstone clasts, few pebbles</td></tr>
<tr><td></td><td>Lower Member</td><td>Lower Member</td><td>purplish siltstones</td></tr>
<tr><td colspan="2">IRONSTONE SHALES</td><td rowspan="2">Middle Member</td><td rowspan="4">INFRA-KAMTHI</td><td>Lithozone 4</td><td rowspan="5">Essentially feldspathic, calcareous or sometimes ferruginous sandstones &</td><td>red mudstones, limonitic shales, purplish siltstones</td></tr>
<tr><td colspan="2" rowspan="4">BARAKAR</td><td>Lithozone 3</td><td>red, green & yellow mudstones and shales</td></tr>
<tr><td></td><td>Lower Member</td><td>Lithozone 2</td><td>carbonaceous or coaly shales & thin coals</td></tr>
<tr><td colspan="2">BARREN MEASURES</td><td>Lithozone 1</td><td>shales with insignificant carbonaceous matter</td></tr>
<tr><td>BARAKAR</td><td colspan="2">BARAKAR</td><td colspan="2">BARAKAR</td><td>carbonaceous shales and coal</td></tr>
<tr><td colspan="7">TALCHIR</td><td colspan="2">Tillites, green shales and sandstones</td></tr>
</table>

then give it an identity of its own. The succession between the Barakar and Kamthi so defined requires, in our opinion, much more information before it can be sorted out. We have therefore preferred to use an informal name 'Infra-Kamthi' to refer to them. However, there are indications to suggest the existence of four lithozones within it, but the information available is too insufficient to give them any formal stratigraphic status at present. These varied use of the different stratigraphic names and their correspondence are summarised in Table 2. The succession is briefly described below.

Barakar Formation

The Barakar succeeds the Talchir Formation without any apparent break and consists of coarse gritty calcareous sandstones, greywhite or yellowish in colour and having pebble bands. They are associated with finer grades of sandstones and shales, and characteristically, much of the shales in this suite are carbonaceous. Perhaps the most important member of this suite is the coal, which is widely mined and is of considerable economic importance.

Much of the details of this formation are known only from bore-hole data. Although exposures of the carbonaceous shales and coal are known they are not all that common. The fine sediments yield good plant fossils.

Infra-Kamthi

Lithozone-1—This consists of a succession of coarse sandstones broadly similar in character to those of the Barakar. The sandstones may be ferruginous and brown in colour; there are interbedded shales, but there is no coal nor any significant carbonaceous matter in this suite. The information leading to the recognition of this lithozone and the next one comes from bore-hole data.

Lithozone-2—This lithozone also consists of sandstones and shales like in the previous lithozone, but is distinguished from the latter by the presence of carbonaceous shales, coaly shales and may be some coal.

Lithozone-3—This consists of a succession of brownish, yellowish or grey feldspathic sandstones with interbedded lenses and bands of mudstones and shales. The sandstones are generally calcareous but may be ferruginous in places. No carbonaceous shales or coal is known from this lithozone.

Very broadly the succession can be thought of as succession of cycles, each cycle consisting of all or some of sandstones, mudstones and shales. However some clarifications are called for. Two traverses taken not too close to each other are unlikely to produce sections which will allow a one-to-one correspondence of their individual units. If the traverses are sufficiently apart such matching may become highly speculative. There is no work yet which brings out the inter-relationships of these units. It is thus evident that the units of these cycles, and perhaps the cycles themselves, are not traceable laterally for any considerable distance.

Lithozone-4—This lithozone is, in a sense, a special case of the previous one in that the shales are brown in colour, fissile, and micaceous with haematite or limonite cement. There may also be some purplish siltstones in some of the cycles. These fissile shales sometimes yield plant fossils.

It will be useful at this stage to consider the following points about the lithozones of the Infra-Kamthi: (1) the exposures of the rocks of these lithozones, except perhaps lithozone 4, are predominantly of sandstones which, as we have noted, have basically similar characters; (2) the essential characters of lithozones 1 and 2 are known only from subsurface data. This is especially true of the characters that distinguish lithozones 2, that is the presence of carbonaceous shales and coaly shales or coal in it. There is at present no clear indication as to how to distinguish these lithozones on the basis of surface characters; (3) the lithozones 3 and 4 are inferred from surface exposures, but, exposures being poor generally, their mappability or even the possibility of defining recognisable boundaries for them (except the upper boundary of lithozone 4) are yet uncertain.

It can only be concluded therefore that these lithozones are not amenable to surface mapping with the information that is available at present. Hence they are best kept as a single unit, at least for the time being. Even the definition of a recognisable upper boundary for the Barakar Formation, for surface mapping, is a difficult proposition. Under the circumstances we prefer to lump them together under a tentative informal name like Infra-Kamthi, until more detailed information becomes available.

Kamthi Formation

Lower Member—This consists of fine- to medium-grained poorly sorted sandstones which are non-feldspathic and ferruginous, and are associated with lenses and bands of purplish siltstones. In the southern part of this area a thick purplish siltstone forms a characteristic basal horizon.

Middle Member—It consists of a sequence of coarse ferruginous loosely cemented sandstones containing numerous siltstone clasts; interbedded with them there may also be thin lenses or partings of the siltstones.

Upper Member—Above this and up to the top of the Kamthi (King) the sequence consists of coarse poorly sorted brown non-feldspathic ferruginous pebbly sandstones, with pebble bands and occasional clasts of siltstones.

Post-Kamthi succession

According to King (1881) this succession has three formations—Maleri, Kota and Chikiala. The Maleri Formation was known to have a Late Triassic vertebrate fauna whereas the Kota Formation had an Early Jurassic vertebrate (fish) fauna. The Maleri was a dominantly clay formation whereas the Kota was predominantly of sandstones with, characteristically, some limestones in it. Yet, their delineation into two separate formations had been so difficult that they were at one time considered to form an inseparable unit and known as the Kota-Maleri (or Maledi) beds. The situation was more confusing because of the occurrence of some plant fossils judged to be younger in age than the Kota fauna, but occuring in beds which were thought to be below those which yielded the fauna. What is more, some of the plant localities stated were well within the Maleri outcrop in King's geological map (Fox, 1931).

Detailed mapping of the area during recent years necessitated the recognition of a number of new formations and also help clarify many of these problems and confusions surrounding the Maleri and Kota formations of King. In the process the Maleri and the Kota were redefined and, in their current usage, carry a more restricted sense than what King had used (*see* Kutty, 1969; Sengupta, 1970).

The Maleri and Kota formations derive their name after the villages of the same names around which their characteristic lithologies and fauna were initially recognised. The extensive red clays and associated subordinate sandstones yielded its characteristic fauna which included the rhynchosaur *Paradapedon* (*Hyperodapedon*) and the phytosaur *Parasuchus*. The limestones that are characteristic of the Kota Formation yielded a fish fauna consisting of *Lepidotes*, *Paradapedium* (*Dapedium*) and *Tetragonolepis*. Over the years, the names Maleri and Kota have become intimately associated with both their lithological characteristics as well as their faunas.

The information that has now accumulated demonstrates that the geology of the area is vastly different from the picture that King visualised. The 'Gangapur beds' in its type area, which were thought by King (1881) to form basal beds of the Kota and which yielded plant fossils, were shown to overlie limestones and associated beds of the Kota Formation with an angular unconformity, necessitating a redefinition of the latter (Kutty, 1969). The succession between the Kamthi and the redefined Kota Formation is an essentially unbroken one except, perhaps, for a minor break at the base of the Kota. A total of four formations, not just one, were recognised and mapped within this succession. The name Maleri Formation was restricted to one of them on lithological and faunal considerations (*see* Jain *et al.*, 1964; Kutty, 1969). It has also become abundantly clear that the geology of this area cannot be properly understood unless and until these formations are mapped.

The post-Kamthi succession, as it stands now, contains the formations Yerrapalli, Bhimaram Sandstone, Maleri, Dharmaram and Kota, and succeeding them, two formations Gangapur and Chikiala, whose inter-relationships are as yet uncertain.

Yerrapalli Formation

This formation recognised by Jain, Robinson and Roy-Chowdhury (1964) succeeds the Kamthi Formation without any significant break (Sengupta, 1970). It is an essentially clay formation with subordinate sandstones. The clays may be variegated, but the dominant colours are red and violet; the latter is particularly characteristic of this formation. The associated rock types include 'lime-pellet' rocks (Robinson, 1964), fine-grained whitish calcareous sandstones, medium to coarse grey-white feldspathic calcareous sandstones, and a black calcareous sandstone whose black colour is due largely to the black colour of the calcite in it. These sand bodies occur as lenses of varying dimensions.

The clays and 'lime-pellet' rocks, sometimes also the sandstones, all yield vertebrate fossils. The fauna includes fishes, amphibians and reptiles; the common characteristic members are a capitosaurid amphibian *Parotosuchus* (*Parotosaurus*) and a kannemeyeriid dicynodont *Wadiasaurus*. Many of the faunal elements are restricted to this formation.

Although the contact with the underlying Kamthi may be gradational or inter-tonguing in places (Sengupta, 1970), such a zone when present is very narrow, and the boundary is almost always readily drawn at the first occurrence of the clays. The main difficulty, that is usually faced, is due to lack of exposure of the contact zone, but in general, the change in topography allows its reasonable inference.

Bhimaram Sandstone

This formation, also recognised by Jain *et al.* (1964), forms a wide sandstone belt. It is essentially a sandstone formation, but may have within it some lenses and bands of red clays. Its lower part, well-developed in the southern part of the area, has a brown, sometimes violetish, coarse feldspathic sandstone which may be often pebbly and contain clay galls. The sandstones usually form rather flat but relatively higher ground which has a loose sandy soil. Sometimes ferruginous concretions and secondarily iron-enriched sandstone boulders are found scattered on the ground. The sandstones as well as the ground thus contrast with the Yerrapalli grounds.

The upper part of the Bhimaram Sandstone is more or less well-developed throughout. It consists of whitish and greywhite calcareous sandstones, fine to medium- and coarse-grained, often having patches of conglomerates whose pebbles appear to be largely of sandstones of similar lithology and clay galls; there may also be some pebbles of quartz and other rock fragments. Evidently these conglomerates are mostly of locally derived material. Towards the top, the sandstones become fine-grained and white in colour and are then overlain by the red clays of the Maleri Formation with a gradational but rapid contact. The soil of this zone is also sandy but firmer and whitish in colour. There is possibly a narrow clay zone between the two parts, but its persistence is uncertain because of the poor exposures.

Maleri Formation

This is a red clay dominated formation with lime-pellet rocks and sandstones. The sandstones are usually fine- to medium-grained and white or greywhite in colour. Variants include a darker grey tougher sandstone with calcite cement, and may have abundant lime-pellets in it. Usually these pellets are small but in places, particularly in the upper part, there may be an abundance of irregular-shaped galls of greyish or greenish tough calcareous mudstones. Red and green claygalls are often present in the sandstones. The Maleri clays are usually a bright vermillion or crimson red in colour; they may also be greenish in places.

The 'lime-pellet' rocks usually occur as lenses of varying thickness and lateral extent, sometimes only a few centimetres thick and extending for not more than a few metres, and sometimes up to a few metres in thickness and extending laterally as a narrow ridge for some tens of metres.

The sandstones, too, have similar occurrences. But, some of the sandstones, though not much thicker, may be persistent laterally, and barring minor breaks, can be traced laterally for considerable distances, sometimes even for a few kilometres. The Maleri sequence can therefore be considered, roughly, as an alternating succession of sandstone and clay bands.

About half the width of the outcrop of the Maleri Formation is occupied by the lowest clay band, i.e., the clay band immediately above the Bhimaram Sandstone. It is therefore a particularly distinctive one in the field. The upper half may have numerous sandstone and clay bands.

Vertebrate fossil remains are fairly common in this formation, and include the rhynchosaur *Paradapedon* (*Hyperodapedon*) and the phytosaur *Parasuchus*, both characteristic members of King's Maleri. The fauna also includes some fishes, a metoposaurid amphibian, an armoured pseudosuchian and some early dinosaurs.

Dharmaram Formation

The Dharmaram Formation has at its base a thick sandstone band. This sandstone band is followed up by more clay and sandstone bands. The sandstones bear superficial resemblance to those of the Maleri, and so too the red clays. But there are distinguishing features. The sandstones of the Dharmaram are generally medium- to coarse-grained and may in places be even gritty; the Maleri sandstones are fine- to medium-grained and almost never so coarse. Although lime-pellet rocks do occur in the Dharmaram, they are less frequent. However, the sandstones may contain abundant lime-pellets, claygalls and irregular-shaped galls of tough limy mudstones.

The wide basal sandstone band often forms low flat ridges with pale-brown loose sandy soil somewhat like the lower part of the Bhimaram Sandstone, contrasting nicely with those of the Maleri which have firm white sandy soil and form narrow ridges. The main problem in demarcating the boundary is due to poor exposures. Vertebrate fossils are from this formation, chiefly from the topmost clay band. None of the characteristic Maleri elements are present. The fauna consists chiefly of prosauropods and includes a large one which may be a plateosaurid (Kutty, 1969).

Kota Formation

Succeeding the topmost clay band of the Dharmaram Formation is a coarse pebbly sandstone which grades up through fine-grained white sandstones into red clays; these red clays are in turn overlain by calcareous shales and limestones yielding the typical fish fauna of the Kota. In fact, there is a distinct faunal change at the pebbly sandstone (Kutty, 1969), and the base of this sandstone forms a well-defined lower boundary of the Kota Formation. Eastwards this sandstone is much thicker and the base is marked by a conglomerate with limestone pebbles (Rudra, 1982). The limestones are followed by some more red clays or ferruginous shales, and these are in turn succeeded by a sequence largely of sandstones and some shales. There is also probably a calcareous zone within this succession.

The presence of a conglomerate or a pebbly sandstone at the base and the abrupt change in the fauna is suggestive of a break in the continuity of the succession. However, it is possible that this break may not be of any great significance.

Gangapur Formation

In the northwestern part of the area, the Kota Formation is overlain by the Gangapur Formation (Kutty, 1969). In the type area near the Cave Temple just north of the village of Gangapur it also corresponds to the 'Gangapur Beds' of King (1881). The formation has in its lower part some coarse and very coarse ferruginous sandstones with many pebble bands. These are then succeeded by an alternating sequence of sandstones and mudstones or silty mudstones. The mudstones characterise this upper part as also some ferruginous concretions that occur within or interbedded with them. The mudstones yield a good flora which is judged to be Early Cretaceous in age (Bose *et al.*, 1982; Ramakrishna & Ramanujam, 1987).

Eastwards, the outcrop of the Gangapur Formation ends against a fault which brings it against Triassic beds. However, even within this limited eastward extent, there is a clear indication of a coarsening of the rocks; the sandstones in its lower part become more pebbly and conglomeratic.

Chikiala Formation

The Chikiala Formation is recognised only in the eastern part of the area and overlies the Kota Formation unconformably (King, 1881; Rudra, 1982). It consists of coarse and very coarse ferruginous sandstones and massive, locally extensive, but highly impersistent lenticular red clays, and some irregular occurrences of calcareous sandstones (Rudra, 1982). The sandstones and conglomerates may sometimes by very highly ferruginous. No fossils are known from the Chikiala Formation.

RELATIONSHIP OF GANGAPUR AND CHIKIALA FORMATIONS

Although both the Gangapur and Chikiala formations are known to overlie the Kota Formation, there is nowhere any physical continuity between their outcrops. Their lithologies also differ considerably, so much so that their relationship to each other is obscure. There are no confirmed reports of fossils from the Chikiala. The Gangapur has a good Early Cretaceous flora, but neither such a flora nor an equivalent fauna of that age are known from the eastern part. Recently, Raivarman *et al.* (1985) have suggested that Gangapur is older than Chikiala on the basis of a fault which is claimed to affect the Gangapur but not the Chikiala. However, this evidence is not unequivocal, since the interpretation of the fault is at variance with that of Rudra (1982) who clearly indicates that the fault affects the Chikiala also.

COMMENTS ON THE MAPPING PROBLEMS

The revised stratigraphy presented above is a vast improvement on the picture that King visualised more than 100 years ago. That it took so long is a reflection of the difficulties encountered in mapping these Gondwanas. Other than the problems due to the generally low relief of these grounds, and those due to the extensive soil cover and the generally poor nature of the exposures, there are three factors that contribute to the difficulties that are, in some sense, special to these Gondwana sediments. These are: (i) the lithological resemblances among rocks of different formations, (ii) the considerable amount of local lithological variations in addition to the regional variations, and (iii) the difficulties in recognising faults. Their compound effect can pose quite serious problems in the field.

It has already been pointed out how confusing lithological resemblances can be, from two sets of examples: (i) the Barakar-Infra-Kamthi group of rocks, and (ii) the red clay-sandstone formations of the Middle and Late Triassic. In the former, the distinction between the Barakar and the lithozones of the Infra-Kamthi were in the fine sediments and the carbonaceous or coaly material in them, which were less often exposed than the more dominant and similar looking sandstones in them. In the latter the difficulty was in differentiating the rather similar looking red clays and sandstones of these Triassic formations.

The confusion so caused is aggravated by the lateral lithological changes seen in them, both local and regional area. The former associated with the variety of depositional environments under the fluvial regime is our main concern as it affects the local outcrop pattern. Coupled with the poor nature of exposures, they present difficulties in tracing beds along their strike; the Maleri amply illustrates this problem. It is made worse by the fact that faults leave little direct evidence on these soft Gondwana rocks, and the normally irregular outcrop pattern of the different lithologies tends to camouflage the shifts of beds due to the faults. It should be evident that, in such circumstances, anything but a detailed mapping can lead to a confused characterisation of the units mapped, and that such a characterisation of a unit may include in it characters that might truly belong to other units. Therefore, it should be clear that no evidence that might help clarify the situation is to be ignored. This includes fossils.

Fossils play a vital supplementary role in mapping. Their use does not make a litho-stratigraphic unit, that is being mapped, a biostratigraphic unit. At best it can become a time stratigraphic unit. The code of stratigraphic nomenclature only demands that a rock stratigraphic unit should not be distinguished *only by its* fossils; it does not demand that its fossil content is to be completely ignored.

It may not be out of place to emphasise here that the formations Yerrapalli, Bhimaram Sandstone, Maleri and Dharmaram are all lithostratigraphic units. They have been characterised and mapped on their lithological distinguishing characteristics, and their boundaries are defined and distinguished on lithological grounds. That some of them have their own distinctive faunas is no disqualification. It is important to note that these formations are not only mappable, but have actually been mapped over a considerable distance (Map 1).

COMMENTS ON THE REVISIONS OF RAIVARMAN *et al.*

The area covered by Raivarman *et al.* (1985) is very large, covering the entire PG Valley and extending further north to include the contiguous Wardha Valley, and the scope of the work is also quite extensive. However, the interpretations of Raivarman *et al.* differ in many respects from all earlier accounts. To mention a few, (i) their mapping has produced a stratigraphic succession which has a number of new formations whose relationship to other existing versions are far from clear, (ii) all the formations are bounded by unconformities and overlaps in contrast to the picture that has been emerging in recent times, of possessing a continuous sequence through Permian and Triassic, (iii) the sequence is interpreted as one marked by repeated marine influences, contrasting with the widely accepted view of being fluvial and lacustrine deposits with an early glacial or glaciofluvial phase, (iv) the tectonics affecting these sediments is claimed to involve thrusting, while previously only normal faulting had been envisaged; and (v) the biota is almost totally ignored.

In so far as the part of the PG Valley under consideration here is concerned, certain inconsistencies with earlier observations are apparent. A few examples are cited below: (1) Raivarman *et al.* claim that there are no coal outcrops in the area, and that the Barakar Formation does not have any surface outcrops and is strictly a sub-surface formation. This is incorrect as coal outcrops do exist. There are also reports of coal occurrences in the literature (King, 1881; Rao, 1982), and an open-cast mine further confirms this point. (2) The Dharmaram Formation is considered by Raivarman *et al.* as a member of their Maleri Formation claiming that it is only traceable for about 17 km. Suffice it to say that the Dharmaram Formation has indeed been recognised and mapped all along from where Kutty (1969) originally mapped it, southeastwards for over 60 km, to near Sironcha (Rudra, 1982; Bandyopadhyay & Rudra, 1985; Map 1 of this paper). An examination of the geological map of Raivarman *et al.* indicates that, in different parts of the area, part or whole of the Dharmaram Formation have been mapped within different formations of theirs; namely, in the 'Kota Formation' west of Wadala, in the 'Maleri Formation' just to the east of Wadala, in a newly proposed 'Tarvai Formation' in the area southeast of Metpalli, in a newly proposed 'Maner Formation' (which appears to be equivalent to the Kamthi Formation) in the neighbourhood of Sironcha and in the Chikiala Formation to the southeast of Sirpur.

It may not be out of place to recall that one of the major controversies, that affected the stratigraphy of this area, concerned with the 'Gangapur beds' of King (1881). A comparison of King's geological map with that presented here (Map 1) suggests that King's problems arose from considering the sandstones of the Dharmaram Formation as the southeasterly equivalents of the sandstones of the Gangapur Formation.

VERTEBRATE FAUNAS

The study of fossil vertebrates from the PG Valley has assumed special importance for several reasons. Firstly, the valley has a fairly unbroken succession of Gondwana rocks, albeit the two breaks in the upper subdivision. Secondly, it is unique among the Gondwana in having a number of distinct vertebrate faunas. Already five faunas are known, all from the northern part of the valley; these are from the Infra-Kamthi lithozone 3, Yerrapalli, Maleri, Dharmaram and Kota. And, there are indications that there might be two more faunas, one from the Lower Kamthi and the other from the Bhimaram. Thirdly, there is sufficient overlap of this faunal sequence with those from the other Gondwanaland areas on the one hand and the Laurasian sequences on the other, thus providing a tie-up of the former with the latter. Jain and Roy Chowdhury (1987) have recently given an account of the vertebrate faunas from PG Valley and hence the following account is somewhat abbreviated.

The Infra-Kamthi Fauna—The vertebrate fauna from the Infra-Kamthi lithozone 3 is yet to be described in detail, but is known to be largely an endothiodont-dicynodont complex with an odd captorhinomorph in it (Kutty, 1972). Also, it has two forms which are close to *Endothiodon* and *Cistecephalus*, both typical of the *Cistecephalus* zone of the Karroo Sequence of South Africa. The fauna is readily correlated to that zone and can be dated as early Late Permian.

The Yerrapalli Fauna—The Yerrapalli fauna is known to consist of a saurichthyd fish (Jain, 1984), dipnoan *Ceratodus* (Chatterjee, 1967), temnospodyl *Parotosuchus* (Roy Chowdhury, 1970a), two dicynodonts—*Wadiasaurus* and *Rechnisaurus* (Roy Chowdhury, 1970b), rhynchosaur *Mesodapedon* (Chatterjee, 1980a), a cynodont (Chatterjee *et al.*, 1969), at least two archosaurs (one proterosuchian and one rauisuchid) and a protorosaurian (Jain & Roy Chowdhury, 1987). The fauna is listed in Table 3.

Table 3—Fossil vertebrates from the Yerrapalli Formation

Faunal List	Geological Range
FISHES	
Chondrostei	
Saurichthys sp.	Triassic
Dipnoi	
Ceratodus sp.	Mesozoic
AMPHIBIANS	
Capitosaurs	
Parotosuchus rajareddyi	Early or Middle Triassic
REPTILES	
Dicynodonts	
Wadiasaurus indicus	Middle Triassic
Rechnisaurus cristarhynchus	Middle Triassic
Cynodonts	
Trirachodontid teeth	Early or Middle Triassic
Rhynchosaurs	
Mesodapedon kuttyi	Middle Triassic
Proterosuchians	
Undescribed genus and species	Early to Middle Triassic
Pseudosuchians	
Undescribed genus and species	Triassic
Protorosaurs	
Undescribed genus and species	Triassic

Among the Yerrapalli dicynodonts, kannemeyeriid *Wadiasaurus* shows advancement over Early Triassic *Kannemeyeria* and could have evolved from the latter (Bandyopadhyay, 1985). Moreover, *Wadiasaurus* shows similarity in several respects with kannemeyeriid genera of definite Middle Triassic age. The dental characters of rhynchosaur *Mesodapedon* show the evolutionary stage attained by Middle Triassic *Stenaulorhynchus* (Chatterjee, 1980a). Colbert (1984) has recently drawn attention to the Yerrapalli rauisuchid showing Middle Triassic affinities. Similarly, Chatterjee (1980b) would like to consider the Yerrapalli protorosaurian as showing Middle Triassic affinities in his scheme of eosuchian evolution. To sum up, the Yerrapalli fauna shows very strong Middle Triassic connections and its comparison with similar faunas found elsewhere in the world suggests an Anisian age.

The Maleri Fauna—The Maleri fauna is characterized by the presence of a dipnoan, a xenacanth (pleuracanth), a temnospondyl, a rhynchosaur, a phytosaur, a coelurosaur, a protorosaur, an aetosaur and a cynodont. The better known members of the fauna are temnospondyl *Metoposaurus* (Roy Chowdhury, 1965), rhynchosaur *Paradapedon* (Chatterjee, 1974), phytosaur *Parasuchus* (Chatterjee, 1978), protorosaurian *Malerisaurus* (Chatterjee, 1980b) and cynodont *Exaeretodon* (Chatterjee, 1982). Other members of the fauna include dipnoan *Ceratodus* (Miall, 1878; Jain, 1968) and xenacanth *Xenacanthus* (Jain, 1980). A coelurosaurian dinosaur, *Walkeria* (Chatterjee, 1987) is known from skull and some postcranial material. A few more forms, including an aetosaur, two more phytosaurs and one more temnospondyl are suspected to be present in the Maleri fauna as suggested by fragmentary remains (Lydekker, 1885; Huene, 1940). A listing of the better known members are given in Table 4.

The temnospondyl and reptilian groups suggest an early Late Triassic age and the evolutionary level of the phytosaur particularly points to a Carnian age. The suggestion made earlier (Romer, 1960) that the rhynchosaur may indicate a Middle Triassic age has been treated by Chatterjee (1980a) to show that the Maleri rhynchosaur is undoubtedly of Late Triassic age. This view has been further reinforced by Colbert (1984), who has compared the Maleri fauna with those of the Keuper of Europe and the Late Triassic Dockum and Chinle of North America.

The Dharmaram Fauna—The vertebrate fauna from the Dharmaram Formation is still not described in detail but a preliminary report indicates the presence of an essentially dinosaur fauna. There are atleast two saurischians, both prosauropods; one is a

Table 4—Fossil vertebrates from the Maleri Formation

Faunal List	Geological Range
FISHES	
Dipnoi	
Ceratodus virapa	Mesozoic
C. hunterianus	Mesozoic
C. hislopianus	Mesozoic
C. nageswari	Mesozoic
Subholostean	
Unnamed genus and species	
Xenacanth	
Xenacanthus indicus	Late Triassic
AMPHIBIANS	
Metoposaurs	
Metoposaurus maleriensis	Late Triassic
REPTILES	
Cynodont	
Exaeretodon statisticae	Late Triassic
Rhynchosaur	
Paradapedon huxleyi	Late Triassic
Eosuchian	
Malerisaurus robinsonae	Late Triassic
Phytosaur	
Parasuchus hislopi	Late Triassic
Pseudosuchian	
Scutes similar to *Typothorax*	Late Triassic
Coelurosaur	
Walkeria maleriensis	Late Triassic
Prosauropod	
cf. *Massospondylus* sp.	Late Triassic

large plateosaurid and the other a small thecodontosaurid. In addition, there is an ornithischian and a sphenosuchid in the fauna. In discussing the age of the Dharmaram fauna, Kutty (1969) noted that the changes between the Dharmaram and Maleri faunas are very similar to those found between the Knollenmergel and Rhatsandstein on the one hand and the Keuper horizons below on the other of the type Triassic succession of Germany. Hence the Dharmaram fauna was provisionally considered to be of Late Norian to Rhaetian age.

The Kota Fauna—The Kota fauna is characterized by the presence of three semionotids, a coelacanth and two pholidophorid fishes. The semionotids, *Paradapadium* and *Tetragonolepis* are restricted to the Liassic (Jain, 1973). The Kota *Lepidotes* is also close to *L. elvensis* from the European Liassic (Jain, 1983). The coelacanth, *Indocoelacanthus*, though not an age marker, is the only example of the group from India (Jain, 1974a). Pholidophorids, well-represented in the European Liassic, are also suggestive of an Early Jurassic age for the Kota Formation (Yadagiri & Prasad, 1977).

The sauropod remains from the Kota Formation are quite well-known. The best known member is *Barapasaurus*, which is claimed as one of the oldest known sauropod in the world (Jain *et al.*, 1975, 1979). In addition, Yadagiri *et al.* (1979) have also suggested the presence of a second dinosaur which is "closer to prosauropods than sauropods." *Campylognathoides*, a pterosaur, known from Liassic of Germany has also been found from the Kota Formation (Jain, 1974b). Fragmentary crocodilian remains from the Kota (Owen, 1852) have been referred to the family Teleosauridae and it has been suggested (Buffetaut, 1979) that the Kota crocodiles may be the earliest representatives of the family.

Discoveries of Early Jurassic mammals from the Kota Formation have been recently reported. On the basis of isolated teeth, Datta (1981) erected *Kotatherium* and Yadagiri (1984) erected *Trishulotherium* and *Indotherium*, all assigned to kuehneotherid symmetrodonts. An amphidontid symmetrodont, *Nakunodon*, has also been identified from the Kota Formation (Yadagiri, 1985). The precise relationship of these teeth with other symmetrodonts is at present quite uncertain. However, in view of the paucity of these early mammals from Gondwanaland and the sparse records of Early Jurassic mammals all over the world, the discoveries of such remains are extremely important. A list of the Kota fauna is given in Table 5.

Yadagiri (1986) has recently given an account of a number of microvertebrates from " the clays immediately underlying the fossiliferous limestone" of the Kota Formation near Paikasigudem (19°16′N, 70°31′E). These include a hybodont shark (*Lonchiodon*), a perch (genus indet.), a pelobatid

Table 5—Fossil vertebrates from Kota Formation

Faunal List	Geological Range
FISHES	
Semionotidae	
Lepidotes deccanensis	Liassic
Paradapedium egertoni	Liassic
Tetragonolepis oldhami	Late Liassic
Pholidophoridae	
Pholidophorus kingii	Liassic
P. indicus	
Coelacanthidae	
Indocoelacanthus robustus	Uncertain
REPTILES	
Dimorphodontidae	
Campylognathoides indicus	Liassic
Sauropod dinosaur	
Barapasaurus tagorei	Early Jurassic
Teleosauridae	
Scutes and other fragments	Uncertain
MAMMALS	
Symmetrodonts	
Kotatherium haldanei	Uncertain
Trishulotherium kotaensis	Uncertain
Indotherium pranhitai	Uncertain
Nakunodon paikasiensis	Uncertain

frog (genus indet.), a sirenian urodele (genus indet.), a sphenodontid (genus indet.) and a varanid reptile (*Paikasisaurus*). Except for the hybodont and the sphenodont, all the other groups are known only from post-Jurassic horizons (Andrews *et al.*, 1967; Panchen, 1967; Appleby *et al.*, 1967); in fact the percoids and varanoids are not known earlier than the Maestrichtian. The apparent occurrence of such an assemblage in beds below the Kota limestones which yield the Liassic fish fauna is paradoxical. The percoids, pelobatids and urodeles are characteristic members of the Deccan Intertrappean fauna (Sahni, 1984). It is generally believed that these areas were once covered by the Deccan Traps and its associated Intertrappean beds, and at present they occur not too far to the west from here. It is not impossible that the observed fossil assemblage may be the result of post-Gondwana contamination.

POTENTIAL FOR TWO MORE FAUNAS

In addition to these five faunas, we noted the potential likelihood of the existence of two other faunas in this sequence. One of them is from the Lower Kamthi (*sensu* Sengupta, 1970). Two reptilian fossil specimens were recently discovered from the basal siltstones of this Lower Kamthi by some local villagers, from a quarry. These specimens are unfortunately not available for study, as the villagers have, believing them to be representations of a deity, started worshipping them and have constructed temples around them. More importantly, they cannot also be prepared to establish their true affinities. One specimen, in two counterparts, shows a near complete articulated reptilian skeleton with only the anterior end and part of the tail missing. The specimen is a little over 40 cm long. Only the occiput of the skull is visible which is low and wide. It is likely to be a dicynodont but does not seem to be either *Lystrosaurus* or any of the later Triassic forms. It may possibly belong to the fauna that is known from the Infra-Kamthi lithozone 3, but it is not unlikely that it belongs to a later Permian fauna, i.e., the equivalent of the *Daptocephalus* Zone of the Karroo.

The second potential fauna is from the Bhimaram Sandstone. This formation has yielded some fragmentary material which indicate the presence in it of at least an amphibian and a dicynodont. There are some indications that this dicynodont may be different from the ones seen in the Yerrapalli. For example, the snout seems to be far more pointed than any seen in the Yerrapalli specimen. It is possible that this might be part of a late Middle Triassic (Ladinian) fauna, as is suggested by its stratigraphic position. But, for the present, it is speculative and inconclusive.

CORRELATION

The discussions so far bring out two important attributes of the Gondwana sequence of the PG Valley. Firstly, it has an almost unbroken succession from Early Permian through Triassic and with a small break into the Early Jurassic. Secondly, it possesses a fairly good sequence of a number of vertebrate faunas of considerable stratigraphic value. In both these respects, it is somewhat unique from among the many Gondwana outcrops in India. This vertebrate sequence not only allows a correlation of the Gondwana of the PG Valley with other well known vertebrate sequences of the corresponding periods from different parts of the world (Table 6), but it also provides useful tie-ups between the European and North American sequences on the one hand and the African and South American sequences on the other.

While the PG Valley sequence allows such world-wide correlations, its correlation with the sequences from the various other Gondwana outcrops in India is far more difficult and speculative. Only two formations, Talchir and Barakar, maintain more or less uniform lithological characteristics in all the outcrops. The post-Barakar succession is variable from outcrop to outcrop and an exclusively lithological correlation becomes just an academic exercise. That, correlations based on lithological similarities alone, even intra-basinal, can lead to misleading interpretation is evident from many examples. It was already pointed out earlier how the similarity of the sandstones of the succession between the Talchir and Kamthi formations led to varied interpretation of the Barakar (Sengupta, 1970; Raivarman *et al.*, 1985). The problem of differentiating one red-clay-dominated formation from another is an age-old one. Fox (1931) visualised the Lower Gondwana Motur Formation and Upper Gondwana Denwa Formation of the Satpura Basin as one and the same formation because of their gross lithological similarities, and pictured their underground continuity with all the intervening beds sitting on them and therefore making them younger. Crookshank (1936) showed such an interpretation to be untenable.

An idea similar to that of Fox (1931) has recently been postulated by Dutta (1987) who suggests that the ridge-forming Kamthi Formation was not stratigraphically between Infra-Kamthi and Yerra-palli, but rested unconformably upon a Triassic sequence of red clays and sandstones starting from the upper lithozone of the Infra-Kamthi. Dutta

Table 6—Correlation of some important vertebrate-bearing sequences of the Permian, Triassic and Early Jurassic

AGE			INDIA (P.G. VALLEY)	SOUTHERN AFRICA	ARGENTINA	WESTERN N. AMERICA	GERMANIC BASIN	CHINA	U.S.S.R.
188 m.y.	JURASSIC	EARLY	KOTA	DRAKENSBERG VOLCANICS	SERRAGERAL VOLCANICS	GLEN CANYON GROUP		LOWER LUFENG	
				CAVE SANDSTONE (CLARENS FM)					
208	TRIASSIC	LATE	DHARMARAM	RED BEDS (ELLIOT FM)	LOS COLORADOS	CHINLE-DOCKUM	KEUPER: RATSANDSTEIN, KNOLLENMERGEL, STUBENSANDSTEIN	? ? ? ? ? ? ?	
			MALERI	MOLTENO	ISCHIGUALASTO		BUNTEMERGEL, SCHILFSANDSTEIN, GIPSKEUPER, LETTENKHOLE		
		MIDDLE	BHIMARAM SANDSTONE		LOS RASTROS CHANARES ISCHICHUCA			KELAMYI; (MARINE)	BUKABAI
			YERRAPALLI				MUSCHELKALK	ERMAYING	DONGUS
		E.	KAMTHI	BEAUFORT: CYNOGNATHUS ZONE, LYSTROSAURUS ZONE	PUESTO VIEJO	MOENKOPI	BUNTSANDSTEIN	SHAOFANGGOU JIUCAIYAN; HESHANGGOU	VETLUGA
245	PERMIAN	LATE	INFRA KAMTHI	BEAUFORT: DAPTOCEPHALUS ZONE, CISTECEPHALUS ZONE, TAPINOCEPHALUS ZONE			ZECHSTEIN	LOWER CANGFANGGOU U JIJICAO	N. DVINA
						FLOWER POT, SAN ANGELO	KUPFERSCHIEFER		DINOCEPHALIAN COMPLEX
		EARLY	BARAKAR	ECCA		CLEAR FORK	ROTLIEGENDE		
			TALCHIR	DWYKA		WICHITA			
286									

therefore suggested a Lower Jurassic age to the Kamthi Formation. The arguments for his conjecture pivoted on the observation that the pole position inferred from the palaeomagnetic data from the Kamthi was inconsistent with the Apparent Polar Wander Path for India (APWP) if the age of the Kamthi were Late Permian to Early Triassic; but a Jurassic age for the Kamthi would make the observation consistent with the APWP. It can be demonstrated unequivocally that field relations do not support such a conjecture. Perhaps the palaeomagnetic data from the Kamthi Formation is not to be related to the age of the Kamthi, but to its ferrugination which is post-diagenetic and secondary (Sengupta, 1970). The Jurassic—or may be even later—age suggested by Dutta (1987) would then refer to this secondary ferrugination.

The other means of correlation that have relevance in this context are the fauna, mainly the vertebrates, and the flora; but both, as of now, have limited usefulness for varied reasons discussed below.

Outside the PG Valley the other Gondwana outcrops have yielded relatively little in the way of vertebrates. Among them, only three formations have yielded anything like a fauna; all others being isolated occurrences, either known from solitary specimens or fragments. These three are, an Early Permian fish-amphibian fauna containing *Archegosaurus* from the *Gangamopteris* beds of the Kashmir marginal facies, an Early Triassic *Lystrosaurus* Zone fauna from the Panchet Formation of the Damodar Valley and a early Late Triassic amphibian reptilian fauna from the Tiki Formation from the South Rewa Gondwana Basin. The Tiki fauna can be equated with that from the Maleri Formation. In the Satpura Gondwana Basin, there are, however, two formations —Bijori and Denwa—which are known to contain distinctive amphibians. The former is known from a single specimen of Permian *Gondwanasaurus* while the latter has so far yielded only fragments of a poorly known *Parotosuchus* of Middle Triassic affinities. The other occurrences are all isolated ones and some outcrops have no known vertebrate occurrences at all. Thus in the Indian context, the vertebrates provide at present very limited control in these inter-outcrop correlations. Under such circumstances, it is probably premature to attempt at a bio-stratigraphic zonation based on vertebrates. However, a very useful beginning on this line has been made by Shah, Singh and Sastry (1971) and followed up by Sastry, Acharyya, Shah, Satsangi, Ghosh and Singh (1979) using vertebrates. No further attempt is made here to extend this bio-stratigraphic zonation.

There are very few detailed studies on the floras from many formations of the PG Valley Gondwana Sequence. There is also a problem in relating some of the earlier reports of plant occurrences to the revised stratigraphy because of the lack of precise locations. It will be of importance if detailed floral assemblages from this area are worked out afresh in accordance with the revised stratigraphic succession. This will not only provide an independent floral succession for this outcrop which can be reliably related to the revised geology, but it will also provide a much needed and necessary tie-up between the floral succession on the one hand and the vertebrate faunal succession on the other.

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Contribution to the stratigraphy and vertebrate fauna of Lower Jurassic Kota Formation, Pranhita-Godavari Valley, India

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Yadagiri, P. & Rao, B. R. J. (1988). Contribution to the stratigraphy and vertebrate fauna of Lower Jurassic Kota Formation, Pranhita-Godavari Valley, India. *Palaeobotanist* **36** : 230-244.

Gondwana Sequence of the Pranhita-Godavari Valley represents a thick succession of sediments ranging in age from Early Permian to Early Cretaceous. The Mesozoic Gondwana sediments contain a number of vertebrate bearing zones which are important for correlation and for assigning age to different units. New data on the vertebrate fossils of Kota formation help trace the evolutionary history of Early Jurassic mammals and dinosaurs and palaeogeographic configuration. The status of Gangapur Formation, as a unit, overlying Kota Formation and underlying Chikiala Formation is elaborated. Its lithological identity is established in the Yamanpalli area. Measured lithostratigraphic column of the limestone zone of Kota Formation is described with the lithological variations and fossil contents. The data is useful for correlation of limestone members in delineating Kota Formation along its strike. Analysis of the geochemical data and vertebrate fossil community of Mesozoic sediments with particular emphasis on the Kota Formation, provide overwhelming evidences for fresh water environment of deposition of the Kota Formation. The evolutionary status of vertebrate fauna consisting of early mammals, dinosaurs and pholidophorid fishes is described which supports Liassic age of the Kota Formation.

Key-words—Stratigraphy, Vertebrate fauna, Palaeoecology, Palaeobiogeography, Pranhita-Godavari Valley, (India).

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साराँश

प्रणहिता-गोदावरी घाटी (भारत) में अधरि जूराई कोटा शैल-समूह के रीढ़धारी जीवजात तथा स्तरविन्यास पर योगदान

पी० यादागिरी एवं बी० आर० जे० राव

गोदावरी घाटी के गोंडवाना अनुक्रम में प्रारम्भिक परमी से प्रारम्भिक क्रीटेशी तक विस्तृत अवसादों का एक बहुत मोटा अनुक्रम विद्यमान है। मध्यजीवी गोंडवाना अवसादों में अनेक रीढ़धारी जन्तुधारक संस्तर विद्यमान हैं जो कि विभिन्न इकाइयों के सहसम्बन्धन तथा आयुनिर्धारण में महत्वपूर्ण भूमिका निभाते हैं। कोटा शैल-समूह के रीढ़धारी अश्मित जन्तुओं के नये आँकड़े प्रारम्भिक जूराई कालीन स्तनधारीयों एवं डाइनोसोरों के वैकासिक इतिहास तथा पुराभौगोलिक आकृति के अन्वेषण में सहायक सिद्ध हुए हैं। कोटा शैल-समूह के ऊपर तथा चिकियाला शैल-समूह के नीचे एक इकाई के रूप में विद्यमान गंगापुर शैल-समूह की स्थिति की विवेचना की गई है। यमनपल्ली क्षेत्र में इसकी शैलिकीय स्थिति भी स्थापित की गई है। कोटा शैल-समूह के चूनापत्थर मंडल के अनुमापित शैलस्तरिकीय कॉलम में प्रेक्षित शैलिकीय विभिन्नताओं तथा उपलब्ध जीवाश्मों का वर्णन किया गया है। उपलब्ध आँकड़े चूनापत्थर सदस्यों के सहसम्बन्धन में महत्वपूर्ण सिद्ध हुए हैं। मध्यजीवी अवसादों विशेषत: कोटा शैल-समूह के रीढ़धारी अश्मित समुदाय तथा भूरासायनिक आँकड़ों के विश्लेषण से कोटा शैल-समूह के निक्षेपणीय वातावरण के प्रमाण मिलते हैं जो कि अलवणी जल-परिस्थितियों में हुआ था। प्रारम्भिक स्तनधारीयों, डाइनोसोरों एवं फॉलिडोफोरिड मछलियों से युक्त रीढ़धारी जीवजात की वैकासिक स्थिति विवेचित की गई है जिससे कोटा शैल-समूह की लिऑसिक आयु की पुष्टी होती है।

Concepts, limits and extension of the Indian Gondwana
(Editors : B. S. Venkatachala & Hari K. Maheshwari)
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THE Gondwana Sequence in the Pranhita-Godavari Valley contains rich vertebrate fossil horizons. The Upper Gondwana sediments were considered as consisting of three units namely Maleri, Kota and Chikiala in the order of succession (King, 1881). Recent remapping of the northern part of the Pranhita-Godavari Valley, especially by Jain *et al.* (1964), Chatterjee (1967), Kutty (1969), Sengupta (1970) and Rudra (1982), has led to substantial revision and modification to the Upper Gondwana stratigraphy as proposed by King (1881). However, the lateral equivalency of the Gangapur Formation and King's Chikiala still remains undecided and needs to be analysed (Rudra, 1982). On the basis of detailed mapping of lithounits around Yamanpalli covering an area of about 600 sq km and collection of *in situ* fossils from different horizons it is found that the Gangapur Formation overlies the Kota Formation with an unconformity and the former is overlain by the Chikiala Formation.

The paper presents the revisions to the stratigraphy of the area around Yamanpalli and the detailed account of faunal content of Kota Formation, and their bearing on palaeoecology and palaeobiogeography.

STRATIGRAPHY

The Maleri according to King (1881), consists of predominant red clays which contain Upper Triassic vertebrate fossils and few interbedded calcareous sandstones. The Kota consists of sandstones dominantly, which are either calcareous or non-calcareous and some intercalated red clays and three strongly developed fossiliferous bedded limestones yielding Lower Jurassic Vertebrate fossils.

The mapping carried out along with collection of fossils between Yamanpalli and Sironcha has helped in establishing the following stratigraphy of the area (Table 1, Text-fig. 1). In the area investigated, the Gangapur unit is recognised overlying the Kota Formation from Radharam to Garkapet. It is also observed that the Gangapur Formation is overlain by Chikiala Formation (Text-figs 2, 3).

King (1881) placed the sandstones found near Annaram and Arjungutta as basal beds of Kota 'Stage' and considered them to be equivalent of Gangapur beds occurring in Jangaon Valley. Kutty (1969) placed Gangapur as a separate unit overlying the Kota Formation with an angular unconformity. Rudra (1986) included the Annaram beds as part of Dharmaram formation. Annaram beds have yielded typical floral elements, viz., *Pagiophyllum, Elatocladus, Araucarites cutchensis*, etc. (Tripathi, 1975), the assemblage being similar to that of the Gangapur Formation. The lithounits comprising coarse sandstones are also comparable to the outcrops occurring near Radharam and Kalamalpet. These are classified under Gangapur Formation.

UPPER GONDWANA LITHOUNITS

Maleri

Good outcrops of Maleri are seen near Nakalapalli, Isnai, Pinnaram and Parpalli. There are three main lithologies in the Maleri Formation namely, clays, lime pellet rocks and sandstones; various intermediate types such as siltstones and silty clays are also common. The clays, in general, are soft and red in colour. The lime pellet rocks are mainly composed of rounded pellets of lime varying in size from a millimeter to about a centimeter in diameter. The pellets have an interstitial matrix of clay and are sometimes cemented together with lime to form a tolerably hard rock. The sandstone is light coloured, fine or medium-grained, and contain green and red clay galls, lime pellets and siltstone fragments. In geomorphic expression, the clays normally form the low ground, whereas the sandstone bodies form fairly long ridges trending parallel to the regional strike.

The Maleri fauna is essentially a vertebrate fauna. Only one invertebrate, a unionid *Tihkia* is known. The vertebrates represent the dipnoan *Ceratodus*, the pleuracanth *Xenacanthus*, the labyrinthodont *Metoposaurus*, the rhynchosaur *Paradapedon* and a coelurosaur and a prosauropod dinosaur.

Dharmaram

The Dharmaram Formation comprises a succession of alternating sandstone and clay bands (Pl. 1, fig. 1), the clays forming the low ground and the sandstones standing out as ridge features. The sandstones are generally pale coloured but occasionally dark. The clays are dominantly red in colour. The sandstones are usually current bedded, rarely fine grained. The occurrence of gypsum flakes in the red clays of Dharmaram near Kureampalli is interesting. The gypsum flakes are 3 to 8 mm in thickness. A number of mud crack nodules are also found. The sandstone exposed north of Nilwai is yellow in colour, coarse and sometimes gritty and poorly sorted. The strike of the beds is N35°W and dip at 9° towards NE direction. The red and green clays overlie them. The Dharmaram Formation is observed to thin down in the south-eastern part.

The Dharmaram Formation can be distinguished from the underlying Maleri Formation by the

Table 1—Lithological sequence in Yamanpalli area

Formation	*Lithology*	*Thickness in metres*	*Characteristic fossils*	*Age*
Chikiala	Ferruginous sandstones with conglomerates	400	Plant fossils	Early Cretaceous
Gangapur	Highly calcareous sandstones; fine grained sandstones with interbedded clays; basal part conglomeratic with pebbles of quartz, quartzite and chert; mudstones, etc.	500	Fossil wood, plant fossils, etc.	Early Cretaceous
Kota	Red clays with interbedded siltstones and thin layers of ferruginous clay	100		
	Argillaceous, bedded limestones, beds locally laminated and with desiccation cracks	30	Fishes, flying reptiles and bivalved crustaceans	Early Jurassic
	Red and green clays with interbedded sandstones	50	Dinosaurs, early mammals	
	Current bedded grey calcareous sandstones grading to conglomerate in places with pebbles of quartzite, quartz and chert	250		
Dharmaram	Sandstones with interbedded red clays at places indurated mudstones	500	Prosauropods	Upper Triassic
Maleri	Red clays with interbedded sandstones and lime concretions	300	Metoposaurs, Rhnchosaurs, Phytosaurs	Upper Triassic

absence of lime pellet rock and white fine-grained sandstones. The contact of Dharmaram Formation with the Kota Formation is demarcated by the presence of pebbly sandstone and conglomeratic horizon.

The fauna from Dharmaram Formation includes at least two dinosaurs, a plateosaurid and a prosauropod.

Kota

The Kota Formation comprises mainly light brown sandstones and grits, red clays and a prominent limestone zone. The basal unit consists of coarse, poorly sorted, pebbly sandstone. The pebbles are of banded chert, quartz, and quartzite. In the upper unit, the pebbles become fewer and smaller and the pebbly sandstone passes into fine-grained white sandstones. These sandstones appear to grade laterally and vertically into red clays. The clays are overlain by the calcareous zone which consists of beds of limestone intercalated with marly clays. Limestones are usually pale grey, creamy or reddish in colour. The limestone is overlain by a highly ferruginous mudstone. The sandstone grades upward into siltstone and fine-grained sandstone.

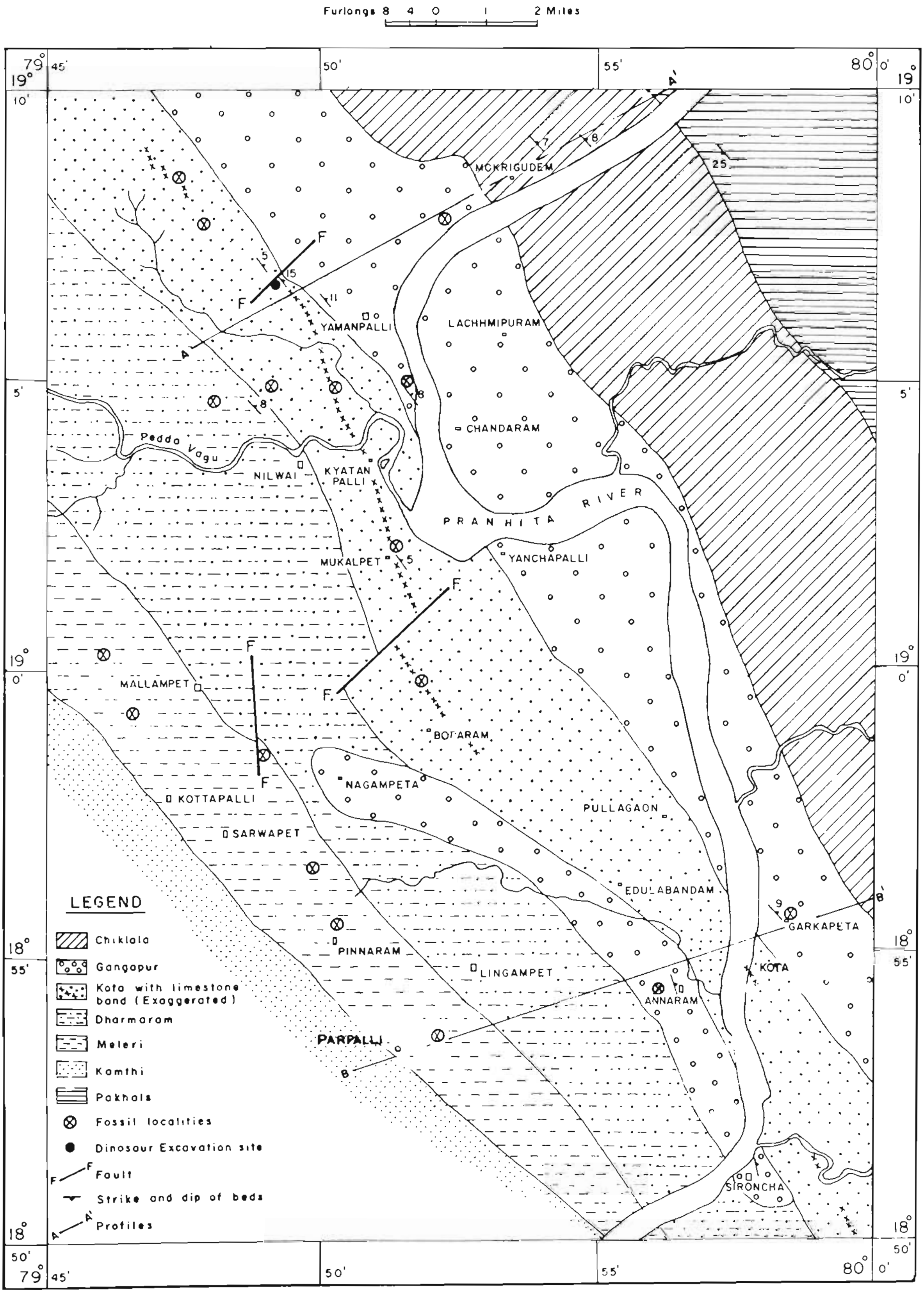
The important marker horizon of the Kota Formation is the limestone horizon (Pl. 1, fig. 3). This is traceable from kadamba in the north to Varidium in the south. In the area investigated, good outcrop of limestone horizon is traceable from Manganpalli to Mukalpet villages. Smaller outcrops are found near Boparam, Kota, Chitur and Varidium.

The basal limestone bed contains abundant ostracod shells (Text-fig. 4) cemented with lime mud. The marly bed immediately underlying this bed has yielded dinosaurian fossils. The succeeding limestone bed is massive, cream-coloured and with a few chert veins. It is stromatolitic at places; a 20-25 cm thick stromatolite-bearing limestone is seen 2 km east of Nagaram. The stromatolites are hemispherical and laterally linked (Pl. 2, fig. 3). Similar structures are also found near Manganpalli and Gorlapalli villages. The third bed is very massive, grey in colour and contains a number of desiccation cracks. The next limestone bed is of laminated variety. Abundant fish fossils are found in this horizon. The topmost limestone bed is nodular. A number of limestone pebbles, varying in size from 1 to 7 cm, are found embedded in the lime mud.

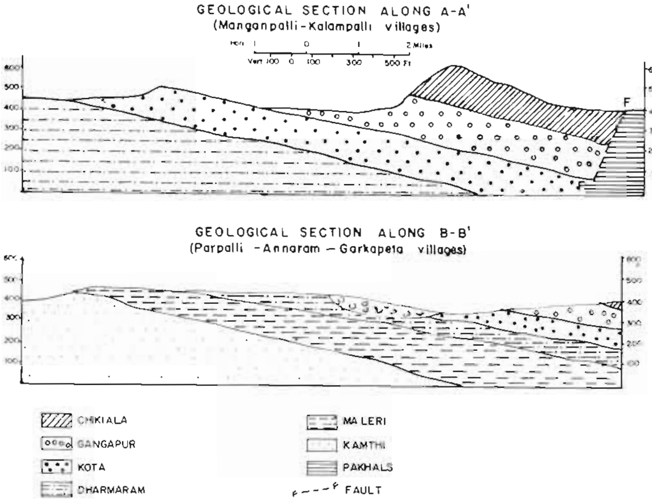
Overlying the limestone bed, the red clays intercalated with fine grained sandstones are found. The red clays are distinctly different from Maleri and Dharmaram clay is being devoid of ferruginous lumps and mudcrack nodules.

Gangapur

In the area investigated, the Gangapur Formation extends from Radharam mound to Garkapeta in the southeast. The basal beds consist of



Text-figure 1—Geological map around Yamanpalli, Adilabad District, Andhra Pradesh.



Text-figure 2—Geological section along A-A (Manganpalli-Kalampalli villages).

pebbly sandstones and mudstones which are locally conglomeratic. The conglomerate consists of pebbles of quartz, quartzite embedded in calcareous matrix (Pl. 1, fig. 2). The quartz pebbles vary in size from 0.5 to 2 cm. Above this horizon, clay clasts are found embedded in a ferruginous matrix. The conglomeratic bed becomes extensively ferruginous in the Pranhita River Section near Yamanpalli. The clay clasts measuring 5 to 50 cm are found sometimes within the conglomeratic bed. They are of pink, lilac, white and yellow colours. The conglomeratic bed is overlain by yellow to brown and lilac coloured sandstones which are soft and friable. This zone extends from Sumtam to Yamanpalli villages. It has yielded large fossil wood trunks. The topmost beds become calcareous and locally nodular limestone in which large fossil wood trunks are found embedded.

The sandstones near Annaram Village are reddish brown to yellowish and are indurated; frequent seams of quartz pebbles and lumps of pink and lilac clay are common. The same horizon extends to Kandampeta and Arjungutta. The strike of the beds is N25° W and the dip is 9° towards NE direction.

The Gangapur Formation has yielded flora representing *Taeniopteris* sp., *Ptilophyllum acutifolium*, *Cycadites* sp. and *Araucarites cutchensis*, etc.

Chikiala

Chikiala Formation represents the youngest unit of Gondwana sequence of the Pranhita-Godavari Basin and outcrops along the eastern fringes of the area. It consists of conglomerates, sandstones and clays. The lower beds consist of predominantly ferruginous conglomeratic sandstone. The conglomerate is composed of rounded to sub-rounded pebbles of quartz, quartzite, chert, hard porcellan clays and jasper in an arenaceous matrix. A good outcrop can be seen north of Makrigudem. The iron content is appreciably high. The conglomerate unit is succeeded by red clays, cross bedded calcareous sandstone which is occasionally conglomeratic towards top. This unit is overlain by brown-coloured loosely packed sandstone, which is ferruginous and rarely conglomeratic. The topmost beds consist of conglomerates with phyllite pebbles and ferruginous sandstone. The sandstones are generally coarse to medium grained (Pl. 2, fig. 2) and ferruginous; those are red, brown or white in colour. The most common of the clays interbedded in current bedded sandstones is red and purple clay. According to King (1881) sandstones of Chikiala are similar in appearance to that of Tirupathi sandstones.

Rao and Shah (1959) have reported a number of plant fossils from Chikiala Formation. The floral assemblage is characterised by the dominance of conifers which resembles the assemblage of Nipania Bed of Rajmahal, East Coast Gondwana and Bhuj Formation of Kutch.

VERTEBRATE FAUNA

The Kota fauna comprises the following taxa:

FISHES

SEMIONOTIDATE:

Lepidotes deccanensis Egerton, 1851
Paradapedium egertoni Jain, 1973
Tetragonolepis oldhami Egerton, 1851

PHOLIDOPHORIDAE:

Pholidophorus kingii Yadagiri & Prasad, 1977
Pholidophorus indicus Yadagiri & Prasad, 1977

COELACANTHIDAE:

Indocoelacanthus robustus Jain, 1974

REPTILES

DIMORPHODONTIDAE:

Campylognathoides indicus Jain, 1974

SAUROPOD DINOSAUR:

Barapasaurus tagoreii Jain *et al.*, 1975
Kotasaurus yamanapalliensis Yadagiri *et al.*, 1979; Yadagiri, 1988

MAMMALS

SYMMETRODONTA:

Kuehneotheriidae—*Kotatherium haldanei* Datta, 1981

Incertae sedis—*Trishulotherium kotaensis* Yadagiri, 1984
Indotherium pranhitai Yadagiri, 1984
Amphidontidae—*Nakunodon paikasiensis* Yadagiri, 1985

The Kota fauna encompasses aquatic, terrestrial, and aerial vertebrates, most of them excellently preserved.

Fishes

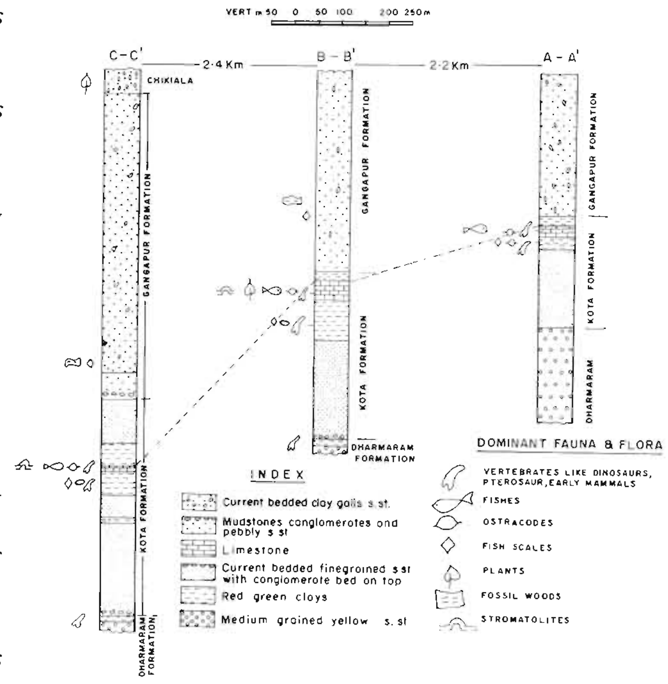
Lepidotes is the most commonly occurring member of the entire Piscine fauna; five species were designated by Egerton (1851). A detailed study of Kota specimens of *Lepidotes* (Yadagiri *et al.*, 1980; Jain, 1983) and an examination of the validity of characters used to distinguish species within the limits of genus, suggest that all Kota specimens should be placed in a single species, viz., *Lepidotes deccanensis.*

The semionotid *Dapedium*, recognized in the nineteenth century, were found morphologically different and a new genus *Paradapedium* was erected (Jain, 1973).

Tetragonolepis, another semionotid, was redescribed by Jain (1973) under the species *Tetragonolepis oldhami.* Two other species of the genus were considered by him as not valid species.

The coelacanth *Indocoelacanthus robustus* Jain, 1974 is estimated to be slightly larger than *Holephaqus.* In the Kota form, the skull bones are heavily tuberculated, except the frontals which are slightly ornamented. Of the species of pholidophorid fishes, namely, *Pholidophorus kingii* and *Pholidophorus indicus, P. kingii* was of smaller size, about 110 mm in length with fusiform body. The length of the head is almost equal to the depth of the body. The ratio of the length of head to the length of the body is 1 : 4. The preoperculum has a very characteristic shape. The posterior margin of the preoperculum is deeply notched with straight sides and convex base, and the anterior margin is inclined; on the body, there are four longitudinal rows of enlarged scales, the deepest being about twice as deep as broad. All scales have even posterior margin. The dorsal fin is directly opposed to the pelvic fin.

The comparison and a critical evaluation of morphological characters of these different pholidophorids known from Early Jurassic sediments have revealed that *Pholidophorus kingii* from India was primitive in pholidophoriform condition than *Oreochima* from Antarctica and Archaeomaenids from Australia.



Text-figure 3—Correlation of measured stratigraphic sections.

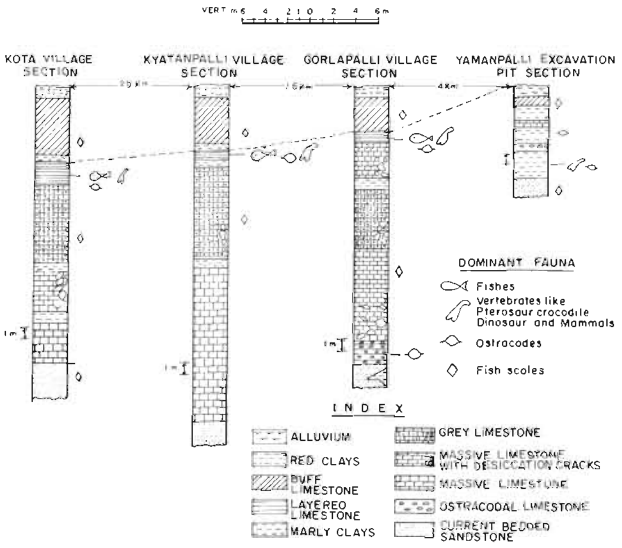
Dinosaurs

A major gap in the understanding of the evolution of sauropod dinosaurs has been due to lack of good fossil material from Lower Jurassic rocks, except fragmentary material *Ohmdenosaurus* described by Wild (1978) from Europe. The discovery of dinosaurian fauna from Kota Formation (Jain *et al.*, 1962) has been a major break through in the knowledge of Mesozoic terrestrial vertebrates from India. A sauropod dinosaur namely *Barapasaurus tagorei* was described from Posampalli area in Maharashtra (Jain *et al.*, 1980). The excavation carried out near Yamanpalli Village, Andhra Pradesh has yielded a number of skeletal parts belonging to different dinosaurs (Yadagiri *et al.*, 1979). In the collection, a new Sauropod dinosaur *Kotasaurus yamanapalliensis* was recognized (Yadagiri, 1988).

The *Kotasaurus* has many sauropodian characters. Its level of development is intermediate between sauropods and prosauropods. It seems to possess a mossaic of prosauropod and sauropod features. The important character of *Kotasaurus* is its elongated and straight pelvis. The ilium of a sauropod is in general rounded in margin with extended pubis process. The ilium of *Kotasaurus* is entirely different. The dorsal margin of the ilium is straight and the anterior and posterior processes are enlarged and tapered. The ilium, in general, is comparable to prosauropodian pelvis.

Table 2—Major and Trace element analysis of clays

Formation	*Sp. No. and locality*	*CaO*	*MgO*	*SiO_2*	*Fe_2O_3*	*Cu*	*Cr*	*Zn*	*V*	*Ni*	*Ba*	*B*	*Rb*	*Ca*	*Li*
			(in percentage)									*(in ppm)*			
Gangapur	91 Sumtam	1.57	2.66	50.3	11.90	25	20	100	10	50	5	20	200	4	—
	331 Arjungutta	1.57	1.33	56.74	6.40	25	100	80	50	70	500	—	—	—	—
	313 Arjungutta	7.24	3.36	54.06	7.80	40	20	100	20	100	5	—	—	—	—
Kota	355 Gorlapalli	1.93	2.58	64.50	5.95	40	100	90	50	80	100	—	—	—	—
												40	400	5	—
	360 Excavation site	18.30	4.03	37.78	5.80	40	10	90	5	110	50	—	—	—	—
	90 Site											5	200	5	—
	403 Gorlapalli											30	500	5	—
	405 —do—											40	500	5	—
	525 Posampalli											20	500	5	—
Dharmaram	32 Nagaram	1.4	0.93	72.31	4.63	25	20	50	10	50	5	20	500	5	—
	152 Kandampet	19.82	2.16	37.40	5.90	40	10	80	20	100	1000	—	—	—	—
Maleri	169 Pinnaram	3.53	2.62	48.96	11.90	60	5	110	5	130	5	—	—	—	—
	173	3.03	2.30	52.12	'1.60	40	10	80	10	110	200	—	—	—	—



Text-figure 4—Correlation of measured sections of Kota limestones.

The femur is very much slender, the slenderness index being 12.0. The slenderness is least compared to other Jurassic sauropods including the *Barapasaurus* which has 13.1. The fourth trochanter in the femur of *Kotasaurus* has an acuminate and slightly declined tip, a feature apparently not seen in later sauropods, but almost universal among the prosauropods. The character of astragalus in *Kotasaurus*, which is ovoidal in shape with low mound in the centre and two depressions on either side, suggests to be prosauropodian.

Some features of *Kotasaurus* strongly indicate relationship with the family Melanorosauridae among the prosauropods, on the other hand, several characteristics indicate, if not close relationship, atleast convergence between *Kotasaurus* and the Sauropod family. It differs from *Barapasaurus* in slenderness of femur, straight ilium, slender scapula, and low mound astragalus. Thus *Kotasaurus* is an intermediate form possessing the characters of prosauropods and sauropods.

Early Mammals

The mammalian history of the Jurassic Period is poorly documented. Any new occurrence, however scanty, from Early Jurassic may help in understanding the early evolutionary history of this important class.

A preliminary report of the Indian Jurassic mammals was published by Datta, Yadagiri and Rao (1978). Three new genera of symmetrodonts, viz., *Kotatherium haldanei* (Datta, 1981), *Trishulotherium kotaensis* and *Indotherium pranhitai* (Yadagiri, 1984) have been described. Recently, an amphidontid symmetrodont *Nakunodon paikasiensis* was also reported (Yadagiri, 1985).

Earlier, *Kotatherium haldanei* was assigned to the *Kuehneotheriid* family but both *Trishulotherium* and *Indotherium* were grouped under *incertae sedis* because of their distinctly different characters from that of *Kuehneotheriids*. The above fossil forms unequivocally indicate complicated and diversified nature of symmetrodont stock represented in the Kota vertebrate fauna.

The discovery of an early mammalian fauna in the Kota Formation has greatly expanded the biogeographic evaluation of the Mesozoic mammals. Earlier reports were confined to Laurasia but the Kota mammals were the first record from Gondwanaland.

PALAEOECOLOGY AND DEPOSITIONAL ENVIRONMENT

An attempt is made to relate the faunal evidences with geochemical and sedimentological data accruing from the Kota Formation.

Geochemistry of clay minerals—The clay samples from Dharmaram, Kota and Gangapur formations and limestone samples from Kota Formation were subjected to geochemical analysis. Nine clay samples were processed for determination of major and trace element distribution (Table 2). In addition, nineteen limestone samples collected from the Kota Formation were also processed for the determination of major and trace elements.

In Maleri clays (in ppm) Cu ranges from 40-60, Cr 5-10, Ni 100-130, Ba 5-1000, Zn 80-110 and V 5-20. The trace elements values in Dharamaram Formation are (in ppm) Cu 25, Cr 20, Ni 50, Ba 50, Zn 50, B 20, Rb 500, Li 70, Ga 5 and V 10-50.

Kota clays have the trace element concentrations as (in ppm) Cu 25, Cr 30, 110, Cr 10-100, Ni 45-110, Ba 5-100, Zn 55-110, B 5-40, Rb 200-500, Li 40-50, Ga 5-5 and V 10-50.

The Gangapur clays have yielded the trace element concentration in the values (in ppm) ranging Cu 25-110, Cr 10-100, Ni 50-100, Ba 5-500, Zn 80-100, B 20, Rb 100, Li 100, Ga 5 and V 10-50.

From these values it can be seen that:

i) Cu values are comparable in Kota and Gangapur clays.

ii) The Maleri clays have lesser quantity of Cu and Dharmaram clays even less.

iii) The V values are comparable in three formations, ranging 10-50 ppm, except Maleri clays where it ranges from 5-20 ppm.

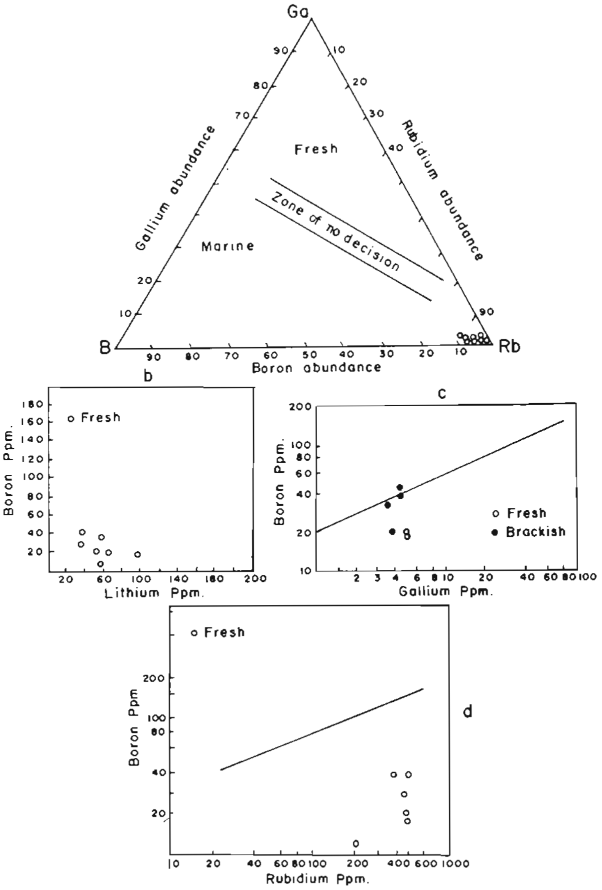
iv) The Cr values are comparable in Kota and Gangapur clays ranging from 10-100 ppm, whereas in Maleri and Dharmaram clays, the values are 5-10 ppm.

v) The Ba values are comparable with a range from 5-40 ppm, in all the four formations.

vi) The Rb values are slightly high ranging from 100-500 ppm in all of them.

The relative abundance of boron, gallium and rubidium of Kota, Gangapur and Dharmaram clays, are plotted on a triangular diagram (Text-fig. 5). All the points have fallen closely near the apex of rubidium and when compared to the diagram standardized by Degens *et al.* (1959), they are in marine zone.

A graph was prepared showing gallium in ppm, on X-axis and boron in ppm, on Y-axis, (Text-fig. 5c). The points are scattered out, all of them falling in fresh water zone except three points (Kota clays) are near brackish line. If we consider the ratio



Text-figure 5—Scatter diagrams of trace elements in clays.

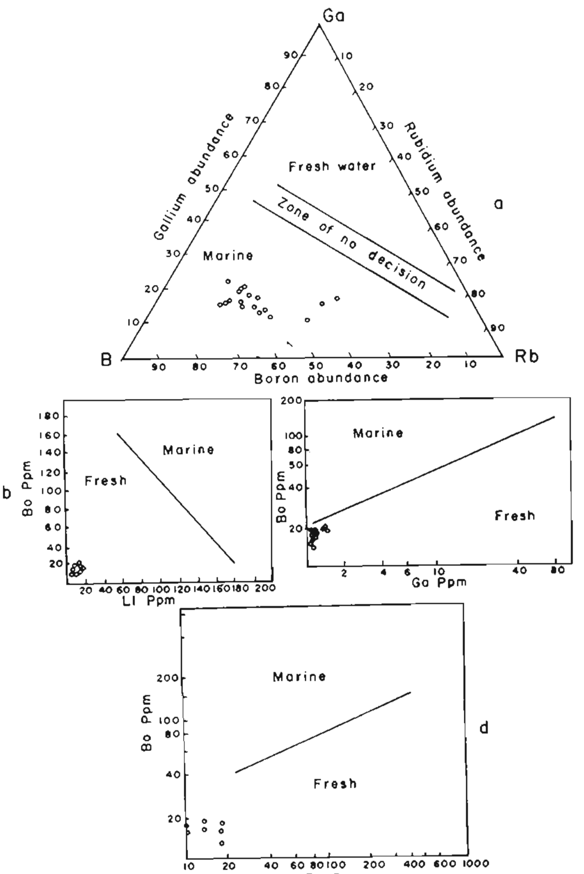
of abundance of two elements of B and Ga as reliable, the clays are deposited in fresh water environment. Some of the Kota clays appear to have been deposited under higher conditions of salinity. Another graph (Text-fig. 5b) was prepared showing the values of Li and B and it was compared with the graph produced by Keith and Degens (1959). The points fall in the zone of fresh water deposition.

