Symposium on Four Decades of Indian Palaeobotany : an introduction

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PLANT fossils form the subject of palaeobotany—an important broad area of research that provides information fundamental for solving certain basic problems in botany. These problems may have a bearing on morphology, taxonomy, ecology, phytogeography and evolution. Palaeobotanists investigate fragmented, disconnected, disjointed plant remains from the distant to immediate past and build an evolutionary pyramid. Plant diversity is the basis for the construction of this pyramid, which many a times got distorted during the geological past due to extinctions. These plant remains represent relics of past vegetation that got entombed in "sedimentary rocks" and were saved from total destruction mostly by carbonification or petrification in suitable depositional environments. But the fossil records which by nature are fragmentarily preserved bring out only random moments of plant history and the entire story has to be reconstructed step by step by investigation, correlation, analysis and synthesis of plant fossil scene.

The present symposium on "Four Decades of Indian Palaeobotany" is aimed to critically analyse the palaeobotanical data generated mostly during the post-Sahni era. Professor Birbal Sahni, the doyen of Indian Palaeobotany and the founder of this Institute envisioned a great potential for plant fossil studies. His own contributions to this science include a wide spectrum of areas like morphology, anatomy, phytogeography, continental drift, phylogeny and evolution. He strived hard to keep the plant fossil studies in the forefront of research and widened the horizons of Palaeobotany. By organizing this symposium we rededicate ourselves to the cause for which this great scientist strived for. He opined that *"the fossil plants represent the debt that botany owes to geology"*. He himself was mixed blend of Geology and Botany. His researches were examples of high scientific calibre and understanding.

The post-Sahni era witnessed diversification of plant fossil studies, of which the initial effort was mostly concentrated on the morphology and anatomy. Gradually palynological data was utilized for stratigraphical correlation. The palaeobotanical and palaeopalynological studies in the post-Sahni era resulted in accumulation of stupendous data. This enormous data should be utilized for more promising ventures. It is essential to unify, update and revise the generated data base so as to renew the state-of-the-art. It is also important for us to have a retrospection of past achievements and take stock of future avenues. While reviewing the advances in Indian Palaeobotany (1921-1938) Professor Sahni (1938) felt that *"With the inevitable specialization of our age continually threatening to divide us, it is no small gain to science in India that the brief period of seventeen years that we have just reviewed has brought about an era of understanding and cooperation between us, with still higher promise for the future. For the true aim of all science is to unite not to separate."* It is still relevant even after these five decades. The changing phases and development of plant fossil researches are an outcome of Professor Sahni's vision.

I shall focus on some of the selected areas of advance in Palaeobotany.

PRECAMBRIAN PALAEOBIOLOGY

Origin and early evolution of life is a major thrust area which requires attention. Indian records of the Precambrian microbiota have been meagre and not commensurate with extensive Precambrian terrain available for study.

The early life on earth was dominated by prokaryotes which were mainly fermentative. These

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prokaryotes responded to a variety of ecological pressures and developed in specialised niches and subsequently rapidly diversified and invented chemical and biological strategies for survival and wider expansion. Eukaryotes developed as a biological strategy to cope with the advent of oxygen, a highly reactive element which was poisonous to the living system present at that time. It is not yet clear when the eukaryotes appeared as it is very difficult to differentiate a fossilized prokaryotic cell from the eukaryotic one. The early biotic evolution was mostly related to metabolic activities while organismal development was minimal. They could have appeared as early as 2 Ga ago. There are positive evidences at 700 Ma of metaphytes and metazoans.

Though considerable data has been generated from the terminal Precambrian in the Indian subcontinent, the complete stratigraphic biochronology is yet to be developed. There are many areas in the outer and inner sedimentary belts of the Lesser Himalaya, different regions of the Vindhyan Basin in central India and the Bhima, Kaladgi, Kurnool basins of south India, where Precambrian-Cambrian rocks are exposed. These successions can be worked out for developing a biochronology.

The recent finds of structurally preserved filamentous microfossils from the Archaean Sandur Schist Belt, Dharwar Craton; coccoid and rod-shaped bacteria resembling sulphur reducing bacteria from the Kudremukh Iron Formation; stromatolitic structure of variable morphology from the Sandur Chitradurga and Shimoga supracrustal belts, and Proterozoic microfossils from the Infrakrol sediments have opened new vistas in Precambrian palaeobiology. In India, the Early Cambrian brachiopod and Redlichid trilobite are known from Lolab Valley in Kashmir and the stratigraphically underlying rocks show presence of trace fossils indicating bioturbation. An intensive search is required to find the Ediacaran fauna in India. Many unconfirmed reports of metazoans from 1000 Ma old rocks of Lower Vindhyan from different localities need to be properly examined in relation to palaeomagnetic and stratigraphic evidences as they may represent Pre-Ediacarian fauna. The reported occurrence of metaphyte-metazoans in the Pre-Ediacaran sediments of India (Suket Shale) also indicates possibility of the existence of platforms and shallow marine shelf conditions in the Indian sub-continent which are conducive for their growth at that time. Studies carried out by the Archaean palaeobiology group in the institute have suggested that stabilized continental crust had developed in the Dharwar Craton as early as Archaean which is much before the stabilization of crust in other parts of the world. Researches on prokaryote-eukaryote transition and possibility of recent contaminants in older sediments should be intensified.

During the scientific deliberations to follow, aspects like palaeobiology of Vindhyan sediments and a retrospection on metaphytes and metazoans in India will be discussed at length. I do hope that some new ideas will emerge to understand significant Precambrian evolutionary steps and their bearing on subsequent colonization of land by organisms.

GONDWANA FLORA

The Gondwana Flora of India is a gymnosperm dominated vegetation. The first definite records of plants are found in shales and sandstones overlying the basal Talchir boulder bed, though there are stray reports of spores and pollen from within the tillite. It is not known as to what the vegetation was like during the glacial period. Did the Gondwana Flora evolve from earlier plant communities that survived in protected niches during glaciation or did it evolve from plants that migrated to Gondwana Supercontinent from other phytochorias after glaciation? This is a question still in need of an answer. Commenting on ice age and Glossopteris flora Professor Sahni (1938) wrote *"It would almost seem that exposure to the rigours of the climate had quickened the pace of evolution, as if inducing saltations on a large scale, a sort of natural vernalization affecting not only the individual life-cycle, but the rate of evolution of species possibly through aberrations in the nuclear cycle."* It is also not known as to exactly in which region of the Gondwana Supercontinent the Gondwana flora originated because in the stratigraphical sequence we find that the flora appears almost at the same level in all the continents.

Species of Gondwana mega-plants were usually identified on the basis of gross morphography. In recent years features of cuticle have been extensively used, particularly in India. However, subjective approach of different investigators has brought about an element of uncertainty in the identification of taxa because similar specimens with and without cuticles have mostly been assigned to different species. If a co-ordination between the two groups of species could be arrived at, these species will become biostratigraphically significant. Even dispersed cuticles could be used for stratigraphical correlation at levels where spores/pollen are not known.

Though much palynological work has been done on the Gondwana sediments, yet the identification of taxa is in a state of flux. Most of the taxa, both at species and generic levels, have been instituted on minor variable characters. Practically an attempt has been made to identify consistent characters. A study of *in situ* spores and pollen could provide requisite data. Study of ultrastructure of the exines could also provide much useful information regarding affinities. Once palynological taxa are objectively circumscribed it would be easier to use them, with a high level of confidence, for zonation and correlation as well as to understand evolutionary patterns. Changes in floral composition can be effectively used to decipher palaeoenvironmental regimes. Reconstructions of vegetation that formed coal in the Gondwana grabens need to be accelerated with the help of plant mega- and microfossil studies. Understanding of the form and function of fossil dispersed organs will help reconstruct the 'plant' and their evolution and development.

Glossopteris-bearing beds in the pericratonic marine sequences of Kashmir contain an inter-mix of Gondwana, Cathaysia and Angara elements. How does this "mixed" vegetation reflect upon the relative position of the three land masses, land connections or otherwise need to be investigated. Probability of parallel evolution of these plants should be examined afresh. Answers to these questions will reflect upon the Continental Drift hypothesis. A flora that is older than the Gondwana flora of the peninsula is known in the Himalayan region. Extensive and intensive investigation of this flora may throw light on the precursors of the Gondwana Flora.

During this symposium a series of presentations covering an entire gamut of Gondwana plant researches will reflect on the state-of-the-art and futuristic trends. These topics include—morphological trends in Gondwana plants, alien elements in the Gondwana Flora, changing patterns of the Permian Gondwana palynoflora, northern extension of the Indian Gondwana on the basis of palynological evidences, marker palynoassemblage zones through the Indian Gondwana sequence, and distribution and environment of Upper Permian flora and transitional Triassic flora. The recently organised Gondwana workshop on "Concept, limits and extension of the Indian Gondwana" at this same venue came out with newer ideas which have been taken up for study in the institute.

It is envisaged that the future researchers will add much more to our understanding of leaf architecture, cuticular features, fine structure of wood and climatic implications, distribution of spores and pollen in time and space, ornamentation patterns and ecological requirements.

MESOZOIC FLORA

In recent years, the question that has been engaging the minds of biostratigraphers demanding indepth research and an answer, is concerning the upper limit of the Indian Gondwana. Does it range into the Neocomian, or does it end by Norian-Rhaetian? Do we consider the Ptilophyllum Flora as an endemic Gondwana flora or did it occupy much of the Eurasian landmass? In the latter case what was the centre of its origin? These questions need be answered to precisely date the Upper Mesozoic sediments of India. Otherwise, as usual, we shall continue to depend upon far-fetched correlations with floras from different floral provinces such as the Yorkshire Flora.

Upper Mesozoic is the point of time where major diversification of plant groups took place. Cycadophytes that constituted a large part of the vegetation are now represented by a few genera. Several groups, such as, Cycadeoidales, Bennettitales, Pentoxylales, that dominated the Jurassic-Cretaceous scene became extinct no sooner than they diversified. It is necessary to study the cause of this extinction and its evolutionary ramifications. In the present symposium life and time of *Williamsonia* (Bennettitales) and evolutionary reproductive strategies of the Mesozoic plants and their endowment to the modern flora will be discussed. The discussions should help to decipher causes of extinction and evolution of newer strategies.

Several features that characterise modern angiosperms are seen in the Early Mesozoic plants. It is, therefore, very necessary to programme concentrated research on the floras of this period. We are fortunate that we have well preserved floras in the Rajmahal, Kutch, Jabalpur, East Coast of India and other areas. Though fossils occurring in these areas have been mostly catalogued, yet we have not been able to evaluate evolutionary lineages and trends.

Plant groups have appeared in spurts and their extinctions also are in spurts making both the events look dramatic. Stratigraphic boundaries are drawn on the basis of such and other events leading to event stratigraphy. Similarly, plant genera and families are artificial and only reflect our present understanding. When this becomes better and better and the criteria are refined and defined the grouping of named species, genera, etc. gets modified. Thus they always tend to remain dynamic mobile reflecting our understanding of their morphology and status in the evolutionary scale or lineage. In fossils, this is more so because, our understanding of each organ is independent of our understanding of the whole plant.

History of the origin of angiosperms is largely concealed in the Early Cretaceous and the Late Cretaceous sediments. In the recent past there have been major discoveries of early angiosperms from the Cretaceous sediments of Europe and America, but, the occurrence of authentic Cretaceous plant megafossils is yet to be recorded in the Indian sediments. This, in fact, is a challenge that needs to be met squarely. However, sporadic records of angiospermic pollen from Upper Aptian and Albian as well as from Cenomanian to Maestrichtian strata are known from the eastern and southern part of the country. Recent researches in this institute have helped to identify angiospermid pollen (aff *Clavatipollenites*) from the first intertrappean beds of Rajmahal Basin. It is essential to strengthen and widen the scope of this investigation by adopting high resolution character assessment of dispersed pollen so as to trace the antiquity, relationship and evolutionary aspects of the early angiosperms in time and space. This study would also necessitate the development of information on the possible favoured regimes, environments and climates in which the early angiosperms appeared, flourished, diversified and rose to the position of dominance.

Another interesting problem relates to the major extinctions and changes at the Cretaceous/Tertiary boundary. While the extinctions was abrupt in animal groups, the plant world witnessed hardly any mass extinction. Are these changes related to the meteoritic impact or extensive volcanic activity? These are the questions that need answers.

DECCAN INTERTRAPPEAN FLORA

The Deccan Trap episode appears to have commenced in the Terminal Cretaceous and holds the key to understand the K-T transition. The flora of the intertrappean sediments is represented by angiospermous woods, leaves, flowers and fruits, besides charophytes and marine algae. Recent studies suggest near synchroneity of the basal basaltic flows in the central, eastern and southern sectors of the Deccan Province. New palynological data integrated with palaeontological and stratigraphical data help to establish stratigraphic correlation between inland continental, marginal offshore and paralic marine sections in which the basalts themselves or their tuffaceous derivatives are encountered. Data derived from the Deccan intertrappeans do not indicate any evidence of mass extinction in the flora along the Cretaceous-Tertiary boundary.

CENOZOIC PALAEOBOTANY

The Tertiary floras register a remarkable qualitative change because of the incoming of a variety of angiosperms and by the abrupt decline of gymnosperms. The decline of gymnosperms from the position of dominance may be related to changes in climate or to the tough competition faced from the vigorously and rapidly evolving group of angiosperms or both. Systematic information on this aspect needs to be developed.

The Palaeogene flora of India has witnessed several changes, particularly during the Palaeocene-Eocene time. Several genera either migrated or faced extinction. The extinction patterns in India may be related to two main causes—(i) Latitudinal changes because of continental drift, and (ii) Palaeoenvironmental condition of sedimentation. It is possible that the relative position of Malaysia and India may have facilitated several inter-continental migrations. The available palaeobotanical and palynological data needs to be re-examined in global perspective in order to understand the possible migratory pathways particularly keeping in view the then geographic locale of the Indian sub-continent.

The Palaeogene floras in India have been quite diverse. They have been related to moist deciduous, wet semi-evergreen and tropical evergreen forests growing mostly under tropical climate. Evolution of the Neogene floras has been largely influenced by the orogeny of the Himalaya. The mid-Miocene orogeny of the Himalaya led to the proliferation of several gymnospermic groups and appearance of several subtropical angiospermic elements. At this juncture the influence of Sino-Japanese and Indo-Malayan floras and their contribution to the development of Neogene floras poses several questions. The Pliocene floral diversification is related to climatic changes and increasing continentality. Distinct floras of tropical, sub-tropical and temperate climate dry/moist/wet are known from the country The problems associated with these floras are of regionalism, endemism and migration/extinction in response to physical and climatic factors which need to be worked out indepth so as to unravel the history of the modern flora of India.

It is also essential to trace the evidences of C_4 and CAM (Crassulacean Acid Metabolism) system plants during the Cretaceous-Tertiary periods. The evolution of these plants is usually attributed to the response to atmospheric changes. Isotopic studies may suggest changing relative frequencies of photosynthetic pathways through time. This may help in understanding development of plant groups adopted to arid environments.

The Palaeocene-Eocene palynoflora is known mainly from coal and lignite deposits of Meghalaya, Assam, Kutch, Cambay, Rajasthan and other basins. This palynoflora is dominantly characterised by swamp dwellers. The Neogene sediments of India are predominantly river deposits and the change in edaphic condition could have also led to the temporary disappearance of the swampy vegetation which dominated the Early Palaeogene. This is the likely explanation for the absence of *Spinozonocolpites-Nypa* during the Upper Palaeogene and Lower Neogene. It appears again in the Quaternary sediments of India and *Nypa* is still extant in some parts of the Indian coastal areas such as Andamans and Sunderbans. This riverine depositional process might also explain the occurrence of Permian, Early Cretaceous and Palaeogene reworked pollen in the Neogene sediments. The occurrence of these reworked pollen in younger sediments have been the reason for apparent extension of some of the Palaeogene taxa into the Neogene.

The tropical Tertiary sediments are replete with a diversity of pollen types; only some of them are useful as stratigraphical and ecological markers. Distributional anomalies of taxa in East and West Coast should be analysed for deciphering provincialism, endemism and migration patterns of vegetation in the subcontinent. It is of utmost importance to identify marker fossils and catalogue them with annotated stratigraphical and ecological notes.

The age of the Cuddalore Sandstone and associated lignite deposits has been a matter of controversy. It has been suggested that typical Eocene palynofossils recorded from the subsurface of the Cauvery Basin occur in the Neyveli Lignite and the lower age limit of the Cuddalore Sandstone may extend to Eocene and the formation may be time transgressive. Recent palynological data suggest a Late Palaeocene to Eocene age to the Neyveli Lignite deposits. Such palynological investigations on Ratnagiri, Kerala and Rajasthan lignites on the West Coast and associated sediments will help to correlate different sedimentary sequences and for preparing palaeogeographical reconstructions.

Using an integrative approach Siwalik sediments exposed in the Himalayan foot-hills and in Nepal were recently studied. The plant micro- and mega-fossil data integrated with palaeomagnetic and stratigraphic data indicate semi-evergreen vegetation and fresh-water swampy conditions of deposition. Such efforts are further needed in many basins.