The critical evaluation of the trace elements shows that in Upper Gondwana clays, the boron is less in quantity, the gallium is also less but unusually the rubidium is high. Degens *et al.* (1959) stated that the rubidium ion is only slightly larger than potassium and can substitute for potassium in inter layer position of rubidium and illite. Kaolinite ratio in fresh water shales was mainly due to the rubidium being combined in detrital illite and mica.

From X-ray analysis (Table 3), it is observed that the kaolinite, illite and mica are present in lesser quantity, whereas montomorillonite mineral is abundant. It may be stated that the rubidium ions might have largely substituted the layers of illite and mica minerals resulting in high percentage of rubidium.

Table 3—Clay minerals determined by x-ray analysis

Formation	*Sp. No. Locality*	*Major*	*Considerable amount*	*Small amount*	*Very small amount*	*Trace*
Chikiala	246 Jagalpet	montmorillonite	quartz	—	feldspar	kaolinite
Gangapur	310 Paikasigudem	kaolinite	quartz	—	—	—
	319 Naogaon	kaolinite	—	quartz montomorillonite	—	—
Kota	223 Manganpalli	montmorillonite	kaolinite	quartz	—	—
	226 Manganpalli after limestone	—do—	—	—do—	—	feldspar
	227 Manganpalli after limestone	montmorillonite	quartz	kaolinite	—	feldspar
	357 Gorlapalli	—do—	—do—	Illite, kaolinite, feldspar	—	—
	360 Excavation site	—do—	calcite and mica	quartz	dolomite	—
Dharmaram	260 Mamdalapalle	—do—	quartz	calcite	—	kaolinite
Maleri	309 Kottapalli	—do—	—do—	—	calcite	mica



Text-figure 6—Scatter diagrams of trace elements in Kota limestones.

In the circumstances, the triangular diagram as suggested by Degen *et al.* (1959) cannot be used as criteria for determining the environment of deposition of Upper Gondwana clays of Yamanpalli area. It is necessary to demarcate more plausible basis of fresh water, marine water interphase on more clay mineral and abundance of trace elements data. Based on critical elements like B, Ga, Cr, Cu and V it can be stated that clays of Maleri, Dharmaram, Kota and Chikiala were deposited in flood basins and lakes and some of the lakes being enriched in salinity.

Kota limestones—The Kota limestones were analysed for major elements and from the same material the trace elements were determined. Nineteen limestones from Kota Formation are analysed (Table 4). The CaO percentage ranges from 41 to 53 whereas the MgO ranges from 0.8 to 10.40. The high of Cu is 5-10, Cr 5, Ni 5, Ba 5-150, and V 5-20 ppm. There is no direct relation between the increase of CaO or MgO to trace elements. B ranges from 15-20, Ga 5-8, Li 4-7 and Rb 5-20 ppm.

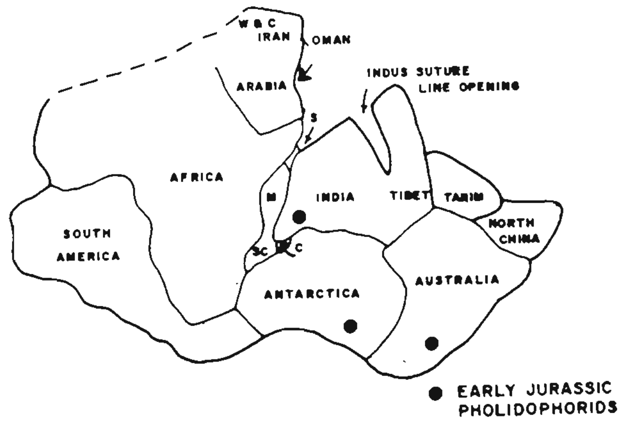
A triangular diagramme (Text-fig. 6a) was prepared with the abundance of the elements of B, Rb and Ga. It can be seen that the points fall closely towards the apex of boron. As per the diagram of Degens *et al.* (1959) they fall in marine zone. As stated earlier, it is necessary to re-evaluate the trace element distribution based on more samples with some samples from closely related marine horizons.

The graph (Text-fig. 6b) between lithium and boron shows the points in fresh water zone. The graph between gallium and boron also show the points in fresh water zone. Another graph between rubidium and boron also shows the points in fresh water zone. All the above graphs point towards a fresh water environment of deposition for the limestones.

Bhattacharya (1980) has recently discussed the depositional patterns in limestones of the Kota Formation. The clay bands associated with limestones are mostly montmorillonite but also include kaolinite and minor quantities of degraded illite. Distribution of clay minerals in insoluble residues of the limestones is similar to that of the clays. Most of the samples have 200-400 ppm of boron and 10-15 ppm of gallium, the points fall in the brackish to non-marine zone. Coccoliths were found almost in all specimens from the region, but they are abundant in marls than in hard limestones. The common forms have a central hole or depression with or without repeated layering and are conical (Bhattacharya, 1980).

Bhattacharya further stated that the well bedded limestones of significant thickness containing chert, dolomite, montmorillonite, microcrystalline ooze and coccoliths with high boron distribution suggest that the carbonates were of marine origin. He assumed that broken ostracodes and microvertebrates were probably transported before burial. It is possible that plankton could live under such conditions and become abundant in estuaries as a result of tidal movements. It is postulated by him that the limestones of the Kota Formation were deposited when the sea penetrated far inside into the subcontinent along a river estuary.

The present investigation does not support the above conclusions. The X-ray analysis shows that montmorillonite is present in Kota as well as in Maleri, Dharmaram and Chikiala clays. The presence of montmorillonite may be explained due to aridity and deposition in flood plain basins (Keller, 1956). The distribution of boron in different clay samples is 20-40 ppm, and of gallium is 4-5 ppm. But rubidium content is slightly high, ranging from 200-500 ppm. The high content of rubidium may be due to the replacement of K molecules in Kaolinite and illite with rubidium molecules, which are of approximately of same size (Keller, 1956). The view expressed about the ostracodes and early mammals that they were transported is not consistent with their nature of preservation. In the marly clays presence of complete carapaces of ostracodes and unworn surfaces of early mammals indicate *in situ* deposition and not transportation and redeposition. The abundance of fossils of land vertebrates also points that the Kota Formation was essentially deposited under fresh water environment with increased salinity possibly resulting from arid climate.



Text-figure 7—Gondwanaland at its maximum extent after Crawford (1974). The reconstruction with Antarctica and Australia in close proximity to India satisfies the condition for dispersal of pholidophorids in them.

With the foregoing discussion, it is concluded that the sandstones were deposited in braided channels and clays were deposited in flood plain basins, partly isolated and the limestones were deposited in lakes with increased salinity.

Vertebrate fauna

The Kota vertebrate remains represent aquatic, semi-aquatic, terrestrial and arboreal habitats. The community structure of the fauna can be discussed in the existing physical and biologic conditions of the formation. Four communities have been distinguished on the basis of the ecological niches of their members. The stream and stream bank community is proximal and is represented by nearly 50 per cent of the members constituting the fauna. This community comprises organisms of stream habitat like fishes, or partially stream bank community like Teleosaurid. The distal elements comprise dinosaurs, early mammals and pterosaurs.

The total number of skeletal elements recovered are analysed for their abundance relations. The most abundant community in the fauna are dinosaurs representing about 45 per cent. The fishes are next to dinosaurs in abundance representing 25 per cent of the total skeletal parts. The remaining percentage includes early mammals and pterosaurs.

There is a regular abundance order in the occurrence of fishes. The semionotid fishes dominate in number over all the fish remains known from the Kota. *Lepidotes* is abundant (17.5% of the total fauna), *Tetragonolepis* is rare (0.47%). The pholidophorids account for 1.4 per cent of the total

Table 4—Major and trace element analysis of Kota limestones

Section	Sp. No.	CaO	MgO	Cu	Cr	Ni	Ba	V	B	Ga	Rb	Li
		(in percentage)					(in ppm)					
Yamanpalli	17	47.88	0.8	5	5	5	5	10	20	5	20	5
Excavation site	361	49.0	2.4	5	5	5	50	20	20	7	7	6
	98	51.52	1.0	5	5	5	50	20	18	8	5	7
Manganpalli	117	51.8	1.0	5	5	5	5	10	18	4	10	7
Kota type section	268	53.76	0.8	10	5	5	5	10	18	6	6	6
	262	44.80	6.6	5	5	5	5	10	20	5	8	5
N.E. of Sironcha	290	47.32	2.40	5	5	5	5	5	20	7	10	7
	288	43.40	0.80	5	5	5	100	10	20	5	10	5
Gorlapalli section	349	52.64	1.60	5	5	5	100	10	16	4	6	5
	347	50.68	1.20	5	5	5	5	10	18	5	8	5
	346	41.16	10.40	5	5	5	5	5	20	7	5	6
	345	48.44	3.00	5	5	5	20	10	15	8	20	5
	344	51.80	1.80	5	5	5	150	10	19	5	10	4
Sumtam (concretionary bed in Gangapur Formation)	59	45.36	1.00	5	5	5	100	5	19	8	20	6

elements whereas the *Coelacanthus* represents 0.7 per cent. The juvenile specimens of actinopterygian fishes are extremely rare, in comparison to medium and large fishes.

Lepidotes is a long ranging genus which has habitat of colonizing in marine and fresh waters. Species of *Lepidotes* occur in the brackish to fresh water Rhaetic; marine Upper Liassic, Oxfordian and Kimmeridgian; brackish to fresh water Purbeckian; fresh water Wealden and Brazilian. The genus may be regarded as euryhaline, so *Lepidotes deccanensis* was probably adaptable and could withstand at least moderate salinity of lake water. It had slender, cylindrical, acutely pointed conical teeth in the dentary and premaxilla; and suited for preying upon fast moving invertebrates including estherids and ostracodes, in addition to worms.

Paradapedium and *Tetragonolepis* had relatively poor development of paired and unpaired fins. *Paradapedium* had acutely pointed conical teeth whereas *Tetragonolepis* had fine pointed teeth. As such, they are presumed to be predators of fast moving prey. *Tetragonolepis* in Europe is known from marine sediments and so also *Dapedium*. It is therefore, likely that they were euryhaline forms which existed in Kota lakes.

The Kota coelacanths were large, with weak dentition, bottom living in shallow lake. The coelacanths in general appear to have been rather sedentary animals lying in wait for their prey. A number of *Lepidotes* scales were found associated in cranial part of *Coelacanthus*. Probably they were preying on juveniles of *Lepidotes*. The extant genus *Latimeria* exhibits a poor dentition and among its gut contents have been found small intact fishes in addition to other food stuff. The Kota pholidophorids have well-developed strong paired and unpaired fins, but poor dentition. They may have been active fishes like *Lepidotes*, but may have depended less on fast moving prey for food rather eating the soft annelids and nibbling aquatic plants.

It is believed that Pterodactyles and Pterosaurs lived near the sea coast because all the fossil material comes from marine sediments, except the Kota Pterosaurs. Kota Pterosaurs can be visualised as inhabiting the trees close by the Kota lake and occasionally sweeping down to prey upon small actinopterygian fishes. The Solnhofen Pterodactyles were also fish eaters.

The Kota dinosaurs, *Barapasaurus* and *Kotasaurus* were herbivorous and were probably similar to better known saurischian Jurassic dinosaurs like *Diplodocus* and *Camarasaurus* in their habits and habitat. Coombs (1975) has recently summed up the habitat of Sauropods. The data on sauropod narial morphology indicates either aquatic or terrestrial habits. The axial and appendicular modifications point primarily to terrestrial behaviour. The deep thorax is an adaptation to problems of terrestrial weight bearing. They definitely entered streams at least sometimes, but sedimentologic evidence does not support immersion in deep lakes as sauropods are frequently pictured. Charig (1979) has suggested that the

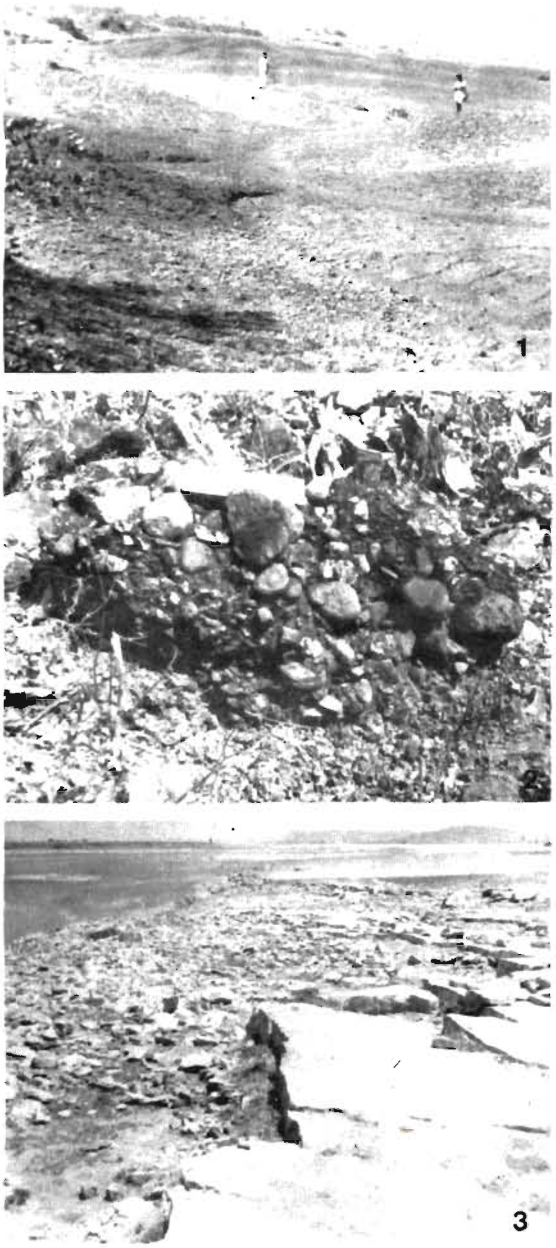


PLATE 1

1. Red clays and sandstones of Dharmaram Formation with prosauropod remains.
2. Conglomerate of Gangapur Formation showing pebbles of quartz, quartzite and chert.
3. Limestone bed near Kota Village showing large blocks.

sauropods were proper land dwellers. It can be assumed that *Barapasaurus* and *Kotasaurus* were inhabiting land close to Kota lake and largely feeding upon nearby vegetation

The early mammals belonging to symmetrodonts and morganucodonts possess sharp conulids for tearing the prey. All of them were considered to be insectivorus in their habitat. Crompton *et al.* (1978) have suggested that the early mammals were probably similar to modern day hedgehogs in maintaining a low body temperature and possessing a reptilian metabolic rate which is three to four times lower than most living mammals. Like the African forms, the Kota mammals appear to be small insectivors, with dentition designed for puncturing and shearing. The view is justified by the abundance of insect occurrence in the Kota Formation.

The Kota Formation contains rather two different kinds of sediments; fluviatile sandstones and clays and thin limestones representing evaporite deposits in inland lake. Robinson (1970) on the basis of geology, Tasch *et al.* (1973) on the basis of conchostracans, and Govindan (1975) on the basis of ostracods support fresh-water deposition of Kota sediments, including the limestone. Bhattacharya (1980) on the basis of petrographic, mineralogic and geochemical analysis of the carbonates, suggested deposition in marine inter-tidal flats where abundant terrigenous material was brought in by a river estuary.

During the present investigation, the results obtained on Kota limestones from the geochemical analysis and other evidences weigh heavily in favour of a fresh-water origin. The vertebrate faunal assemblage with their habitat also suggest a fluviatile environment with flood channels and lacustrine deposit, for Kota Formation.

PALAEOBIOGEOGRAPHIC SIGNIFICANCE OF KOTA FAUNA

The significance of Kota fauna as evidence of Lower Jurassic geographic configuration can be discussed on three different counts: (a) early mammals, (b) *Pholidophorus* fishes, and (c) dinosaurs.

A major evidence in understanding the evolutionary transition from synapsids to mammals is being facilitated by increased refinement of determination of the ages and correlations of local faunas that until recently were considered of Late Triassic (Rhaetian) or Early Jurassic age (Clemens *et al.*, 1979). Current research shows that so-called "Rhaetic fissure fillings" of England and Wales, which have produced a wealth of specimens of early mammals and advanced synapsids, were deposited at various times during this interval. Most of the fillings yielding *Morganocodon* and *Kuehneotherium* are now thought to be of Liassic, probably Sinemurian age (Kermack, Mussett & Rigney, 1981). In the light of the new findings, the Kayenta Formation of North

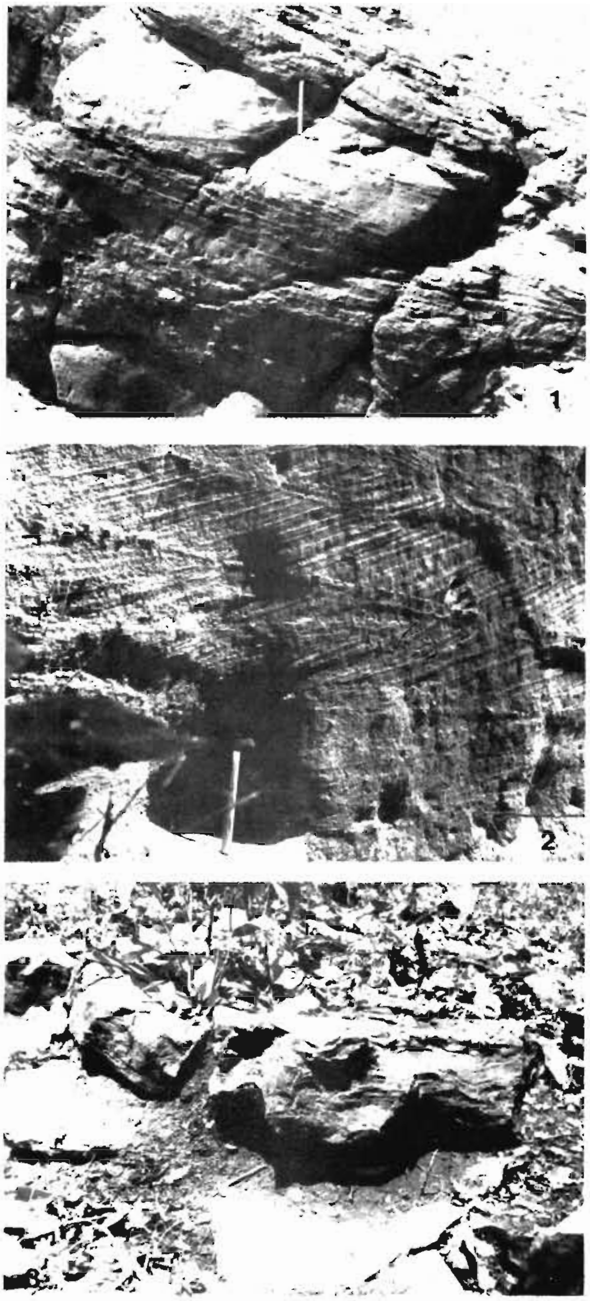


PLATE 2

1. Cross bedding in Gangapur sandstones seen in the Pranhita River Section near Kalmalpet.
2. Current bedding seen in Chikiala sandstones near Makrigudem.
3. Stromatolitic structures seen in massive limestone near Nagaram Village.

America, the upper part of the Stormberg Group of South Africa, the Kota Formation of India, and the Lufeng beds of China are now thought to be broadly correlative units and of Early Jurassic age. The aforesaid occurrences suggest that early mammals were widely dispersed through Laurasia and Gondwana before fragmentation of the supercontinents.

The find of pholidophorid fishes in India has great palaeogeographic significance in the sense that it adds a new evidence to evaluate the position of India vis-a-vis the position of other continents of the Gondwanaland before its fragmentation. Tasch *et al.* (1973) brought out the significance of estherids for continental fit. Jurassic beetles and palaeolimnadids from Antarctica and India and Triassic palaeolimnadids and estherinids in India and Australia required nonmarine dispersal routes which suggest the proximity of the three continents. They pointed out that the configurations of Smith and Hallam (1969) and Veevers *et al.* (1971) are not adequate to explain the dispersal of the fauna in three continents.

Schaeffer (1972) mentioned that the presence of fresh-water Archaeomaenidae both in Australia and Antarctica during the Jurassic was not surprising as these two continents were in contact throughout the Mesozoic. However, the position of India relative to Antarctica and Australia remained uncertain. All the pholidophorid fishes from three continents, viz., Australia, Antarctica and India *were fresh-water forms* and were restricted to Early Jurassic horizons. Thus, the occurrence of pholidophorids supports the view of Australia, Antarctica and India to be in close proximity. The fossil evidence is in conformity to the configuration (Text-fig. 7) as suggested by Crawford (1974). The pholidophorids might have dispersed from India to Australia through Antarctica.

The presence of sauropod dinosaurs namely *Barapasaurus* and *Kotasaurus* in the Kota Formation suggests its close proximity to the South African region, as dinosaurs of Late Triassic and Middle Jurassic period are found in the latter continent. The occurrence of *Rhoteosaurus* in the Middle Jurassic sediments also supports the view that during Early Jurassic to Middle Jurassic peninsular India was a land-locked part of Gondwanaland.

CONCLUSIONS

From a study of the Upper Gondwana sequence in the Yamanpalli area of Adilabad District, Andhra Pradesh, the following points emerge which are significant for Gondwana stratigraphy:

1. Kota Formation is underlain by Dharmaram Formation and overlain by Gangapur Formation.
2. The Gangapur Formation is overlain by Chikiala Formation.
3. Kota limestone horizon consists of three beds of limestone separated by marly beds; considerable difference is recognisable in the distribution of vertebrate fauna in these beds.

4. The geochemical and clay mineral studies of Upper Gondwana sediments have revealed that no diagnostic change is recognisable from Dharmaram, Kota and Gangapur formations and a more indepth study of elemental distribution in sediments is required for palaeoenvironmental characterisation of Kota for marine depositional environment.
5. The evidences favouring marine depositional environment are wanting; rather, evidences of fauna weigh heavily in favour of lacustrine accumulation for Kota Limestone with salinity of water being more than in normal lacustrine environment.
6. Early mammals and dinosaurs recorded from Kota Formation have distinct Liassic affinity in their evolutionary level.
7. The palaeogeographic implication of early mammalian vertebrates and pholidophorid fishes from the Kota Formation suggests a landlocked set up for peninsular India.

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Vertebrate faunas from the Indian Gondwana Sequence

P. P. Satsangi

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In the thick pile of continental sediments of the Gondwana Sequence of India, the vertebrate-bearing horizons occur at nine stratigraphic levels; three of these are in the Palaeozoic and six in the Mesozoic. A vertebrate sequence covering the period from Upper Permian to Lower Jurassic is now known from the Indian Gondwana Formations. A brief review of the vertebrate faunas with their stratigraphic and palaeogeographic significance has been presented.

Key-words—Vertebrate fauna, Gondwana stratigraphy, Palaeogeography, Permian, Lower Jurassic (India).

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साराँश

भारतीय गोंडवाना अनुक्रम से रीढ़धारी जन्तुजात

पी० पी० सत्संगी

भारतीय गोंडवाना अनुक्रम की मोटी सतह वाले अवसादों में नौ विभिन्न स्तरिकीय तलों में रीढ़धारी-धारक संस्तर मिलते हैं। इनमें तीन पुराजीवी कल्प के तथा शेष छः मध्यजीवी कल्प के हैं। भारतीय गोंडवाना शैल-समूहों से अब उपरि परमी से अधरि जूराई तक विस्तृत रीढ़धारी जन्तुओं से युक्त एक अनुक्रम ज्ञात है। रीढ़धारी जन्तुजातों के स्तरिकीय एवं पुराभौगोलिक महत्व की संक्षिप्त विवेचना भी प्रस्तुत की गई है।

IN the last three decades new continental faunas have been discovered and well-preserved and more complete specimens of already known faunas have been brought to light in the Gondwana Sequence of India. It has helped in determining the age of the bed containing them and their stratigraphic correlation.

In the Palaeozoic Gondwana the vertebrate fossil horizons have been found to occur at three stratigraphic levels, viz. (i) Lower Permian Mamal Formation (Vihi Bed) of Kashmir, (ii) Upper Permian stratigraphic unit from Pranhita-Godavari Valley, considered as equivalent of Motur Formation of Satpura Basin, and (iii) Late Permian basal beds of the Kamthi from Pranhita-Godavari Valley and its equivalent the Raniganj Formation of Damodar Valley and South Rewa Basin and Bijori Formation of Satpura Basin (Table 1).

In the Mesozoic sequence six stratigraphic levels have been recognised. The Triassic horizons are: (i) Lower Triassic Panchet Formation of Raniganj and South Karanpura coalfields and its equivalent the Mangli Bed of Wardha Basin, (ii) Middle Triassic Yerrapalli Formation of Pranhita Godavari Valley and Denwa Bed of Satpura, (iii) ?late Middle Triassic Bhimaram Sandstone, (iv) Early Late Triassic Maleri Formation of Pranhita-Godavari Valley and its equivalent Tiki Formation of South Rewa Basin, and (v) Late Triassic Dharmaram Formation of Pranhita-Godavari Valley (Table 2). The Lower Jurassic fauna is known from the Kota Formation of Pranhita-Godavari Valley.

Concepts, limits and extension of the Indian Gondwana
(Editors : B. S. Venkatachala & Hari K. Maheshwari)
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Table 1—Correlation of Permian Gondwana formations of India

Age *Area*	*Damodar Valley*	*Narmada Valley (Satpura Basin)*	*Son-Mahanadi Valley*	*Wardha-Pranhita-Godavari-Valley*	*Kashmir*
Late	Raniganj Formation*	Bijori Formation*	Kamthi Formation*	Kamthi Formation*	
Upper	Barren Measures/ Ironstone Shale	Motur Formation	—?—	Motur Formation*	
Lower	Barakar Formation Karharbari Formation	Barakar Formation Karharbari Formation	Barakar Formation Karharbari Formation*	Barakar Formation	Mamal Formation* Panjal Volcanics Nishatbagh Formation
	Talchir Formation	Talchir Formation		Talchir Formation	Agglomeratic slate

*Indicates vertebrate bearing horizons

PALAEOZOIC VERTEBRATE FAUNA

Lower Permian Fauna

The oldest horizon from which vertebrates have been reported from the Indian Gondwana formations is the Gondwana plant bed of Kashmir, commonly known as 'Gangamopteris bed' (Hayden, 1907). The first plant bed with Gondwana flora and vertebrates was discovered by Noetling (1902) at Risin in Vihi District. Later, plant beds were discovered at a number of places at different stratigraphic positions. Kapoor (1977) who examined the stratigraphic position of these plant beds observed that they occur at two stratigraphic levels: (i) at the base of the Panjal Trap, and (ii) overlying the Panjal Trap. The vertebrates have been found at widely scattered localities but in all the localities the vertebrate-bearing plant bed overlies the Panjal Trap. At Risin, from which most of the vertebrate fossils have come from, the Mamal Formation (Vihi Bed) (Singh *et al.*, 1982) directly underlies the marine Zewan Formation.

The vertebrates known from Mamal Formation of Kashmir include fishes and labyrinthodont amphibians. Woodward (*in* Seward & Woodward, 1905) identified species of palaeoniscoid genus *Amblypterus, A. kashmiriensis, A. symmetricus* and *Amblypterus* sp. from Risin. Gupta *et al.* (1978) described a new species, *Gardenericthys tewarii* from the same locality. *G. tewarii* bears close resemblance to *G. latus* (= *Amblypterus latus*) known from Lower Permian of Saar Basin, Germany. It also shows affinity with the fishes described by Woodward but Gupta *et al.* (1978) are of the opinion that the fishes may not belong to *Amblypterus*. Gupta (1971) had recorded another fish *Phlyctaenicthys pectinatus* from Apharwat but no details of the same is available. *Phlyctaenicthys* is a genus of Redfelidae which are common in Triassic; the genus is reported from Middle Triassic of Australia (Romer, 1966, p. 353).

It may be pointed out that the fusiform palaeoniscoids though exhibit similarity in general appearance, yet vary considerably in structural details. The main diagnostic character of these primitive actinopterygians is the structure of the cheek, particularly in the suspensorium of the jaw apparatus which undergoes modification during evolution (Gardiner, 1963). In most of the specimens studied by Woodward, the skull region is either crushed or missing. It hardly needs emphasis that the revision of the fishes of the Mamal Formation is much desired in the light of the recent advances in the study of primitive actinopterygians.

The amphibians reported from the Mamal Formation are the rhachitomous labyrinthodonts. Amongst the long snouted forms two species of *Archaegosaurus, A. ornatus* Woodward (1905) and *A. kashmiriensis* Tewari (1962) are known. Romer (1947) considers the assignment of these Kashmir forms to *Archegosaurus* as uncertain since both the snout and the post-orbital regions are less elongated than the European form and the lateral lines are more conspicuous. It may be pointed out that the long snout is generally attributed to piscivorous habit and the lateral line grooves are related to aquatic habit of the animal. The relatively less elongated snout and conspicuous lateral lines in Kashmir specimens may be due to ecological factors (Tewari, 1962) and this possibility cannot be entirely ruled out.

Associated with these archeosaurids are eryopsids, *Actinodon risinensis* Wadia & Swinton (1928) and *Lyspipterygium deterrai* Branson (1935). The former is known from Risin and the latter from Zewan. Branson (1935) pointed out the possibility of *Lyspipterygium deterrai* being generically, if not specifically, identical with *Actinodon risinensis*. The comparison between the two is not possible because *Actinodon risinensis* is known from the skull roof alone and *Lyspipterygium deterrai* mainly by the palatal aspect of the skull, and only a part of the inter-orbital region of the skull roof is preserved.

Table 2—Correlation of the Triassic Gondwana formations

Age *Area*	*Damodar Valley*	*Narmada Valley (Satpura Basin)*	*Son-Mahanadi Valley*	*Wardha-Pranhita Godavari Valley*
			Parsora Formation	Dharamaram Formation*
Upper		Bagra Conglomerate	Tiki Formation*	Maleri Formation*
Middle	Mahadeva Formation (Supra Panchet)	Denwa Bed*	? Mahadeva Formation*	Bhimaram Sandstone*
				Yerrapalli Formation*
Lower	Panchet Formation*	Pachmarhi Sandstone	Nidpur Bed	Mangli Bed*/ Kamthi Formation*

*Indicataes vertebrate bearing horizons.

Verma (1962) reported another labyrinthodont from Marahoma which he found to be similar to *Chelydosaurus* known from the Lower Permian of Bohemia. He referred it to a new species *Chelydosaurus marahomensis*. The specimen is far too incomplete for specific determination.

The vertebrate fauna akin to that of Mamal Formation is not known from any other part of Gondwanaland. It shows distinct European affinity. The labyrinthodont, *Archegosaurus* and *Actinodon* are common in the Lower Permian of Saar Basin in Germany and Autun Coal Basin of France. The palaeoniscoid fishes are also common in Permian of Europe and North America; *Garderinicthys* is known from the Lower Permian of Saar Basin in Germany. The vertebrate fauna from the Mamal Formation on the whole, indicates a Lower Permian age (Chakravarty, 1968). On the basis of the overlying marine Zewan beds and the underlying Agglomeratic Slates, the age of the Mamal Formation has been suggested as early Artinskian to Early Kungurian (Kapoor, 1977).

The presence of this fauna with strong European affinity at the northern fringe of India, in Kashmir, signifies infiltration from Laurasia. This is also supported by the presence of floral elements of northern affinity in plant beds of Kashmir (Kapoor, 1969; Srivastava & Kapoor, 1969).

The Mamal Formation is considered to be deposited near the coast as lagoonal, if not coastal deposit (Kapoor & Nakazawa, 1973). It is not improbable that the migration of the fauna from North might have taken place through isthmus links or dense archipelago in Kashmir region (Sahni, 1926; Wadia, 1938) or through development of island in the Tethyan region as suggested by Nakazawa *et al.* (1975).

Upper Permian Fauna

The next higher stratigraphic level in the Gondwana Sequence from which fossil vertebrates have been known is from a lithological unit in between the Kamthi and Barakar formations in northern part of Pranhita-Godavari Valley. It has lithological resemblance with the Motur Formation of Satpura Basin. The fauna is essentially a dicynodont assemblage in which a captorhinomorph reptile (Kutty, 1972) is also present. The dicynodonts include endothiodontids in which a species of the genus *Endothiodon* has been recognised. Another skull has been found to show affinities to *Cistecephalus*.

The presence of *Endothiodon* in association with *Cisticephalus* makes the fauna directly correlatable with *Cistecephalus* zones of Kitching (1977). It is difficult to compare the fauna with *Tropidostoma-Endothiodon* Assemblage Zone and *Aulacephalodon-Cistecephalus* Assemblage Zone of Keyser and Smith (1979) as details of the reptilian fauna from Pranhita-Godavari Valley is still not known. It may, however, be pointed out that so far both *Tropidostoma* and *Aulacephalodon* are known only from Africa. *Endothiodon* is reported from three Gondwana continents, i.e., from Rio do Rasto Formation of Parana Basin of Brazil, Beaufort Group of South Africa and Motur Formation of Pranhita-Godavari Valley. *Cistecephalus* is known from Madumabisa mudstone of the Luanzwa Valley in Zambia and Pranhita-Godavari Valley; a closely related genus *Kawingasaurus* is recorded from Kawinga Series of Ruhuku in Tanzania (Keyser, 1980). The two assemblage zones, the *Tropidostoma-Endothiodon* Assemblage Zone and the *Aulacephalodon-Cistecephalus* Assemblage Zone, are correlated with the *Cistecephalus* zone of Kitching (Keyser, 1980).

The association of the captorhinomorph reptile with the dicynodonts assemblage of Pranhita-Godavari Valley is significant as captorhinomorphs are mainly distributed in the Lower Permian of Europe and North America. The only exception is Nigeria (Taquet, 1969), where it is recorded from beds equivalent to *Endothiodon* and *Cistecephalus* zones. The Nigerian *Moradisaurus* is a large form while the Indian form is very small.

Late Permian Fauna

From the succeeding stratigraphic units, namely, the Bijori Formation of Satpura Basin and the Raniganj Formation of Sidhi District, South Rewa Basin, labyrinthodont amphibians are recorded. Both the formations have yielded typical Raniganj flora suggesting a Late Permian age. A few scales of palaeoniscoid fishes have been noted from the Raniganj Formation of Raniganj Coalfield (Mukherjee & Ghosh, 1973).

The Bijori labyrinthodont is known by a skull and part of skeleton which was named as *Gondwanosaurus bijoriensis* (Lydekker, 1885). The form is apparently close to capitosaurs but could be best classified among the neorhachitomes. Romer (1966, p. 363) has preferred to group it under Benthosuchidae and assigned it an Eotriassic age.

The other labyrinthodont amphibian collected from the Raniganj Formation near Marhwas, Sidhi District, Madhya Pradesh, is preserved as a mould showing impression of the skull roof in which eye orbits are conspicuous. Tripathi (1962a) has identified it as a new species of *Rhinesuchus*, *R. wadiai*. The comparison of *R. wadiai* with *Gondwanasaurus bijoriensis* is not possible as the bones of the skull roof in the Bijori specimen are not preserved. Rhinesuchid labyrinthodonts are known from the Permian of East and South Africa.

Recently a reptile has been found within the sandstone of the Kamthi Formation near Jaipuram in Pranhita-Godavari Valley (GSI News, Coal Wing, January 1986). The animal is represented by a medium-size dicynodon skeleton in which the skull, though present, is not well-preserved. It is not improbable that the form represents a daptocephalid dicynodon. The presence of dicynodont, in the Kamthi Formation overlying the *Endothiodon*-bearing Motur Formation points to the possibility of the presence of the reptilian fauna of the *Deptocephalus* Zone of the Karoo Sequence in the basal part of the Kamthi Formation of Pranhita-Godavari Valley.

TRIASSIC VERTEBRATE FAUNA

Lower Triassic Fauna

The Triassic vertebrate fauna is known from the Panchet Formation of Raniganj and North Karanpura coalfields and its equivalent the Mangli Formation of Wardha Basin.

The Panchet vertebrate fauna has been studied by several workers (Huxley, 1865; Lydekker, 1885; Das Gupta, 1922, 1928; Von Huene & Sahni, 1958; Tripathi, 1962b, 1969; Tripathi & Satsangi, 1963; Satsangi, 1964). Brief reviews of the fauna have been made earlier by von Huene (1942), Chatterjee and Roy Chowdhury (1974) and Satsangi (1987).

The Panchet fauna is predominated by therapsid dicynodont genus, *Lystrosaurus*, alongwith the carnivorous cynodont reptile *Thrinaxodon*, the thecodont reptile, *Chasmatosaurus*, and a cotylosaurian reptile showing affinities with *Procolophon*. Associated with the reptiles are the labvrinthodont amphibians represented by brachiopod, lydekkerinid, early capitosaurid, and trematosaurid amphibians. The fishes are represented by palaeoniscoid referred to *Amblypterus* (White: *in* Gee, 1932, p. 59).

The labyrinthodont amphibians in the Panchet fauna vary from short-faced triangular brachyopid forms to elongated long snouted trematosaurid amphibians.

The short-faced labyrinthodont *Indobrachyops panchetensis* was considered to be a brachiopid by von Huene and Sahni (1958); Welles and Estes (1969) and Cosgriff (1969) excluded *Indobrachyops* from brachyopidae on the consideration that the posterior portion of the quadrate bone is almost in line with the occipital condyles, a character which is not found in brachiopods. They pointed out that the *Indobrachyops* lacks the arched palate, broad pterygoid and ectopterygoid tusks of true brachiopids and it may represent a capitosaurid amphibian. Cosgriff and Zowiskic (1979) have grouped it in rhytidosteoidea under a separate family Indobrachyopidae.

A true brachyopid, *Brachyops laticeps*, is however, known from Mangli Bed (Owen, 1855; Broom, 1915; Watson, 1956; Welles & Estes, 1969) which is correlated with Panchet Formation (Fox, 1931). This correlation is also supported by the conchostracans.

Tripathi (1969) recognised new forms of labyrinthodont amphibians in the Panchet fauna showing affinity with Russian neorhachitome genus *Benthosuchus* and the Spitsbergen form *Lyrocephalus*. He also identified a new species of *Lydekkerina*, a rhinesuchid labyrinthodont, commonly known from the *Lystrosaurus* zone of South Africa.

The trematosaurid amphibian *Gonioglyptus* recorded from the Panchet Formation of Raniganj Coalfield (Huxley, 1865; Tripathi, 1969) is also known from the Lower Triassic *Prinolobus* Bed of Salt Range (von Huene, 1920). A specimen of the skull figured by Tripathi (1969, pl. 11, figs 4, 5) represents the anterior part of the skull of *Gonioglyptus*. Comparing it in association with the skull fragments described by Huxley (1865) and von Huene (1920), it gives a fair idea of the elongated snout of *Gonioglyptus* which shows close similarity to *Aphaneramma* known from the Early Triassic.

The most dominant, abundant and characteristic fossil of the Panchet fauna is *Lystrosaurus*. It is known by atleast four species namely, *L. murrayi*, *L. platyceps*, *L. maccaigi* and *L. rajurkari* (Tripathi & Satsangi, 1963; Colbert, 1974). The first three species are common in South Africa, Antarctica and India. *Lystrosaurus* is also known from China (Yuan-Young, 1934) and probably from Indo-China (Cluver, 1971).

The other associated therapsid is the carnivorous cynodont reptile *Thrinoxodon* very much similar to *Thrinoxodon liorhinus* known from the Lower Triassic *Lystrosaurus* zone of South Africa and Fremouw Formation of Antarctica (Satsangi, 1987). The Panchet cynodont is represented by a single specimen of a well-preserved skull with attached lower jaw. The sutures of the bones on the skull roof are not fused completely and the animal appears to be an young individual. The snout region of the skull is relatively long and slender as compared to *Thrinoxodon liorhinus*. The Antarctic forms of *Thrinoxodon* are large and robust.

The other common reptile in the Panchet fauna is the thecodont *Chasmatosaurus* (von Huene, 1942; Hughes, 1963; Satsangi, 1964). It is represented by a single species, *Chasmatosaurus indicus* von Huene. The association of *Chasmatosaurus* with *Lystrosaurus* has been known from the *Lystrosaurus* zone of South Africa, Fremouw Formation of Antarctica and Thungushan Formation of Sinkiang and Wuhsiang beds of Shansi in China (Young, 1958). A cotylosaurian reptile referable to procolophnid is also recorded in the Panchet fauna (Tripathi, 1962b) but the details are not known.

The presence of the dominant dicynodont genus *Lystrosaurus* in the Panchet Formation in association with *Thrinoxodon* and *Chasmatosaurus* makes it directly correlatable with the Lower Triassic *Lystrosaurus* zone of the Karoo Sequence of South Africa and the Fremouw Formation of the Beacon Group of Antarctica. The presence of atleast three common species of *Lystrosaurus* in Africa, Antarctica and India strongly supports closer land connection among these continents forming continuous landmass as part of Gondwanaland during Early Triassic. The occurrence of *Lystrosaurus* in China and also probably in Indo-China indicates the possibility of these areas being part of the Gondwanaland (Colbert, 1974). *Lystrosaurus*, though adopted to semiaquatic habitat, was essentially a denizen of land. It was incapable of crossing large sea and therefore its presence in China and Indo-China could be explained either by accepting these areas to be part of Gondwanaland or assuming a long migration route from Africa to Laurasia through Spanish-Moroccan region and then to further east into China (Colbert, 1974).

Middle Triassic Fauna

In the Pranhita-Godavari Valley all the stratigraphic units of the Gondwana Sequence overlying the Kamthi Formation have yielded vertebrates. The vertebrate fauna equivalent to the Lower Triassic Panchet fauna has so far not been recorded from Pranhita-Godavari Valley. The earliest undoubted Triassic horizon is the Yerrapalli Formation.

The Yerrapalli fauna, distinct from the Maleri fauna, was discovered by Jain *et al.* (1964). It consists of fishes, the *Saurichthys* (Jain, 1984) and the dipnoan, *Ceratodus*. The labyrinthodont amphibians are represented by the capitosaurid *Parotosaurus rajareddyi* (Roy Chowdhury, 1970a) and a brachyopid. The reptiles are the rhynchosaur, *Mesodapedon kuttyi* (Chatterjee, 1980), a triracodontid cynodont and the dicynodonts *Wadiasaurus indicus* and *Rechnisaurus cristarhynchus* (Roy Chowdhury, 1970b). Two archeosaurs and a prolacertid similar to *Tanystrophèus* have also been recorded.

The Yerrapalli stahlekeriid dicynodont *Rechnisaurus* is comparable to *Dinodontosaurus* from the Middle Triassic of South America (Colbert, 1984) and Middle Triassic Natware Formation of Zambia (Roy Chowdhury 1970a, b; Crozier, 1970; Cox, 1969). The rhynchosaur *Mesodapedon* is close to the form reported from the Middle Triassic Manda Formation of Tanzania (Chatterjee, 1980).

The capitosaurid *Parotosaurus rajareddeyi* has been shown to be more advanced than typical Lower Triassic forms like *P. nasutus* from Bunter of Germany and *P. haughtoni* from the *Cynognathus* zone of South Africa. It is more close to *P. pronus* from the Middle Triassic Manda Formation of Tanzania in the nature of the tabular horns (Roy Chowdhury, 1970a, b). The Yerrapalli fauna is closer to Middle Triassic though it contains common form of *Cynognathus* zone fauna like *Saurichthys*.

The other horizon which is now considered equivalent of the Yerrapalli Formation is the Denwa Bed of Satpura Basin where a specimen of a tabular horn of *Parotosaurus* has been recorded by Chatterjee and Roy Chowdhury (1974). The semi-closed nature of the otic notch of the specimen is a character present in the Middle Triassic species of *Parotosaurus*. It is also seen in *P. rajareddyi* known from the Yerrapalli Formation. The Denwa Bed was earlier equated with the Maleri and Tiki formations on the basis of the presence of *Mastodonsaurus indicus* Lydekker (1885). Chatterjee and Roy Chowdhury (1974) have shown that the identification of *Mastodonsaurus* was based on insufficient diagnostic characters and therefore it should be abandoned.

From Nidpur area in Singrauli Basin fish fragments showing thick ganoid scales have been reported by Ghosh, Singh and Shah (personal communication) from the beds overlying the *Dicroidium* bearing Lower Triassic Nidpur beds. The scales are not the palaeoniscoid type found in the Permian Mamal and Raniganj formations and in the Lower Triassic Panchet Formation.

?Late Middle Triassic Fauna

The Bhimaram Sandstone overlying the early Middle Triassic Yerrapalli Formation and underlying the early Upper Triassic Maleri Formation, is considered to be of ?late Middle Triassic age. The vertebrates recorded from this horizon are labyrinthodont and dicynodont (Kutty, Jain & Roy Chowdhury, 1987, p. 41), the details of which are still not known.

Upper Triassic Fauna

The vertebrate fauna from Maleri Formation of Pranhita-Godavari Valley and its equivalent Tiki Formation of Son-Mahanadi Valley contains some common identical forms. The fishes include the lang fish *Ceratodus* represented by four species (Jain, 1968); a subholostean and the pleurocanth shark, *Xenacanthus indicus* (Jain, 1980). The labyrinthodont amphibian is known by the solitary form *Metoposaurus maleriensis* (Roy Chowdhury, 1965). The reptiles are represented by the cynodont *Exaeretodon statiscae* (Chatterjee, 1982), the protosaurian *Malerisaurus robinsoni* (Chatterjee, 1980), the phytosaur *Parasuchus hislopi* (Chatterjee, 1978) and the rhynchosaur *Paradapedon huxleyi* (Chatterjee, 1974). Besides, the fauna also contains pseudosuchians scutes similar to *Typothorax* and a possible coelurosaurian dinosaur (Jain & Roy Chowdhury, 1987).

The most common forms of the Maleri and Tiki fauna are the metoposaurs, the rhynchosaurs and the phytosaurs. The Maleri amphibian *Metoposaurus* is similar to those known from Germany and is identical with the North American form *Eupelor*. The genus *Metoposaurus* is known from the Upper Triassic beds of North America and Germany, equivalent to Schilfsandstein through Stubensandstein (Roy Chowdhury, 1965).

The rhynchosaur *Paradapedon* was considered as an advance form and grouped with *Hyperodapedon* of Scotland and *Scaponyx* of South America in the sub-family Hyperdapedontinae by Chatterjee (1969). He subdivided the family Rhynchosauridae into three sub-families: the Mesosuchinae, Rhynchosaurinae and Hyperodapedontidae representing three stages of rhynchosaur evolution. These stages are considered characteristic of Lower, Middle and Upper Triassic respectively.

The phytosaur *Parasuchus* is similar to *Palaeorhinus*, a North American form known from the lower part of the Upper Triassic. Chatterjee (1978) on the basis of the evolutionary level of the Maleri phytosaur indicated a Carnian age to the Maleri Formation.

A podokesaurid theropod, *Walkeria maleriensis*, has recently been reported by Chatterjee (1987) which is very similar to *Coelophysis* of North America and *Procansoguathus* of Germany and *Syntarsus* of Zimbabwe and North America. This is the earliest known dinosaur from the Asia.

The Maleri fauna was considered to be of lowermost Upper Triassic age by von Huene (1942) who pointed out the strong relationship of the Maleri Labyrinthodont and phytosaur to the forms of the Northern Hemisphere. Colbert (1958, 1984) also indicated the close affinity of the Maleri fauna with the faunaş known from the Keuper of Europe and North America.

Late Triassic Fauna

The fauna from the Dharamaram Formation which overlies the Maleri Formation in Pranhita-Godavari Valley is characterised by an archosaur fauna consisting of prosauropods. These are represented by one large plateosaurid and another archosaurid (Jain & Roy Chowdhury, 1987). The typical members of the Maleri fauna are not present. The fauna has been considered to be Late Norian and Rhaetian in age by Kutty (1969) who compared the changes between Dharamaram and Maleri faunas to be much similar to those seen between Knollenmergel and Rhätsandstein of Germany and their equivalents.

Lower Jurassic Fauna

The Lower Jurassic vertebrate fauna is known from the Kota Formation of the Pranhita-Godavari Valley. It consists of fishes, sauropod dinosaur, pterosaur, crocodiles and mammals. The fishes are represented by seminotids, a coelocanth and pholidophorids. The seminotids are known by three forms: *Lepidotes deccanensis, Paradapedium egertoni* and *Tetragonolepis oldhami.* These seminotids resemble very much with Liassic marine forms of Europe. *Lepidotes deccanensis* is much similar to *L. elevensis* which is known from the Upper Liassic. *Paradapedium* (Jain, 1973) is closer to *Dapedium* which is reported from Rhaetic to Upper Liassic. The presence of *Pholidophorus* in Kota fauna was first recognised by Satsangi and Shah (1973) and later two species, *P. indicus* and *P. kingii* have been described by Yadagiri and Prasad (1977). Pholidophorid fishes are common in the European Liassic. The coelocanth, *Indocoelocanthus robustus* Jain (1974a) is not known elsewhere. Thus, on the basis of the seminotolid and pholidophorid fishes the age of the Kota Formation is Liassic.

The dinosaurs reported from the Kota Formation are the best known sauropods from the Lower Jurassic anywhere in the world (Jain *et al.*, 1975, 1979; Yadagiri *et al.*, 1979). Two forms of sauropods have been recognised: one is named as *Barapasaurus tagorei* (Jain *et al.*, 1979) which is one of the best known sauropod from the Lower Jurassic and another an unnamed form which is closer to prosauropods (Yadagiri *et al.*, 1979). A pterosaur was noted by Rao and Shah (1963) in the Kota Formation. Jain (1974b) recorded another specimen of pterosaur which he named as *Campyglognathoides indicus.* The genus is also known from the Liassic Hoezmaden deposits of southern Germany (Colbert, 1979).

The crocodilian remains recorded by Owen (1852) have been referred to Teleosauridae (Buffetant, 1979) who has suggested that the Kota crocodiles may represent the earliest member of the group like those known from Chile.

One of the significant addition to the Kota fauna are the Early Jurassic mammals. The record of Mesozoic mammals is extremely poor from the southern continents. The forms discovered by Datta *et al.* (1978) from Kota are referable to symmetrodonts. Datta (1981) described a new form of symmetrodont *Kotatherium haldeni* and later Yadagiri (1984) added two more new forms, *Trishulotherium kotensis* and *Indotherium pranhitai.* Yadagiri (1985) described a new amphidontid symmetrodon, *Nakunodon paikasiensis,* from the Kota Formation. The relationship of the Kota symmetrodonts with other Jurassic mammals is still not clear. Yadagiri (1986) recorded fresh water hybodontid Shark, percoid fishes, urodele and palaeobatid amphibians and sphanodontid and platynoid reptiles from the Kota Formation.

From Gangapur Bed which overlies the Kota Formation in Pranhita-Godavari Valley and is considered to be Lower Cretaceous in age, fish-scales have been reported. No other recognisable vertebrate is known from the Lower Cretaceous sediments.

CONCLUSION

A vertebrate faunal succession covering the period from Upper Permian to Lower Jurassic is now known from the Indian Gondwana. Six of the vertebrate faunas in this succession are well represented and are directly correlatable with similar faunas known elsewhere.

The aquatic and semiaquatic vertebrate fauna known from the Mamal Formation of Kashmir has distinct affinity with the Lower Permian fauna of Europe and North America. The presence of this fauna suggests a close proximity of this part of Gondwanic India to Laurasia in Lower Permian allowing free migration of tetrapods from Laurasia through island connections.

The discovery of characteristic reptilian genera of South African Karoo Sequence in the Indian Gondwana permits direct correlation of this part of the Permian-Triassic Sequence with the well known reptilian biozones: *Endothiodon, Cistecephalus, Daptocephalus* (?) and *Lystrosaurus* zones of the Karoo Sequence. It also points out to the close connection between South Africa and India during Upper Permian and Lower Triassic.

The occurrence of common species of *Lystrosaurus* in South Africa, Antarctica and India provides strong evidence of contiguity of these land masses during Lower Triassic. The presence of *Lystrosaurus* in China and Indo-China (?) supports the idea of these areas being part of Gondwanaland during Lower Triassic.

The dominance of fauna of northern affinity over the southern genera in the Maleri fauna indicates a palaeontological link between India and Laurasia during Upper Triassic time.

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Jurassic and Lower Cretaceous dinoflagellate cysts from India with some remarks on the concept of Upper Gondwana

Rahul Garg, Khowaja-Ateequzzaman & K. P. Jain

Garg, Rahul, Khowaja-Ateequzzaman & Jain, K. P. (1988). Jurassic and Lower Cretaceous dinoflagellate cysts from India with some remarks on the concept of Upper Gondwana. *Palaeobotanist* **36** : 254-267

A critical re-evaluation of the known records of dinoflagellate cyst assemblages from Jurassic and Lower Cretaceous sediments of India is made and stratigraphically significant taxa are identified and tabulated. Emphasis is laid on integration of dinocyst and ammonite evidences for stratigraphic precision. Significance of dinocysts in age determination of Kimmeridgian-Tithonian sequences of Kutch and Malla Johar is recognised. Berriasian dinocysts are not known from India. It is suggested that dinocyst assemblages documented from subsurface of East Coast of India are not older than Hauterivian as no conclusive evidence for Valanginian age, assigned by earlier workers, is available.

The traditional view of regarding coastal marine Lower Cretaceous sequences as part of Gondwana is not tenable. It is suggested that the term Gondwana be reserved for inland, predominantly non-marine, fluviatile-lacustrine sediments as a lithostratigraphic unit. In view of the lack of any definite evidence of Jurassic sediments in intracratonic basins and the prominent post-Triassic hiatus, Late Triassic be considered to mark the upper age limit of Gondwana sequences.

Key-words—Dinoflagellate cysts, Stratigraphy, Jurassic, Lower Cretaceous, Upper Gondwana (India).

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साराँश

भारत से जूराई एवं अधरि क्रीटेशी घूर्णीकशाभ पुटीयाँ तथा उपरि गोंडवाना की अवधारणा पर कुछ टिप्पणियाँ

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भारत के जूराई एवं अधरि क्रीटेशी अवसादों से ज्ञात घूर्णीकशाभ-पुटी समुच्चयों के अभिलेखों का विशेष पुनर्मूल्याँकन किया गया है तथा स्तरिकीय दृष्टि से महत्वपूर्ण वर्गक अभिनिर्धारित एवं तालिकाबद्ध किये गये हैं। स्तरिक यथार्थता हेतु घूर्णीकशाभ पुटीयों एवं ॲमोनाइटों के प्रमाणों के एकीकरण पर बल दिया गया है। कच्छ एवं मल्ला जोहर के किम्मॅरिडजिअन-टिथोनियन अनुक्रमों की आयु-निर्धारण में घूर्णीकशाभ पुटीयों का महत्त्व अभिनिर्धारित किया गया है। भारत से बेरिएशियन कालीन घूर्णीकशाभ पुटीयाँ अभी तक विदित नहीं हैं। यह प्रस्तावित किया गया है कि भारत के पूर्व तट के उपसतह से ज्ञात घूर्णीकशाभ पुटी समुच्चय हॉटीरीवियन से अधिक पुराने नहीं हैं क्योंकि इससे पहले शोधकर्त्ताओं द्वारा निर्धारित वालेन्जीनिअन आयु का कोई प्रमाण नहीं मिलता। तटीय समुद्री अधरि क्रीटेशी अनुक्रम गोंडवाना का ही एक भाग हैं, यह दृष्टिकोण मान्य नहीं है। यह प्रस्तावित किया गया है कि 'गोंडवाना' नामक शब्द का प्रयोग एक शैल-स्तरिकीय इकाई के रूप में अंतःस्थलीय असमुद्री, नदीय-सरोवरी अवसादों हेतु होना चाहिये। अन्तःक्रेटानी द्रोणीयों में जूराई अवसादों तथा स्पष्ट पश्च-त्रिसंघी दरार के निश्चित प्रमाण की अनुपस्थिति में गोंडवाना अनुक्रमों की उपरि आयु सीमा अनंतिम त्रिसंघी मानी जानी चाहिये।

JURASSIC and Lower Cretaceous sedimentary rocks of shallow marine to paralic facies are confined primarily along the margins of the Indian Craton. A remarkably complete sequence of these rocks was laid down only in the Tethys Himalayan belt in a unique tectono-sedimentary set-up under shallow to deeper marine environment. Deposition of Middle Jurassic-Lower Cretaceous rocks in Rajasthan and

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Kutch and thick Lower Cretaceous clastic sequences along the East Coast of Peninsular India took place in marginal marine basins.

Micropalaeontological studies of these sequences have primarily been confined to microfauna and microflora (spore-pollen assemblages). Earlier records of dinoflagellate cysts from Jurassic sediments of India are sporadic and have little biostratigraphic value (Jain, 1974). Recent systematic documentation of dinocysts from richly fossiliferous Jurassic sequences of Kutch (Jain *et al.*, 1986; Kumar, 1986a, 1987a, b) and Tethys Himalaya (Jain *et al.*, 1984) has highlighted their biostratigraphic potential. For a better stratigraphic resolution, integration of dinocysts data with ammonite evidences has also been attempted (Jain *et al.*, 1984; Garg *et al.*, 1986).

In Kutch Basin, richly fossiliferous marine Jurassic rocks are extensively developed. Dinocysts are described from Jhurio (Kumar, 1987a) and Jhuran formations (Jain *et al.*, 1986; Kumar 1986a, 1987a,b). The assemblage from Jhurio Formation of Jhura Dome Section is poorly preserved and consists of 18 dinocyst species. Significant taxa of this assemblage are *Atopodinium prostratum, Chytroeisphaeridia chytroeides, C. scabrata, Ctenidodinium* sp. cf. *C. ornatum, Ctenidodinium* sp. cf. *C. tenellum, Escharisphaeridia pocockii, Pareodinia ceratophora, P. prolongata, Prolixosphaeridium granulosum, Rigaudella* sp. cf. *R. aemula* and *Tubotuberella dangeardii.* Kumar (1987a) assigned Bathonian-Callovian age, though dinocyst data is inconclusive for age determination. Most of these species are long ranging, recorded from Middle to Late Jurassic of Europe, Australia and Blake-Bahama Basin. This assemblage may extend into Oxfordian as well. Agarwal (1957) assigned Callovian-Oxfordian age to this sequence on molluscan evidence.

Jain *et al.* (1986) described 22 genera and 29 species of dinocysts from various levels of Jhuran Formation. Kumar (1986a, 1987b) recorded 35 species from a section exposed westwards of Bhuj, which according to him belongs to the Middle Member of Jhuran Formation. This section is exposed along the banks of the Khari Nadi (river) near the Cremation Ground on the western outskirts of Bhuj town. Two of us (K.P.J. & R.G.) investigated and sampled this section during a joint field trip of BSIP/ONGC in 1986 alongwith Drs S.V. Deshpande (ONGC) and H.K. Maheshwari (BSIP). The lithological sequence is characterised by thick, medium to coarse, brownish sandstone and thin siltstone alternations with very thin greyish black shale/silty shale partings in the lower part and very thick current bedded sandstone with fewer siltstone partings towards the top. This lithology is typical of the Upper Member of the Jhuran Formation (Biswas, 1977). It is our contention that the dinocyst assemblage recorded by Kumar (1986a, 1987b) is actually from the uppermost part of the Upper Member and not from the Middle Member of the Jhuran Formation. Hence, this assemblage is accordingly tabulated in the species list (Table 1) with Upper Member assemblages. Significantly, the Jhuran assemblages documented by Kumar (1986a, 1987b) and Jain *et al.* (1986) are qualitatively quite different and have only a few common elements. Dinocyst assemblages from Lower and Middle members of the Jhuran Formation documented by Jain *et al.* (1986) are quite similar. Except for *Escharisphaeridia pocockii,* all the 14 species present in the Lower Member extend into younger assemblages. Only a few species are restricted to Middle Member, viz., *Surculosphaeridium vestitum, Adnatosphaeridium filamentosum* and *A. paucispinum,* which are long ranging. However, common occurrence of *Scriniodinium dictyotum, Sentusidinium echinatum, Egmontodinium polyplacophorum, Gonyaulacysta ehrenbergii, Gonyaulacysta jurassica, Ellipsoidictyum cinctum* and *Scriniodinium luridum* in Lower and Middle members of Jhuran Formation reflects Early Kimmeridgian aspect. Dinocysts from Patasar Shale (unpublished data) have provided first hand correlation between Jhuran Formation of Kutch mainland and lower shaly part of Wagad Sandstone Formation of eastern Kutch for which no mega or microfaunal evidences are yet available except for the ammonites in the immediately underlying Dhosa Oolite and Kanthkot Ammonite band in respective regions. It is interesting to note that the two Upper Member assemblages recovered from Ugedi Well (Jain *et al.*, 1986) and Cremation Ground (Kumar, 1986, 1987) are qualitatively distinct, though there are certain common taxa amongst the two. The Ugedi assemblage has 14 significant species, only four including *G. jurassica* and *Scriniodinium dictyotum* extend from Lower and Middle members, while 10 including *Tanyosphaeridium torynum, Tubotuberella apatela* and *Broomea ramosa* are confined to this assemblage. The Cremation Ground assemblage interestingly shows seven additional species extending from Lower to Middle Member including *Egmontodinium polyplacophorum, Sentusidinium echinatum* and *Ellipsoidictyum cinctum.* Significantly *Broomea ramosa* is not recorded by Kumar (1986) but several other species are additionally documented. Presence of *Tanyosphaeridium torynum, Broomea ramosa, Pareodinia verrucosa, Chlamydophorella wallala* in Upper Member assemblages of Kumar (1986a, 1987b) and Jain *et al.* (1986), is indicative of Middle-Late Kimmeridgian (*sensu anglico*) age, not younger than *Pectinatus* Zone, probably equivalent to early-Middle Tithonian in the Tethyan realm. It should, however, be noted that stratigraphic ranges of most of the dinocyst species are primarily defined in terms of well established ammonite zonation of boreal region. The extension of European boreal dinocyst ranges to this part of the Tethyan realm is bound to be tenuous and correlations should be attempted cautiously. For this purpose, only a few selective cosmopolitan and well known species have been chosen for age determination and correlation.

A high degree of provincialism among ammonites during Late Jurassic has led to the establishment of different zonation schemes for Tethyan, boreal and Russian platform regions using Tithonian, Kimmeridgian/Portlandian and Volgian Stage names respectively (Hallam, 1975). Precise correlation of ammonite zones in these regions is still not firmly established. In view of this the age determination based on dinocysts in terms of boreal ammonite zones are difficult to integrate with Tethyan ammonite zones. Reliability in dinocyst dating and correlation can only be achieved by defining dinocyst ranges in terms of Tethyan ammonite successions and their subsequent tagging, as far as possible, with boreal ammonite schemes.

Integration of dinocyst and ammonite evidences in the Tethyan Sequence is attempted by Jain *et al.* (1984) in their study of Spiti Shale Formation sequence exposed in Malla Johar area. They proposed an informal dinocyst biozonation scheme for a part of Spiti Shale and integrated dinocyst assemblages with ammonite zones defined by Krishna *et al.* (1983) for the same succession. This assemblage is rich and diversified. In all, 67 species are recorded. A significant aspect of this assemblage is the co-occurrence of *Gonyaulacysta jurassica* and *Omatia montgomeryii* at the same stratigraphic level in the upper part of Middle Spiti Shale sequence. *G. jurassica* has its last occurrence while *O. montgomeryii* has its first appearance in the boreal *Pectinatus* Zone, of early Late Kimmeridgian which is probably equivalent to late Middle Tithonian or early Late Tithonian. Krishna *et al.* (1983) placed this part of the Spiti Shale within the *Blanfordiceras* Assemblage of late Late Tithonian. In order to resolve this controversy, Garg *et al.* (1986) investigated dinocysts recovered from ammonite specimens duly identified and provided by Dr Jai Krishna (BHU). It has been observed that ammonites from the upper part of the Middle Spiti Shale, viz., *Virgatosphinctes* and *Kossmatia* both contain *G. jurassica* and *O. montgomeryii*; *Blanfordiceras* from suprajacent levels yielded poor dinocysts containing only *Gonyaulacysta* sp. cf. *G. perforans* and cf. *Batioladinium.* On dinocyst evidence, Jain *et al.* (1986) suggested to shift the tentatively defined boundaries of ammonite assemblage, a few meter higher up. The topmost part of the Spiti Shale sequence appears to be condensed, characterised by bedded cherts and hardgrounds and is totally devoid of organic matter. It is quite likely that Late Tithonian ammonite zones may be confined within short intervals in the uppermost part of the Spiti Shale sequence.

Another stratigraphically significant event among Spiti Shale dinocysts is the first appearance of *Broomea simplex* which can be tagged with *Troquatisphinctes-Aulacosphinctes* Assemblage of Early Tithonian. In terms of boreal ammonite zones its first appearance is within the *Wheatleyensis* Zone of early Middle Kimmeridgian. However, it should be noted that several dinocyst species have different ranges in Indian sequences as compared to Europe. *Adnatosphaeridium aemulum, A. filamentosum, A. paucispinum, Lithodinia jurassica, Nannoceratopsis pellucida, Scriniodinium luridum, Prolixosphaeridium mixitispinosum, Ellipsoidictyum cinctum* and *Wanaea clathrata* are recorded from Oxfordian-Early Kimmeridgian or Early Kimmeridgian in Europe but have extended range in definite Tithonian sequence of Tethyan Himalaya. *Peridictyocysta mirabilis* which has its earliest appearance in *Scitulus* Zone is documented from definite Early Tithonian sequence referable to *Torquatisphinctes-Aulacosphinctes* assemblage.

Jurassic dinocysts known from India are tabulated (Table 1) and stratigraphically significant species are sorted out (Table 2). Late Jurassic dinocyst assemblages from Kutch and Tethyan Himalaya are quite distinct from each other. There are several common species but absence of *Omatia* species in Kutch Assemblage and *Egmontodinium* in Malla Johar Assemblage is noteworthy. Kumar (1986) suggested the possibility of some degree of provincialism among Late Jurassic dinocysts based on their differential distribution in Kutch and Tethyan Himalaya. However, *Egmontodinium polyplacophorum* as well as *Indodinium khariensis* and *Nannoceratopsis radiatus* documented from Kutch have recently been recovered from the ammonite *Kossmatia* collected from Kibber Section in Spiti (Garg *et al.*, 1986). It is, therefore, difficult at this juncture to speculate on provincialism despite some palaeobiogeographic distinction between the dinocyst assemblages of the two regions, because these are yet to be documented in detail and the observed distinction may actually be deceptive.

Records of Lower Cretaceous dinocysts are confined to the sedimentary basins along the east

Table 1—Distribution of Jurassic dinocysts from India

		KUTCH			*MALLA JOHAR*				
		Jhuran Formation			*Spiti Shale (Formation)*				
DINOCYST TAXA	*Jhurio Formation*	*Lower Member*	*Middle Member*	*Upper Member*	*Assemblage*			*Zones*	
					A	*B*	*C*	*D*	*E*
Atopodinium prostatum	+								
Chytroeisphaeridia chytroeides	+								
C. scabrata	+								
Cleistosphaeridium cf. *C. varispinosum*	+								
Ctenidodinium cf. *C. ornatum*	+								
Ctenidodinium cf. *C. tenellum*	+								
Dichadogonyaulax sp.	+								
Dingodinium sp.	+								
Leiosphaeridia sp.	+								
Meiourogonyaulax sp.	+								
Pareodinia prolongata	+								
Prolixosphaeridium granulosum	+								
Rigaudella cf. *R. aemula*	+								
Sentusidinium sp.	+								
Xenicodinium sp.	+								
Tubotuberella dangeardii	+			+					
Escharisphaeridia pocockii	+	+	+	+					
Pareodinia ceratophora	+	+	+	+	+				+
Scriniodinium dictyotum		+							
Sentusidinium echinatum		+		+	+				
Egmontodinium polyplacophorum		+	+	+					
Ellipsoidictyum cinctum		+	+	+					+
Gonyaulacysta jurassica jurassica		+	+	+					+
Leptodinium eumorphum		+	+	+					
Gonyaulacysta ehrenbergii		+	+						
Adnatosphaeridium aemulum		+	+						+
Occisucysta sp.		+	+						
Scriniodinium luridum		+	+						
Apteodinium granulatum		+	+		+				
Nannoceratopsis pellucida		+	+			+	+		
Adnatosphaeridium filamentosum			+						
Adnatosphaeridium pausispinosum			+						
Gonyaulacysta sp. cf. *perforans*			+	+					
Systematophora orbifera			+	+	+				
Surculosphaeridium vestitum			+				+		
Nannoceratopsis radiatus				+					
Egmontodinium torynum				+					
Sentusidinium hexagonalis				+					
Oligosphaeridium pulcherrimum				+					
Sentusidinium pelionence				+					
Sentusidinium sp. A				+					
Sentusidinium creberbatum				+					
Scriniocassis downiei				+					
Parvocavatus scabratus				+					
Escharisphaeridia psilata				+					
Geiselodinium inaffectum				+					
Indodinium khariensis				+					
Indosphaera bhujensis				+					
Mendicodinium granulatum				+					
M. microreticulatum				+					
Pareodinia verrucosa				+					
P. imbatodinensis				+					
Broomea ramosa				+					
Prolixosphaeridium anasillum				+					

(Contd.)

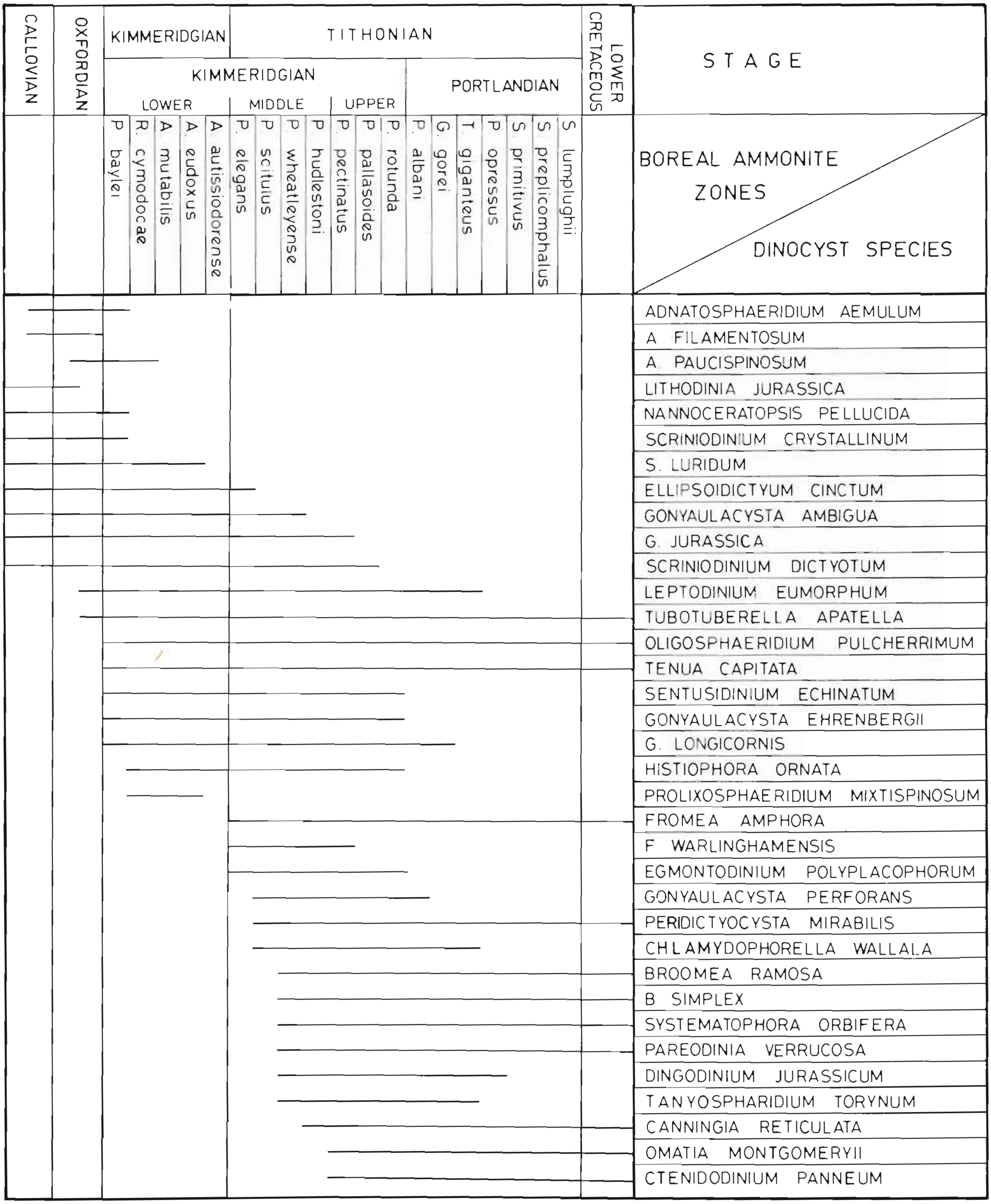
Table 1—(*Contd.*)

Chlamydophorella wallalla	+					
Ctenidodinium culmulum	+					
Scriniodinium echinatum	+		+			
Tubotuberella apatela	+	+				
Systematophora panicillata	+	+				
Canningia reticulata		+				
Chytroeisphaeridia sp. A		+				
Cribroperidinium granulatum		+				
Ellipsoidictyum sp. A		+				
Fromea amphora		+				
Lithodinia sp.		+				
Oligosphaeridium dictyophorum		+				
Oligosphaeridium sp. cf. *anthophorum*		+				
Prolixosphaeridium capitatum		+				
Scriniodinium indicum		+			+	
Prolixosphaeridium dictyophorum		+				
Oligosphaeridium sp.		+				
Broomea simplex		+	+			+
Prolixosphaeridium granulosum			+			
Cyclonephelium sp. A			+			
Lanterna sp. A			+			
Peridictyocysta mirabilis			+			
Wanaea clathrata			+			
Broomea sp. A			+			
Prolixosphaeridium sp. A			+			
Sentusidinium sp. A			+	+		
Sentusidinium sp. B			+	+		
Apteodinium nuciforme				+		
Canningia apiculata				+		
Ovoidinium waltonii				+		
Pseudoceratium spitiensis				+		
Scriniodinium galeritum				+		
Tanyosphaeridium jurassicum				+		
Chlamydophorella fenestrata						+
Emmetrocysta sarjeantii						+
Histiosphora ornata						+
Lithodinia jurassica						+
Membranilarnacia leptoderma						+
Omatia montgomeryii						+
Omatia pisciformis						+
Prolixosphaeridium mixtispinosum						+
Rhyncodiniopsis ambigua						+
Tubotuberella sp. A						+
Leptodinium sp. A						

coast of peninsular India. Sharma *et al.* (1977) referred and illustrated a few dinocysts alongwith a rich spore-pollen assemblage from the subsurface of Krishna-Godavari Basin. The same sequence was subsequently investigated in more detail for dinocysts by Kumar (1982, 1986). Khowaja-Ateequzzaman *et al.* (1985, 1988a, b) and Jain and Khowaja-Ateequzzaman (1984) have documented a rich dinocyst assemblage from subsurface Lower Cretaceous Sequence of Palar Basin besides carrying out detailed morphological studies of some taxa. Mehrotra and Sarjeant (1984a, b, c) made detailed morphological studies of some Lower Cretaceous dinocyst taxa from subsurface of Cauvery Basin. Subsequently, they (1986) documented a fairly rich dinocyst assemblage from the same sequence.

Kumar (1982, 1986b) tabulated a rich dinocyst assemblage comprising 78 species recovered from 19 core samples collected at various depths from 8 different shallow wells in Krishna-Godavari Basin. Based on a comparison with Australian and European assemblages, Valanginian to Hauterivian age is assigned with the possibility of the upper age limit extending into Barremian. In our opinion this assemblage is most closely comparable with type Barremian assemblages documented by Srivastava (1984) from southern France and Duxbury (1980) from England and also with Australian assemblage documented by Berger (1980, 1982). According to Kumar (1986), the Krishna-Godavari assemblage is most closely comparable with Australian assemblages documented by Berger (1982) from

Table 2—Stratigraphic ranges of selected Jurassic dinocysts species



DK2 and DK3 zones which are assigned to Valanginian and Hauterivian to possibly Early Barremian age respectively. Helby *et al.* (1987) recently reviewed Burger's data and extended the upper limit of DK2 Zone to the top of Zone DK3a, corresponding to their *Muderongia testudinaria* Zone of Middle Hauterivian. In our opinion, presence of *Bachidinium polypes* (now *Kiokansium*

Table 3—Distribution of Lower Cretaceous dinocysts from India

Dinocyst Species	Krishna-Godavari Basin (*Arun Kumar, 1986b*)	Cauvery Basin (Mehrotra & Sarjeant, 1986)	Palar Basin (Khowaja Ateequzzaman, 1988 a, b)
Achomosphaera ?neptunii	×		
A. ramulifera	×		
Achomosphaera cf. *sagena*		×	
Alterbidinium minor			×
Aprobolocysta sp.		×	
Aptea anaphrissa			×
Apteodinium conjunctum	×		
A. grande	×		
A. granulatum	×		
A. maculatum	×		
A. spinosum	×		
Ascodinium acrophorum	×		
Bacchidinium polypes (Now *Kiokansium polypes*)	×		
Batiacasphaera aptiense	×		
B. crassicingulata	×		
B. echinata	×		
Batiacasphaera cf. *macrogranulata*		×	
B. minor	×		
B. pilosa	×		
B. scrobiculata	×		
B. spumosa	×		
Batiacasphaera sp.	×		
Batioladinium micropodum	×		
B. jeageri			×
Callaiosphaeridium asymmetricum			×
Canningia colliveri	×		
C. reticulata	×		
Canningia sp. A (Burger, 1980)	×		
Cassiculosphaeridia magna	×		
C. reticulata	×		
Chlamydophorella nyei	×		
Chlamydophorella cf. *nyei*		×	
Cleistosphaeridium aciculare	×		
C. granulatum	×		
C. huguoniotii			×
Cleistosphaeridium sp. (Brideaux, 1977)	×		
Coronifera oceanica	×		
Cribroperidinium apione	×		
C. cornutum			×
C. muderongense	×		
Cribroperidinium cf. *orthoceras*		×	
Cribroperidinium sp.		×	
Cyclonephelium areolatum	×		
C. densebarbatum	×		
C. distinctum	×		
C distinctum subsp. *laevigatum*		×	
C. hystrix	×		
Dapsilidinium multispinosum	×		
Dingodinium cerviculum	×	×	×
Discorsia nanna	×		×
Druggidium jubatum			×
Endoscrinium luridum	×		
Ellipsodinium cf. *reticulatum*			×
Exochosphaeridium phragmites	×		
Fromea amphora	×	×	
F. fragilis	×		
F. glabella	×		
Gonyaulacysta sp. A		×	

(*Contd.*)

Table 3—(*Contd*)

Gonyaulacysta sp. B		×	
Hystrichodinium oligacanthum	×		
H. pulchrum	×	×	
Hystrichogonyaulax serrata	×		
Hystrichosphaeridium arborispinum	×		
H. tubiferum	×		
Imbatodinium fractum		×	
Kallosphaeridium granulatum	×		
K. norvickii	×		
K. romaense	×		
Kleithriasphaeridium eoinodes	×		
K simplicispinum	×	×	
K. corrugatum			×
Leberidocysta chlamydata	×		
L. defloccata	×		
Leptodinium simplex	×		
Leptodinium sp.	×	×	
Lithodinia cf. *jurassica*	×		
cf. *Mendicodinium* sp.	×		
Meiourogonyaulax bulloidea			×
Muderongia mcwhaei	×	×	×
Muderongia cf. *mcwhaei*		×	
M. staurota	×		
M. tetracantha		×	×
Muderongia sp.		×	
Odontochitina operculata			×
Oligosphaeridium asterigerum		×	
O. complex	×		×
O. dictyophorum	×		
O. diluculum		×	
O. pulcherimum	×		×
O. totum totum			×
Palaeoperidinium cretaceum			×
Pareodinia cf. *ceratophora*	×		×
Phoberocysta neocomica	×		
Polygonifera eisenackii		×	
Prolixosphaeridium capitatum	×		
P. conulum	×		
P. deirense			×
Protoellipsoidinium sp.	×		
Pterodinium premnos			×
Rhynchodiniopsis aptiana	×		
R. fimbriata			×
R. hyalodermopsis	×		
Rhombodella vesca			×
Scriniodinium attadalense	×		
Spiniferites pterosus	×		
S. ramosus granomembranaceous	×		
S. ramosus ramosus	×	×	×
S. scabrosus	×		
S. dentatus		×	
Tanyosphaeridium cf. *isocalamus*	×		
T isocalamus		×	
Trabeculidium quinquetrum			×
Wallodinium anglicum		×	
W. glaessneri	×		
Wallodinium cf. *luna*		×	

polypes), Canningia colliveri, Fromea fragilis, Batioladinium micropodum, Discorsia nanna, Muderongia staurota, Cleistosphaeridium aciculare, Kallosphaeridum norvickii and *Batiacasphaera spumosa* in Krishna-Godavari Assemblage indicates Hauterivian-Barremian age. Absence of *Odontochitina operculata*, though a negative evidence, suggests that this assemblage may not be younger than Lower Barremian.

Kumar (1986b, p. 33) suggested the possibility of reworking of older Jurassic sediments in view of the occurrence of *Apteodinium granulatum,*

Table 4—Stratigraphic ranges of selected dinocyst species known from Lower Cretaceous sequences of India

STAGE / DINOCYST SPECIES	JURASSIC	BERRIASIAN	VALANGINIAN	HAUTERIVIAN	BARREMIAN	APTIAN	ALBIAN
KLEITHRIASPHAERIDIUM EOINODES		—	—	—	—	—	
PHOBEROCYSTA NEOCOMICA		—	—	—	—	—	
KLEITHRIASPHAERIDIUM CORRUGATUM		—	—	—	—		
HYSTRICODINIUM PULCHRUM		—	—	—	—	—	—
DINGODINIUM CERVICULUM			—	—	—	—	—
KLEITHRIASPHAERIDIUM SIMPLICISPINUM			—	—	—	—	—
MUDERONGIA MCWHAEI			—	—	—	—	
DAPSILIDINIUM MULTISPINOSUM			—	—	—		
SPINIFERITES DENTATUS				—	—		
MUDERONGIA STAUROTA				—	—		
DISCORSIA NANNA				—	—	—	
BATIOLADINIUM MICROPODUM				—	—	—	→
FROMEA FRAGILIS				—	—	—	→
CANNINGIA COLLIVERI				—	—	—	→
CORONIFERA OCEANICA				—	—	—	→
MUDERONGIA TETRACANTHA				—	—		
BACCHIDINIUM POLYPES				—	—	—	→
PROTOELLIPSOIDINIUM SPINOSUM				—	—	—	—
BATIACASPHAERA SPUMOSA					—	—	
KALLOSPHAERIDIUM NORVICKII					—	—	—
BATIOLADINIUM JAEGERI					—	—	—
HYSTRICHOSPHAERIDIUM TUBIFERUM					—	—	—
CLEISTOSPHAERIDIUM ACICULARE					—	—	→
ODONTOCHITINA OPERCULATA					—	—	→
PALAEOPERIDINIUM CRETACEUM					—	—	→
APTEA ANAPHRISSA					—		

Batiacasphaera crassiangulata, Lithodinia sp. cf. *L. jurassica, Oligosphaeridium dictyophorum, Prolixosphaeridium capitatum* and *Pareodinia* sp. cf. *P. ceratophora*. This statement needs explanation as no marine Jurassic sequence is developed along the East Coast where sedimentation is believed to have commenced only sometimes in Late Neocomian with the development of marine sea way as a prelude to the disruption of Gondwanaland. These dinocyst species might have extended stratigraphic ranges or may need careful taxonomic reassessment.

Mehrotra and Sarjeant (1986) described 27 dinocyst species from 7 conventional core somples spread between a depth of 95 to 143 m in Priyavadavadi shallow well-1, Cauvery Basin. Of these, 13 species are provisionally assigned or identified up to generic level only, due to the unsatisfactory state of preservation. A majority of taxa range within Neocomian-Aptian which occur along with some species of Albian or younger age. The authors, however, differentiated Valanginian to Aptian sediments within a thickness of 48 metres, primarily based on meagre or dominant occurrence or absence of *Muderongia mcwhaei* (Hauterivian-Aptian) alongwith *Dingodinium cerviculum* (Valanginian to Middle Albian) and *Batiacasphaera* sp. cf. *B. macrogranulata* whose range is given by Mehrotra and Sarjeant (1986, table 1) as Neocomian. It is to be noted that the youngest assemblage shows predominance of *Achomosphaera* sp. cf. *A. sagena, Chlamydophorella* sp. cf. *C. nyei, Cyclonephelium distinctum* subsp. *laevigatum, Dingodinium cerviculum, Imbatodinium fractum, Muderongia* sp. cf. *M. mcwhaei* and *Polygonifera eiseneckii*. Except for *Muderongia* cf. *mcwhaei* all other species persist almost throughout the sequence. Further, occurrence of *Chlamydophorella* cf. *nyei* (Aptian-Maastrichtian) is noted in good numbers in the older samples while *Wallodinium anglicum* (Albian-Early Cenomanian) and *Tanyosphaeridium isocalamus* (Late Albian) occur rarely in the younger horizon. Stratigraphic range of *C. nyei* actually extends down to Late Berriasian (Burger, 1982, text-fig. 11). In view of meagre representation of *W. anglicum* and *T. isocalamus* and predominance of *M. mcwhaei*, Mehrotra and Sarjeant assigned Aptian age to younger assemblages. However, predominance of *Oligosphaeridium asterigerum*, having restricted range within Valanginian-Lower Hauterivian, as well as occurrence of *Spiniferites dentatus* (Hauterivian-Barremian) at this level is not considered by them. In our opinion, dinocyst evidence is inconclusive for precise age assignment and differentiation of various Early Cretaceous stages within 48 m of this shallow bore-hole is not acceptable. We believe that no conclusive evidence is available for Valanginian dating and the documented assemblages may range within Hauterivian-Aptian or may represent only a part of this time span.

Khowaja-Ateequzzman *et al.* (1988a, b) recorded rich and diversified dinocyst assemblages from a bore-hole drilled up to a depth of 760 m in Puduvoyal, Palar Basin. A characteristic Barremian dinocyst assemblage recovered from a conventional core at 440-444 m depth is dominated by *Odontochitina operculata, Muderongia mcwhaei, M. tetracantha, Discorsia nanna* and *Aptea anaphrissa*. Its equivalence with the European *Aptea anaphrissa* subzone of *O. operculata* Zone of Middle Barremian age (Davey, 1979) is suggested (Khowaja-Ateequzzaman *et al.*, 1988a). Other significant species in this assemblage are: *Trabeculidinium quinquetrum, Pterodinium premnos, P cingulatum, Kleithriasphaeridium simplicispinum, Rhynchodiniopsis fimbriata, Ellipsodinium reticulatum, Druggidium jubbatum, Prolixosphaeridium dierense, Batioladinium jaegeri, Cribroperidinium cornutum* and *Meiourogonyaulax hugoniotii*.

The dinocyst species known from Lower Cretaceous of India are tabulated (Table 3). Stratigraphic ranges of some key taxa are given separately (Table 4). Occurrence of some Lower Cretaceous dinocysts in the Flysch succession of Tethys Himalaya has been postulated by Jain and Garg (1986). In fact, Mehrotra and Sinha (1981) provided a brief account of dinocysts from Upper Flysch Sequence of Malla Johar area and suggested Palaeocene-Lower Eocene age for a major part of the succession. Jain and Garg (1986) reassessed the assemblage on face value as repository of type slides could not be traced, suggesting many taxonomic reallocations and considered the assemblage to be not younger than Cretaceous. Occurrence of *Endoceratium ludbrookiae* (identified as *Deflandrea* by Mehrotra & Sinha, 1981) and also *Odontochitina* sp. is probably suggestive of Lower Cretaceous reworking in younger Flysch sequence.

The only record of dinocysts from intracratonic Gondwana Basin is by Jain *et al.* (1982) from Jabalpur Formation. The carbonaceous shale sample which yielded dinocysts, spores and pollen, was collected from the lower part of Jabalpur Formation from Morand River Section near Morghat, Satpura Basin. The dinocyst assemblage consists of *Kalyptea, Sentusidinium* and *Canningia*. Jain *et al.* (1982) doubtfully placed the assemblage in Late Jurassic in view of the then available palynological evidences. *Kalyptea indica* closely resembles cysts recorded from Lower Cretaceous of Australia. Similar forms are also recorded from Lower Cretaceous of East Coast of India and Kutch (unpublished data) but are not known from Jurassic sequences. Forma A (Jain *et al.*, 1982, p. 25; pl. 1; fig. 13) resembles *Batioladinium* known from the Lower Cretaceous of East Coast of India and Australia. In the absence of any marker taxa, and in view of the recent spore-Pollen evidences (Singh & Venkatachala, 1988, in this volume) we would prefer to place the present assemblage in Lower Cretaceous.

Jain *et al.* (1982) suggested that in view of the so far believed non-marine origin of Jabalpur sediments, the dinocyst assemblage may be non-marine too. However, they kept their views open on this aspect. It is difficult to envisage any marine influence during Lower Cretaeous in Jabalpur area at this juncture as evidences for existence of any marine seaway are yet lacking. The only possible channel for marine incursion in this region seems to be the Narbada rift which is known to have undergone a transgressive event during Late Cretaceous time. Estuarine (Singh, 1981) or non-marine (Brookfield & Sahni, 1987) environment has been suggested for Late Cretaceous Lameta Group of sediments. The possibility of re-activation of Narbada rift in Early Cretaceous times, so as to bring in marine influence, albeit for a short period, during the deposition of Jabalpur Formation is a moot question. There is absolutely no sedimentologic or palaeontologic evidence as yet available supporting such an early transgressive event along Narbada rift. The discovery of dinocysts is probably the first evidence which should initiate more cautious and unbiassed approach in future biostratigraphical and palaeoenvironmental studies in this area.

REMARKS

It is our contention that so far no definitive dinocyst evidence for older than Hauterivian age is available from any of the basins along the East Coast of India. The Lower Cretaceous Sequence in these basins has traditionally been termed as coastal Gondwana and Late Jurassic or Early Cretaceous age is indiscriminately assigned on the evidence of *Ptilophyllum* floral assemblage. Their reference to coastal Gondwana stems out because of supposed non-marine origin, so considered in view of megaflora, punctuated with some definite marine ammonite bearing horizons of Barremian age. However, their supposed Gondwana affinity has been a matter of dispute among workers (Rao & Venkatachala, 1971) and it would be appropriate for us to briefly discuss the concept of Gondwana and division of Upper Gondwana at this juncture.

Concept of Upper Gondwana

The term Gondwana, has been used rather indiscriminately as a serve-all-purpose term. It has been used formally or informally to serve variously as lithostratigraphic, biostratigraphic or chronostratigraphic unit besides being used with a palaeobiogeographic and palaeogeographic connotation. The literature is replete with terms like 'Gondwana Series or System', 'Gondwana Group or Supergroup', 'Gondwana Flora', 'Gondwanaland', *Glossopteris* bearing 'Lower Gondwana', *Ptilophyllum* bearing 'Upper Gondwana', *Dicroidium* bearing 'Middle Gondwana', 'Coastal Gondwana', marine intercalations in Gondwanas; Gondwana continent, 'Gondwana time', 'Gondwana Era', 'Gondwana Period', 'Gondwana sedimentation', 'Gondwana Facies', 'Peninsular Gondwana', 'Extra-peninsular

Gondwana', or simply as 'The Gondwana', or 'The Indian Gondwana'. This amply demonstrates the urgent need to review the status and use of the term Gondwana.

The typical Gondwana succession, documented by Feistmantel (1876) and subsequent workers, is developed in peninsular India in widely separated inland basins having their own depositional history. A critical perusal of available data suggests that in Damodar Koel Basin there is a thick Permian to Lower Triassic Sequence followed unconformably by Upper Triassic sediments; in Rajmahal Basin the thick Permian Coal Measures are unconformably overlain by ?Triassic sediments and are capped unconformably by Lower Cretaceous lava flows and plant-bearing Intertrappeans; the Son-Mahanadi Basin shows the development of thick Permo-Triassic succession; the South Rewa Basin shows development of Permian and Triassic sediments followed unconformably by plant-bearing Lower Cretaceous sediments; in the Satpura Basin a Permian and Triassic sequence is overlain unconformably by Lower Cretaceous sediment while in Pranhita-Godavari Basin an almost complete Permian-Triassic sequence occurs overlain unconformably by ?Lower Jurassic and Lower Cretaceous sediments.

Based primarily on floral evidences, 2-fold or 3-fold classification of Gondwana Sequence has been proposed. In two fold classification the line of division is placed above Panchet Formation, the Lower Gondwana being characterised by the Glossopteris Flora and the Upper Gondwana by the Ptilophyllum Flora. In the tripartite division, The Panchet and Mahadeva formations are included in the Middle Gondwana which is characterised by the *Dicroidium* 'Mixed Flora' as well as Triassic vertebrate fauna. The tripartite sub-division has even been fitted into the Standard Geologic Time Scale as Permian, Triassic and Jurassic-Lower Cretaceous, attributing chronostratigraphic status to the 3 floristic units despite the fact that time relationships of stratigraphic boundaries of these divisions are yet to be established firmly and precisely. It has been observed that diachronous nature of lithologic boundaries, stratigraphic breaks and floral changes in various intracratonic basins render intrabasinal biozonation and correlation extremely difficult and rule out the feasibility of any unified, all pervasive stratigraphic framework for Gondwana sequences (Mitra *et al.*, 1979).

Occurrence of clastic sequence of Lower Cretaceous age containing 'Ptilophyllum Flora', unconformably overlying the Permo-Triassic sequence is restricted to a few intracratonic basins. However, presence of *Ptilophyllum* Flora in East Coast and western India has led to the inclusion of these sequences in the Upper Gondwana despite the fact that no typical Permo-Triassic Gondwana facies is developed in these basins. If we take note of the fact that *Ptilophyllum* is also known from the upper part of Jhuran (Katrol) Formation in Kutch, should we not include Jhuran also in Upper Gondwana?

In fact, occurrence of *Ptilophyllum* Flora in a succession, implying thereby non-marine environment of deposition, has been the most important criterion for identification of Upper Gondwana units. However, evidences based on trace fossils, facies interpretation, foraminifera and dinocysts suggest that Lower Cretaceous clastic sequences of Kutch (Krishna *et al.*, 1983), Jaisalmer (Krishna, 1982; Garg, 1983) and East Coast (Rao & Venkatachala, 1971; unpublished data) are coastal marine deposits.

According to prevailing concept Rajmahal, Jabalpur and Umia plant beds are considered to comprise the Upper Gondwana Sequence, in an ascending order. These sequences are developed in geographically widely separated and genetically different basins and their presumed order of superposition is without any substantial stratigraphic evidence. Obviously the supposed Jurassic age of Rajmahal beds and occurrence of Aptian ammonites in Umia beds led to the construction of such sequence. Subsequent to the recovery of plant megafossils from East Coast sequences, the latter were also included in Upper Gondwana but were not sandwitched between the established succession despite the fact that Barremian ammonites were found in association with plant fossils (Mamgain *et al.*, 1973) and thus deserved a logical inclusion in Upper Gondwana hierarchy. However, with precise radiometric data of Rajmahal traps available recently, all Upper Gondwana units are infact most likely coeval belonging to Lower Cretaceous time span. Thus the Upper Gondwana should now be restricted to certain Lower Cretaceous plant bearing formations in peninsular India and questionably included East Coast and western Indian sequences of a comparable age. The inclusion of these coastal marine sequences in Upper Gondwana has been questioned by several authors in past (Pascoe, 1959; Rao & Venkatachala, 1971; Casshyap, 1977; Biswas, 1977, 1983; Krishna *et al.*, 1983; Krishna, 1983).

The lower boundary of the Gondwana Sequence is clearly defined lithologically in all intracratonic basins by glacial/glaciomarine beds with more or less precise time control. However, the upper boundary has never been defined lithologically and a perusal of literature suggests that very variable and stratigraphically untenable criteria have been used for the purpose. Perhaps youngest known occurrence of Ptilophyllum Flora is one of the criteria. Its uppermost association with datable ammonite fauna is used to fix the upper limit at Neocomian in East Coast sequences and Neocomian Aptian in western as well as in peninsular regions (Sastry *et al.*, 1979). Fixation of such a broad Neocomian-Aptian age, spread over a timespan of nearly 30 Ma, as the upper limit of any lithologic sequence only on floral-faunal evidence and without any lithological attributes, is stratigraphically not tenable. Thus the boundary is supposed to lie arbitrarily within continuous coastal marine sequences. It has also been suggested that Gondwana sedimentation in southern continents generally closes with extensive development of basic Volcanic flow (Krishsnan, 1968). Though considering Rajmahal traps as the coeval event in India, the upper limit of Gondwana succession was extended well up to Middle Cretaceous due to the occurrence of similar flora in younger sediments. It should, however, be noted that in Pranhita-Godavari Graben the most complete Gondwana Sequence is unconformably overlain by Deccan Traps and associated intertrappeans which are treated separately despite having distinctive floral attributes. The upper limit of the Gondwana Sequence is also related to the timing of separation of Indian Plate from the Gondwanaland Super-continent. None of these criteria, based on floral and plate tectonic context, however, helps to place a well defined lithological boundary.

In peninsular India, accumulation of continental sedimentary sequences in intracratonic basins continued during Permian and Triassic without any major breaks. Evidences are now forthcoming that this thick succession of Gondwana facies characterised by distinctive lithological and floral attributes is punctuated with minor marine incursions during Permian at more than one level even in basins which lay well within the craton (Venkatachala & Tiwari, 1988, this Volume). It should, however, be noted that shorelines that may be defined by the distribution of marine strata of Permian age, bear little or no relationship with future continental fragments of the Gondwanaland. Towards the close of Triassic or in Early Jurassic time, the long period of tectonic quiescence in the Gondwanaland craton come to an end and initial phases of disruption of the Supercontinent were initiated. Initiation of tectonic reactivation which foreshadowed the continental breakup was accompanied by widespread cessation of sedimentation in peninsular basins near the end of Triassic with the only possible exception in Pranhita-Godavari Graben where occurrence of broadly dated Liassic sequence is suggested. As a consequence of rifting associated with fragmentation of Gondwanaland, a narrow marine though opened up during Early Jurassic on the western margin between India—Madagascar and Africa which led to the origin of Kutch and Jaisalmer basins. Marine conditions are now known to have been established along the East Coast during the Early Cretaceous with the opening of another narrow marine seaway as a sequel to rifting between India and Antarctica-Australia, leading to the deposition of a thick clastic coastal marine sequence along emerging shorelines, followed by richly fossiliferous marine Upper Cretaceous sequences.

At about the same time during Early Cretaceous, the Rajmahal volcanic activity resulted in the outpouring of basaltic flows interspersed with plant bearing intertrappeans. After a long stratigraphic gap, sedimentation within peninsular India was resumed but was much restricted in distribution and confined to only a few intracratonic basins. There are compelling reasons to believe that the marginal marine basins differ conspicuously from these earlier continental basins and are undoubtedly the first geological structures which actually defined the margins/borders of the future continental fragments.

If coastal marine sequences of pericratonic basins are excluded from the Gondwana fold, the known Upper Gondwana sedimentary sequences are then restricted only to Satpura, Rewa and Pranhita-Godavari basins. It needs to be realised that deposition of these sequences took place under regional and inter-regional tectonic control entirely different from that prevailing during that deposition of typical Gondwana facies during Permian and Triassic. The Lower Cretaceous sedimentation event in intracratonic basins is most likely contemporaneous with the coeval trap activity of Rajmahal which has been related to the initial phases of disruption/breakup of the eastern part of the Gondwanaland supercontinent (Barron *et al.*, 1981). Consideration of this localized trap activity as the event marking close of Gondwana sedimentation in the entire Indian sub-continent based only on certain floral attributes without precise correlation potential would be stratigraphically untenable. The enormous time gap between the Permian-Triassic sequences and Rajmahal trap activity and coeval sedimentation event in peninsular India needs not to be overemphasised.

It is, therefore, suggested that Lower Cretaceous sequences in intracratonic peninsular basins and coastal marine pericratonic basins should be treated separately as these can not be included in any all-pervasive stratigraphic scheme in view of their different origin and sedimentation history. The typical Gondwana facies in peninsular India is better delimited by two most remarkable and wide spread events, the glaciomarine/glacial beds of Early Permian age at the base and the post-Triassic hiatus above the continental red sandstones in almost all the intracratonic basins. The Lower Cretaceous intracratonic sequences should be treated independently as are the other continental formations of a later period, e.g., Cuddalore Formation, Siwalik Group, etc. The Rajmahal Traps and Intertrappeans should be accorded an independent status as given to the Deccan Traps. Both are now regarded to be associated with different phases of rifting history of the Gondwanaland and are characterised by diagnostic floral associations. The Deccan trap activity straddles across the Cretaceous-Tertiary boundary and contemporaneous sedimentary sequences in CauveryBasin, Simla Himalaya and in South Shillong Plateau are all treated independently in Indian stratigraphy.

It is urged that the stratigraphic status of Gondwana sequences should be properly defined and strictly adhered to. It is better to treat Gondwana as a litho-stratigraphic unit of a higher rank (Krishnan, 1968; Sastry *et al.*, 1977) rather than a biostratigraphic unit for which floral zones should be applied.

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Biological evidence for better appreciation of the Indian Gondwana

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The Gondwana sequences in India are located in intraplate graben or semi graben basins along Narmada-Son-Damodar, Son-Mahanadi and Pranhita-Godavari ancient fracture zones. The basal glacial tillite of these sequences as also their diverse geological similarities, specially the coal-bearing lower part, was well and uniformly understood very widely even beyond the frontiers of India in distant Africa, South America, Australia, Madagascar and Antarctica which are now separated by several thousand kilometers of intervening land, sea or oceanic distances. Obviously, it did not take many years for the Gondwana as a stratigraphic unit of super-order to receive wide acceptance through the length and breadth of the southern hemisphere. With refinement in stratigraphic terminology over the last several decades and growing information about the dissimilarities which were not so evident in the beginning, the usage of the term Gondwana inspite of such spectacular and sound foundation as stratigraphic unit went into disuse in other Gondwanaland constituents in favour of local names while the term Gondwanaland as a supercontinent became firmly entrenched in global geological literature. Moreover, in view of the multidimensional nature of the Indian Gondwana stratigraphic units, viz., their physical, lithological, climatic, tectonic, stratigraphic, facies floral, faunal and other expressions added often to lack of their precise comprehension and usage in line with modern stratigraphic nomenclature there has crept in lot of misunderstanding, contradictions and confusions. An effort has been made to resolve problems concerning classification, definition, distribution, dating and correlation using biological evidences and geological information from the Indian Gondwana and coeval units.

Key-words—Stratigraphy, Palaeoclimate, Lithology, Biological evidence, Gondwana (India).

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साराँश

भारतीय गोंडवाना के परिबोधन हेतु जैविकीय प्रमाण

जय कृष्ण

भारत में गोंडवाना अनुक्रम नर्मदा-सोन-दामोदर, सोन-महानदी एवं प्रणहिता-गोदावरी के प्राचीन क्रमभंग मंडलों के संग-संग अन्तर-प्लेट द्रोणिका अथवा अर्ध-द्रोणिकाओं में विद्यमान हैं। इन अनुक्रमों का आधारी हिमानी टिलाइट, विशेषतया कोयला-धारक अधरि भाग, दूर-दूर तक समान रूप से फैला हुआ था यहाँ तक कि यह भारतीय सीमा से परे दूर स्थित अफ्रीका, दक्षिण अमेरिका, ऑस्ट्रेलिया, मेडागास्कर एवं अंटार्कटिका में भी विद्यमान था। निस्संदेह दक्षिणी गोलार्ध के देशों में गोंडवाना को एक स्तरिकीय इकाई के रूप में स्वीकार किए जाने में बहुत वर्ष नहीं लगे। पिछले कई दशकों में हुए स्तरिकीय अनुसंधान तथा विजातीयताओं के आधार पर एकस्तरिक इकाई के रूप में स्थानीय अन्य गोंडवाना सम्बन्धी देशों में अब प्रयोग नहीं किया जा रहा है जबकि ग्लोबीय भूवैज्ञानिक साहित्य में एक महा-महाद्वीप के रूप में 'गोंडवानाभूमि' शब्द का प्रयोग इतनी शीघ्रता से गभीरकृत हो गया। अपितु, भारतीय गोंडवाना स्तरिकीय इकाइयों की बहुआयामी प्रकृति अर्थात् उनकी भौतिक, शैलिकीय, जलवायवी, विवर्तनिक, स्तरिकीय, फ़ेसीज वनस्पतिजातीय, जीवजातीय आदि के कारण आधुनिक स्तरिकीय नामपद्धति के दृष्टिकोण से इनकी यथार्थ अवधारणा एवं प्रयोग में कुछ कमीयाँ रह गई हैं जिनके फलस्वरूप अनेक भ्रान्तियाँ, असंगतियाँ एवं भ्रम पैदा हो गये हैं। भारतीय गोंडवाना एवं समकालीन इकाईयों से उपलब्ध जैविकीय प्रमाण एवं भूवैज्ञानिक जानकारी का उपयोग करके वर्गीकरण, परिभाषा, वितरण, कालनिर्धारण एवं सहसम्बन्धन से सम्बन्धित समस्याओं को सुलझाने का प्रयास किया गया है।

Concepts, limits and extension of the Indian Gondwana
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MEDLICOTT understood and named the Gondwana Sequence in a lithostratigraphic sense, although, the modern three tier concept of stratigraphic units had then not developed. Moreover, not much distinction was then in vogue among litho-, bio- and chronostratigraphic units. In recent years, the Indian Gondwana Sequence and its subdivisions have been formalised as lithostratigraphic units (Gondwana Lexicon, Sastry *et al.*, 1977). The Gondwana stratigraphic units on account of similar origin of depositional basins, climate, tectonic control, source rocks, etc. exhibit exemplary similarity of lithology, coal content, facies, cyclicity, fauna, flora, etc. However, the most striking similarity catching the eyes of the Gondwana specialists has been the megafloral similarity. Over the decades, the megaflora has received prime consideration for identification, definition or inclusion of contemporary Indian stratigraphic units into Gondwana fold, for the principal reason that in the classical sense presence of rich land flora also guaranteed non-marine origin to the stratigraphic units which happened to be one of the major features of the Gondwana stratigraphic units as per original definition. As a consequence, all contemporary units enclosing the characteristic Gondwana floral elements whether fulfiling basic conceptual requirements of Gondwana by original definition or not were brought to the Gondwana fold as 'coastal/pericratonic/mixed/marine Gondwana, viz., Agglomeratic Formation of Kashmir, Ranjit Formation of Sikkim, Subansiri Formation of Assam, Umaria Formation of Madhya Pradesh, Umia Formation of Kachchh, Vemavaram Formation of East Coast, Kagbeni Formation of Nepal.

An analysis of Medlicott's original definition of Gondwana as stratigraphic unit, clearly projects forth their essential requisites as also many auxiliary features as follows:

Essential requisites of Gondwana lithostratigraphic units:

1. Lithological similarity in the form of substantial coal-bearing lower part in a glacial boulder/conglomerate, coal and red sand ascending sequence.
2. Preservation and/or deposition in intracratonic narrow linear faulted basins.
3. Largely fluvio-lacustrine depositional environment, except for the glacio-marine influence near the base.

Additional or auxiliary features of Gondwana lithostratigraphic units:

1. Presence of a large unconformable gap below the base of the Indian Gondwana Sequence from latest Precambrian (plus doubtful lowest Cambrian) to Upper Carboniferous (Table 4).
2. Absence of marine body fossils in view of their largely non-marine origin as per original definition except in the glacio-marine basal part.
3. Spectacular megafloral and land vertebrate similarity.
4. Cyclic fining upward sequences with sandstone shale and coal repetition in that order.
5. Northwest pointing palaeocurrent and palaeoslopes throughout the span of Gondwana Sequence.
6. Major unconformity above the Gondwana Sequence.
7. Presence of regional discontinuities within the sequence.

It is emphasised here that any of the above additional characteristics is no guarantee for recognition of lithostratigraphic units as Gondwana. However, these auxiliary characteristics can often be objectively used to resolve disputes and confusions about the Gondwana units. The only obligation or condition is that the auxiliary feature used must be in line with the essential requisites. The true Gondwana units need be recognised on the basis of their characteristic lithology (glaciogene boulder bed at the base followed by rich coal-bearing sediments with a cap of red sandstones) and other physical attributes observable by naked eyes in the field. Floral or faunal characteristics have no relevance in defining or recognising a lithostratigraphic unit.

Looking at the so-called 'Gondwana lithostratigraphic units' of Lesser Himalaya and many marginal areas in the west, north and east, it becomes amply clear that the said units do not exhibit the true Gondwana lithological characteristics. For example, the units like Agglomeratic Formation of Kashmir or Subansiri Formation of Assam or Badhaura Formation of Rajasthan or Umaria Formation of Madhya Pradesh are all largely neither rich in coal nor capped by red sandstones nor thick like the true Gondwana. In fact these units although containing the characteristic Lower Gondwana *Glossopteris* floral elements are otherwise products of different tectonic, stratigraphic and depositional setting, from that of true Gondwana as detailed in Tables 1 and 4. It is clear from the elaborate tables that the true Gondwana units are largely non-marine and differ markedly from, florally similar but, largely marine contemporaneous non-Gondwana stratigraphic units in origin of the basins, stratigraphic set-up below, above and within, lithology, faunal elements (both land and sea, micro or mega), trace fossils, physical structures, thickness, sedimentation cycles,

Table 1—Diverse similarities/differences between largely non-marine true Gondwana and largely marine non-Gondwana

TRUE GONDWANA UNITS	*OTHER FLORALLY SIMILAR CONTEMPORARY UNITS*			
	Lesser Himalaya	*High Himalaya*	*Western India*	*Indian East Coast*
1. Glacial conglomerate, at the base like Talchir Boulder Member	Glacial sediments mostly lacking, e.g., in Dogadda (U.P.)	Glacial sediments lacking, e.g., Productus Shale Formation in Spiti or Krinkrong Formation of Kumaon	Glacial sediments present, e.g., Bap Formation	Glacial sediments absent, e.g., Palar Formation
2. Rich coal content in the Permian part, e.g., Damuda Group or its equivalents	Thin carbonaceous shales or coal present but never very rich as in true Gondwana mostly Lower Permian only	Thin carbonaceous shales or coal present but never very rich	Thin carbonaceous shales or coal present but never rich, mostly Lower Permian only	Thin carbonaceous shales or coal present but never rich
3. Coal rich Permian part invariably followed by coal devoid red sandstones of Triassic age	Except for the lower part rest of the Permian and Triassic is unrepresented	Permian and Triassic nearly complete but without coal and red sandstones respectively	Permian and Triassic absent except Lower Permian excluding western Rajasthan where Triassic is known in subsurface	Permian and Triassic absent except for Lower Permian at Palar
4. Thickness of the sequence (Permian & Triassic) large, several thousand meters	Florally similar units always thin	Florally similar intercalations always very thin	Florally similar part very thin	Florally similar part very thin
5. Sedimentation mostly fluvio-lacustrine non-marine except for glacio-marine influence in Lower Permian	Sediments formed mostly by marine depositional processes	Sediments exclusively marine	Sediments exclusively largely marine	Sediments exclusively largely marine
6. Stratigraphic units marine fossil devoid except the basal lower Permian part	Units with marine fossils	Sediments with abundant marine fossils	Sediments with rich marine body or trace fossils	Sediments with rich marine body or trace fossils
7. Abundance of *Glossopteris* and *Dicroidium* floral elements respectively characterising the Permian and Triassic	*Glossopteris* floral elements present	Megaflora present only occassionally during Permian and Triassic	Glossopteris flora present in Lower Permian	
8. Exclusively found in inland, narrow linear faulted basins which originated from a wide regional tectonic event at the start of Permian, by reactivation of Precambrian weak fracture zones	Along narrow linear tracks near the tectonic contact of Lesser Himalaya and Outer Himalaya	Along the High Himalaya in basins existing since Precambrian	In Kutch the basin originated only near the base of the Triassic/Jurassic/ boundary	The basins except Palar originated only near the Jurassic/Cretaceous boundary
9. Palaeodrainage and palaeoslope in general converging towards the north west, west or north for the entire Permian and Triassic	Westerly or north westerly palaeoslopes	Northerly, north-westerly or westerly palaeoslopes	Westerly or north westerly palaeoslopes	South-easterly palaeocurrent and palaeoslopes during Lower Cretaceous

(*Contd.*)

10. "Upper Gondwana" of inland Gondwana basins included later into the Gondwana Sequence as per original definition of Medlicott characterised by *Ptilophyllum* megafloral elements in non-marine sediments at Jabalpur, Bansa, Rajmahal, etc. of Lower Cretaceous age unconformably overlying Triassic sandstones	Mostly absent or very rare unconformably over mostly Precambrian	Exclusively marine with abundance of marine body fossils and only locally containing *Ptilophyllum* floral elements conformably overlying Palaeozoic to Mesozoic (nearly continuous sequence)	Exclusively or largely marine with abundant marine trace fossils and also *Ptilophyllum* megafloral elements conformably overlying the Jurassic	Exclusively or largely marine with the marine body fossils only in thin bands but rich in *Ptilophyllum* megafloral elements unconformably overlying Precambrians mostly linear basins along the East Coast originating near the Jurassic/Cretaceous boundary

palaeodrainage/palaeoslope, palaeocurrent, etc. These largely marine non-Gondwana equivalents are found in the peninsular linear basins, Lesser Himalaya, High Himalaya, western India and East Coast. Unlike the Permian to Triassic span of the largely non-marine Gondwana Sequence these marine equivalents are largely of Lower Permian and Lower Cretaceous ages; major part of the Permian and entire Triassic is mostly absent.

These non-Gondwana units not only fail to qualify as true Gondwana units in terms of the essential physical requisites (lithology and others) but also fail in exhibiting most of the auxiliary true Gondwana features. It seems that the striking floral similarity of *Glossopteris* elements in Lower Permian and *Ptilophyllum* elements in Lower Cretaceous has been the only binding force for the erroneous admission of largely marine Lower Permian and Lower Cretaceous non-Gondwana stratigraphic units into their largely non-marine equivalents (Gondwana or others). It is also very necessary now to objectively analyse the relevance of land flora for differentiating a sedimentary rock formed by non-marine or marine depositional processes. At the same time it is also desirable to use other evidences like physical and biogenic structures specially in less obvious or disputed apparently marine body fossil devoid, land plant fossil rich, coarse clastic dominated units. We need to remind ourselves that coastal land plants or animals very characteristic of fluvio-lacustrine depositional systems could always be transported or drifted in a nearby marine paralic or allied depositional system. Thus similar floral characteristics could well be displayed both in non-marine and marine sediments. On the contrary, members of an exclusively marine fossil group like Brachiopoda or Cephalopoda can hardly ever be transported from a marine to non-marine depositional system. Thus presence of plant fossils in any stratigraphic unit can neither guarantee non-marine origin nor provide exclusive right for admission into Gondwana fold, while presence of marine body or trace fossils provides guarantee of marine depositional framework. Another crucial application of biogenic evidence is in deciphering the depositional processes of rock formation through the study of the traces made by animals while living. In recent years, many prolificly plant-bearing but marine body fossil devoid, coarse clastic dominating Lower Cretaceous stratigraphic sequences in western India, East Coast and elsewhere traditionally understood as non-marine have been interpreted as having been essentially formed by marine depositional processes (Bhalla, 1972; Baksi, 1977; Biswas, 1977; Casshyap, 1979; Krishna, 1983a, b, 1987; Krishna *et al.*, 1983; Bose *et al.*, 1986). Their *Ptilophyllum*-bearing floral similarity with inland non-marine units can not qualify them as non-marine. On the other hand, looking at the Gondwana lithostratigraphic units in the above perspective, their inland coal-bearing, largely non-marine conceptual characteristics by original definition become very obvious, hardly leaving any scope for confusion or misunderstanding in their recognition and distinction from contemporary largely marine non-Gondwana units. Adhering to the above understanding, it is here recommended that largely marine coal devoid/deficient sequences in Lesser Himalaya or marginal areas in the north, east and west of mostly Lower Permian and Lower Cretaceous, be excluded from the Gondwana fold. Also should be excluded the Lower Cretaceous non-marine stratigraphic units of Gondwana basins for neither being part of the Gondwana lithological or of tectonostratigraphic framework (Table 2).

DATING AND CORRELATION

Many of the Gondwana litho-and biostratigraphic units are mostly diachronous. The boundaries of such units, specially biostratigraphic

Table 2—Lower Cretaceous part of traditional Gondwana Sequence here recommended for exclusion from true Gondwana as per original definition of Gondwana Sequence by Medlicott.

PERIOD		REWA	GODAVARI	NARMADA	RAJMAHAL
CRETACEOUS (LR.)	ALB. APT.				
	UPP. NEOC.	BANSA FN.	GANGPUR FN. CHIKIALA FN.	JABALPUR FN.	RAJMAHAL FN.
	LR. NEOC.				
JURASSIC			? KOTA FN.↓		

units, are often ill-defined in measured lithocolumns. Also the lithological and floral changes are mostly not simultaneous, some time lag seems to be always involved. For example, the flora of the Karharbari Formation (Damuda Group) is similar to that of the underlying Talchir Group- much different from that of the overlying Damuda Group Many a times, the Gondwana lithostratigraphic unit names have also been used for biostratigraphic units with change of suffix, viz., Barakar Formation as Barakar 'Series/Stage'. This has led to lot of confusion. The Talchir/Damuda lithostratigraphic boundary is defined by a lithologic change at the base of Karharbari Formation, while the floral change is at the top of Karharbari Formation. If duplication of the same name with different suffix like Formation and Stage is ignored, the biostratigraphic boundary between Talchir and Damuda 'Series' becomes altogether different from the lithostratigraphic boundary between the two lithostratigraphic units. The flora of the Barakar 'Series/Stage' excludes the flora of the Karharbari Formation which is otherwise allied and included with the flora of the Talchir Group. This is greatly confusing and such usages must be abandoned. As a rule, florally based biostratigraphic units must be named after single taxon or assemblage of fossil taxa instead of locality names already employed and occupied for lithostratigraphic nomenclature. Similarly, usage of expressions like 'Rajmahal flora' or 'Barakar flora' must also be abandoned because that does not precisely clarify as to whether the flora refers to the same or different sequence of beds constituting the Rajmahal or Barakar Formation. Better would be to specify the range of a particular flora in the section. It is worth while to comment here on Banerjee's (this workshop) question as to whether Karharbari is a formation or biozone. Her answer is correct except that name of the megafloral or microfloral biozone has to be after fossil taxa instead of the duplication of Karharbari which is already occupied for lithostratigraphic unit.

Another significant aspect of most of the land plants and animals, mega- or micro-, is their relatively long ranging nature. As a consequence chronology and correlation of Gondwana litho- or bio-stratigraphic units have been far from satisfactory. Floral and vertebrate control on geological time is comparably either much less or little understood than control on time provided by many marine elements. Dating and correlation based on floral elements alone has led to gross absurdities specially with regard to dating of Gondwana lithostratigraphic units. For example, Rajmahal Formation used to be dated on the strength of *Ptilophyllum* and allied floral elements independently as Lower Jurassic since similar floral

Table 3—Revised lithostratigraphic scheme proposed here

PERIOD			DAMODAR	SONE-MAHANADI	REWA	GODAWARI	NARMADA	RAJMAHAL
GONDWANA	TRIASSIC	UPPER	MAHADEVA FN. (SUPRA PANCHET FN.)	SUPRA PANCHET FN.	PARSORA FN.	KOTA FN. DHARMARAM FN. MALERI FN.	BAGRA FN.	DABRAJPUR FN.
		MIDDLE				BHIMARAM FN. YERAPALLI FN.	DENWA FN.	
		LOWER	PANCHET FN.	PANCHET FN.			PACHMARHI FN.	
	PERMIAN	UPPER	RANIGANJ FN. BARREN MEASURES	RANIGANJ KAMTHI FN. B. MEASURES	PALI-TIKI FN.	KAMTHI FN. MANGLI FN.	BIJOURI FN. MOTUR FN.	RANIGANJ FN.
		LOWER	BARAKAR FN. KARHARBARI FN. TALCHIR FN.	BARAKAR FN. KARHAR BARI FN. TALCHIR FN.	BARAKAR FN. KARHAR BARI FN. TALCHIR FN.	BARAKAR FN. TALCHIR FN.	BARAKAR FN. TALCHIR FN.	BARAKAR FN. TALCHIR FN.

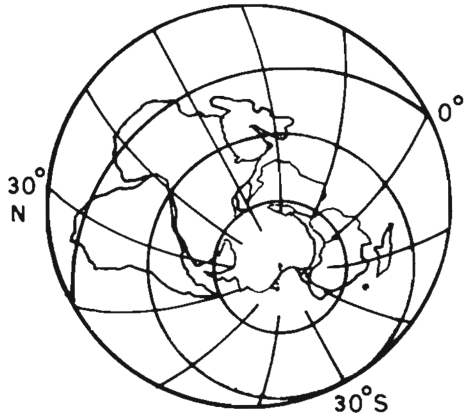
Table 4—Stratigraphic set-up in Gondwana and non-Gondwana basins (Cambrian to Lower Cretaceous)

Period	*Gondwana Basins*	*Non-Gondwana Basins*			
		Lesser Himalaya	*Tethys Himalaya*	*Western India*	*East Coast*
Cretaceous (Lower)	Rajmahal Trap	Mostly stratigr. gap or marine	Marine	Marine	Marine
Jurassic	Stratigr. gap			Marine	
Triassic	Non-Marine without coal	Stratigr. gap	Nearly continuous Marine		Stratigr. gap
Permian	Coal bearing	Marine		Stratigr. gap	Locally marine at Palar
Carboniferous Cambrian	Stratigr. gap	Stratigr. gap			Stratigr. gap

elements were found in the Lower Jurassic of England. This was in utter disregard of the fact that *Ptilophyllum* and allied floral elements range from Triassic to Cretaceous. In a recent lexicon on Indian Gondwana (Sastry *et al.*, 1977) essentially Lower Cretaceous lithostratigraphic units have been dated from Upper Triassic to late Lower Cretaceous by different palaeobotanists. To a present day stratigrapher, such plant fossil based vague/broad independent dating amounts to a futile exercise completely lacking any time control in real sense. Another example of a different kind is the similarity of flora of Lathi Formation of Lower Jurassic age and Lower Cretaceous units which age wise should have been entirely different (Lexicon, 1977) like Rajmahal Formation. The non-marine sequences of Gondwana grabens involving a time span of about 180 million years (including the disputed Lower Cretaceous) have been ambitiously split into 13 floral assemblage (Shah *et al.*, 1971) with an average assemblage duration of about 15 million years without actual correlation with universal marine stages and zones. This was entirely unrealistic as proved later. The ones referred to Jurassic turned out to be Cretaceous, the ones referred to as successive turned out to be coeval, the variation in floral content being possibly due to climatic and geographic considerations. The whole exercise seems to have been based on circular argument/presumption like that Rajmahal, Jabalpur and Umia units are in ascending stratigraphic order. Nobody thought that the said units being located far apart do not show any such stratigraphic relationship. Thus such a difficult situation warrants dating of the plant-bearing units only with the help of short ranging index fossils or assemblages based on precise data on taxa ranges. Moreover, the Gondwana stratigraphic units lacking index taxa can be better dated by relating them to their marine contemporary non-Gondwana units, both being products of the same tectonic framework. Wherever possible indirect temporal control provided by marine index fossils from the underlying or overlying units in contemporary pericratonic units needs also be made use of. In addition, absolute radiometric dates can be obtained for igneous rocks, stratigraphically/structurally related to Gondwana units. Fission-Track dating of apatite and glauconite bearing rocks has shown excellent promise in recent years (Radiometric Dating Laboratory, Birbal Sahni Institute of Palaeobotany). Microfloral elements over the years have shown increasing potential in terms of their quantitative distribution through time, still the boundaries resulting from such statistical counts of microfloral elements are difficult to correlate with standard universally applicable inter and intra stage time divisions. There is grave allround need to investigate quantitative aspects of microfloral assemblages in marine units for the integration of the two. The best bets for Permian and Triassic appear to be Salt Range and Kashmir for such integration, since these areas, compared to High Himalaya sequences, had similar climatic framework specially temperature conditions as those of true Gondwana units. For the Lower Cretaceous or the Jurassic/Cretaceous boundary Kachchh appears to be a good proposition for relating to non-marine Lower Cretaceous of Gondwana grabens, although recommended here for exclusion from true Gondwana units for various other reasons.

TECTONO-STRATIGRAPHIC FRAMEWORK

It is generally agreed that several early Precambrian orogenies in succession expressed in the form of the Dharwar, Aravalli, Eastern Ghat, Satpura and Delhi fold belts assimilated to constitute the basement of the Indian plateform, the Indian Plate for a long duration from Upper Precambrian to close of Cretaceous did not again witness mountain

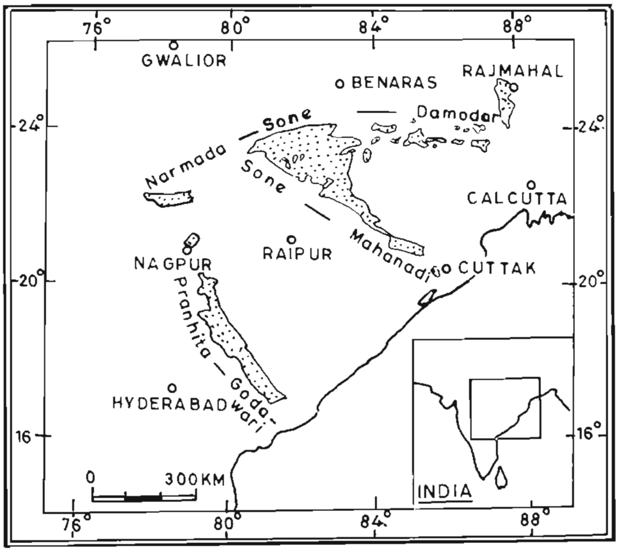


Text-figure 1—Gondwanaland at the start of Gondwana sedimentation at Carboniferous/Permian boundary.

building activity. On the other hand vertical epierogenic tectonics dominated the scene in this part of the world. Thus the span of time during which Gondwana sequences were deposited, the Indian subcontinent witnessed several major or significant vertical tectonic events. These events invariably resulted in reactivation of the major ancient basement fracture zones, prior, concomitant and subsequent to the Gondwana sedimentation. Thus reactivation along ancient fracture zones seems to have played crucial role not only in the deposition and preservation of Gondwana sequences but also has been responsible for the creation of some linear faulted basins or closure of some other such basins irrespective of their marine or non-marine nature and intra or pericratonic location. These events affected the marine and non-marine basins simultaneously in similar or different manner. These reactivation events have proved very helpful in understanding the time relationship of stratigraphic events from one basin to the other, towards formulation of a sort of composite stratigraphy and correlation. Some stratigraphers have termed this composite understanding of geological events as Event Stratigraphy. The major tectonic events of Late Palaeozoic and Mesozoic of relevance to Gondwana sedimentation and dated mostly on fossil evidence can be summarised as follows:

Basal Permian (Tatarian/Asselian Boundary) event (Text-figs 3, 4)—This was a very widely spread event reflected specially in the form of vertical tectonics in the Indian subcontinent. This event also signalled the initiation of protorifting/fracturing, etc. which later during Late Mesozoic caused the break-up of Gondwanaland. Before this event peninsular India, or better to say the major part of the Indian Plate was beyond the reach of the Tethys Sea from Middle Cambrian to close of Carboniferous except the High Himalaya belt undergoing almost continuous sedimentation since Late Precambrian. The basal Permian event caused reactivation in Bikaner and Jaisalmer, along narrow linear zones in Lesser Himalaya, along Narmada-Son-Damodar, Pranhita-Godavari and Son-Mahanadi fracture zones, and Palar Basin along East Coast. Several linear faulted basins were created in these areas. Except for few such basins which were in the heart of the Indian Plate the rest of the basins were transgressed by the Tethys on account of a global sea level rise. The basins located in the high relief region in the heart of India and in general beyond the reach of the Tethys witnessed non-marine sedimentation. Central and southeast India being relatively closer to the spread of polar ice caps had in its basins sedimentation influenced by glacial processes resulting in glaciogene tillite sedimentaries. A significant aspect of the Permian intracratonic true Gondwana units is the increasing physical, biological and chemical evidence of marine influence up to stratigraphically as high as Barren Measures or equivalents or even younger Raniganj Formation (Chaudhri, 1988 Venkatachala & Tiwari, 1988, this Volume). Most of these influences in a largely non-marine framework are probably of transient nature but still suggesting the possibility of occasional rare marine connection from Narmada to Palar through the Godavari Graben. Localised mild fracturing in Palar parallel to East Coast and incursion of very shallow paralic sea from north-east can not be altogether ruled out.

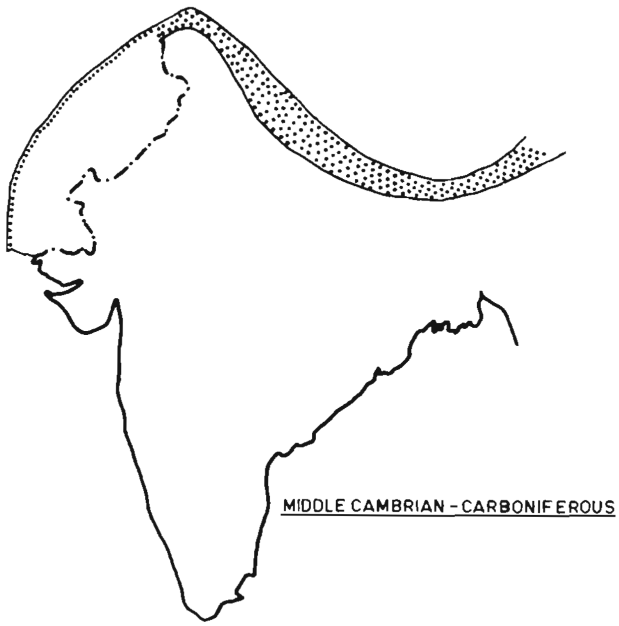
The dating of the event as Lower Permian or Asselian is based on wide spread occurrence of *Eurydesma-Conularia-Deltopecten-Productus* assemblage of Upper Asselian age besides fusulinid foraminifera, conodonts, etc. in High Himalaya. The lowest stratigraphic units of largely non-marine Gondwana sequences in all the Gondwana basins lately have provided increasing transient marine influence (Venkatachala & Tiwari, 1988 this Volume). In Gondwana grabens the basal sediments are glaciogenic. Unlike the traditional thinking that these basal beds also include some part of latest Carboniferous, no definite evidence until yet has come forth in support of a partly Upper Carboniferous age. It appears that most of the Indian literature indicating Upper Carboniferous age of the basal beds is possibly due to transfer of previously held Upper Carboniferous sediments in the Permian stratotype of USSR into basal Permian on the basis of their faunal affinity specially that of fusulinid foraminifera much after the original establishment of the Permian. Partly Upper Carboniferous age is also not supported by the present relatively refined evidence of uppermost Carboniferous representing a stratigraphic gap in all the High Himalaya areas otherwise having relatively complete upper Palaeozoic sequences. Since, the start of sedimentation in Gondwana grabens is genetically tied to the same tectonic event causing wide spread Asselian transgressive sedimentation, the origin of Gondwana grabens should not be older. Recently, Mitra (1988, this Volume) has reported substantial thickness of the sediments in an exploratory borehole in the neighbourhood of Daltonganj from even below the glaciogene conglomeratic sediments which in turn underlie the Asselian *Eurydesma-Conularia*-bearing beds, thus suggesting older than Asselian (possibly uppermost Carboniferous) age for the sediments underlying the glaciogene conglomerate. In this context probably lowest Asselian age for these lowest beds should be a better proposition in view of the Upper Carboniferous being a regressive phase in all High Himalaya basins. Such substantial thickness of clastic sediments can well be deposited in a relatively small span of time within Asselian itself. Thus the lower age limit of the Gondwana Sequence when critically evaluated in context of the regional expression in High Himalaya marine basins is basal Permian on account of the stratigraphic framework in the entire region, both being products of the same wide regional tectonic event. Florally Talchir Shale Member is characterized by radial monosaccates and absence of saccates or colpates (Bharadwaj, 1987). It is suggested to study the microflora in better dated Lower Permian of High Himalaya, for example Spiti and Kumaon areas for refining the temporal resolution of the microfloral elements. Comparison and correlation with Salt Range Lower Permian may be still better in view of similar cold subpolar climatic conditions (Singh, 1987) in Salt Range as well as Gondwana basins. Flora of Karharbari Formation shows near absence of Varitriletes and zonate Triletes while *Sulcatisporites* dominates the assemblage. According to Bharadwaj (1987) Talchir Formation and Karharbari Formation are Artinskian in age which needs confirmation by comparing the flora from these stratigraphic units with that from otherwise firmly dated Artinskian sediments. According to Shah and Dickins (1987) Talchir Formation is Asselian, Badhaura Formation is Sakmarian and Agglomeratic Formation is Asselian/Sakmarian. Shah and Dickins (1987) have suggested a break between Nilawan Group (=Speckled Sandstone Formation) and the overlying Productus Limestone Formation at the base of Amb Member in Salt Range equivalent to Sakmarian and Artinskian stages. They have dated Panjal Trap Formation and intercalated plant-bearing beds as mostly Kungurian and Ufimian (=Wordian) while Zewan Formation is assigned to Kazanian and Tatarian. According to Shah and Dickins (1987) there



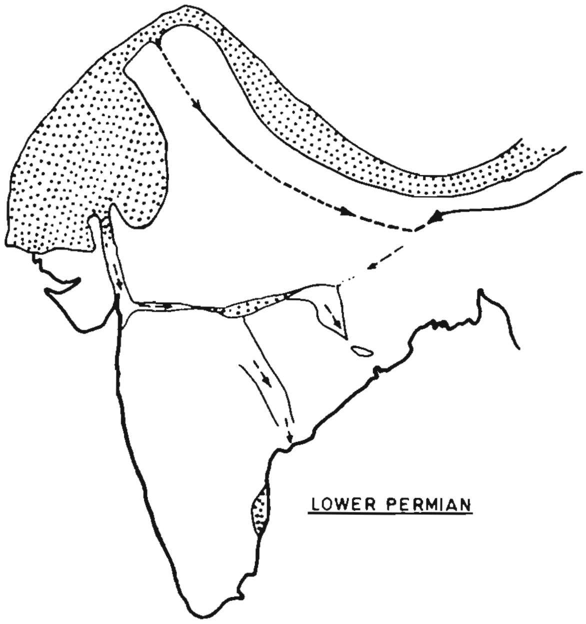
Text-figure 2—Distribution of Gondwana formations (fluvial intracratonic) in India.

is another depositional break between Amb Member and overlying Virgal Formation. In addition they indicate a drastic climatic change from cold to warm between Asselian and Kungurian suggesting a climatic event. A similar climatic event has been envisaged between Talchir and Barakar Formation with a stratigraphic break at the base of Barakar Formation. On the strength of climatic event alone Amb Member can be broadly correlated with Barakar Formation. In terms of stratigraphic setting Chidru Member can be broadly correlated with Raniganj Formation. It will be worthwhile to compare the flora of Chidru Formation of Upper Permian age with that of the Raniganj Formation of Gondwana grabens. Recently, Balme (1970) has precisioned Permian/Triassic boundary to the best, possible extent in terms of floral assemblages in Pakistan comparing and correlating it with Australia, Madagascar, South Africa (*see* Wright & Askin, 1987). This line of approach appears to be promising in integrating the successive floral assemblages from Talchir and Damuda groups with standard universally understood stages and zones.

Permian/Triassic Boundary event (Text-fig. 5)—Excluding at least one intra- Permian event near (the Lower/Middle Permian), the next major event supposedly occurred near the Permian/Triassic boundary. All along the High Himalaya, there is evidence of lowest Triassic (*Otoceras woodwardi* Zone of basal Schythian Stage) transgressive over the latest Permian sediments. In Gondwana grabens, the event marks the cessation of coal formation suggesting a significant climatic change from lush forest vegetation favouring climate (warm humid temperate with intermittent rainfall) to dry and arid



Text-figure 3



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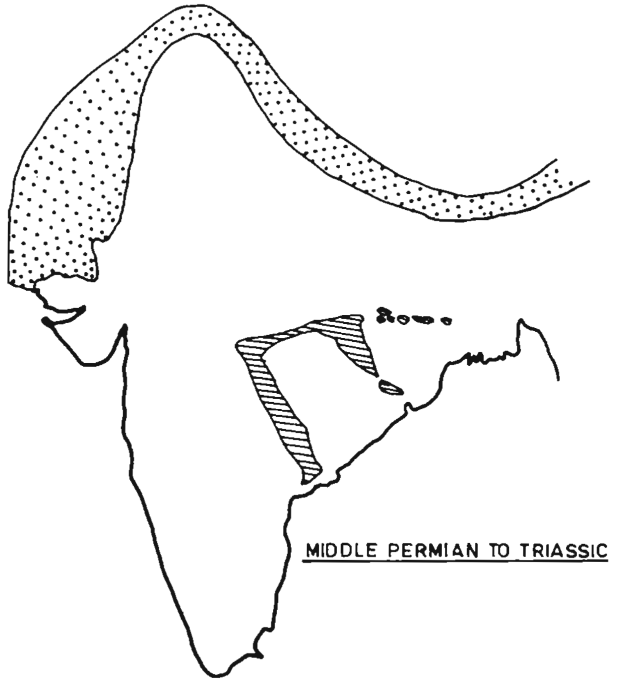

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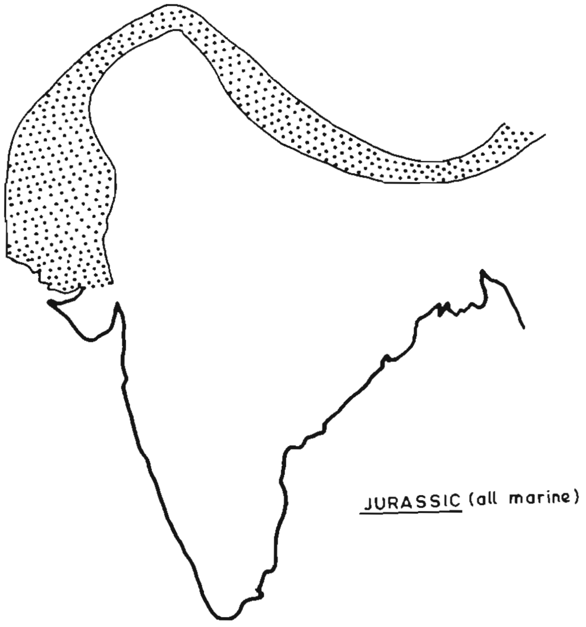
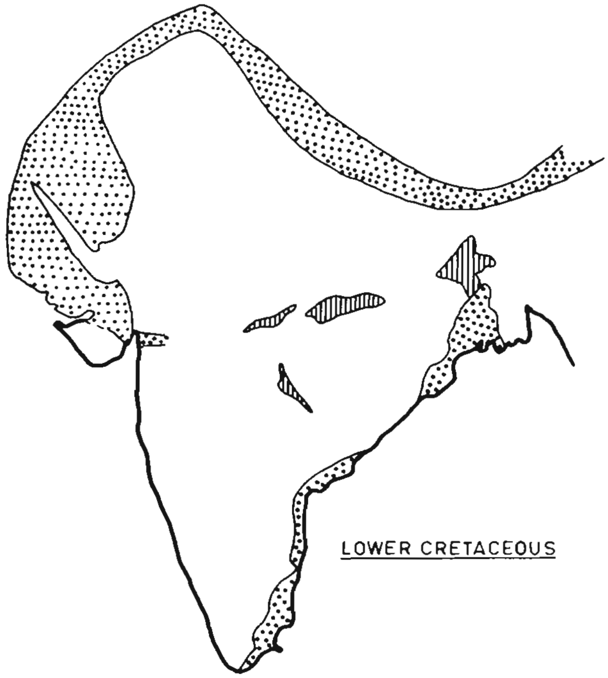


Text-figure 6

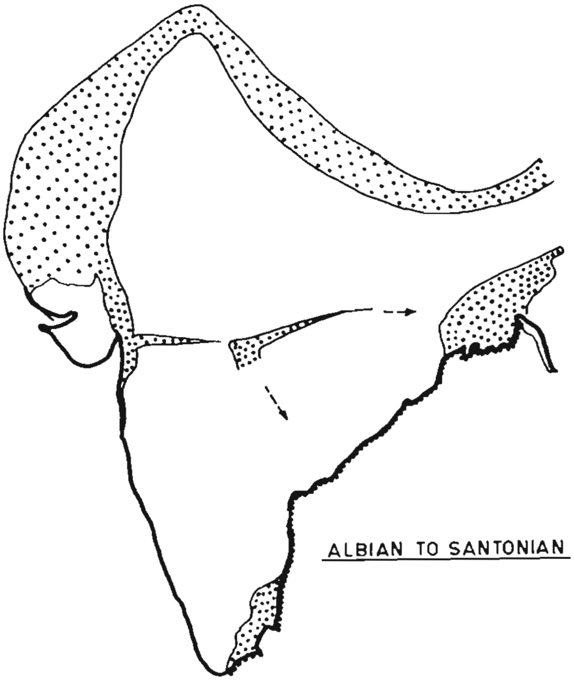
Text-figures 3 to 6—Postulated schematic distribution of land and sea along with fresh water Gondwana sediments in the Indian subcontinent during Middle Cambrian to Carboniferous, Lower Permian, Middle Permian to Triassic and Jurassic.

conditions detrimental for preservation of plants and their transformation into coal (Chandra & Chandra, 1988, this Volume). Microflorally the Triassic is dominated by Trilete spores while in marine High Himalaya basins there is noticed increasing dominance of ammonoids. Megaflorally there is only gradual transition from dominance of *Glossopteris* to that of *Dicroidium* and allied elements. The microfloral transition has been dated within or above the Dorashamian (=Tatarian) Stage of Permian near the Permian/Triassic boundary in Salt Range (Balme, 1970).

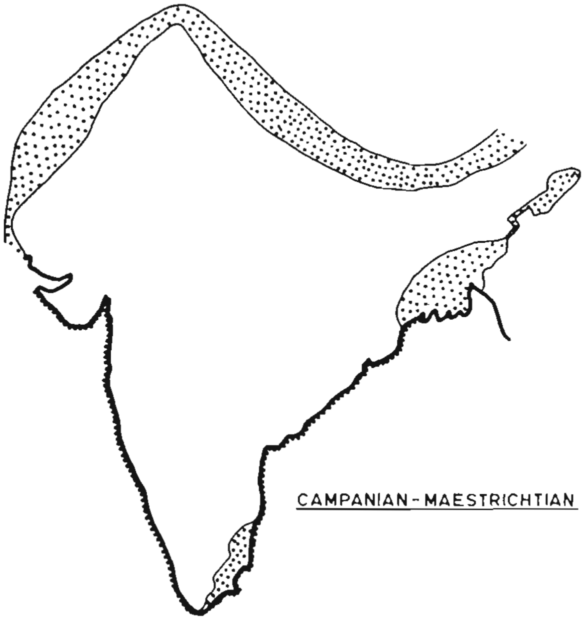
Mitra (1987) has suggested a compressional tectonic event above Panchet Formation and below



Text-figure 7



Text-figure 8

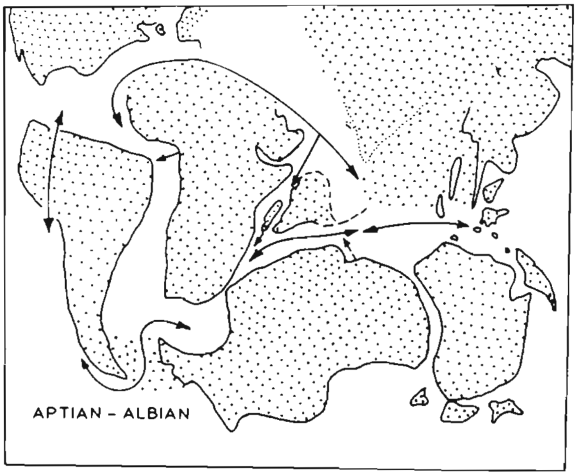


Text-figure 9

Text-figures 7 to 9—Postulated schematic distribution of land and sea along with fresh water Gondwana sediments in the Indian subcontinent during Lower Cretaceous, Albian to Santonian and during Campanian to Maestrichtian.

Supra-Panchet Formation in Pranhita-Godavari and Son-Damodar basins which is also marked by regional discontinuity. It appears that either this event was very localised or of very light intensity because there is no evidence of such a compressional event from any High Himalaya area having a nearly continuous sequence of Triassic sediments. More logical explanation is provided by Bose and Mukhopadhyay (1985) about these folds being second order domes and basins along the flanks of buried ridges somewhat similar to Jurassic domes in Kachchh and for such second order bending a compressional event is not necessary. However, there is some evidence of mountain building activity during Triassic at marginal areas of Gondwanaland as Ellsworth mountain of Antarctica, Cape fold belt of South Africa and Sierra fold belt of Argentina.

Regarding the dating of Triassic Gondwana stratigraphic units the situation is not very

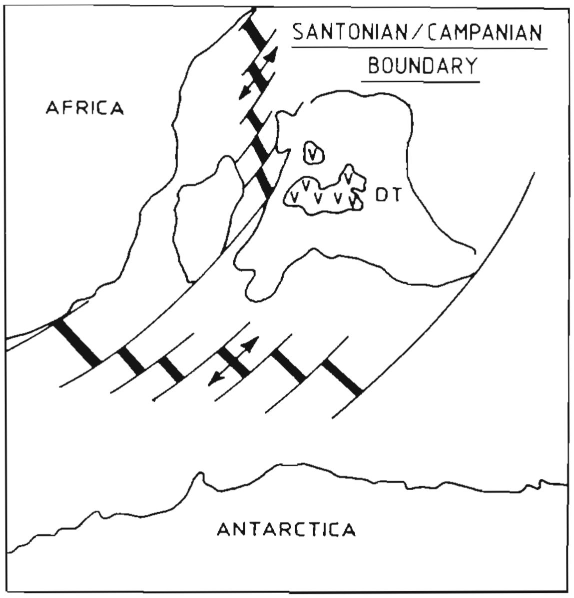


Text-figure 10—Palaeogbeographic reconstruction showing marine faunal dispersal routes to and from India in the southern hemisphere during Aptian-Albian.

satisfactory. Panchet Formation has been dated as Lower Triassic or Scythian mainly on the evidence of *Lystrosaurus* of Lower Triassic age in many Gondwanaland continents. There is regional discontinuity of unequal duration between Panchet Formation and Supra-Panchet or their equivalents in different Gondwana grabens. Sometimes this discontinuity sets in at the close of Damuda Group or its Raniganj Formation, however, the duration of this regional disconformity is not precisely known in different basins. Most of the Supra-Panchet Triassic stratigraphic units have been mostly dated as Upper Triassic or within Upper Triassic except for Pranhita-Godavari Basin where the stratigraphic gap is possibly of the shortest duration among different Gondwana grabens. In Pranhita-Godavari Valley there is succession of five lithostratigraphic units as indicated in Table 1. These supposedly range from Middle to latest Triassic or even doubtful lowest Jurassic. The topmost lithostratigraphic unit of this sequence is Kota Formation with significant fresh-water fish fauna. Among the fishes the genera *Paradapedium* and *Tetragonolepis* suggest Liassic affinity, while another fish *Lepidotes* is similar to another European Liassic species (Jain, 1987). Sauropod dinosaur remains and mammals also known from Kota Formation are also assigned Lower Jurassic age. It is significant to note that many of these faunal elements range from Rhaetian to Liassic, however, precise taxa ranges in different parts of Gondwanaland are not yet available. In context of the regional tectono-stratigraphic framework the Triassic Gondwana stratigraphic units are not known to extend into Lower Jurassic with exception of Kota Formation which prompts to favour a Rhaetian top for Kota Formation rather than Liassic until a definite conclusive evidence is available in favour of Liassic which, however, can not be altogether ruled out. There is evidence of the Tethys having advanced as for south as Jaisalmer in India (subsurface Triassic evidence in Dutta, 1983). During the Triassic, like the Permian the integration of Triassic microflora with that from better dated marine units of high Himalaya should prove rewarding. The best propositions in this aspect would be Kashmir, Spiti or Kumaon sections.