Some of the presentations in this Symposium will discuss—Palaeogene-Neogene flora of peninsular India, Himalayan orogeny and Tertiary flora, Stratigraphy of Tertiary palynological succession in northeastern and western India and palynology, palaeoecology, correlation and age of Neyveli lignites and associated sediments. I am optimistic that these presentations will definitely create more awareness to formulate better research programmes.

QUATERNARY VEGETATIONAL PATTERNS

Study of palaeoclimate and phytogeography of the Quaternary period involves an interdisciplinary approach that involves Geology, Meteorology, Oceanography, Geophysics, Geochemistry, Archaeobotany, Palynology, Tree-ring analysis, etc. Data obtained from these varied disciplines are integrated and ultimately understood in geochronological frame work. In India, investigations for understanding palaeoclimates have been carried out on Quaternary deposits in parts of the Himalaya, the arid zone of Rajasthan and some parts of western India.

The time scale considered to be meaningful for understanding different aspects of the climatic problem are 0-1,000 years, 0-30,000 years and 0.1 Ma. The interval of 0-30,000 years is considered to be the most important as the effects can be examined during a major change in climate. Here the ^{14}C dates provide a geochronological frame work for precise interpretations. Phytogeographic and palaeoclimatic models based on plant megafossils, palynofossils and tree-ring analysis need to be designed to unravel the record of the last 40,000 years.

Studies of past climates provide opportunities to examine the interaction between the atmosphere, oceans, cryosphere and the land surface. Climatic changes have a direct bearing on the evolution of the biosphere, evolution of man and his cultures. Palaeoclimatic research documents changes in floral development, sedimentological indices and geomorphological parameters as a consequence of atmospheric variations. Often it is necessary to correlate clay layers within sandstone bodies to identify water-bearing horizons in a basin. Palynology can help in working out a unified biostratigraphic zonation for the aquifers.

The tree-ring studies offer an exciting opportunity for lengthening and extending the spatial coverage of high resolution information which will specially be useful in studying decadal to century scale climatic variations. Conifers have distinct annual growth-rings which show a high degree of environmental sensitivity. In tropics, teak has the potential for the reconstruction of past rainfall. These studies may provide information about the glacial/interglacial phases of the recent past and their probable feedback links to the monsoon climate.

High resolution palynostratigraphy can help work out history and causes of deterioration of the mangrove ecosystem. In deltaic sediments of Bengal and Orissa dated 6,000-7,000 years B.P. and younger, pollen analysis has brought out phases of mangrove development and deterioration. Human influence on the deterioration of mangrove ecosystem is recorded at 3,000 years B.P. resulting in soil erosion and subsequent degeneration of mangrove forests.

The Shola forest that established itself in the south Indian montane region started gradually receding around 7,000 years B.P. Palynological studies suggest that anthropogenic factors were probably responsible for such deterioration. Pollen researches on Sat Tal, Naukuchia Tal, Bhim Tal and Rewalsar Lake areas helped to reconstruct the climate of these regions. Likewise pollen studies on forests of Annamalai Hills, Silent Valley, Chilka Lake contributed to understand ecosystem changes. Similarly, palynological studies on Rajasthan Desert suggest the existence of arid conditions and strong winds around 20,000 years B.P.

Various aspects of tree ring researches, palaeoclimatic oscillations in western Himalaya, Holocene history of mangrove vegetation, and patterns of vegetation in the inter-montane Kashmir Basin will be discussed during the following days and I am sure that the presented data will serve to prepare palaeoecological models.

Additional data will be generated in coming years to understand the glacial/interglacial phases of recent past and their probable link with the past climate. Data on fine resolution palynostratigraphy will throw light on palaeoenvironments. Computer aided programmes should be formulated for ecological modelling and related aspects.

ARCHAEOLOGICAL PLANT REMAINS

Plant remains, such as seeds, fruits, cuticles and wood charcoal of cultivars, weeds and wild species recovered from archaeological excavations provide information about the subsistence pattern of a cultural level. Through archaeobotanical investigations it is possible identify plants that are endemic to India and those that have been introduced from alien cultures. These studies reflect on agriculture, forestry, medicine, economics and culture of the society at that particular period of time and thus help write the chronological history of interaction between Man and Biosphere.

Archaeobotanical studies have helped to identify grains of wild and cultivated rice from the Neolithic levels, 7-6 millenium B.C., at Koldihwa near Allahabad, which constitute the earliest record of cultivation of rice in the world. Finger-millet has been found at Hallur in Karnataka around 1,800 B.C. Signatures of viticulture by the Harappans at Rohira in Punjab have been found in the form of grape seeds and vine-stem charcoals. The Harappans who populated the area around 2,300-2,000 B.C. also maintained ornamental plants and grew vegetable crops. Cultivation of drug-yielding plants is noticed at 1,000-200 B.C. in the Ghaghra Valley.

The presentation on the archaeological plant remains in ancient cultural and socio-economical dynamics of the Indian subcontinent will reflect some of the recent trends in archaeobotanical, ecological and ethnographic studies.

BIOPETROGRAPHIC STUDIES

Fossil fuels are non-renewable resources and need planned exploration and exploitation. This necessitates the need of an indepth knowledge of coal and lignite characterization and rank assessment, to understand their economic suitability for specific application in a particular industry or area. The information can be acquired mainly through chemical and biopetrographic studies. Biopetrographic methods have a distinct advantage over chemical assessment, as these provide requisite information in a relatively shorter time and through much simpler techniques using light microscopes.

Biopetrographic assessment of Permian and Tertiary coals is expected to provide information regarding the nature, rank and abundance of various maceral groups. A relative position of maceral groups and rank will in turn help in determining various properties of coal, particularly the coking potential for working out a blending scheme between high grade and low grade coals, which can help in substantially increasing the life of prime coking coal reserves of the country. Further, the dominance of hydrogen-rich liptinitic contents in a particular coal is likely to indicate its suitability for liquification (hydrogenation).

Studies on the biodiagenesis of lignites will help in deciphering coalification trends, genesis, palaeoenvironmental condition and economic suitability of a deposit. In addition to this, dispersed organic matter (D.O.M.) studies on some oil source rocks are designed to enhance our understanding regarding the evolution of source material under various processes of degradation. Recent organic petrological studies on Raniganj (Permian) coals suggested susceptibility of these coals to spontaneous combustion. Spectral fluorescence studies on coals help to distinguish resinite types. More efforts are needed to delineate various stages in organic matter maturation.

Some of the presentations in the present symposium deal with—Himalayan coals, their nature, formation, composition and rank; temporal and spatial variation of the type and rank of Gondwana coals and genesis of Indian Tertiary coals and lignites.

FOSSIL FUEL SOURCE ROCK STUDIES

Most of our coalfields are confined to the Palaeozoic and Tertiary basins whereas the known oilfields are restricted to the Tertiary basins only. Recently, hydrocarbons have been discovered in the Cambrian sediments of Rajasthan. Palynostratigraphic, palaeoecological and source rock studies of the fossil fuel-bearing strata are very important. It is necessary to establish a large data base.

Professor Birbal Sahni while requesting Prime Minister Jawaharlal Nehru to lay the Foundation-Stone of the Institute of Palaeobotany highlighted the importance of fossil plant studies in coal and oil exploration and said "...*Today the study of fossil plants, pursued with modern techniques and with due regard to its repercussions upon all the bordering sciences, already occupies a respectable place among the sciences and fully deserves the support that it is now receiving all over the world. It not only allows us glimpses into the evolutionary history of plants, but helps us more and more accurately to tell the ages of strata and thereby to explore the mineral wealth of the earth, particularly coal and oil.*" Now we know that palynological study helps to understand and correlate coal and hydrocarbon bearing sediments. Palynofossils and other vegetal remains of the past also help interpret ancient environmental condition favourable for organic matter accumulations and their conversion to fossil fuels by transformation and subsequent thermal alteration. Quantitative distribution of palynofossils mostly determines the approximate location and configuration of near-shore marine deposits which happen to be the locale for formation and accumulation of hydrocarbons. Generation of hydrocarbons is related to the occurrence and nature of organic matter in source sediments. The main source for hydrocarbons is vegetal debris including phytoplankton, marine and terrestrial algal and lipid-rich land plant remains. Palynology affords an effective tool in stratigraphic geology and can be exploited in tapping organic fuel resources. Evaluation of hydrocarbon source rock potential necessitates recognition of type and amount of organic matter contained in the sediment and the level of thermal alteration.

Biozonation, correlation and dating of sedimentary formations on the basis of dinoflagellate cysts, nannoplankton are emerging as useful tools in identifying promising hydrocarbon rich sediments. Such studies are already in progress on the sediments of Cauvery, Palar and Krishna-Godavari basins and Meghalaya areas. Marine Cretaceous-Tertiary deposits encompassing reefoidal limestones reflect algal life and their role in carbonate sedimentation.

Some of the presentations in this symposium are related to fossil dinoflagellate cysts, siliceous microfossils, nannofossils and calcareous algae and the data will help to demonstrate their utility in establishing time boundaries, sedimentary environments and palaeo-oceanographic interpretations.

Integrated palynological research involving spore-pollen-phytoplankton studies, organic matter facies using both transmitted and reflected light microscopy is needed to decipher environmental and source rock regimes. This new dimension will certainly augment interpretative palynological study.

To sum up I quote Professor Sahni (1922) *"The rapid expansion of the domain of botany within the last few decades makes it impossible for any one of us to keep a vigilant eye on all the newly acquired territory. While this tends to restrict our fields of activity, and inevitably deprives us of a certain width of outlook it has, let us hope, brought a corresponding gain in a power of critical vision. But from time to time, and of late more often than heretofore, it becomes necessary for us, lest we become permanently short-sighted, to lift up our eyes and cast at the horizons of the kingdom.*

Even of our little province, occasional bird's-eye views, divested of confusing detail, will not infrequently be of value for they will help in tracing the main directions of past work; in bringing out in relief lines of work that have borne fruit; and, above all, in striking out new paths into obscure and more promising fields".

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Metaphyte and Metazoan fossils from Precambrian sediments of India : a critique

Mukund Sharma, Manoj Shukla & B. S. Venkatachala

Sharma M, Shukla M & Venkatachala BS, 1992 Metaphyte and Metazoan fossils from Precambrian sediments of India : a critique. *Palaeobotanist* **40** : 8-51

Evidences of multicellular life from the Indian Precambrian sediments have been reviewed. Their nature, morphology, biogenecity and syngenecity are evaluated in the light of associated evidences. The published records have been grouped under 13 categories, viz., Archaeocyatha, *Chuaria-Tawuia* group, frondoid forms, Hyolithoides, *Longfengshania*, medusoids, metaphytic algae, *Sekwia excentrica*, shelly forms, spiral forms, trace fossils, trilobitoid and eurypteroid and enigmatic group. Contrary to the world wide records of multicellular organisms only at the Terminal-Precambrian (≅ 600 Ma), some of the Indian reports are 1,000-2,500 Ma old. This older antiquity needs proper explanation. In the present review after reassessment, all the records have been classed as true fossil, non-fossil and dubiofossil. In few cases, it has not been possible to comment upon the structure reported due to non-availability of specimen and poor photographic reproduction in print, such records have been grouped separately without any comments.

In several cases synaeresis and mud cracks have been described as trace fossils. Sedimentary structures have also been described as *Sekwia, Longfengshania, Cyclomedusa,* Archaeocyatha, Dasycladaceae algae, *Epiphyton*, lamellibranchs and such other forms Some records though of undoubted biogenic nature, viz., *Katnia singhi* and *Vindhyavasinia misrai* and Ajaicicyatha (from Krol sediments) need reassessment concerning their taxonomic affinity.

The oldest authentic biogenic structures in this review are considered to be about 1,000 Ma old. These records of metaphytes and metazoans—*Ramapuraea vindhyanensis*, vendotaenid forms, trace fossils, megascopic spiral algal forms and *Chuaria-Tawuia* assemblage, are mostly from the base of Kaimur and top of Semri groups. Trace fossils from Bhander Limestone of Vindhyan Supergroup; a metaphytic alga *Renalcis* from the Calc-Zone of Pithoragarh, and frondoid forms, trace fossils as well as small shelly fauna from the Krol-Tal sequence belonging to younger sediments of probable Vendian-Tommotion age are authentic records.

The multicellular plants and animals undoubtedly proliferated during the Vendian, but there are a few authentic exceptional records of multicellular life prior to 600 Ma from India. Similar earlier records are also known from China and Canada. These records are important in understanding the antiquity of multicellular life.

Key-words—Metaphyte, Metazoans, Morphology, Biogenecity, Syngenecity, Precambrian, India.

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सारॉंश

भारत के कॅम्ब्रिय-पूर्व अवसादों से मेटाफ़ाइटी एवं मेटाजीवी जीवाश्म–एक समालोचना

मुकुन्द शर्मा, मनोज शुक्ला एवं बेंगलूर श्रीनिवासा वेंकटाचाला

भारतीय कॅम्ब्रिय-पूर्व अवसादों से बहुकोशिकीय जीवन के प्रमाणों की समालोचना की गई है। सहयुक्त प्रमाणों के आधार पर इनकी प्रकृति, आकारिकी, जीवजनिकता तथा सहजनिता का मूल्याँकन किया गया है। सभी प्रकाशित अभिलेखों को 13 समूहों में विभाजित किया गया है ये आर्कियोस्यॅथा, **चुआरिया-तबुइया** समूह, फ्रॉन्डॉयडी प्ररूप, ह्योलिथॉयड, **लौंगफेंगशानिया**, मेडुसॉयड, मेटाफाइटी शैवाल, **सेकविया एक्सेन्ट्रिका**, शैल-प्ररूप, कुन्तलाकार प्ररूप, ट्रेस जीवाश्म, ट्राइलोबिटॉयड एवं यूरिप्टेरॉयड तथा रहस्यात्मक समूह हैं। विश्वभर से बहुकोशिकीय जीवाश्मों के अभिलेखों (लगभग 600 एम-ए०) के विपरीत कुछ भारतीय अभिलेख 1,000-2,500 एम-ए० पुराने हैं। इन आँकड़ों की यथार्थता हेतु समुचित पुष्टी की आवश्यकता है। कुछ में प्रादर्श उपलब्ध

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न होने के कारण तथा अच्छे छायाचित्र न प्राप्त होने से कुछ भी टिप्पणी करना सम्भव नहीं है। इस प्रकार के अभिलेखो को अलग कर दिया गया है।

कुछ प्ररूपों में दलदली दरार आदि को ट्रेस जीवाश्म के रूप में वर्णित किया गया है। अवसादी संरचनाओं को **सेकविया लौंगफेंगशानिया**, **साइक्लोमेडुसा**, आर्कियोसियॅथा, डेसीक्लेडेसी शैवाल, **एपिफ़ाइटन**, लेमॅलिब्रैंक तथा अन्य सदृश प्ररूपों के रूप में वर्णित किया गया है। कुछ अभिलेखों जैसे **कटनिआ सिंघाई** एवं **विन्ध्यवासनिआ मिसराई** तथा ऍजेसियथा की वर्गिकर्णिक स्थिति विचारणीय है।

इस शोध-पत्र में प्राचीनतम् स्पष्ट जीवजनित संरचनायें लगभग 100 एम-ए० आयु की मानी गई हैं। मेटाफ़ाइटियों एवं मेटाजीवियों के **यै** अभिलेख—**रामापुरिया विन्ध्यानेन्सिस**, वेन्डोटीनिड प्ररूप, ट्रेस जीवाश्म, शैवालीय प्ररूप एवं **चुआरिया-तवुइया** समुच्चय अधिकतर कैमूर के आधारी भाग तथा सेमरी समूह के ऊपरी भाग से हैं। विन्ध्य महासमूह के भन्डेर चूनापत्थर से ट्रेस जीवाश्म; पिथौरागढ़ के चूनामंडल से **रेनालसिस** शैवाल तथा क्रोल ताल से फ्रान्डॉयडी प्ररूप, ट्रेस जीवाश्म व छोटे शैल वाले जीव जो सम्भवतः वेन्डियन-टोमोटियन आयु के हैं, प्राप्त अभिलेख हैं।

वेन्डियन काल में निस्संदेह बहुकोशिकीय जन्तुओं एवं पौधों का विकास हुआ। परन्तु भारत से 600 एम-ए० से पहले बहुकोशिकीय जीवन के कुछ अपवाद-अभिलेख भी हैं। चीन एवं कनाडा से भी इसी प्रकार के अभिलेख विदित हैं। बहुकोशिकीय जीवन की यथार्थता समझने हेतु ये अभिलेख अत्यन्त महत्वपूर्ण हैं।

THE advent of multicellular life was a landmark transition achieved in the course of evolution. As a result, there was considerable change in the morphologies ultimately leading to the advent of skeletogenous organisms. Evidences available from the palaeontological records suggest a phase where in major transition occurred during the Terminal Precambrian System. These evidences of fossil metaphytes and metazoans help us to understand their advent, proliferation and also about the organismal experimentations and advancing organisations in the course of their evolution. It is, therefore, necessary to critically evaluate fossil records from Precambrian sedimentary successions and to put them in a proper taxonomic order. It is also necessary, to look into the reproduciblity of these records. It is pertinent to assess the records with reference to the age of the host rock and the palaeoecological conditions under which the organisms lived *vis-a-vis* deposition of sediments. Consideration of fossil records without such assessment may lead to incorrect inference on the antiquity and distribution of metaphytes and metazoans.