Triassic/Jurassic Boundary event (Text-fig. 6)—This is a significant event with different expressions in intracratonic Gondwana basins and pericratonic non-Gondwana areas. This event marks the origin of Kachchh Basin in western India parallel to Narmada and Delhi fracture trends as suggested by Rhaetian/Liassic microflora from the Banni exploratory well (Koshal, 1983). It also marks the closure of sedimentation in all the Gondwana basins. It is worth pointing out here that for a long time it was anticipated that the whole Jurassic Period is represented in the largely non-marine nearly continuous basal Permian to Lower Cretaceous Gondwana Sequence. Most of the 'Upper Gondwana' stratigraphic units were also for a long time assigned Lower, Middle and Upper Jurassic ages. There are still many specialists, including some palaeobotanists, who have yet not reconciled with the otherwise widely accepted absence of nearly the entire Jurassic in the Gondwana grabens based on precision dating of the floral assemblages rather indirectly from underlying and overlying units in contemporary marine sequences of western India and East Coast. There is also evidence of two generations of post Supra-Panchet Mesozoic faults in Gondwana basins. These faults are mostly high angled faults often cutting the earlier system of faults. One generation of these faults has affected Supra-Panchet sediments but predates igneous intrusives related to Rajmahal volcanic activity of Aptian-Albian being in turn affected by them. This is here broadly dated with Triassic/Jurassic or Jurassic/Cretaceous boundary events. The younger generation of Mesozoic faults are related to Deccan volcanic activity. There is evidence of gradual sea level rise during the Jurassic on a global scale. Since Jurassic is unrepresented in the Gondwana basins possibly the reactivation of the Gondwana basins resulted in their uplift to cause closure of sedimentation. On the northern margin of the Indian Plate the South Tibet micro-block seems to have separated from the parent Indian Gondwana Plate and rifted northward as suggested by sudden decrease of post-Triassic floral similarity between different basins on the Indian Plate and South Tibet, in contrast to strong earlier similarity of the Glossopteris Flora between India and South Tibet.

Jurassic/Cretaceous Boundary event (Text-fig. 7)—It needs to be understood that although the Gondwana sedimentation by and large had almost closed near the Triassic/Jurassic boundary, the Gondwana superplate as a tectonic and geographic unit remained compositely united as a single unit except for separation of micro plate on its northern margin throughout the Permian to Middle or even latest Cretaceous, when came forth the first evidence of the somewhat north-south running shallow arm of the Tethys reaching across to the southeast Pacific along the East and South African Coast (Krishna, 1983b, 1987). The evidence is in the form of sudden increase in topmost Tithonian (Micracanthum Zone) ammonoid faunal similarity between the Indo-East-African marine faunal province areas (western India, High Himalaya, East Africa, Madagascar, etc.) and southeast Pacific marine faunal province areas (Argentina, Peru, Mexico). This suddenly increased similarity is in contrast to low similarity for nearly the whole of Middle and Upper Jurassic until topmost Tithonian between the said faunal province areas (Krishna, 1987). This suggests that there has been sudden dispersal of topmost Tithonian South American ammonoid genera, viz., *Corongoceras* Spath, *Substeuroceras* Spath, *Argentiniceras* Spath, *Groebericeras* Leanza, etc. to either Kachchh or Himalaya (Krishna, 1983a; and unpublished work) due to the creation of shallow marine corridor from western India to South America. It may be particularly emphasised here that presence of such a shallow strait of the Tethys Sea almost midway between western and eastern part of Gondwanaland does not mean continental separation of the two by creation of new ocean floor which in fact took place distinctly later in latest Cretaceous. I have revised my own earlier views (Krishna, 1983a) on the continental separation between East Africa and India during Aptian-Albian in favour of later separation near the base of Campanian related to Deccan volcanic activity. The revision is in better agreement not only with the ammonoid and other shallow marine faunal distribution (Krishna, 1983a, 1987) but also with regard to general similarities of Indian and Madagascar vertebrate remains with those of Africa, Arabia, Europe, North and South America (Sahni *et al.*, 1987) allowing dispersal of land animals until high up in the Cretaceous which could not have been otherwise possible, in case the Indian Plate has had separated from Africa in Aptian-Albian. The revised model does not envisage separation of India from Gondwanaland (at least its western half) until the beginning of Campanian. Near the Jurassic/Cretaceous boundary also originated linear

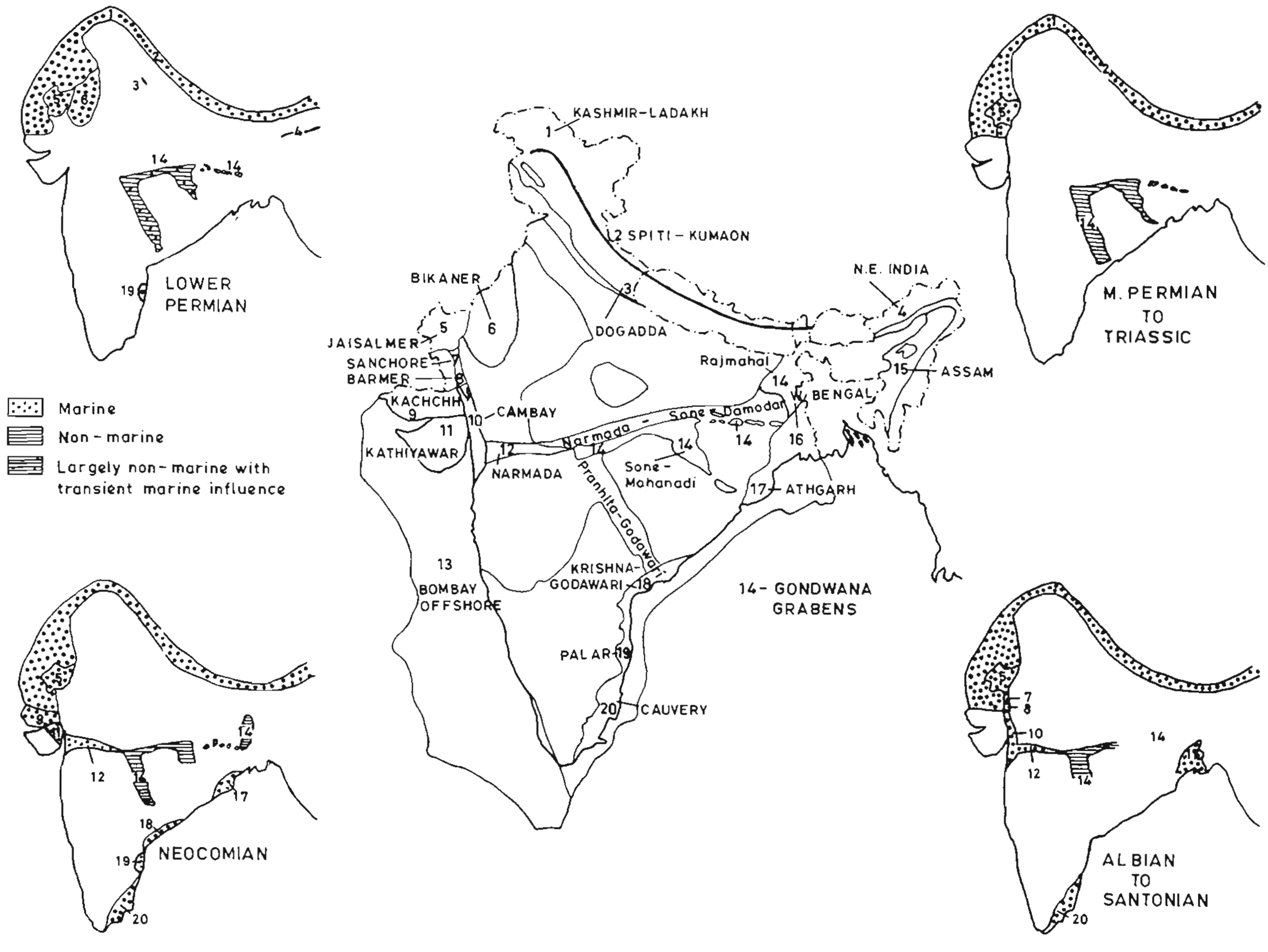


Text-figure 11—Complete isolation of the Indian Plate from its immediate neighbouring component plates of the Gondwanaland (Africa in the west and Antarctica in south or east) with continental separation/creation of new ocean floor (proto-Indian ocean) both in the west and south or east of India.

clastic basins of Kathiawar and several basins on the East Coast between Athgarh (Orissa) to Cauvery (southern Tamil Nadu). There is also witnessed renewal of non-marine sedimentation in only few of the Gondwana grabens (Narmada, Rajmahal, Rewa & Godavari) as a consequence of a fresh reactivation unconformably overlying the Late Triassic with the stratigraphic gap spanning nearly through the whole of Jurassic. The Jurassic/Cretaceous event also indicates reversal of palaeocurrents and palaeodrainage towards southeast in contrast to north-west and west during Permian and Triassic. Most of these Lower Cretaceous clastic sequences in marginal areas of India either in the east or west are sedimentologically and lithologically alike largely lacking in recognisable marine body fossils while being prolificly plant-bearing except for thin marine fossil-bearing rather localised intercalations. Several such basins arose parallel to the East Coast almost in a row from Orissa to southernmost Tamil Nadu suggesting the creation of a shallow corridor type of sea between India and eastern half of Gondwanaland near the Jurassic/Cretaceous boundary almost in a similar fashion to that in the west from India to South America. The precise dating of these Lower Cretaceous sequences whether in the west or east has been very difficult because the mega- and micro-flora as also benthonic micro-fauna are long ranging. The occasional control provided by thin marine body fossil-bearing horizons (particularly the ammonoids) has allowed indirect dating of the largely plant fossil-bearing sequences. Such broad ages of the mega- micro-floral assemblages also in turn help the dating of similar plant-bearing non-marine sequences in the intraplate Gondwana grabens. The spore and pollen assemblages from different late Upper Jurassic to Lower Cretaceous sequences of India reflect microfloral continuity near the Jurassic/Cretaceous boundary. The microflora of Vemavaram Formation of Upper Neocomian age is relatively closer to that of Katrol Formation (Tithonian) than that of Bhuj Member (post Lower Albian). The contention of many (Srivastava, 1983; and others) that the first appearance of *Cicatricosisporites australiensis* marks the Jurassic/Cretaceous boundary, does not seem to be correct in at least Indian context. In fact, the first appearance of this taxon takes place distinctly much after the Jurassic/Cretaceous time boundary as defined and understood throughout the Tethyan realm between Jaccobi and Grandis ammonoid zones. The Jurassic/Cretaceous boundary as suggested by Singh and Venkatachala (1988, this Volume) on the basis of palynomorphs between 'Jhuran' and 'Bhuj Formation' is distinctly younger than the Jurassic/Cretaceous boundary much more precisely demarcated by ammonoids within the basal Umia glauconitic/oolitic ammonitiferous Member in western Kachchh (unpublished discovery of Berriasian index ammonoid *Argentiniceras*). Similar discrepancy still continues between the age of 'Bhuj Formation' (=Umia Formation excluding the basal member) based on palynomorphs and the other based on ammonoids. Inter-area correlation of successive palynological assemblages likewise shows discrepancies with that of the correlations based on ammonoids. So also continues the fallacy of elementally quite different palynofloral assemblages of Kachchh, Jaisalmer, Rajmahal, Jabalpur and East Coast areas indirectly dated and also now widely accepted as being coeval of Neocomian. Caution needs to be observed before correlating definite ammonoid based Albian sediments with Neocomian *M. antarcticus* zone and likewise definite Lower Albian with Upper Albian-Cenomanian *Triporoletes reticulatus* Zone in Cauvery Basin. The need of the hour is to integrate the palynofloral data with ammonoid based dates wherever available in surface sections and later to extend such control to subsurface or non-marine surface sections which would permit differentiation of individual stages. It does not look satisfying to refer the entire sequence qualitatively as Lower Cretaceous. Better control on time is available from scarce ammonoids like Barremian *Holcodiscus*, from Krishna Basin in Vemavaram Formation, *Puzosia* of Lower Albian in Dalmiapuram Formation of Cauvery Basin, *Pascoeites* and *Gymnoplites* of Hauterivian-Barremian age from Sivaganga and Budavada units which should be taken help of in formulating further differentiation of Lower Cretaceous palynoflora. Efforts of integration of ammonoid and dinocysts (Garg *et al.*, unpublished work) has been quite rewarding and presents a good example in this direction which needs to be extended to other areas and microfloral groups.

Aptian-Albian event (Text-figs 8, 10)—This tectonic event has found diverse expressions in different parts of India. Several basins for example Kachchh, Jaisalmer, Kathiawar and all the East Coast basins, except for Cauvery, indicate wide-spread regression or withdrawl of the sea. However, in a few areas along ancient fractures zones like Narmada, Barmer, Sanchore, Bengal and Cambay because of reactivation linear basins were created. Cauvery Basin, on the other hand, witnessed continuous sedimentation until the close of Cretaceous with a strong transgressive impulse in Upper Albian. The Narmada and Cauvery sequences although being contemporary for a considerable length of time have little in common in terms of marine faunas particularly the ammonoids suggesting existence of separate shallow seas in western India (Tethys) and southern India (Indo-Pacific sea). Sahni (1983) has suggested the possibility of very short duration transiant marine connection between the said areas via Pranhita-Godavari ancient fracture during the early Upper Cretaceous. This activity is also expressed in terms of wide-spread volcanic activity in eastern India (Bihar, Bengal, Assam, etc.) as Rajmahal Traps and Sylhet Traps radiometrically dated around 100 to 110 million years. It is suggested here that continental separation of India from eastern part of Gondwanaland in the eastern sector is related to this volcanic activity. Early continental separation and isolation of Indian Plate as suggested in most of the plate tectonic reconstructions is found inconsistent with the distribution of both shallow, marine and land vertebrates in Madagascar, India, Africa and Laurasia. This event was also responsible for closure of sedimentation in Gondwana inland grabens in Narmada, Rewa, Rajmahal and Godavari valleys.

Santonian/Campanian Boundary event (Text-figs 9, 11)—This marks another phase of reactivation resulting in the origin of Assam Basin and closure of Narmada and Jaisalmer basins. This is the time around which began the Deccan volcanic outpouring which is related with the continental separation of India from Madagascar and Africa. Sahni *et al.* (1987) have explained the presence of dinosaurian remains



Text-figure 12—Origin of different sedimentary basins of India, intracratonic or pericratonic, marine or non-marine from basal Permian to basal Campanian.

of *Laplatosaurus, Antarctosaurus* and *Titanosaurus* in the Upper Cretaceous Lameta Formation which are otherwise known from the Upper Cretaceous of Central and South America, Madagascar, Africa and western Europe by free intermigration through a Cretaceous island are system located between the Asian Plate and the drifting Indian Plate. It could also be alternatively and rather better explained by the separation of India, Madagascar and Africa near the beginning of Campanian altogether disallowing complete isolation of India until that time. It is also interesting to note the contrast in the distribution of ammonoid family Kossmaticeratidae between pre- and post-Campanian durations of Cretaceous in various Gondwana component plates (Macellari, 1987). The family appeared in Turonian in India, spread to Indian southeast Coast, Madagascar and Africa during Coniacian, later in Santonian to New Zealand. The family rapidly diversified in Early Campanian in Madagascar and Africa. Being adapted to cold water conditions, became restricted during Campanian and Maestrichtian in the most southerly shallow seas of South America, Antarctica, New Zealand, etc. The sudden marked decrease of the family from Campanian onwards and its rapid diversity in the polar vicinity in Antarctica, South America and New Zealand appears related to continental separation and movement apart of India Madagascar and Africa from one another as also from the rest of the Gondwanaland comprising South America, Antarctica, New Zealand and Australia which for some more geological time remained united during the Cenozoic. At the same time, this also supports that India did not separate from the Gondwanaland until the Lower Campanian.

EXTENT OF INDIAN GONDWANA

In light of available data, modern concepts of depositional framework and the current international and national rules of stratigraphic nomenclature, we should strive towards uniform acceptance of the original concept of the Indian Gondwana as lithostratigraphic units although permitting qualified careful usage otherwise in plate tectonic and/or biogeographic context. The usage, however, in plate tectonic and biogeographic context, will show variation in extent with geological time.

The problem of extent reduces to resolving the age old dispute as to whether the present graben geometry is pre- or post-Gondwana which is quite complex in itself since there have been several reactivations along the said zones from time to time. Individual Gondwana basins invariably exhibit a single or only a few of the several different depositional facies developing in a composite fluvial system. The component facies represented in a fluvial complex are proximal, medial and distal, while usually the component preserved is medial one. Proximal or distal or both components are found removed by weathering and erosion. and the preserved component is found abruptly truncated by either of the faulted margins clearly suggesting the post Gondwana nature of either or both marginal faults (Casshyap, 1979; Ghosh & Upadhyay, 1985; Niyogi, 1987; Mitra, 1987; Ahmad & Ahmad, 1979). In recent years, presence of Gondwana sediments has been encountered or interpreted in subsurface wells or through geophysical investigations concealed under Deccan Traps in the west and under Bihar, Bengal, and Assam alluvium in the east suggesting much wider original extent of the Gondwana Sequence.

It is yet not clear as to whether these subsurface Gondwana sediments are also similarly fault bounded along some or other ancient fracture zones. It is also important to remember that many marine sequences of Lower Permian and post-Triassic ages are also preserved in fault bounded graben basins in western India and East Coast with all the component facies of the complex depositional system not always present. Thus partial preservation and part removal both laterally and vertically are inherent consequential aspects of vertical or epierogenic tectonics both in intracratonic and pericratonic areas. While accepting greater original extent than the now preserved, it looks rather premature to accept the original depositional extent of Indian Gondwana units as very extensive large scale platform cover like as advocated by Mitra (1987). It looks more realistic that the Gondwana basins originated as a result of a transient short-lived wide regional initial protorifting/fracturing at the base of Permian signalling the initiation of the long episodic weak zone reactivation history in India and neighbourhood which also resulted in creation of pericratonic largely marine non-Gondwana basins. The Gondwana basins indicate transient marine influences in pre-Raniganj Permian time while rest of the Permian and Triassic is exclusively non-marine although the whole span of Gondwana sedimentation is punctuated with regional discontinuities. Huge thickness and regional discontinuities clearly suggest repetitive reactivation of faults during the course of sedimentation. Truncated preservation, however, is due to post-Gondwana Late Mesozoic or Cenozoic tectonics. The presence of rather huge stable oregons (positive blocks) in between the Gondwana basins seems to have controlled the overall geodynamic evolution of the Indian Plate and these positive blocks should not have favoured continuous interconnected expanse of Gondwana Sequence from central and eastern India to Assam in the northeast. Biological evidence present in the Gondwana and contemporary non-Gondwana units also supports the above observations and interpretations about the geographic extent of the true Gondwana lithostratigraphic sequences as defined in this paper.

It is generally accepted today that Gondwanaland as a composite superplate did not come into existence at the base of Permian but existed as such right at least since late Precambrian. The Gondwana superplate existed from Late Precambrian to at least latest Cretaceous, i.e., until the time of complete continental separation of the Indian Plate from other Gondwanaland component plates. It may also be remembered that during the long Late Precambrian to latest Cretaceous duration, epierogeny dominated tectonics affected the present day Indian subcontinent which presumably allowed in succession separation of some micro block or micro-plate at its northern boundary accreting later to the Asian Plate. Thus the Indian Gondwanic Plate witnessed regular episodic truncation at its northern boundary with obvious reduction in size each time until the accretion of the entire left over Indian Plate (inclusive of South Tibet during Permian, and reduced to present High Himalaya belt) to Asia during Early Palaeogene.

The salient points that have emerged forth by way of conclusion can by summarised as follows:

1. The Indian Gondwana are unmistakably lithostratigraphic units. The term, however, can also be used in geographic context with proper clarification, e.g., the Indian Gondwana Plate or Indian Gondwana floral or faunal province at any particular geologic time. The Gondwanaland existed at least right since Late Precambrian and continued as a single geographic unit until Upper Cretaceous, i.e., for a much longer duration than the Indian Gondwana Sequence.
2. The Indian Gondwana (lithostratigraphic units) need be recognised exclusively on the basis of

their characteristic lithological set-up, i.e., glaciogene base dominantly coal-bearing lower part, and sandstones in ascending order, the coal-bearing feature being their most important lithological expression.

3. Plant fossils should not be used for recognition of Indian Gondwana.
4. Indian Gondwana exclusively located along intracratonic grabens are largely non-marine except for glaciomarine influence in the early part by original definition of Medlicott and should not be confused or mixed up with their pericratonic or otherwise largely marine non-Gondwana contemporary units having different lithological, depositional and tectonostratigraphic framework.
5. Geographic extent of the Indian Gondwana is confined to the intracratonic graben basins, the east-west running Narmada-Son-Damodar belt and northwest-southeast running Pranhita-Godavari and Son-Mahanadi belts. On the contrary extent of the Indian Gondwana Plate was inclusive of the South Tibet during Permian, but delimited by the High Himalaya or Tibetan Himalaya during the Mesozoic prior to complete continental separation during late Upper Cretaceous both in the east and west from the rest of the Gondwanaland comprising South America, Antarctica and Australia. At this time India got not only separated from Africa but also bereft of Madagascar (genetically related to Deccan volcanic activity) and the present Indian East and West Coasts took shape with creation of Bombay Off-shore Basin in the west and Assam Basin in the east.

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Volcanism in Gondwanas

C. Tripathi

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In India the Lower Permian event is marked by a major volcanic episode in the Himalayan belt and rift faulting in the Peninsula which gave rise to various Gondwana basins. The Lower Cretaceous major volcanic episode represented by the Rajmahal Trap represents the termination of Gondwana sedimentation. Lower Permian volcanism is represented by the Panjal Volcanics in Kashmir Basin and its equivalent, the Volcanics in Spiti-Zanskar Basin and Rotung Volcanics (Abor Volcanics) in Arunachal Pradesh. In Karakoram Basin of Ladakh, volcanism is associated with Changtash and Aqtash formations of Permian age.

The Agglomeratic Slates in Kashmir are supposed to have originated as explosive volcanism in the form of pyroclastics which was followed later by flows of the Panjal Volcanics represented by subaqueous and subaerial tholeiitic basalt with occasional basaltic, andesitic and rhyolitic volcanics. The Agglomeratic slates are divided into two divisions, the Lower Diamictite and the Upper Pyroclastic. At the base of the Pyroclastic division and at the top of the Diamictite division, we get Eurydesma-Deltopecten Fauna of Lower Permian age. It is thus established that volcanism in Kashmir, Spiti-Zanskar and Ladakh is restricted to Lower Permian only. The sills and dykes associated in the underlying sequence in Syringothyris Limestone and Fenestella Shale in Kashmir, in Lipak and Po formations in Spiti are related to this volcanism.

Key-words—Gondwana, Volcanism, Peninsular India.

C. Tripathi, Geological Survey of India, Lucknow, India.

सारांश

गोंडवाना में ज्वालामुखीयता

सी० त्रिपाठी

भारत में अधरि परमी घटना हिमालयी पट्टी में प्रधान ज्वालामुखीय घटनाओं तथा प्रायद्वीप में रिफ्ट भ्रंशों से अभिलक्षणित है जिसके फलस्वरूप विभिन्न गोंडवाना द्रोणीयों का जन्म हुआ है। राजमहल ट्रैप से निरूपित अधरि क्रीटेशी कालीन प्रधान ज्वालामुखीय गोंडवाना घटना गोंडवाना अवसादन की समाप्ति इंगित करती है। अधरि परमी ज्वालामुखीयता काश्मीर द्रोणी में पंजाल ज्वालामुखी तथा इसके समतुल्य अरुणाचल प्रदेश में रोटंग ज्वालामुखी (अबोर) एवं स्पिती जन्सकार द्रोणी में ज्वालामुखीयों से निरूपित है। लद्दाख की कराकोरम द्रोणी में ज्वालामुखीयता परमी आयु की चाँगटाश एवं अकटाश शैल-समूहों से सम्बद्ध है। काश्मीर में संज्वालाश्म स्लेटें ज्वलखंडाश्मीयों के रूप में विस्फोटी ज्वालामुखीयता के कारण बनी हैं और इसके पश्चात् वहाँ पंजाल ज्वालामुखी का लावा बहा है। संज्वालाश्म स्लेटें अधरि डायामिक्टाइट तथा उपरि पायरोक्लास्टी नामक दो मंडलों में विभक्त की गई हैं। पायरोक्लास्टी मंडल के आधार पर तथा डायामिक्टाइट मंडल के ऊपर अधरि परमी आयु का **यूरीडेस्मा-डेल्टोपेक्टॅन** जीवजात मिलता है। इस प्रकार यह स्पष्ट हो गया है कि काश्मीर, स्पिती-जन्सकार एवं लद्दाख में ज्वालामुखीयता अधरि परमी कल्प तक ही सीमित है। स्पिती में लिपाक एवं पो शैल-समूहों तथा काश्मीर में साइरिंगोथाइरिस चूनाश्मों और फ़ेनेस्टॅल्ला शैलों में अधरिशायी अनुक्रम में सहयुक्त सिल एवं डाइक इसी ज्वालामुखीयता से सम्बद्ध हैं।

GONDWANA of the Indian Peninsula comprises a thick sequence of continental sediments laid down in glacial, fluvial and locally, lacustrine environments. They occur in several isolated linear belts or grabens roughly in consonance with the present day river valleys. We have thus, Gondwana basins in Damodar Graben, Son-Mahanadi Graben and the Godavari Graben. The orientation of the

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different grabens is such that they converge towards a main line, the Son-Narbada Lineament. The Damodar Graben is aligned almost to east-west, Godavari Graben to NNW-SSE while the Mahanadi Graben has an intermediate alignment from NW-SE. Thus their linearity, convergence of their trend to a common line, the Son-Narbada Lineament and the trend of the peripheral basins across the coastal trend are some of the features that link their sedimentation to pre-existing structures. Their east-west linearity is ridge trend. The linearity of the Godavari Gondwana basins is due to the sedimentation having taken place along a north-westerly drainage accentuated by subsequent faulting along the northern margin. This convergence of the trend of Gondwana basins might be ascribed to the great horst-like Maikala ranges in conjunction with the Satpura ranges and the Netarhat-Mainpat Plateau acting as a broad watershed. It is of interest to mention here the "Great Bhandara Triangle" of Late Durga Shankar Bhattacharji (1932) of the Geological Survey of India is located not far from this region whence all the great trends of the Indian Shield, the Dharwarian trend (N-S), the Eastern Ghat trend (NE-SW), the Mahanadi trend (NW-SE) and the Satpura trend ENE-WSW meet to form a triangle.

The structural framework of the peninsular Gondwana is, thus, reflected by boundary and marginal cross-faults which owe their origin to the reactivation of the pre-existing fault zones within the Precambrian basement. The intrabasinal cross-faults are mostly antithetic in nature and came into existence to cope up with the tensile stress of the sediments. Two such trends are most common, the NW-SE trend and the NE-SW or E-W trend. In the Godavari Graben, NW-SE trend dominates. In the Pench-Kanhan Basin also, the same trend continues. In the Son-Mahanadi Graben, the southern part that is the Talchir and Sohagpur Basin shows a NW-SE trend whereas the Singrauli Basin, the northernmost one as expected, being in the vicinity of the Satpura Range, E-W trending faults coupled with N-S trending faults dominate over the NW-SE trending ones. In the Damodar Graben, the westernmost Karanpura Basin, the E-W trending faults dominate over the N-S trending ones but the NW-SE trending faults occur in significant amount. In Bokaro Basin, NW-SE, NE-SW to NS trending faults occur almost evenly. In Jharia Basin NW-SE trending faults dominate over others whereas in the Raniganj Basin, NE-SW trending faults dominate over others. In the distant Rajmahal Basin, N-S trending faults occur predominantly. In Garo Hills, the Singrimari Basin shows the predominance of NNW-SSE to NW-SE trending faults over the NE-SE trending ones. These faults occur as simple linear structures or as a zone. The analysis of these fractures in different basins points out to a very interesting fact, that is this main NW-SW fault trend is roughly parallel to the main structural elements of the Indian Plate and one would to be tempted to draw this conclusion that this broad similarity is the result of identical events that pervaded the shield as well as the adjoining ocean (De, 1977). It is in fact a complex set of *en echelon*, NE-SE trending spreading zones and NW-SW to EW fracture zones. The Gondwana grabens on the Indian Craton and the inferred deep zones of extension along the synthetic as well as antithetic fault pattern have probably been formed due to the extension of the crustal slab as a result of tensional forces that operated perpendicular to the graben axis. Similar phenomena were most probably responsible in the formation of the structure of the Indian Ocean floor. The extension of the crustal slab in both areas might have taken place during the time of drifting of the Indian Plate in an anticlockwise rotation with probable centre of location around the Pamir Knot (De, 1977). As the Gondwana tectonism started at least in the Late Sakmarian, it is reasonable to believe that the spreading zones as well as compensatory fracture zone of the Indian ocean are also of the same age. It is interesting to note that these fracture zones get reactivated intermittently, once in Jurassic, then in Tertiary. Some of the faults in the Damodar Basin have been ascribed to Tertiary by Auden. The marine transgression in Permian on the Indian Shield indicates a Permian fragmentation of the Indian Plate. The linearity of these occurrences on the Indian Shield might also point out to fracturing along well-pronounced zones. The creation of the Indian Ocean also began at this time with the downwarping between India and East Africa that approached Malagasy, then not far south as now.

It is believed that faulting or subsidence along the margins or within the basins did not start before the deposition of the Karharbari Formation. Krishnan (1982) assigned a general Lower to Upper Triassic age to the major faults in the Godwana basins. Major faulting was followed by ultrabasic intrusions which in turn were followed by the emplacement of dolerite dykes. The dolorite dykes have displaced the mica-peridotite dykes proving conclusively that the former are older than the latter. The alignment of basic dykes of the Deccan Trap along definite fault planes indicates that faulting preceded the outpouring of the Rajmahal/Deccan lavas. The mica-peridotite dykes are actually a lamprophyre or phlogopite rich ultrabasic rock comprising olivine, calcite, phlogopite, leucite and apatite. It has no great thickness (1-2 m at the most) but whenever it has penetrated through the coal-seams, it has burnt them to *Jhama*, because of its high fluidity and high temperature. It occurs both as sills and dykes. They have a preference for the coal-seams and invade them at their interface with sandstones. They occur in Damodar Valley and the Lower Gondwana of the Eastern Himalaya. They are younger than the basal Panchet and invade strata older than the *Lystrosaurus*-bearing red and crimson shales. In the Eastern Himalaya, they occur below the *Estheria*-bearing shales. Hence, in all probability, they mark the Permian-Triassic boundary, in any case occurring not later than Triassic.

The Rajmahal Traps were emplaced around 100 million years ago. The type area of this phase of stupendous volcanic activity is the Rajmahal Hills located at the head of the Ganga delta near the border of Bihar and Bengal. The traps comprise 450-600 m of basaltic lava flows with intercalated carbonaceous shales and clays and porcellanites. Some of the flows resemble pitchstone in composition. The intertrappean sediments between the lower four or five flows contain plant remains, fossil wood and Unionids. *Thinnfeldia, Ptilophyllum, Williamsonia* and *Nipanioxylon* are some of the principal plant forms. They are Lower Cretaceous in age, coeval with the Cimmerian orogeny.

The Deccan basalts, even after 65 million years of weathering, occupy an area of 32,000 sq km in Maharashtra, Gujarat, Madhya Pradesh and parts of Deccan. Northwards they extend up to Orai in Jalaun, Belgaum in south, Rajmahendri in SE and Kutch or Sind in NW. Eastwards, they extend up to Ranchi Plateau. They are product of fissure eruption that is they erupted through long narrow fissures or cracks in the earth's crust. They are mostly horizontal except some flows on the west coast which show dips seawards. They are punctuated with many layers of intertrappeans throughout their thickness. They have been divided into following groups :

Upper Traps—Bombay and Kathiawar with numerous intertrappean beds and dykes

Middle Traps—Central India, Malwa with numerous ash beds and almost devoid of intertrappeans in upper part with profusion of dykes

Lower Traps—Madhya Pradesh and east of it up to Ranchi Plateau, with intertrappeans and ash beds.

Compositionally, they are plateau basalts comprising dolerite and basalt but in Girnar and Osham Hills, lamprophyre, limburgite, monchiquite, olivine gabbro, porphyrite, andesite, monzonite, nepheline syenite, granophyre, rhyolite, obsidian, pitchstone, etc. are also found. The carbonatite of Jhabua District, Madhya Pradesh needs a special mention in this context. The Deccan Volcanics roughly coincide with the rapid spreading of the ninety-east ridge of the Indian Ocean (66-62 million years). It has now been found that flows of Deccan volcanic episode occur associated with the Jurassic-Cretaceous rocks in Kathiawar region, which make them coeval with the Rajmahal Volcanics. The author has recently located volcanic rocks in the basal part of the Niniyur Stage of Tiruchirapalli Cretaceous. It is therefore certain that Deccan volcanic activity is as old as Jurassic-Cretaceous and may span well into Tertiary. This would indicate a protracted process of extrusion-intrusion in the Indian Craton. The Sylhet Traps and Abor Traps (Rotung Volcanics) and the Khasi Hill carbonatite occurrences and the eastern ophiolite belts of Mishmi-Naga-Patkai ranges are all coeval. The same holds good for the Indus Suture ophiolite zone of the Western Himalaya.

In the extra-peninsular or the Himalayan region, the Gondwana sediments occur as paralic facies where plant-bearing horizons containing Gondwanic floral elements are found intercalated with marine sedimentary sequence with contemporaneous volcanism. Here again, they are developed into two distinct tectonostratigraphic domains, namely, the Lesser Himalayan belt and the Tethyan Himalayan belt. In the Lesser Himalaya, Gondwana of Permian age shows more or less a continuous development from Arunachal Pradesh to central Nepal, tectonically emplaced between the Mio-Plio-Pleistocene Siwalik molasse and the Precambrian metasediments. Gondwana plant-bearing horizons of Jurassic-Cretaceous age are known from Tansen area in central Nepal. Volcanics in some form or the other occur throughout, associated with the Permian rocks and later in Jurassic and or Cretaceous and even Tertiary.

In the Tethyan Himalaya, Permian Gondwana are developed intermittently from one end of the Himalaya to the other. In the west, they occur in Salt Range and Kashmir. In the east and northeast they occur in Sikkim and Bhutan. Jurassic-Cretaceous Gondwana are also known from Salt Range in Pakistan, Ladakh in India, Thakkhola in central Nepal and Lingshi in Bhutan.

In Arunachal Pradesh, the Abor Volcanics comprise a thick sequence of volcanic flows and sedimentary beds in Siang District. Similar volcanic rocks found in Ranga Valley, Subansiri District are considered equivalent. Besides, lamprophyre dykes of the minette type are also found included in marine Gondwana sediments of Ranga Valley. The Abor Volcanics were found to contain Tertiary plants in the Intertrappean beds associated with them. To accommodate this age span, it was split into two, the Rotung Volcanics and the Geku Volcanics. The former was assigned a Permian age while the latter, a Tertiary age. Later workers found that all these volcanics belong to Tertiary suite only. If that be so, and it is quite likely that it is so, the flows associated with the Gondwana sediments in various sectors of Arunachal Pradesh Himalaya, would belong to the Permian phase of extrusion. Quite distinct from these flows and dykes the occurrence of minette-like lamprophyre dykes associated with the Ranga Valley Gondwana point out to their similarity with those of the Darjeeling Hill area and the peninsular Gondwana. On the basis of their association with the Permian strata in Arunachal Pradesh I venture to date them as Late Permian or Early Triassic.

The Abor Traps of the type area in Siang District comprise predominantly pahoehoe and "a-a" type lavas, agglomerates and volcaniclastic breccia with possibly pillow lavas also. In Siang District, a consanguinous assemblage of basaltic to andesitic flows, silicic tuffs, lapillis, agglomerates, volcinistic sediments, basaltic sills and dykes occur. They are of Permian age. A thick succession of basaltic to andesitic flows occurs in the Ranga Valley in various Lower Gondwana horizons. In short, seven of the Abor Volcanics of the type area are included entirely in the Tertiary. There are volcanics in plentiful associated with the Permian strata. The serpentinite rocks associated with the Tidding Limestone in Mishmi Hills are the northern extension of the ophiolite belt of Naga-Patkai ranges.

The likes of Abor Traps are found in the Kashmir area in the form of Panjal Traps, entirely Permian in age. They comprise massive or amygdaloidal, spilitic pillow lavas and tuff breccia. Nakazawa and Kapoor point out to the oceanic character of these lavas and the basement being continental, they must have been formed by rifting. They began as explosive type of volcanism in the form of Agglomeratic slates, which culminated into thick bedded flows of andesitic to basaltic composition. Acid varieties such as rhyolite, dacite and trachyte are also found in them. The dolerite dykes associated with older rocks in Spiti Zanskar (Lipak and Po group of rocks), Karakoram Basin of Ladakh (Changtash and Aqtash formations) are all of Permian age. Volcanism is extensive in the Permian and Jurassic Gondwana of the intervening area particularly Nepal. Thus, Permian and Jurassic are two important phases of volcanic episode in the Himalaya besides the Cretaceous-Tertiary volcanism.

To sum up, the igneous activity in the Gondwana of peninsular India is represented by dykes and sills of dolerite, lamprophyres and basalt as in the coalfields of Raniganj, Jharia, Giridih, Jainti, Bokaro and Karanpura. Although the age of these intrusives/ effusives is uncertain, they are considered to form spatial link between the traps of Rajmahal and the lavas of the Deccan. In most of the cases these dykes and sills are associated with marginal faults of the Gondwana basins. In contrast, volcanism in Upper Palaeozoic in the Himalayas is mostly synsedimentational.

The volcanism associated with the fragmentation of the Gondwanaland is thus, a consequence of distensional tectonics. This distension was genetically related to the movement of the Gondwanic continents towards the northern continent. Evidences for distensional tectonics in other Gondwanic continents are also common. The Parana Basin of Brazil shows marginal faults which are associated with basic volcanics. Extensive volcanic activity associated with Early Mesozoic sediments occurs in Argentina and Patagonia. The volcanic activity associated with the Karroo basins of Africa is considered to have initiated in the Triassic. In the central Transantarctic Mountains of Antarctica. Early to Late Permian volcanogenic sediments lie within the coal-measures. Permian Radok conglomerate of NE Antarctica is overlain by the Bainmedart Coal Measures and the entire sequence is intruded by lamprophyre and basic volcanics.

This distensional tectonics which was the immediate cause of impending break-up of the Gondwanaland was accompanied by voluminous eruption of tholeiitic flood basalts and emplacement of dolerite sills and dykes. In certain cases this igneous activity predates actual fragmentation and drifting of the Gondwanic continents. The Ferrar Supergroup tholeiites in the Transantarctic Mountains are considered to have been emplaced at about 179 ± 7 Ma. The Stormberg Volcanics in the Karroo Basin is a continental tholeiitic sequence of Jurassic flood basalts and dolerites. Radiometric age determinations indicate Early and Middle Jurassic age for these volcanics. In the Australian part of the Gondwanaland, Early to Late Triassic calcalkaline volcanics are restricted only to areas of tectonism along the borderlands of the New Zealand Geo-syncline. In Late Triassic/Early Jurassic, the basic continental magmas began to increase relative to calcalkaline volcanism in eastern Australia. The basic magmatism reached a peak by Middle Jurassic in the Australian mainland. Main fragmentation and drifting of the continental parts in these areas which started in Late Cretaceous/Early Eocene was accompanied mainly by basic volcanism.

Thus the Ferrar Supergroup of tholeiites (in Transantarctic Mountains), Karroo magmatism (in Africa), calcalkaline and basic magmatism in the Australian region, the basic volcanism of Parana Basin (in South America), the Abor/Rajmahal, Sylhet and Deccan traps as well as the intrusives in coalfields of the peninsular India were the major volcanic activities associated with fragmentation of the Gondwanaland. It may, however, be pointed out that the Ferrar Supergroup and Karroo magmatism predate the Parana, Rajmahal/Sylhet/Deccan trap activity and are about 40 Ma older than the oldest known seafloor magnetic anomaly associated with spreading between Gondwana fragments. From the above, the following conclusions may be drawn:

1. That accompanied magmatism did not necessarily form the sites of subsequent continental separation.

2. Igneous activity that accompanied Gondwana rifting was independent of any plate boundary.

3. Rifting was controlled possibly by pre-existing zones of weakness.

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Limits of Greater Indian Plate during Gondwana time

S. K. Acharyya

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Limits of the Greater Indian Gondwana continent varied with its break-up and collisional episodes. Late Palaeozoic basal Gondwana type glaciogene and associated sediments containing cold-water marine fauna, with or without *Glossopteris*, Cathaysian floral remains or admixtures, occur in and across the Himalaya, in south Pamir, Tibet and in Shan-Tenesserim-Malaysian area, i.e., across the Late Mesozoic peri-Indian ophiolite belts. Cathaysian Flora with or without *Glossopteris* intercalations also occurs in western Iraq and New Guinea, both representing parts of the Gondwanic shield. Thus during Late Palaeozoic the Gondwana continents also hosted Cathaysian flora, especially in low palaeolatitudinal positions. The Himalaya, parts of Middle-East, Tibet, Shan-Tenesserim and Malaysian continental blocks therefore possibly formed parts of the Greater Indian Gondwanic continent.

The Late Cretaceous and Eocene olistostromal flysch belts tectonically flooring the ophiolite melange of the Indus-Tsangpo and Naga-Chin Hills-Andaman belts respectively delineate the northern and eastern continental margins of the Indian Plate. The present subduction zone beneath the Andaman island arc represents a westerly relayed Neogene margin of the Indian Plate.

Key-words—Gondwana, Greater Indian Plate, Palaeogeography, Plate Tectonics, Continental Drift.

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साराँश

गोंडवाना काल में बृहत् भारतीय प्लेट की सीमायें

ऍस० के० आचार्य

बृहत् भारतीय गोंडवाना महाद्वीप की सीमायें संघट्टनों एवं टूटने के कारण भिन्नता प्रदर्शित करती हैं। अनंतिम पुराजीवी आधारी गोंडवाना के हिमजनित एवं शीतल जलीय समुद्री जीवजात, **ग्लॉसॉप्टेरिस**, कैथेसीय वनस्पतिजातीय अवशेष या सम्मिश्रण से सहयुक्त अथवा इनसे विहीन सहयुक्त अवसाद हिमालय, दक्षिण पामीर, तिब्बत तथा शान-टॅनॅस्सेरिम-मलेशिया क्षेत्र में पाये जाते हैं। **ग्लॉसॉप्टेरिस** से युक्त अथवा इसके बिना कैथेसीय वनस्पतिजात पश्चिमी ईराक एवं न्यू गिनी में भी पाया जाता है। ये दोनों देश गोंडवाना प्लेट के ही भाग हैं। अतएव अनंतिम पुराजीवी कल्प में गोंडवाना, महाद्वीपों में विशेषतया निम्न पुराअक्षांसी स्थितियों, में विद्यमान था। इस प्रकार हिमालय, मध्य-पूर्व के भाग, तिब्बत, शान-टॅनॅस्सेरिम एवं मलेशिया ने मिलकर सम्भवतः बृहत् भारतीय गोंडवाना महाद्वीप के भागों का निर्माण किया है। अनंतिम क्रीटेशी एवं आदिनूतन कालीन ऑलिस्टोस्ट्रोमी फ़्लिश पट्टियाँ भारतीय प्लेट की उत्तरी एवं पश्चिमी सीमाओं का चित्रण करती हैं। अन्डमान द्वीप-चाप के नीचे स्थित वर्तमान प्रत्यावर्तित मंडल भारतीय प्लेट की पश्चिमी क्रम-व्यवस्थित पश्च-तृतीयक सीमा का निरूपण करता है।

THE Gondwanic Indian continent is now separated from its continental neighbours by wide oceans. The Gondwana elements, like glaciogene or coal-bearing facies in its lower sediments, floral and faunal elements are controlled by physiography and mainly palaeolatitudinal and climatic setting of the continent. It is possible to identify the extent of epicontinental shelf flanking the positive Indian

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landmass. Presence of 'northern' palaeogeographic elements in extra-peninsular area may indicate palaeoclimatic variation within a large continent.

The situation is more complex for the Indian continent because of its fragmentation from the Gondwanaland and later accretion with the Laurasia to form the present Eurasia and thus create the Himalaya. Evidence in support of a wide Tethys separating the Gondwanaland and Laurasia is largely wanting. An older palaeo-Tethys possibly separated the Laurasia from the long narrow "Cimmerian" continent (Sengor, 1985) or chain of continents located close to the northern peripheral parts of the Gondwanaland. These were possibly fragmented earlier from the Gondwanaland and a younger Neo-Tethys was thus created. Closing of the Palaeo-Tethys by Cimmeria-Laurasia continental collision was in phase with opening of the Neo-Tethys (Stocklin, 1983; Sengor, 1985). This was followed by main break-up of the Gondwanaland, creating the Atlantic and Indian oceans and leading to closure of the Neo-Tethys by the collision of Cimmeria with Indian and African continents. Remnants of these palaeo-oceans occur as ophiolite remnants along collision sutures. Several such suture zones and continental fragments forms a complex mosaic along the peri-Indian mobile belt (Text-fig. 1). Deciphering the spatial extent of Gondwanic India within such a crustal mosaic of "displaced terrains" is by no means an easy task.

GONDWANA SEDIMENTS FROM INDIAN SHIELD AND HIMALAYA

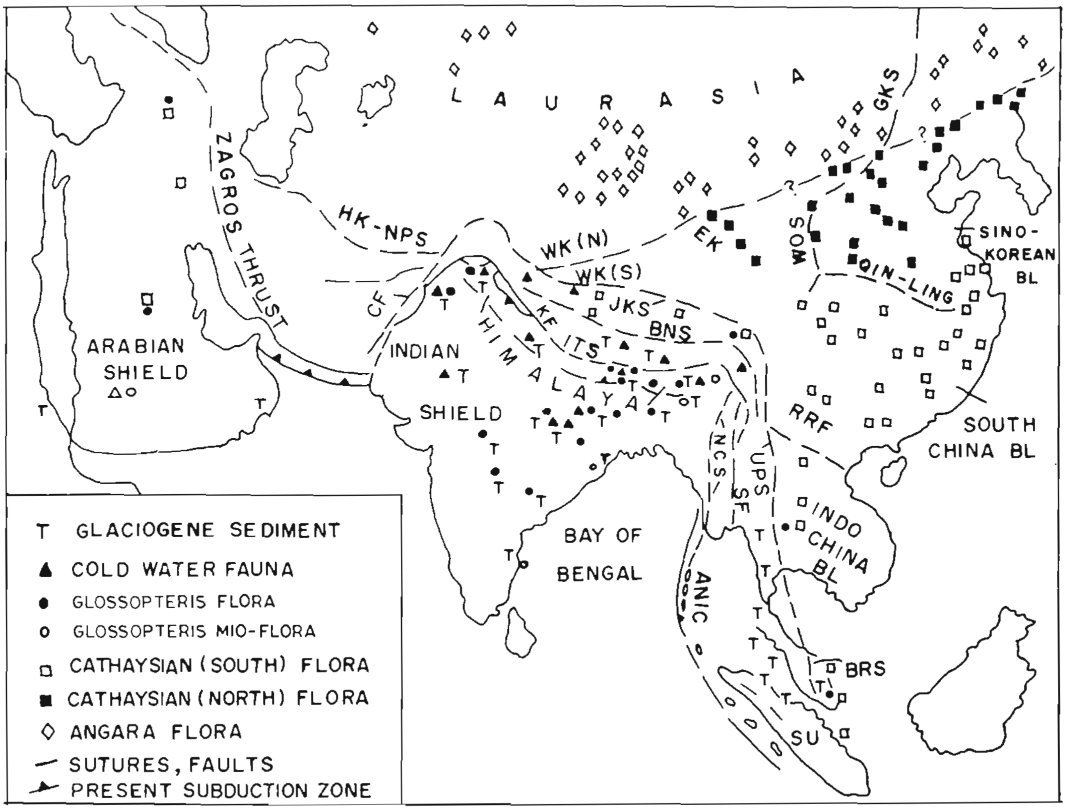
Typical Gondwana sediments occur in broadly linear intra-cratonic basin belts in the peninsular Indian shield. The distribution is different for the Upper Gondwana (?Jurassic-Early Cretaceous) sediments, especially for their paralic facies equivalents which usually occur as basal sediments in the peri-cratonic Cretaceous—Tertiary basins and shelfs. Contemporaneously widespread flood basalts erupted which also occur in other Gondwana continents. These appear to be related to main break-up of the Gondwanaland.

Gondwana type sediments containing characteristic floral/faunal elements also occur in the Himalaya. Late Palaeozoic Lower Gondwana sediments are much better represented. Phanerozoic sediments in the Himalaya occur as two belts on either side of the Central Crystalline Axis made up of reactivated Proterozoic continental basement. The Phanerozoic shelf with minor breaks, mainly represented by shallow marine facies, is more complete, and thicker in the Tethyan Himalayan belt. In the Lesser Himalaya, the Palaeozoic and Mesozoic succession is truncated and thinner, the latter being more accentuated by tectonism. Best developed tract of Late Palaeozoic Gondwana in the Lesser Himalaya is from eastern Nepal to western Arunachal Pradesh (Acharyya *et al.*, 1979; Bashyal, 1980; Tripathy & Roy Chowdhury, 1983; Banerjee & Dasgupta, 1983). It occurs as a continuous linear belt over 600 km in length where fluviatile and paralic Damuda type coaly facies contain well-preserved Glossopteris Flora (Early and Late Permian). A significant find from Kameng area, was stems of lycopods of Cathaysian affinity occuring in association of *Glossopteris* (Anon, 1984). In eastern Arunachal Pradesh, equivalent beds are mainly shallow marine nodular-black slate in facies with local association of coaly beds having Lower Gondwana spores, linoproductid dominant *Stepanoviella-Cyrtella*-bearing Sakmarian fauna and occasionally preserved Late Permian marine fauna (Acharyya *et al.*, 1979). The basal Gondwana diamictite-bearing unit, locally containing *Eurydesma* (Asselian) and/or linoproductid dominant (Sakmarian) or other fauna has wider extent and nearly cover the entire Himalaya. Equivalent beds occur even beyond as would be discussed later.

The Gondwana and associated sediments from the Lesser Himalaya are usually highly disturbed. These have narrow linear open-ended distribution, without any evidence of basin closure, basement relation, etc. The diamictite and associated sediments are often closely associated with contemporaneous volcanics and volcaniclastics (Acharyya, 1973; Acharyya *et al.*, 1979; Bashyal, 1980). Clasts in the diamictites as well as from the associated immature sediments are derived from adjacently exposed older rocks and contemporaneous volcanics. All these indicate rift tectonic setting for the Late Palaeozoic rocks from the Eastern Himalaya which is corroborated by the geochemical signatures of the associated volcanics (Acharyya, 1985).

Base of these Late Palaeozoic sediments is invariably unexposed, but from their nature, age and rarely preserved contact with the older rocks, these appear to generally disconformably overlie the Lesser Himalayan Proterozoic sediments with a pronounced time gap. A major break in sedimentation also occurs above the Permian sediments in the Lesser Himalaya.

In eastern Siang District, Arunachal Pradesh, the Abor Volcanics are widespread and extensive, but possibly include suites of more than one age. Volcanics having intercalation of black shales with Permian Gondwana spores, interbedded nature with older quartzite-limestone sequence and close



Text-figure 1—Distribution of Late Palaeozoic flora, coldwater fauna and glaciogene sediment in Eurasia (modified after Sengor, 1985). **ITS**—Indus-Tsangpo Suture, **BNS**—Bangong-Nujiang Suture, **JKS**—Jinsha-Jiang-Kokoxiil Suture, **HK-NPS**—Hindu Kush North Pamir Suture, **WK**—western Kunlun (North & South belt shown), **EK**—eastern Kunlun, **NCS**—Naga and Chin Hills Suture, **SF**—Shan Fault, **UPS**—Uttaradit-Paklay Suture, **BRS**—Bentong-Raub Suture, **RRF**—Red River Fault, **WOS**—West Ordos Suture, **GKS**—Great Khingan Suture.

association with volcaniclastics containing Eocene plant fossils substantiate such contention.

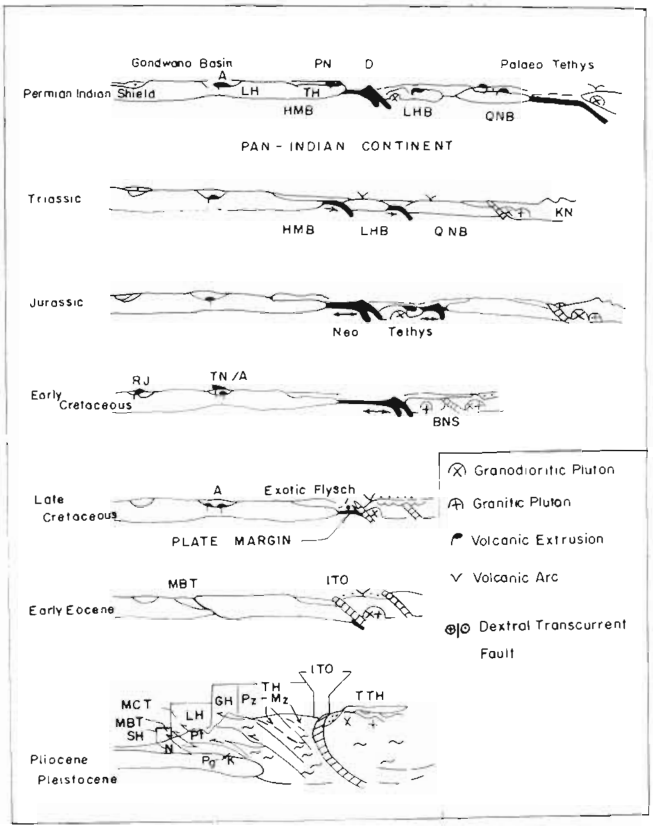
In the Tethyan Himalayan belt, the Gondwana affinity is best reflected from the Kashmir Valley and Mount Everest area. The Gondwana plant beds in the former area occur at two stratigraphic levels. The tuffaceous Nishatbagh plant bed overlies the Agglomeratic Slate and a lower volcanic flow, whereas, the other plant and vertebrate beds overlie the Panjal Volcanics but underlie the Zewan beds. The upper plant beds contain *Glossopteris* together with cones and stems of Cathaysian flora (Kapoor, 1979; Gopal Singh, Pers. comm., 1986). Further, the *Archaegosaurus-Actinodon* labyrinthodont fauna is closely similar to Early Permian European fauna (Acharyya *et al.*, 1977, Chaterjee, 1984; J. Schneider, Pers. comm., 1987). Diamictites, a lower *Eurydesma* dominant Asselian fauna and a linoproductid dominant Sakmarian fauna occur within the 'Agglomeratic Slate' (Acharyya & Shah, 1975). A homotaxial sequence of diamictites with associated cold-water marine fauna and *Glossopteris* floral remains have been recorded from Mount Everest area, South Tibet (Chang & Pan, 1984). Diamictites and associated sediments with plant fragments or Gondwanic spores have been recorded from the Lachi Formation, northern Sikkim and Lingshi Basin, Bhutan.

The Late Palaeozoic diamictite and associated sediments from other parts of the Tethyan Himalaya are also often associated with similar cold-water marine fauna and usually have a minor time break at their base. These are also associated with contemporaneous volcanics like the Panjal, Phe, volcanics from central Nepal, etc. of which the Panjal is most extensive. These volcanics, their equivalents from the Lesser Himalaya and the Abor Volcanics are dominantly tholeiitic to alkaline basaltic in nature with minor percentage of acid volcanics and volcaniclastics. Trace element geochemical signature mainly based on contents and relative proportions of Ti, P, Zr, Y, Nb, Sr and B from Panjal, Abor Volcanics and those from Sikkim and east Nepal Lesser Himalaya suggest within-plate rift tectonic setting (Bashyal, 1980; Sinha Roy & Furnes, 1978; Honegger *et al.*, 1982; Bhat, 1984; Acharyya, 1985).

It should be mentioned that there is uncertainty about the glaciogene origin and age of some of the Himalayan diamictites, e.g., Blaini Formation which were earlier correlated with the basal Gondwana diamictites to which they are lithologically very similar. But these occur in association with Late Precambrian sediments. These are closely associated with virtually unfossiliferous limestones. Earlier reports of Gondwanic spores from some of these could not be confirmed. Ill-preserved acritarchs of Upper Precambrian affinity were recorded from macerated samples (matrix and stones) of the Blaini diamictite from Luxmanjhula area, Garhwal. Thus chance of reworking cannot be ruled out. Biota recorded by thin section and SEM study from the shale associated with the Blaini from Sivipuri area is not age conclusive but indirectly supports Upper Precambrian age (Dhoundiyal & Moitra, 1987). These possibly represent Late Precambrian rift related or glaciomarine sediments. These diamictites are, however, not closely associated with volcanics as the Gondwana diamictites.

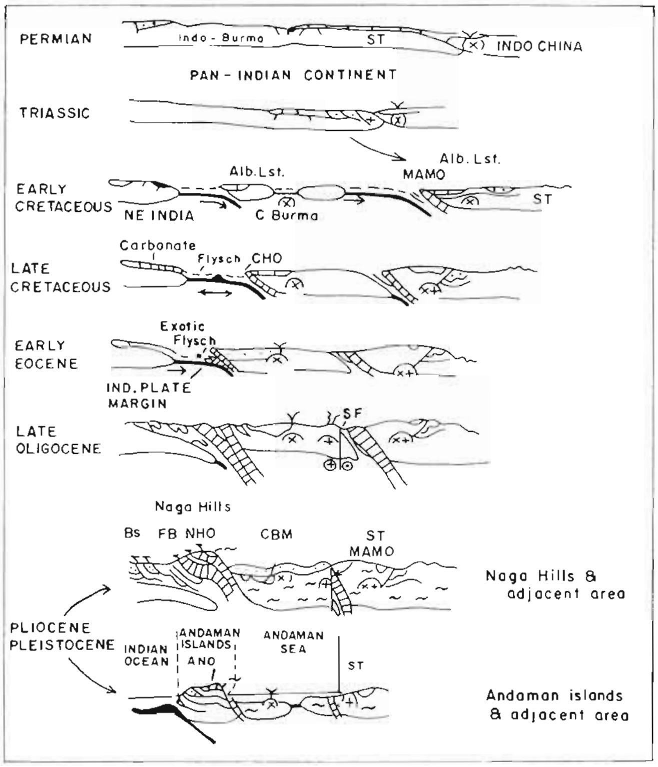
Paralic to land facies with *Ptilophyllum* floral intercalations resembling the Upper Gondwana sediments occur sporadically at a few locations only in the Himalaya. The Triassic shallow marine sediments from the Kumaon Tethyan Himalaya of Malla Johar area have yielded spores of Gondwana affinity. Spore assemblage is richer in the underlying Permian sediments (Tiwari *et al.*, 1980). In Tansen area, Nepal Lesser Himalaya, the Fenestellid-bearing Late Palaeozoic diamictites are unconformably overlain by fluvial volcaniclastic conglomerates and then by basaltic flows. Lower parts of the sediments contain plant beds with rich Ptilophyllum Flora (Sakai, 1983). The succession closely resembles the Rajmahal Volcanics and associated plant beds. The Tansen Volcanics are unconformably followed by Late Cretaceous-Eocene marine sediments (Sakai, 1983).

This singular occurrence of Upper Gondwana with subaerial Early Cretaceous basalts from Lesser Himalaya_ occur within its narrow Late Palaeozoic Gondwana belt. Presence of younger Eocene volcanics within the Abor Volcanics occurring further east along the same belt was mentioned earlier. The Abor Volcanics from the Siang River Section, where these are not in stratigraphic association with datable sediments, have yielded Cretaceous K-Ar whole-rock dates (90-140 Ma, Geochronology Division, GSI unpubl. report). The volcanism appears to be subaqueous having well-developed pillow structures in some of the dated sections (SKA, unpubl. data). It is worth noting that contemporaneous Early Cretaceous (110-121 Ma) mantle derived minette intrusives (Sarkar *et al.*, 1980) also occur restricted to the same belt from Darjeeling foot-hills to Siang River Section (Acharyya *et al.*, 1979) and connect the occurrences of volcanics from Tansen and Abor (Acharyya, 1985). It thus appears that failed Late Palaeozoic rift activity along the Lesser Himalaya was reactivated during Early Cretaceous. Similar cases of reactivations have also been noted elsewhere within the Indo-Himalayan Block (Acharyya, 1986b).



Text-figure 2—Plate tectonic cartoons showing break up and collisional history of the Pan-Indian continent and shifting northern margin of Indian Plate with time. **A**—Abor Volc, **PN**—Panjal Volc, **D**—Dras Volc, **LH**—Lesser Himalaya, **TH**—Tethyan Himalaya, **KH**—Kunlun, **RJ**—Rajmahal Volcanics, **TN**—Volcanics of Tansen area, **ITO**—Indus Tsangpo Ophiolite, **MBT**—Main Boundary Thrust, **MCT**—Main Central Thrust, **SH**—Sub-Himalaya, **GH**—Great Himalaya, **TTH**—Tibetan Trans-Himalaya; Plio-Pleistocene cartoon enlarged view.

In the Tethyan Himalayan belt, *Ptilophyllum* floral intercalations have been recorded from Thakkhola Basin, Nepal and Lingshi Basin, Bhutan, placed between the Spiti Shale and the Neocomian-Aptian marine beds (Barale *et al.*, 1978; Ganeshan & Bose, 1982). These successions resemble closely the Upper Gondwana from the coastal tracts of peninsular India.



Text-figure 3—Plate tectonic cartoons showing break up and collisional history of the Pan-Indian continent and shifting eastern margin of the Indian Plate with time. Plio-Pleistocene cartoons for Naga Hills and Andaman along with their adjacent areas shown separately. **CB**—Central Burma, **MAMO**—Myitkyna-Mandalay ophiolite, **NACHO**—Naga and Chin Hills ophiolite, **ST**—Shan-Tenesserim Block, **CBVL**—Central Burma volcanic line, **BS**—Belt of Schuppen, **FB**—Flysch belt Naga Hills, **NHO**—Naga Hills ophiolite, **CBM**—Central Burma molasse basin, **Ind-Oc**—Indian Ocean, **ANO**—Andaman ophiolite, **ANS**—Andaman Sea.

Thus the Gondwanic Indian shield did extend up to the northern margin of the Tethyan Himalaya. The Indus-Tsangpo Suture was generally regarded as the northern margin of the Indian Gondwana Plate to which some even now subscribe (Honegger *et al.*, 1982; Zhang *et al.*, 1984). Presence of Permian Cathaysian floral and European tetrapod remains from Kashmir Tethyan belt was believed to represent a land-bridge between the Indian and northern continent. But the facies, floral and marine faunal elements from the Late Palaeozoic rocks of Kashmir Valley and those from the Eastern Lesser Himalaya are closely similar. The Kashmir Valley sequence is also similar to those at Salt Range (Fatmi, 1973) which structurally corresponds to the Indian Shield. A similar sequence of Late Palaeozoic diamictite with cold-water marine fauna and Late Mesozoic-Tertiary marine shelf facies is developed in Jaisalmer Basin, western India (Rao *et al.*, 1979).

PALAEOGEOGRAPHIC AFFINITY OF PAMIR-AFGHANISTAN BLOCKS

Recent studies in Pamir and Afghanistan show that the earliest Permian foraminiferal complex from south Afghanistan, south Pamir; Early Permian bivalve and brachiopod from Basardara suite, SE Pamir; brachiopod fauna from Dachet-E-Nawer region, central Afghanistan are characterised by cold-water fauna. These beds are also often associated with glaciogene facies indicating Gondwanic affinity. The earliest Permian foraminifer from North Pamir and Permian fauna from North Afghanistan, juxtaposed against those of the south block by the North Pamir—Hindukush Suture, are of thermophilic type (Leven, Novikov & Montenant *et al. in* : Belov *et al.*, 1986; Lapparent *et al.*, 1970). The Early Palaeozoic sediments from Iran, Afghanistan and South Pamir also indicate Gondwanic affinity by the absence of thermophilic Ordovician corals which are also rare during Early Silurian (Belov *et al.*, 1986).

PALAEOGEOGRAPHIC AFFINITY OF TIBETAN BLOCKS

The Tibetan Plateau may be subdivided into two continental blocks, e.g., Lhasa and Qantang bounded by the Indus-Tsangpo, Bangong-Nujiang and Jinsha Jiang-Kokoxili sutures (Text-fig. 1). The Kun Lun belt occurs to the north of the last named suture (Allegre *et al.*, 1984a; Chang *et al.*, 1986).

Setting of the continental blocks

Presence of Late Palaeozoic Gondwanic tilloid and *Gangamopteris* beds in Harpa-Tso Formation, eastern Karakorum (Norin, 1946) indicating extension of the Indian Gondwana continent beyond the Indus-Tsangpo Suture has been substantiated and supplemented by recent studies on Tibet. Glacio-marine tilloidic and ice-rafted sediments, locally associated with coid-water fauna containing *Eurydesma, Stepanoviella, Lytvolasma, Monodiexodina*, etc. have been recorded from extensive area, as far as to the north of Qantang Block in North Tibet and reaching south slope of Karakorum mountains (Chang & Pan, 1984; Tingdong *et al.*, 1986; Belov *et al.*, 1986). But such records from the Qantang Block are sparce and rare compared to those from the Lhasa Block. The record of Dammung-Linzhu diamictite and Permian Cathaysian flora from Lhasa Block was initially regarded anomalous and glacial origin for the former was doubted because "the Cathaysian flora is traditionally interpreted as being typical of an equatorial climate" (Allegre *et al.*, 1984b). Later studies, however, corroborate glaciomarine nature of the former based on dropstone and other characters and association of cold-water Gondwanic marine fauna. Similar occurrences were also recorded from some additional locations from Lhasa Block. But no mention is made about the record of Permian Cathaysian flora from Lhasa Block (Chang & Pan, 1984; Chang *et al.*, 1986). This flora, however, is recorded from a few locations from the Qantang Block and from its eastern part Cathaysian and *Glossopteris* mixed flora is reported (Xiao & Gao, 1984; Chang & Pan, 1984; Chang *et al.*, 1986).

From the consideration of facies and marine faunal character, there is no palaeogeographic distinction or discontinuity up to Early Permian between the Himalayan and both the Tibetan blocks. The Glossopteris Flora is mainly restricted to the south of the Indus-Tsangpo Suture. On the other hand, Cathaysian Flora with typical elements like *Gigantopteris* is recorded from the Qantang block. A faunal distinction is noticed north of the Indus-Tsangpo Suture since early Late Permian. The cold Gondwanic fauna gets gradually replaced by thermophillic *Neoschwagerina* fusulinids and *Iranophyllum-Wentzelella* corals together with some lingering cold-water brachiopods (Chang & Pan, 1984).

The diamictites from Lhasa area contain clasts of feldspar-phyric felsite (Chang *et al.*, 1986). Basaltic flows occur within the overlying Early Permian limestone which underlie coal-bearing beds (Chang & Pan, 1984). North-west of Lhasa, basaltic flows unconformably underlie Late Triassic-Jurassic reef limestone and clastics. Occurrence of thick Triassic platform carbonates containing emersion surfaces and elsewhere limestone turbidites indicate platform break-up (Chang *et al.*, 1986). In the Qantang block, the oldest exposed rocks are transitional to alkaline basalts with minor agglomerates and acidic flows which underlie the Permian plant beds. Both subaerial and submarine flows are present. These Late Palaeozoic volcanics from Lhasa and Qantang blocks indicate rift setting (Chang & Pan, 1984; Chang *et al.*, 1986).

Allegre *et al.* (1984a) have highlighted on palynomorph assemblage from latest Triassic sediments from north of Lhasa which closely resembles those from equatorial European areas and lacks any Indian taxa; record of silicified wood *Protopodocarpoxylon* from the Early Cretaceous clastics exposed in and around Lhasa, the wood being widely represented from western Europe, northern Africa and South-East Asia but never from India. Presence of growth rings in these fossil-woods suggesting a palaeolatitude not too close to equator during Early Cretaceous is in agreement with palaeomagnetic studies indicating low northern palaeolatitude (Allegre *et al.*, 1984a).

The Triassic clastic sediments in Lhasa area are associated with calc-alkaline volcanics. Argillaceous and carbonate sediments with basalt-andesite intercalations are widespread from east of Lhasa (Chang & Pan, 1984). In the Qantang block also, thick Triassic fluviatile gravels derived from north are overlain by calc-alkaline arc-related volcanics. Preliminary palaeomagnetic results from these lavas show a northern hemispheric location. Thick Late Mesozoic molassic red-beds are derived from the uplifted Kunlun Range (Chang *et al.*, 1986).

Mention may be made also about the *Ptilophyllum*-bearing Fukche flora of Middle-Late Jurassic age, recorded from the Upper Indus Valley, north of the Ladakh Range and close to the Karakorum fault (Bose *et al.*, 1983). The floral assemblage with some new elements is different from the Upper Gondwana assemblages recorded from the Indian Shield and those few from the Himalaya. Instead it broadly resembles the Jurassic assemblage known from the Tethys-Karakorum belt. A *Cladophlebis*-bearing floral assemblage, possibly corresponding to same tectonic unit occurs about 5 km south of Fukche.

The Kunlun belt occurring to the north of Jinsha-Jiang-Kokoxiili Suture contain warm-water Carboniferous fauna with Laurasian coral, brachiopod and foraminifera (Chang & Pan, 1984; Chang *et al.*, 1986; Belov *et al.*, 1986). The Late Palaeozoic Angara Flora is well-developed north of Kunlun mountains. Northern Cathaysian Flora together with warm-water fauna are developed in east Kunlun belt (Xiao & Gao, 1984; Sengor, 1985).

The phytogeographic map of Eurasia for the end of Early Permian by Durante (in Belov *et al.*, 1986) shows conspicuous absence of mixed Angara-Cathaysian floristic complexes indicating that their respective domains were separated by the Palaeo-Tethyan ocean. However, during end of Late Permian there was mutual infiltration of plants, the Angara elements moving south and the Cathaysian elements north indicating considerable shrinkage of the oceanic barrier.

Nature of the oceans

The Indus-Tsangpo Ophiolite (ITO) is regarded as an intra-Gondwanaland rift zone which created a narrow Permian-Jurassic ocean (Crawford, 1974; Chang & Pan, 1984), or it created an ocean by Mesozoic rifting (Honegger *et al.*, 1982; Xiao, 1984;

Allegre *et al.*, 1984a). Late Palaeozoic rifts active both in the Himalayan and Tibetan blocks possibly created some oceanic crust remnants of which could be recognised from the Tibetan suture zones and magmatic arcs (Acharyya, 1985). The Triassic arc-related volcanics in Lhasa block was inferred to have been produced by earlier subduction of the Indus-Tsangpo ocean (ITO) (Chang & Pan, 1984, p. 198). Contemporaneous arc-related volcanics also occur in the Qantang block located to the north of the Bangong-Nujiang suture. Further, the Dras Volcanics from the ITO, the Gaik and another granite body from the Ladakh and Gangdise batholiths have yielded closely consistent 235-265 Ma, Rb-Sr whole-rock isochron age and 0.703-0.708 Sr_i (Honegger *et al.*, 1982; Trivedi *et al.*, 1982; Yu, 1982). The gneisses from Brakhor area, north of Shyok ophiolite belt has also yielded contemporaneous 260 Ma, $^{39}Ar/^{40}Ar$ age (Reynolds *et al.*, 1983). Exotic blocks of Late Palaeozoic limestones, usually believed to represent sea-mount facies, are well known from the ITO belt and have also been recorded from the Shyok belt (Reynolds *et al.*, 1983). Permian radiolarites have been also recorded recently from the ITO and Bangong-Nujjang Ophiolites (Jingehuan, 1984). Thus narrow Permian oceans were possibly created between the Himalayan, Lhasa and Qantang blocks.

Excluding the possible Permian remnants, the oldest recorded age from the magmatic sections from the ITO from Xigaze area correspond to 120 Ma (Allegre *et al.*, 1984a) and from Kohistan arc-complex and Shyok Ophiolite corresponds to 130-150 Ma (Reynolds *et al.*, 1983). The lowermost chert or detritic sediments forming normal cover over the pillow volcanics from the south Tibetan ITO belt are also Middle Cretaceous in age (Bassoullet *et al.*, 1984). Similarly the Shyok Ophiolite containing Early Cretaceous microfauna are followed by Late Cretaceous flyschoid sediments (Srimal & Bhandari, 1985). Thus the oceanic domains of ITO from South Tibet to Kohistan arc, and that from Shyok are broadly contemporaneous and Late Mesozoic in age. The Indus-Tsangpo ocean separated the Karakorum-Lhasa and the Himalayan microcontinents. Initiation of Mesozoic rifting along the northern edge of the Himalayan microcontinent had commenced since Triassic as evidenced by occurrence of pockets of alkaline pillow volcanics associated with Early Triassic pelagic limestone within the Lamayuru exotic flysch (Honegger *et al.*, 1982; Chang & Pan, 1984) which tectonically underlies the ITO melange. Collapse of the Tethyan Himalayan shelf is also indicated by the thick pile of Mesozoic flysch sequence developed closer to the ITO belt.

In the Bangong-Nujiang suture zone, the pillow basalts south of Amdo are succeeded by Late Jurassic deep-sea pelagic sediments, whereas west of Danquiao weathered ophiolites are transgressively covered by paralic patch-reefs of late Upper Jurassic age (Chang *et al.*, 1986). These broadly constrain the date of closing of this ocean, which must have had Mesozoic to Permian, continuous or discontinuous, development history.

The age and nature of the ocean represented by the Jingsha-Jiang suture is not clearly known. It is generally considered to represent the Palaeo-Tethyan ocean with Late Palaeozoic-Early Triassic oceanic remnants (Xiao & Gao, 1984; Belov *et al.*, 1986). According to others, the Bangong-Nujiang ocean represents the main Palaeo-Tethyan ocean whose northward subduction created a Late-Early Permian-Mesozoic back-arc basin along the Jinsha-Jiang belt (Tingdong *et al.*, 1986).

A convergence between the Indo-Himalayan and Lhasa-Karakorum blocks, corroborated by palaeomagnetic data, caused subduction of the Indus-Tsangpo oceanic crust beneath the northern block creating a magmatic arc of Middle Cretaceous to Middle Eocene (95-40 Ma) in age (Scharer *et al.*, 1984). This palaeo-subduction zone thus became the margin of the Gondwanic Indian Plate. The Indus-Tsangpo Ophiolite (ITO) appears to be accreted during Late Cretaceous as evidenced by 75-80 Ma, $^{39}Ar/^{40}Ar$ age of phengite from blue schist at Shangla, Swat (Maluski & Matte, 1984) and contemporaneous K/Ar mineral dates from Kargil granodiorite and Dras Volcanics indicating rapid cooling (Sharma, 1987). This was possibly caused by initial collision between the Kohistan-Dras island arc with the Karakorum Lhasa continent (Acharyya, 1985). The accreted ITO also resulted in formation of exotic flysch of latest Cretaceous age which tectonically floors the ITO (Text-fig. 2). The ITO was then thrust over the Tethyan Himalayan shelf sediments because of terminal Indo-Himalaya and Tibetan continent-continent collision during Middle Eocene. The tectonic zone represented by exotic flysch possibly representing oceanic trenchal or continental margin sediments, and the ITO melange in their palinspastic position represent the northern limit of the Gondwanic Indian Plate during end of Cretaceous.

PALAEOGEOGRAPHIC SETTING OF INDO-BURMESE RANGE AND ANDAMAN-NICOBAR ISLAND ARC

The Indo-Burmese Range is mainly constituted of a frontal Neogene molasse, and a Palaeogene shelf and flysch deposited on the Indian continent overriden by the Naga and Chin Hills ophiolite sequence of Cretaceous-Eocene age (Acharyya, 1986a). Towards east, the range is flanked by the Central Burma Basin mainly housing Tertiary sediments and a N-Q arc-related volcanic belt. The Andaman-Nicobar island arc geologically closely resembles inner parts of the Indo-Burmese Range and represents its southern extension. The Tertiary shelf sediments in north-east India flanking the Indo-Burmese Range contain significant fraction of reworked Permian Gondwanic spores. Recently an exploratory well in Barapathar area, in Mikir foot hills, Assam has intersected Gondwana sediments below the Upper Cretaceous-Tertiary shelf sequence. It is interesting to note that the truncated Gondwana sediments here are similar to those from Athgarh and Palar basins of the Indian east-coast belt occurring further south-west. The Upper Gondwana sediments with Late Mesozoic spores directly overlie the Talchir equivalent sediments which also contain shallow marine palynomorphs.

Based on age of oceanic pelagic sediments recorded from the ophiolites of Naga Hills and Andaman islands, K-Ar date of a pegmatite intruding the Chin Hills Ophiolite, Burma, broad geological setting of the Naga-Chin Hills-Andaman Ophiolite (NACHAO) and geo-chemical signatures mainly recognised within the ophiolite volcanics from Naga Hills and Andaman island, it has been inferred that the NACHAO belt represents an once connected narrow ocean which was possibly created by Late Mesozoic break-up of India and Burmese continents (Acharyya, 1986a; Acharyya *et al.*, in press; Ray *et al.*, in press). India and Burma converged and collided in stages, during Middle Eocene and Late Oligocene causing accretion and emplacement of this ophiolite over the downgoing Indian continent (Text-fig. 3) (Acharyya, 1986a, b; Acharyya *et al.*, in press). An extensive and broadly contemporaneous olistostromal Eocene flysch sediments tectonically underlying the Naga-Chin Hills-Andaman Ophiolite possibly represent eastern margin of the Indian continent during Eocene when accretion of the ophiolites was in progress. The present subduction zone of the Indian Ocean crust below the accretionary wedge of the Andaman island-arc possibly represents a post-collisional westerly relayed Neogene plate margin. This subduction has resulted in creation of back-arc Andaman sea and arc-related volcanism in Andaman and central Burma basin (Text-fig. 3).

PALAEOGEOGRAPHIC AFFINITY OF SHAN-TENESSERIM-SUMATRA BELT

Broadly N-S trending Shan-Tenesserim-Sumatra belt occurs to the east of the Indo-Burmese Range and the Andaman Nicobar Island Arc. Further east occurs the Indochina block (Text-fig. 1) major part of which is covered by Late Mesozoic continental sediments overlying mainly Precambrian metamorphic basement or folded Silurian-Early Carboniferous sediments occurring mostly along the periphery of the Precambrian craton. Upper Carboniferous, Permian and Triassic marine sedimentation also occured around the enlarged craton and were later subjected to Triassic-Jurassic Indosinian folding (Workman, 1975).

Though traditionally excluded, the Shan-Tenesserian-Sumatra block is now believed to be a fragment of the Gondwanaland during Late Palaeozoic (Acharyya, 1979; Stauffer, 1983; Bunopas & Vela, 1984). A nearly continuous and extensive (< 2000 km) belt of "Pebbly mudstone", diamictite with local intercalations of volcanic rocks from this belt was compared and correlated with those from Late Palaeozoic basal Gondwana diamictites from Tibet and Himalaya by Acharyya (1979). Presence of drop-stones exotic blocks and other glacio-marine features and often close association of Carboniferous to basal Permian cold-water peri-Gondwana fauna has been corroborated subsequently (Stauffer, 1983; Bunopas & Vella, 1984). A review is thus necessary of the extensive shelf carbonates closely associated with and overlying the pebbly-mudstones which were earlier believed to indicate warm-water facies (Gobbett & Hutchison, 1973). Fusuline species reported from the Ratburi Limestone in Thailand and equivalent beds from Malayasia have been analysed from palaeogeographic point of view by Toriyama *et al.* (1978). The Middle Carboniferous to early Late Carboniferous fauna indicates good connection with the Arctic and Tethyan realms. During late Early Carboniferous and early Early Permian the Tethyan sea maintained some connection with the Arctic realm. A remarkable palaeogeographic change occurred after early Early Permian when the fauna developed eastern Tethyan character with no Arctic elements. Based on petrological studies also it was inferred that the Chuping Limestone has been formed in cool climate, whereas the overlying Triassic Kodiang Limestone from West Malaya has been formed in warm tropical climate (Rao, in Gatinsky *et al.*, 1984). A close similarity of the Palaeozoic fauna from the Shan-Tenesserim block and Tibet with those from Australia record by Archbold *et al.* (1982), Burret and Stait (1985) also corroborates their Gondwana affinity. Palaeomagnetic studies on Late Palaeozoic diamictites from Thailand also corroborate southern hemispheric location and same appears to be valid also for the Malayan peninsula contrary to earlier belief (Bunopas & Vella, 1984).

The extensive belt of pebbly-mudstone facies from this block possibly also represents rift-related sediments associated with glacio-marine setting (Stauffer, 1983; Bunopas & Vella, 1984; Gatinsky *et al.*, 1984). Further east of these pebbly facies in Malaya and south Thailand, contemporaneous sediments are of normal shallow marine facies (Stauffer, 1984, p. 1076).

Placed between the western Thai-Malaysian and Indo-China-East Malayan blocks, the belt of mafic-ultramafic rocks along the Uttaradit-Pak Lay belt in northern Thailand and those along the Bentong-Raub line in Malaya are regarded to represent a Palaeo-Tethyan suture. Their ophiolite nature, age and in between continuity is still in doubt (Thanasuthipitak, 1978; Stauffer, 1983; Helmecke, 1985). Closely parallel and east of this so-called suture in Thailand occurs the Loei-Phetchabun fold belt whose eastern and western limits are concealed below the Late Mesozoic strata. A strong unconformity occurs over the folded Silurian-Lower Carboniferous rocks overlain by the Permian limestone and flysch. Permian section in Loei and Phetchabun areas have also yielded Cathaysian Gigantopteris Flora with *Glossopteris* elements present in the latter place. Though earlier explained as a stray migrant or a case of parallel evolution, the Phetchabun Flora requires re-examination in view of Gondwana affinity now recognised for Thailand till basal Permian.

Existence of Permian-Triassic calc-alkaline volcanics, Triassic granites with high Sr_I ratio, and a later phase of lower-middle Triassic folding along this belt is consistent with convergence, easterly subduction and collision of the Shan-Tenesserim and Indo-China blocks (Workman, 1975; Stauffer, 1983) and true oceanic crust may or may not have separated them wide apart (Text-fig. 3).

Similarly sharp difference in sedimentary-magmatic and tectonic setting of Palaeozoic and Triassic rocks across the Bentong-Raub line in Malaya, character of the Main Range Granite can be explained suitably assuming the Bentong Raub line as the site of a closed ocean. Upper Carboniferous clastic facies with volcanic intercalations from Central and East Malaya had occasionally yielded *Lepidodendron*-bearing Cathaysian floral elements (Gobbett & Hutchison, 1973). A significant recent floral find from eastern Malaya contains *Gangamopteris* occurring in association with tilloidic beds (Azher, in Stauffer, 1983). The situation thus is comparable to that inferred from Thailand. In eastern Sumatra, the Djambi nappe comprising Late Palaeozoic clastics, limestone, volcanics and volcaniclastics has yielded thin coal and rootlet beds with well-preserved Gigantopteris Flora overlying a *Pseudoschwagerina*-bearing limestone.

Late Triassic-Jurassic *Sagenopteris*-bearing plant assemblage from the Tembelling Formation, Central Malaya is similar to European-Central Asian flora. *Ptilophyllum* occurs with this as well as, younger Mesozoic formations of Malaya (Gobbett & Hutchison, 1973). *Glossopteris* in association with *Dictyophyllum, Taeniopteris*, etc. is recorded within the Upper Triassic red-beds of Central Yunnan (Coggin Brown, 1922).

CONCLUSION

1. Late Palaeozoic to Early Cretaceous Gondwana facies and biotic elements occur both in the Lesser and Tethyan Himalayas where they are associated with shallow marine sediments and rarely contain Cathaysian floral remains.

2. Based on presence of cold-water marine fauna and association of glacio-marine facies during major parts of Late Palaeozoic, the South and Central Afghanistan-South Pamir block, Tibetan blocks, Shan-Tenesserim-Sumatra block bear Gondwana affinity and they possibly constituted the Pan-Indian continent. Contemporaneously North Afghanistan-North Pamir block, Kunlun block north of Jinshajiang suture housed thermophilic marine fauna. Cathaysian Flora of northern affinity occur in eastern Kunlun belt. The Angara Flora occurs further north of the Kunlun belt. These two palaeogeographically distinct continental domains were possibly separated by the Palaeo-Tethys.

3. Permian Cathaysian Flora of southern affinity with rare *Glossopteris* floral intercalations occurs in the Qantang block, Tibet. Similar relation is also recorded from the Lhasa block and the Gondwanic Arabian Shield (McClure, 1980; Stauffer, 1983). Similarly the Indo-China-East Malayan block with dominant Late Palaeozoic Cathysian floral character has some *Glossopteris* floral intercalations close to their converging margin flanking the Shan-Tenesserim-West Malayan block.

4. Thus during Late Palaeozoic, the *Glossopteris* and Cathaysian floras appear to be more closely related and their distribution might have been climatically controlled. On the other hand, no such intermingling occurs between the contemporaneous Cathaysian and Angaran flora till end of Late Permian.

The polarwander paths from the South China and Sino-Korean block also corroborate that these blocks were also parts of the Gondwanaland assembly at least during Early Palaeozoic (Lin *et al.*, 1985).

5. Late Palaeozoic Gondwanic rocks from the Himalaya and Tibet (both belts) are closely associated with rift-related volcanism.

Contemporaneously narrow oceans possibly perforated and separated the two Tibetan blocks at places and remnants of these are recognisable within the Indus-Tsangpo, Shyok and Bangong-Nujiang suture zones. Triassic arc-related volcanism in Lhasa and Qantang blocks may have been produced by closing of these narrow oceans. Late Palaeozoic diamictites from Shan-Tenesserim belt are also associated with rift-related sedimentation.

6. During Late Triassic and Early Cretaceous the floral records from Lhasa block are distinctly different from the Gondwana and have northern (Cathaysian/Angaran) affinity. In the Shan-Tenesserim belt arctic faunal elements disappeared after early . Early Permian when the fauna also assumed eastern Tethyan affinity. The Triassic Kodiang Limestone from western Malaya were deposited in warm tropical climate. The Triassic-Jurassic flora from Central Malaya has European and Central Asian affinity, whereas, the Upper Triassic red-beds from Central Yunnan still contain *Glossopteris*.

7. The peri-Indian ophiolites, like the Indus-Tsangpo, Shyok, Bangong-Nujiang occurring to the north of the Himalaya and the Naga-Chin Hills-Andaman and parallel but less extensive belts occurring in central part of Central Burma, western flank of East Burma, central belt of Sumatra, represent remnants of Neo-Tethys which were mainly created by Late Mesozoic rifting and fragmentation of the peripheral parts of the Pan-Indian continent. Some of these Mesozoic rifts were controlled by and superposed over earlier Late Palaeozoic structures.

The Pan Indian Plate so created contained the Gondwanic continental fragments and narrow Neo-Tethy an Ocean.

8. The northward movement of the Indian continent, as revealed by palaeomagnetic data, was not as an island-continent, as generally believed, but along with its crustal neighbours (Acharyya, 1986a, b). This explains closer similarity of Early Permian to Late Cretaceous Tetrapod fauna from Indo-Himalaya with those from Europe and China in addition to Gondwanic South Africa and South America (Chatterjee, 1984). The Pan-Indian Plate possibly developed space constraints during its protracted northward journey causing convergence of its continental fragments. Thus new active plate margins were developed along the northern margin of the Himalayan microcontinent and eastern margin of the extension of the Indian continent flooring the Indo-Burmese Range and its possible extension southward to the Andaman Island arc (Text-figs 2, 3).

9. The belt of exotic flysch possibly representing trenchal sediments bordering the subduction zone or continental margin sediments, and the over-riding Indus-Tsangpo or Naga-Chin Hills-Andaman ophiolite melange in their palinspastic position would represent the northern and eastern active margins of the Indian Plate during latest Cretaceous and Eocene respectively. The present eastern active margin of the Indian Plate below the Andaman Island arc possibly represents a westerly relayed Neogene subduction zone which caused opening up of the Andaman Sea and N-Q arc-related volcanism in Central Burma and in Andaman Sea.

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Indian Gondwana Plate margin and its evolutionary history

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The outline of the Indian Plate in the Gondwanaland Plate mosaic has been reconstructed. The basic premise for the reconstruction lies in the identification of the suture zone along Indus-Yarlung tectonic zone and Indo-Burman range, both of which are wreathed with ophiolite complexes. The north-eastern margin of the Indian part of the Gondwana Plate, which was ill-defined in many earlier reconstructions, is now more precisely delineated with the find of slide-generated olistostrom bodies representing plate marginal trench setting around Ukhrul-Paoyi-Kiphire area of the ophiolite belt of Manipur-Nagaland. The recent report of continental Gondwanas close to this suture zone lends credence to this palaeogeographic reconstruction. On the north, the continental sediments having distinct Gondwana entity rarely extend to the Tethyan basin and as such the Indus-Yarlung Suture truly delimits the Gondwana Plate domain. The Himalayan front is regarded as a Tethys-facing margin of the Gondwana continent. Along the eastern margin of Indian Plate, rifting as a sequel to ocean floor spreading led to the evolution of coastal troughs of Cauvery, Palar, Godavari-Krishna and Athgarh which bear records of marine transgressions during Aptian-Albian time from a juvenile Indian Ocean. These oceanward tilted troughs may represent the rifted arm of a triple junction formed during the continental fragmentation. The discovery of such troughs in the Upper Assam and Bengal Basin suggests that the separation of India from Eastern Gondwanaland occurred in a NE-SW direction. The Cambay and the Kutch basins document similar evolutionary history along the western margin of Indian Plate. As a consequence of crustal tension accompanying the fragmentation, outpour of tholeiitic basalt took place in Rajmahal, Khasi-Garo-Mikir Hills and Upper Assam at 100-105 million years along the west coast. The earliest manifestation of volcanism has been recorded in Saurashtra which is considered to be contemporaneous with Rajmahal volcanicity. It is suggested that both the eastern and western margins of the Indian Gondwana Plate bear closely related records of fragmentation in Early Cretaceous time.

Key-words—Indus Suture, Indian Plate, Palaeogeography, Continental Drift, Plate Tectonics.

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साराँश

भारतीय गोंडवाना प्लेट की सीमा एवं इसका वैकासिक इतिहास

ऍन० डी० मित्रा

गोंडवाना प्लेट में भारतीय प्लेट की पुनर्रचना इन्डो-बर्मा श्रेणी एवं सिंधु-यारलुंग विवर्तनिक मंडल के संग-संग स्थित सूचर मंडल के अभिनिर्धारण के आधार पर की गई है। ये दोनों ही ऑफ़ियोलाइट-सम्मिश्र के साथ संलग्न हैं। गोंडवाना प्लेट के भारतीय भाग की उत्तर-पूर्व सीमा, जो कि अभी तक पूर्व पुनर्रचनाओं में सुस्पष्ट नहीं की गई थी, को सूक्ष्म रूप से परिसीमित किया गया है। इस सूचर मंडल के निकट अलवणीजल गोंडवाना की हाल की प्रस्तुत रिपोर्ट पुराभौगोलिक पुनर्रचना की पुष्टी करती है। उत्तर में गोंडवाना मूल से भिन्न अलवणीजल अवसादों का विस्तार टॅथीय द्रोणी तक बहुत ही कम है और इसी प्रकार गोंडवाना प्लेट सिंधु-यारलुँग सूचर से परिसीमित है। हिमालय का अग्र भाग गोंडवाना अवसादों की टॅथीय की ओर की सीमा के रूप में माना गया है। भारतीय प्लेट की पूर्वी सीमा के संग-संग समुद्र तल में हुई रिफ्ट के कारण ही कॉवेरी, पलार, कृष्णा-गोदावरी एवं अथगढ़ तटीय द्रोणीयों का निर्माण हुआ है जिनसे ऍप्शियन-ऍल्बियन काल में समुद्री अवनमन के प्रमाण मिलते हैं। उपरि असम एवं बंगाल द्रोणियों में ऐसी द्रोणिकाओं की उपस्थिति इंगित करती है कि

Concepts, limits and extension of the Indian Gondwana
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पूर्वी गोंडवानाभूमि से भारत का सम्बन्ध विच्छेद उत्तर पूर्व-दक्षिण पश्चिम दिशा की ओर हुआ है। कैम्बे एवं कच्छ द्रोणियों से भी भारतीय प्लेट की पश्चिमी सीमा के संग-संग हुए वैकासिक परिवर्तनों के प्रमाण मिलते हैं। भूस्तरिक तनाव एवं विखंडन के फलस्वरूप राजमहल, खासी-गारो-मिकिर पहाड़ियों एवं उपरि असम में पश्चिम तट के संग-संग थोलाइटी बासाल्ट का निर्माण हुआ है। सौराष्ट्र में प्राचीनतम् ज्वालामुखीयता का प्रमाण मिला है जो कि राजमहल के समकालीन माना गया है। यह प्रस्तावित किया गया है कि भारतीय गोंडवाना प्लेट की पूर्वी एवं पश्चिमी दोनों ही सीमाओं पर प्रारम्भिक क्रीटेशी काल में हुए विखण्डन से घनिष्ठ सम्बद्ध चिन्ह अभिलिखित हैं।

THE precise outline of Indian Gondwana Plate and the inter-relation between India, Antarctica and Australia have long been a topic of lively discussion. Of the various fits, the one proposed by Smith and Hallam (1970) has received wide acceptance. In this fit the eastern edge of the Indian Plate lies in Assam and is separated from Australia by an oceanic gulf 'Sinus Australia'. Later it was postulated that Sinus Australia was occupied by a continental block which continues into the Indian crustal plate in an entity called Greater India (Veevars *et al.*, 1975; Sonson *et al.*, 1976). But the fact remains that in all these reconstructions the outline of the northeastern margin of Indian Gondwana Plate remains ill-defined. Recent geological studies in Assam, Mismi Hills, Nagaland and Manipur have yielded certain basic data which permit precise delineation of northeastern boundary of Indian Gondwana Plate.

There are also divergent views about the extent of northern margin of Gondwanic India. Debate persists whether the Indus Suture Zone defines the relic of a closed ocean that lay between Indian Gondwana Plate and Asia or the suture zone is intracontinental in origin. Further studies on Indus-Tsangbo Zone have thrown considerable light on the question of plate boundary. Similarly the data of offshore drilling and geophysical survey in coastal areas of India provide significant clues for outlining the Gondwana crustal plate along east and west coasts of India. A synthesis of all available information has been made for the reconstruction of Indian Gondwana Plate which is outlined in Text-figure 1.

NORTHERN MARGIN OF INDIAN PLATE

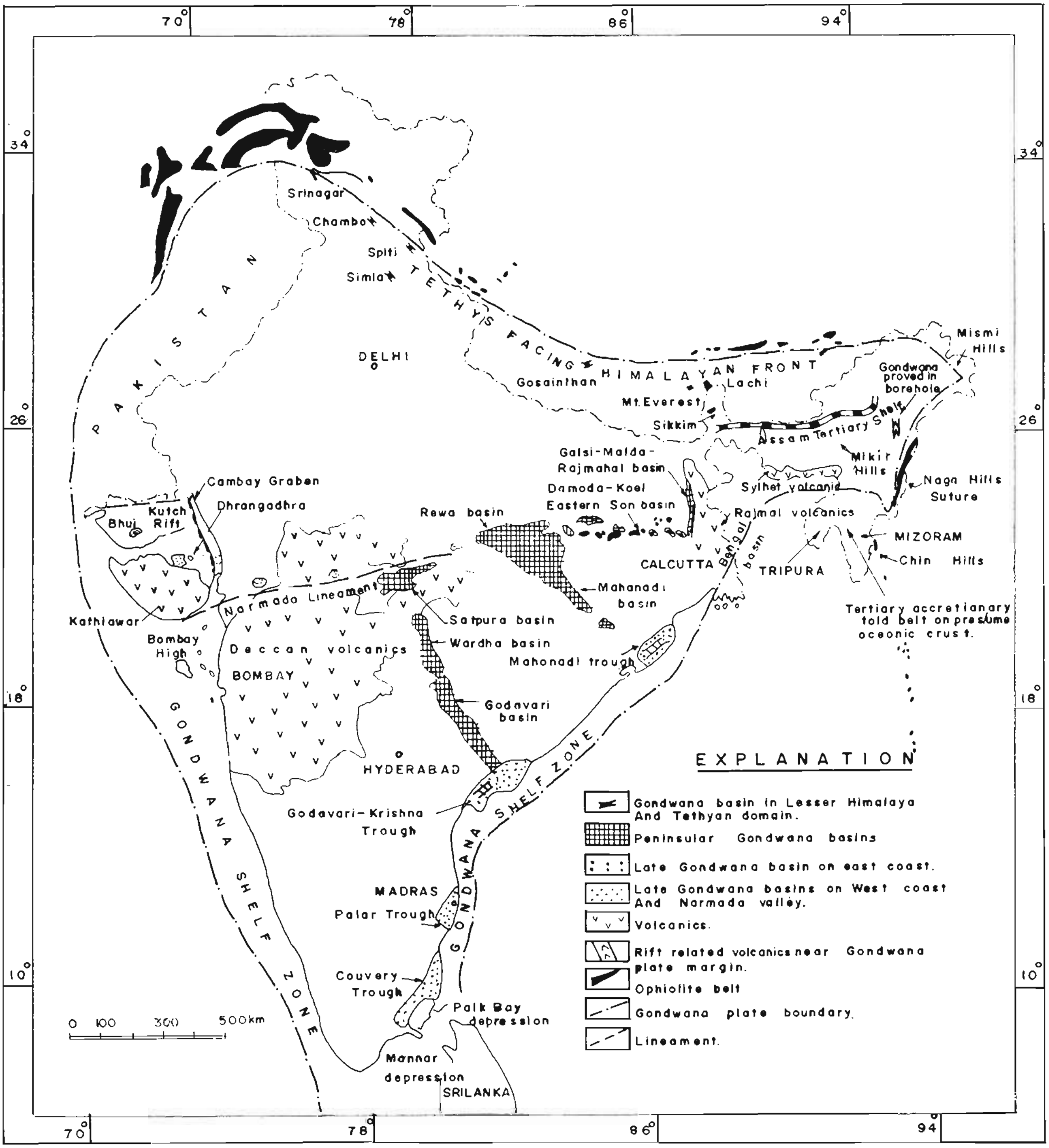
The northern and northeastern margins of Indian crustal plate are now occupied by two major geosutures exposing resurrected ophiolitic masses of ancient oceanic lithosphere. The Indus-Tsangbo suture of the north, however, can not be continuously traced around the northeastern tip of India into the ophiolite belt of Nagaland-Manipur. The physical continuity is disrupted in Miami Hills and it is a point of debate whether these two sutures are dislocated portion of the same belt, preserving the records of a single event of collision history or they represent two separate belts of different history. With the objective of reconstruction of Indian Gondwana Plate the critical information from these sectors are reviewed.

The ophiolite belt along Indus-Tsangbo Zone extends for 2,000 km along the upper reaches of the Indus-Yarlung-Tsangbo River. In this zone the dismembered suite of ophiolites is represented by tectonised harzburgite, layered gabbros, sheeted dykes and pillow lavas. A plutonic calc-alkaline belt known as Gangdise or Trans-Himalayan pluton follows the Indus Suture to the north over a distance of 2,000 km. The U-Pb ages substantiate that this magmatic activity lasted from 94 million years (Cenomanian) to 41 million years (Lutetian; Scharer *et al.*, 1984). South of the suture the Tethyan facies is characterised by a sedimentary sequence which formed in shelf environment on the Indian Shield. These comprise Palaeozoic-Mesozoic, richly fossiliferous shallow marine, largely neritic limestone with interbands of sandstone and shales. A characteristic facies of the Tethyan zone near the suture is a wild flysch horizon with exotic blocks ranging in age from Permian to Palaeocene as shown in Text-figure 2A. These exotic blocks are regarded to be olistoliths which have slid off the Tethyan carbonate shelf and have been tectonically incorporated within the sediments both during deposition and emplacement (Brookfield & Andrews, 1984).

There are three divergent opinions regarding the northward extent of the Gondwana continent vis-a-vis time of creation of the oceanic crust now represented in the Indus-Tsangbo Suture:

(i) The Tibetan Block is included as part of Gondwanaland (Stocklin, 1983) on the basis of occurrence of cold-water Permocarboniferous fauna and glossopterids in northern Tibet (Shang & Lee, 1974) in alleged glaciofluvial deposits. The common history ended in Late Palaeozoic when Tibet rifted away as a microcontinent, and got accreted to the Asian Plate which is indicated by the significant differences in sedimentary and tectonic history between Tibetan and Himalayan margin during Mesozoic.

(ii) The Indian Gondwana Plate extended up to the southern margin of Kunlun-Animaching mobile belt on the basis of geophysical data (Kaila & Narain, 1981).



Text-figure 1—Schematic outline of Indian Gondwana Plate showing plate margin along Indus-Tsangbo and Naga Hills suture zones. The plate boundary along coastal areas is drawn based on geophysical and offshore borehole data. **1**, Gondwana basins in Lesser Himalaya and Tethyan domain; **2**, Peninsular Gondwana basins; **3**, Late Gondwana basins on east coast; **4**, Late Gondwana basins on west coast and Narmada Valley; **5**, Volcanics; **6**, Rift related volcanics near Gondwana Plate margin; **7**, Ophiolite belt; **8**, Gondwana Plate boundary; **9**, Lineament.

(iii) The Indus-Tsangbo Suture is the northern limit of Gondwanaland and marks the location of closure of the tethys.

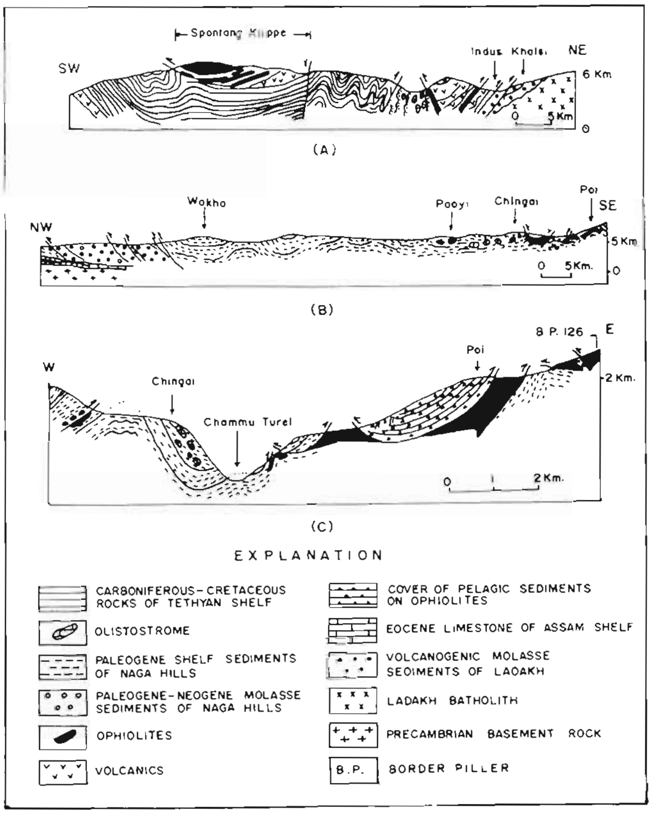
The first two opinions receive support from the doubts raised by workers about the existence of 6,000 km wide Tethyan ocean separating India from Palaeo-Asia (Stocklin, 1983). For delineation of Indian Gondwana Plate margin the evidences from this debated zone are re-examined. The find of Glossopteris Flora from northern Tibet has not been accepted by other Chinese geologists (Hsü, 1976). On the contrary Early Permian Cathaysian flora, discovered in the Lhasa Block, does not contain Gondwanic elements. The Rhaetian palynoflora from north of Lhasa shows close relation with the equatorial flora and lacks any Indian taxa (Allegre *et al.*, 1984). This find suggests that the Lhasa Block, which has been interpreted as part of 'Greater India', was actually situated near equator as early as Late Triassic.

The reported occurrence of *Lystrosaurus hedini* and *L. youngyi* from north of Tienshan in Tarim-Sino Korean Block is rather enigmatic. These remains of Lystrosauridae are comparable to those of India, South Africa, Antarctica and Laos (Zhang *et al.*, 1984). It is, however, quite striking that there exists a similarity between the Triassic vertebrates of South Africa and those of USSR for which migration via a circuitous route has been envisaged. On the same line it may be argued that the Triassic reptiles in China migrated from Russian segment of Angaraland. In other words, *Lystrosaurus* may be regarded as Pangean vertebrate. It is also to be examined whether the Lystrosaurus Fauna from different places of Northern Hemisphere document a history of parallel evolution (Dutta & Mitra, 1982). Upper Gondwana floral elements including *Elatocladus plana* and *Ptilophyllum* are reported from the area north of Indus Suture (Sharma *et al.*, 1980). These plants are, however, not strictly restricted to Gondwana Sequence as in Upper Jurassic-Lower Cretaceous Period the provincialism of flora is not clearly manifest.

The Cretaceous pole derived from Albian-Aptian red beds of southern Tibet placed the margin near Lhasa at a palaeolatitude of 11.5 ± 3°N (Phillippa & Achache, 1984). On the other hand, Eocene limestone sample from south of Indus Suture on northern margin of Indian Plate gives a palaeolatitude of 6°S. Based on palaeomagnetic studies it is visualised that northern margin of India collided with Ladakh island arc nearly 54 million years ago.

Seismic exploration of deep structures in Lhasa Block and bordering sutures shows that in the area to the north of Himalayas 70 km deep Moho can be traced at approximately that depth until it is abruptly terminated in the region of Yarlung-Tsangbo. Here 20 km change in Moho depth is recorded (Hirn *et al.*, 1984). This abrupt change in crustal thickness is consistent with the model of plate junctions and post suture strike slip movement. High heat flow values recorded from southern tibet are also in conformity with the data in old continental collision zones (Francheteau *et al.*, 1984).

The above evidences document that rocks with Gondwanic affinity *sensu stricto* never extended beyond the Indus Suture Zone. On the other hand,

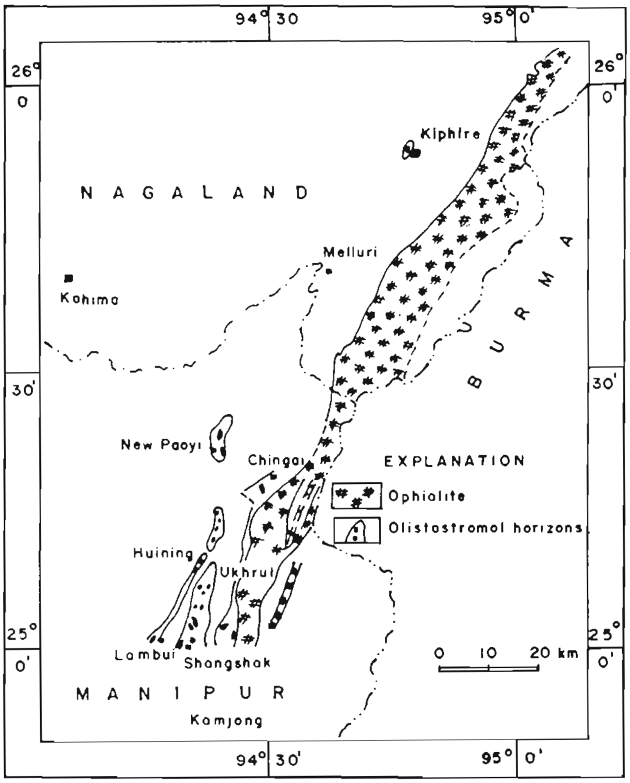


Text-figure 2—Geological sections across Indus Tectonic Zone and Naga Hills suture showing the disposition of olistostrome horizons and ophiolite bodies. **1**, Section across Indus Tectonic Zone, Ladakh; **2**, Section across Naga Hills; **3**, Section across the ;suture zone in Manipur, Naga Hills; **4**, Palaeogene-Neogene molasse sediments of Naga Hills; **5**, Ophiolites; **6**, Volcanics; **7**, Cover of pelagic sediments on ophiolites; **8**, Eocene limestone of Assam shelf; **9**, Volcanogenic molasse sediments of Ladakh; **10**, Ladakh batholith; **11**, Precambrian basement rock.

tectonic signature along the Indus Suture clearly points out that this zone marks the site of a collision. The calc-alkaline magmatism of Gangdise belt is therefore, a product of subduction of Tethyan oceanic lithosphere beneath continental margin of Asia. Evidently, Gondwanic India with its sedimentological and palaeontological entity extended northwards up to Indus-Tsangbo suture and the Himalayan front was the Tethys facing margin of Indian Gondwana Plate.

NORTH-EASTERN MARGIN OF INDIAN PLATE

In the northeast the only reported occurrence of Gondwana rocks of Talchir and Barakar formations is from Singrimari in the western tip of Meghalaya craton. However, the predominance of Lower Gondwana miospores from the younger Tertiary sediments of Upper Assam has indicated that



Text-figure 3—Map showing the distribution of olistostromal horizons in Manipur-Nagaland ophiolite belt. **1,** Ophiolite; **2,** Olistostromal horizons.

Gondwana rocks had earlier a wider spread on the Assam Shelf. Recently Oil and Natural Gas Commission has proved near Borpathar close to the western periphery of the Naga Hills, the glaciogene Talchir Formation of Gondwana Sequence at depth beneath the cover of younger Tertiary rocks. This find suggests that the domain of Lower Gondwana sedimentation encompassed the large segment of Upper Assam Shelf.

As the terrestrial Gondwana rocks and their homotaxial marine facies have mostly been denuded by pre-Tertiary erosion in Upper Assam Shelf and the adjoining continental margin to the east, it poses serious limitations in defining the plate boundary. Further, the Tertiary fold belts which have been accreted on the northeastern margin have added to the complexity of the problem. However, the recent analysis of stratigraphy and structure of Cretaceous-Tertiary rocks of Nagaland-Manipur gives a better insight into the problem of Gondwana Plate boundary.

MISMI HILLS SECTOR

Geological data from Mismi sector is rather scanty and it still remains an unknown gap in the jigsaw puzzle. On the basis of information collected during a couple of geological traverses in the area, attempts of palaeotectonic reconstruction have been made. The Indus-Tsangbo Suture gets lost eastwards in the complex structural set up of the Eastern Himalayan Syntaxis. Along Mismi Thrust, an accepted tectonic feature in the frontal belt, quartzites, and marbles override the Quaternary sediments. In Tidding Valley cutting across this Mismi pack of sediments, a highly folded limestone is flanked by a silver of sheared serpentinites. Further northeast, the metasediments are juxtaposed against a diorite granodiorite complex (Nandy, 1980; Chattopadhyay & Chakraborty, 1984). On the basis of this limited geological account contradictory tectonic models have been proposed. According to Acharyya (1981) the granite granodiorite complex possibly joins up with the Trans-Himalayan batholiths and the serpentinites correspond to the ophiolite belt of Mitkyina and Mandaley in Burma. Nandy (1980) postulates that the serpentinites represent ophiolite emplacement along palaeosutures and they have no linkage with Tsangbo Zone. Chattopadhyay and Chakraborty (1984), however, observed that the serpentinites are intrusive into the limestone, producing wollastonite. The diorite-granodiorite complex according to these authors shows intrusive relation with the Mismi metasediments. They have suggested a cryptic suture lying south of Tidding.

Correlation of the serpentinites with the ophiolites of Mogok belt of Burma appears unrealistic as the magmatic event in Mogok suite of Surma is characterised by rift related alkaline rocks (Goossen, 1978). The intrusive relationship shown by the serpentinites with the adjoining metasediments makes them unacceptable as an ophiolite association correlatable with any nearby ophiolitic rocks of the area. In the absence of any radiometric age for the diorite granodiorite complex, it is highly speculative to correlate the magmatic activity with Trans-Himalayan granitic events.

It is possible that these metasediments together with the serpentinite and the acid igneous rocks represent a cover transported along Mismi Thrust. As such, rocks of Gondwanic affinity if at all developed in the northeast periphery of the Indian Plate, are likely to be covered by this transported mass. The Gondwana Plate boundary, therefore, seems to be underneath the thrusted mass.

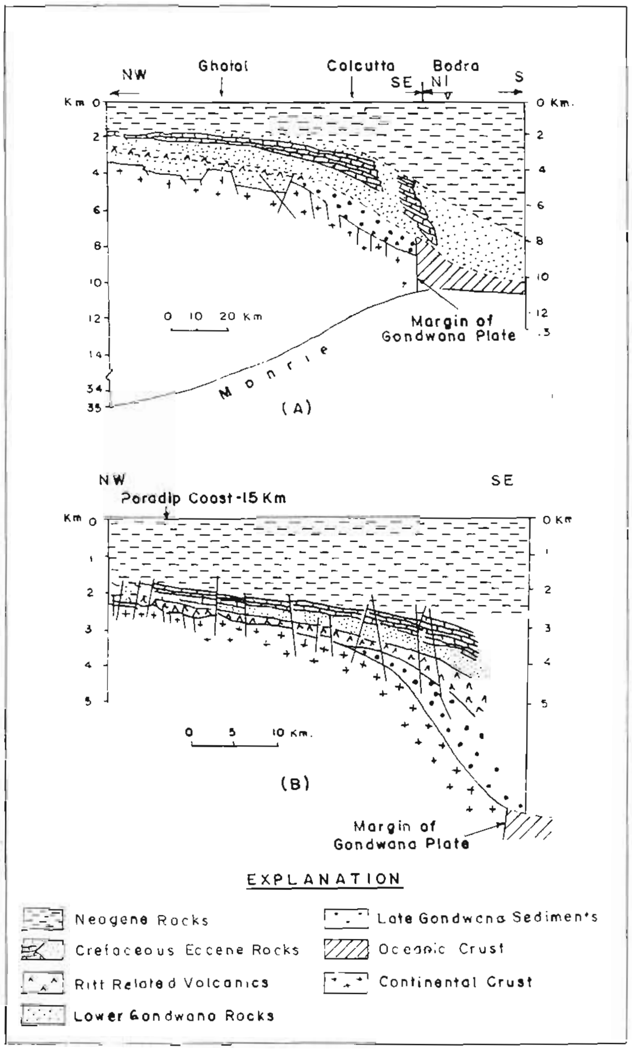
NAGALAND-MANIPUR SECTOR

The continental Gondwanas have recently been proved close to the western periphery of the Naga Hills. The Gondwana crustal plate, however, extended to the east beyond the confines of continental Gondwana basins. Precise delineation of plate margin involves an integrated study of the ophiolite melanges in Naga Hills, olistostromal bodies of Manipur-Nagaland and the rift related volcanics near plate margin.

Breaking up of Indian Plate from Gondwanaland plate mosaic in Lower Cretaceous period was accompanied by distension of the crust along the margin of the plate. This caused volcanism in the plate margin which is recorded in Koliajan and other places of Mikir Hills on Assam shelf. It is felt that the rift related volcanics in Mikir Hills are genetically linked with the Sylhet volcanics which have a large spread in the southern periphery of Meghalaya craton. The Sylhet Volcanics in turn join up across the Bangladesh subsurface with the Rajmahal volcanic suites of Bihar and Bengal Basin which is dated 100-105 Ma (McDougal & McElhinny, 1970). The Sylhet volcanics 250-600 m thick comprise predominantly tholeiitic basalt with subordinate alkali basalts, rhyolites and acid tuffs. Closely associated are alkali lamprophyre dykes in eastern Garo Hills.

The continental Gondwana and associated rift related volcanics of Mikir-Upper Assam Shelf are covered by a thick sequence of shelf sediments of Palaeogene age which are over-riden by tectonised and dismembered ophiolite suite of rocks in Nagaland Palaeogene age which are over-riden by tectonised and dismembered ophiolite suite of rocks in Nagaland and Manipur. The ophiolite suite includes tectonised peridotite, garnet Iherzolite, dunite, harzbargite, Iharzolite, ultramafic and mafic cumulates, plagiogranites, alkaline to tholeiitic volcanics with interbedded radiolarian cherts and pelagic limestone (Acharyya *et al.*, in press). The fossil assemblages of the radiolarian chert and limestones show mainly a Maestrichtian affinity though in Manipur the volcanics show Lower Eocene age based on the biota of interbedded limestones. Nevertheless, the thick sequence of volcanics, which are preserved in some segments of this belt, definitely point to an earlier age of the oceanic crust, may be Aptian-Albian. The ophiolites have a thick cover of oceanic pelagic sediments characterised by variegated shales and radiolarian cherts.

The Naga Hills ophiolite belt defines a prominent suture which is linked southward with Chin-Arakan-Andaman-Indonesian arc. This narrow tectonised belt is believed to represent the Palaeo-Tethys sea which was consumed during the collision of Indian Plate with the Eurasian Plate. In this suture zone the ophiolites are juxtaposed against rocks which show significant regional variation in their depositional environment. In Naga Hills, Eocene shelf deposits have been imbricated with the ophiolites during the obduction of oceanic lithosphere. On the other hand, along this suture zone in southern Burma and Andaman, the ophiolites are juxtaposed against rocks which were not deposited on the shelf of Gondwana continent. Rather they rest over the oceanic basement which was formed after the breakup of Gondwanaland. Here the present day plate edge lies along Sunda-Andaman arc and this tectonic zone from western flank of Mentwai-Nias Ridge has been traced northward into the young fold belts of Chittagong and Tripura (Roy, 1983). The adjoining Mizoram fold belt has also evolved from similar arc trench related subduction and subsequent continental accretion. Thus the resurrected oceanic crust of Palaeo-Tethys



Text-figure 4—Crustal sections across plate margin, **A**, Bengal basin; **B**, Mahanadi offshore area, Orissa. The cross sections show the limit of Gondwana crustal plate; **1**, Neogene rocks; **2**, Cretaceous-Eocene rocks; **3**, Rift related volcanics; **4**, Lower Gondwana rocks; **5**, Late Gondwana sediments; **6**, Oceanic crust; **7**, Continental crust.

is juxtaposed both against Gondwana crustal rocks as well as against young accreted fold belts along this arcuate Andaman-Nagaland. Suture. However, an orderly analysis of palaeoenvironment of the Early Tertiary sediments lying against the sutured edge of the ophiolite belt provides clues for the reconstruction of Gondwana Plate outline.

The most significant information for the reconstruction of palaeoplate margin in Nagaland-Manipur is provided by stratigraphically ordered olistostrome bodies which occur in a distinct belt flanking the outer edge of the suture from New Paoyi to Huining and from Chingai to Lambui in Manipur as shown in text-figures 2B, 2C and 3. To the north it extends up to Kiphire in Nagaland. This facies occurs in the upper part of Disang Formation (Eocene) which has a large spread as distal shelf facies on the northeastern periphery of Gondwana Plate. The majority of olistoliths are of limestone blocks which measure up to 150 m along the long axis. The blocks are composed of rocks of Maestrichtian (*Globotruncana*-bearing), Palaeocene and Middle Eocene (with Nummulites, *Discocyclina* biota) age. The olistostromal facies is usually formed in marginal trenches as a result of tectonic disruption of continental margin followed by a major phase of gravity sliding (Robertson, 1977). The age of this synorogenic rock is provided by youngest fossil record of the exotic blocks and as such a late Middle Eocene age for Naga Hill olistostromal deposits is suggested. Based on the distribution of olistostromal facies in autochthonous Early Tertiary deposits of Naga Hills it has been possible to define the palaeoplate boundary in northeastern India as these facies mark the site of ancient continental margin The occurrence of olistostromal bodies in identical tectonic level along the northern margin of Indian Plate close to Indus-Tsangbo Suture corroborates this approach of plate delineation.

SUTURING HISTORY

There has been a developing opinion of physical continuity of the Indus-Tsangbo Suture through Mismi Hills to Myithyina in Burma. It is further postulated that this suture, after an offset along dextral Sagaing transform fault, reappears in Naga-Chin Hills (Mitchell, 1984). This outline of the suture, which closely follows the Gondwana Plate margin, is based on certain presumed tenets. The new data emerging from present surveys are not in harmony with such an oversimplified model. Goossens (1978) suggests that in north Burma, which is essentially a region of Precambrian rocks, the Indus-Tsangbo Suture Zone and Naga Hills ophiolite belt are transected by ESE faults. As such the sutured edge of Gondwana Plate is often found to be disrupted by younger tectonic movements and the concept of a continuous peri-Indian suture line merits reappraisal.

Along the continental margin south of Indus Suture and west of Naga-Chin Hills there are changing scenes in depositional history. The rocks against which the oceanic rocks come to rest are different in various segments due to complex tectonic setting as seen in Text-figure 2. The northern Tethyan facies, south of Indus Suture, comprise mainly Triassic-Cretaceous rocks along with wild flysch which yield youngest fossils of Maestrichtian to Palaeocene age. In Manipur-Nagaland the ophiolites are juxtaposed against Disang Formation (Eocene). Often the western edge of the ophiolite in Naga Hills is marked by olistostromal units of Disang Formation. The exotics have youngest fossils of Middle Eocene age. In the Chin Hills, on the other hand, the olistostromal bodies associated with ophiolite belt are of Senonian and Upper Campanian age. The different ages of the tectonically controlled olistostromal deposits document that the ophiolites in different segments of continental margin were emplaced in different times. In fact, in Chin Hills the ophiolite was subducted, detached, emplaced and buried beneath the unconformity by Upper Albian times (Mitchell, 1984).

Further, in the arcuate Andaman-Naga Hills ophiolite belt the subduction is oblique as the polarity of the movement of the plate is at an angle to the trend of the suture while in the Indus Suture the polarity is towards the north. It is quite likely that the dynamism in the eastern fringe of Gondwana Plate could start only after the northerly movement of Gondwana Plate was hindered. Thus the suturing along Indus-Tsangbo Zone in Palaeocene time facilitated the oblique subduction in the eastern margin. The ocean floor data also suggests that Palaeocene was the time of change in relative plate motion in the entire Indian Ocean with the slowing of the rate of sea floor spreading (Sclater & Fisher, 1974).

In short, the suturing of the Gondwana Plate along the Indus-Tsangbo Zone and the oblique subduction in Naga Hills are in a sequential order which is in harmony with the motion of Gondwana Plate. But the Chin Hills document a much earlier history of emplacement unrelated to Gondwana plate margin and this may be a manifestation of intra plate (Burmese Plate) suturing. The occurrence of another ophiolite belt to the west of Chin Hills in Haka probably corroborates this postulate The Late Tartiary tectonic history with accretion of fold belt to the continents imposed a broad linearity in the lay of ophiolite belt of Naga Hills and Chin Hills despite their independent evolutionary trends in different plates.

PLATE MARGIN ALONG EAST AND WEST COASTS

The delineation of plate boundary along east and west coasts has been made after an orderly analysis of the rifting episode. The rifting history of Indian Gondwana Plate along coastal areas is documented by an evolutionary sequence of uplift, rifting and uplift generated triple junction formation leading to continental break up. The Godavari-Krishna coastal trough on the east coast for example, represents the rifted arm during the continental fragmentation while the main Godavari-Gondwana Basin behaved as failed arm (Dutta & Mitra, 1982). On the west coast the Gulf of Cambay is, likewise, considered to be a triple junction with Cambay Graben as a failed arm. The high geothermic gradient in this region and occurrences of extensive volcanic plugs testify to the mantle plume activity in triple junction formation (Biswas & Deshpande, 1983).

Along the east coast, Aptian-Albian period of basin formation corresponds to the fragmentation history of Gondwana Plate. This involved fundamental changes in basement mosaic. In Cauvery, Palar and Godavari-Krishna coastal basins, down to basement faults define a series of horsts and grabens which are aligned NE-SW paralleling the present configuration of the coast (Kumar, 1983). The separation of Indian continent from eastern Gondwanaland evidently occurred in a NE-SW direction.

The seismological data and other surface and subsurface information from Godavari-Krishna Basin reveal that Late Gondwana (Lower Cretaceous) and younger Mesozoic sediments fill all the fault bounded depressions. Their deposition was evidently in response to the periodic marine transgressions from the juvenile Indian Ocean. Succeeding the deposition of Lower Cretaceous Gondwana sediments and younger cover rocks, the basinal area witnessed volcanic episode (Rajamundri Volcanics) in Maestrichtian period.

The Cauvery coastal basin is likewise segmented into a series of NE-SW trending horsts and grabens. The Palk Bay depression and Mannar depression of Cauvery Basin separating India from Sri Lanka are such pericratonic rift basins which evolved in response to the distension in the crust accompanying the fragmentation of Indian Gondwana Plate. This rifting episode is also characterised by thinning of the crust to induce volcanism. The volcanic rocks have been proved beneath the Upper Cretaceous sediments in a bore hole drilled in Gulf of Mannar.

In Mahanadi Shelf area in Orissa, a series of highs and lows aligned in NE-SW direction along continental shelf edge has been detected by bouguer gravity survey. The gravity high trend is interpreted to be a reflection of crustal changes from continental to oceanic type (Jagannathan *et al.*, 1983). Evidently the Gondwana continental margin runs along the zone of crustal change as shown in Text-figure 4B. The shelf margin of Gondwana Plate appears to represent a pull apart type of basin paralleling the coast line based on seismic refraction data. Here Late Gondwana sediments are closely associated with volcanics. Thus basin formation after the rifting is closely linked with a synchronous volcanic episode.

In the onshore Bengal Basin, the seismic survey shows a distinct basin architecture for Late Gondwana sediments as indicated in Text-figure 4A. The strong reflectors beneath the trap constitute the Late Gondwana sediments preserved in NE-SW trending troughs (Roy Burman, 1983). Similar morphotectonic configuration of Late Gondwana basins is envisaged in respect of Upper Assam Shelf

This analysis charters a continuous spatial distribution of the Late Gondwana coastal troughs and rift related volcanic episode which permits a precise delineation of the boundary of Gondwana crustal plate.

The rifting history of Indian Gondwana Plate in Early Cretaceous left similar tectonic signature along the west coast of India. The entire western shelf is segmented by NW-SE to N-S faults into many horsts and graben structure. This style of faulting shaped the architecture of newly evolving basins of Late Gondwana sediments.

The earliest history of rifting in Jurassic period is documented in the Kutch Peninsula followed by creation of rifted Cambay and Barmer basins in Lower Cretaceous. The phase of crustal fracturing, basin formation and marine transgression in Kutch commenced in Bathonian-Oxfordian period (Biswas & Deshpande, 1983). During Lower Cretaceous (Aptian) the basin witnessed shallow deltaic environment of deposition favouring accumulation of Umia beds with Upper Gondwana floral elements.

The rifting along the west coast led to the evaluation of Cambay Graben in Lower Cretaceous period. This basin is differentiated into uplifts and depressions and has morphotectonic configuration comparable with that of east coast Late Gondwana basins. The basin formation in Saurashtra denotes a coeval event. Here the deltaic sedimentation on newly evolved shore line commenced in Early

Cretaceous period. This history of basin opening in Jurassic-Lower Cretaceous period in Kutch-Saurashtra is closely related with the volcanism, which evidently predates the main phase of Deccan Trap volcanicity. The earliest manifestation of Deccan volcanism in western India is recorded from Saurashtra which is dated as 101 ± 3 million years (Alexander, 1981). In a bore-hole near Dhandhuka in Saurashtra, several older basaltic layers were also recorded below the main Deccan Trap flows with intervening parting of sandstones (Biswas & Deshpande, 1983). In other words rifting history of Indian Plate along western margin is linked with a phase of pre-Deccan Trap volcanism. The ocean opening and basin formation on Kerala Coast shows a close temporal relation. Here the presence of infratrappean deltaic sequence of Early Cretaceous age testifies to synchronous rifting history.

Thus the palaeogeographic and structural changes along the east and west coasts in Early Cretaceous period were manifestation of the similar response of Indian Gondwana crustal plate to the rifting event.

SYNTHESIS

On the basis of the geological evidences presented so far the following conclusions can be drawn:

(i) On the basis of newly acquired information the outline of the Indian Gondwana Plate in the north-eastern sector can be precisely drawn along the zone of olistostromal deposits which convincingly mark the margin. The northern margin of the Indian Plate is also drawn on the basis of identical reasoning.

(ii) The olistostromal deposits point out that the trenchal deposits along northern margin of India formed earlier than those along the northeastern margin. It is possible that closure of Tethyan Ocean in the northern margin starts an easterly journey of the Indian Plate when suturing along the northeastern margin takes place.

(iii) Along the eastern suture varying tectonic domains are juxtaposed and like the northern margin this zone does not mark the Indian Gondwana margin plate boundary all through its length. This is true for the Nagaland-Manipur sector but in Andaman it marks a subduction zone along which ocean floor created during and after Gondwana rifting is being destroyed. Here the margin of Indian Gondwana domain lies much to the west near the Indian coast line. The ophiolites of Chin Hills document a much earlier history of emplacement, unrelated to Gondwana Plate margin.

(iv) The geophysical and drill data show a unified history of rifting along the east coast. The offshore gravity high parallel to Indian coast marks the crustal change from continental to oceanic type. Lower Cretaceous volcanic rocks, which are possibly rift related, are often associated with the Late Gondwana sediments. The coastal basins are fault bounded and preserve Lower Cretaceous Gondwana sediments and younger covers. It is evident that during rifting of India from the Gondwana mosaic, its marginal parts suffered tension producing fault generated depression and contemporaneous volcanism. The proto-Indian ocean inundated these depressions forming the coastal basin. This together with the parallel gravity high precisely mark the outline of the Indian Gondwana Plate.

(v) The development of Kutch, Cambay and Barmer basins along the western margin of India indicates a history of rifting identical to that of the east coast. The Lower Cretaceous stratigraphy of Cambay and Saurashtra basins suggests that happenings along both east and west coasts are contemporaneous. The Jurassic record in the Kutch peninsula points out that rifting along the west coast of India might have started earlier in certain segments and the rift generated depression of Kutch was innundated by the proto-Arabian Sea during Jurassic period.

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Extra-peninsular 'Gondwana' basins—stratigraphy and evolution

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The stratigraphy and evolution of the plant-bearing horizons of the extra-peninsular region are reviewed and their similarities and differences with typical peninsular Gondwana are discussed to assess the problem of concepts, limits and extension of Gondwana in this region. It is inferred that the Lesser Himalayan Sequence represents continuation of the peninsular Gondwana Sequence, while that of Tethyan Himalayan region departs from typical mainland Gondwana in sedimentation, flora and geological set up. Thus the use of the informal stratigraphic term Gondwana Sequence for this belt is not justificable. However, the use of the term in palaeogeographic sense, which is widely used appears to be appropriate; for which the term 'Peri-Gondwana' has already been suggested. The evolution of floral beds may be related to the major tectonic events, the imprints of which are well documented in the Tethyan belt.

Key-words—Stratigraphy, Palaeogeography, Peninsular Gondwana (India).

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साराँश

बाह्य-प्रायद्वीपीय गोंडवाना द्रोणीयाँ—स्तरविन्यास एवं विकास

हरी मोहन कपूर एवं गोपाल सिंह

बाह्य-प्रायद्वीपीय क्षेत्र के पादप-धारक संस्तरों के स्तरविन्यास एवं विकास की समीक्षा की गई है तथा इस क्षेत्र में गोंडवाना की अवधारणा, सीमायें एवं विस्तार की समस्या के निर्धारण हेतु सामान्य प्रायद्वीपीय गोंडवाना से इनकी सजातीयताओं एवं विभिन्नताओं की विवेचना की गई है। ऐसा अनुमान है कि लघु हिमालय अनुक्रम प्रायद्वीपीय गोंडवाना अनुक्रम की निरन्तरता का निरूपण करता है जबकि टॅथीय हिमालय क्षेत्र भूवैज्ञानिक स्थिति, वनस्पतिजात एवं अवसादन में सामान्य गोंडवाना मुख्यभूमि से पृथकता प्रदर्शित करता है। अतएव इस पट्टी के लिए अनौपचारिक 'गोंडवाना अनुक्रम' शब्द का प्रयोग उचित नहीं है। तथापि, पुराभौगोलिक दृष्टिकोण से इस शब्द का प्रयोग उचित प्रतीत होता है जिसके लिए 'पैरी-गोंडवाना' शब्द पहले से ही प्रस्तावित है। वनस्पतिजातीय संस्तरों का विकास प्रधान विवर्तनिक घटनाओं से सम्बद्ध किया जा सकता है और इसके प्रमाण टॅथीय पट्टी में भी सुपरिरक्षित हैं।

THE plant-bearing horizons of Palaeozoic-Mesozoic times in the extra-peninsular region, particularly in the Tethyan Himalaya, occur in the marine domain, unlike those of Gondwana of the peninsular region, where they are essentially of glacio-fluvial, fluvial and fluvio-lacustrine environment and continental in nature. In fact, Himalayan occurrences have been included under Gondwana due to the presence of Gangamopteris and Glossopteris flora. Inclusion of Tethyan Himalayan sequences under Gondwana also received support in the presence of diamictite and associated *Eurydesma* and Sakmarian marine fauna known from peninsular region and being so characteristic of other Gondwana countries.

Concepts, limits and extension of the Indian Gondwana
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To the contrary, the Tethyan Himalayan sequence could be different from that of peninsular region due to the fact that the flora contains some elements which have affinity with the northern floras and the beds have a different stratigraphic set up with younger marine basement unlike in the Peninsula where it is always Precambrian. The lithology of the Himalayan beds has no genetic relationship with the peninsular Gondwana and have different environmental history. Further, there is no established continuity of Himalayan sequence with any of the peninsular sequences except linkage through marine beds which bear *Eurydesma* fauna.

In this paper, the distribution and stratigraphy of various plant-bearing horizons of extra-Peninsula, their comparison with peninsular occurrences in general and the evolution of plant horizons are discussed with the objective to assess the problem of concepts, limits and extension of Gondwana in this region.

DISTRIBUTION OF FLORAL HORIZONS

The plant beds in extra-Peninsula are known both in the Lesser and the Tethyan Himalayan belts. Rocks of the Gondwana Sequence in the Lesser Himalaya occur tectonically emplaced between Neogene-Quaternary deposits and Precambrian formations. They are developed semicontinuously from central Nepal to Arunachal Pradesh and mainly represent Lower Gondwana Sequence except a solitary record of Upper Gondwana in Tansen area of Nepal. From the Lesser Himalaya of Uttar Pradesh, and Himachal Pradesh no definite sequence of Gondwana is known. Blaini rocks which were earlier equated with the Gondwana, have lately been dated as Precambrian. The reported occurrence of the plants from Nainital area from Infra-Krol has also been questioned. However, the diamictite of Lower Bijni Unit of Garhwal sequence which has Lower Permian marine fauna is significant and worth mentioning though no overlying plant-bearing horizons are developed.

The northern Tethyan Himalayan belt, with an almost complete Proterozoic-Mesozoic, dominantly marine sequence, is stretched from Kashmir-Ladakh to Bhutan and encompasses a number of sedimentary basins (Text-fig. 1), such as, Kashmir, Pira-Mandi, Kumaon, Nepal, Lachi (Sikkim), Lingshi (Bhutan), etc. All these basins lie south of the Indus Suture Zone except Karakoram Basin lying north of the Indus Suture. Several plant-bearing horizons are known from this belt but Kashmir and Spiti show better development of different Palaeozoic floral beds. Jurassic-Lower Cretaceous flora, however, is known from Nepal, Bhutan and Karakoram basins.

There are a few breaks and hiatus in the Tethys Himalaya related to the tectonism which might have played some role in the development of these plant beds. One such important event is referred as Hercynian gap, represented by complete absence of Carboniferous in Kumaon and Salt Range. Transgression and regression of the sea in the basins are demonstrated by different sequence of plant and marine horizons in the Lower and early Middle Carboniferous sequence of Kashmir and Spiti.

STRATIGRAPHY OF LESSER HIMALAYAN GONDWANA

The Gondwana Sequence in the Lesser Himalaya unconformably overlies the Precambrian metasedimentaries and is mainly developed in the Eastern Himalaya in the Daling Basin. They are traceable almost continuously from foot-hills of Darjeeling to Siang District of Arunachal Pradesh. They are mainly Permian in age. West of the Daling Basin, however, they are known from eastern and central Nepal, where Permian and Jurassic/Lower Cretaceous floras corresponding to Lower and Upper Gondwana are developed.

Arunachal Pradesh

Gondwana beds in Arunachal Pradesh are developed in a linear and narrow belt, 300 km long, in the districts of Kameng, Subansiri and Siang and unconformably overlie the Miri Buxa Formation. They are composed of Rangit Pebble Slate, Rilu Formation (=Garu Formation with lower Rilu Member and upper Bomte Member of Singh, 1987), Gensi Formation and Bhareli Formation (Tripathi & Roy Chowdhury, 1983). The last three formations have been grouped under Dumuda Subgroup.

The basal diamictite, Rangit Pebble Slate, about 300 m thick, comprises pebbly to gritty slates and lithic wackes, quartzites, pyritous and carbonaceous argillites, rhythmites, volcanoclastics and marl. A persistent fenestellid bryozoa dominated fauna has been traced for about 50 km in the Kameng District. The assemblage comprises *Fenestella, Polypora ampla, Geinitziella*, brachiopods, bivalves, crinoids, etc. (Acharyya *et al.*, 1975). *Eurydesma, Schizodus*, etc. are also known from Khuppi locality.

The overlying Rilu Formation developed in Siang and Subansiri districts is about 300 m thick and composed of black carbonaceous shale. It contains in the lower part *Eurydesma-Deltopecten* Assemblage and in the upper part *Linoproductus-Uraloceras* Assemblage with *Stepanoviella, Warthia*, etc. (Tripathi & Singh, 1987). From this formation

Parasaccites - Plicatipollenites - Cannanoropollis Assemblage of Talchir and *Callumispora-Parasaccites-Potonieisporites* Assemblage of Karharbari have been recognised (Singh, 1979, 1987).

In Kameng District, the oldest unit, Khelong Formation is composed of shale, marl, calcareous sandstone, feldspathic wacke and contains *Glossopteris* and *Gangamopteris*.

The succeeding 300 m thick Gensi Formation represents oscillatory deltaic facies (Tripathi & Singh, 1987) and is composed of sandstone and slaty shale with occasional marine fossils. The youngest Bhareli Formation represents continental fluvial facies (Acharyya *et al.*, 1979; Tripathi & Singh, 1987) and is composed of sandstone, siltstone, shale containing coal lenses and associated Rotung volcanics. Shales contain *Glossopteris, Vertebraria, Phyllotheca, Schizoneura, Palaeovittaria* and remains of labyrinthodonts. Bhareli group of rocks is considered to be of Late Permian age. A recent record of northern element from Arunachal Pradesh has come to notice (pers. comm. Dr S. K. Acharyya). Abor Volcanics associated with the Gondwana is another significant feature of this part of the Himalaya.

Bhutan

The Bhutan Gondwana is a continuation of the Arunachal sequence. Arenaceous and carbonaceous Damuda Subgroup overlies the Diuri Pebble Slate (=Rangit Pebble Slate) both in eastern and western Bhutan. Damuda Group, however, underlies the diamictite (Jangpangi, 1974). Acharyya *et al.* (1979) consider that reversal of sequence is due to tectonism otherwise stratigraphic polarity is normal. The Gondwana Sequence is composed of coal-bearing quartzite sandstone, carbonaceous slates, calcareous slates and marl containing Lower Gondwana plants. In Dewathung area, east Bhutan fenestellid bryozoans and gastropod-bearing calcareous nodules occur within the carbonaceous shale. Khelong and Bhareli formations of Arunachal Pradesh are believed to continue in Bhutan. The presence of plant fragments and spores of Gondwana is also known from northwestern Bhutan (Gansser, 1984).

Sikkim

The Gondwana represented by the lower Rangit Pebble Slate overlain by the Damuda Sandstone is developed in Rangit Valley, where they are exposed in a tectonic window beneath the overthrusting Daling and Darjeeling metamorphites. The Rangit Pebble Slate is composed of diamictite. Marine fossils reported from Khemgaon and Wak areas of West Sikkim include *Fenestrellina, Protoretepora, Eurydesma, Neospirifer moosakhailensis, Ambikella fructiformis*, etc.

Damuda sandstone is composed of feldspathic sandstone, micaceous siltstone, black laminated siltstone with plant fossils and thin seams of crushed coal. From Khemgaon *Glossopteris, Vertebraria, Schizoneura* and *Phyllotheca* are known. There are also records of older *Glossopteris-Gangamopteris* Assemblage at places (Acharyya *et al.*, 1979).

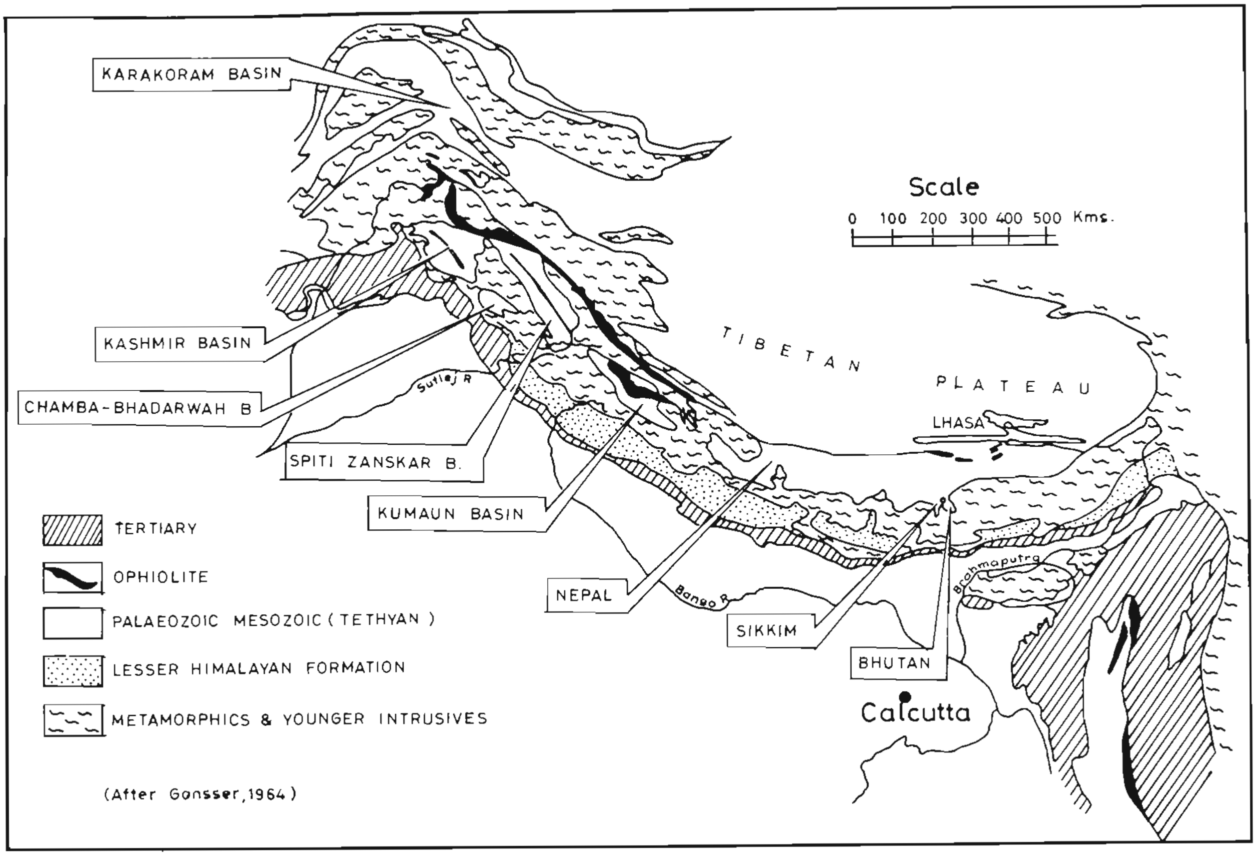
Darjeeling

Darjeeling is the western extension of Arunachal Gondwana. *Eurydesma* in association with *Praeundolomya, Wilkingia, Leptodesma*, etc. was reported from Rangit Pebble Slate of Tindharia in Darjeeling area (Acharyya, 1973). From Damuda Sandstone a rich flora comprising *Phyllotheca, Glossopteris* and *Vertebraria* is known (Acharyya, 1973). The palynological assemblage indicates a Late Permian age.

Nepal Lower Himalaya

Lower Gondwana diamictite with coal-bearing Damuda and Upper Gondwana with volcanics, both are known from Lower Himalaya of Nepal. Crinoid stems have been reported from diamictite associated with slates and conglomerates, black quartzite and streaks of coal from north of Butwal in central Nepal (Singh, 1973). Damuda Sequence, however, is developed in the lower gorge of Sapt Kosi River in eastern Nepal and extends further west in central Nepal. It is composed of coal-bearing sandstone and is underlain by boulder bed. Plants are known from Barahkshetra and miospore *Vittatina* and tracheids from north of Butwal.

Lower and Upper Gondwana have been reported recently by Sakai (1983) in the Tansen area of west central Nepal. Upper Gondwana designated as Taltung Formation of the Tansen Group is composed of basic rock, conglomerate and shale. The formation is divided into two members. The lower member is characterised by cyclic sedimentation of conglomerate, sandstone and shale and the upper member by rhythmic alternations of sandstone and shale. A rich flora composed of *Ptilophyllum, Pterophyllum* and *Elatocladus* is known from siltstone layers of the conglomerate of the lower member. Underlying the Taltung Formation, the Sisne Formation comprises diamictite and black shale of glacial influence. Plant remains are known from this formation and is correlative with the



Text-figure 1—Palaeozoic-Mesozoic basins of Tethys Himalayas.

glacio-fluvial Lower Gondwana. Bryozoans have also been found in the floating blocks (Kapoor & Tokuoka, 1985).

Garhwal Lesser Himalaya

In Bijni nappe, part of the Garhwal nappe, the Boulder Slate sequence called Bijni Tectonic Unit contains a rich marine fauna comparable with that of Agglomeratic Slate of Kashmir. The fauna, worked out by Chaturvedi and Talent (1971), Ganesan (1972), Shanker and Ganesan (1973), Shanker *et al.* (1973), Waterhouse and Gupta (1978) and Bhatt and Singh (1981), contains bryozoa, brachiopods, gastropods, bivalves, etc. Gupta and Visscher (1980) also reported Lower Gondwana palynomorphs.

PRE-GONDWANA AND GONDWANA SEQUENCE IN TETHYAN HIMALAYA

In the Tethyan Himalayan sector, the Palaeozoic-Mesozoic plant-bearing strata can be grouped into three types, (i) with well-developed megaflora and referred as floral beds, (ii) which include fragmentary plant remains, particularly woods and twigs associated with marine fauna, and (iii) marine strata which have yielded palynoflora. Sediments with continental megaflora are mainly important and have been taken into consideration in developing geological history.

The Himalaya including Salt Range and Trans-Indus ranges in Pakistan, according to Nakazawa and Kapoor (1979), represents peri-Gondwana province of Central or Middle Tethys. Here Early Permian sediments have Gondwanic faunal and floral elements, and are succeeded by Late Permian to Jurassic Tethyan sediments.

In this belt, two distinct floras, viz., the pre-Gondwana flora of Devonian-Carboniferous age and "Gondwana" flora of Permian and Mesozoic age are developed.

PRE-GONDWANA FLORA AND ASSOCIATED FORMATIONS

Kashmir Basin

Devonian—The earliest records of plants are from post-Muth sequence, the Aishmuqam Formation (Singh *et al.*, 1982; Tripathi & Singh, 1984). This formation is divisible into two members. Member A is represented by variegated quartz-arenite with blotchy siltstone and Member B by light yellowish and greenish siltstone with thinly to thickly bedded intercalations of quartz-arenite. The light-coloured siltstone of Member B has yielded *?Protolepidodendron* and *?Taeniocrada* at Kotsu Hill, Diuth Spur and the Spur near Ayun in the Liddar Valley. No associated marine fauna has so far been recovered from this formation.

The overlying Syringothyris Limestone contains Tournaisian conodonts and brachiopods while the underlying Margan Shale contains Devonian brachiopods.

Carboniferous—Three formations, namely, Syringothyris Limestone, Fenestella Shale and part of the Agglomeratic Slate (Diamictite division) are included in the Carboniferous. The last formation will be discussed with the Gondwana.

Syringothyris Limestone has been divided into three members by Singh *et al.* (1982). Member A is yellow-weathering arenaceous limestone with partings of shale and quartzarenite. Member B comprises mainly bedded dark limestone and contains Tournaisan brachiopod fauna. Member C is characterised by limestone, arenite and shale. This member is divisible into four units. Flora has been reported from middle unit of Member C of Syringothyris Limestone throughout the Liddar Valley but important localities are Kotsu Hill, Gokhan gali and Ichhnar Spur. The assemblage includes *Lepidodendropsis fenestrata* and *Palmatopteris* cf. *furcata* and has been dated as Visean on the basis of fauna of the overlying and underlying strata.

Fenestella Shale has also been divided into 4 members (Singh *et al.*, 1982). Member A, referred as Passage Bed by Middlemiss (1910) and Gund Formation by Pal (1978), is dominated by quartz-arenite with shale/siltstone intercalations. Member B, dominated by shale and siltstone with bands of arenite, contains marine fossils. Member C, characterised by arenite with shale intercalations, lithologically resembles Member A and is well-exposed at Wallaroma in Liddar Valley. Member D is similar to Member B and rich in marine fauna. Members A and C contain plant fossils and represent regressive phases. Plant assemblage in both the members is similar and is found at Wallaroma, Kotsu, Gaos, Manigam, etc. in the Liddar Valley and at Gund in Banihal area. They have been dealt in detail by Pal (1978), Pal and Chaloner (1979) and Singh *et al.* (1982). Floral assemblage of Fenestella Shale is more like that of Lower Carboniferous assemblage from Po Series of Spiti (Høeg *et al.*, 1955; Dhar *et al.*, 1980) and has been assigned mid-Visean Bashkirian age based on the fauna from Member B and D.