The present review, discussess the biogenecity, syngenecity and affinity of macrofossil records from Precambrian sediments of India published up to 1990. New information is added in the form of observations. The fossil records are classified as true fossil (definitely biogenic); dubiofossil (probably biogenic but whose nature is still not certain), and non-fossil (definitely non-biogenic). In few cases it has not been possible to categorise the records into any of the above three categories due to non-availability of specimens or insufficient evidences, hence, no comments have been offered. True phyletic position of most of the Precambrian fossils are not yet confidently established or known; they have, thus, been grouped here into the following 13 categories for easy reference based on their morphologies.

1. Archaeocyatha
2. *Chuaria-Tawuia* group
3. Frondoid forms
4. Hyolithoides
5. *Longfengshania*
6. Medusoids
7. Metaphytic algae
8. *Sekwia excentrica*
9. Shelly forms
10. Spiral forms
11. Trace fossils
12. Trilobitoid and Eurypteroid
13. Enigmatic forms

Additional remarks are also provided to highlight salient features that may aid proper assessment of the records. Attempts have been made to study most of the original specimens. In cases where the original specimens could not be studied, comments are based on the descriptions and illustrations provided by the authors in their publications. Records of multicellular life from Krol belt of Himalaya, which have already been reviewed by Singh (1981) published up to 1980, have not been re-reviewed. Each citation of a record includes the original name of the fossil, author's name, year of publication, illustration, figure number, repository when known (as given in the publication) and description. It is followed by remarks on the specimen incorporating our observations and critical comments based on the restudy of the specimen and supplimenting it with fresh photodocumentation. Line diagrams are added to substantiate our views in cases of those specimens which could not be located. The results of our study are tabulated (Table 1) summarising the present status of Precambrian metaphyte and metazoan records from India.

ARCHAEOCYATHA

Members of the group Archaeocyatha are considered inhabitants of coastal Cambrian shallow

Table 1—Present status of metazoan and metaphytic records of India

FORM (GENERIC OR SPECIFIC NAME)	STRATIGRAPHIC LOCALITY	REFERENCE
DUBIO FOSSILS		
Ajacicyathus	Topmost part of Krol E	Singh & Rai, 1983
Archaeocyatha & *Korgaicyatha*	Topmost part of Krol E	Tewari 1988, 1990
Beltanella sp. cf. *B. gilesi*	Upper part of Krol Formation	Mathur & Shanker, 1990
Beltanelliformis sp. cf. *B. brunsae*	Upper part of the Krol Formation	Mathur & Shanker, 1989
Bhanrerichnus damohensis	Maihar Quartzite Formation	Mathur & Verma, 1983
Brachiopod shell	Kajrahat Limestone Formation	Prakash, 1966
Dasycladaceae algae	Limestone of Cuddaph Supergroup	Rao, 1943
Drag markings, Lonzenge-shaped bodies, Mud volcanoes like structures	Bhander Group	Chakrabarti, 1990.
Epiphyton	Upper part of Krol Formation	Singh & Rai, 1983
Hyolithes rohitaswei	Rohtas Limestone Formation	Rode, 1949
Jelly fish	Nimbahera Limestone Formation	Sisodiya, 1982
Misracyathus vindhyanus	Rohtas Limestone Formation	Misra, 1949
Organic plates	Different stages of Dharwar, Bhima & Kaladgi	Venkatachala & Rawat, 1972, 1973; Viswanathiah *et al.*, 1975, 1976, 1977
cf. *Podolithus* sp.	Suket Shale Member	Shukla & Sharma, 1990
Renalcis	Upper part of Krol Formation	Singh & Rai, 1983
Sajania	Calc-zone of Pithoragarh	Shukla, 1984
Sonjiwashman basuhariensis	Basuhari Sandstone Formation	Mathur, 1982
Trace fossils	Dodguni Formation, Dharwar Supergroup	Shivarudrappa, 1981
FOSSILS		
Aulichnites	Lower Tal Formation	Banerjee & Narain, 1976
Burrow	Rohtas Limestone Formation	Misra & Awasthi, 1962
Burrows	Bhander Limestone Formation	Chakrabarti, 1990
Burrows	Morwan Sandstone Formation	Sisodiya & Jain, 1984
Chuaria circularis, Tasmanites ?kaljoi	Gangurthi shale, Bhima Supergroup	Suresh & Raju, 1983
Chuaria minima, Tawuia dalensis	Rohtas Limestone Formation	Maithy & Babu, 1983
Chuaria, Tawuia & *Tasmanites*	Suket Shales Member	Maithy, 1968
Obruchevella	Lower Tal Formation	Ahluwalia, 1979, 1985, 1988
Gordia sp. cf. *G. marina*	Upper part of Krol Formation	Mathur & Shanker, 1989
Katnia singhi	Rohtas Limestone Formation	Tandon & Kumar, 1977
Medusinites sp. cf. *M. asteroides*	Upper part of Krol Formation	Mathur & Shanker, 1990
Pteridinium	Upper part of Krol Formation	Mathur & Shanker, 1989 Shanker & Mathur, 1991
Ramapuraea vindhyanensis	Suket Shale Member	Maithy & Shukla, 1984 Shukla *et al.*, 1989 Shukla & Sharma, 1990
Renalcis	Calc-zone of Pithoragarh	Shukla, 1984
Small Shelly Fauna	Lower Tal Formation	Singh & Shukla, 1981 Azmi & Pancholi, 1983 Bhatt *et al.*, 1985
Small Shelly Fauna	Upper Krol & Lower Tal Formation	Bhatt & Mathur, 1990
Small Shelly Fauna	Lower Tal Formation	Brasier & Singh, 1987 Kumar *et al.*, 1987
Small Shelly Fauna	Upper Krol Formation	Das *et al.*, 1987
Spiroichnus beerii	Rohtas Limestone Formation	Beer, 1919 Mathur, 1983
Tawuia	Suket shales	Maithy & Shukla, 1984
Trace fossils/Pseudo Fucoids	Shirbu Shale Formation	Vredenburg, 1908 Mathur, 1983
Tirasiana	Upper part of Krol Formation	Mathur & Shanker, 1990
Trace fossils	Morwan Sandstone Formation	Shukla & Sharma, 1990
Trace fossils	Bhander Limestone Formation	Verma & Prasad, 1968 Das, 1987
Tyrasotaenia	Suket Shale Formation	Shukla & Sharma, 1990
Vindhyavasnia misrai	Rohtas Limestone Formation	Tandon & Kumar, 1977

Contd.

Table 1—Contd.

NON-FOSSILS		
Ajaicicyathus tandoni	Hinoti Limestone Formation	Maithy & Gupta, 1981
Allatheca	Suket shales member	Maithy & Shukla, 1984
Annelid traces	Rohtas Limestone Formation	Maithy *et al.*, 1986
Beltanelloides	Rohtas Limestone Formation	Maithy, 1990
Burrows	Bhander Limestone Formation	Sarkar, 1974
Coleolella billingsi	Suket shales member	Maithy & Shukla, 1984
Cyclomedusa davidi	Dholpur shales Formation	Maithy, 1990
Epiphyton	Calc-zone of Pithoragarh	Shukla, 1984
Foraminifera & Gastropoda	Krol "D" upper Krol Formation	Kumar, 1979
Frondoid Form	Rohtas Limestone Formation	Maithy, 1990
Fusiform structures	Sullavai Sandstone Formation	Bose, 1977
Vendotaenid remains	Ghurma shale Formation Rohtas Limestone Formation	Maithy, 1990
Vendotaenia & Krolotaenia gnilovaskayi	Lower Krol Formation	Tewari, 1988 Tewari, 1989
Ichnogenus type "A" & "B"	Ghurma Shale Formation	Maithy & Babu, 1988
Ichnofossil	Gulcheru Quartzite Formation	Mukherjee *et al.*, 1987
Krishnanid Forms	Rohtas Limestone Formation	Maithy, 1990
Lamellibranchs, etc.	G. R. Formation, Dharwar	Iyengar, 1905 Sambe Gowda *et al.*, 1978
Longfengsahnia chopanensis	Rohtas Limestone Formation	Maithy & Babu, 1988
Longfengsahnia stipitata	Rohtas Limestone Formation	Maithy & Babu, 1988
Muniaichnus	Glauconitic Sandstone Formation	Kumar, 1978
Puratanichnus bijawarensis	Amronia Quartzite Formation	Mathur & Chattri, 1986
Rohtasia tandonii	Rohtas Limestone Formation	Singh & Chandra, 1987 Maithy, 1990
Sekwia excentrica	Rohtas Limestone Formation	Maithy & Babu, 1988
Sekwia excentrica	Rohtas Limestone Formation	Maithy *et al.*, 1986
Skolithos	Glauconitic Sandstone Formation	Saxena, 1980
Tubocyathus vindhyanensis	Nagod Limestone Formation	Maithy & Gupta, 1981
Vendotaenia	Rohtas Limestone Formation	Maithy & Babu, 1988 Maithy, 1990
Worm track	Rohtas Limestone Formation	Misra & Awasthi, 1962
No Comments		
Asteriradiatus karauliensis	Karauli Quartzite Formation	Mathur, 1982
Chordoichnua latouchei	Red Sandstone of Marwar Group	La Touche, 1902 Mathur, 1983
Dasycladaceae algae	Dogra slates	Rao & Mohan, 1953
Misraea	Porcellanite Formation	Maithy & Babu, 1986
Ostracoda	Upper Krol Formation	Das *et al.*, 1990
Trace fossils	Bhander Limestone Formation	Das *et al.*, 1987
Trilobitid & Eurypterid Forms	Ganurgarh shales & Nagod Limestone Formation	Dubey, 1982

sea. They could have lived in large numbers on calcareous bottoms forming 'gardens' of sessile benthos, but do not form reefs (Moore, 1955). This extinct phylum appeared near the base of Cambrian, spread rapidly by the middle part of the Early Cambrian and probably became extinct early in the Middle Cambrian and as such is considered an index fossil group for the Early Cambrian in carbonate facies (Rigby & Gangloff, 1987).

Misracyathus vindhyanus Vologdin 1959

Text-figure 29

Repository—Not mentioned. Misra, 1949, fig. 2. Misra (1949) reported 'a verticillate alga with a slender jointed stalk terminated by a globular head' from the carbonaceous limestone of upper most Rohtas Stage (Murli Hill Limestone Formation) at Banjari quarries and related it with dasycladaceaeous alga. Vologdin (1959, *in* Balakrishnan, 1974) did not agree with the algal affinity but designated it as a very early form of the phyla Archaeocyatha, and erected a monospecific new genus *Misracyathus vindhyanus* Vologdin.

Remarks—Archaeocyathids are generally found in association with stromatolite building organisms in the shallow water environments of Cambrian sea. Rohtas Limestone Formation, Rohtas, from which these records have been made was deposited in subtidal to intertidal environment. Records of algal activity are not known from this formation. The age of these sediments on correlation has been considered ~ 1,100 Ma (Shukla & Sharma, 1990). Therefore, the chance of finding archaeocyathids in this horizon are remote. Zhuravlev (1986) also contradicted Vologdin's (1959) opinion of associating the fossil recovered by Misra (1949) with archaeocyathids and expressed the view that this specimen may be some other microfossil or oolite. Therefore, the specimen reported by Misra (1949) is neither alga nor archaeocyatha. But in the absence of original specimen the specimen can only be referred to a biogenic structure and classified as a 'dubiofossil'.

Ajacicyathus tandoni Maithy & Gupta 1981

Pl. 1, figs 4, 5

Tubocyathus vindhyanensis Maithy & Gupta 1981

Pl. 1, figs 1-3

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Slide nos. 5950, 5951; Maithy & Gupta, 1981, figs 1-7.

Maithy and Gupta (1981) described *Ajacicyathus tandoni* from Hinaoti Limestone Formation of Semri Group and *Tubocyathus vindhyanensis* from Nagod Limestone Formation of Bhander Group of Vindhyan Supergroup exposed in central India; the former formation is dated ~ 1,100 Ma, while later about 800 Ma.

Remarks—The formations containing these fossils have many well developed oolitic beds (Sarkar, 1973; Singh, 1976; Chanda & Sarkar, 1977; Kumar, 1978a). The petrographic sections containing the taxa under review are also dominantly oolitic. A re-examination of slide nos. 5950 and 5951 reveal that few selected grains of ooids have been described by Maithy and Gupta (1981) as archaeocyathids because of their apparent similarity. The specimens exhibit only the cross section of ooids with inorganic mineral grain in the centre. The specimens attributed to the two taxa under review are similar and do not show any major difference in size. They also lack the diagnostic features of *Ajacicyathus* and *Tubocyathus*. Archaeocyatha are known from the shallow coastal zones rather than in high energy environment of the oolite formation. The genus *Ajacicyathus* is known from Early Cambrian of North America, Europe, Asia and Australia (Rigby & Gangloff, 1987), while genus *Tubocyathus* is known from Middle Cambrian of Asia (Raaben, 1981). Their record in 800-1,100 Ma old sediments needs a rethinking. Zhuravlev (1986) and Debrenne *et al.* (1990) have already suggested these records to be either microfossils or oolites. Our observations support their oolitic nature. Therefore, these two specimens are 'non-fossils'.

Archaeocyatha sp.

Text-figures 52, 53, 58, 59, 60, 61

Repository—Geology Department, Lucknow University, Lucknow; Specimen and slide nos. not known; Singh & Rai, 1983, pl. 1, figs 2-7; pl. 2, fig. 12; Singh & Rai, 1984, figs 1-6.

Singh and Rai (1983) described archaeocyatha in a polished slab collected from the top most part of the Krol E of Mussoorie hill, Dehradun, as 'cups of 1 to 2 cm in diameter and almost 3 to 4 cm in length. The wall (both outer and inner) are highly porous, the central cavity is filled with dessepiments. This form compares with *Ajacicyathus*. There are other forms, some of them discoidal, other appear to be broken and roled pieces often· in poor state of preservation.' It is again described as a separate report by Singh and Rai (1984).

Remarks—The figured specimen (as informed by Dr V. Rai) presently is on loan to Prof. Antonio Perejon, Spain for detailed study. Therefore, our comments are limited to the observations made by other workers. Zhuravlev (1986), Brasier and Singh (1987), Cowie and Brasier (1989) doubted the affinity of the specimen under review with archaeocyathids. Brasier and Singh (1987) further

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PLATE 1

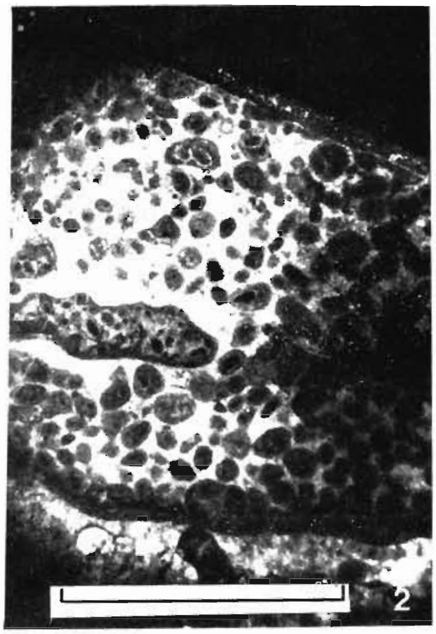
(Scale in figs 1, 4, 6, 7 & 8, 1 div. = 1 cm, and in fig. 2 = 5 mm, fig. 3 = 1 mm and fig. 5 = 1.5 mm)

1-3. *Tubocyathus vindhyanensis* sp. nov. of Maithy & Gupta 1981. 1. Shows general view of the slide containing *T. vindhyanensis* showing the oolitic nature of the thin section; 2. shows the close up of the oolite; and 3. shows the closer view of some of the oolites, Slide no. BSIP-5951.

4, 5. *Ajacicyathus tandoni* sp. nov. of Maithy and Gupta, 1981. 4. Shows general view of thin section containing *A. tandoni*. Close observation shows the presence of numerous oolites in thin section, some of them have been enlarged and shown in fig. 5, Slide no. BSIP-5950.

6-8. *Pteridinium* of Mathur & Shanker 1989 and Shanker & Mathur, 1991. 6. Due to fragmentary nature of figure it is considered non-fossil; 7. considered dubiofossil; 8. shows characteristics of *Pteridinium*, viz., primary furrow, secondary furrow and median axis, hence considered true fossil, Specimen nos. GSI-20283, 20285 and 20286.