Spiti Basin

Devonian—From the basal and top portions of the Takche Formation some doubtful plant remains are reported. Some doubts have been expressed on their botanical affinity (Tripathi & Singh, 1982) and as such are not dealt in detail. The age of the formation ranges from Ordovician to Early Devonian.

Carboniferous—The Carboniferous Po Formation of Spiti contains Lower Thabo Member characterised by shale and quartz-arenite followed by Upper Fenestella Shale Member with bryozoans and brachiopods of marine affinity. Floral assemblage from Thabo includes *Rhacopteris, Sphenopteridium, Rhodeopteridium* and lycopsids (Høeg *et al.*, 1957; Dhar, 1980).

LOWER 'GONDWANA' AND ASSOCIATED BEDS

In the Tethyan belt, mainly Permian plant-bearing horizons comparable to Lower Gondwana of Peninsula are developed in different basins. Permian sequences are widely distributed throughout the Tethyan belt, though development of plant beds is confined to Kashmir, Thanamandi-Pira, Bhallesh-Chamba and Karakoram basins. The advent of Permian is a major biological event and begins with the beds having *Eurydesma-Deltopecten* and *Taeniathaerus-Stepanoviella* assemblages, which are considered to be related to Gondwanic realm and show a regional development in Himalaya. The recent find of these beds from Kumaon (V.D. Mamgain & R. S. Mishra, pers. comm.) has also bridged the gap. These are succeeded by plant-beds with Lower Gondwana flora and both these successions represent up to basal part of Kungurian. In Kashmir, the contact between Lower Permian and Upper Permian is para-unconformable and is true for other parts of Tethyan Himalaya also (Kapoor & Tokuoka, 1985). The hiatus in between represents missing of strata of "Middle Permian".

Kashmir Basin

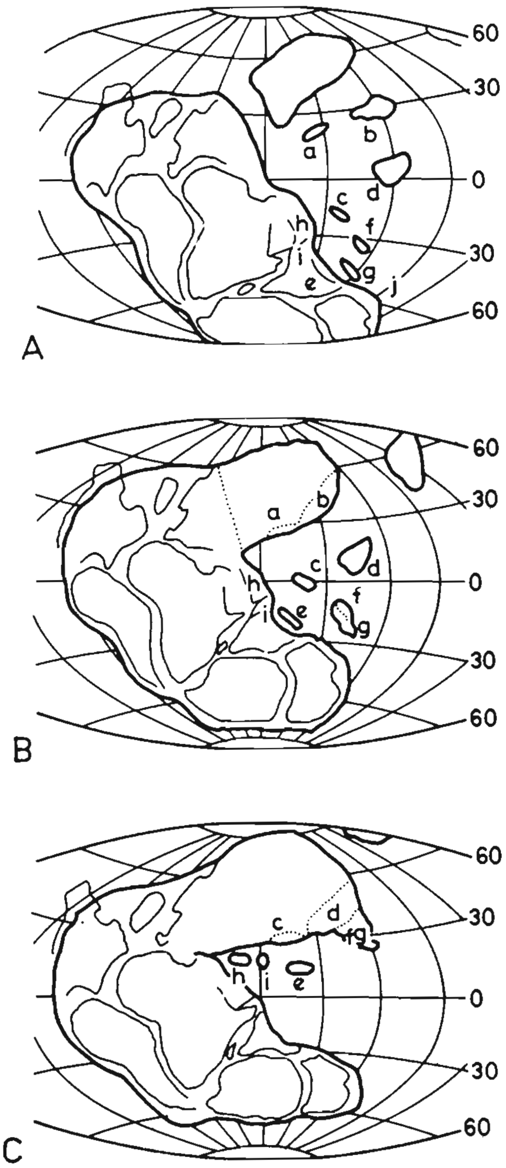
The Panjal Group (Kapoor & Nakazawa, 1981) includes Agglomeratic Slate, Nishatbagh Formation, Panjal Volcanics and Mamal Formation in ascending order (Kapoor, 1979; Kapoor & Shah, 1979; Singh *et al.*, 1982; Tripathi & Singh, 1987). The formations of this group are formed by the effect of composite diastrophic changes in the basin (Nakazawa *et al.*, 1975). Panjal Group is overlain paraunconformably by Vihi Group of marine rocks ranging in age from Late Permian to Jurassic.

Agglomeratic Slate is a marine succession with several faunal zones occurring at different stratigraphic levels. Nishatbagh and Mamal formations contain continental flora. Panjal volcanics show a mixed nature of subaerial and subaquous deposition and contain many intertrappean layers of slates and limestones. Limestone intertrappean exposed at Barus Spur contains marine brachiopods (Middlemiss, 1909), which suggest that marine influence existed at times during the volcanic episode.

Agglomeratic Slate is widely distributed and has been divided into lower 'diamictite' and upper 'pyroclastic' division. Diamictite division is composed of varied lithology of immature sediments grouped under diamictite and include grits, grey wacke, slates, boulder slates, etc. The upper division is composed of tuffaceous slates with cinders and volcanic bombs. There are a number of flows within this formation. Late Asselian *Eurydesma-Deltopecten* assemblage is known from various localities, viz., Bren (near Srinagar), near Virseran in Liddar Valley and near Kulgam in Pir Panjal, 30 m below the top of the diamictite division and at times contains fossil wood.

Very little is yet known of the fauna of the Agglomeratic Slate below *Eurydesma-Deltopecten* Zone, except that of *Syringothyris cuspidata* var. *lydekkeri* Zone in the lower horizon in the Marbal Valley, and is considered to be Muscovian (Late Carboniferous) by Bion and Middlemiss (1928). Recently one of us (GS) has encountered another lower horizon in Liddar Valley containing Deltopectenid bivalves of Lower Permian affinity suggesting the possibility of an Upper Carboniferous hiatus. From the upper part of the Agglomeratic Slate of Budil—Pir—Parasing area of Pir Panjal (=Nishatbagh Formation of later workers), Sharma (1976) reported a thick plant bed containing *Rhacopteris* as well as *Gangamopteris* in different layers from Parasing-Gurwatan area. The occurrence of these two elements of different floras together is interesting but need more detailed field studies. Recently Verma *et al.* (1986) brought to light the occurrence of *Rhacopteris, Triphyllopteris* and calamean stems from Fenestella Shale of the same area. This raises the question whether *Rhacopteris* continued in Kashmir in much younger horizons and if so what is its relationship with the marker horizon of Late Asselian faunal zone, as Nishatbagh from available data is not older than Artinskian. Tripathi and Singh (1984) have already pointed out a floral hiatus in Late Carboniferous.

The Nishatbagh Formation overlies the "pyroclastic division" characterised by *Taeniathaerus, Buxtonia, Praeundolomya, Bucaniopsia-Warthia* assemblages representing Sakmarian and Early Artinskian (Nakazawa & Kapoor, 1979). The stratigraphic sequence described as



Text-figure 2—Reconstruction of the palaeogeography (after Nakazawa, 1985). **A.** Early Permian, **B.** Latest Permian, **C.** Late Triassic. **a:** Tarim block, **b:** Sino-Korea block, **c:** Quangtang block, **d:** Yangtze block, **e:** Lhasa block, **f:** Indo-China block, **g:** Malaya block, **h:** Central Iran block, **i:** Central Afghanistan block, **J:** Timor.

Nishatbagh Bed by Kapoor (1977) has been redefined by Singh *et al.* (1982) as Nishatbagh Formation and is the lowest Lower Permian plant-bearing horizon in Kashmir Basin. It was known earlier in north-west Kashmir only (Kapoor, 1979) but lately has been found in Liddar-Naubug valleys, Pir Panjal as well as in Chamba. The formation is composed of shales, quartz arenites and varvites. The floral assemblage includes *Gangamopteris kashmirensis, Glossopteris nishatbaghensis,* *Psygmophyllum, Cordaites,* etc. Nishatbagh Bed represents the advent of the land condition in Kashmir.

Four floral beds reported by Kapoor (1979) lying at different levels and showing changes in floral pattern have been grouped under the Mamal Formation by Singh *et al.* (1982) due to common lithological elements like novaculite, limestone, tuffaceous and siliceous shales, arenite, etc. In Pir Panjal area, however, there is absence of novaculite and development of thin bed of conglomerate at the base (Kapoor, 1977). The earlier Vihi Bed, representing lagoonal environment contains several layers with *Gangamopteris kashmirensis, Psygmophyllum* spp., *Cordaites, Vertebraria* and lycopsid remains, as well fishes and labyrinthodonts supposed to be of European affinity. Insect fossils are also known. Most interesting, however, is the presence of a layer of limestone with *Schwagerina* (Azmi, 1976), wherein one of us (HMK) has also observed the presence of bryozoans and algae showing definite marine influence. The succeeding Marahoma Bed exposed at Marahoma Spur, where both Vihi and Marahoma beds are separated by a flow, is characterised by species of *Glossopteris, Gangamopteris, Schizoneura, Sphenopteris, Sphenophyllum, Cordaites, Vertebraria,* etc. No vertebrate has been found in this bed.

The next younger Munda Bed contains a few species of *Gangamopteris, Glossopteris, Psygmophyllum,* etc. with appearance of *Taeniopteris* and *Pecopteris.* The youngest of all is the Mamal Bed from where Kapoor (1977) and Singh *et al.* (1982) reported an assemblage that contains "Cathaysian" as well as Gondwanic elements.

Thanmandi-Pira Basin

From Thanmandi-Pira Basin both Agglomeratic Slate and Permian plant horizons are known after the pioneer work of Wadia (1928) and later observed by geologists of the Geological Survey of India mentioned in unpublished reports. *Gangamopteris* and ill-preserved labyrinthodont from Mandi area suggest correlation with Mamal Formation in Kashmir basin.

Bhallesh-Chamba Basin

This basin has fossiliferous sequence from Early Permian to Lower Triassic, the Bhallesh Group (Kapoor, 1975). It includes Tramawala Formation, Batile Trap and Talai Formation which are similar to Agglomeratic Slate, Panjal Volcanics and Zewan Formation of Kashmir Basin in order of succession. Tramawala Formation includes both diamictite and volcanic divisions and has a lower *Eurydesma-Deltopecten* Assemblage and an upper *Taeniathaerus-Buxtonia-Streptorhynchus* Assemblage of Sakmarian age. Between Batile Trap and faunal zone of Sakmarian, Kapoor (1975) reported faint impressions of leaves in dark slates near Mashan Ghatti Gali. This observation has now been confirmed by G. Kumar who also found a well-preserved leaf of *Gangamopteris kashmirensis* exactly in the same position from Chamba. Thus the formation equivalent to Nishatbagh is developed in this basin also.

Zanskar-Spiti Basin

Fragmentary plants have been recorded in Lower Permian marine beds in Kinnaur (Bassi *et al.*, 1983) and at the contact of calcareous sandstone with Kuling in Kinnaur and Spiti River Section (Bassi *et al.*, 1983; Hayden, 1904).

The marine sequence in the basin is represented by two formations, viz., the Ganmachadam and the Kuling. The Lower Permian Ganmachadam Formation is composed of a 300 m sequence of diamictite, gritstone and quartzite. The Kuling Formation is divided by Srikantia (1981) into Gechang (=Calcareous sandstone of Hayden, 1904) and Gungri members. The Gechang Member, 60 m thick, is composed of calcareous sandstone and gritstone; while Gungri Member has shale with thin limestone.

Eurydesma-Deltopecten Assemblage is known from Lahul (Gupta & Waterhouse, 1978; Srikantia *et al.*, 1978) and Kinnaur (Bassi *et al.*, 1983) from calcareous sandstone of Gechang Member; in the same member, but in younger layers from Spiti, Bhatt and Joshi (1981) reported Artinskian fauna. The fauna of Gechang closely resembles with that of Agglomeratic Slate of Kashmir showing Gondwanic affinity. The fauna of the Gungri Member, however, is close to that of the Late Permian Zewan Formation.

In Zanskar area diamictite and volcanic flows (Ralakung Formation) are known in Lunek Valley which are correlated with the Agglomeratic Slate and Panjal Volcanics (Nanda *et al.*, 1978; Singh *et al.*, 1982).

Kumaon Basin

The Permian Kuling Formation directly overlying the Devonian Muth Quartzite was correlated with Late Permian sequence of other parts of Himalaya and absence of the Lower Permian was considered to be a conspicuous feature. Recently V.

D. Mamgain and R. S. Mishra (pers. comm.) have located a 16 m thick siliceous Limestone at the base of Kuling Formation in Girthi Valley (Malla Johar) continuing in Painkhanda and Byans. This unit contains brachiopods of the family Buxtonidae and Spiriferidae, comparable to the fauna of Gechang Member of Spiti and supports a regional Lower Permian marine transgression throughout the Tethys Himalaya.

Nepal

Bordet *et al.* (1971) and Colchen (1975) recorded a number of faunal zone within Thini Chu Formation from Thakkhola and Nigi-Shang area. The uppermost zone characterised by *Spiriferella rajah* assigning Late Permian age and lower with *Buxtonia Stepanoviella* indicating Early Permian age. Fuchs (1977) has reported prints of tetrapod and plant remains in the Dolpo region, western Nepal. Details of flora are not yet known. Acharyya and Shah (1975) have mentioned the presence of Gondwana spores from this formation.

Mount Everest-Sikkim-Bhutan basins

In the Mount Everest area the Upper Carboniferous to Early Permian Jilong Formation is overlain by Qubu Formation which has yielded *Glossopteris communis, Sphenophyllum speciosum* and *Raniganjia qubuensis.* This formation is conformably overlain by Quberga Formation. The Jilong Formation which is composed of variegated conglomerate, siltstone and sandstone has yielded Early Permian *Stepanoviella, Lissochonetes, Attenuatella, Trigonotreta,* etc.

In north Sikkim, Carboniferous and Permian are represented by Lachi Formation which is composed of 170 m thick shales, sandy shale and quartzite, followed by 200 m thick pebble bed (diamictite), the 100 m arenaceous shale and quartzite and 100 m quartzite and shale. No plant-bearing horizon is known except the mention of plant fragments in the top most 100 m thick quartzite and shale by Acharyya and Sastry (1979). The underlying sequence contains Late Permian forms of *Spiriferella rajah* and *Marginifera himalayaensis* Zone. In north Bhutan, the Permian Shodug Formation comprises diamictite, pink limestone, shale and quartzite but no plant bed. However, in the upper part of the sequence plant fragments and Gondwana type spores are reported from black shales (Acharyya & Sastry, 1979).

Karakoram Basin

A sedimentary sequence of Carboniferous to Cretaceous Tethyan facies is developed over metamorphics of Pangong Tso and Baltic groups. The Chongtah and Aqtash formations represent Permian group of rocks (Gregan & Pant, 1983). The Chongtash Formation is composed of siltstone, sandstone with occasional occurrence of equisetaceous stems and black shale interbedded with volcanic flows. Volcanic lavas have a number of intertrappeans of sandy slate and calcareous shale which contain fusulina showing affinity with the western Tethys. The Aqtash Formation is made of volcanics, conglomerate and grey massive limestone and shale.

Thakur (1984) recorded a thick sequence from the eastern Karakoram above the Fenestella shale represented by Harpatso Formation. This formation consists of diamictite, Gangamopteris Bed and limestone with fusulina.

UPPER GONDWANA FLORA AND ASSOCIATED BEDS

Plant-bearing horizons of Jurassic Lower Cretaceous age are known only from Nepal, Bhutan and Karakoram basins of Tethyan Himalaya. The presence of ill-preserved plants from several horizons between Late Permian and Jurassic are also known. In addition mioflora has also been worked out from some Mesozoic sediments of Kashmir and Kumaon Basins. Nautiyal and Sahni (1976) reported from Kashmir basin the presence of microplankton from basal Khunamuh Formation (Lower Triassic) of Pahalgam. The presence of fragmentary twigs were also noticed by one of us (HMK) at the contact of Zewan and Khunamuh formations at Guryul Ravine Section and plant impressions from a few centimeter thick shaly layer within the Upper Triassic, exposed south of Qazigund. In Wumuh Formation (Jurassic), a carbonaceous shale layer exposed at Sanger and Wumuh, occasionally shows unidentifiable fragmentary plant remains. From Spiti Basin, Hayden (1914) recorded a layer with plant remains in calcareous sandstone at the base of Coral Limestone (Middle Norian). Most interesting, however, is the record of miofloral assemblages from Kuti Shale, Passage Bed (Norian), Kioto Limestone (Rhaetian) and Spiti Shale (Jurassic) by Tiwari *et al.* (1980) from Kumaon Basin. The mioflora of Kuti Shale and Passage Bed, as well of the underlying Kuling Shale is of Gondwanic type.

Karakoram Basin

Norin (1946) listed a few plant fossils from Lingshithang-Depangi Quarutagh and upper Shyok drainage area, which included *Nilssonia* spp. and *Podozamites lanceolatus.*

The plant-bearing horizon at Fukche in the upper Indus Valley, north of the Ladakh range is thrusted over granite (Sharma *et al.*, 1980). The flora is of Middle to Late Jurassic age and compares favourably with the Eurasian flora and not with the Upper Gondwana (Bose *et al.*, 1983). Sukh-Dev *et al.* (1983) also reported *Cladophlebis* from Kayul, eastern Ladakh within the same formation.

Nepal

At the village Thakkhola (upper part of the Kali Gandaki Valley) plant-bed is known from the Kagbeni Sandstone Member of Chukh Formation (Bassoullet & Mouterde, 1977; Bordet *et al.*, 1968, 1971; Barale *et al.*, 1978). Bordet *et al.* (1971) consider the plant-bed to be Wealden in age as it overlies strata containing Tithonian ammonites and underlies beds with Neocomian fauna.

Bhutan (Lingshi Basin)

Mesozoic plant-bearing horizons are known from Mochu and Chebesa formations of Lingshi Group in the Lingshi Basin (Ganesan & Bose, 1982). Mochu Formation consists of laminated quartzite, sandstone and carbonaceous shale; the carbonaceous shale in its upper part shows development of fossil flora. The succeeding Chebesa Formation is mainly marine in nature and is composed of carbonaceous slate and quartzite. The quartzite sometimes contain thin streaks of plant-bearing shale. The age of these plant horizons is assigned Middle to Late Jurassic by Ganesan and Bose (1982).

EVOLUTION OF PLANT BEDS

The evolutionary history of Lesser Himalayan and Tethyan Himalayan belts are different. The Gondwana of Lesser Himalaya developed in the eastern part from Nepal to Arunachal Pradesh, more or less in a continuous linear belt, are continuation of the peninsular Gondwana with the similar stratigraphic set up and represent northern most rift system of the Indian Peninsula (Tripathi & Roychowdhury, 1983). The Gondwana overlie the Precambrian basement with a strong unconformity and have more of a continental facies with a minor marine influence at the base. The presence of Upper Gondwana and associated volcanics in central Nepal further supports this contention. However, being the marginal portion of the Gondwanaland, it has some correlatability to the Tethyan belt, specially with the Lower Permian sequence of Kashmir due to the presence of Abor Volcanics comparable to Panjal Volcanics, which seems to be a feature of the Tethyan belt.

Since the report of Gangamopteris Bed from Kashmir in 1902, evolution and development of floral beds in the Tethyan Himalaya has been of great scientific interest. These floral beds and their distribution, in a marine domain, unlike those of Peninsula, bear the testimony of the palaeogeography, specially the extent of the Gondwanaland to the north. The evolution of these beds can be explained variously, as given below:

1. development of plant beds over an island or a dense archipelago in the Tethys.
2. plant beds developed as coastal vegetation near the southern coast of Tethys.
3. development of land condition due to diastrophic changes and associated transgression and regression of the sea.

The evolution of various plant beds of Palaeozoic-Mesozoic in Tethyan region is complex, as they show local developments and the history of different basins is not identical. The appearance of first land plant on the globe is now considered to have been in Late Silurian. In Himalaya, except some doubtful plants from Ordovician-Silurian in Spiti Basin, the first definite land plant is from Late Devonian of Kashmir. In the Himalayan region, only two basins, namely, Kashmir and Spiti, exhibit continuous Late Devonian to Early Permian stratal sequence. The imprints of major tectonic events are documented in the Tethyan realm, where minor and major changes can be inferred on the palaeontological and stratigraphical evidences.

The shallow water Cambro-Ordovician sequence in the Tethyan Himalaya, ultimately became extremely shallow, where coastal to beach conditions prevailed depositing in the form of Muth Quartzite. This gave rise to the suitable environment, as such the sequence with definite land plants appeared in the Aishmuqam Formation (Muth Quartzite of Middlemiss, 1910) in Kashmir, possibly related to the Caledonian orogeny. This event was followed by a major Lower Carboniferous transgression in northwest and Nepal Himalaya, depositing the Lower Carboniferous Sequence representing the lower carbonate sediments (Syringothyris Limestone, Lipak Formation, Tilicho Lake Formation) and upper argilo-arenaceous sediments (Fenestella Shale, Po Formation, part of Thini-Chu Formation). During this time, the sea level was fluctuating resulting into alternate plant bearing dominately arenaceous sequence representing the regressive phase of the sea and invertebrate bearing marine argillaceous sequence representing the transgressive phase (Tripathi & Singh, 1984).

The instability of the basin became more conspicuous during the deposition of the Agglomeratic Slate and ultimately resulted in the outpouring of extensive lava flows in the Northwest Himalaya during Early Permian. This was followed after some hiatus, by a Late Permian transgression coinciding with the development of rifts in peninsular India.

Nakazawa and Kapoor (1973), Nakazawa *et al.* (1975), Kapoor (1979) and Kapoor and Shah (1979) explained that during Late Carboniferous and Early Permian the Kashmir region faced an unstable condition. The deposition of the Agglomeratic Slate is the effect of composite diastrophic changes in the basin. The lower part of the formation is formed on the depression in a rising crust, while ash and volcanic bombs, confined to the upper part, are of explosive type and were deposited both in depressions and raised portions (Nakazawa *et al.*, 1975). The effects of the Hercynian orogenic movements are reflected in deposition of Agglomeratic Slate and its equivalent in a marine regime. The magma below became mobile and in the initial stages selected weaker portions and forced the crust to rise, and later emitted to the surface through linear fissures; by this time most of the shelf portions were already raised above the sea-surface, as evidenced by the plant-bearing Nishatbagh Formation which underlies the main volcanic flows. In recent years evidences have come that Nishatbagh land conditions had a geographical extent up to Chamba. The emissions of the flows were intermittent, as indicated by a number of intertrappeans. The first plant beds overlying the volcanics and named as Vihi Bed developed in a lagoonal condition. It is interesting, however, to note that beds overlying the trap show a gradual floristic change, though lithological elements in all the beds are the volcanogenic sediments. The presence of the different floral beds above volcanics has been explained by Nakazawa *et al.* (1975) due to overlap and formations of different basins of deposition. Gradual shifting of the trap towards the east was explained by these authors, based on the example of Marahoma Spur, where Vihi Bed is separated by Marahoma Bed by a flow and show different floristic contents. They also presumed for Upper Munda and Mamal beds the same hypothesis of younger level based on floral evidences. Thus according to them during Early Permian there had been development of different basins over the emerged land; where flora of different times got deposited.

The Agglomeratic Slate where Asselian and Sakmarian fauna is found below plant-beds represents a major marine transgression and possibly got linked up with Salt Range on one side and with the eastern Himalaya through Spiti-Kumaon-Sikkim on the other side.

The occurrences of diamictite and plant bed in Karakoram, as well as in southern Tibet from where *Stepanoviella* and Glossopteris Flora are reported are interesting, due to their position further north. For this the palaeogeographic maps produced by Nakazawa (1985) give a good explanation that these portions in the Early Permian were situated further south and were part of the same province (Text-fig. 2).

Nakazawa *et al.* (1975), Kapoor and Shah (1979), Kapoor (1979) and Singh *et al.* (1982) visualised Kashmir region to be an island in Early Permian. It was presumed to be closer to the Gondwanaland and not very far from Cathaysian province. The available information, till date also links the Tethyan region through only marine bed with that of the Peninsula, but the development of the strata in which the flora is found have different sedimentological history. The succeeding Late Permian history, however, is different marine transgressive history of Tethyan realm and took place after Kungurian-Ufimian-Kazanian time gap.

Nothing can be commented about the Kungurian-development of thin floral layers occurring in Triassic in Kashmir and Spiti, and may only be due to near shore conditions. The Jurassic Cretaceous plant beds, however, are possibly attributes of the regression caused at the time of fragmentation and shifting of the Indian Shield from the mainland.

DISCUSSION AND CONCLUSION

There are two models to explain geological history of the extra-Peninsula. First model envisages the presence of two geosynclinal basins, one in the south (Lesser Himalaya) and other in the north (Tethyan or Tibetan) separated by Central Cystallines. The second model considers Lesser Himalaya to be the continuation of peninsular region with the same geological history. It has already been pointed out that the Gondwana of eastern part of the Lesser Himalaya is nothing but a continuation of the peninsular Gondwana as visualised in the second model. It may also be mentioned here that Blaini Formation of Lesser Himalaya, earlier believed to represent Gondwana deposits has now been proved to be older. Therefore the nearest Gondwanic deposits in the western part only is from the Salt Range in Pakistan. However, it has more affinity with that of the Tethyan belt. The question, however, arises whether to include the Tethyan sequence within the limits of

Gondwana? It is normally considered that Indus-Yarlung-Zangbo Suture marks the northern limit of the Gondwanaland but the recent studies have indicated that northern margin of the Gondwanaland had varied and got fragmented at various geological periods, thus its northern limit varied from time to time.

The widespread occurrences of diamictite, similarities in Asselian and Sakmarian marine fauna and Glossopteris Flora (also known from countries of southern hemisphere), in general provide correlation of Gondwana Sequence of Peninsula with those of the Tethyan belt.

All the sedimentation models of the peninsular and Lesser Himalayan regions envisage glaciofluvial, fluvio-glacial and lacustrine environment of the deposition. This has the influence of some marine transgression in the basal part in some of the areas of Peninsula and Lesser Himalaya. The Tethyan Himalaya on the contrary represents paralic to marine sedimentation in the shelf environment. The main difference, between the peninsular and Tethyan belt, however, is in the geological set up. Peninsular Gondwana Sequence deposited over the Archaean basement with a strong unconformity, unlike Tethyan belt where this forms part of the continuous marine Palaeozoic-Mesozoic sedimentaries with both conformable and unconformable contacts at times.

Diamictite, which marks the begining of the Gondwana, though widely distributed both in the Peninsular and Tethyan domains, have also distinct dissimilarities in lithology and the sedimentary history. Diamictite in the Tethyan region are always marine and deposited in an unstable basin. In Peninsula, diamictites are mainly glacial or fluvio-glacial and occasionally marine. They were deposited within the basement depressions in the embryonic basins (Mitra *et al.*, 1979). The Lower Permian Sequence above diamictite in the Tethyan belt is mainly volcanogenic sediments or volcanic flows which are entirely absent in the peninsular region. In Lesser Himalaya, however, there is some evidence of the volcanism (Abor) that possibly indicates that Lower Permian volcanism was confined to the northern margin. Another interesting observation worth mentioning is the occasional marine influence in Lower Permian plant-beds as reported in the Vihi Bed of Kashmir, which has though dominantly *Gangamopteris* bearing lithounits but in some units marine fauna is also present and accordingly the bed has been referred to show a lagoonal environment. No such environment has yet been found in the peninsular region in the Lower Permian. In the peninsular region the Upper Permian and Triassic sequence is represented by argillo-arenaceous continental deposits unlike Tethyan region where the deposits are dominantly argillo-calcareous marine sedimentaries with distinct fauna confined to central Tethyan Province. The Upper Gondwana of the Lesser Himalaya and the peninsular India have close similarity in lithology and associated volcanism of the Jurassic/Lower Cretaceous age. However, in the Tethyan realm, the plant bearing horizons are closely associated with the marine strata and at times contain thin layers of plants, which indicate an overall marine environment. Further no volcanics or volcanogenic sediments have yet been reported from the Tethyan belt.

Another significant aspect of correlating the Tethyan belt sedimentaries with the Gondwana is the floral contents. The Lower Permian flora of Tethyan belt, particularly of Kashmir and Mount Everest area have some definite Gondwana elements like *Gangamopteris cyclopteroides, Glossopteris communis, G. indica, Vertebraria*, etc. but at the same time contain some Cathaysian elements, as known from Mamal Bed, like *Paraspbenophyllum thonii, Lobatannularia ensifolia*, with several endemic species like *Gangamopteris kashmirensis, G. nishatbaghensis, Rhabdotaenia kashmirensis*, etc. This mixing of flora has been explained variously; due to migration, due to parallel evolution (or homoplasy), or representing a distinct transitional floral belt within Tethyan realm, lying between Gondwana flora in south and Cathaysia flora in the north. None of these explanations can be regarded as conclusive.

In succeeding Triassic Tethyan sequence no major plant-bearing horizon with identifiable flora is known except for a record from the Salt Range in Pakistan of *Equisetites, Cladophlebis* and *Indotheca sakesarensis*. Its correlatability with the peninsular domain is not clear.

Jurassic/Lower Cretaceous floras are known from Bhutan, Nepal and Karakoram basins. Bhutan and Nepal have flora similar to the Upper Gondwana assemblages, while the Karakoram assemblage is comparable to the Eurasian flora thus considered to be a part of the Asian block. However, the differentiation of the Mesozoic flora which is generally of cosmopolitan nature, present in marine Tethyan sediments in Bhutan and Nepal keeps the question open for future work.

It is not out of place to mention about the pre-Gondwana flora in the Tethyan belt, which has been compared with the northern flora, though same elements are also found in the southern continents but not in peninsular India. The Lower Carboniferous flora in general is considered to be cosmopolitan by some workers; others believe that differentiation in the flora started earlier and the similarities are apparent and not actual. The Carboniferous floral beds which are confined only to Kashmir and Spiti basins, thus are important to study the evolution of Glossopteris Flora but till date the Carboniferous stratigraphy is not known in detail and there is a lacuna of Upper Carboniferous flor

The faunal aspect and its correlatability gives a peculiar picture. The Asselian and Sakmarian fauna of both Peninsula as well as extra-Peninsula are alike and thus are the result of the common sea. However, vertebrate fauna known from Vihi beds in Kashmir is distinct from that of Peninsula. The fishes and labyrinthodonts, though have been compared with European forms, are endemic specifically. The fusulinid found in the same bed are only known from the similar set up of the Salt Range area and not in Peninsula.

Tectonostratigraphically the Tethyan and peninsular domains fall apart and have distinct dissimilarities, though tectonic event of one domain is reflected in another being the adjacent part to each other. The Lower Permian commences with an important event both in Peninsula as well as extra-Peninsula. Extra-Peninsula witnesses a major sea transgression which invaded even some parts of the Peninsula; while in Peninsula, it gives rise to basin in which thick piles of continental deposits were laid. The Upper Permian transgression in the Tethys Himalaya possibly took place at the time when rifting took place in the peninsular region and different Gondwana basins are formed during post Barakar times. In the raised portion of the marginal shelf of the Tethyan belt, which might have acquired land condition, volcanogenic sediments got deposited in the depressions during Lower Permian There is also a brief hiatus (Kungurian-Ufimian-Kazanian) in the Gondwanic history and Late Permian transgression in Tethyan Belt.

There are diversified views for the use of the term Gondwana in the stratigraphic sense. This aspect was discussed at length in a Colloquium at Geological Survey of India, Calcutta in 1984 and consensus was as follows :

"The Gondwana in stratigraphic sense includes naturally related succession of essentially sedimentary rocks with sandstone, shale, coal, carbonaceous sediments, tillites/tilloids, as well as closely associated rocks which are also characterised by floral and faunal remains having Gondwana affinity; it is thus an observable stratigraphic unit, diagnosed by mainly terrigenous facies (as referred to earlier) which also have Gondwanic floral/faunal bondage, since there is no provisions for formal stratigraphic nomenclature for succession characterised by natural assemblage of both litho- and bio-stratigraphic aspects, this informal term Gondwana sequence appear adequate. Both lithological and bio-aspects are utilised in defining the Lower and Upper contact of the Gondwana sequence. In Indian subcontinent the sequence ranges in time span from basal Permian to Early Cretaceous".

Based on the above discussions, it can be inferred that the Gondwana of the Tethyan belt, shows a distinct departure from the typical Gondwanic sedimentation and floral contents; and the use of the term Gondwana in formal sense of stratigraphy does not appear to be justified. Effort should be to formalise this term in a stratigraphic sense, rather than continuing the informal term Gondwana Sequence. However, the use of the term Gondwana in the palaeogeographic sense as 'Gondwana realm' is widely used and acceptable, for which the term 'Peri-Gondwana' has already been proposed for extra-Peninsula (Tethyan belt) by Nakazawa and Kapoor (1979).

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Permian palynofossils from the eastern Himalaya and their genetic relationship

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Srivastava, Suresh C., Anand-Prakash & Singh, Trilochan (1988). Permian palynofossils from the eastern Himalaya and their genetic relationship. *Palaeobotanist* **36** : 326-338.

Palynofossils from the Permian sediments of the eastern Himalaya have been critically revised with reference to the marine invertebrate fossils contained at various levels. The Pebble Slate Member of the Rangit Formation having sporadic presence of *Eurydesma* (Biozone 1) has not yielded palynofossils but the younger Rilu Member has yielded a radial monosaccate rich assemblage (Biozone 2). The association of *Leiosphaeridia* in this assemblage in Barpathar area characteristically indicates marine influence. Biozone 3 characterised by *Callumispora* + *Parasaccites* association is present in marine Garu Formation in Siang and Subansiri, non-marine Bhareli Formation in Kameng and Lower Coal Measures in Darjeeling District. *Scheuringipollenites* rich Biozone 4 is characteristically associated with the marine invertebrates in Siang District (Garu Formation) only; elsewhere it occurs independently. Biozones 5 and 6 are characterised by the abundance of striate-disaccate pollen grains, the latter having *Indospora, Thymospora* and *Crescentipollenites* and represent Upper Barakar and Raniganj palynofloras, respectively.

The Permian sediments in eastern Himalaya are in lithological contrast with the intracratonic continental sediments of the Peninsula but their floristic resemblances are close. Biozones 1 and 2 are comparable to Talchir palynoflora which is related to glacio-marine model of sedimentation. During the deposition of sediments containing Biozone 3, comparable to Karharbari palynoflora, the marine environment seems to have existed continuously from Siang to eastern Kameng but westwards certain areas were under fresh water environment. Similarly the Biozone 4 is associated with marine fossils in Siang only but elsewhere it is typically associated with fluvial sediments. Thus an eastward regression of sea is plausible during Karharbari and Lower Barakar times. During the younger palynofloras having Upper Barakar (Biozone 5) and Raniganj (Biozone 6) affinities the conditions of deposition appear to be exclusively fluvial in nature. It is clearly indicated that a larger segment of sedimentation in these marginal basins of eastern Himalaya has continued under marine environment while in peninsular India the intracratonic depositional basins were under fluvial environment during the same time span.

Key-words—Palynology, Stratigraphy, Biozonation, Genetic relationship, Permian sediments (India).

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साराँश

पूर्वी हिमालय से परमी युगीन अश्मित परागाणु एवं इनकी आनुवंशिक बन्धुता

सुरेश चन्द्र श्रीवास्तव, आनन्द प्रकाश एवं त्रिलोचन सिंह

पूर्वी हिमालय के परमी अवसादों से उपलब्ध परागाणविकरूपकों का विशेष पुनरीक्षण किया गया है तथा विभिन्न स्तरों में विद्यमान समुद्री अरीढ़धारी अश्मित जन्तुओं पर भी विशेष ध्यान दिया गया है। **यूरीडेस्मा** (जैवमंडल 1) की कदाचनिक उपस्थिति से युक्त रेंगीट शैल-समूह के गोलाश्म स्लेट सदस्य में

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परागाणविकरूपक उपलब्ध नहीं हुए हैं परन्तु अल्पायु रिलु सदस्य से अरीय एक-कोष्ठीयों से युक्त समुच्चय (जैवमंडल 2) उपलब्ध हुआ है। बारपथर क्षेत्र में इस समुच्चय में **लिओस्फ़ेयरीडिआ** का साहचर्य लाक्षणिक रूप से समुद्री प्रभाव प्रदर्शित करता है। **केल्यूमिस्पोरा** + **पेरासेक्काइटिस** साहचर्य से अभिलक्षणित जैवमंडल 3 स्याँग और सुबनसिरी में समुद्री गारू शैल-समूह, कामेंग में असमुद्री भरेली शैल-समूह तथा दार्जिलिंग जनपद में अधरि कोयला-मेज़र्स में विद्यमान है। **श्यौरिंगीपोलिनाइटिस** से भरपूर जैवमंडल 4 लाक्षणिक रूप से केवल स्याँग जनपद में समुद्री अरीढ़धारीयों का साहचर्य प्रदर्शित करता है, अन्य स्थानों पर यह स्वछंद रूप से मिलता है। जैवमंडल 5 एवं 6 रेखीय-द्विकोष्ठीय परागकणों की बाहुल्यता से अभिलक्षणित हैं। ये जैवमंडल **इंडोस्पोरा**, **थाइमोस्पोरा** एवं **क्रीसेंटीपोलिनाइटिस** से युक्त हैं तथा क्रमशः उपरि बराकार एवं रानीगंज परागाणुवनस्पतिजातों का निरूपण करते हैं।

पूर्वी हिमालय में परमी अवसाद प्रायद्वीप के अन्तराक्रेटानी अलवणीय अवसादों से शैलविन्यास में भिन्न हैं परन्तु इनमें घनिष्ठ वनस्पतिजातीय समानता है। जैवमंडल 1 एवं 2 तालचिर परागाणुवनस्पतिजात से तुलनीय हैं जिसे अवसादन के हिमानी-समुद्री मॉडल से सम्बद्ध किया गया है। जैवमंडल 3 से युक्त अवसादों के निक्षेपण के समय करहरबारी परगाणुवनस्पतिजात से तुलनीय समुद्री वातावरण स्याँग से पूर्वी कामेंग तक अविच्छिन्न रूप से विद्यमान प्रतीत होता है परन्तु पश्चिम की ओर कुछ क्षेत्र अलवणीय जल-वातावरण से प्रभावित थे। इसी प्रकार जैवमंडल 4 केवल स्याँग में समुद्री जीवाश्मों से सहयुक्त है और अन्यत्र यह नदीय अवसादों से सम्बद्ध है। अतएव करहरबारी एवं बराकार काल में समुद्र का पूर्व की ओर अवनमन तर्कसंगत लगता है। उपरि बराकार (जैवमंडल 5) एवं रानीगंज (जैवमंडल 6) से सजातीय अल्पायु परागाणुवनस्पतिजातों के समय निक्षेपणीय परिस्थितियाँ अधिकतर नदीय प्रतीत होती हैं। यह स्पष्ट रूप से इंगित किया गया है कि पूर्वी हिमालय की इन तटीय द्रोणीयों में अवसादन का अधिकतर भाग समुद्री वातावरण में रहा है जबकि प्रायद्वीपीय भारत में अन्तराक्रेटानी निक्षेपणीय द्रोणीयाँ इसी कल्प में नदीय वातावरण से प्रभावित थीं।

THE sedimentary sequence of the eastern Lesser Himalaya occurs continuously from the foot-hills of Darjeeling to Siang District. The Permian sediments are tectonically emplaced between Tertiary rocks of the sub-Himalaya and the metamorphics of the Lesser and Central Himalaya. The Tethyan sedimentary sequence in the north forms almost a parallel belt and is rich in marine fauna whereas the Permian of the Lesser Himalaya is largely unfossiliferous. The Permian sediments are customarily compared to the Gondwana sediments of peninsula and on the basis of fossil contents are equated to the Damuda Group. However, the tectonics and environment of deposition of the Lesser Himalayan Permian sediments is in typical contrast with the intracratonic continental sediments of the Peninsula. The continuity of the Permian sediments in the direction of strike is truncated east of Siang by the Siang Fracture Zone (Nandi, 1976) or the Dibang Section (Jain & Thakur, 1975). The apparent discontinuity at some places along the alignment is largely due to the intermittent cover caused by the thrust slices of other formations.

The Permian sediments are wedged in between two thrusts. The southern boundary is against the Siwalik Group, usually referred to as Main Boundary Fault (MBF), while the northern boundary is marked by a plane of discordance against the metamorphic rocks. The sediments are highly deformed and show a wide range of lithological variation. The general dip of the rocks is northwards, thus bringing the younger rocks apparently under the older ones near the thrust. The basal sediments are characterised by the diamictite in Arunachal Pradesh and pebble slate in Bhutan, Sikkim and Darjeeling areas. These lithounits are comparable to the Talchir sediments of the Peninsula. Therefore, it is suggested that in Eastern Himalaya also a similar pattern can be followed for describing these sediments under one common name. With this idea, the diamictite and pebble slate units exposed in various parts of eastern Himalaya have been described here under Rangit Formation. The lithofacies variations and nature of fossil contents in different areas are as follows :

DARJEELING

Acharyya (1972) divided the Permian sediments into three formations, viz., Dalingkote Formation (Upper Coal Measures), Chunabati Formation, and Rongtong Formation (Lower Coal Measures). However, Pawde and Saha (1982) have preferred to keep the Permian Sequence unclassified. As the Permian sediments occur in thrust slices at various places it appears difficult to correlate them on lithological characteristics alone.

The lowermost unit, Rangit Pebble Slate, comprises pebbly to gritty slates and pebbly quartzitic sandstones. This unit is normally correlated to the Talchir Boulder Bed of the Peninsula. Acharyya (1972) has reported a marine fauna which includes *Eurydesma* sp. and has assigned a Lower Permian age.

The sediments of the Damuda Group have been divided into two units. The Lower Coal Measures have a very limited aerial extent and include sandstone, shale and coal. The sandstones are largely fine-grained and have been compared with the Barakar Formation. The Upper Coal Measures have a comparatively wider extent and comprise predominantly sandstones which are medium-to coarse-grained. The coal seams in this unit are highly crushed and semi-anthracitic. This unit has been correlated with the Raniganj Formation on the basis of the dominance of *Glossopteris* over *Gangamopteris*.

The Chunabati Formation equated to the Barren Measures Formation is, however, debatable as the rocks exposed around the type area Chunabati are exclusively Tertiaries. The lithological similarity of the above sequence with the equivalent sediments in the Peninsula is, however, only apparent as there are distinct differences in details. The comparison is furthermore difficult due to the effect of tectonism as the sediments are often influenced by the metamorphism. The sandstones have become quartzitic, shales have turned into slates and coals are highly crushed and semi-anthracitic in nature.

SIKKIM

Permian sediments of north Sikkim form a part of the Tethyan Sequence. In south Sikkim the sediments occur in the Lesser Himalayan Zone and are exposed in the Rangit Tectonic Window, in Rangit River Valley. Here the sediments are overridden by the rocks of Daling and Buxa groups on all sides. The stratigraphic sequence of Permian sediments is as follows:

Namchi Formation	Sikkip Member	Dark grey to bluish grey sandstone, carbonaceous shale, coal
	Namchi Member	Coarse gritty grey sandstone, conglomerate, shale
Rangit Formation	Rangit Pebble Slate	Poorly sorted clasts embedded in argillaceous matrix, siltstone and thin limestone
		.... Thrust ....
Buxa Group		

The Rangit Pebble Slate comprises poorly sorted clasts that range in size from granules to pebbles to boulders embedded in argillaceous matrix. The matrix is also calcareous at places. Generally, the rocks do not show stratification except near Tatapani where they have attained a slaty character.

Sinha Roy (1980) has grouped the overlying unclassified Permian sediments in Namchi Formation. In the present synthesis the Namchi Formation has been further differentiated into two members, the Namchi Member and Sikkip Member.

The Namchi Member has been restricted to older unit comprising sandstone and conglomerate. The sandstones are grey in colour, coarse to gritty and hard in nature. The conglomerate includes well polished, rounded to oval-shaped pebbles cemented in arenaceous matrix. Dark grey slaty shales are also associated with this sandstone. This member has yielded well-preserved brachiopods, gastropods and bryozoans.

The Sikkip Member is characterised by interbedded sandstone, slaty shale and coal. The sandstones are dark grey, hard, quartzitic, fine- to coarse-grained and often gritty in nature. Well-preserved ripple marks, current bedding and graded bedding are seen in the sandstones.

The slaty shales often contain plant fossils, viz., *Glossopteris, Gangamopteris, Vertebraria, Schizoneura*, etc. Coal occurs as thin bands between the shales and sandstones and is highly crushed, semi-anthracitic to graphitic in nature. Bands of calcarenite and thin limestone are also found associated with gritty sandstones.

BHUTAN

The Permian sediments in Bhutan occur as thin, discontinuous thrust slices. In eastern part they form a continuous patch and attain their maximum thickness. The stratigraphic sequence is divided into Diuri Boulder Slate Formation and Thungsing Quartzite Formation.

The Diuri Boulder Slate Formation is marked by the presence of dark grey, boulder and pebble slate, carbonaceous and silty slate and quartzitic sandstone. This formation attains maximum thickness of 2,500 m and its contact with the overlying Permian Sequence is sheared and faulted. It is interbedded with Thungsing Quartzite at one place while in other sections it overlies the same.

The Gondwana sediments include quartzitic sandstone, carbonaceous slates, coal, calcareous slate and marl, etc. The interbedded slate often contains fragmentary plant remains (*Glossopteris, Vertebraria, Gangamopteris*, etc).

ARUNACHAL PRADESH

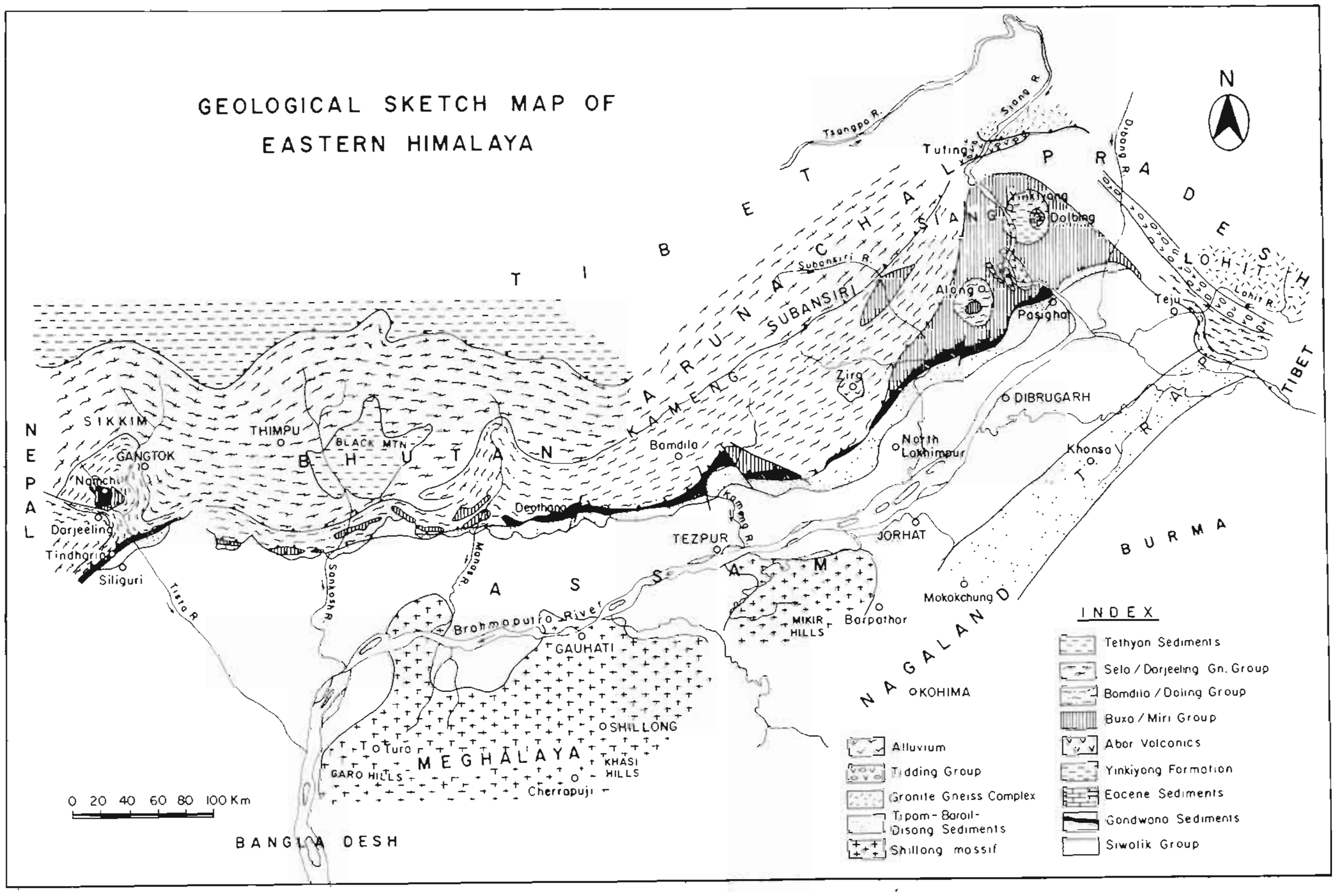
The Permian sediments extend from Kameng District in the west to Siang District in the east. The geological setting in each district is being described here separately.

Kameng District

The stratigraphic succession of Permian sediments is as under :

Bhareli Formation	Light grey, white or yellowish, pepper and salt type felspathic sandstone, impersistent carbonaceous shale and coal seams
Rangit Formation	Greenish or khaki, pebbly or gritty, frequently pyritous lithic wackes (i.e. diamictite), splintery shales, siltstone, quartzite-wacke, impure limestone

The Rangit Formation is a bryozoa dominated horizon. This assemblage includes well-preserved



Map 1—Geological sketch map of eastern Himalaya.

shells of *Eurydesma*. A Lower Permian age has been assigned to this formation.

The Bhareli Formation shows coarse, gritty felspathic sandstone showing parallel and cross lamination. The sequence represents finning upward cycle and is rich in plant fossils, viz., *Glossopteris, Dictyopteridium, Vertebraria, Phyllotheca, Schizoneura, Samaropsis*, etc.

Khelong Formation (Acharyya *et al.*, 1975) is not lithologically distinguishable in the type area and has been included in the Bhareli Formation. The bryozoa-dominated horizon (Acharyya *et al.*, 1975) near Khuppi represents a part of the Bhareli Formation and has no resemblance with the sediments of Rangit Formation.

Subansiri

The Permian sediments are exposed in a very narrow belt that pinches out at many places due to the overthrusting of Miri and Bomdilla group of rocks. The diamictite unit is not exposed in Subansiri District. The Permian sediments are exposed near Petepara on Kimin-Zero Section, and ahead of Bini in Tamen-Bini-Gogamukh Section. However, at Kheel in Doimukh-Sagalee Section, these sediments are very much reduced and almost sandwiched between the Siwalik sandstones in the south and gneisses in the north.

The Permian sediments are characterised by green-coloured shale, siltstone and mudstone having poorly sorted small clasts, dark grey to black carbonaceous shale with coal balls. There is no record of plant fossils from these sediments as yet. The fauna associated with coal balls includes a variety of invertebrate fossils. The interbedded sandstones are fine-grained and soft. Characteristic coal lenses are also found associated with shale and siltstone.

Godwin-Austen (1875) reported some clayey shale, often carbonaceous in nature, interstratified with coarse-grained sandstone exposed in Dikrang River Section. These carbonaceous shales often grade into splintery coal. The sequencee is considered to be continental in nature.

Siang District

The Permian sediments occur in a linear belt forming low hills in between the high hills of

Siwalik sediments in the south and Miri rocks in the north. The sediments attain maximum thickness towards west near Tatamari and thins out eastwards being cut off by two thrusts near Daring. Further east they reappear again near Renging on Passighat—Along Road and are again cut off further east by the Siang River. The sequence in the southern part of the district is as follows:

Garu Formation		Predominantly carbonaceous shale, coal and sandstone. Coal balls containing marine animal fossils
Rangit Formation	Rilu Member	Olivegreen splintery shale, greenish siltstone and mudstone with scattered clasts
	Diamictite Member	Massive conglomeratic rock with poorly sorted, angular clasts set in dark-grey or greenish argillaceous matrix. Interstratified siltstone and shale
	Thrust	
Miri Formation		Dominantly quartzites and limestones

Rangit Formation

The Rangit Formation constitutes the lowermost unit of the Permian Sequence and includes pebble slate, shale, siltstone, mudstone, etc. The formation is stratigraphically emplaced above the Miri Formation and the contact between the two is by and large tectonised.

Diamictite Member—The diamictite Member is massive and conglomeratic in nature and contains poorly sorted polymictic clasts which possess characteristic faceted and striated appearance. It often contains stratified layers of siltstone and shale. The diamictites are predominantly dark grey or greenish in colour and argillaceous in nature. The clasts are mostly derived from the adjacently exposed metamorphic rocks which vary in size from granules to boulders.

Isolated outcrops of this unit are present on Garu-Basar Section, Renging-Rotung Section and Bodak-Maryang Section. The lower and upper contacts of the Diamictite Member are usually tectonised. However, an unconformable relationship has been assumed on the basis of local nature of phenoclasts derived from the subadjacent and adjacently exposed pre-Permian rocks. The authors have observed that the Permian sediments were deposited over the uneven basement of Miri rocks like most of the Gondwana sediments of the Peninsula deposited over metamorphics. The erosional contact with the Miri rocks has been observed at many places, particularly in the sections exposed along the Garu-Basar Road and along the Passighat-Renging Road. However, due to the severe tectonic affect the true nature of the contact is visible only at few places.

Rilu Member—The Rilu Member consists of olive-green splintery shale with intercalated thin bands of fine-grained greenish siltstone. The splintery shales grade upwards into buff-grey to greenish-grey earthy mudstone containing scattered clasts of pink quartzite. Calcareous concretions of varying size are commonly found in the mudstone. This member attains maximum thickness near Rilu, east of Garu Village.

The Rilu Member was earlier included in the Garu Formation by Kumar and Singh (1974). The Siki-Abu Member or the Upper Diamictite Unit described by Kumar and Singh (1974) is considered here as a part of the Diamictite Member.

Garu Formation

The Garu Formation includes a succession of carbonaceous shale, coal layers and sandstone. Sedimentary structures are generally lacking. It extends from Tatamari to Renging and its maximum thickness has been observed near Gensi. Its contact with the Rilu Member is conformable. The Garu Formation now refers only to Bomte Member of Kumar and Singh (1974).

The sediments are highly crumpled and contorted. The maximum thickness has been observed near Bomte but the thickness reduces on either sides. The sandstones are generally bluish grey, coarse to medium-grained and often contain carbonaceous matter and well-preserved bryozoa. Coal balls, containing invertebrate fossils, occur irregularly dispersed in coal and carbonaceous shales and are largely calcareous in nature. Near Tatamari a 23 cm thick bed, so rich in fossils that it may be termed as 'Coquina' or named as 'Productus Bed', has been observed. In addition to these, dolomitic and cherty coal balls are also present in these sediments. The sandstones in the upper part of the sequence are largely ferruginous and often contain ferruginous or pyritous concretions which rarely contain animal fossils. The marine invertebrate fossils occur in all the units of Garu Formation including the sandstone but mostly are frequent in the carbonaceous units, particularly in coal balls.

The black shales and felspathic sandstones of the Gondwana sediments described by Jain *et al.* (1974) and the 'Garu Shale' and 'Gensi Formation' described by Roy Chowdhury and Boral (1978) from the same area also represent Garu Formation.

Coal Balls—The term 'Coal Ball' has been recently assigned to the concretions occurring among the coal and associated sediments of the Garu Formation (Anand-Prakash *et al.*, 1988). These concretions can be marked on the outcrop surface by their rounded to subrounded, oval-elongated shape and hard nature which protects them from weathering. The coal balls are mostly composed of calcium carbonate while those having magnesium carbonate, iron carbonate and iron-oxide are comparatively less common. Most of the coal balls, especially those rich in calcium and magnesium carbonates, have yielded well-preserved invertebrate marine fossils as well as palynofossils. Ferruginous concretions showing concentric rings often do not contain fossils.

Abor Volcanics

The Abor Volcanics mark the abrupt culmination of the general ENE to NE oriented structural trend of Kameng-Subansiri-Siang Himalaya. Abor Volcanics are developed in Igo-Along Section intersliced with Miri Formation as well as younger Permian Sequence. The volcanic sequence consists of basaltic to andesitic flows, silicic tuffs, lapillis, and agglomerates. It also includes basaltic dykes and sills. A few intertrappean beds within the Abor Volcanics have been reported in the type area, the Siang District. The rocks of Abor Volcanics are associated with the rocks of Miri Formation and the basal Diamictite Member of the Rangit Formation.

Yinkiong Formation

The Yinkiong Formation occupies a large tract in Siang and Yamne valleys in Siang District and is best exposed between the Dihang Bridge and Yinkiong on Geku-Yinkiong Road. Jain *et al.* (1974) considered it to be of Precambrian to Middle Palaeozoic in age. Singh (1984) has assigned a Permian age to these beds on the basis of brachiopods *Chonetes, Chonnetina, Marginifera* and cephalopods—*Nucula* and *Nuculina* discovered by Chatterjee *et al.* (1981). These fossils were recovered out of rolled boulders near Geku and their *in situ* presence still remains unknown. Hence, the age of Yinkiong Formation remains an open question.

Meghalaya

The Permian sediments are exposed around Singrimari (Hallidaygunj). The general stratigraphic sequence (Geological Survey of India, 1981) is as follows:

Group	Formation	Lithology
Lower Gondwana Group	Karharbari Formation	Very coarse to coarse grained sandstone with conglomeratic lenses/bands at the base, siltstone, shale, carbonaceous shale and coal—110 m thick
	Talchir Formation	Basal tillite, sandstone with conglomerate bands, siltstone and shale—75 m thick
....	Unconformity	....
Precambrian		

The Talchir Formation consists of basal tillite, yellow siltstone, sandstone, khaki-green to green shales with a few outsized clasts. The uppermost bed is marked by a thick conglomeratic band.

The Karharbari Formation includes coarse-grained sandstone, grey shale, carbonaceous shale and coal. The general contact with the underlying Talchir Formation is conformable and shows a general dip towards west. The full thickness of this formation is not exposed due to alluvial cover and the Barakar Formation may overlie in the west in the subsurface.

Palynology

The palynological studies of the Permian sediments of north-east Himalaya are limited to few reports only. There is no record of palynofossils from the Rangit Pebble-Slate/Diamictite units while the overlying carbonaceous sequences have yielded varied assemblages. A check list of palynomorphs recorded so far is given below :

Leiotriletes tenuis, L. plicatus, Hennellysporites sp., *Callumispora gretensis, C. barakarensis, Pseudoreticulatispora barakarensis, Brevitriletes unicus, Didecitriletes* sp., *Psilalacinites* sp., *Indotriradites korbaensis, I. sparsus, Jayantisporites pseudozonatus, Caheniasaccites indicus, C. ellipticus, C. elongatus, Divarisaccus ovatus, D. lelei, D. strengeri, Parasaccites obscurus, P. diffusus, P. bilateralis, P. distinctus, Plicatipollenites densus, P. indicus, P. gondwanensis, P. stigmatus, Virkkipollenites densus, Crucisaccites indicus, C. medius, Stellapollenites* sp., *Potonieisporites crassus, Limitisporites* sp., *Sahnites jayantiensis, Vesicaspora* sp., *Scheuringipollenites tentulus, Faunipollenites varius, Circumstriatites talchirensis, Striatopodocarpites multistriatus, Ginkgocycadophytus vetus, Quadrisporites horridus, Leiosphaeridia* sp., *Botryococcus* sp., *Maculatasporites* sp.

The detailed palynological compositions of Permian sediments from various areas are described here.

Darjeeling District

The palynostratigraphic succession of Permian sediments, specially the coal and associated sediments, has been described by Ghosh (1973, 1983). We have investigated palynofossils from the Lower Unit south of Tindharia. The palynological assemblages demarcated in the Coal Measures are described here.

Lower Coal Measures

Parasaccites Assemblage—Parasaccites (36%), *Scheuringipollenites* (12%), *Crucisaccites* (9%), *Caheniasaccites* (8%), *Ibisporites* (8%) and *Vesicaspora* (6%) are important elements. The assemblage is characterised by the abundance of monosaccate pollen (56%). Nonstriate disaccate pollen are 29 per cent. The trilete spores are rare. Striate disaccate pollen grains are also low (8%).

Lophotriletes Assemblage—The assemblage is rich in trilete spores. *Lophotriletes* (28%), *Horriditriletes* (12%), *Brevitriletes* (9%) and *Cyclogranisporites* (6%) are characteristic elements. Striate disaccate pollen grains represented by *Striatopodocarpites* and *Faunipollenites* average up to 20 per cent.

Faunipollenites + Striatopodocarpites Assemblage—Striate disaccate pollen rise to overall dominance (60%). *Faunipollenites* (16%), *Striatopodocarpites* (14%) and *Lahirites* (13%) are the chief constituents. Trilete spores are only 16 per cent.

Upper Coal Measures

Striate-disaccate Assemblage—The palynoflora recovered from the coal of Upper Unit is rich in striate disaccate pollen grains (60-70%) represented chiefly by *Striatites, Verticipollenites, Crescentipollenites, Striatopodocarpites*, etc. A sizeable percentage of trilete and monolete spores 924-38%) is recorded. The presence of *Indospora, Thymospora, Verticipollenites, Crescentipollenites, Distriatites* and *Gnetaceaepollenites* in this assemblage is significant.

The palynological assemblage of the Lower Unit (Ghosh, 1983) is also rich in striate disaccate pollen grains and almost all the genera mentioned above occur in the Lower Unit. The percentage of *Striatopodocarpites, Lahirites* and *Indospora* increase in the Lower Unit. Thus the two units show a continuation of same Palynological assemblage which compares with the Raniganj palynofloras of the Peninsula. The Upper Barakar affinity as suggested by Ghosh (1983) is apparent only in view of the presence of striate disaccate pollen grains but the consistent presence of *Indospora, Thymospora, Verticipollenites, Crescentipollenites, Distriatites, Gnetaceaepollenites* alienates it more closer to the flora of Raniganj. The *Faunipollenites + Striatopodocarpites* Assemblage of the Lower Coal Measures shows similarity with the palynoflora of Lower Unit of Ghosh (1983) in having the dominance of striate disaccates but the above mentioned Upper Permian (Raniganj) taxa have not been observed in the Lower Coal Measures.

SIKKIM

Sikkip Member—Important elements in the coal and associated sediments of Sikkip Member are *Striatites* (18%), *Brevitriletes* (17%), *Scheuringipollenites* (13%) and *Lophotriletes* (10%). The trilete spores together total up to 35 per cent, striate disaccate pollen 34 per cent and nonstriate-disaccate 21 per cent. Monolete spores, colpate pollen and alete spores are also present.

The dominance of *Brevitriletes* along with nonstriate and striate-disaccate pollen alienates it with the Lower Barakar palynoflora of the Peninsula. However, in this assemblage nonstriate disaccate genera appear to be on the decline, while striate disaccates show a rising trend. Such a change is usually present near the transition from Lower to Upper Barakar palynofloras.

BHUTAN

The Permian sediments exposed along Darranga River near Dewthung in East Bhutan (Banerjee & Das Gupta, 1983) show dominance of *Scheuringipollenites* (18%), *Primuspollenites* (10.9%), *Cyclogranisporites* (9%) and *Marsupipollenites* (8%).

The above assemblage has been compared with the Middle Barakar palynoflora by Banerjee and Das Gupta (1983). However, the high frequency of *Marsupipollenites* in high percentage is significant as this genus is present in similar frequency in Upper Permian *Vittatina* Assemblage of Australia (Balme, 1964). The presence of *Microfoveolatispora, Densipollenites, Crescentipollenites, Gnetaceaepollenites* and *Vittatina* also indicates a younger aspect to this palynoflora.

ARUNACHAL PRADESH

Kameng District

The sediments exposed along Bhareli River near Elephant Flat have yielded a palynoflora which is characterised by the presence of trilete spores (43%), chiefly *Callumispora* (34%). This is associated with *Parasaccites* (25%), *Plicatipollenites,*

Table 1—Biostratigraphic zonation of Permian sediments in eastern Himalaya

	Siang	*Subansiri*	*Kameng*	*Bhutan*	*Sikkim*	*Darjeeling*	*Meghalaya*	*Barpathar*	
Biozone	*Palynoassemblage/ Invertebrate fossils*	*Palynoassemblage/ Invertebrate fossils*	*Palyno-/ Plant assemblage*	*Palynoassemblage/ Invertebrate fossils*	*Palynoassemblage/ Invertebrate fossils*	*Palynoassemblage/ Invertebrate fossils*	*Palynoassemblage*	*Palynoassemblage*	*Peninsular equivalent*
6			*Glossopteris*-dominant *Gangamopteris*-absent (Acharyya *et al.*, 1975)			*Striatopodocarpites, Indospora, Verticipollenites* (Ghosh, 1983)			Raniganj
5					*Striatites, Brevitriletes*	*Faunipollenites, Striatopodocarpites*			Barakar
4	*Scheuringipollenites/ Uraloceras, Ambikella, Linoproductus, Productus*			*Scheuringipollenites* (Banerjee *et al.*, 1983)	*Ambikella, Productus*	*Lophotriletes, Brevitriletes*	*Scheuringipollenites* (Banerjee *et al.*, 1977)		
3	*Callumispora/ Subansiria, Fenestella, Deltopecten, Eurydesma*	*Callumispora/ Subanisria, Syringothyris, Eurydesma*	*Callumispora, Parasaccites*	*Fenestellids, Bryozoa, Gastropods* (Dewathung Area)	*Eurydesma, Fenestella* (Singh, 1981)	*Parasaccites*			Karharbari
2	*Parasaccites, Plicatipollenites*							*Parasaccites, Leiosphaeridia*	Talchir
1						*Eurydesma, Sanguinolites* (Acharyya *et al.*, 1975)			

Caheniasaccites and *Indotriradites* are in low percentages. Monosaccate pollen are up to 36 per cent. These sediments comprising the Bhareli Formation, were equated with the Raniganj Formation by Acharyya *et al.* (1975). The palynological investigation, however, reveals that atleast a part of Bhareli Formation contains Lower Karharbari palynoflora (Dutta *et al.*, ms).

Subansiri District

The carbonaceous shales exposed near Kheel contain a palynoflora similar to that observed in Kameng District suggesting a Lower Karharbari aspect to these sediments.

Siang District

The Permian sediments exposed between Tatamari and Passighat contain three distinct palynological assemblages :

Parasaccites + Plicatipollenites Assemblage—The argillaceous olive green splintery shales of Rilu Member contain a palynoflora rich in radial monosaccate pollen (up to 60%) (Miofloral Zone 1 of Srivastava & Dutta, 1977; Rilu Member Assemblage of Singh, 1979). *Parasaccites* is the dominant component and is associated with subdominant *Plicatipollenites*. *Virkkipollenites, Potonieisporites, Caheniasaccites, Rugasaccites* and *Stellapollenites* also occur persistently though in low percentages. Trilete spores are represented by *Callumispora, Microbaculispora, Lacinitriletes* and *Leiotriletes*. Disaccate pollen grains are very rare and so also the alete spores which are represented by *Leiosphaeridia, Pilasporites, Quadrisporites* and *Maculatasporites*.

Callumispora Assemblage—The black carbonaceous shales of Garu Formation show rise of the genus *Callumispora* to overall dominance (40-

60%), *Parasaccites* decreases to subdominance (20-30%). *Indotriradites* also increases to 10-15 per cent. In some samples near Passighat the percentage of *Indotriradites* has been observed to attain even higher values only next to the genus *Callumispora*. *Crucisaccites* is confined to this assemblage alone. *Caheniasaccites* is also associated with this assemblage and its percentage increases towards Passighat but in all the cases it remains next to the genus *Callumispora* or *Indotriradites*.

Scheuringipollenites Assemblage—In the carbonaceous sediments of the Garu Formation exposed near Takso Village *Scheuringipollenites* attains overall dominance while radial monosaccate pollen and trilete spores decrease considerably. Striate and nonstriate disaccates record increase in their percentage.

Coal Balls

The coal balls, particularly the calcareous coal balls, have yielded well preserved microflora which is similar to the palynoflora of the Garu Formation. In addition to the spores and pollen grains conodonts and microforaminifers have also been recovered, though their percentage is less.

Abor Volcanics

Roy Chowdhury (1977) has reported the occurrence of *Cyclogranisporites, Striatopodocarpites, Vittatina, Scheuringipollenites (= Sulcatisporites)* in the inter-trappean carbonaceous shales in Dihang Valley. Laskar and Roy Chowdhury (1979) consider these forms to represent Lower Gondwana.

Barpathar Area, Assam

The subsurface Permian sediments of Barpathar Area, Jorhat District (Assam) have yielded the following palynoflora (Sharma *et al.*, 1986):

Parasaccites + Plicatipollenites Assemblage—This assemblage shows dominance of radial monosaccate pollen (60-70%), e.g., *Parasaccites* (up to 40%) and *Plicatipollenites* (25-30%). *Callumispora* remains subdominant (10-15%). The total percentage of monosaccate pollen grains range between 60-70 per cent. Other trilete spores represented by *Jayantisporites, Microbaculispora, Indotriradites* range between 10-15 per cent. The presence of *Leiosphaeridia* is significant. Its frequency is up to 26 per cent in the older sediments but progressively reduces in younger sediments yet remains significant. Sporadic presence of *Botryococcus, Maculatasporites* and *Pilasporites* has aso been observed.

Meghalaya

The Permian sediments exposed on the western margin of Garo Hills near Hallidaygunj in Meghalaya has been studied by Banerjee *et al.* (1977). The assemblage is rich in *Scheuringipollenites* while other group of spores are present in low amounts.

The quantitative representation is not known and hence a correct assessment remains to be done. It appears that Lower Barakar palynoflora has already developed in the younger part of the sequence which are at present classified as Karharbari Formation. Lithologically the Barakar sediments are suspected to be present under the alluvial cover westwards in Hallidaygunj area.

BIOSTRATIGRAPHY

The frequent lithological variations, vertical and lateral both, limit the certainty of correlating the various rock units from different areas. The lithologic development, both marine and continental, is better pronounced in Arunachal Pradesh as compared to other areas of Eastern Himalaya. Similarly the fossil contents are also better preserved in Arunachal Pradesh. Therefore, a tentative stratigraphic sequence has been attempted on the basis of their biotic contents.

Biozone 1

Acharyya (1973) has reported Eurydesma Fauna from the Rangit Pebble Slate/Diamictite from Darjeeling Area. Fenestellids, bryozoa and gastropods have also been reported from Diuri Boulder Slates from Dewathung area in Bhutan. On the basis of the invertebrate fossils the Rangit Pebble Slate/Diamictite Member is dated as Asselian (Lower Permian) and is correlated with the Talchir Boulder Bed of the Peninsula.

Biozone 2

Biozone 2 has a radial monosaccate dominant assemblage which is comparable to the Talchir palynoflora of the peninsula. It is recorded from the Rilu Member. A similar assemblage is also known from the subsurface sediments in Barpathar area (Sharma *et al.*, 1986). This *Parasaccites + Plicatipollenites* Assemblage is rich in leiosphaerids in the lower part of the sequence but the same decreases in the younger part. The assemblage of the Rilu Member which contains smaller percentage of leiosphaerids is comparable to the upper part of the sequence in Barpathar area.

Biozone 3

The *Callumispora* Assemblage of the Garu Formation represents Biozone 3. The invertebrate fossils present in these sediments include *Deltopecten, Megadesmus, Phestia, Subansiria* and *Fenestella* in the lower part of Bomte Member; *Subansiria, Ambikella, Spirifer, Chonetes,* *Syringothyris, Connularia* and *Eurydesma* in Subansiri District; and *Eurydesma* and *Fenestella* in Namchi Member (Namchi Formation) from Sikkim (Singh, 1981). These faunal assemblages are closely similar to the *Eurydesma-Deltopecten* Assemblage of the Agglomerate Slate, Kashmir corresponding to Sakmarian age. Thus, the palynoflora as well as the fauna both complement each other in Siang, Subansiri and eastern Kameng. The *Callumispora* Assemblage is also present in the coal and carbonaceous sequence exposed in Bhareli River near Elephant Flat in Kameng District. However, the coal balls and animal fossils are totally absent in this section. Thus, the Karharbari palynoflora is associated with animal fossils in Siang and Subansiri while in Kameng it occurs independently. The faunal assemblage similar to that of the Garu Formation (rich in fenestellids, bryozoa and gastropods) is also reported from Dewathung area, east Bhutan. In south Sikkim the fauna described from the sediments of Namchi Member also correlates with that of the Garu Formation being rich in *Eurydesma, Fenestella, Spirifer*, etc. In Darjeeling the animal fossils are not known from the coal and carbonaceous shales which contain radial monosaccate dominant assemblage (Upper Karharbari). The above evidences tend to indicate that the Eurydesma Fauna and Karharbari palynoflora have occurred contemporaneously and hence are coeval.

Biozone 4

It is represented by the *Scheuringipollenites* Assemblage from the carbonaceous sediments of Garu Formation exposed near Takso village in Siang District and is comparable to the Lower Barakar palynoflora of the peninsula. In Darjeeling the Lower Barakar palynoflora (*Lophotriletes* Assemblage) is rich in trilete spores alongwith striate-disaccate pollen grains. The palynoflora described from Dewathung area, Bhutan (Banerjee *et al.*, 1983) shows dominance of *Scheuringipollenites*. However, the presence of *Marsupipollenites* in this assemblage indicates a younger aspect. The *Scheuringipollenites* dominant assemblage from Hallidaygunj area, Meghalaya (Banerjee *et al.*, 1977) also represents a Lower Barakar palynoflora. The *Scheuringipollenites* dominant assemblage recorded from the upper part of the Garu Formation in Siang is associated with *Linoproductus, Uraloceras, Ambikella* and crinoids. The comparable flora is not known from Sikkim. However, a fauna comprising *Ambikella, Spirifer* and *Syringothyris* described from Namchi Member (Singh, 1981) may be considered equivalent to this biozone. All the above faunal elements suggest Artinskian age.

Biozone 5

Faunipollenites + *Striatopodocarpites* Assemblage recorded from the Lower Coal Measures of Tindharia, Darjeeling District represents Biozone 5 and is comparable to the Upper Barakar palynoflora of the Peninsula. The striate-disaccate dominant assemblage described from Sikkip Member (Namchi Formation, Sikkim) has also been included in this biozone, though it contains trilete spores and nonstriate-disaccate pollen in subdominance.

Biozone 6

The youngest biozone is also characterised by the dominance of striate disaccate pollen grains which is present in Upper Coal Measures from Darjeeling District (Ghosh, 1983). This assemblage shows its similarity with that of Biozone 5 in view of higher percentage of striate disaccate pollen grains but the same is differentiable by the presence of *Indospora, Thymospora, Distriatites, Crescentipollenites* which indicates a younger aspect and as a whole is comparable with the Raniganj palynoflora. There is no other record of such assemblage from any other area in eastern Himalaya at present. The megafossils showing dominance of *Glossopteris* and absence of *Gangamopteris* in the Bhareli Formation from Kameng District is considered to be equivalent to the Raniganj flora (Acharyya *et al.*, 1975).

PALAEOENVIRONMENT

The Rangit Pebble Slate/Diamictite Member of the eastern Himalaya is usually correlated to the Talchir Boulder Bed of the Peninsula (Oldham, 1887; Fox, 1931; Auden, 1934, 1935). This major key horizon in eastern Himalaya exhibits distinct lithologic dissimilarity with those of the peninsular Talchir Boulder Bed. The genesis of this member is debatable. Some consider them to be glacial in origin (Ghosh, 1952, 1956; Nautiyal *et al.*, 1964) while the others view them to have been formed due to slide/slump or turbidity currents (Rupke, 1968; Acharyya, 1973).

The presence of *Eurydesma* fauna (Acharyya, 1973) in Rangit Pebble Slate suggests a cold marine environment during the deposition of these sediments. The Diamictite of Arunachal Pradesh is characterised by poorly sorted angular to subangular clasts which are mostly faceted; some of them show striations and polishing. These evidences document a glacial origin of these diamictites. The palynoflora of the Rilu Member in Siang and also subsurface sediments in Barpathar area further substantiates a wide spread glaciation associated with marine influence for at least a part of the Rangit Formation.

The black carbonaceous shales and coal succeeding the Rilu Member are characterised by the Lower Karharbari palynoflora. The fauna in the coal balls and also the sediments containing them is rich in *Eurydesma, Chonetes, Spirifer* and *Productus.* The species of *Eurydesma* are more varied in Siang, Subansiri (Garu Formation) and South Sikkim (Namchi Member) than in the Rangit Pebble Slate Member. Perhaps the Garu Formation and the equivalent sediments represent the acme of *Eurydesma* with its first appearance in Rangit Pebble Slate Member. *Productus* marks its appearance but remains low in occurrence and the number of species recorded is also low. The presence of *Eurydesma* fauna in these sediments suggests continuance of a cold marine environment. The development of black shales and coal which are devoid of any sedimentary structures except fine laminations and also the formation of coal balls suggests deposition in stagnant and tranquil waters. It is possible that reducing environment, developed under anaerobic conditions in coastal lagoons formed as a result of regressive epicontinental sea, has generated formation of black shales and coal of Bomte Member and other equivalent sediments. These conditions of deposition have prevailed all along in the Siang and Subansiri districts but in Kameng were restricted to eastern part only as west of Khuppi the sediments are exclusively continental. Further west the existence of similar fauna in Bhutan and Sikkim suggests the presence of similar depositional environment but in Darjeeling the sediments are again continental. Thus, the above evidences clearly suggest that these sediments were deposited during the regressive phase of sea and fluvial conditions were already under development, though restricted in aerial extent.

The depositional environment during the sedimentation of the upper part of the Garu Formation containing Lower Barakar palynoflora in Siang District appears to have been marine as the *Ambikella-Uraloceras* rich fauna is also present in the same sediment. This is the youngest record of marine influence in Arunachal Pradesh and also Sikkim (Namchi Member) as elsewhere in Bhutan (Banerjee *et al.*, 1983), Sikkim (Sikkip Member), Darjeeling (upper part of the Lower Coal Measures) and Hallidaygunj (Meghalaya) the sediments are characteristic of deltaic environment as the sandstones show horizontal ripples and laminations. The coal and carbonaceous shales are also thinner and streaky as compared to that of the Garu Formation.

The sediments of the Bhareli Formation in Kameng and Upper coal Measures in Darjeeling District show full development of sandstone and coal seams. These sediments represent a typical fluvial facies. Megafossils as well as the microfossils both represent a land flora and there are no evidences of marine elements.

GENETIC RELATIONSHIP

The term 'Gondwana' was applied to essentially fluviatile sediments which were widely distributed in peninsular India and are believed to have been deposited in tectonically controlled linear-sublinear basins/grabens. The eastern Himalayan Permian sediments, however, occur as allochthonous sheets all along the foothills of Himalaya, or as windows or discontinuous thrust sheets within the older metamorphics (Acharyya, 1975). The lithological similarity of the Rangit Pebble Slate/Diamictite is in typical contrast with those of the Talchir Boulder beds. However, the faunal and floral relationships are closely similar with their peninsular counterparts. The presence of *Eurydesma* at the base of Talchir Formation in Manendragarh is comparable with the Eurydesma Fauna of Rangit Pebble Slate. Similarly the *Parasaccites* + *Plicatipollenites* dominant assemblage of Rilu Member is also comparable with the *Parasaccites* Assemblage of Manendragarh (Bharadwaj *et al.*, 1979).

The black carbonaceous shale and coal of the Garu Formation contain *Callumispora* Assemblage in association with marine invertebrate fossils. The Lower Karharbari sediments of the Peninsula though resemble palynologically yet are devoid of animal fossils. The sediments of the Garu Formation are also characteristically associated with the faunal coal balls which are totally absent in Karharbari Formation. The overlying assemblage near Takso Village in Siang District (*Scheuringipollenites* Assemblage) is also associated with animal fossils in which *Linoproductus-Ambikella* predominates. Thus, there is a distinct contrast in sedimentational history of Peninsula and eastern Himalayan Permian sediments. The sediments of the Lower Permian sequence were largely under marine influence which continued as late as Lower Barakar times while in the Peninsula it is restricted to the Talchir times only. Venkatachala and Tiwari (1988—this Volume) have also suggested the presence of marine incursions throughout the Gondwana Sequence. However, the marine conditions never prevailed during the formation of coal in the peninsular Gondwana basins and whatever marine intercalations are known are associated with the shales and sandstones of the Talchir Formation. Besides, the occurrence of true faunal coal balls having marine fossils suggests that atleast the Arunachal Permian coals are autochthonous in origin. Contrary to this the peninsular Gondwana coals are believed to be of allochthonous origin. Therefore, it is difficult to compare the coals and associated sediments of eastern Himalaya with the Gondwana sediments of the Peninsula as they are different in nature as well as in their mode of formation. So far, these sediments have been grouped together mainly on the basis of their general appearance and regional lithologic characters. But a critical assessment of their genesis and mode of formation indicates that both these sediments are of entirely different nature, particularly having no similarity in their depositional history, as one is largely marine and the other is exclusively continental. Thus, to group these sediments together in Gondwana Sequence seems to be illogical, atleast without modifying the present concept of the Gondwana litho-unit which can only accommodate continental sediments. However, some minor marine intercalations may be placed in this unit. But how a dominantly marine sequence with such a large aerial extent can be placed in a unit designated and defined for essentially fresh water deposits? Under the circumstances it is suggested that if the Permian sediments of lesser Himalayan Zone of eastern Himalaya are to be grouped in the Gondwana Sequence a suitable modification is required in the prevailing concept else these sediments may be given a separate identity of their own. The similarity grows closer only during late Permian as the sediments in both the places are exclusively fluvial and show lithological similarity alongwith the fossil evidences.

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Reflection on relationship of Tethyan palynoflora

R. S. Tiwari & Vijaya

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The Early Carboniferous palynoassemblage from Spiti in Tethyan Himalaya has a restricted comparability with that of Cathaysia, more pronounced relationship with that of Australia and Middle-East while apparent form-similarity with the western Tethyan region. During the Permian, few elements are definitely common between Himalayan Tethys zone and the Angara-Cathaysia assemblages but there are strong indications of an influence of Indian palynoflora on Himalayan Tethys belt. Towards western Tethys wedge, the resemblance decreases gradually and new palynotaxa are observed indicating the European affinity. Similar type of relationship among palynofloras of Tethys realm exists during Triassic. The Jurassic palynoassemblage of Tethyan Himalaya region also exhibits greater affinity with those of Indian Peninsula, although more uniform pattern appears in the assemblages of the globe during Jurassic. It has been concluded that distinct provinciality existed during Carboniferous, Permian and Triassic times. The Himalayan Tethys belt has some relationship with Cathaysia, Middle-East and western Tethyan region; it has a few elements of its own but main thrust of influence is from the Indian Peninsula. The palynological relationship of a greater Indian Plate is thus indicated up to northern Tibet and narrower Tethys sea could have been the cause of such a qualified reflection.

Key-words—Palynology, Tethyan Himalaya, Cathaysia, Indian Plate, Gondwana.

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साराँश

टॅथीय परागाणुवनस्पतिजात की बन्धुता की समीक्षा

राम शंकर तिवारी एवं विजया

टॅथीय हिमालय में स्पिती से उपलब्ध प्रारम्भिक कार्बनीफ़ेरी परागाणुसमुच्चय कैथेसिआ से सीमित तुलना प्रदर्शित करती है, ऑस्ट्रेलिया एवं मध्य-पूर्व से अपेक्षाकृत और अधिक बन्धुता इंगित करती है जबकि पश्चिमी टॅथीज़ क्षेत्र से स्पष्ट सजातीयता व्यक्त करती है। परमी कल्प में हिमालयी टॅथीज़ मंडल एवं अंगारा कैथेसिआ समुच्चयों में कुछ अवयव निश्चित रूप से सामान्य हैं परन्तु हिमालयी टॅथीज़ पट्टी पर भारतीय परागाणुवनस्पतिजात के प्रभाव के प्रभावकारी संकेत हैं। पश्चिमी टॅथीज़ सीमा की ओर सजातीयता शनैः-शनैः कम होती जाती है तथा नये परागाणुवर्गक मिलने लगते हैं जिससे यूरोपीय सजातीयता प्रदर्शित होती है इसी प्रकार की बन्धुता त्रिसंघी कल्प में टॅथीज़ के परागाणुवनस्पतिजातों में प्रेक्षित की गई है। टॅथीय हिमालय के क्षेत्र की जूराई कालीन परागाणुसमुच्चय भी भारतीय प्रायद्वीप से अधिक समानता प्रदर्शित करती है यद्यपि जूराई कल्प में ग्लोब की समुच्चयों में एक-सा स्वरूप प्रतीत होता है। यह निष्कर्ष निकाला गया है कि कार्बनीफ़ेरी परमी एवं त्रिसंघी कल्पों में विभिन्न क्षेत्रीयतायें विद्यमान थीं। हिमालय की टॅथीज़ पट्टी का कैथेसिआ, मध्य-पूर्व एवं पश्चिमी टॅथीय क्षेत्र से कुछ सम्बन्ध रहा है; इसमें अपने निजी कुछ अवयव हैं परन्तु इसमें भारतीय प्रायद्वीप का अधिक प्रभाव रहा है। इस प्रकार बृहत् भारतीय प्लेट की परागाणविक बन्धुता उत्तरी तिब्बत तक प्रदर्शित की गई है और इस प्रकार की महत्वपूर्ण घटना के लिए सम्भवतः सकरे टॅथीज़ समुद्र की महत्वपूर्ण भूमिका रही होगी।

THE variation of spore-pollen assemblages is caused by hereditary mechanism as well as the diversified environment. The changing pattern of palynofloras evolves gradually through time by uncoding genetic changes in the back-drop of changing climatic conditions. The degree of speciation is more dependent on the climate and stress-levels induced by palaeogeographical positioning of landmasses.

Concepts, limits and extension of the Indian Gondwana
(Editors : B. S. Venkatachala & Hari K. Maheshwari)
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During Early Devonian, some indications of megafloral provincialism have already started to show (Chaloner & Lacey, 1983; Meyen, 1972, 1979, 1982); however, distinctly marked floral provinces came into being during Late Carboniferous-Early Permian. This was resulted from the environmental stress produced by the widespread glaciation in the Gondwanaland. The Tethys sea which was formed as a shallow new sea, though above the Hercynian basement in mediterranean also contributed in differentiation of provinicialiry. Fragmentation of the Gondwanaland started in Early Mesozoic era (McElhinny, 1973). The northwards movement of Indian Plate and uplifting of Himalaya played a vital role in deciding the evolution, seggregation, admixing and identity of well-known floras.

The biological evidences can be utilized to solve intricate problems concerning nature of Tethyan extent, existence of greater Indian Plate and relationship of floras in circum-Tethys region. The bio-entities are controlled by evolution. They can sort out relationships amongst assemblages of widely separated regions reflecting the degree of their mutual relationship (Visscher, 1967).

In the present communication, the palynological reflections of relationship in Tethys Himalaya have been identified. However, the variable factors, such as differences in environment, taxonomic disparity of palynotaxa, apparent form-similarity, homoplasy and gene-pool relationship of the distant past, have been kept in mind while making comparisons.

PROVINCIALITY OF FLORAS

The Hercynian orogeny as well as the southward polar wandering was responsible for significant climatic changes, which initiated Carboniferous-Permian glaciation in Gondwanaland, but continental climate prevailed in northern hemisphere. Such changes promoted evolution of biota. During Permo-Triassic time also, great changes were initiated and a major part of Palaeozoic flora disappeared and new types of Mesozoic plants appeared in Late Triassic.

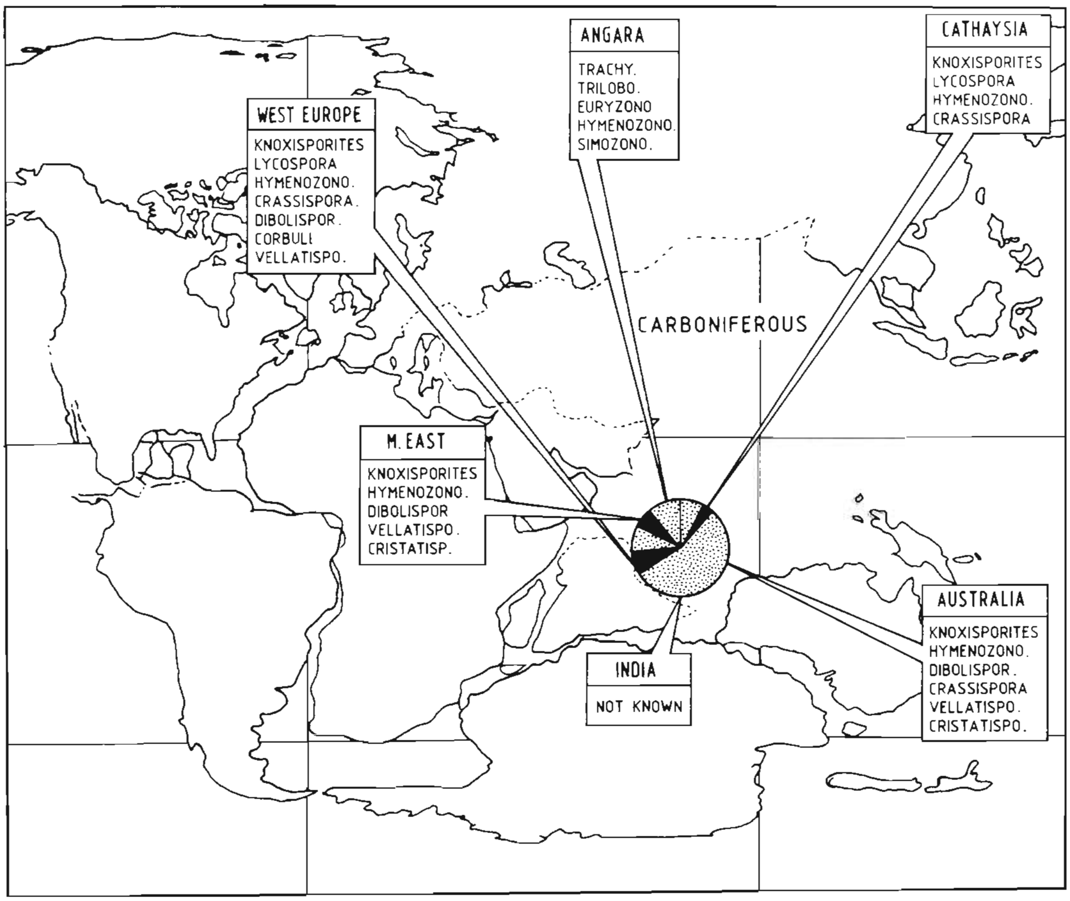
In Late Palaeozoic (Carboniferous to Permian), there were four floras—Angara flora in north, Euramerican flora and Cathaysia flora in middle part, and Gondwana flora in southern region of the globe. These floras were distributed in definite parallel latitudinal belts individually, and least on the longitudinal belts (Asama, 1985). The three northern floras have some common elements amongst themselves; however, the Gondwana flora has its individuality. The earliest view of a cosmopolitan Carboniferous flora held by megafossil workers has been challenged. According to Meyen (1982) the Gondwana megafloral province can be indentified by the Early Carboniferous time. These distinctions become clearer in Permian (Barthel, 1982). The differences are because of palaeogeographical environments and the climate resulting from the marked latitudinal disparity. Therefore, floral interchange between Gondwanaland on one hand and Euramerica and Cathaysia on the other was limited as well as qualified (Asama, 1985).

Search of megaplants beyond the conventional northern margin of the Indian Gondwana Plate may be purposefully utilized in locating its extension. Such attempts have resulted into the discovery of Glossopterids of Gondwana flora in Turkey, southern Tibet and Kashmir Himalayas which indicates that these regions had an influence of Gondwanaland (Wagner, 1962; Hsü, 1976; Singh, Maithy & Bose, 1982; Li, 1986).

Extensive faunal assemblages are on record for Tethys realm. The available data of Himalayan Tethys has revealed a cold water faunal affinity with Gondwana in the Early Permian and Tethyan warm water relationship in Late Permian (Waterhouse, 1976; Dickins & Shah, 1980; Dickins, 1985). The conclusion that a relatively uniform pattern of marine fossils existed in the Mesozoic times needs revision as the latitudinal disparity still existed, and continental positions did not make a drastic change when compared to Permian times. So also, the concept of a globally uniform vegetation in Mesozoic can be questioned, since latitudinally controlled distribution of megafossil provinces has been recognised (Barnard, 1973). Normally, the megafloral and palynofloral range of spatial occurrences do not coincide because of their mode and extend of dispersal from their original habitat. During recent years, much palynological data has been generated from the Tethys realm. In the present communication the comparisons have been done in the broader aspect of Carboniferous, Permian, Triassic and Jurassic palynoassemblages. The relationship has been evaluated on the generic occurrence of some precisely identifiable, characteristic forms with short range of vertical distribution and the assessment has been made after resolution of morphotaxonomy in each case.

INTER-RELATIONSHIP OF PALYNOFLORAS FROM TETHYS HIMALAYA BELTS

The Tethys Himalaya contains a more or less complete succession of rocks ranging in age from Late Precambrian to Upper Cretaceous (Gansser, 1964). From Cambrian, the occurrence of palynofossils and associated microfragments,

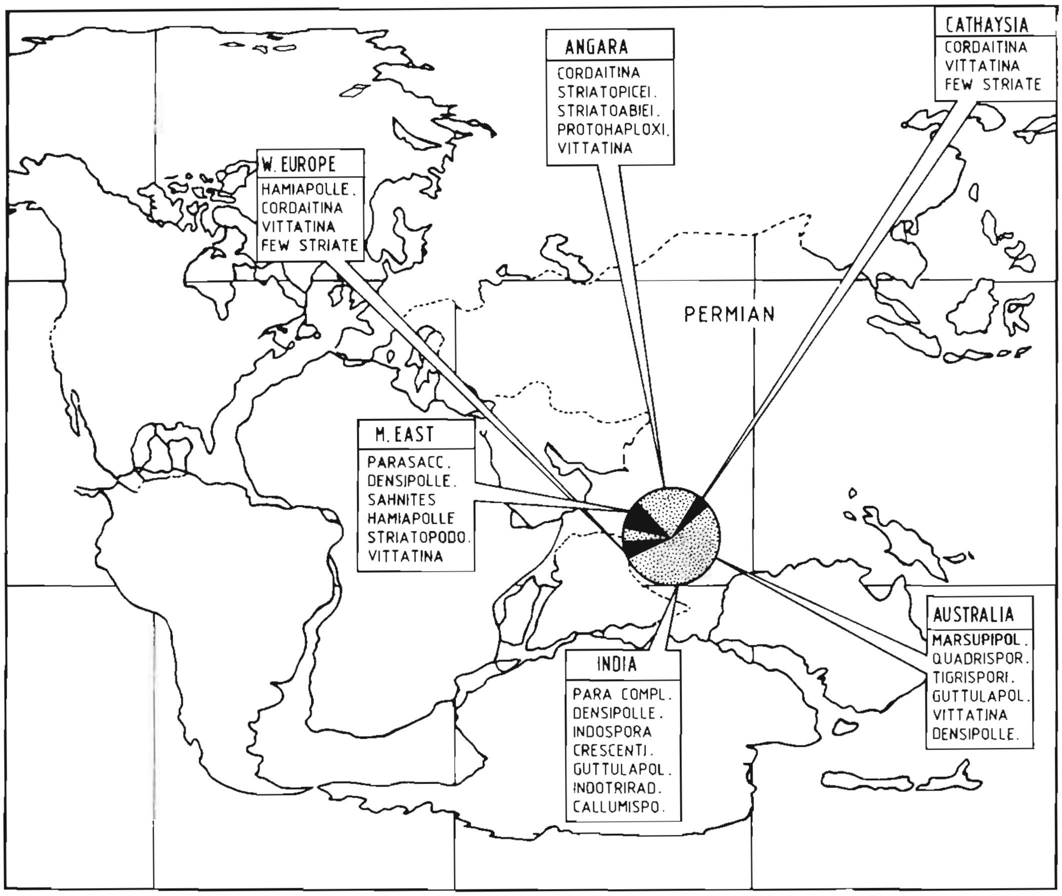


Text-figure 1—Reflection of palynological relationship in circum-Tethys region during Carboniferous time.

apparently comparable to much younger assemblages, has been recorded from Spiti Section and Kashmir region (Ghosh & Bose, 1952; Jacob *et al.*, 1953). However, later search of palynofossils in same horizon proved to be futile. Moreover, the advanced organization of the reported types has made such data a non-acceptable one. From Ordovician and Silurian sediments, groups of microfossils other than spore-pollen are reported from Spiti and Malla Johar areas (Khanna & Sah, 1980; Khanna *et al.*, 1985). Similarly, from Devonian sediments of Tethys Himalaya, the shales associated with Muth Quartzite were analysed by Tiwari *et al.* (1984) but except for chitinozoa, no spores or pollen were recovered. The palynoflora of Lower Carboniferous, Po Formation, Spiti Valley (Khanna & Tiwari, 1983) contains *Retusotriletes, Lycospora, Cristatisporites, Crassispora, Knoxisporites, Hymenozonotriletes, Vallatisporites, Dibolisporites, Retispora, Corbulispora, Phyllothecotriletes, Cingulatisporites, Tripartites, Raistrickia, Apiculiretusispora*, etc. The Teth an Permian palynoflora is on record from the sediments of Amb Formation, Wargal Limestone and Chhidru Formation—Salt Range, Pakistan. The characteristic genera are—*Camptotriletes, Schizosporis, Parasaccites*-complex, *Faunipollenites, Hamiapollenites, Guttulapollenites, Scheuringipollenites*, etc. (Balme, 1970). An younger affinity in the upper part of Chhidru Formation is reflected by *Lundbladispora, Densoisporites, Playfordiaspora, Satsangisaccites*, etc.; thus, a transitional phase from Permian to Triassic is depicted for this assemblage. The prevalence of monolete spore *Polypodiidites, Reticuloidosporites, Lunulasporites* at this level is unique for this region.

Permian sediments of Tethyan origin in Malla Johar area have been studied for their palynological content by Tiwari *et al.* (1980, 1984). The Kuling Shale Formation of Rawalibagar Group, from amongst the whole Permian sequence of this area, has yielded *Callumispora, Lophotriletes, Parasaccites, Densipollenites, Scheuringipollenites, Faunipollenites, Crescentipollenites* and *Striatites* in association with *Lundbladispora*.

The Lower and Middle Triassic sediments at Salt

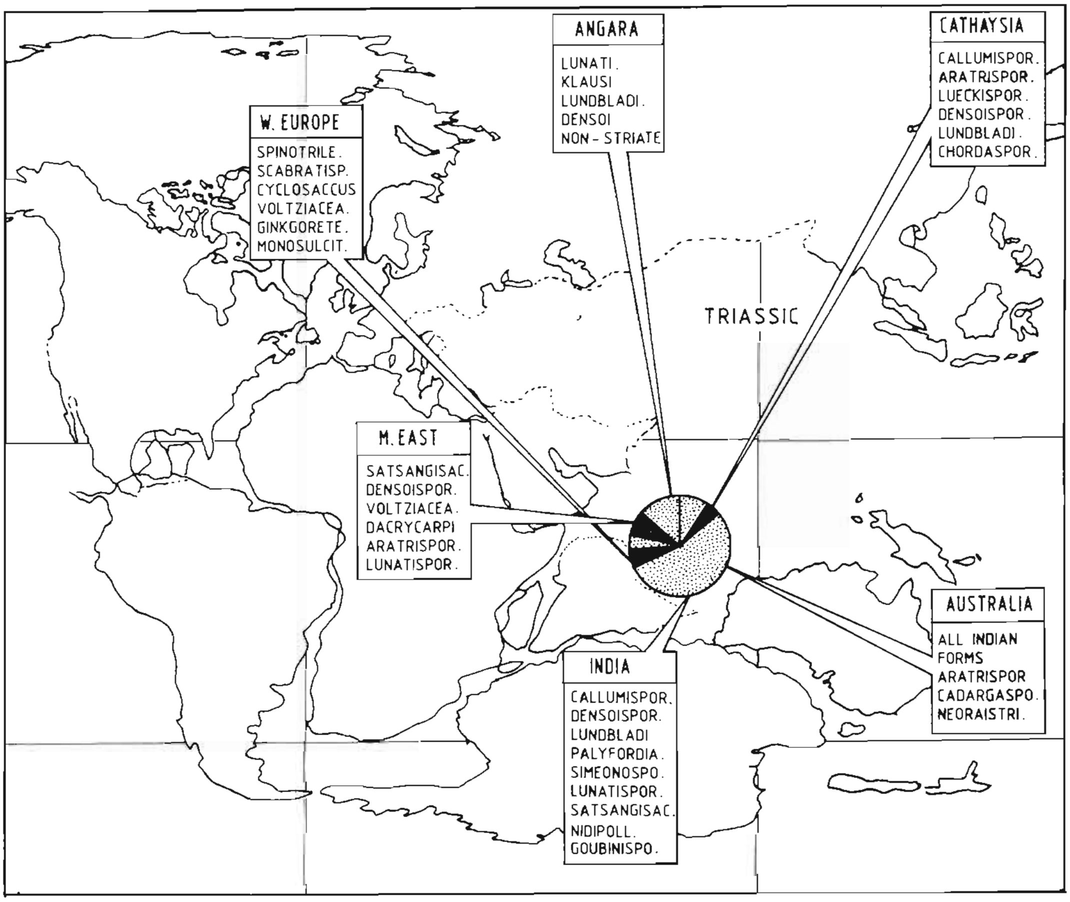


Text-figure 2—Reflection of palynological relationship in circum-Tethys region during Permian time.

Range region represented by Mianwali Formation and Tredian Formation, respectively, have been palynologically investigated by Balme (1970); this study has provided useful data for comparisons. Palynoassemblage of Kathwai Member, thought to be the oldest bed of Triassic, is poor in preservation. In the next two younger horizons, better palynofossils are documented. Significant genera from Mianwali Formation are—*Callumispora = Punctatisporites), Densoisporites, Lundbladispora, Lunatisporites (= Taeniaesporites), Klausipollenites, Osmundacidites, Playfordiaspora, Simeonospora, Aratrisporites, Satsangisaccites (= Falcisporites).* In the sediments of Tredian Formation (Middle Triassic) palynofossils are abundant but less diversified, represented by *Calamospora, Verrucosisporites, Triplexisporites (= Tigrisporites), Densoisporites, Lundbladispora, Playfordiaspora, Aratrisporites, Lunatisporites, Satsangisaccites, Scheuringipollenites*, etc.

From the Triassic sediments of Malla Johar area, Tiwari *et al.* (1980, 1984) reported scanty occurrence of palynofossils from various units of Kalapani Limestone, Kuti Shale, Passage Formation and Kioto Limestone. Recently, a well preserved and diversified palynoflora was found in the top most horizon of the Kalapani Limestone (Late Triassic) Formation by Vijaya *et al.* (1988) containing—*Callumispora, Simeonospora, Neoraistrickia, Scabratisporites, Cadargasporites, Spinotriletes, Tethysispora, Lundbladispora, Playfordiaspora, Voltziaceaesporites, Alisporites, Satsangisaccites, Striatopodocarpites, Lunatisporites, Chordasporites, Cordaitina, Ginkgoretectina*, etc. The Norian palynoflora known from Kuti Shale and Passage Formation comprises *Densoisporites, Lundbladispora, Klausipollenites, Striatopodocarpites, Lunatisporites* and *Pretricolpipollenites.* The Rhaetian palynoflora from Kioto Limestone shows the presenee of *Lundbladispora, Goubinispora, Lunatisporites*, etc. but is poor in contents.

From Kashmir Himalaya, palynological report from Lower Triassic argillaceous sequence of Pahalgaon (Nautiyal & Sahni, 1976), records microplankton and non-striate bisaccate pollen—*Klausipollenites, Platysaccus* and *Scheuringipollenites.* However, this information is too meagre to be considered for comparisons. The Jurassic



Text-figure 3—Reflection of palynological relationship in circum-Tethys region in Triassic time.

palynoflora from variegated shale, Mammal Gorge, Salt Range (Jain & Sah, 1969) contains 22 taxa; the dominant forms are *Classopollis*-complex, *Perinopollenites*, followed by *Matonisporites*, *Eucommidites*, *Podocarpidites* and *Araucariacites*. The saccate pollen are poorly represented.

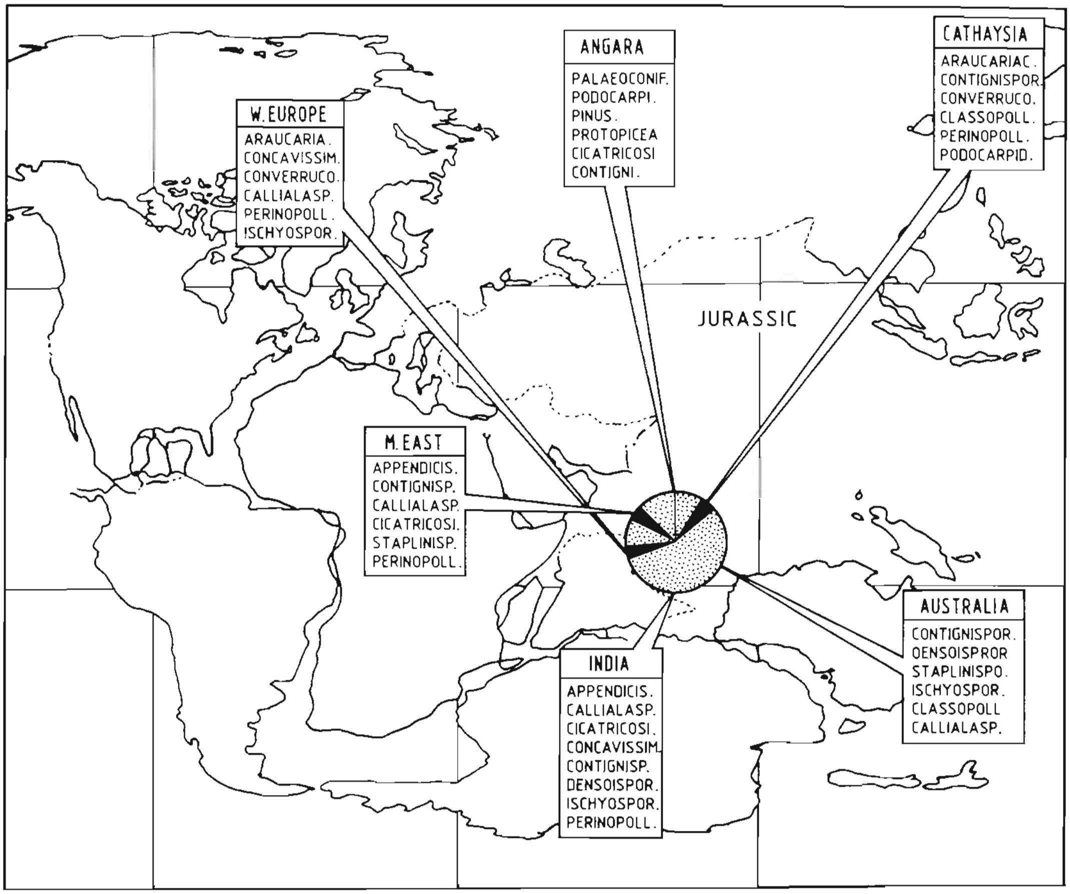
Palynological information is available from Spiti Shale unit of Malla Johar Supergroup, Kumaon Himalaya (Tiwari *et al.*, 1980, 1984; Jain *et al.*, 1984), a Late Jurassic age has been suggested on the basis of hystrichospheres, following pollen spore taxa are identified in this assemblage—*Concavissimisporites*, *Contignisporites*, *Cicatricosisporites*, *Callialasporites*, *Densoisporites*, *Appendicisporites*, *Alisporites*, *Couperisporites*, *Podocarpidites* and *Todisporites*.

Pantic *et al.* (1981) reported the presence of few palynomorphs from Jurassic sediments of Barsong Formation in eastern Bhutan. Beside other micro-organisms, the spore-pollen identified are *Callumispora* (= *Punctatisporites*), *Deltoidospora* and *Alisporites*.

No palynoflora is on record from Cretaceous of Tethys Himalayan belt. From amongst the available data enumerated above, the Salt Range and Malla Johar assemblages of Permian age are relatively better known than the others. These are closely affiliated with each other in most of their palynotaxa constituents, yet some differences can be identified, e.g., the presence of *Camptotriletes*, *Hamiapollenites* and abundance of monolete spores (*Polypodiidites*, *Lunulasporites*, *Reticuloidosporites*) in the Permian of Salt Range, but their absence in Malla Johar.

Palynofloras from the Triassic sediments of Tethys Himalaya in Salt Range, Malla Johar and Kashmir Himalaya are closely related with each other except that a few endemic taxa are present in Kalapani Limestone Formation of Malla Johar area, such as *Tethysispora*, *Lunatisporites tethysensis*, *Striatopodocarpites auriculus*, which are absent from the Salt Range. A significant resemblance is deciphered in the presence of *Cordaitina* in the Triassic of these two areas.

The known palynoassemblages from Jurassic sediments of Salt Range and Malla Johar belong to two different horizons, i.e., Early and Late Jurassic, respectively. Hence, no direct comparison is possible. Only certain taxa of long ranging nature are shared between the two areas, for example—



Text-figure 4—Reflection of palynological relationship in circum-Tethys region in Jurassic time.

Todisporites, Matonisporites, Lycopodiumsporites, Alisporites, Podocarpidites, etc.

REFLECTIONS ON RELATIONSHIP OF TETHYAN PALYNOFOSSILS

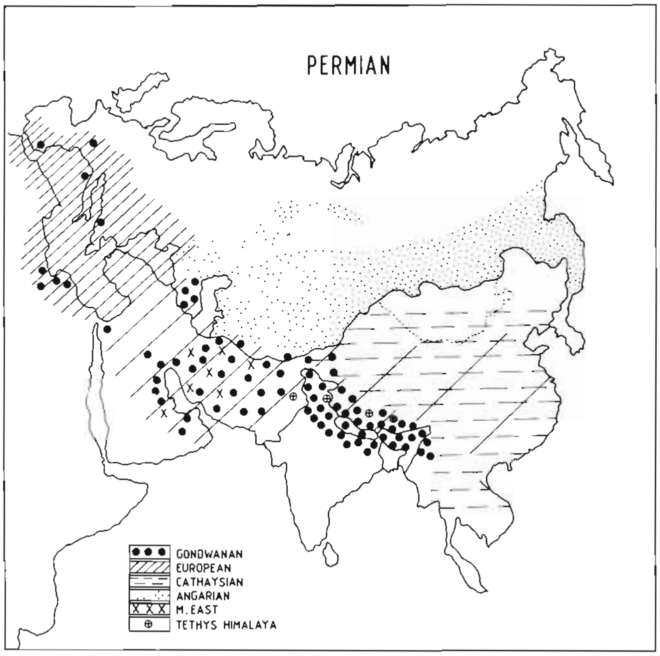
The Himalayan Tethyan palynofloras indicate various degrees of relationships with those of other Tethyan as well as circum-Tethys region. Such comparisons are brought out in the following account. These conclusions are not exclusively based on quantitative data. The qualitative resemblance, relative abundance and comparative prominence have also been determined on the basis of existing information.

Carboniferous

Cathaysian Middle and Upper Carboniferous assemblages, known from Henshanbu, Ningxia (Hui, 1984) and Shaanxi Formation, Gansu Province (Shu & Li, 1980; Du, 1986) do not show close affiliation with the sole record of Lower Carboniferous flora from Spiti Valley, Tethys Himalaya (Khanna & Tiwari, 1983). Leaving aside the long ranging taxa, like *Leiotriletes, Latosporites,* etc. the Cathaysian assemblage is characterised by *Dictyotriletes, Torispora, Pseudolycospora, Reinschospora, Florinites, Stellisporites, Trimontisporites, Waltziaspora, Trachytriletes* and striate and nonstriate disaccate pollen. However, a mild relationship is visible between the assemblages of two areas by the common presence of *Knoxisporites, Microreticulatisporites, Crassispora, Hymenozonotriletes* and *Lycospora.* Such observation opens a possibility of some ground for further comparison which could be purposeful for palaeogeographic determinations.

Assemblages of spore-pollen from Shaanxi and Gansu (Du, 1986), Cathaysian province, have been assigned an Early Permian age but they also contain several characteristic taxa, e.g., *Triquitrites, Torispora, Convolutispora, Lycospora, Florinites* which are characteristic of Late Carboniferous. The Early Carboniferous assemblage of Po Formation does not exhibit remarkable relationship with Shaanxi and Shihhotze palynofloras but, at the same

Text-figure 5



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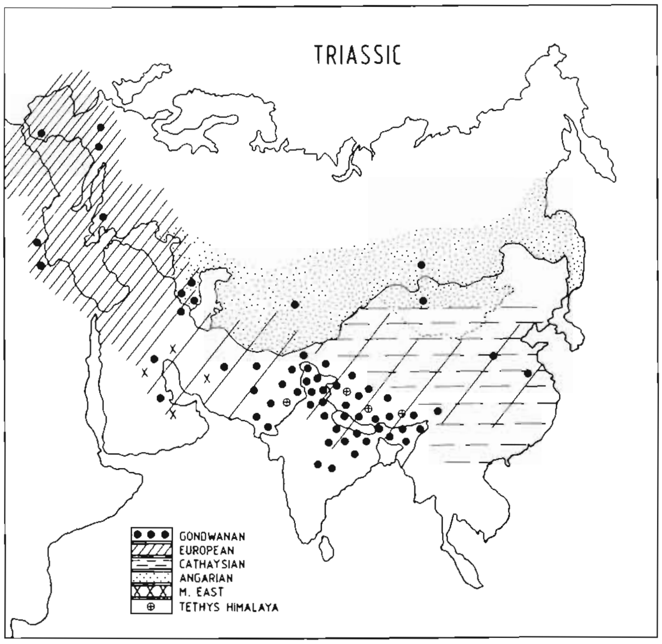

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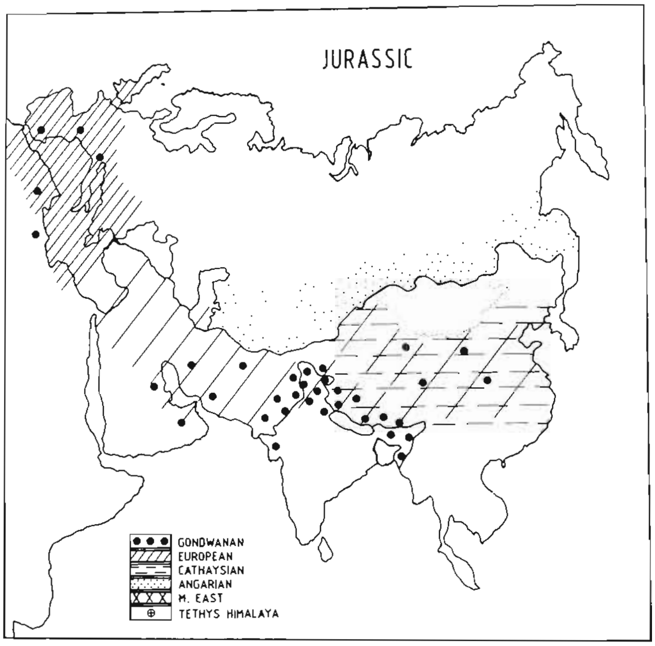

Text-figure 8

Text-figures 5-8—Relative affiliations in palynological composition of circum-Tethys region in various periods : **5**, Carboniferous; **6**, Permian; **7**, Triassic; **8**, Jurassic.

time, a few taxa, e.g., *Lycospora, Knoxisporites* might show some form-similarity.

There is no palynological record of Carboniferous age from Indian Peninsula. With the Australian Carboniferous assemblages (Evans, 1969; Playford, 1976, 1978) the affinity of Himalayan Carboniferous assemblage is reflected in the presence of *Knoxisporites, Hymenozonotriletes, Dibolisporites, Vallatisporites, Crassispora*, etc.

Record of few common elements between the Po Formation and Libyan Carboniferous (Coquel & Morean-Benoit, 1986) is interesting. However, Libyan palynoflora is more akin to the western Tethys realm in the presence of *Dictyotriletes, Geminospora, Cristatisporites, Umbonatisporites, Grandispora* and *Auroraspora,* rather than the eastern Tethys region in overall composition and, as such, only a limited degree of relationship is marked with that of the Himalayan-Australian region in the occurrence of *Dibolisporites, Hymenozonotriletes, Vallatisporites* and *Cristatisporites.*

The Tournasian palynoflora from Saudi Arabia (Hemer, 1965) has a conspicuous set of taxa revealing its individuality, but at the same time, in context to the Po Formation (inspite of age discrepancy of the two within the Carboniferous), a relationship is reflected in the common occurrence of *Densoisporites, Vallatisporites* and *Cristatisporites*; thus a qualified continuity of spore-pollen groups from Himalayan Tethys up to Saudi Arabia is evident.

Carboniferous palynofloras from western Tethyan province are extensively known (*see* Clayton *et al.*, 1977; Wagner *et al.*, 1983). A limited resemblance between the Po Formation assemblage and the west European palynofloras is indicated in the presence of a few common genera, such as : *Vallatisporites, Lycospora, Knoxisporites, Hymenozonotriletes, Corbulispora,* etc. Otherwise, the European palynofloras are distinct in having *Auroraspora, Grandispora, Spelaeosporites,* etc.

The Angara palynoflora of Early and Middle Carboniferous age is distinguishable by the presence of *Trachytriletes, Trilobozonotriletes, Euryzonotriletes* and *Perisaccus.* The apparent resemblance in the presence of *Lophotriletes, Leiotriletes, Hymenozonotriletes, Simozonotriletes,* etc. is diminished when the complex nature of forms and distinctiveness in species of the Angara palynoflora are carefully analysed.

Inspite of insufficient palynological data on the Carboniferous, a closer affinity of Himalayan Tethys with eastern Gondwana continent is evident, which appears to decrease with western Tethyan region. It remains limited with Cathaysian assemblages. Yet, it is clear that some genera are shared by most of the assemblages from Australia, Middle-East, Mediterranian and the Cathaysian region (Text-fig. 1).

Permian

Permian palynoflora from Tethyan Himalaya is comparable in the common occurrence of *Verrucosisporites, Sahnites, Corisaccites, Chordasporites, Platysaccus, Pityosporites, Piceaepollenites,* with the Early Permian assemblages from NW Shansi (Shu, 1964), Shaanxi Formation, Gansu (Du, 1986) and south west Tarim (Hui, 1985). As such, these assemblages are unique in themselves and show closer relationship with Russian Platform. The reflection of Cathaysian palynoflora in Himalayan Tethys are traceable as there exist few distinct forms which are similar in characters.

Most of the palynofossils from Tethys Himalaya reveal closeness with those from India and Australia (Evans, 1969; Balme, 1964, 1970; Kemp *et al.*, 1977; Foster, 1979; Tiwari & Tripathi, 1988, in this Volume; Vijaya & Tiwari, 1988). Some differences, however, can be marked, e.g., absence of *Dulhuntyspora, Rugulatisporites* and *Converrucosisporites,* in Tethys Himalayan, Permian and Indian Permian (Lower Gondwana) and their presence in Australian Upper Permian. Similarly, occurrence of *Cordaitina* in Tethys Himalaya makes it different from other comparable floras of this region. These assemblages are the product of widely extended Glossopteris Flora of the Gondwanaland and variations recorded are attributed to local environmental influence on their composition.

The relationship of Salt Range and Madagascar palynofloras (Goubin, 1969; Balme, 1970) is striking in the overall composition. The common presence of the genus *Guttulapollenites* has been given importance for such a relationship (Bharadwaj, 1976).

From the areas of Middle-East, Permian palynoassemblages are known from Saudi Arabia (Hemer, 1965; Cameron, 1974), north-east Iran (Chateauneuf & Stampfli, 1979), Iraq (Singh, 1964) and southern Israel (Horowitz, 1973, 1974). A limited relationship of these palynofloras with Tethys Himalayan assemblage is evidenced in the presence of *Parasaccites, Indospora, Densipollenites, Hamiapollenites* and *Faunipollenites (= Protohaploxypinus)*; at the same time, however, each assemblage of Middle-East can be distinguished from the Tethys Himalayan palynoflora by occurrence of certain taxa, e.g., *Striatoabietites, Perotriletes, Iraquispora, Fimbriaesporites, Masulipollenites, Wilsonia* and *Labiisporites,* etc. which are absent from the latter. The Middle-East floras are relatively closer to the European palynoflora in the presence of *Endosporites, Gardeniasporites, Perisaccus, Jugasporites* and *Limitisporites.*

A distant resemblance is indicated between the Libyan palynoflora and that of the Tethys Himalaya but the differences are more pronounced (Kar *et al.*, 1972). Well-illustrated palynological information is on record from Southern Alps and Germanic Permian (Klaus, 1963; Visscher, 1966; Visscher *et al.*, 1974). Frequency of identical palynofossils in assemblages of this region and Tethys Himalaya is low, as exemplified by the presence of *Cordaitina,* *Hamiapollenites* and *Vittatina* only. The increase in dissimilarity among the assemblages of two areas is attributed to their palaeolatitudinal positions during Permian time, and it is evidenced by the presence of *Strotersporites, Gigantosporites, Nuskoisporites, Gardenasporites, Perisaccus, Endosporites, Jugasporites, Limitisporites* and *Illinites.*

The Permian palynoflora of Angara region is rich and diversified. The taxonomic treatment is broad-based and morphographic significance attached to organization of spores and pollen varies; hence, comparative determinations cannot be ascertained in each case (Luber, 1970; Zauer *et al.*, 1969). Some pollen of *Parasaccites*-type appear to be present but most varied forms of apparently similar taxon *Cordaitina* are dominating in the Angaraland. This genus is also recorded from Himalayan Tethys. The striate disaccates have form-similarity. *Striatopodocarpites* with different species, is shared but other members of the group, such as *Striatopiceites, Striatoabieites, Protohaploxypinus,* etc. distinguish the Angara flora. The group *Vittatina* and monocolpate-complex although recorded from Tethys, are distinctive elements at specific levels (Sivertseva, 1966; Pokrovskaya, 1966). *Lueckisporites* is shared by both the floras so also some similar non-striate bisaccate pollen.

It is concluded that the Tethys Himalayan Permian palynoflora is rich and qualitatively diversified; it resembles Indian and Australian Lower Gondwana palynoflora. The degree of comparability declines in the Middle-East region and ultimately the spore-pollen complex met within the western most Tethys region shows restricted relationship with Tethys Himalayan assemblage. The pattern observed in Angaran and Cathaysian provinces *vis-a-vis* Tethyan Himalaya are different except for few elements (Text-fig. 2), which are shared by them.

Triassic

Significant palynological data is known from the Triassic sediments in the areas of Gansu (Liu, 1980; Du, 1985) and western Hubei (Li & Shang, 1980) Sichuan. The palynofossils from Cathaysia differ from those of other provinces; consequently, the Chinese workers proposed several new generic names. The remaining forms were placed in Angaran and European taxa which treatment appears to be casual rather than definitive. The Cathaysia palynoflora exhibits its individuality but at the same time it has limited relationship with the Tethys Himalayan assemblage, viz., in the presence of certain non-striate saccate pollen comparable to *Satsangisaccites, Nidipollenites, Klausipollenites* and *Playfordiaspora,* and trilete spores: *Callumispora, Lundbladispora, Densoisporites.* In general, it may be said that certain similarity exists between the two regions.

Resemblance between the assemblages in Triassic of Indian Peninsula and NW Australia with that of Tethys Himalaya has been discussed by Vijaya *et al.* (1988), and an impressive similarity is evident in gross morphography of palynofossils of the two regions. However, in the occurrence of a few endemic forms as well as some elements of other provinces, Tethys Himalaya flora differentiates itself; these taxa are—*Tethysispora, Striatopodocarpites auriculus, Spinotriletes, Voltziaceasporites, Colpectopollis* and *Ginkgoretectina.*

From the areas of Middle-East, rich and diversified palynoassemblages are known from Saudi Arabia (Hemer, 1965), Israel (Horowitz, 1973) and Iran (Kimyai, 1979). A limited qualitative continuity is indicated between the Triassic of Middle-East and Tethys Himalayan palynofloras in the common presence of *Kraeuselisporites, Playfordiaspora, Lunatisporites, Satsangisaccites* and *Voltziaceaesporites.* The Middle-East assemblages are more akin to the European palynofloras rather than those of Himalayan Tethys. The presence of *Jugasporites, Triadispora, Duplexisporites, Ovalipollis* and *Striatoabietites* in the Middle-East having resemblance in species with western Tethyan palynofloras is noteworthy.

The same kind of relationship of Tethys Himalaya is evident with the Triassic palynofloras from Libya (Kar *et al.*, 1972), southern Tunisia (Grignani, 1967) and Sahara (Reyre, 1970).

A comprehensive data on Triassic is known from the widely scattered Triassic sediments of south-west Europe in the areas of south east Spain (Adloff & Doubinger, 1970, 1978; Besems, 1981; Besems & Simon, 1982; Boutet *et al.*, 1982), France (Schuurman, 1977), Germanic and Alps region (Klaus, 1960, 1964; Mädler, 1964; Schulz, 1966; Scheuring, 1970, 1978; Schuurman, 1979; Visscher & Brugman, 1981), extending to western Dolomites, Italy (van der Eem, 1983), Sicily (Visscher & Krystyn, 1978) and Sardinia (Demelia & Del Rao, 1980; Demelia & Flaviani, 1982). The Triassic assemblages of Tethyan Himalaya have only few common elements with western Tethys and surrounding region, e.g., *Spinotriletes, Scabratisporites, Voltziaceaesporites.* Beside these, other taxa having wider distribution are also found to be common between these two areas; they are—*Klausipollenites, Aratrisporites, Lundbladispora* and few bisaccate-striate pollen which are also present in eastern Gondwana and the Tethys of Himalayan region. The latter also exhibits some broader aspects of palynological similarity during Triassic with Angara flora in the taeniate and non-taeniate simple disaccate pollen group (Chalishev & Varukhina, 1966; Romanovskaya, 1966). Recent trend to identify Russian palynotaxa on international pattern has resulted into identification of several species of *Taeniaesporites, Klausipollenites, Lundbladispora, Densoisporites*, etc. Thus, a relationship of Angara flora with the Tethys of Himalayan zone (Yaroshanko, 1978, 1980), could be deciphered. A generalized trend of relationship during Triassic time is depicted in Text-fig. 3.

Jurassic

Jurassic palynoflora from Cathaysian Province is known in the areas of Gansu Province (Liu *et al.*, 1981; Du *et al.*, 1982), Hebei (Zhen-bo, 1986) and SW Shandong (Li & Shu, 1980), where it is characterised by the prominence of *Cyathidites, Monosulcites, Chasmiatosporites, Asterisporites, Duplexisporites* and mainly cytheaceaous spores, and pollen of Cycadopsida, Ginkgopsida and Coniferopsida (*Pinuspollenites, Cerebropollenites, Abietineaepollenites*). On comparison with the Jurassic palynological assemblages of Tethys Himalaya (Jain & Sah, 1969; Tiwari *et al.*, 1984; Jain *et al.*, 1984) a fair degree relations is observed, as indicated by the common presence of *Todisporites, Dictyophyllidites, Perinopollenites, Callialasporites, Concavissimisporites, Contignisporites, Alisporites, Podocarpidites* and *Lycopodiumsporites*.

Indian Jurassic palynofloras are well known. A general account of various assemblages in Jurassic sediments of Peninsular India (Srivastava, 1966; Venkatachala *et al.*, 1969; Venkatachala, 1969; Singh, 1974) reveals that in the older sequence, the *Classopollis*-complex is dominant in association with *Cyathidites, Osmundacidites, Ischyosporites, Cingulatisporites, Monosulcites, Araucariacites* and *Callialasporites*. This closely compares with that of varigated shales of Salt Range (Jain & Sah, 1969). In the next younger horizon, the assemblage is dominanted by *Callialasporites*, or *Araucariacites*-complex. A qualitative change in the spore-pollen spectrum is marked by the appearance of new palynofossils. The Indian Jurassic palynofloras have great resemblance with that of Tethys Himalaya in their quantitative composition. The qualitatively important taxa are—*Perinopollenites, Araucariacites, Cicatricosisporites, Concavissimisporites, Contignisporites, Todisporites, Podocarpidites*, etc.

The same kind of affinity is indicated in Australian Jurassic palynoassemblages (Filatoff, 1975) and that of the Tethys Himalaya. Both eastern and western Australian palynofloras of Early Jurassic are characterised by high proportions of *Classopollis*, but in Middle Jurassic the genus *Callialasporites* becomes more important. The palynofossils from Tethys Himalaya are too few to allow meaningful horizonwise quantitative comparison but qualitatively there is a marked relationship among the taxa—*Ischyosporites, Lycopodiacidites, Alisporites, Perinopollenites*, etc.

Australian Late Jurassic palynofloras are relatively lesser known. Nevertheless, they contrast with the older assemblages by containing morphologically distinctive species, as *Contignisporites cooksoniae* and *Cicatricosisporites australiensis* which range from Late Jurassic to Early Cretaceous assemblages in Australia. However, the mode of relationship with Tethys Himalayan palynoflora is not clear at the present juncture.

In the Middle-East, palynological data is known from Jurassic sediments of Saudi Arabia. The only comparable taxon in known Jurassic palynoflora of Tethys Himalaya is *Appendicisporites*. Recently, more data has been generated from Iraq, Afganistan and Israel (Horowitz, 1974; Achilles *et al.*, 1984; Bharadwaj & Kumar, 1986). Palynofloras of these areas are different in their composition and only a limited comparison of their relationship can be made out in the presence of *Alisporites, Todisporites, Podocarpidites*, etc. which are common with Tethys Himalaya. However, these taxa are universally present, hence their significance is limited.

Early Jurassic palynofloral data from European region is relatively extensive (Mädler, 1964; van Erve, 1977; Del Rio, 1976, 1984; Achilles, 1981; Fisher & Dunay, 1981). The most striking aspect of assemblages from Europe is the high percentage of *Circulina* and smooth trilete spores. The quantitatively dominant taxa of assemblage are different from that of Gondwanaland and also the Tethyan Himalaya. Only qualitative resemblance is depicted with the latter by those forms which are widely distributed and mostly cosmopolitan, such as *Todisporites, Matonisporites, Ischyosporites, Concavissimisporites, Perinopollenites, Callialasporites, Staplinisporites*.

According to Filatoff (1975) more uniform flora was existing during the Jurassic time than other geological period. However, palynological evidences suggest that subtle differences existed and regional distinctions can be brought out by careful comparisons (Text-fig. 4).

DISCUSSION AND CONCLUSION

The reflections of relationship amongst palynofossils in Tethyan realm in Carboniferous through Jurassic periods are variable because the

Tethys cut across the northern and southern subtropical and tropical belts extending up to higher latitude of temperate and subantarctic region of the southern hemisphere. The pattern of land-sea distribution has been changing through this time span. The floral compositions have changed from time to time along the coastal as well as continental domain adjacent to it, which contributed to the pollen-spore population of the Tethyan deposits.

The spores and pollen grains must have been deposited through water and air medium, by travelling from near as well as distant areas in the adjacent landmasses. The vegetation which was growing in nearby areas is expected to be represented dominantly in the palynoflora. To this set up the environmental nitche and floral migration have added further complexity.

The Carboniferous palynoflora—The Himalayan Tethyan palynoflora has closer affinity with Gondwanan palynofloras which progressively decreases towards the Mediterranean wedge (Text-fig. 5). The Angara and Cathaysia palynoassemblages also possess a few comparable forms but their individuality is outstanding. Such situation is the result of distribution of landmasses during Carboniferous time, which were placed at highly differential latitudinal position. At the end of Carboniferous, the continents assembled tightly to form Pangea but Siberia and Cathaysia were still separate landmasses. The distinctions in palynological components can be exemplified by Australian palynoflora which differs from that of the Euramerian, as the latter has been obtained from coal-measures represented by special tropical vegetation (Chaloner & Meyen, 1973). Nonetheless, links are observed with North Africa, Europe and eastern North America (Balme, 1964; Playford, 1976; Galtier *et al.*, 1986). The Carboniferous palynoflora from Cathaysia is mainly dominated by *Triquitrites* in association with *Lunzisporites, Trimontisporites, Crassispora, Codiospora*, etc. but in other respect it is equatable to European assemblages (Shu, 1964; Hui, 1984). Similarly, the interplay of latitudinal belts in shaping the comparability of palynofloras can be demonstrated by greater similarity of Arabian Carboniferous assemblage with Russian assemblage of respective age (Hemer, 1965).

The Permian palynoflora—The Tethys Himalaya palynoflora has much greater similarity with that of the Gondwanan region. The differences increase with the western Tethyan region and the Angara-Cathaysia blocks (Text-fig. 6). Such a marked provinciality in palynofloral distribution during most of the Permian times is attributed to Hercynian orogeny when a complex topographic configuration and sharp climatic gradients were resulted on the northern as well as southern continents. The polar regions remained cold and the equatorial belt was hot. Consequently, distinct floras came into existence; the *Glossopteris* flora remained remarkably unique to south (Plumstead, 1973). In the north, the Siberian and Cathaysian plant communities were styled in their own identity owing to the high latitudinal positions (Chaloner & Meyen, 1973; Li & Yao, 1981). The Tethyan Himalayan palynoflora of Permian age exhibits an impressive similarity with the Gondwanan belt; the minor differences do not warrant a zonal distinction (Balme, 1964; Segroves, 1969, 1970; Vijaya *et al.*, 1988). At the same time, some influence of the western circum-Tethys region has also been recorded by the presence of *Cordaitina* and striate-disaccate pollen genera. An increasing influence of northern palynoflora on the Tethyan Himalayan region occurred because of the decreasing impact of glacial episodes (in Late Permian) in the southern continents; consequently, warming up of climate led to migration of tropical floras into southern region. However, the differences between Eurasian and Gondwanan plant population kept pace even with the southerly migration of floras because the climate of northern hemisphere also became warmer in response to the retreat of southern glacials. The migration must have taken place through the southern shore line and adjacent region of Tethys. This is shown in the progressive dissimilarity of palynofloras of Tethys Himalaya with those of western Tethys, as concluded here.

The Middle-East and Arabian Peninsula have greater influence of Mediterranean region (European belt) than that of India and Australia (Singh, 1964; Hemer, 1965; Horowitz, 1973; Kremp 1974, 1975; Vijaya *et al.*, 1988); this appears to be the result of their being positioned in same broader latitudinal belt which was occupied by northern coniferalean plants.

The Angara and Cathaysia Permian palynofloras have dissimilarity with Tethyan Himalayan belt. Still, certain forms appear to be shared by Cathaysia and the Himalayan Tethys which indicate that some sort of floral admixture has occurred. New data in these areas, particularly from China, may throw light on migratory routes.

The Triassic palynoflora—In Triassic the great Supercontinent Pangaea took its final form encompassing all major segments of continental crust. The floral provinces of Permian time did not change significantly in the Triassic. The Euramerian flora grew under warmer and drier conditions at low latitude while Gondwana flora, though experienced relatively warmer climate than Permian, lay at the southern higher latitude. The infiltration of

European and Mediterranean elements into Himalayan Tethys is more pronounced (*Spinotriletes, Voltziaceaesporites, Colpectopollis, Ginkgoretectina*, etc.) in Triassic because of less intensive climatic variation from equator to the temperate zone, yet the influence of Gondwanic flora remains dominant on the Tethys Himalaya (Text-fig. 7).

The Triassic palynofloras of Gansu and Sichuan Province are distinctive from Tethyan Himalaya yet a few common elements do exist. Some comparability of Cathaysia also exists with European assemblage. This in turn reflects certainly warm and wet climate for this region belonging to subtropical type (Lei, 1986). These trends of relationship implicitly express that the distances between Himalayan region and the Cathaysia were not that great which prevented any intermixing.

The Jurassic palynoflora—In the Jurassic sediments of the Tethys Himalayan belt, the palynofloras are found to be qualitatively comparable in their constituents with almost all other contemporary Tethyan assemblages, but more pronounced resemblance is indicated with India and north-west Australia in the occurrence of podocarpaceous species. Certain forms, e.g., *Matonisporites, Ischyosporites, Concavisporites, Classopollis, Staplinisporites, Callialasporites, Podocarpidites* appear to be present in widely separated areas of circum-Tethys region, but quantitatively they are inconsistent as well as long ranging in distribution. *Classopollis* is an example which reveals a latitudinally controlled abundance in Eurasia and North Africa in the Late Jurassic with the highest frequency occurring nearest to the equator (Hughes, 1973). In other forms also, the qualitative comparisons suggest that Jurassic plants flourished under a wider spectrum of climate. Such a phenomenon of low diversity has been assigned to the temperature gradients which were gentle from equator to pole throughout Jurassic Period. This gave a less diversified character to the climate of the global area, and consequently, the occurrence of relatively more cosmopolitan elements was recorded. However, on reviewing the quantitative composition of assemblages, some differences amongst the Jurassic palynofloras are also clearly brought about. For example, plant microfossils from northern hemisphere are distinguished by paucity of Araucariaceous type pollen and monosulcate pollen, while they are abound in southern hemisphere (Filatoff, 1975; van Erve, 1977; Achilles *et al.*, 1984). Similarly, except for rare forms appearing to be cosmopolitan in distribution during Jurassic time, the palynoflora of Middle-East area has little affinity with the Tethys Himalayan palynoflora, when viewed after moderation of taxonomic discrepancies. It is concluded that although many elements appear to be widely represented in Jurassic palynofloras of the world, the quantitative differences exist and also the qualitative distinctions can be made at specific levels (Text-fig. 8).

The Himalayan Tethys at north-west and western region of India has a great influence of the Gondwanan elements of palynoflora. Positively during Permian and Triassic times, some mild influence of Cathaysia as well as Tarim are evident which indicates that the width of the Tethys sea at this time period was not as great as envisaged so far, but a shallow epicontinental sea must have had existed. India must not have been far away from northern block and the admixing, although of a limited nature, had existed in the circum-Tethys region. With this line of approach, the model proposed by Xuchang and Yanlin (1984) having accretion of four microplates drifted at different period and a narrower Tethys may explain the palynological reflections discussed here. Beside palynology, other palaeontological findings of Gondwanan elements in north Tibet and evidences from tectonics as suggested by Acharyya (1988, in this Volume) further support the contention of a greater Indian Plate extending up to north Tibet and a narrower Tethys. Does the Expanding Earth Theory answer to such indications? (*see* Carrey, 1983; Owens, 1983; King, 1983).

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Northern limits of the eastern Gondwana : palaeobotanical evidence

Hari K. Maheshwari & Usha Bajpai

Maheshwari, Hari K. & Bajpai, Usha (1988). Northern limits of the eastern Gondwana: Palaeobotanical evidence. *Palaeobotanist*, **36** : 354-368.

The northern margin of the Gondwanaland along the Indian block has been debated for sometime now. According to the earlier view the northern margin ran along the Indus-Yarlung-Zangbo Suture. Newly acquired data has been interpreted to show that eastern Gondwana was much bigger than generally believed.

In the present work we analyse the floras that grew around the northern margin of the eastern Gondwana assembly to see if the distribution of plant fossils also provides supporting evidence for a 'greater' India. The floras that have been examined in the present synthesis originate in the Permian of New Guinea, Sumatra (Indonesia), Malaysia, Thailand, Tibet, Northern China, Kashmir (India), Saudi Arabia, Iran, Iraq and Turkey and Mesozoic of Ladakh (India), Bhutan and Nepal.

The analysis shows that though some of the floral assemblages contain certain elements that could be of Gondwana affinity yet the overall composition of almost all the floral assemblages, except the one from Kashmir, is basically Cathaysian. Whether these Cathaysian type floral assemblages occupied the northern margin of the eastern Gondwana or they flourished on the southern margin of Laurasia, or they grew all along the shores of the Tethys, has to be examined.

The latitudinal variation in vegetation, however, does not seem to explain the intermixing of elements of different floral provinces in the coastal vegetation on the two shores of a fairly wide, though shallow, Tethys as in Kashmir and in southern Tibet. Even if both these regions were on the same side of Tethys, intermixing of Gondwana and Cathaysia floras is not explained as no direct migratory routes from Laurasia are available in Gondwana assemblies.

This coupled with the occurrence of northern Mesozoic flora at Fukche, Ladakh, and near Lhasa indicate that the Indian Gondwana did not extend north of the Indus-Yarlung-Zangbo Suture Zone.

Key-words—Gondwana, Indian Plate, Continental Drift.

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साराँश

पूर्वी गोंडवाना की उत्तरी सीमायें : पुरावनस्पतिक प्रमाण

हरिकृष्ण माहेश्वरी एवं ऊषा बाजपेयी

गोंडवाना के भारतीय ब्लॉक की उत्तरी सीमा वाद-विवाद का विषय रही है। पूर्व मतों के अनुसार उत्तरी सीमा सिंधु-यारलुंग-जाँगबो सूचर से परिलक्षणित थी। नये आँकड़ों की व्याख्या से अनुमान लगाया गया है कि पूर्वी गोंडवाना अपेक्षाकृत कहीं अधिक बड़ा था।

क्या पादपाश्मों का वितरण भी 'विशाल' भारत के लिए समर्थक प्रमाण जुटाता है? यह जानने के लिए उन वनस्पतिजातों का विश्लेषण किया गया है जो कि पूर्वी गोंडवाना की उत्तरी सीमा के आस-पास उगते थे। न्यू गिनी, सुमात्रा (इंडोनेशिया), मलेशिया, थाइलैंड, तिब्बत, उत्तरी चीन, काश्मीर (भारत), सउदी अरब, ईरान, ईराक एवं तुर्की के परमी कल्प में तथा लद्दाख (भारत), भूटान एवं नेपाल के मध्यजीवी कल्प के वनस्पतिजातों का विश्लेषण किया गया है।

विश्लेषण से व्यक्त होता है कि यद्यपि कुछ वनस्पतिजातीय समुच्चयों में ऐसे कुछ अवयव हैं जो कि गोंडवानी सजातीयता व्यक्त करते हैं, पर काश्मीर को छोड़कर प्रायः सभी वनस्पतिजातीय समुच्चयों की संरचना वस्तुतः कैथेसीय है। कैथेसीय प्ररूप वनस्पतिजातीय समुच्चय पूर्वी गोंडवाना की उत्तरी सीमा पर

Concepts, limits and extension of the Indian Gondwana
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प्रस्थापित थे या लॉरेशिया की दक्षिणी सीमा पर विकसित थे, अथवा टॅथीय तटों के संग-संग उगे हुए थे, इस विषय का अभी अध्ययन किया जाना है।

वनस्पति की अक्षांसी विभिन्नता से भी विस्तृत परन्तु छिछले टॅथीज़ की तटीय वनस्पति में विभिन्न वनस्पतिजातीय क्षेत्र के अवयवों का अन्त:मिश्रण सुस्पष्ट नहीं होता जैसा कि काश्मीर एवं दक्षिणी तिब्बत में है। यहाँ तक कि यदि ये दोनों क्षेत्र टॅथीज़ के एक ही ओर विद्यमान थे तो भी गोंडवाना एवं कैथेसीय वनस्पतिजातों का अन्त:मिश्रण स्पष्ट नहीं होता।

फ़ुक्से, लद्दाख एवं ल्हासा के समीप उत्तरी मध्यजीवी वनस्पतिजात की उपस्थिति के साथ-साथ इससे इंगित होता है कि भारतीय गोंडवाना सिंधु-यारलुँग-जाँगबो सूचर क्षेत्र के उत्तर में विकसित नहीं था।

THE concept of an Indo-oceanic Supercontinent—the Gondwana—that developed with Suess, has been so well discussed in the past in all its aspects that it needs no introduction. The generally accepted reassembly of the Gondwana Supercontinent comprises two segments: (i) western Gondwana consisting of South America and Africa; possibly Iran-Afghanistan as well, and (ii) eastern Gondwana consisting of Antarctica, Australia and India (Map 1). (We have dropped the suffix 'land' from Gondwanaland as *Gondwana* in vernacular means *land of Gonds*).

The northern margin of the eastern Gondwana has been variously demarcated and has recently become a matter of much discussion or rather speculation. Earlier it was believed that the northern limit of the Indian Gondwana block extended along the Indus Suture Line (Jhingran, Thakur & Tandon, 1982; Shanker, Padhi, Prakash, Thussu & Das, 1982; Nandy, 1982). A few others believe that the Central Crystalline Axis (south of Indus Suture Zone) represents the northern limit of the Indian Plate.

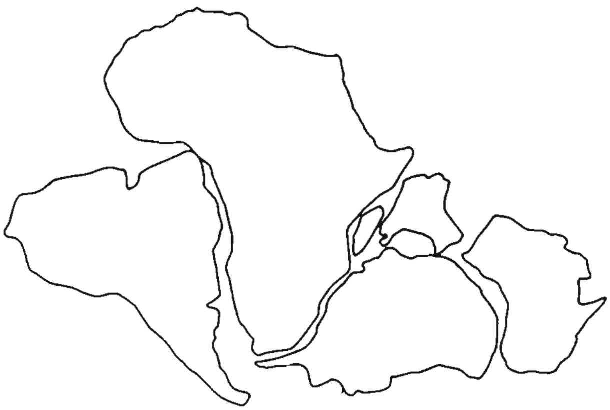
Crawford (1974a, b) opined that the Indus Suture Line is a relic of Permian-Jurassic oceanic opening rather than a relic of oceanic subduction preceding collision. He postulated a Gondwana Supercontinent much bigger than generally believed. The northern boundary of the Indian Plate was pushed beyond Tibet on the north side of the Tarim Basin block and was supposed to probably include parts of northern China, forming one huge crustal unit, the southern half emerged, the northern submerged. Along the former northern oceanic boundary of the Gondwana now lie the Shan mountains. Kaila and Narain (1981) have expressed almost identical views. Rastogi (1981) does not agree with this hypothesis. According to him 'if the northern boundary of the Indian Plate is placed in Central Asia it would pass through some of the stable blocks and cut across or include some portions of very large strike-slip faults'.

However, Crawford (1982, p. 291) changed his opinion and declared that 'There is no evidence whatsoever for assuming that the fragment was more than slightly larger than the present Peninsular continental unit, though it appears always to be assumed by workers that it was very substantially larger'. He also opined that India was never very far from Asia. Carey (1982, p. 401) also believed that 'India has never been further from Asia than she now lies'.

Audley-Charles (1983) proposed substantial additions of large continental blocks to the Gondwana thus drastically changing the northern contour of the eastern Gondwana. These blocks include Turkey, Iran, central Tibet and Indochina besides southern Tibet, Burma, Thailand, Malaysia and Sumatra. Tarling (1972) had earlier gone to the extent of suggesting that southern China and possibly southern Korea were both attached to India and lay west of Australia.

Patriat and Achache (1984) analysed the palaeomagnetic data from southern Tibet and suggested that 'greater' India extended between 500 and 1,000 kilometers further north of than the present northern limit of the Indian subcontinent but that southern Tibet formed southern margin of Eurasia. The northern margin of India collided with Ladakh Island Arc before anamoly 24 (53 Ma). India and Australia became part of the same plate after anamoly 20 (44 Ma). Between these two events about 400 kilometers of Indian continental crust subducted beneath southern Tibet.

Further support to the views detailing the concept of 'greater' Gondwana is derived from several disciplines. For example, the distribution of *Daphniopsis* in Antarctica, Australia, Tibet and Inner Mongolia suggests association of Tibet with Australia (Servenly, 1929). The known distribution of the labyrinthodont *Lystrosaurus* in Tarim, India, South Africa and Antarctica can also be explained under this assumption (Termier & Termier, 1981). It may be noted here that palaeomagnetic evidence shows that the Tarim block was a part of Laurasia in Late Permian (McElhinny *et al.*, 1981). The distribution of conodonts in the Triassic is interpreted to favour placement of Iran adjacent to Arabia and Malaysia adjacent to northwestern Australia and Timor as a part of Gondwana margin (McTavisch, 1975). The distribution of other major groups of marine fauna has also been taken into consideration for grouping southern Tibet, Burma and Southeast Asia at the northern margin of eastern Gondwana. However, Stauffer and Gobbelt (1972) have pointed out that



Map 1—Configuration of Gondwana during Early Permian.

these faunas and lithofacies indicate a tropical or subtropical climate and hence Southeast Asia could not have formed a part of the Gondwana. Palaeomagnetic evidence also does not support the view that Malaysia was a part of the Gondwana (McElhinny *et al.*, 1974).

Tiwari *et al.* (1980) reportedly found Gondwana palynotaxa in the Tibetan Series of the Malla Johar area in Kumaon Himalaya and postulated that this find supports the position of the Indian Plate boundary beyond Tibet in China. It is worth while to record here that almost all the palaeobotanists believe and admit that Tibet had a typical Cathaysian Flora (Li & Yao, 1982).

From the foregoing summary of some of the major works following controversial points arise that need our attention:

(i) The eastern segment of Gondwana was much bigger than previously delineated and that its northern territory included southern Tibet, Northern China and most of Southeast Asia;

(ii) The Indian block extended further north of Indus Suture Line, may be from 2,600 to 4,000 kilometers and that the northern margin of the Indian Plate corresponded with the Tien Shan Ranges, north of Tarim Basin.