1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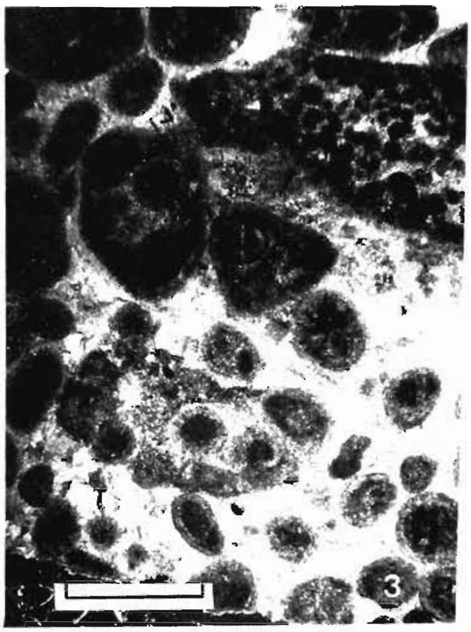
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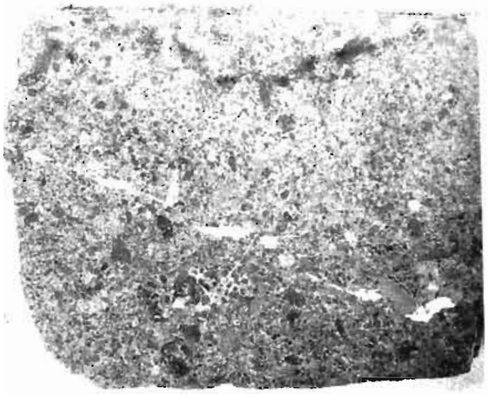

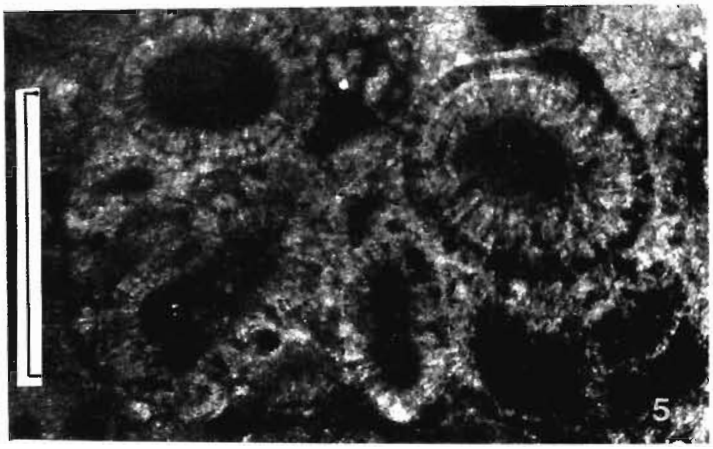
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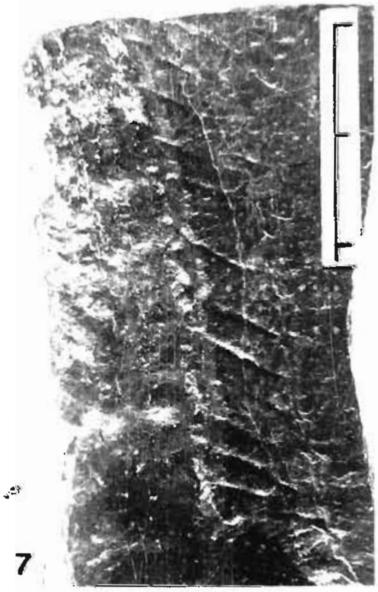

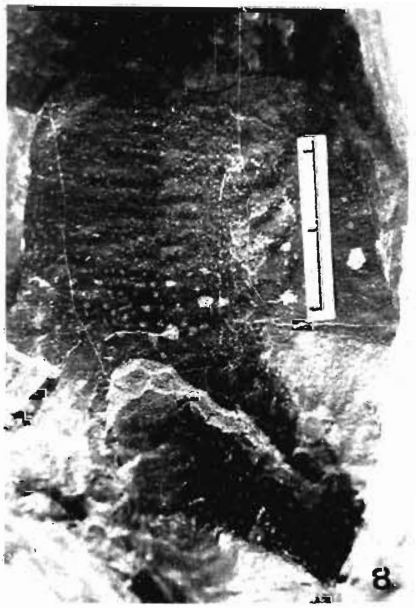
8

PLATE 1

commented that the specimens of Singh and Rai (1983, pl. 1) resemble thrombolitic fabric. Material containing similar structures from the same horizon (shown to Brasier & Singh by P. Kalia) exhibits a complex fenestral and fissure filling texture. Debrenne *et al.* (1990) after restudy of topotype similar material further comment that 'Critical examination of the original description shows that on the weathered surfaces, the authors considered the light material as a porous skeleton, while on polished surfaces the dark material is proposed as the intervallar skeleton. This is inconsistent with our observations; the light material is highly recrystallized (calcite and dolomite) while the dark material is interpreted as detrital filling displaying cryptalgal fabric, in columnar like structures'. Kumar (1989) made a thorough search of the horizon in Mussoorie area but could not locate such specimens.

We also consider that the features of the specimens are apparently biogenic and may be compared with thrombolite; and classified under the category of 'dubiofossil'.

Archaeocyatha and *Korgaicyatha* Tewari 1988

Text-figure 64

Repository—Not mentioned. Tewari, 1988; Tewari, 1989, pl. 7, fig b.

Tewari (1988, 1989) reported the presence of *Archaeocyatha* and *Korgaicyatha* without any description in Krol E and neither mentioned the locality nor repository.

Remarks—The illustrated figure lacks diagnostic features to justify the assignment. The comments offered on the specimens figured by Singh and Rai (1983, 1984) are also applicable here. This record is also considered as 'dubiofossil'.

CHUARIA, TAWUIA AND ALLIED FORMS

Chuaria, Tawuia and allied forms are found as carbonaceous compression, impression and sometimes as mineralised cast. They have invariably been reported from 1,000-600 Ma old sediments. There are many records of *Chuaria* and *Tawuia* from Suket Shale of Rampura, district Mandsaur. Maithy and Shukla (1984b) have already reviewed these records. However, here we confine to those reports published after 1984 or which could not be incorporated in the earlier review of Maithy and Shukla (1984b) and those specimens which are available in the repository of Birbal Sahni Institute of Palaeobotany, Lucknow. *Chuaria, Tawuia* and allied forms are now considered to be eukaryotic algae, such forms were attributed earlier to brachiopods (*Fermoria, Protobollela,* etc.).

Tasmanites Newton

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Slide no. 2804; Maithy, 1968, pl. 1, fig. 6.

Suket shales from Rampura have yielded *Tasmanites* with other microfossils, viz.,

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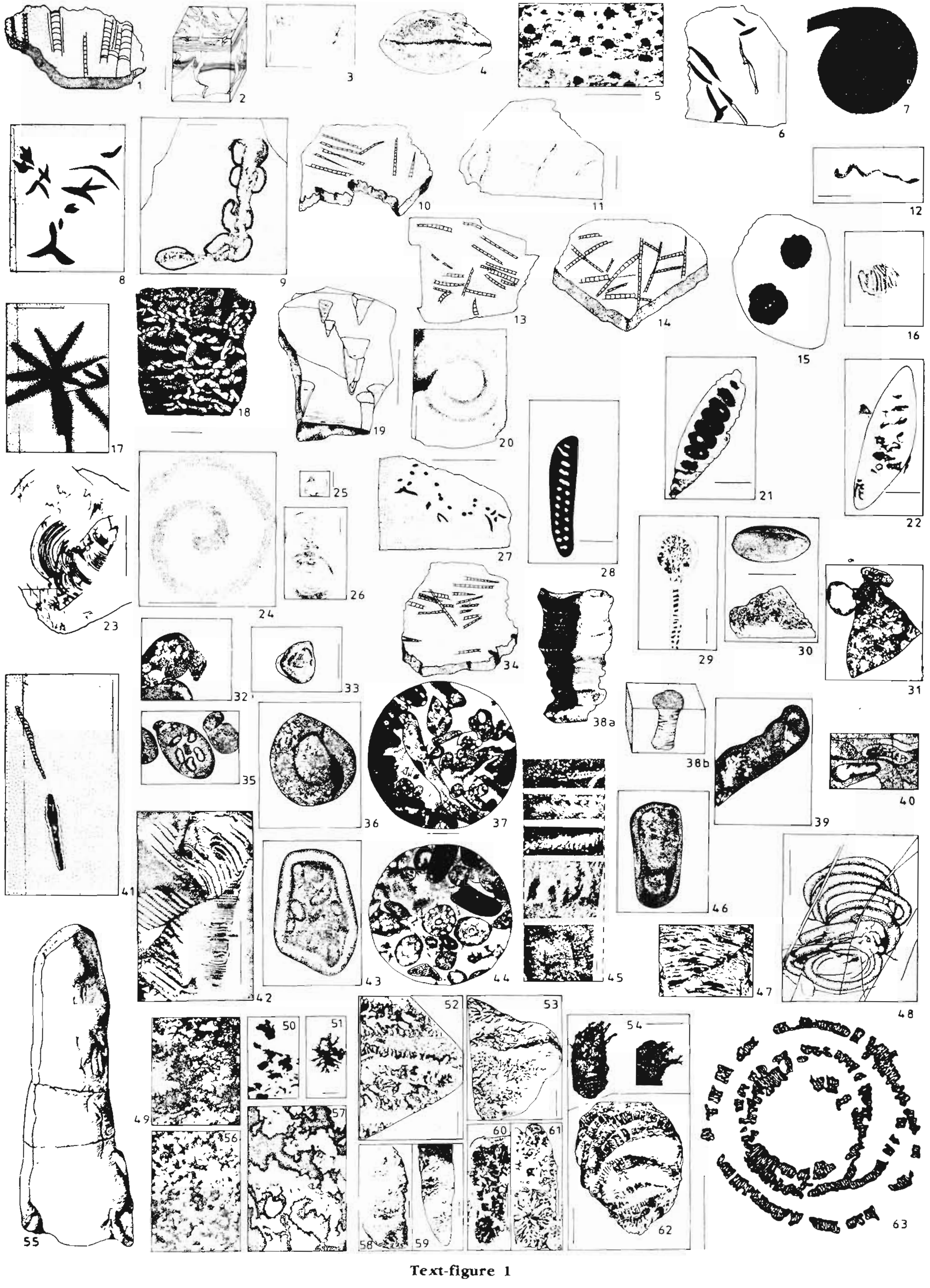
Text-figure 1—Figures **1, 10, 13, 14, 34**: Ichnofossils (Das *et al.*, 1987, pl. 1, figs 1-3; pl. 2, figs 1-2), Scale is same as in fig. 1 = 2 cm. **2.** Burrows (Sarkar, 1974, fig. 4D), Scale = 1.5 cm. **3.** Jelly fish (Sisodiya, 1982, fig. 1). Scale = 2 cm. **4, 5.** Ostracoda (Das *et al.*, 1990; pl. 1, fig. 1b & 2c), Scale = 100 μm. **6.** Work track (Misra & Awasthi, 1962, fig. 15), Scale = 5 cm. **7, 15.** *Chuaria circularis* (Suresh & Raju, 1983, figs 2.1 & 2.2), Scale = 1.5 mm. **8.** Trace fossil (Saxena, 1980, fig. 1), Scale = 7 cm. **9.** *Bhanrerichnus damohensis* (Mathur & Verma, 1983, fig. 1), Scale = 2 cm. **11.** *Sonjiwashmam basuhariensis* (Mathur, 1982, fig. 2b), Scale = 2 cm. **12.** *Muniaichnus* (Kumar, 1978b, pl. 2, fig. 1), Scale = 29 cm. **16.** Shell-like form (Prakash, 1966, fig. 1), Scale = 4 cm. **17.** *Asteriradiatus karauliensis* (Mathur, 1982, fig. 2A), Scale = 2 cm. **18.** Fusiform structure (Bose, 1977, fig. 1), Scale = 4 cm. **19.** *Hyolithes rohitaswei* (Rode, 1946, fig. 1), Scale = 4 cm. **20.** *'Rohtasia tandonii'* (Maithy, 1990, pl. 1, fig. 7), Scale = 5 cm. **21, 22, 28.** Foraminifera and Porifera. *Archaediscus, Pachypholia (?), Palaeobigenerina* (Ahluwalia, 1979, 1a, 1b, 1c), Scale = 350 μm. **23.** Ichnofossil (?) (Shivarudrappa, 1981, pl. 1, fig. 2), Scale = 10 cm. **24.** Spiral impression, *Spiroichnus beerii* (Beer, 1919, pl. 30, fig. 1; Mathur, 1983, pl. 2, fig. 1), Scale = 0.5 mm. **25.** *Medusinites* (Maithy, 1990, pl. 2, fig. 9), Scale = 1 cm. **26.** *Cyclomedusa* (Maithy, 1990, pl. 2, fig. 8), Scale = 1 cm. **27.** Trace fossil (Sisodiya & Jain, 1984, pl. 1, fig. 1), Scale = 10 cm. **29.** Dasycladaceae/*Misracyathus vindhyanus* (Misra, 1949, fig. 2), Scale = 600 μm. **30.** "Lamellibranchs, etc." (Gowda *et al.*, 1978; pl. 2, figs b, d), Scale = 7.5 cm. **31.** *Paraboultonia* foraminifera (Kumar, 1979, pl. 2, fig. 5). **32.** *Diplotermina* foraminifera (Kumar, 1979, pl. 2, fig. 3). **33, 38a, 38b.** Conical structures (Misra & Awasthi, 1962, fig. 7, 8, 9), Scale = 1 cm (for fig. 33 = 2 cm). **35.** Umblical view of *Tetrataxis*-foraminifera (Kumar, 1979, pl. 2, fig. 4). **36.** *Gourisina* foraminifera (Kumar, 1979, pl. 1, fig. 3). **37, 44.** Dasycladaceae algae (Rao, 1943, fig. 1; Rao, 1949, fig. 1), Scale = 0.5 mm. **39.** *Novella* foraminifera (Kumar, 1979, pl. 1, fig. 1). **40.** *Nodosaria*-foraminifera (Kumar, 1979, pl. 1, fig. 2). **41.** *Puratanichnus bijawarensis* (Mathur & Chattri, 1986, pl. 1, fig. 1), Scale = 5 cm. **42.** Frondoid form (Maithy, 1990, pl. 2, fig. 7), Scale = 4 cm. **43.** *Tetrataxis* foraminifera (Kumar, 1979, pl. 1, fig. 5). **45.** Dasycladaceae algae (Rao & Mohan, 1954, figs 2-5), Scale = 1,000 μm. **46.** *Lunucanmina perforata* foraminifera (Kular, 1979, pl. 2, fig. 1). **47.** Vendotaenid form (Maithy, 1990, pl. 2, fig. 1), Scale is same as in fig. **42. 48, 62, 63.** *Katnia singhi* (Conway-Morris, 1989, fig. 2b; Tandon & Kumar, 1977, fig. 1), Scale is same as in fig. 48 = 10 mm. **49.** *Sajania* (Shukla, 1984, pl. 1, fig. 5). **50, 51.** *Epiphyton* (Shukla, 1984, pl. 1, figs 3, 4), Scale = 3,000 μm. **52, 53, 58, 59-61.** Different view of Archaeocyatha (Singh & Rai, 1984, pl. 1, figs 1-6), Scale = 1 cm. **54.** *Vindhyavasinia misrai* (Tandon & Kumar, 1977, fig. 3), Scale = 0.5 mm. **55.** *Chordoichnus latouchei* (Vredenburg, 1908, pl. 34, Mathur, 1983, pl. 1), Scale = 6 cm. **56, 57.** *Renalcis* (Shukla, 1984, pl. 1, fig. 1 & 2). Scale = 3000 μm.



Text-figure 1

Leiosphaeridia sp., *Protoleiosphaeridium* sp., *Retisphaeridium vindhyanensis* Maithy and *Gloeocapsamorpha* sp. *Tasmanites* is described as circular vesicles ranging from 500-1,000 μm in size having numerous puncta and pores that appear as shallow depressions (Maithy, 1968).

Remarks—The authors are in agreement with Maithy (1968) that the morphological features of *Tasmanites* are closely comparable to the morphological features of macerated specimens of *Chuaria* at least in some cases. The biological affinity of *Tasmanites* has been discussed in detail by Wall (1962) who related them to Parsinophyceae. The present specimen is a 'true macrofossil' comparable with *Tasmanites/Chuaria*.

Chuaria **Walcott**

Text figures 7, 15

Repository—Not mentioned. Gowda *et al.* 1979; Gowda, 1980; Suresh & Godwa, 1981, pl. 1, fig. 2; Suresh & Sunder Raju, 1983, fig. 2.

Chuaria circularis, Tasmanites kaljoi, ? and allied forms (acritarchs) have been described from Gangurthi shales of Bhima Basin from the Gangurthi locality in Gulbarga District, Karnataka (Gowda *et al.*, 1979; Gowda, 1980, Suresh & Gowda, 1981; Suresh & Sunder Raju, 1983). *Chuaria* are discoidal and elliptical in shape and occur both as compression and impression. They are also found in the macerated residue. They are considered as marine phytoplankton of algal origin (comparable to *Volvox*) (Suresh & Sunder Raju, 1983).

Remarks—We could not examine the described specimens, still our study of the material from this area, supports the occurrence of *Chuaria* from the Late Proterozoic sediments and confirm the validity of the identification of *Chuaria circularis* and *Tasmanites kaljoi*?. They are considered as 'true macrofossils'.

Tawuia **Hofmann**

Pl. 8, fig. 1

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Specimen no. 25277; Maithy & Shukla, 1984a, pl. 1, fig. 4; Shukla & Sharma, 1990, pl. 1, fig. 6.