In the present work we are concerned mainly with an indepth analysis of the floras that grew around the northern margin of the eastern Gondwana assembly. We examine the palaeofloras to extract supporting evidence, if any, for a 'greater' eastern Gondwana or 'greater' India. A serious attempt in this direction has been lacking probably due to the fact that no accepted diagnosis of a typical Gondwana Flora is available. The genetic affinity of the so-called mixed floras has also been unclear.

We consider a typical Gondwana Flora to be one that is of Early Permian to Late Triassic age and more or less conforms to any one of the peninsular Indian Gondwana floras. The simple occurrence of *Glossopteris*-like leaves outside the main Gondwana provinces does not automatically depict a Gondwanic affinity or connection to a flora unless supported by the presence of typical fertiligers or atleast by the *Vertebraria* axes. *Glossopteris*-like leaves are infact reported from the Rhaeto-Liassic of Vietnam and Yunnan (Zeiller, 1902-1903) and Upper Triassic to Middle Jurassic of Central America (Delevoryas & Person, 1975; Ash, 1981) besides from the Upper Permian of many parts of Soviet Union (Zimina, 1967) and Mongolia (Bobrov & Neuburg, 1957). But we know for sure that these leaves do not represent the *Glossopteris* plant. The glossopteroid venation is reported to occur in a number of unrelated gymnosperms (Chaloner & Meyen, 1973), for example, *Zamiopteris, Pursongia, Mexiglossa, Sagenopteris*, etc. Of course, there is also much difficulty in defining a typical Jurassic—Cretaceous Gondwana Flora because a large number of taxa is cosmopolitan.

The sporadic presence of a sterile northern or southern element, particularly at generic level, does not necessarily make a flora a mixed one, for example, the equisetale *Schizoneura*, originally reported from the Middle Triassic of Europe, has a wide lateral and vertical distribution. It is reported from the Permian of Gondwana, Korea and Japan, Middle Triassic of Australia, Upper Triassic of New Mexico, South Africa, Europe, Siberia and Korea and Lower-Middle Jurassic of Europe (Ash, 1985). But the fructifications of this genus wherever known are different. The same is also true for the genera *Neocalamites* and *Phyllotheca* (Meyen, 1971). Even the distribution of the genera *Sphenophyllum* and *Rhipidopsis* needs a critical reappraisal. All such occurrences need critical reappraisal of (i) their identification, (ii) the reason for their presence, if confirmed—accidental transport, homoplasy in that organ, or actual occurrence. Otherwise one may unwittingly draw fanciful conclusions.

For example, the species *Glossopteris angustifolia, Glossopteris indica, Palaeovittaria kurzii* and *Noeggerathiopsis hislopii* identified in Rhaeto-Liassic of Yunnan and Vietnam were taken as solid evidences of migration of Gondwana elements in the Cathaysia Flora. However, we know that these were wrongly identified (Hsü, 1978). According to Pant (1975) 'there are hardly any structurally or reproductively identified common forms between Late Palaeozoic floras of Laurasia and Gondwanaland'. According to Edwards (1955) 'records of northern glossopterids should now be treated with utmost suspicion unless they are based on very characteristic fructification.'

In our definition of the Gondwana floras we have intentionally left out taxa based on spores and pollen because their taxonomy and nomenclature are still in a developing stage. It would seem that (i) only a limited number of characters is available for permutation and combination, and (ii) spores and pollen being enclosed in sporangia and pollen sacs respectively did not get much exposure to the vagaries of nature and hence there is not much differentiation geographically at any given period of time. The major phytochorias of the Permian Period are: the Euramerica, the Angara, the Cathaysia and the Gondwana. Vakhrameev *et al.* (1970) designate the Gondwana phytochoria as the Gondwana Kingdom and the other three phytochorias as Union of Northern Kingdoms.

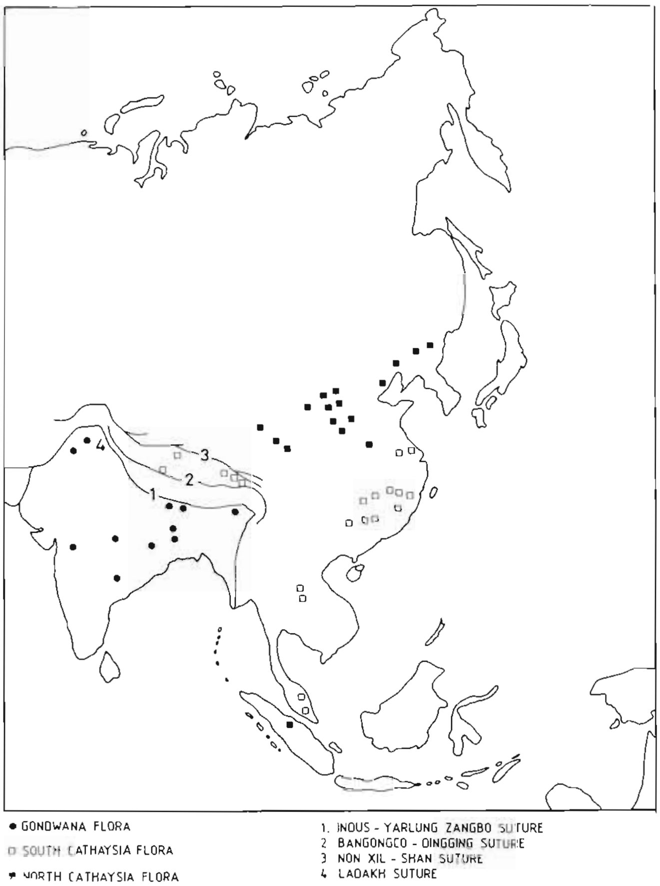
The Euramerica Flora extended from Oregon in the west to Urals in the east. The Angara Flora occupied the Siberian region. The Cathaysia Flora covered much of China and extended as south as Sumatra. The Gondwana Flora covered all the southern continents and India.

The Euramerican palaeofloristic province mostly has a lepidodendrid rich assemblage with a fair intermingling of calamites, sphenophylls and pteridosperms. The appearance of *Callipteris conferta* and the presence of *Lebachia* and *Ernestiodendron* mark the Lower Permian. The Angara Flora is generally poorer in lycopods but has many endemic distinctive cordaites and pteridosperms. In the Cathaysia, *Lobatannularia* seems to have been distinctive genus alongwith *Tingia, Emplectopteris* and *Cathaysiopteris*. *Gigantopteris* and allies mostly occur in the upper phase of the Cathaysia Flora. The main constituent elements of the Gondwana Flora are *Raniganjia, Trizygia, Gangamopteris, Glossopteris, Palaeovittaria, Pteronilssonia, Rhabdotaenia, Vertebraria, Noeggerathiopsis, Dicroidium, Glossotheca, Eretmonia, Ottokaria, Dictyopteridium, Lidgettonia,* etc.

The floras that are examined in the present synthesis originate in the Permian of New Guinea, Sumatra, Malaysia, Thailand, southern Tibet, central Tibet, northern Tibet, northern China, Iran, Iraq, Saudi Arabia, Turkey, Kashmir and Mesozoic of Tibet, Nepal and Bhutan.

TURKEY (Hazro Flora)

Wagner (1959, 1962) recorded some Gondwana elements in an otherwise typical Cathaysian Flora of Late Permian age from Hazro, Southeast Anatolia. Biogeographically this region was earlier considered to be a part of the Euramerica Province. Most important amongst his finds was a leaf resembling *Glossopteris stricta* Bunbury 1861 (later renamed as *Glossopteris anatolica* Archangelsky & Wagner, 1983). However, according to Plumstead (in discussion on the paper of Wagner, 1962) the Hazro *Glossopteris* may not be related to the Gondwana plant. She rightly remarked that it is 'unwise to extend a name, which is already the subject of much confusion, to a new leaf from a distant area'. In the words of Asama (1966, p. 188) 'in fossil plants the form-genus merely refers to a similarity of form and does not necessarily signify the same genus of the same phylogenetic relation'. In our opinion, too, parataxa based on detached organs may not always be related and could have belonged to different eutaxa. In the absence of a definite glossopterid fertiliger and the root axis *Vertebraria* in the Hazro Flora, and in the lack of knowledge about its fine structure, the affinity of the Hazro *Glossopteris* with the Gondwana plant remains suspect.



Map 2—Distribution of Gondwana and Cathaysia floras with relation to each other.

Another plant of supposed Gondwana affinity in the Hazro Flora is that figured as *Dicroidium*? vel *Thinnfeldia*? sp. Lacey (in discussion on the paper of Wagner, 1962) compared these specimens with the basal part of a frond of *Neuropteridium validum* Feistmantel and later (Lacey, 1975, p. 129) placed it under the genus *Gondwanidium* Gothan which many believe is a junior synonym of the genus *Botrychiopsis* Kurtz. Three species of the genus *Botrychiopsis* have been recorded but the Hazro specimen is so fragmentary that it can not be compared with any of these. The Hazro material is inadequate for a proper identification. Two other species from the Hazro Flora, viz., *Pecopteris phegopteroides* (Feistmantel) and *Cladophlebis roylei* Arber, supposed to indicate a Gondwana affinity, have now been transferred to *Pecopteris nitida* Wagner and *Cladophlebis tenuicostata* (Halle), respectively (Archangelsky & Wagner, 1983).

It is thus evident that there is no element in the Hazro Flora that may even remotely suggest a Gondwana connection. The revised list of the taxa identified in the Hazro Flora is as under:

Lobatannularia heianensis (Kodaira) Kawasaki
Sphenophyllum sp. cf. *S. koboense* Kobotake
Botrychiopsis sp. ?
Pseudomariopteris hallei (Stockmans & Mathieu) Wagner
Cladophlebis tenuicostata (Halle) Archangelsky & Wagner
Sphenopteris sp.
Pecopteris calcarata Gu & Zhi
Dizeugotheca sp. ?
Pecopteris nitida Wagner
Pecopteris pirae Wagner
Fascipteris hallei (Kawasaki) Gu & Zhi
Glossopteris anatolica Archangelsky & Wagner
Bicoemplectopteris hallei Asama
Taeniopteris sp.
Cordaites sp.

The overall assemblage has a typical Cathaysian aspect. The Gondwana connection of the flora is not proved inspite of the contention of Archangelsky and Wagner (1983) that the Hazro Flora is of very Late Permian (Dzhulfian) age, the Anatolian species of *Glossopteris* had sufficient time to migrate northwards from northern India. Had it been so, we should find its remnants in the Permian floras of Afghanistan and Iran. The Permian flora of Afghanistan comprises a mixture of Cathaysian and Angaran elements, e.g. *Lobatannularia* sp., *Pecopteris* sp. cf. *P. hemiterioides*, *Pecopteris* sp. cf. *P. cyathea* and *Taeniopteris* sp. The Upper Permian flora of Afghanistan has characteristic fossils of the Zechstein (Vozenin-Serra, 1984). It is also necessary to take into account the view that *Glossopteris* was a temperate plant whereas Anatolia lay on the southern margin of Permian fusilinid belt indicating a tropical to subtropical climate (Craig, 1961).

SAUDI ARABIA (Unayzah Flora)

Permian strata of Unayzah and Khuff formations in Qasim Province, Saudi Arabia have yielded three successive floral assemblages (El-Khayal, Chaloner & Hill, 1980; Lemoigne, 1981; Hill & El-Khayal, 1983; El-Khayal & Wagner, 1985). The age of the Unayzah Formation is probably early Late Permian while that of the Khuff Formation is later Late Permian. The Unayzah Flora has following taxa:

Lobatannularia lingulata (Halle) Kawasaki
Sphenopteris spp.
Cladophlebis sp.
Fascipteris hallei (Kawasaki) Gu & Zhi
Qasimia schyfsmae (Lemoigne) Hill *et al.*
Dizeugotheca sp. ?
Pecopteris pirae Wagner
Pecopteris sp.
Gigantonoclea sp.
Cordaites sp. cf. *C. principalis* Germar

This flora shows a certain resemblance with the Hazro Flora of Turkey in the common presence of *Fascipteris hallei, Dizeugotheca*? and *Pecopteris pirae*. Surprisingly, however, the Unayzah Flora has no element which may even remotely suggest a Gondwana link. The specimen with reticulate venation identified as *Zamiopteris* sp. by Lemoigne (1981) is not related to the glossopterids.

The Khuff Formation Flora comprises (Hill & El-Khayal, 1983):

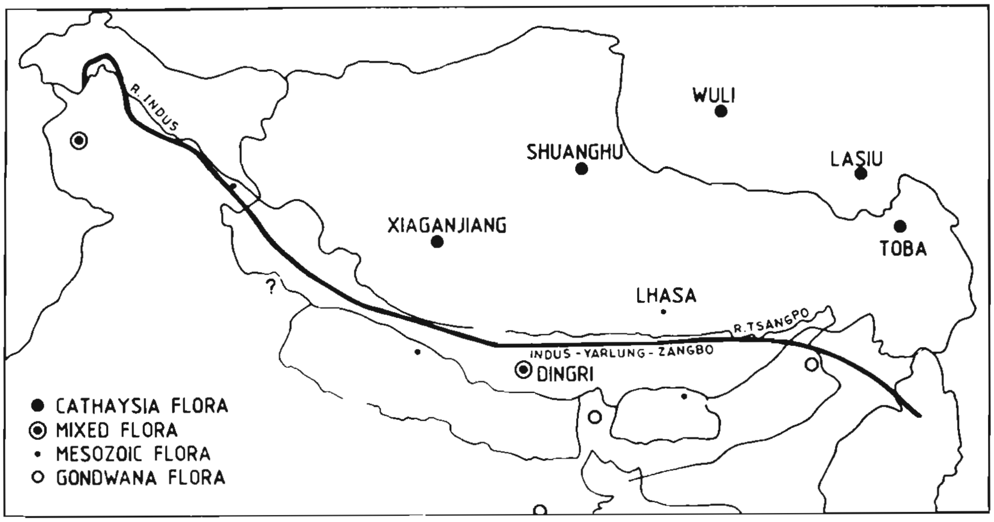
Palaeonitella tarafiyensis Hill & Wagner
Pecopteris sp.
Taeniopteris
Ulmannia
Pseudovoltzia liebeana (Geinitz) Florin
Culmitzschia sp.
Female cone

These are all characteristic elements of Late Permian Euramerican flora.

It is to be noted that the Unayzah and the Khuff floras occur much to the south of Hazro Flora, comparatively near to India and East Africa. If any migration of Gondwana plants into Turkey took place from East Africa, Saudi Arabia should have been *en route*. Even the Permian Ga'ara Flora of Iraq has only typical Cathaysian elements, e.g. *Lobatannularia heianensis* and *Plagiozamites oblongifolius* (Ctyrôky, 1973). The total absence of Gondwana elements in the Permian of Saudi Arabia and Iraq further reduces the possibility of any such occurrence in the Permian of Turkey. Evidently, Afghanistan, Iran, Iraq, Turkey and Saudi Arabia did not form part of the Gondwana floral province.

SOUTHERN TIBET (Qubu Flora)

Hsü (1973) reported a very interesting flora of supposed pure Gondwana affinity from Wolulio, about 30 kilometers north of Mount Jolmo Lungma in Dingri District. He recorded *Glossopteris*



Map 3—Distribution of Gondwana, Cathaysia and mixed floras in relation to the Indus—Yarlung—Zangbo Suture.

communis Feistmantel, *Sphenopteris* sp. cf. *S. hughesii* (Feistmantel) Arber and *Pecopteris* sp. and correlated the beds with the Raniganj Formation of the Indian peninsula.

In 1976, Hsü reported an interesting assemblage of presumed pure Gondwana affinities from the Qubu Formation around Qubu and Kujian, Pazhuo Region, Dingjie District. It is reported to have a predominance of *Glossopteris communis* Feistmantel. Other species recorded are *Glossopteris angustifolia* Brongniart, *Glossopteris indica* Schimper, *Trizygia speciosa* Royle, *Raniganjia qubuensis* Hsü, *Dizeugotheca qubuensis* Hsü and *Dichotomopteris qubuensis* Hsü. This flora, too, is compared with that of the Raniganj Formation.

The fern specimens from Woluluo (Hsü, 1978, p. 132) are too fragmentary to be definitely identified even at generic level. *Raniganjia qubuensis* is believed to belong to the typical Cathaysian genus *Lobatannularia* (Singh *et al.*, 1982). *Dichotomopteris qubuensis* is conspecific with *Pecopteris* sp. cf. *P. arcuata* (Li, 1986) and *Dizeugotheca qubuensis* has been transferred to *Pecopteris qubuensis* (Li, 1983). The venation pattern of *Sphenophyllum (Trizygia) speciosum* illustrated by Hsü (1976, pl. 1, figs 2, 3) does not resemble that of typical *Trizygia speciosa* from the Raniganj Formation. None of the *Glossopteris*-like leaves is complete; no glossopterid fertiliger or *Vertebraria* axes are associated. The fine structure of these leaves is also not known. In the absence of anatomical and reproductive criteria it is hardly justifiable to identify fragmentary specimens with the Indian species (Kon'no, 1968, p. 202).

CENTRAL TIBET (Xiagangjiang Flora)

Li, Wu and Fu (1985) have reported a Permian flora from Xiagangjiang of Gerze District. In all they have identified 17 taxa at species level, of which 6 taxa are assigned a Gondwanan affinity, 3 taxa a Cathaysian affinity; the affinities of the other 8 taxa are not known. However, a look at the photo-illustrations of the so-called Gondwana elements shows that the identifications need confirmation. *Phyllotheca* sp. cf. *P. australis* and cf. *Schizoneura gondwanensis* are recognised only from ribbed stems. However, in the absence of leaf-sheaths these genera can not be identified. Li *et al.* (1985, p. 166) too, believe that 'It is impossible to identify these stem-casts precisely, since species of *Phyllotheca* and *Schizoneura* commonly show little variations in external morphology of their stem-casts'. As mentioned earlier these two genera even otherwise have a wide distribution but the Gondwanan, Cathaysian and Angaran articulates are not genetically related even though the foliage is superficially similar. Their fertile structures differ considerably. The other Gondwana genus identified is *Noeggerathiopsis*. The specimens are badly preserved and in the absence of a cuticle it is difficult to say if they do not belong to *Cordaites*—a northern genus.

NORTHERN TIBET (Shuanghu Flora)

This is supposed to be westernmost extension of the typical Cathaysian flora and is known from Changdu and Shuanghu. The Shuanghu Flora occurs within 250 kilometers northeast of Arunachal Gondwana in India. The taxa recorded are:

Lepidodendron sp.
Annularia pingoloensis
Lobatannularia multifolia
Sphenophyllum sp.
Pecopteris echinata
Pecopteris shuanghuensis
Gigantonoclea quizhouensis
Compsopteris contracta

This flora is totally different from that of central Tibet or southern Tibet and is similar to that of the Panxians (Hsü, 1978). Even the Late Triassic palynological assemblage from the Togmela Formation in northern Tibet (Shang, 1980) is different from Late Triassic palynological assemblage from India (Maheshwari & Kumaran, 1979; Kumaran & Maheshwari, 1980) or Australia (Dolby & Balme, 1979).

SOUTHERN CHINA (Longtang Flora)

Lee (1974) recorded the occurrence of:

Sphenophyllum speciosum
Glossopteris quizhouensis
Schizoneura manchuriensis
Phyllotheca sp. cf. *P. etheridgei*
Rhipidopsis sp. cf. *R. ginkgoides*

in the Longtang Flora and postulated a close Gondwana connection.

According to Hsü (1978) *Schizoneura manchuriensis* is distinct from the Gondwana schizoneuras. *Phyllotheca* and *Rhipidopsis* are quite common in the Angara Flora as well (Vakhrameev *et al.*, 1970). *Glossopteris quizhouensis* is too poorly preserved to be correctly identified.

INDIA (Mammal Flora)

The Upper Palaeozoic Sequence of the Kashmir Valley shows six plant-bearing horizons; the lower four contain a Devonian—Lower Carboniferous flora and the top two have yielded a Lower Permian flora (Pal, 1978; Singh *et al.*, 1982; Pant *et al.*, 1984). Ahmad *et al.* (1978) date the two upper plant beds as Lower and Upper Permian respectively.

The Upper Palaeozoic succession in the valley is:

Upper Permian	— Zewan Formation	
	— Mammal Formation	— Plant bed 6
Lower Permian	— Panjal Volcanic	
	— Nishatbagh Formation	—Plant bed 5
Upper Carboniferous	— Agglomeratic Slate	
Lower Carboniferous	— Fenestella Shale	—Plant beds 3-4
	— Syringothyris Lst	— Plant bed 2
Upper Devonian	— Aishmuqam Formation	— Plant bed 1
Muth Quartzite		

The Permian megafossil assemblage of the valley is somewhat similar to that of the peninsula but has some characteristic Cathaysian elements. There are many reports on the Permian flora of Kashmir. Hazra and Prasad (1957) and Kapoor (1969) recorded:

Lepidodendron sp.
Alethopteris whitbyense Göppert
Pecopteris phegopteroides Feistmantel
Gangamopteris angustifolia McCoy
Gangamopteris kashmirensis Seward
Glossopteris communis Feistmantel
Glossopteris indica Schimper
Noeggerathiopsis hislopii (Bunbury) Feistmantel
Taeniopteris feddenii (Feistmantel) Arber
Taeniopteris kashmirensis Hazra & Prasad
Psygmophyllum haydenii Seward
Psygmophyllum sahnii Ganju
Vertebraria indica Royle

Apparently this flora has a pure Gondwana affiliation. But recently, Singh *et al.* (1982) and Pant *et al.* (1984) have discovered a number of Cathaysian elements in the Permian of the valley. This flora needs a thorough reinvestigation, but the present list reads:

Sphenophyllum thonii Mahr (varieties)
Trizygia speciosa Royle
Lobatannularia ensifolia Halle
Lobatannularia lingulata Halle
Lobatannularia sinensis var. *curvifolia* Kon'no & Asama
Rajahia mamalensis Singh *et al.*
Gangamopteris kashmirensis Seward
Glossopteris longicaulis Feistmantel
Glossopteris nishatbaghensis Singh *et al.*
Glossopteris intermittens Feistmantel
Glossopteris sp. cf. *G. communis* Feistmantel
Glossopteris sp. cf. *G. feistmantelii* Rigby
Glossopteris sp. cf. *G. taeniopteroides* Feistmantel
Glossopteris angustifolia Brongniart
Psygmophyllum haydenii Seward
Psygmophyllum sahnii Ganju
Vertebraria sp.
? *Cordaites* sp.
? *Nummulospermum* sp.

Though no glossopterid fertiliger has so far been reported, the definite record of *Vertebraria* from one of the localities (Hazra & Prasad, 1967, pl. 10, fig. 9) points towards a Gondwana assemblage notwithstanding the presence of several elements having an undoubted Cathaysian affinity. Pant *et al.*

(1984) doubt the presence of the Genus *Rajahia* in the Kashmir flora. *Sphenophyllum thonii* like plants are known from the peninsula, too (Srivastava & Rigby, 1983; Singh, Srivastava & Maheshwari, 1988).

Mention may also be made here of the discovery of Upper Palaeozoic plant fossils from the Blaini-Infrakrol Sequence exposed in a stream cutting near Birbhatii (*vern.* Bir = Beer, bhatii = brewery), Nainital area (Tewari & Singh, 1981). The floral assemblage is reported to comprise: *Lepidodendron* sp., *Calamites* sp., *Annularia* sp. cf. *A. stellata, Phyllotheca* sp. cf. *P. indica, Sphenophyllum* sp., *Gondwanidium* sp., *Gangamopteris* sp. and *Glossopteris leptoneura.* Unfortunately later attempts by many field parties have failed to locate even a single plant fossil in this area and hence this report is not authentic. It is possible that some fossiliferous shale that came mixed with the coal for the brewery was rejected and dumped. With the closure of the brewery, the origin of the dump was forgotten and later strew shale was inadvertently collected as if it was *in situ.*

Tiwari *et al.* (1984) have reported the occurrence of Gondwana spores-pollen in the Malla Johar area of the Kumaon Himalaya. However, the perservation of the microflora is highly unsatisfactory and hence much remains to be done about taxonomy and nomenclature. The preservation is so poor that a specimen originally identified as pteridophytic cf. *Deltoidospora* (Tiwari *et al.*, 1980, pl. 1, fig. 10) was later identified by the same group as gymnospermous *Callialasporites dampieri* (Tiwari *et al.*, 1984, pl. 2, fig. 11). Presence of some modern contaminants also can not be ruled out (Maheshwari, 1982). Malla Johar being located to the north of Main Central Thrust, in alignment with the Dingri locality of Tibet, might have had some Cathaysian elements but the authors have made no comparison with the Cathaysian palynological assemblages (e.g. Onyang, 1964). They have rather tried to decipher an Angara link overlooking the fact that the intervening areas of Tibet had a Cathaysian Flora. Of the thirty odd genera of palynofossils identified by Tiwari *et al.* (1984) from the Malla Johar Succession, atleast 16 genera were first reported in the northern palynological assemblages.

It may be mentioned here that in Arunachal Pradesh, south of the Main Boundary Fault, typical Gondwana mega- and palyno-taxa do occur (Jacob & Banerji, 1954; Srivastava & Dutta, 1977; Acharyya *et al.*, 1979). These include *Phyllotheca griesbachii, Schizoneura gondwanensis, Glossopteris angustifolia, G. conspicua, G. damudica, G. formosa, G. indica, G. longicaulis, G. stenoneura, Gangamopteris cyclopteroides, Vertebraria indica, Dictyopteridium* sp., *Samaropsis* sp. and probably *Trizygia speciosa.*

THAILAND (Phetchabun Flora)

Permian plant fossils were first discovered by Komalarjun at Khlong Wang Ang, Changwat, Phetchabun. Kon'no (1963) identified following taxa:

Bowmanites sp.
Sphenophyllum trapaefolium Stockmans & Mathieu
Alethopteris thailandica Kon'no
Glossopteris sp. cf. *G. angustifolia Brongniart*
Palaeovittaria parvifolia Kon'no
Taeniopteris sp. cf. *T. serrulata* Kon'no
Taeniopteris hallei Kawasaki
Poacordaites phetchabunensis Kon'no

According to Kon'no (1963) 'the Phetchabun flora contains the typical Glossopteroideae, which authenticates the direct migration of the Gondwana floral elements into the Cathaysian floral province through some passageways from the neighbouring Gondwanaland'.

The prospect of cold-temperate Gondwana elements migrating into a warm and humid Cathaysian Province, crossing a wide, though shallow Tethys can not be comprehended. Asama (1966) therefore re-examined the glossopterids in the Kon'no collection and found them to be 'imperfect and few, being one each for the species'. The leaves are so poorly preserved that even the venation is not seen. To confirm the presence of the glossopterid elements in the Phetchabun Flora, Asama made further collection of fossil plants from the same area and identified the following taxa:

Sphenophyllum phetchabunense Asama
Pecopteris sp.
Protoblechnum wongii Halle
Taeniopteris thailandica Asama
Taeniopteris nystroemii Halle
Taeniopteris konnoi Asama (= *T.* cf. *serrulata* of Kon'no)
Taeniopteris hallei Kawasaki
Taeniopteris iwaii Asama
Taeniopteris sp.
Cordaites principalis (Germar) Geinitz
Poacordaites linearis Grand'Eury (= *P. phetchabunensis* of Kon'no)
Psygmophyllum komalarjunii Asama
Samaropsis sp.

Evidently, the Asama collection does not contain even a single glossopterid element and hence any connection of the Phetchabun Flora with the Gondwana Flora, either through migration or otherwise, may be ruled out completely.

THAILAND (Loei Flora)

Permian fossil plants have also been discovered at Loei, north-north-east of Phetchabun. Though the specimens are fragmentary and poorly preserved, yet following taxa have been identified (Asama, Iwai, Veeraburas & Hongnusonthi, 1968):

Sphenophyllum oblongifolium (Germar & Kaulfass) Unger
Pecopteris lativenosa Halle
Pecopteris hemiterioides Brongniart
Ptychocarpus sp.
Shirakiopteris loeiensis Asama
Alethopteris sp.
Protoblechnum wongii Halle
Bicoemplectopteridium longifolium Asama
?*Bicoemplectopteris hallei* Asama
?*Gigantonoclea lagrelii* (Halle) Koidzumi
Taeniopteris nystroemii Halle
Taeniopteris hallei Kawasaki
Poacordaites sp.
Samaropsis sp.

Though, the location of the Loei Flora is geographically close to that of the Phetchabun Flora, yet the former does not possess a single, even doubtful, Gondwana element. It rather has some elements that are typical to the Gigantopteris Flora, e.g. *Bicoemplectopteridium longifolium*, *Bicoemplectopteris hallei* and *Gigantonoclea lagrelii*. Some elements are typically Cathaysian, e.g. *Pecopteris lativenosa*, *Protoblechnum wongii* and *Shirakiopteris loeiensis*. It is thus evident that during the Permian, Thailand had no Gondwana connection.

MALAYSIA (Jengka Flora)

Kon'no and Asama (1970) have recorded the following taxa from the Permian flora of the Jengka Pass, Pahang, West Malaysia:

Paratrizygia koboensis (Kobatake) Asama
Annularia shirakii Kawasaki
Lobatannularia johorensis Kon'no & Asama
Lobatannularia suntharalingami Kon'no & Asama
Calamitaceae (ramulus)
Neuropteridium yokoyamae Kon'no & Asama
Neuropteris sp.
Pecopteris arcuata Halle
Bicoemplectopteris hallei Asama
Cathaysiopteris sp. cf. *C. whitei* (Halle) Koidzumi
Protoblechnum sp. cf. *P. wongii* Halle
Taeniopteris iwaii Asama
Taeniopteris multinervis Weiss
Taeniopteris latecostata Halle
Taeniopteris shansiensis Halle
Taeniopteris taiyunanensis Halle
Taeniopteris sp. cf. *T. thailandica* Asama
Cordaites schenkii Halle
Cordaites sp. cf. *C. simplicinervis* Jongmans & Gothan
Cordaianthus sp. cf. *C. volkmannii*
Trigonocarpus

The Jengka Flora contains a number of index-fossils of Upper Shihhotse Series which is equivalent to the northern Cathaysia Flora, but not a single Gondwana element.

MALAYSIA (Linggiu Flora)

Kon'no, Asama and Rajah (1970) investigated a Late Permian flora from Linggiu in the Gunong Blumut area in central Johore, very near to the Jengka Pass. They identify the following taxa:

Lepidodendron sp. cf. *L. chosenense* Kawasaki
Tingia subcarbonica Kon'no & Asama
Paratrizygia koboensis (Kobatake) Asama
Paratrizygia glossopteroides cf. *minor* (Kawasaki) Asama
Trizygia sinocoreanum (Yabe) Asama
Trizygia speciosa Royle
Calamites sp. cf. *C. suekowii* Brongniart
Annularia shirakii Kawasaki
Lobatannularia fujiyamae Kon'no & Asama
Lobatannularia johorensis Kon'no & Asama
Lobatannularia johorensis subsp. *minor* Kon'no & Asama
Lobatannularia suntharalingamii Kon'no & Asama
Cladophlebis ozakii Yabe & Oishi
Neuropteridium yokoyamae Kon'no & Asama
Neuropteris sp.
Pecopteris arcuata Halle
Pecopteris yinii Kon'no & Asama
Ptychocarpus malayanus Kon'no
Rajahia bifurcata Kon'no
Rajahia linggiuensis Kon'no
Rajahia pseudohemiterioides Kon'no
Rajahia rajahii Kon'no
Rajahia sengensis Kon'no
Bicoemplectopteridium longifolium (Kodaira) Asama
Bicoemplectopteridium hallei Asama
Gigantonoclea lagrelli (Halle) Koidzumi
Gigantopteris nicotianaefolia Schenk
Tricoemplectopteris taiyuanensis Asama
Validopteris sinensis Stockmans & Mathieu
Aphlebia spp.
Taeniopteris sp. cf. *T. crassicaulis* Jongmans & Gothan
Taeniopteris hallei Kawasaki
Taeniopteris sp. cf. *T. multinervis* Weiss
Taeniopteris nystroemii Halle
Sphenozamites sp.
Rhipidopsis baieroides Kawasaki & Kon'no

Cordaicarpus cordae cf. *elongata* Jongmans & Gothan
Gigantospermum posthumi Jongmans & Gothan
Carpolithus spp.

From the foregoing list it is evident that the flora contains distinctive index-fossils' of north Cathaysian *Gigantopteris-Lobatannularia* Flora.

INDONESIA (Djambi Flora)

The Djambi Flora is of great interest because it represents the southernmost occurrence of the Cathaysian elements, geographically very close to the present day India. The Djambi Flora was very luxuriant and comprised species of the following genera (Jongmans & Gothan, 1935; Jongmans, 1937, 1940):

Lepidodendron (3 spp.)
Lycopodites sp.
Stigmaria (2 spp.)
Maroesia rhomboidea
Calamites (2 spp.)
Annularia (2 spp.)
Asterophyllites (2 spp.)
Palaeostachya incrassata
Sphenophyllum (4 spp.)
Sphenophyllostachys sp.
Sphenopteris (9 spp.)
Monocarpia posthumii
Pecopteris (15 spp.)
Asterotheca (2 spp.)
Aphlebia (8 spp.)
Alethopteris strictinervis
Macroalethopteris hallei
Callipteridium (3 spp.)
Dictyocallipteridium sundaicum
Gigantopteris (3 spp.)
Neuropteris sp.
Neuropteridium sp.
Cyclopteris (3 spp.)
Taeniopteris (9 spp.)
Cordaites (3 spp.)
Poacordaites sp.
Artisia sp.
Cordaitanthus sp.
Cordaicladus sp.
Schuetzia sp.
Tobleria bicuspis
Cordaicarpus (6 spp.)
Rhynchogonicum permocarbonicum
Trigonocarpus sp.

Though this flora is supposed to represent the southernmost extension of the Cathaysia Flora, it rather has 27 Euramerican species as compared to only nine Cathaysian species; not a single Gondwanan element has been recorded. To us it seems that in the lesser known Southeast Asian floras, the identifications and nomenclature of fossils have mostly been subjective. This has depended upon the familiarity of the workers with floras of their own region.

NEW GUINEA

Jongmans (1940) reported Permian plant fossils from two localities in western New Guinea. One of the localities yielded:

Sphenophyllum verticillatum Schlotheim
Pecopteris unita Brongniart
Pecopteris sp. cf. *P. arcuata* Halle
Pecopteris sp. cf. *P. paucinervis* Jongmans
Pecopteris sp. cf. *P. orientalis* Schenk
Taeniopteris sp. cf. *T. multinervis* Weiss
Taeniopteris sp. cf. *T. taiyuanensis* Halle

The other locality, about 10 kilometers from the former, has yielded *Vertebraria* sp. This flora is considered to be of definite Cathaysian affinity and contemporary to the Djambi Flora of Sumatra, but the presence of *Vertebraria* sp. needs explaining.

Visser and Hermes (1962) investigated Permian plant megafossils from another 3 localities in the same general area and recorded following taxa:

Locality 3
Trizygia sp. cf. *T. speciosa* Royle
Cladophlebis sp. cf. *C. australis* Morris
Pecopteris monyi Zeiller
Pecopteris unita Brongniart
Validopteris sp.
Glossopteris sp. cf. *G. browniana* Brongniart

Locality 4
Glossopteris sp. cf. *G. indica* Schimper
Glossopteris sp. cf. *G. retifera* Feistmantel
Vertebraria sp.

Locality 5
Taeniopteris sp. cf. *T. hallei* Kawasaki

The fossils from locality 4 seem to have a Gondwana link in the presence of *Vertebraria* sp.

BHUTAN

Ganesan and Bose (1982) have reported rather poorly preserved plant fossils of Mesozoic age from the upper part of Mo Chu Formation in Lingshi Basin, Bhutan. Tiwari *et al.* (1984), however, locate the Lingshi Basin in Nepal.

The identifiable taxa are:

?Cladophlebis sp.
Pachypteris sp. cf. *P. indica* Bose & Roy
Ptilophyllum acutifolium Morris
Elatocladus jabalpurensis

Pagiophyllum sp.
Coniferocaulon sp. cf. *C. rajmahalense*

The overall composition of the Lingshi plant assemblage is said to be similar to that of the assemblages recovered from Jatamao in Satpura Basin and Kurbei in Kutch Basin. The Jatamao records are, however, not reliable because the fossiliferous rock was not collected *in situ*. The specimens were lifted from loose rabble around pillars erected to mark the boundary of forest divisions (vernacular Kup). Even otherwise the taxa recorded are not such that could be taken as typical Gondwanic. Interestingly, the palynoflora from the Jurassic Barishong Formation, too, has cosmopolitan palynotaxa (Pantic, Hochuli & Gansser, 1981). Palynotaxa from the Permian of Bhutan, on the other hand, seem to have a Gondwana affiliation (Banerjee & Das Gupta, 1983).

NEPAL (Kagbeni Flora)

Bordet, Krummenacher, Mouterde and Remy (1964) discovered a fossiliferous outcrop of Mesozoic age in the Kagbeni Sandstone in Thakkhola River near Kagbeni. Bordet, Colchen, Le Fort, Mouterde and Remy (1971) and Barale, Bassoullet and Bose (1976) identify following taxa in the assemblage:

Nilssonia orientalis
Otozamites abbreviatus
?Taeniopteris spatulata
Ptilophyllum acutifolium Morris
cf. *Ptilophyllum cutchense* Morris
Araucarioxylon nepalensis Barale *et al.*

The palaeobotanical data available is too meagre for postulating on genetic affinities of the flora. It may or may not have a Gondwana connection.

NEPAL (Taltung Flora)

Sakai (1983) collected plant fossils of Mesozoic age from the Taltung Formation outcropping at several localities between middle reaches of Kali Gandaki and Main Boundary Fault in Lesser Himalaya. Kimura, Bose and Sakai (1985) identify the following taxa:

Cladophlebis indica (Oldham & Morris) Sahni & Rao
? Sphenopteris sp.
Pachypteris sp.
Pterophyllum spp.
?Taeniopteris/Pterophyllum
cf. Ptilophyllum cutchense Morris
Weltrichia sp.
Elatocladus tenerrimus (Feistmantel) Sahni

Like the Kagbeni Flora, the Taltung Flora, too, has no marker taxa to indicate its genetic affinities, though Kimura *et al.* (1985) believe that their work 'further supports the view that Upper Gondwana extended right up to the Lesser Himalaya, east of Thakkhola Valley, Nepal.'

INDIA (Ladakh Flora)

Sharma, Gupta and Sah (1980) reported some Mesozoic plants from a newly discovered locality near Fukche, north of Indus Suture Zone, Ladakh. The plant assemblage as reinvestigated by Bose *et al.* (1983) comprises.

Raphaelia diamensis Seward
Piazopteris sp. cf. *P. branneri* (White) Lorch
Acrostichopteris sp.
Taeniopteris sp. cf. *T. uwatokoi* Oishi
Nilssonia sp.
Cycadites wadianus Bose *et al.*
Pterophyllum sp.
Anomozamites sp. cf. *A. minor* (Brongniart) Nathorst
Ptilophyllum sp.
?Zamites sp.
Desmiophyllum spp.
?Elatides sp.

Evidently, the Fukche assemblage does not show any Gondwana element. It is rather more like that of Jurassic of Tethys-Karakorum (Jacob & Shukla, 1955). According to Bose *et al.* (1983) the Fukche assemblage 'suggests that the region just to the north of the Ladakh Range in Demgti-Kayul area represents the southern margin of the Eurasian Landmass'.

Slightly older plant fossils have been reported from the Kayul Group exposed about 5 km south-west of the Fukche locality. These have been referred to *Cladophlebis* (*?Klukia*) sp. and *Cladophlebis* sp. (Sukh-Dev *et al.*, 1983). These taxa are so far not known from the peninsular Gondwana.

DISCUSSION

It is evident that though some of the Permian floral assemblages contain certain elements that apparently seem to have a Gondwanic affinity, yet the overall composition of all these assemblages is basically Cathaysian. Did these Cathaysian type floral assemblages occupy the northern margin of the eastern Gondwana or did they flourish on the southern margin of Laurasia?

The latitude usually controls temperature and precipitation, and hence the vegetation. Gondwana was a huge landmass and hence different communities of vegetation could have occupied different latitudinal belts. For example, in South America and Africa there are no definite records of the Gondwana type of vegetation, north of the Amazon and north of Niger, respectively. Rather at places these areas have an Euramerican type of vegetation. It is, therefore, possible that the eastern Gondwana had a main Gondwana floral belt, to the north of which existed a Cathaysia floral belt. But the existence of such Gondwana and Cathaysia floral belts would imply a close connection with the main Cathaysian province that colonised China and also Southeast Asia. In case of such a close connection one would expect a rather generous intermingling of Gondwana and Cathaysian floral elements. But it is not so. Except for a couple of records of *Glossopteris* from Turkey and southern Tibet, no definite Gondwana element is known from regions stretching from Iraq to China to Sumatra. Even the genus *Glossopteris* refers to a generalised leaf form which may belong to biologically unrelated plants (Delevoryas, 1973). Similarly the calamite *Lôbatannularia* known from the Kashmir 'Gondwana' may not be related to the northern form. We have already seen that phyllothecas and schizoneuras of the north and south have different types of fructifications.

These vegetative types probably evolved independently, though not necessarily simultaneously, in different floristic provinces from related ancestral forms. During the Early Carboniferous Period, practically the same forms of plants occurred all over the world. Separation of Laurasia and Gondwana could have been a major cause of Late Carboniferous differentiation which became significant in the Early Permian. However, pre-Carboniferous germplasm being common, some of the features may have been repeated in Laurasia and Gondwana.

Foster (1978) and Meyen (1979) do not advise the use of palynotaxa, apparently common to two or more floristic zones, for correlation because these, too, may have resulted due to parallel evolution and may belong to biologically different plants. For example, disaccate-striate pollen have been found in the ovules of the Permian glossopterid *Senotheca* (Banerjee, 1969) and the Triassic conifer *Rissikia* (Townrow, 1969). We must, however, admit that in the Late Triassic and younger periods the quantum of 'shared' taxa is such that it can not be easily explained by parallel evolution. Probably by that time channels of emigration between Gondwana and Eurasia had again materialized. According to Colbert (1979, p. 139) Gondwana was somewhat less isolated from Laurasia in Late Triassic and by Middle Jurassic there was a route of intercontinental movements between the two.

Thus, the data at hand is as yet not convincing enough to support the concept of 'mixed' floras, atleast in Permian of eastern Gondwana. Apparently the Cathaysia and Gondwana floral provinces were widely separated from each other and occupied different climatic zones. Palaeontologic and palaeomagnetic data have been interpreted to show that Tibet, China and Southeast Asia had a tropical to subtropical climate and occupied an equatorial position up to 20° north during the Permian (Stauffer & Gobbelt, 1972; Vine, 1973; McElhinny *et al.*, 1981). The well-diversified fern taxa in the Cathaysia Flora also indicate warm, humid conditions of the tropical/subtropical equatorial belt. On the other hand, the Permian Gondwana vegetation thrived in a temperate climate at higher latitudes.

Palaeobotanical evidences therefore do not support the views that Southeast Asia, China and Tibet north of Indus-Yarlung-Zangbo Suture formed a part of eastern segment of the Gondwana Supercontinent (Map 2). The presence of a typical northern flora in the Jurassic of Fukche, Ladakh and a Cathaysian Flora in Permian of central Tibet firmly rules out the possibility of the Gondwana boundary extending beyond the Indus-Yarlung-Zangbo Suture (Map 3). The palaeomagnetic estimates, too, extend the Indian Plate margin only up to Dingri, the district in which Qubu Flora of southern Tibet is located (Besse *et al.*, 1984). A Wealden flora reported from Linbuzong and Niumagaon near Lhasa in Tibet also does not show any Gondwanic affinity. The flora comprises (Tuan *et al.*, 1977): *Weichselia reticulata* (Stokes & Webb) Ward, *Zamiophyllum buchianum* (Ettingshausen) Nathorst, *Cladophlebis Browniana* (Dunker) Seward, *Ptilophyllum* spp., *Taeniopteris* sp. and *Onychiopsis* sp. The Lower Cretaceous palynomorphs from Tibet also do not exhibit any Gondwana connection (Pons & Vozenin-Serra, 1984).

Though, we are not in a position to support Stauffer's (1974) view that Malaysia was originally attached to the northern coast of Africa, yet we agree with him that Tibet was not adjacent to India until after Oligocene—Miocene Period. The glacial deposits of Arabia or Tibet have to be explained in some other way. In case it is proved that 'mixed' floras did flourish in Kashmir and Tibet, then we shall have to look for alternative explanations. It is then possible that the Indian plate margin extended up to the Bangongco-Dingging Suture Zone and a typical Gondwana Flora occupied the territory A part that included Kashmir and southern Tibet broke away and migrated northwards to join northern Tibet by the Upper Permian. Northern Tibet already had a Cathaysia vegetation and this provided an opportunity for an intermixing of Cathaysia and Gondwana floras in southern Tibet and Kashmir. This could have also provided *Glossopteris* a migration route to the Soviet Far-East via northern China. A separate Tibetan Plate has already been delineated by Pereira (1977) and McElhinny *et al.* (1981). However, this premise does not satisfactorily explain the Lower Permian occurrence of *Lobatannularia* in Kashmir.

In this case again it is more likely that the Indus-Yarlung-Zangbo Suture marked the northern limit of the Gondwanic India and that the exchange of some elements between subtropical Cathaysia and warm-temperate Gondwana floral provinces took place from northern China through central Tibet, Iran, Saudi Arabia, northern Africa to Kashmir and vice-versa. Such a migration route is supported by the Mesozoic distribution of *Matonidium* and *Phlebopteris*.

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Coal resources in the Indian Gondwana

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THE per capita consumption of energy is a true index of a nation's wealth and progress. This can be judged by the fact that the overall energy consumption of about eight terrawatt (1 terrawatt = 10^{12} watt) is concentrated mainly with the developed countries while in the developing countries the consumption is of the order of 2 terrawatt (1984). The most significant commercial sources of energy are coal, oil and electricity while non-commercial fuels are fire wood, agricultural waste and animal dung. Our country is endowed with practically every form of energy source in small or large measures. Coal occupies the leading place in so far as the availability of resources are concerned. The share of coal in the total commercial energy consumption/production (1984-85) of our country is of the order of about 59 per cent.

COAL OCCURRENCES

The workable coal deposits in India occur only in two stratigraphic horizons, viz., the Permian Gondwana and the Tertiary (Eocene and Oligocene). The Gondwana coals are largely confined to peninsular India and constitute about 99.5 per cent of the total coal resources of the country. The Gondwana coal deposits are restricted in the south eastern quadrant bounded by 78°E longitude and 24°N latitude leaving major part of the country devoid of any workable coal occurrences (Map 1). Some minor deposits of Gondwana coal with complicated geo-mining conditions also occur in foot-hills of the Himalaya in West Bengal, Assam, Arunachal Pradesh and Sikkim.

The Gondwana coalfields are generally aligned along prominent river valleys, viz., Damodar-Koel, Son-Mahanadi, Pranhita-Godavari and Satpura area. The Rajmahal Hill coalfields aligned N-S are located north-east of Damodar Valley. All the Gondwana coalfields excepting that in the Godavari Valley fall within the command area of the Coal India Limited. The major coalfields in which mining is going on within the command area of the various coal companies are as follows:

Eastern Coalfields Ltd.—Raniganj, Rajmahal and Saharjuri coalfields.

Bharat Coking Coal Ltd.—Jharia and North-Western part of Raniganj Coalfields.

Central Coalfields Ltd.—East Bokaro, West Bokaro, Ramgarh, North Karanpura, South Karanpura, Daltonganj, Hutar, Giridih and Jainti coalfields.

Western Coalfields Ltd.—Umrer, Kamptee, Chanda-Wardha, Pench-Kanhan and Pathakhera coalfields.

Southeastern Coalfields Ltd.—Umaria, Johilla, Sohagpur, Jhagrakhand, Sonhat, Jhilimili, Chirimiri, Bisrampur, Korba, Mand-Raigarh, Ib-Valley and Talcher coalfields.

Northern Coalfields Ltd.—Singrauli Coalfield.

The Gondwana coalfields occupy a total area of 63,605 sq km, only 1.9 per cent of the total area of the country. This, however, is not the true index of the coal-bearing potential of the coalfields involved. Sizeable areas are covered by non-coal-bearing formation excluding which the coal-bearing area represents only about 14,000 sq km. This coal-bearing area represents only about 0.5 per cent of the total area of the country.

GEOLOGICAL SET UP

The prominent coal-bearing formations in the Gondwana are the Karharbari (Basal Coal Measures) and the Barakar (Lower Coal-Measures), which account for the bulk of the resources available in the country. The Raniganj Formation (Upper Coal-

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Measures) is well-developed in the Raniganj Coalfield and contains the bulk of the superior grade non-coking coals as well as blendable coals.

The distribution of coal in the various stratigraphic horizons within Gondwana is as follows:

Age	*Geological Formation*	*Occurrence*
Lower Cretaceous	Umia and Jabalpur formations	Thin coal seams in Gujarat
Lower Jurassic	Kota and Chikiala formations	Thin coal seams in Satpura and Godavari
Upper Permian	Raniganj Formation and equivalents	Peninsular India and
Middle Permian	Barren Measures	Himalayan foot-hills
Lower Permian	Barakar & Karharbari formations	

The individual Gondwana coal basins usually represent a "half graben" configuration with one side delineated by a pronounced boundary fault running generally parallel to the structural trend of the surrounding Precambrian rocks. The other margin of the basin shows unfaulted sedimentary contact though punctuated by many cross faults. Intrabasinal faults occur in all the coalfields having wide variation in magnitude.

Basic (dolerite) and ultrabasic (lamprophyre and periodotite) intrusives occur in varying amounts in different basins and are generally correlated to the Rajmahal (Early Cretaceous) and the Deccan (Late Cretaceous to Early Eocene) volcanic activities. The lamprophyre and other alkaline igneous rocks occurring mostly in the Damodar Valley coalfields have extensively damaged the coal deposits in these coalfields.

COAL CHARACTERISTICS

The Gondwana coals are sub-bituminous to bituminous in rank and usually contain high ash. Even the best quality seams rarely have less than 15 per cent ash. This is primarily due to the very nature of the environment in which the coals accumulated. Because of the inherent high ash content, the average heat value is around 5,000 KCal/kg.

The moisture content of Barakar coal in the eastern and central Damodar Valley is generally low, while in other areas it is as high as 6 to 10 per cent. Moisture is also invariably on higher side in Raniganj coals, except in a few seams in the western part of the Raniganj Coalfield. The volatile matter ranges from low to medium in the Barakar coals of Damodar Valley and medium to high in other areas. The coals from the Raniganj Formation are also high in volatile content. The sulphur content is generally low rarely exceeding 0.6 per cent, in Gondwana coals (Table 1). The average reflectance in oil generally varies between 0.5 and 1 (Table 2).

In general, the Gondwana contain moderately thick to very thick coal seams. In some of the coalfields like Raniganj, Rajmahal, East and West Bokaro, North and South Karanpura, Korba, Singrauli, Ib-River and Talcher 20 to 40 m thick coal seams occur in the Lower Barakar Formation. These thick seams, however, contain numerous dirt bands rendering the quality of coal inferior.

The coalfields of Damodar Valley are relatively deeper basins (1,200 to 1,500 m) and contain a number of coal seams (12 to 15) while those of the other coalfields the basin depth mostly restrict to 600 m with on an average 4 to 5 coal seams within it.

COAL RESOURCES

Based on the available information, through geological mapping, regional drilling and detailed exploration, the total coal resources in India has been assessed in April, 1986 by a Sub-group on coal exploration formed at the instance of the Working Group constituted by the Planning Commission in connection with the development of an Energy Model. This Sub-group on Coal Exploration represented by CMPDI, GSI and MECL has estimated the total coal resources in Indian Gondwana at 157,624 million tonnes spread over in 45 coalfields. These resources are available in seams of 0.5 m and above in thickness and up to 1,200 m depth. The break up of the resources under different categories, types and depth cut-offs are given below:

Depth	*Type*	*Resource in million tonnes*			
		Proved	*Indicated*	*Inferred*	*Total*
Up to 300 m	Prime Coking	2166	155	2	2323
	Medium Coking	6082	4334	394	10810
	Blendable	607	330	26	963
	Non-Coking	29238	38197	19396	86831
	Total	38093	43016	19818	100927
300-600 m	Prime Coking	1369	759	287	2415
	Medium Coking	2448	3280	412	6140

	Blendable	154	723	103	980
	Non-Coking	3210	12778	15688	31676
	Total	7181	17540	16490	41211
600-1200 m	Prime Coking	88	644	—	732
	Medium Coking	707	1898	28	2633
	Blendable	77	245	561	883
	Non-Coking	158	2594	8486	11238
	Total	1030	5381	9075	15486
Up to 1200 m	Prime Coking	3623	1558	289	5470
	Medium Coking	9237	9512	834	19583
	Blendable	838	1298	690	2826
	Non-Coking	32606	53569	43570	129745
	Total	46304	65937	45383	157624

It may be seen from the above Table that 64 per cent of the coal resources of the Gondwana basins is available within 300 m depth range, while 26 per cent is confined to 300 to 600 m depth and the balance 10 per cent occurring at depth more than 600 m. Further, of the total reserves, only 30 per cent fall under the "proved" category.

The state-wise and grade-wise (for proved reserve only) distribution of the coal inventory is given in Table 3. Quality-wise, coking coal resources (prime, medium and blendable) amount to only 18 per cent of the total coal resources and are confined almost entirely to the Damodar Valley coalfields. This region also contains bulk of the superior grade non-coking coal resources which amount to only 26 per cent (up to 25% ash) of the total coal resources of the Gondwana. In general, there is an acute shortage of direct feed coking coal and low ash (less than 19%) non-coking coal. These two types together constitute about 6 per cent of the total resources of the Gondwana.

COAL DEMAND PROJECTIONS AND EXPLORATION PREPAREDNESS

The post-nationalisation period has seen the country's coal production increase from about 77 million tonnes in 1972-73 to 166 million tonnes in 1986-87. The Planning Commission in its VII Plan documents have envisaged a coal demand of 237 million tonnes by 1989-90, 326 million tonnes in 1994-95 and 417 million tonnes by the turn of the century. Of the above demand projection of total India, only about 2 to 3 million tonnes in different plan periods is expected to come from Tertiary coalfields. Further, the Coal India's share would be about 88 per cent of the total demand in different terminal years.

In order to meet the ever increasing demand of coal, as indicated above, long-term perspective plans are the essential feature and detailed coal exploration being the first input. On this background, CMPDI drew up a long term exploration programme which envisaged a total drilling of 2.77 million metres within a period of 8 years beginning from 1982-83 and ending in 1989-90 to meet the demand of coal by 1999-2000. For executing this programme, it was envisaged to deploy on an average 200 drills of various exploration agencies. Conventional methods of exploration have been supplemented by modern techniques, viz., photogeology/remote sensing, non-coring drilling, drill hole survey, surface and bore hole geophysical survey, hydrogeological and geo-engineering investigations, geo-statistical studies and computer applications.

As a result of the above indicated concerted efforts, CMPDI has almost completed the detailed exploration in respect of all the mining blocks programmed for production up to 2000 AD excepting only in 27 blocks where detailed exploration is either in progress or is about to be taken up shortly. In any case, the exploration requirement for 2000 AD would be met well before 1989-90 thereby providing a lead time of about 10 years for mine development. Additionally, a large number of blocks (21) have been proved and kept in shelf for meeting any spurt in demand. Additionally, drilling is also in progress in 30 blocks which have not been identified for production up to 2000 AD.

DETAILED EXPLORATION COVERAGE AND FUTURE STRATEGY

An overview of the status of detailed coal exploration would indicate that of the total 14,000 sq km coal-bearing area in Gondwana basins, a considerable area has already been covered by detailed exploration. This detailed coal exploration has so far been restricted mostly to the developed areas where infrastructural facilities were generally available. As it stands today, the coverage of detailed exploration in different major coalfields can be broadly grouped under the following four heads:

(i) Coalfields where detailed exploration largely (above 90%) completed:

1. Barjora (20 sq km)
2. Deoghar (25 sq km)
3. Jharia (400 sq km)
4. West Bokaro (120 sq km)
5. Ramgarh (50 sq km)
6. South Karanpura (80 sq km)
7. Daltonganj (44 sq km)
8. Umrer (4 sq km)

Table 1—Chemical properties of coal from different coalfields of India

Coalfields	*Seams*	Analyses on air-dried basis				*Analyses on dry mineral free basis*				*Gray King (L.T.C.) coke type*
		Moisture %	*Ash* %	*Sulphur* %	*Phosphorous* %	*Volatile matter* %	*Calorific value* (Kcal/kg)	*Carbon* %	*Hydrogen* %	
1	2	3	4	5	6	7	8	9	10	11
(A) LOWER GONDWANA COALS										
Damodar-Koel Valley										
1. Raniganj										
(a) Raniganj Formation	Dishergarh, Sanotoria, etc.	2.5-3.5	15-20	0.5-0.7	0.01-0.15	39-44	8110-8450	83-85	5.3-5.8	E-G_1
	Samla-Jambad, etc.	3.0-11.0	13-25	0.5-0.7	0.01-0.15	39-42	7610-8170	79-82	5.2-5.5	A-B
(b) Barakar Formation	Laikdih-Chanch, etc.	0.8-2.0	15-25	0.5-0.7	0.01-0.20	25-36	8440-8830	86-90	4.5-5.4	E-G
	Salanpur, etc.	0.8-2.0	23-35	0.5-0.8	0.01-0.18	25.35	8300-8800	87-90	4.5-5.2	B-D
2. Barjora	I-IX	3.0-8.0	26-36	0.4-0.9	0.01-0.36	37-43	7810-8060	81-84	4.8-5.7	A
3. Jharia										
(a) Raniganj Formation	Mohuda, Lohpiti, etc.	1.5-2.2	20-25	0.5-0.7	0.20-0.40	36-40	8440-8550	85-87	5.4-5.8	E-F
(b) Barakar Formation	I-VIII	0.6-1.5	18-35	0.5-0.8	0.05-0.30	17-28	8550-8890	90-93	4.5-4.9	C-F
	IX-XVIII	0.6-2.0	15-25	0.5-0.7	0.05-0.30	22-35	8440-8890	87-91	4.6-5.4	G-G_8
4. East Bokaro, Barakar Formation	Jarangdih to Uchitdih	0.8-2.4	15-27	0.5-0.9	0.05-0.40	28-36	8330-8670	85-90	4.5-5.4	D-G_2
	Kargali top, Karo Bottom	0.7-1.9	17-28	0.5-0.7	0.06-0.17	24-37	8440-8780	86-90	4.5-5.4	E-G_4
5. West Bokaro, Barakar Formation	Kuju, Murpa, etc.	4.2-4.7	15-22	0.5-0.7	0.10-0.35	34-37	8170-8370	84-86	4.9-5.1	C-D
	V-VIII	0.5-2.5	21-35	0.5-0.6	0.03-0.35	21-36	8440-8780	86-91	4.6-5.3	D-G_3
6. Ramgarh (Block-I, II, IV) Barakar Formation	VI-VIIIA	0.5-3.0	18-30	0.6-1.0	0.01-0.25	24-38	8220-8780	85-87	4.5-5.3	E-G
7. North Karanpura, Barakar Formation										
(a) Chano-Rikba, Badam-Isko, etc.	I-VI	0.5-3.0	20-35	0.5-1.0	0.06-0.34	30-40	8330-8780	85-91	4.9-5.3	E-G_3
(b) Bachra, Churi, Manki, Pinderkom, etc.	I-VI	5-10	15-30	0.2-0.8	0.01-0.23	35-42	7400-8000	79-82	4.0-4.9	A-C
8. South Karanpura, Barakar Formation	Krgoda group Sirka, Saunda, Nakaria, etc.	2.5-8.0	15-30	0.4-0.8	0.03-0.2	37-40	78008-8100	80-84	4.7-5.2	A-C
9. Hutar, Karharbari Formation	II	6-10	8-14	0.3-0.5	0.005-0.01	35-40	7500-7700	80-81	4.2-4.5	A
10. Daltonganj, Karharbari Formation	Rajhara 'A'	3-4	13-18	0.4-0.7	0.005-0.01	9-13	8500-8560	89-93	3.5-4.0	A
Giridih—Rajmahal Area										
1. Giridih										

(*Contd.*)

Table 1—*Contd.*

(a) Karharbari Formation	Upper and Lower Karharbari Bhadua	0.6-1.3	12.22	0.4-0.6	0.01-0.04	27-33	8725-0950	89-91	4.7-5.2	E-G6
(b) Barakar Formation	Khandiha, Balihill, etc.	0.7-1.3	20-34	0.3-0.4	0.02-0.16	27-33	0000-8850	88-90	4.6-5.1	D-E
2. Deogarh, Barakar Formation	I-III	5-9	15-35	0.3-0.5	0.002-0.04	38-42	7300-7900	80-83	4.5-5.2	A
3. Rajmahal, Barakar Formation	I-XII	8-10	20-45	0.3-9.7	0.005-0.01	38-40	7400-7800	78-81	4.0-5.2	A
4. Darjeeling, Barakar Formation	—	1-5	19-23	—	—	14-18	8450-8700	90-93	3.5-4.0	A
Son-Mahanadi Valley										
1. Singrauli										
(a) Raniganj Formation	Jhingurda	8-9	25-35	0.4-06	0.01-0.04	40-42	7095-7300	76-78	4.5-4.8	A
(b) Barakar Formation	Turra, Purewa, etc.	7-9	15-30	0.5-0.7	0.02-0.03	37-45	7640-7750	78-81	4.4-5.3	A
2. Sohagpur										
(a) Rungta, Kotma, Jhagrakhand	I-III, Kotma, etc.	5-9	15-30	0.4-0.6	0.001-0.009	34-40	7740-8465	79-84	4.8-5.2	A
(b) Churcha-Kutkona, etc.	II-V	2-4	15-25	0.3-0.6	0.002-0.005	33-40	8220-8440	85-87	4.9-5.2	C-D
3. Chirimiri	I-III	5-7	12-20	0.3-0.4	0.005-0.016	36-38	7750-8100	80-83	4.8-5.2	A
4. Bisrampur	Pasang, Patpahari, etc.	5-9	14-18	0.4-0.6	0.004-0.015	35-38	7600-8100	80-83	4.2-4.8	A
5. Korba	Jatraj, Ghordewa, etc.	6-9	15-35	0.5-0.8	0.005-0.016	32-41	7780-8170	81-84	4.2-5.3	A
6. Lakhanpur	—	7-10	15-20	—	—	35-38	7300-7600	78-81	4.2-4.8	A
7. Ib-River	Ib, Rampur, Lajkura, etc.	6-9	15-35	0.5-0.7	—	32-40	7400-7800	78-84	4.3-5.1	A
8. Talchir	I-IV	6-8	15-40	0.5-0.7	0.003-0.04	35-45	7830-7940	79-82	4.9-5.3	A-B
Pench-Kanhan-Tawa Valley										
1. Detla West, Rawanwara, etc.	I-III	2-6	15-25	0.5-0.7	0.02-0.05	32-38	7650-8140	82-85	4.8-5.4	C-D
2. Darua, Rakhikole, etc.	II-III	2-5	18-24	8.6-1.0	0.05-0.06	32-38	8520-8710	86-89	5.1-5.5	D-F
3. Pathakera	I-IV	2-4	25-30	0.5-0.8	—	33-40	8500-8790	84-86	5.4-5.8	C
4. Tandsi-Nankharak area	I-III	2-4	20-25	—	—	33-35	8620-8730	87-89	5.3-5.4	C-D
Wardha Valley										
1. Kamptee, Umrer, Pipla, etc.	II-V	7-10	15-30	0.5-0.9	0.01-0.04	35-40	7250-7860	78-82	4.2-4.6	A
2. Mairi, Ballarpur, Ghugus, Rajur, etc.	I-IV	8-11	15-25	0.4-0.8	0.01-0.05	38-45	7220-7750	76-80	4.3-5.1	A

(*Contd.*)

Table 1—*Contd.*

Godavari Valley										
1. Kothagudem, Tandur, Ramagundam, etc.	Salarjung, King, Queen, Ross, etc.	6·8	15·25	0.3·0.7	0.005·0.04	35·40	7300·7950	78·82	4.2·5.1	A
2. Gollet, Lingola, Belampalli	I·IV	5·8	15·30	0.4·0.8	0.01·0.05	35·42	7590·8000	78·83	4.5·5.4	A
			(B) *TERTIARY COALS*							
Assam										
1. Makum, etc.	—	2·3	5·15	2.0·6.0	0.001·0.01	42·48	8000·8500	79·82	5.4·6.0	G·G3
2. Dilli, Jeypore, etc.	—	4·16	8·20	0.4·8.0	0.01·0.02	45·50	7250·8000	75·79	5.5·63	A·B
Jammu & Kashmir										
1. Kalakot, Jangalgali, etc.	—	0.5·2.0	10·35	0.6·7.0	0.002·0.01	13·17	8380·8730	91·93	3.9·4.2	A
			(C) *TERTIARY LIGNITES*							
Tamil Nadu										
1. Neyveli	—	10·30	5·10	0.5·2.0	0.011·0.002	52·60	6450·6600	70·73	4.6·5.5	—
Gujarat										
1. Panandhro	—	15·35	7·20	3·6	—	50·60	6720·7000	68·72	5.1·5.6	—
2. Umarser	—	10·25	10·18	2·3	0.002·0.004	45·55	6500·7230	68·70	4.5·5.3	—
Rajasthan										
1. Palana	—	25·37	4·8	2·4	0.004·0.02	45·58	6870·7000	72·75	4.5·5.5	—
Kashmir										
1. Nichahom	—	10·25	40·54	0.5·0.9	—	60·65	5500·6500	65·69	4.5·6.8	—

Coal Resources of India: Its formation, distribution and utilisation—Mukherjee *et al.*, 1982.

Table 2—Petrographic characteristics of some Gondwana coals

Coalfields	*Seams*	*Petrographic composition (Visible mineral free basis)*			*Average reflectance in oil (Ro %)*
		Vitrinite (vol.) %	*Exinite (vol.) %*	*Inertinite (vol.) %*	
1	2	3	4	5	6
(A) Prime coking coals					
Jharia	IX-XVIII	35-70	0-2.5	30-65	0.9-1.3
Giridih	Lower and Upper Karharbari	50-60	0-1	40-50	1.2-1.4
(B) Medium coking coals					
East Bokaro	Kargali Bermo,	45-65	1-5	35-50	0.85-0.95
	Karo	35-50	1-3.5	45-65	0.9-1.05
Raniganj	Laikdih, Chanch, etc.	45-65	3-7	30-50	0.85-0.95
West Bokaro	V, VI, VII	35-60	6-12	45-55	0.75-0.90
Ramgarh	VI, VII, VIII	45-60	4-12	38-50	0.7-0.90
Jharia	Mahuda Group	65-85	2.5-10	10-30	0.75-0.85
Jharia	V-VIII	25-45	0-1	55-75	1.2-1.5
Pench-Kanhan Valley (Damua, Rakhikole, etc.)	Main seam	57-60	8-10	32-34	0.93-0.96
(C) Semi-coking coals					
Raniganj	Dishergarh, Sanctoria	70-85	4-10	10-20	0.75-0.85
Raniganj	Poniati, Hatnal, Koithi, Burradhemo	70-85	5-10	10-20	0.70-0.85
Sonhat (Churcha Kutkona)	V	40-60	5-10	30-50	0.65-0.75
(D) Non-coking coal					
South Karanpura	Argada, Sirka, Hathidari, etc.	50-70	3-10	25-40	0.6-0.8
Hutar	II	40-45	3-5	50-55	0.4-0.6
Rajmahal	Lalmatia	20-25	2-3	75-80	0.45-0.50
Singrauli	Jhingurdah	70-75	2-5	20-25	0.4-0.45
Singrauli	Turra, Purewa	40-50	5-12	40-50	0.45-0.50
Chirimiri	II, III	35-45	5-8	50-60	0.55-0.65
Bisrampur	Pasang, etc.	25-30	10-15	55-60	0.5-0.6
Sohagpur	Bottom Seam	50-55	7-10	35-40	0.55-0.65
Korba	Jatraj, Ghordewa, etc.	40-45	5-10	45-50	0.60-0.65
Umrer	I, II	35-45	5-10	45-55	0.50-0.55
Talcher	Bottom seam (I)	40-45	5-10	45-50	0.50-0.55
Talcher	Jagannath (II)	60-65	5-10	25-30	0.50-0.55
Pench-Kanhan Valley (Eklehara, Rawanwara, etc.)	III	45-55	8-12	35-45	0.50-0.60
Wardha Valley (Ballarpur, Ghugus, Majri, etc.)	Main seam	25-35	15-20	50-55	0.55-0.60
Godavari Valley (Singareni, Kothagudem, Ramagundam, Tandur, etc.)	King, Queen, Ross, Salarjang, etc.	35-45	5-15	40-60	0.55-0.60

Table 3—Grade-wise and State-wise break up of coal resources in India (figure in million tommes)

Non-coking coal

State	*Proved*								*Indicated*	*Inferred*	*Grand Total*
	A	*B*	*C*	*D*	*E*	*F*	*G*	*Total*			
West Bengal	224	1335	2882	754	1143	283	424	6166	11726	8037	25928
Bihar	95	312	633	1106	4849	3299	687	8901	17769	5044	31714
Orisa	129	151	165	251	365	1939	496	1555	18966	19944	34465
Uttar Pradesh	—	—	48	130	151	253	183	685	445	—	1130
Madhya Pradesh	222	761	723	1082	1264	2900	528	7588	9413	4977	21970

(*Contd.*)

Table 3—*Contd.*

Maharashtra	—	80	198	1813	725	74	8	2088	1887	1920	5075
Andhra Pradesh	—	363	1125	1453	436	254	—	5886	2185	3648	9463
Gondwana coal	670	3862	4857	5799	8931	9141	2166	32098	53569	43570	129745
Assam and others		Ungraded (High Sulpher-low ash Coal)						55	264	492	841
Total								32691	53833	44862	130586

Prime coking coal

State	*Proved*								*Indicated*	*Inferred*	*Grand Total*
	Steel Grade I	*Steel Grade II*	*Washery Grade I*	*Washery Grade II*	*Washery Grade III*	*Washery Grade IV*	*More than 35% Ash*	*Total*			
Bihar	260	390	560	750	850	60	213	3623	1558	289	5470

Medium coking coal

West Bengal	—	84	2	8	9	9	12	112	133	43	288
Bihar	5	231	548	1447	1316	3373	2052	8972	8949	693	18614
Madhya Pradesh	—	—	—	45	35	18	55	153	430	98	681
Total	5	315	550	1500	1360	3400	2107	9237	9512	834	19583

Semi-Weakly Coking Coal

State	*Proved*				*Indicated*	*Inferred*	*Grand Total*
	Semi Coking I	*Semi Coking-II*	*Ash more than 24%*	*Total*			
West Bengal	174	285	57	516	814	608	1938
Bihar	—	—	271	271	461	82	814
Madhya Pradesh	26	25	—	51	23	—	74
Total	200	310	503	838	1298	690	2826
Grand Total				46389	66201	45875	158465

Note 1 Resources estimated for seems 0.5 m and above in thickness and up to 1,200 m depth; 2. Grade-wise break up of reserve tentatively worked out at CMPDI.

9. Jhilimili (35 sq km)
10. Chirimiri (75 sq km)

(ii) Coalfields where more than 50 per cent detailed exploration completed:

1. Raniganj (650 sq km)
2. East Bokaro (60 sq km)
3. Pench-Kanhan (250 sq km)
4. Pathakhera (40 sq km)
5. Kamptee (60 sq km)
6. Johilla (20 sq km)
7. Korba (250 sq km)
8. Singrauli (100 sq km)

(iii) Coalfields where detailed exploration coverage is less than 50 per cent:

1. Rajmahal (35 sq km)
2. Hutar (35 sq km)
3. North Karanpura (135 sq km)
4. Chanda-Wardha (130 sq km)
5. Bander (10 sq km)
6. Sonhat (17 sq km)
7. Umaria/Korar (10 sq km)
8. Bisrampur (40 sq km)
9. Sohagpur (30 sq km)
10. Talcher (125 sq km)
11. Ib River (60 sq km)
12. Lakhanpur (10 sq km)

(iv) Coalfields where detailed exploration yet to be taken up:

1. Auranga
2. Sendurgarh
3. Tatapani-Ramkola
4. Mand-Raigarh
5. Hasdo-Arand

Though it may appear from the detailed exploration coverage statistics and also from the share of proved reserve in total coal inventory that a lot more detailed exploration is required to be carried out to bring the resources under 'Proved' category, yet the coalfield-wise position would reveal that the coverage is quite high in the case of the developed coalfields having infrastructural facilities and also in the areas where the exploitation could be done economically. Broadly, it can be concluded that the proving so far done is quite adequate to meet the coal demand up to 2000 AD or even little beyond 2000 AD. However, it is necessary to prove more resources for the purpose of selection of blocks on least cost option basis and also to provide more lead time for development of mine beyond 2000 AD.

So far the detailed exploration has been mostly confined to 300 m depth horizon because of the fact that most of the existing and projected mines (up to 2000 AD) would be tapping resources within this depth. In future, CMPDI would extend its detailed exploration activity to upgrade the yet unexplored resources available within 300 m depth particularly, in virgin coalfields where infrastructural facilities are not available now like Auranga, Hasdo-Arand, Mand-Raigarh, Sendurgarh, etc. The exploration activity would also extend to tap the resources up to 600 m depth in developed coalfields and even up to 1,200 m depth for proving coking coal and superior grade non-coking coals in Jharia, Raniganj and East Bokaro coalfields.

CONCLUSION

Gondwana coals are generally inferior in nature and contain high percentage of ash because of their inherent nature and also due to existence of number of dirt bands within coal seams.

There is an acute shortage of coking coal (particularly direct feed prime coking coal) and low ash (less than 19%) noncoking coal in the country. These two types of coal together constitute only about 6 per cent of the total coal resources of the country. With the emphasis on extensive detailed coal exploration that is being conducted all over the country, a substantial portion of 'Indicated' and 'Inferred' resources are expected to be brought under 'Proved' category, yet no major change is expected in the proportion of superior grade coals except with only some chance findings. The deficit of such types of coal is expected to be more in future with adoption of large scale machanised mining and stress on opencast mining for achieving greater output. Further, because of inherent high ash content, these coals generally do not respond to economic beneficiation and washing. To overcome such situation in future, it is worthwhile to undertake vigorous studies on technology front to accommodate more and more inferior grade coals in place of superior grade coals both in industries as well as in power plants.

The Gondwana coals because of their basic inferior nature render the exploitation difficult at depth on economic consideration. As such, more emphasis should be given in future to upgrade yet unproved coal up to 300 m depth which accounts for about 63 per cent of the total coal estimated within this depth.