A compression of *Tawuia dalensis* Hofmann has been reported from Mandsaur, Suket Shale of Semri Group in Madhya Pradesh. It is 0.83 cm in length 0.2 cm in width, rod-like in shape, straight or curved with smooth surface and rounded end (Maithy & Shukla, 1984a; Shukla & Sharma, 1990).

Remarks—The specimen described by Maithy and Shukla (1984a, pl. 1, fig. 4) and Shukla and Sharma (1990, pl. 1, fig. 6) is comparatively much smaller than the holotype of *Tawuia dalensis* (1-8.5 mm wide and several centimeters long). As per description of Hofmann (1979, in Hofmann & Aitken, 1979) and Hofmann (1985), the holotype is a carbonaceous compression or impression of straight and curved, roundly terminated, tomaculate (sausage-shaped) structure. Hence, the form reported by Maithy and Shukla (1984a) and Shukla and Sharma (1990) is comparable with *Tawuia*. It can not be attributed to *T. dalensis* Hofmann 1979. The specimen reported by Maithy and Shukla (1984a) is a 'true macrofossil'.

Chuaria **Walcott and *Tawuia* Hofman**

Pl. 3, figs 6, 7

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Specimen no. 36105; Maithy & Babu, 1988, pl. 1, figs 1-6.

Maithy and Babu (1988) described *Tawuia dalensis* as a platyspermic sausage-shaped carbonised compression on 'grey coloured limestone' with rounded ends, measuring 5-10 mm in length and 2.5 mm breadth with smooth surface. The specimens of *Chuaria minima* were described as platyspermic carbonised circular to oval disc measuring 2-4 mm on 'black coloured limestone'. According to them some specimens have small central area indicating possible opening. Discs have smooth surface and show fine puncta.

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PLATE 2

(Scale in all figures, 1 div. = 1 mm)

1. *'Longfengsahnia chopanensis'* of Maithy & Babu 1988, note the yellow silty material as grey coloured in photograph', Specimen no. BSIP-36111.
2. Side view of the specimen shown in fig. 1. Note the presence of thin vener of fibrous calcite on either side of the slab marked with arrow.
3. *'Longfengsahnia chopanensis'* of Maithy & Babu 1988, Holotype. Note the weathering feature of the clast, attached on the bedding plane of a limestone, Specimen no. BSIP-36112.

4, 7 *'Longfengsahnia stipitata'* of Maithy & Babu 1988. General view of the slab having specimen. Note the nature of the intraformational conglomerate with clast. One such clast shown in fig. 7 is considered as *L. stiptata* by Maithy & Babu, Specimen no. BSIP-36110.

5, 6. *'Longfengsahnia stipitata'* of Maithy & Babu 1988. General view of the slab containing specimen marked with arrow. Note the intraformational conglomeratic nature of slab with several clasts on it. One such clast has been enlarged and shown in fig. 6 and is considered as *L. stiptata* by Maithy & Babu, Specimen no. BSIP-36109.


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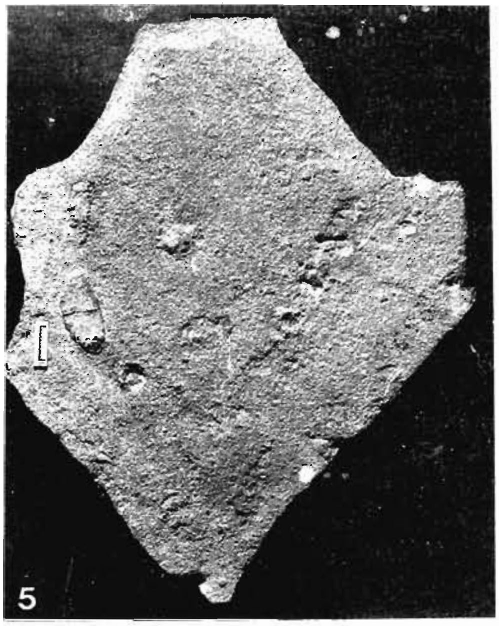
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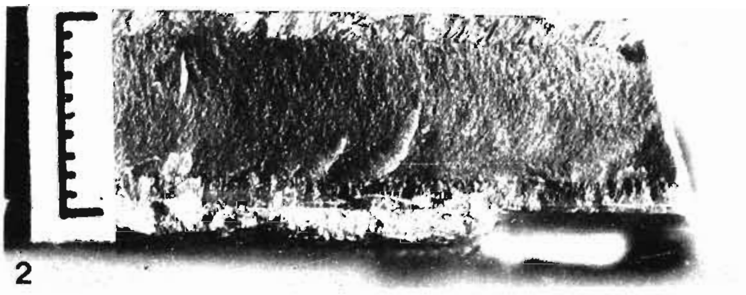
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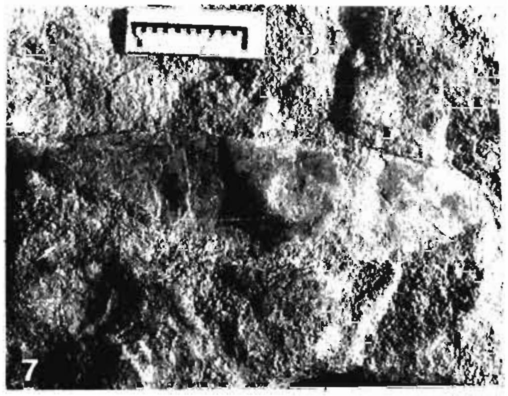
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PLATE 2

Remarks—Chuaria and *Tawuia* present on the 'same grey coloured limestone'. They are aligned in one direction suggesting possible drift from the place of growth in the open sea to the tidal zone along the current direction. These discoid specimens show wide ranging morphology from circular, ovoidal to oblong to slender long specimens. They are impressions and do not show any trace of carbon on the specimen (carbonaceous crust present on the surface have been removed for the study-pers. communication—Maithy, 1992).

Restudy shows presence of 22, long slender specimens (attributed to *Tawuia dalensis* Maithy & Babu 1988) on the rock surface. They measure 4-11 mm in length and 1-2.5 mm in breadth. Maithy and Babu (1988, pl. 1, figs 3-6) reported bulbous structures, with a fluffy nature and sickle shaped, on the fossils in a SEM study. These doubtful artifacts may have been formed during preparation of the material for study. Close observation of the specimen under optical microscope reveals the presence of annulation on some parts of *T. dalensis*. The fragmentary and incomplete preservation of annulation on different regions suggests that they were probably annulated organisms. The presence of annulation on the body could indicate movement through peristalsis. On this basis a metazoan affinity could be attributed for these specimens. *T. dalensis* sensu Hofmann, 1979 in all probability is of algal origin and can not be a metazoan. However, the specimens described by Maithy and Babu, 1988, pl. 1, figs 1-6 show characters attributable to metazoa. Thus the specimens under review cannot be identified as *T. dalensis*. There are reports of fossils of soft bodied animals predating the Ediacara fauna from the Late Precambrian rocks of Huai River China (Junyuan, 1988). The specimens described from China are better preserved and show several characters in developed stage which are also noticed on the fossils attributed to *T. dalensis* by Maithy and Babu (1988).

The specimens of *Tawuia* under review are 'true macrofossils' though their taxonomic assignment need reassessment in the light of above comments.

Further, *Chuaria minima* present on the same rock surface has a wide range of shape, from circular, ovoid to oblong. They are found as impressions on the bedding surface. In all, 128 specimens of *Chuaria* are present on the limestone slab. Their diameter varies from 1.5 to 3 mm ($x = 2.2$; $N = 30$). The central opening as reported by Maithy and Babu (1988) could not be observed in the specimens. The size parameter and morphological details suggest that these specimens are 'true macrofossils'.

FRONDOID FORMS

Pteridinium

Pl. 1, figs 6, 7, 8; Pl. 3, fig. 3

Repository—Geological Survey of India, Calcutta; Specimen nos. 20283, 20285, 20286 and 20287; Mathur & Shanker, 1989, pl. 1, figs 2, 4, 5, 6; Shanker & Mathur, 1991, pl. 1, figs 1-4; pl. 2, fig. 4.

Mathur and Shanker (1989) described bilaterally symmetrical frond like body with median axis giving rise to primary and secondary furrows from the upper part of Krol Formation exposed in the southern limb of Nainital syncline. On the basis of fresh collection made from the same locality, organic nature of the *Pteridinium* was questioned by Misra (1990, pp. 114-115), Bhatt and Mathur (1990b, pp. 115-117) and Azmi and Tewari (1991). According to these authors the primary and secondary furrows are either concentrated patterns formed due to folding on the fold axis, or represent ripple marks. Shanker & Mathur (1991) redescribed this form and considered it authentic.

Remarks—Re-examination of the specimens of Mathur and Shanker (1989) and also fresh collection available with them shows the presence of *Pteridinium* like structure both in the depressed as well as on the elevated zone of rock surface. Thus, structures described by Mathur and Shanker (1989) are not merely compressional features concentrated

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PLATE 3

(Scale in figs 1, 2 & 3, 1 div. = 1 cm; fig. 4 = 2 cm; fig. 5 = 2 mm and
6 & 7, 1 div. = 1 mm)

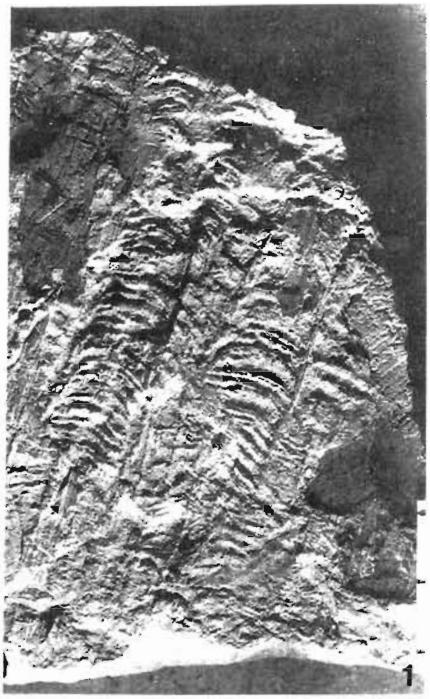
1, 4. Frondoid form of Maithy, 1990, which is present on thin vener of clacite; 1. shows general view of slab containing Frondoid form; and 4. shows the close up of fig. 1, Specimen no. BSIP-36226.

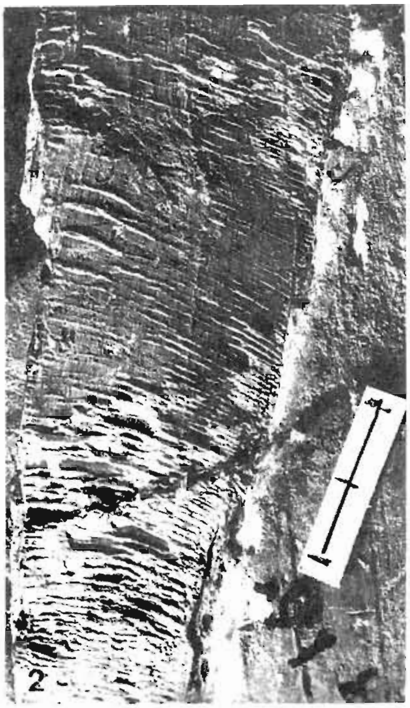
2. Frondoid form of Maithy, 1990, which is present on thin vener of clacite, Specimen no. BSIP-35959.

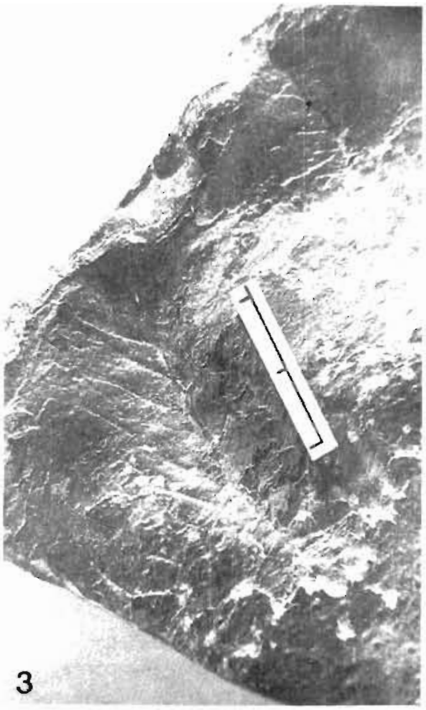
3. *Pteridinium* of Mathur & Shanker, 1989. Note the fragmentary nature of the specimen of *Pteridinium*, Specimen no. GSI-20287.

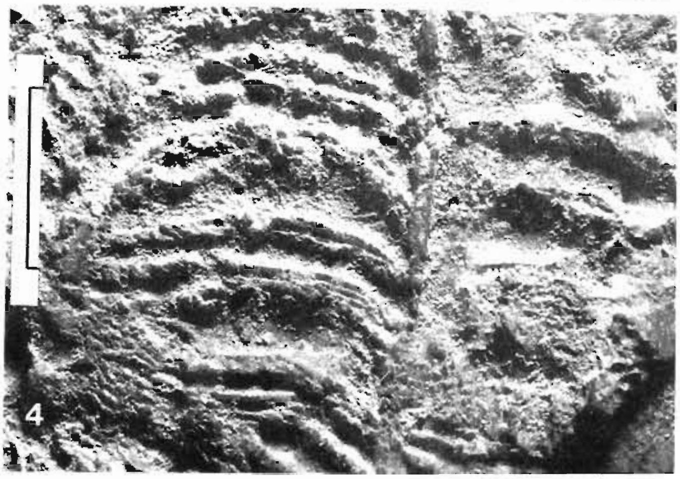
5. *'Rohtasia tandonii'* of Maithy, 1990, the specimen is product of weathering and is present on shale, Specimen no. BSIP-35960.

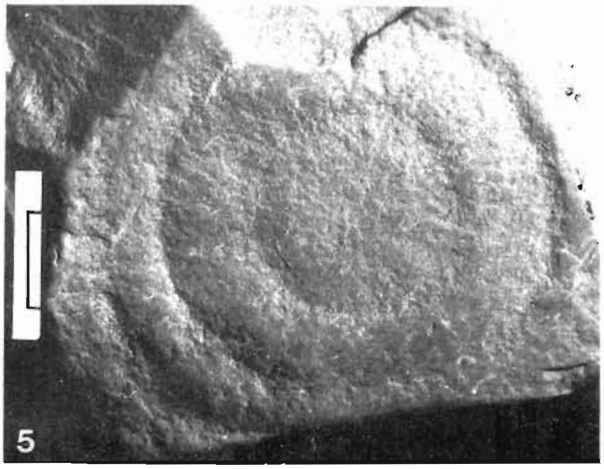
6, 7. *Chuaria* and *Tawuia* of Maithy & Babu, 1988. 6. Shows general view of the specimen showing rounded *Chuaria* and elongated *Tawuia*; 7 close up of fig. 6, elongated specimens have annulations, specimen no. BSIP-36105.

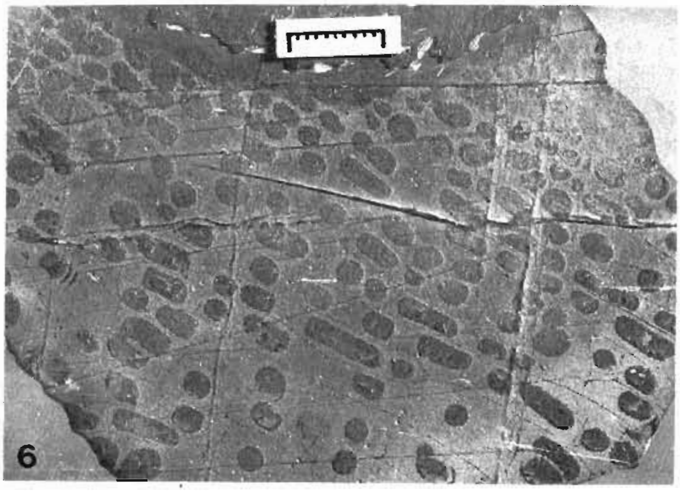












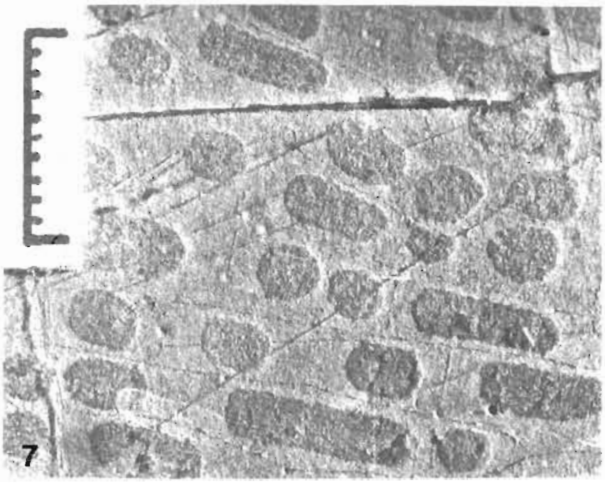


PLATE 3

on fold axis. The fossil has also been interpreted as a sedimentary structure resembling a ripple mark. A ripple-marked surface should show a flat surface and other surface should show crests and depressions signifying wave action. The specimen observed in the collection of Mathur and Shanker do not show this feature and hence possibilities of these structures being ripple marks can be ruled out. Field studies carried out by us indicate the presence of folded/ripple marked structures, along side with the fossils. In our opinion the sedimentary structures are distinctly different from the forms identified as frondoid form by Mathur and Shanker (1989, pl. 1, fig. 5). Since, nearly all the diagnostic features of frondoid form, viz., primary furrow, secondary furrow and median axis are clearly observable in this form it is considered here as a true representative of metazoan affinity. Late Professor Glaessner (corresp. to editor Jour. GSI) and Professor Narbonne (pers. comm. to G. Kumar) have also expressed a similar view. It is difficult to comment on the specimens described on pl. 1, figs 2, 4, 6 of Mathur and Shanker, (1989) due to their fragmentary nature, though, Prof. Narbonne (pers. comm. to G. Kumar) has opined that figs 4 and 6 look more similar to *Charniodiscus*.

Hence, we consider the form described by Mathur and Shanker (1989, pl. 1, fig. 5) as 'true fossil' while those in (Mathur & Shanker, 1989, figs 4, 6) may be considered as 'dubiofossil'. The form described in figure 2 may be considered 'non-fossil' since it does not show any diagnostic features, besides apparently similar structures of inorganic origin are also present in the same locality.

Frondoid forms

Pl. 3, figs 1, 2, 4.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Specimen no. 36226, number for fig. 7 not mentioned; Maithy, 1990, pl. 2, figs 6, 7.

Maithy (1990) described frondoid forms having an overall morphology similar to petalonamid form —*Pteridinium* from the Rohtas Limestone Formation of Vindhyan Supergroup. He further expressed an opinion that these forms may not be related to coelenterates due to the absence of autozooids and scyphozooids and he favoured an algal affinity for these structures. He also compared them with members of Rhodophyceae and Chlorophyceae (*Caulerpa*).

Remarks—The structures described in plate 2, figure 6 of Maithy (1990) are present on a thin vener of fibrous secondary calcite spread throughout the limestone slab and biogenecity of any structure present on such surfaces is doubtful. The specimen illustrated by Maithy (1990, pl. 2, fig. 7) is not available for observation; however, the illustration shows morphological features similar to those in the specimen figured on plate 2, figure 6 (Maithy, 1990). This specimen is from the same locality. It is, therefore, most likely that this specimen also is present on similar thin vener of fibrous calcite which covers the limestone surface. Hence, we consider the frondoid remains (Maithy, 1990; pl. 2, figs. 6, 7) as 'non-fossils'.

HYOLITHIDS

Hyolithes rohitaswei Rode

Text-figure 19

Repository—Not mentioned; Rode, 1946, fig. 1.

Rode (1946) noticed symmetrical, conical straight shells with numerous striae on the surface of a slab collected from talus, possibly representing the top zone of Rohtas Stage (Rohtas Formation, now referred to as Murli Hill Limestone Formation), Semri Series (Semri Group) 4.5 km west of Ramdhera in Rohtas District, Bihar. He considered them to be *Hyolithes rohitaswei*.

Remarks—No details of repository are available. Photographic illustrations are also absent. The line diagram and description of the fossil are complimentary. Such a form has neither been recorded by later workers nor Hyolithids are known from the Precambrian sediments. Therefore, this record is classed under the category 'dubiofossils'.

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PLATE 4

(Scale in figs 1, 2, 3, 1 div. = 1 cm; 4 & 5 = 1 mm & 6, 7 & 8 = 5 mm)

1-3. Vendotaenid form of Maithy, 1990. 1, 2 Show cris cross pattern of mineral vein like feature present on either side of the rock piece, vein marked with arrow has been considered as vendotaenid remain; and 3. shows enlarged view of the vein, Specimen no. BSIP-35958.

4, 5. *Sekwia excentrica* of Maithy & Babu 1988. 4. Shows general view of weathered limestone bedding plane, having ovoidal clast This clast has been enlarged in fig. 5, it has no diagnostic characters to be assigned to *Sekwia excentrica*, Specimen no. BSIP-36106.

6, 7 Crinoidal holdfast-like structure Shukla & Sharma 1990, Specimen no. BSIP-25222/273.

8. *Tyrasotaenia* of Shukla & Sharma, 1990 showing flat brown films on the slab without any reproductive organs, Specimen no. BSIP-25211/273.

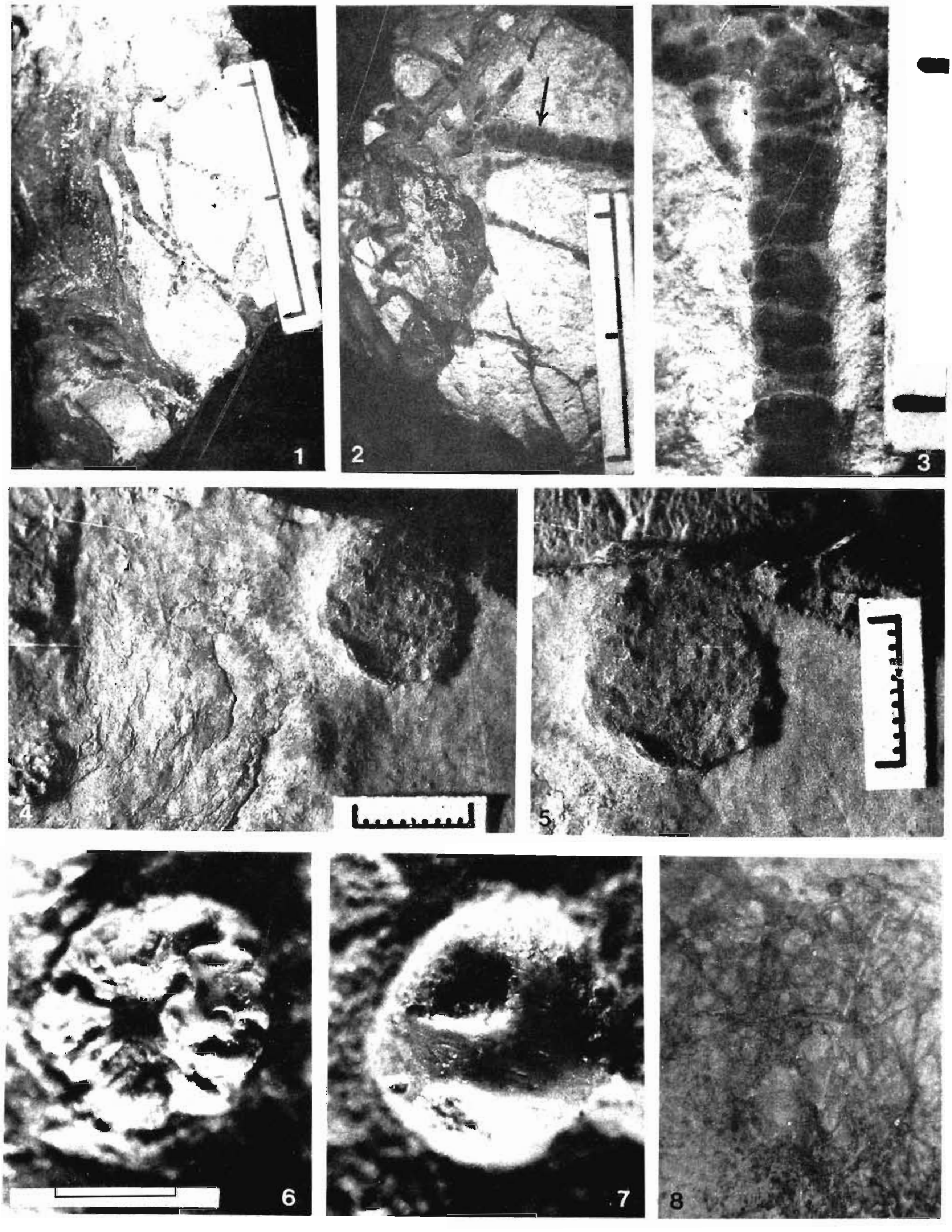

PLATE 4

LONGFENGSHANIA

Du and Tian (1985) described *Longfengshania* as a foliate structure with a stalk-like parastem and occasional rhizome at the base. The presence of parastem is a diagnostic feature. It not only supports the foliate structure and connects it with rhizome, but also exposes it towards sunlight for photosynthesis in water. The size of both the parastem as well as the foliate structure depends on the ecological realm. Many forms exhibit surface ornamentation such as marginal rings of variable width, ring veins and inner ring veins. Some of them appear to exhibit 'organic differentiation' similar to that of higher plants.

***Longfengsahnia (Longfengshania) stipitata* Maithy & Babu**

Pl. 2 figs 4-7

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Specimen no. 35919; Maithy & Babu, 1988, pl. 2, figs 2, 3; Specimen nos. 36109, 36110; Maithy, 1990, pl. 2, fig. 4.

Maithy and Babu (1988, pl. 2, figs 2, 3) described '*Longfengsahnia stipitata*' from Ghurma Shale Formation of Kaimur Group, Vindhyan Supergroup, as an elongate oval impression measuring 8-40 mm long and 4-12 mm wide with the broadest region at 1/3 length from apex; basal end with stalk like structures which are ± 0.5 mm wide and ± 2 mm long and rounded distal end with smooth surface.

Remarks—Longfengsahnia (Longfengshania) stipitata (Maithy & Babu, 1988, pl. 2, fig. 2) is present on a fine grained sandstone having clastic fragments on its upper surface (specimen no. BSIP 36110 instead of BSIP 36109 as mentioned by Maithy & Babu, 1988). The slab is a part of intraformational conglomerate, wherein thin/tabular pieces of shale are embedded in a sandy matrix. Such flat pebble conglomerates are usually known in the formation composed of alternating shale and sandstone bands and the shale pieces attached on the surface may be a product of subaqueous fragmentation perhaps "pull aparts" produced by turbidity flow (Pettijohn, 1957, p. 277). Thus, it is quite apparent that the structure described by Maithy and Babu (1988, pl. 2, fig. 2) is an inorganic clast. The other similar specimen having *L. stipitata* reported and photodocumented by Maithy and Babu (1988, pl. 2, fig. 3) is also a fine grained sandstone. The reported structure and its counterpart both are deposited under the specimen number BSIP-36109 instead 36110 as mentioned in their publication. Both cast and mould of '*L. stipitata*' reported and photodocumented by Maithy and Babu (1988, pl. 2, fig. 3) is also a fine grained sandstone. The reported structure and its counterpart both are deposited under the specimen number BSIP-36109 instead 36110 as mentioned in their publication. Both cast and mould of '*L. stipitata*' are present on a thin vener of shale. Besides, there are several other fragmentary clasts present on the surface of the bedding plane. The structure is an oblong clast rimmed by black material and is also part of an intraformational conglomerate. Thus, the specimens described by Maithy and Babu (1988, pl. 2, figs 2, 3) are part of an intraformational conglomerate and hence the structures are 'non-fossils'.

In a subsequent publication Maithy (1990, pl. 2, fig. 4) has reported a Krishnanid remain (specimen no. BSIP 35919). It is infact the same specimen which was earlier considered as '*Longfengsahnia stipitata*' (Maithy & Babu, 1988, pl. 2, fig. 2 BSIP specimen no. 36110). The author has apparently reassessed the taxonomic status of this structure, though without referring to his previous report (Maithy & Babu, 1988). On the specimen no. BSIP 35919 we found Krishnanid remains reported by Maithy, 1990, in pl. 2, fig. 3 rather than the form reported by him in the same paper (Pl. 2, fig. 4). Further, the difference in the spelling of the original holotype *Longfengshania* to *Longfengsahnia* in two successive publications (Maithy & Babu, 1988; Maithy, 1990) is apparently due to oversight and therefore these specimens are to be considered Dyslexotype—a specimen whose name is mis-spelt on the museum label; in the present case it has also been published twice.

***Longfengsahnia (Longfengshania) chopanensis* Maithy & Babu 1988**

Pl. 2, figs 1-3

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PLATE 5

(Scale in fig. 2 = 1 cm and in others 1 div. = 1 cm)

1, 2. *Tasmanadia dassi* of Verma & Prasad, 1968. 1. Shows general view of the specimen having movement traces; and fig. 2 shows a enlarged but not parallel pair of movement trace of probable arthropod, Specimen no. GSI-18357

3. *Rouaulita rewanensis* of Verma & Prasad, 1968 showing a drag mark formed by movement of an animal, Specimen no. GSI-18356.

4, 5. *Bostrichophyton bankuiyanensis* of Verma & Prasad, 1968. 4. Shows the distribution of ichnofossils, and fig. 5 shows the details of ichnofossils, Specimen no. GSI-18355.


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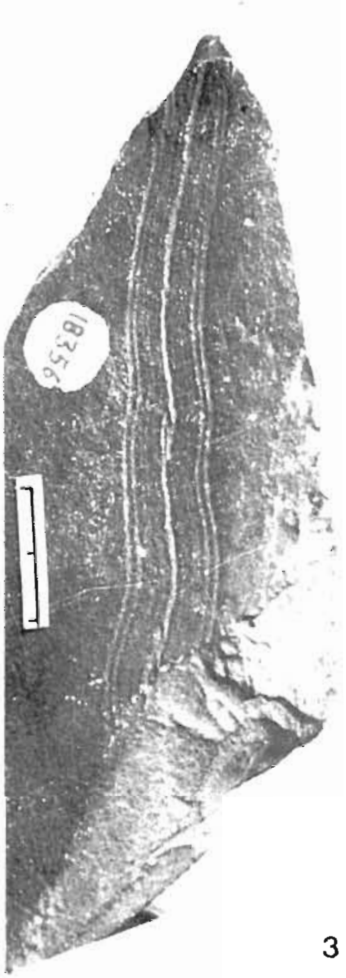

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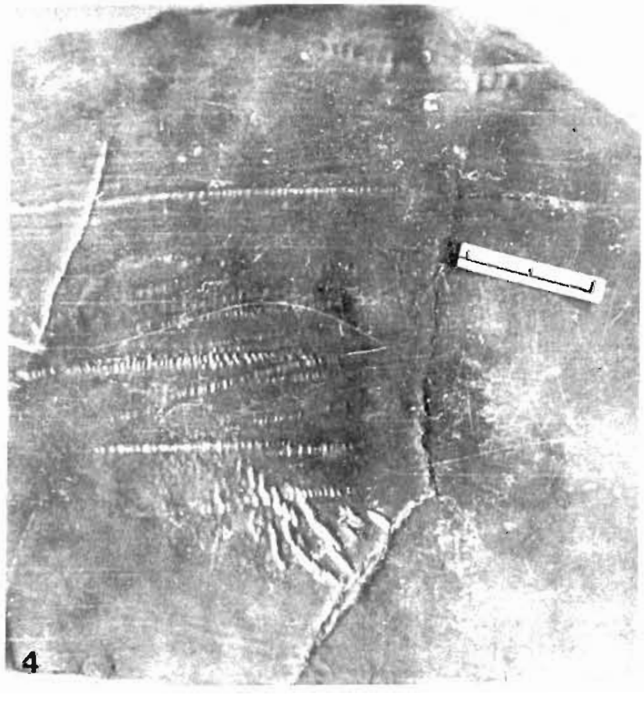
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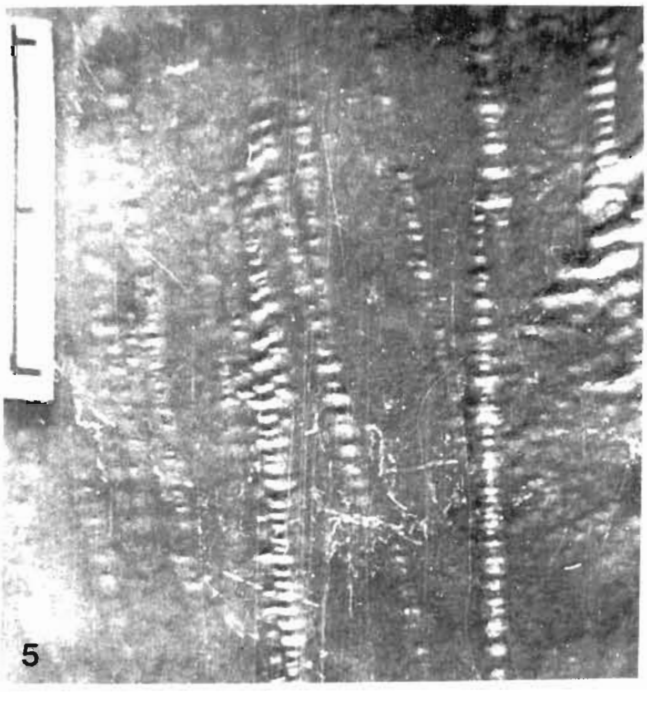
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PLATE 5

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Specimen nos. 36111, 36112; Maithy & Babu, 1988, pl. 2, figs 4, 5.

The specimens reported by Maithy and Babu (1988, pl. 2) from Rohtas Limestone Formation of Semri Group, Vindhyan Supergroup, exhibit pear-shaped external mould on the limestone surface. Nearly fifty specimens (4-50 mm long and 3-30 mm broad) having rounded apical end and tapering basal end with circular scar, measuring 2-3 mm in diameter are present in an area of 6 × 5 cm. Semicircular thickenings with cross connections extend from one margin to another on the surface. The small polygonal or trapezoidal areas gradually reduce in size from apical to basal end.

Remarks—The specimen reported by Maithy and Babu, (1988, pl. 2, fig. 4) is having small millimetric, pear shaped structures filled with yellow shaly material noted on one side of a millimeter thick fibrous calcite vener which is present on either side of the 7 mm thick limestone specimen. Such pear-shaped structures are common on the fibrous calcite found over bedding plane in the limestone quarries of Rohtas area (Pl. 9, figs 7, 8). The calcite vener is of secondary origin. Therefore, syngenecity of these structures, present on secondary surface is doubtful. Another 35 × 25 mm ovoid structure has been reported by Maithy and Babu (1988, pl. 2, fig. 5) as *L. chopanensis* on grey coloured limestone. This structure, made up of weathered calcareous shale, is impregnated with calcite and has uneven wrinkled and fractured surface indicating its incomplete or broken nature. Such ovoidal structures are commonly formed due to weathering or solutional activity at limestone and shale contact. Hence, these specimens reported by Maithy and Babu (1988, pl. 2, figs 4, 5) are considered as 'non-fossils'.

MEDUSOID FORMS

Jelly fish

Text-figure 3

Repository—Not mentioned; Sisodiya, 1982, fig. 1.

Sisodiya (1982, fig. 1) reported fossil impression of Jelly fish from Nimbahera Limestone Formation of Semri Group, Vindhyan Supergroup exposed in Mandsaur District, Madhya Pradesh. The described structures are semicircular and rectangular with maximum diameter of ≅ 12 mm with central depression representing mouth part.

Remarks—The description provided by the author is insufficient to diagnose the fossil, the photographs also are not clear for evaluation. It is thus not possible to assess the biogenicity and taxonomic status of these forms. Its affinity with jelly fish is also not valid and is considered here as 'dubiofossil' pending availability of fresh data.

Ramapuraea vindhyanensis

Pl. 10, fig. 3

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Specimen no 27341; Maithy & Shukla, 1984a, pl. 1, figs 1-3; Shukla *et al.*, 1989; pl. 1, figs 3, 4; Shukla & Sharma, 1990, pl. 2, fig. 2; Maithy, 1990, pl. 1, fig. 6.

Ramapuraea vindhyanensis has been reported from the Suket Shale, Semri Group, Vindhyan Supergroup. This specimen is variously described as carbonised impression of medusoid affinity (Maithy & Shukla, 1984), Jelly fish comparable to *Cyclomedusa* Sprigg (Shukla *et al.*, 1989) and 'Chuarid remains' by Maithy (1990). Maithy (1990) considered them allied to *Chuaria* and doubted their coelenterate affinity. However, Shukla and Sharma (1990) on restudy considered it a medusoid remain though of older antiquity (Shukla *et al.*, 1991).

Remarks—Re-examination of the specimen further supports the views of Maithy and Shukla (1984), Shukla *et al.* (1989, 1991), Shukla and Sharma (1990). These carbonised impressions on black shales show a central part-mouth, radiating structure in the middle part considered as the

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PLATE 6

(Scale in fig. 1, 2, 3, 1 div. = 0.5 mm & fig. 5 = 5 mm and figs. 4, 6, 7 & 8 1 div. = 1 cm)

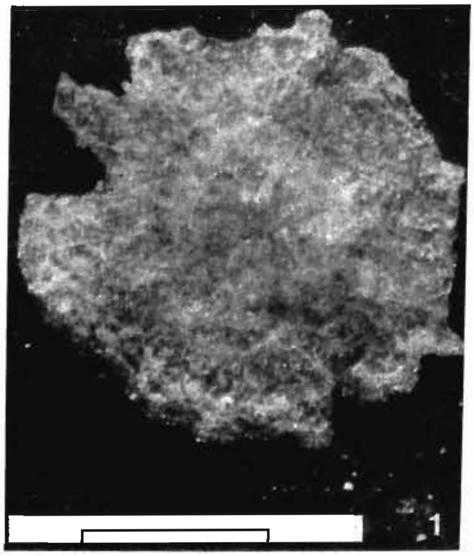
1, 3. *Rohtasia tandoni* Singh & Chandra 1987. 1, 2, 3. Show three different specimens of *R. tandoni* note their encrustative nature on shale. These mineralic encrustation have been considered as medusae cast, Specimen nos. LUTS-306, 307 and 308.

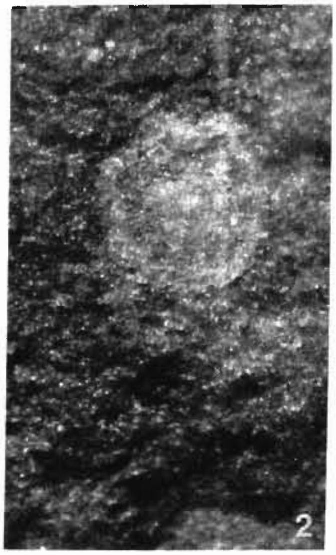
4, 5. A general view of rock slab (collected from Suket Shale Member from Mandsaur) having structure similar to that of *R. tandoni*, a specimen marked with arrow has been enlarged in fig. 5 which shows mineralic incrustation nature, Specimen no. BSIP-36793.

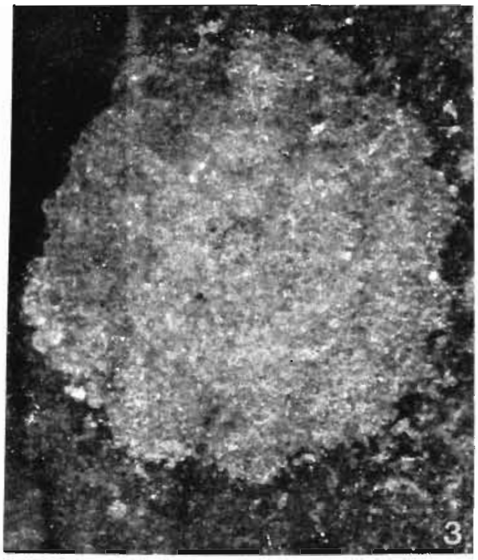
6. Krishnanid forms—Small petiolate structure present on thin vener of fibrous calcite on limestone, Specimen no. BSIP-35919.

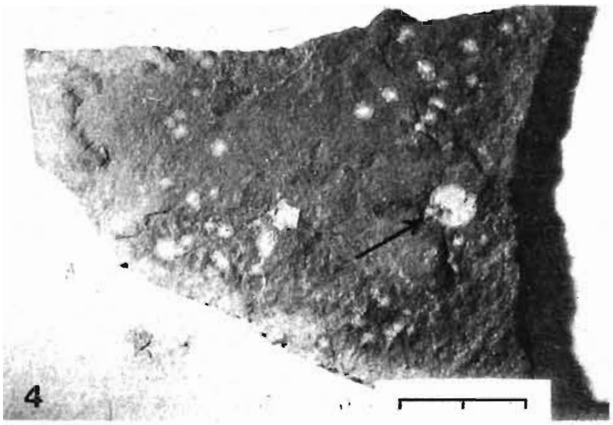
7. Star-shaped radiating structures on a sandstone slab. These are typical synaresis cracks from LaTouche's collection available at GSI, Calcutta bearing temporary number K-1/963.

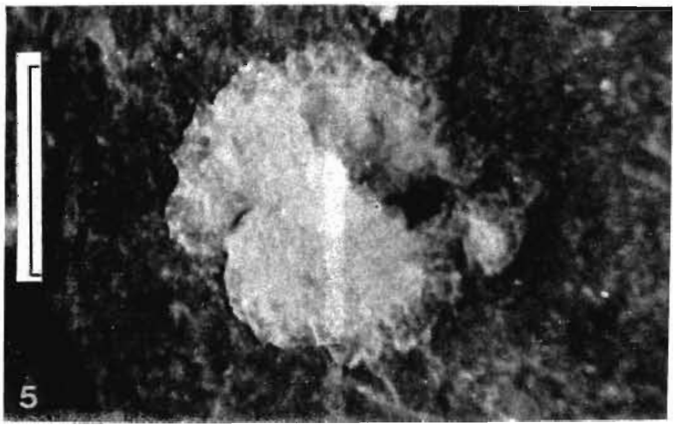
8. *Beltanelloides* Maithy 1990. The deposited specimen bears the circular bodies which are algal balls made up of thin stratiform algal layer. The specimen does not bear any feature similar to that reported by Maithy, 1990, pl. 1, fig. 4, Specimen no. BSIP-35956.











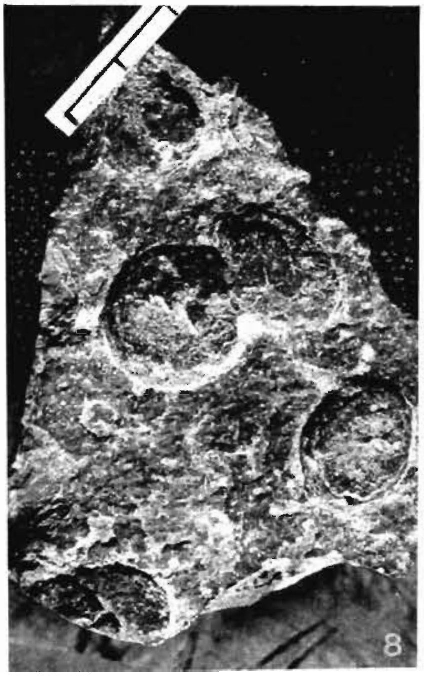


PLATE 6

umbrella and an outer flange. The compactly packed globular structure in the central part of *R. vindhyanensis*, which prompted Maithy (1990) to consider it as a cyst, is a preservational feature formed due to uneven surface of shale. We do not agree with Maithy (1990) in grouping forms of different affinities such as *Rohtasia 'tandonii'*, *Ramapuraea vindhyanensis* and *Chuaria* in a single basket of 'chuarid remains' of planktonic origin. *R. vindhyanensis* is considered 'true fossils' of medusoid like form which formed part of the vast and varied planktonic biota in Pre-Ediacaran sea.

Rohtasia tandoni

Pl. 3, fig. 5; Pl. 6, figs 1-5

Repository—Geology Department, Lucknow University, Lucknow; Specimen nos. LUTS-306, 307-309; Singh & Chandra, 1987, pl. 1, figs 1-6. Birbal Sahni Institute of Palaeobotany, Lucknow; Specimen no. 35960; Maithy, 1990, pl. 1, fig. 7.

Singh and Chandra (1987) described *Rohtasia tandoni* from Rohtas Limestone Formation of Murli Pahar, as cast of medusoid which are nearly flat, small, circular in shape, thin and white in colour. Maithy (1990) doubted their medusoid affinity due to the small size and absence of recognisable feature of coelenterates and grouped them under 'Chuarid remains', considering them allied to *Chuaria*. Maithy (1990, pl. 1, fig. 7, specimen no. BSIP 35960) also recorded *R. 'tandonii'* from the same locality and horizon.

Remarks—The specimens described by Singh and Chandra (1987) are of extremely small size (0.52-1.26 mm) and are present on black coloured shale as a paper thin mineralic encrustation. They do not leave any mark when detached from the surface, thus, negating that they are casts. The black-shale contain high percentage of carbonaceous matter and sulphides alongwith trace elements, viz., Vanadium, Nickel, Copper, etc. (see analysis of a sample of black calcareous shale from Murli Pahar, Table 2, 3). The structures reported by Singh and Chandra (1987, pl. 1, figs 1-6) are the result of oxidation of sulphides present in the sediment producing a swelling and disintegrating of the rock on exposure. In such cases a white efflorescence of melanterite or iron sulphate is left as a product covering the surface (see Pettijohn, 1957, p. 363). EDAX analysis of similar specimens collected from Suket shales indicates that the specimens are made up of high amount of Barium and Sulphur (see, Table 4). The reported effervescence produced on treatment of the cast with HCl (see Singh & Chandra, 1987) may be due to minute amount of calcareous matter present. The specimens described by Singh and Chandra (1987) are 'non-fossil'.

Table 2—Trace Element Analysis of Murli Pahar calcareous shale having similar structure

Element	Concentration [(PPM (μg/ml)]	Element	Concentration [(PPM (μg/ml)]
Sc	11.45	Co	8.40
Zn	142.01	Sr	67.99
Nb	10.92	La	7.03
Nd	4.59	Gd	1.08
Ho	0.17	Yb	1.33
Ta	0.74	Ni	33.57
V	102.04	Y	11.61
Ga	17.69	Ce	12.03
In	—	Tb	0.14
Sm	0.99	Lu	0.14
Er	0.72	Cu	—
Cr	110.90	Zr	107.57
Rb	231.17	Pr	1.21
Ba	216.50	Dy	1.21
Eu	0.11	Hf	2.26
Tm	0.17		

(ICP-MS-analysis by V. Balram, NGRI, Hyderabad.

Maithy (1990, pl. 1, fig. 7) also recorded *R. 'tandonii'* from the same locality and horizon. Re-examination reveals clear circular markings on the bedding plane. No top and bottom of the specimen is mentioned, hence it is difficult to determine whether it is a cast or mould. Many similar features were observed by us, in the same locality which are present both on the top and bottom of the bedding surface as well as on the fractured planes. Their occurrence on the fractured surfaces indicate its

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PLATE 7

(Scale in figs 1-5, 1 div. = 1 mm and scale in fig. 6 is same for 6, 7, 8 = 2 mm)

1-3. *Sekwia excentrica* Maithy *et al.* 1986. 1. Shows general distribution of specimens on the vener of calcite on Limestone; 2. shows those specimens which were considered by Maithy *et al.* as *S. excentrica*; and 3. shows the side view of the same specimen exhibiting the presence of fibrous clacite on either side of the slab, Specimen no. BSIP-35857

4, 5. *Sekwia excentrica* Maithy & Babu 1988. 4. Shows general view of the limestone piece having oblong nodular structure which do not have any striation or excentric groove or wrinkles on the margin to assign it to *Sekwia excentrica*, Specimen no. BSIP-36108.

6-8. *Misraea*, a new body fossil described by Maithy & Babu, 1986. Note that the characters described by Maithy and Babu like inwardly curved body margin with an inner concave hollow depression are not observable. Specimen nos BSIP-35820, 35821 and 35823.


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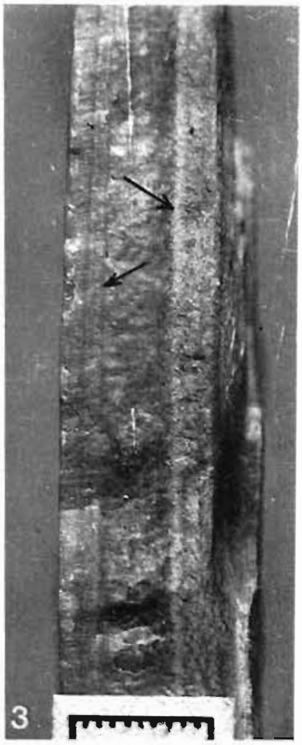
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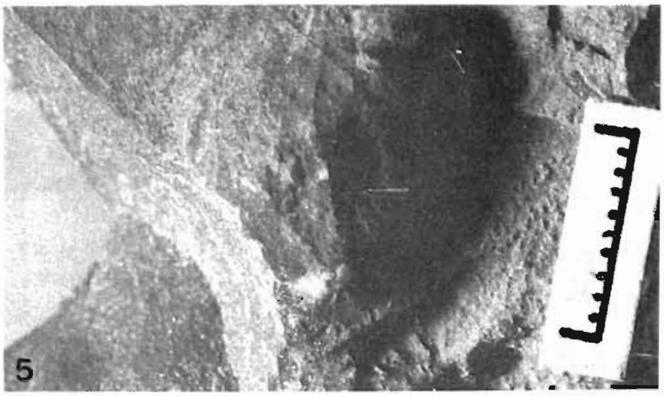
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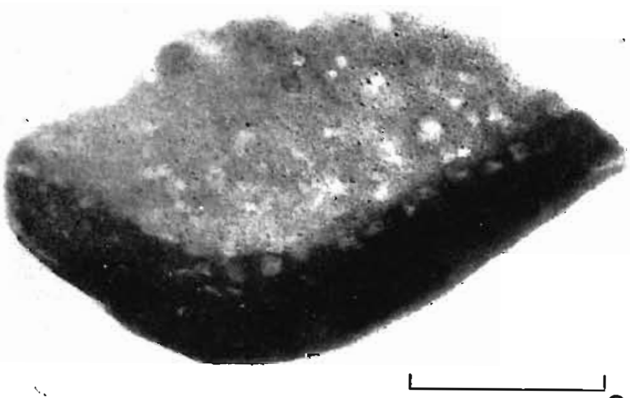
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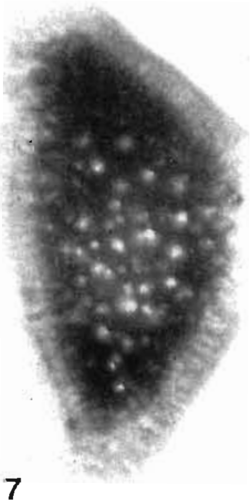
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8

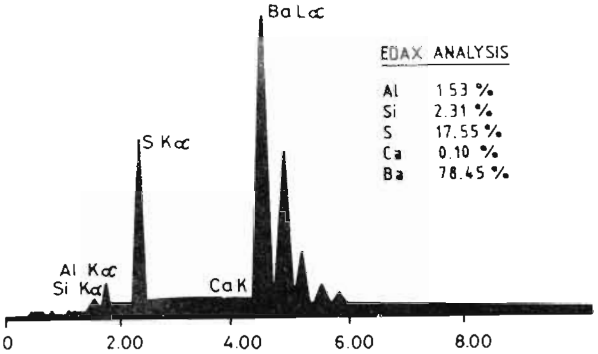
PLATE 7

Table 3—Chemical composition of the calcareous shale of Murli Pahar (XRF data) (in per cent)

SiO_2	—	62.95
TiO_2	—	0.59
Al_2O_3	—	14.90
Fe_2O_3	—	4.72
CaO	—	4.45
MgO	—	6.28
Na_2O	—	BDL
K_2O	—	5.05
MnO	—	0.024
P_2O_5	—	0.12

BDL—Below Detection Lable.
Analysed by P. K. Govil, NGRI, Hyderabad.

Table 4—Graph shows the Edax analysis of the structure similar to *Rohtasia tandoni* Singh & Chandra 1987 from shales. It shows the high percentage of Barium and sulphur which represent the evaporite of Barium



secondary origin. Such feature are commonly formed in shales due to weathering and hence the object described as *Rohtasia 'tandonii'* by Maithy (1990) is a 'non-fossil'.

Tirasiana sp.

Pl. 9, figs 2, 4

Repository—Geological Survey of India, Calcutta; Specimen nos. 20308, 20309; Mathur & Shanker, 1990, pl. 1, figs 1, 2.

Mathur and Shanker (1990) described two specimens of *Tirasiana* as impressions along the bedding plane. One of them is preserved as concave epirelief and the other as convex hyporelief with a diameter of 7-9 mm and relief of 1-1.5 mm which have tripartite organisation. Small central tubercle and circular groove separate the inner narrow disc from the broader outer one which sometimes has indistinct radial markings.

Remarks—Azmi and Tiwari (1991, p. 5) believe that these structures may be biogenic in nature though they did not find typical characteristic features of *Tirasiana* in specimens described by Mathur and Shanker (1990). They found these structures more comparable with *Protoniobia* Sprigg which was later considered as concretion by Cloud (1968). Poor photodocumentation of *Tirasiana* (Mathur & Shanker, 1990, pl. 1, figs 1, 2) has probably created a doubt about the biogenicity of the fossil (see Azmi & Tewari, 1991). Re-examination supports their biogenic origin but due to the absence of diagnostic characters it is not possible to assign the fossil with certainty to *Tirasiana*. The metazoan assemblage including *Tirasiana* from the upper part of Krol Formation is mostly biogenic. More finds are needed to support their correlation with 'Ediacaran' assemblage. The structure reported as *Tirasiana* are considered 'true fossil'.

Medusinites sp. cf. *M. asteroides* Sprigg

Pl. 9, fig. 1

Repository—Geological Survey of India, Calcutta; Specimen no. 20310; Mathur & Shanker, 1990, pl. 1, fig. 3.

It is a lone specimen recorded by Mathur and Shanker (1990) as an impression preserved along the bedding plane. It is subcircular, with convex hyporelief, composed of smooth central disc which is separated from the broad, smooth outer ring by a subcircular groove; the disc is half the diameter of the whole structure, outer diameter of specimen is 8 mm and the disc diameter 4 mm, relief nearly 1 mm; outer ring shows faintly preserved radial grooves.

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PLATE 8

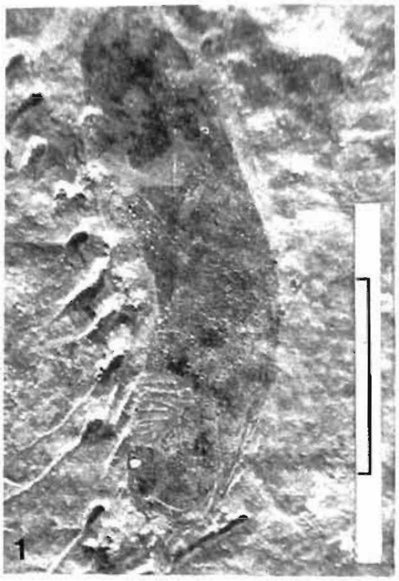
(Scale in all the figures 1 div. = 1 mm, except 3 & 4 which are = 200 μm)

1. *Tawuia dalensis* Maithy & Shukla 1984. Note the smaller size of the specimen, Specimen no. BSIP-25277.
2. *Sekwia excentrica* of Maithy & Babu, 1988, pl. 1, fig. 8—note the oblong structure on the weathered limestone surface; also note the absence of diagnostic characters of *S. excentrica*, Specimen no. BSIP-36107

3, 4. *Allatheca* of Maithy & Shukla, 1984. Note rounded nature and smaller size of the grains, Slide no. BSIP-8001.

5, 7. Trace fossil 'A' & 'B' of Maithy & Babu, 1988 & Vendotaenid remains of Maithy, 1990; note the branching pattern, angle of bifurcation and size making them a closer candidate of *Manchuriophycus* Endo which was later considered as shrinkage cracks. 5. Considered as vendotaenid remain by Maithy, 1990, Specimen no. BSIP-36113.

6, 8. Annelid traces of Maithy *et al.*, 1986, note the cris-cross branching pattern typical of Sun crack, Specimen no. BSIP-35858.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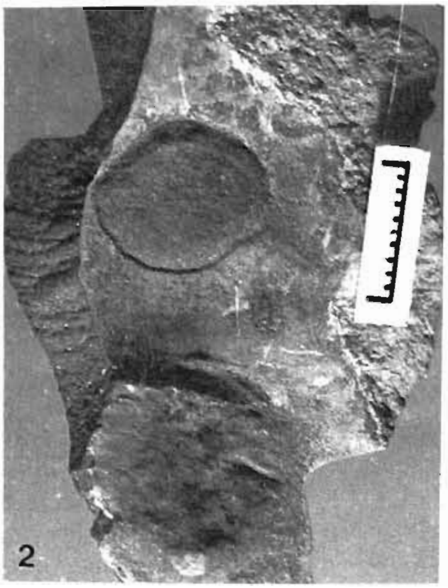
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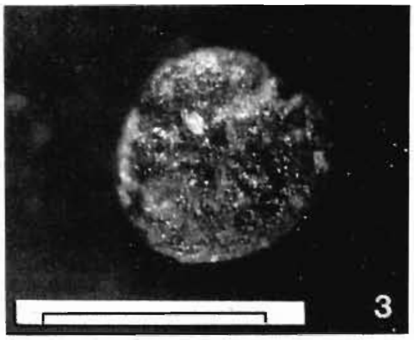
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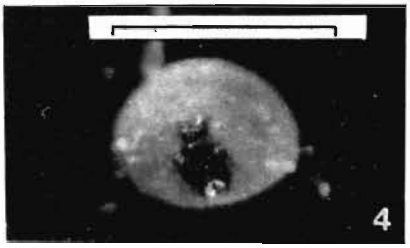
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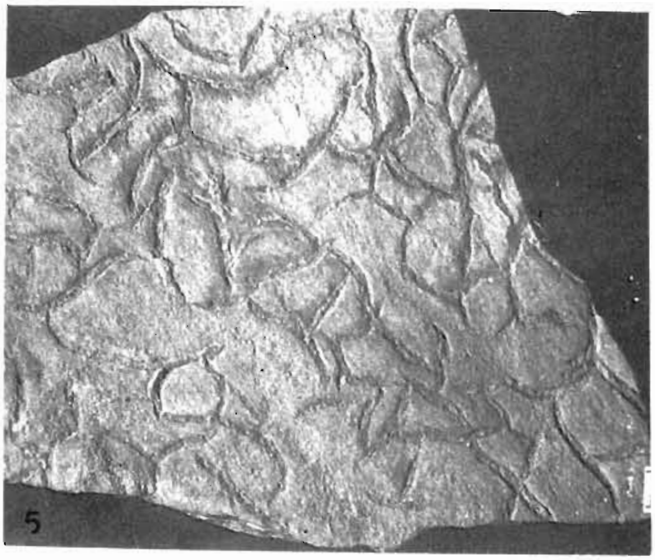
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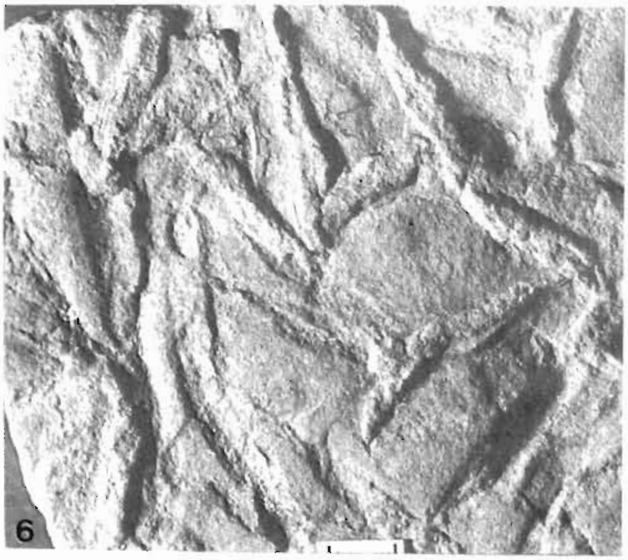
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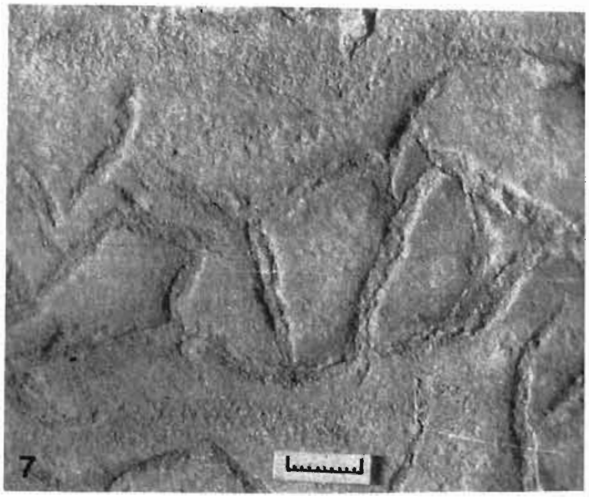
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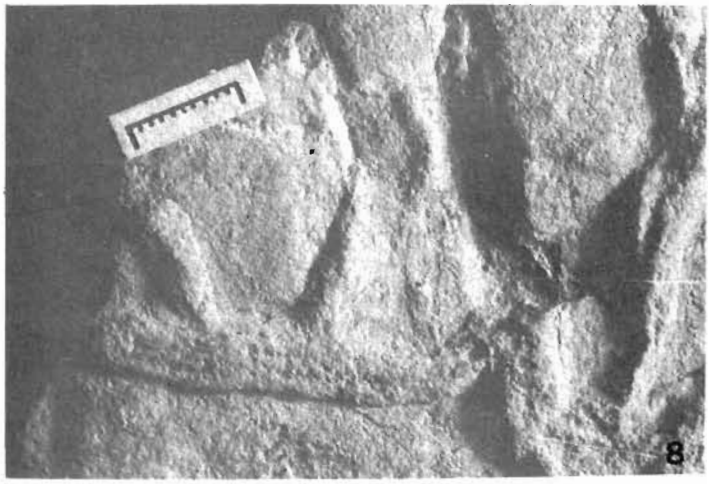
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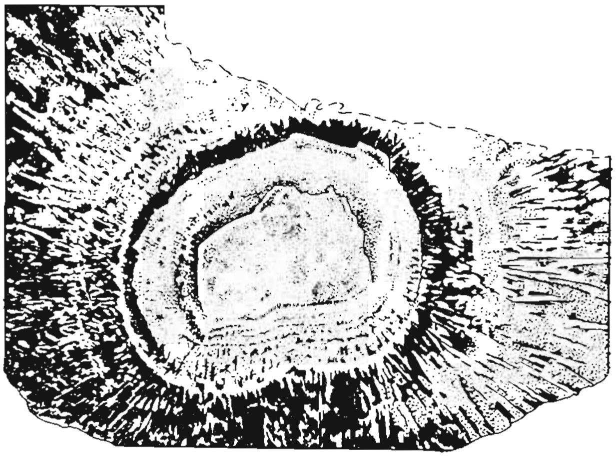
PLATE 8



Text-figure 64—*Korgaicyatha* (Tewari, 1989, pl. 7, fig. b), Scale is not given in original text.

Remarks—Azmi and Tewari (1991) assessed the specimens on the basis of published photograph and opined that the specimen does not reveal annual furrow or groove separating the central disc. They also felt that in the absence of radial furrows on the outer ring and concentric markings on the central disc which are characteristic features of *M. asteroides*, this fossil is of doubtful origin.

Re-examination of the specimen allows us to consider that the figured specimen no. GSI 20310 is a 'true fossil' of metazoan affinity. Taxonomic reassessment is needed.

***Beltanella* sp. cf. *B. gilesi* Sprigg.**

Pl. 9, fig. 3

Repository—Geological Survey of India, Calcutta; Specimen no. 20311; Mathur & Shanker, 1990, pl. 1, fig. 4.

Mathur and Shanker (1990) reported *Beltanella* sp. as an impression, preserved along the bedding plane. It is a smooth disc with a narrow rim, 16 mm in diameter and 1.5 mm in relief and surrounded by a flange about 7 mm in width preserved in convex hyporelief. The record is from the upper part of Krol Formation in Nainital. Azmi and Tewari (1990) have doubted the identification of *Beltanella* and opined that neither it compares with the forms from South Australia, nor Wernecke Mountain, Canada (Narbonne & Hofmann, 1987). They felt that relatively small size with a central disc of about 16 mm diameter and absence of 'outer flange' precludes its assignment to *Beltanella* sprigg.

Remarks—We agree with the observations of Mathur and Shanker (1990). The biogenic nature of the genus *Beltanella* is still under debate. This form is considered as 'dubiofossil'.

***Cyclomedusa davidi* Sprigg**

***Medusinites* Glaessner & Wade**

Text-figures 25, 26

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen nos. 10256, 10258; Maithy, 1990, pl. 2, figs 8, 9.

Maithy (1990) recorded the presence of *Cyclomedusa davidi* (Maithy, 1990, pl. 2, fig. 8) and *Medusinites* Glaessner & Wade (Maithy, 1990, pl. 2, fig. 9) from Dholpur shales of Bhander Group. He did not provide detailed descriptions.

Remarks—Attempts failed to locate the specimens (nos. 10256, 10258) in the BSIP repository. On the suggestion of the author (Dr P. K. Maithy) specimen numbers 36388 to 36393 of the same locality were examined to locate the figured specimens, but again failed. However, similar structures which we consider as product of weathering are present on the rock surface of these specimens. Hence, this record is considered as 'non-fossil'.

METAPHYTIC REMAINS

Non mineralised, megascopic, ribbon-like fossils attributed to Vendotaenids, dasycladaceous algae, *Renalcis, Epiphyton* and *Sajania* are discussed. Vendotaenids are non-mineralized organic, shapeless brown films occurring profusely in the Vendian. There are few records from older sediments. Microscopic study of vendotaenid fragments separated through maceration has proved useful in ascertaining its biogenicity. Vendotaenids can be divided into two subgroups (i) ribbon-like forms occasionally bifurcating, viz., *Vendotaenia, Dvinia, Anataenia, Tyrasotaenia;* and (ii) cord-like intensely branching form *Eoholynia* Gnilovaskaya 1979. *Vendotaenia* is one of the oldest metaphytes with a thalloid structure. Gnilovaskaya (in Sokolov & Iwanowski, 1990) considers a phaeophycean affinity on the basis of general habit and nature of sporangia. Various morphological features have been described under Vendotaenid/metaphytic remains but most of these forms have been described on the surface observations only. The multicellular nature of forms reported from India, however, has mostly not been confirmed through maceration. Shukla *et al.* (1989) and Shukla and Sharma (1990) initiated the study of forms by isolation through maceration techniques.

***Krolotaenia gnilovaskayi* Tewari**

Text-figure 65

Text-figure 65—*Krolotaenia* (Tewari, 1989, pl. 4, figs a, c), Scale is not given in original text.

Repository—Not mentioned. Tewari, 1988; Tewari, 1989, pl. 4, fig. a, c.

Tewari (1988, 1989) mentioned the presence of *Krolotaenia gnilovaskayi* and *Vendotaenia* in the Lower Krol sediments and did not provide a description.

Remarks—An evaluation of illustrations provided by the author indicates similarity of these fossils with roots of extant grass preserved in the forms of impression on the bedding plane. Such impressions may form on the parting surface of shales when the grass roots penetrate into the rocks (see Frey & Pemberton, 1985; Boyd, 1975). The author has also not used the technique of maceration to prove the biogenicity of these forms. Hence, the reported specimen of *Krolotaenia gnilovaskayiv* from the Lower Krol is considered as 'non-fossil'.

Vendotaenid remains/forms

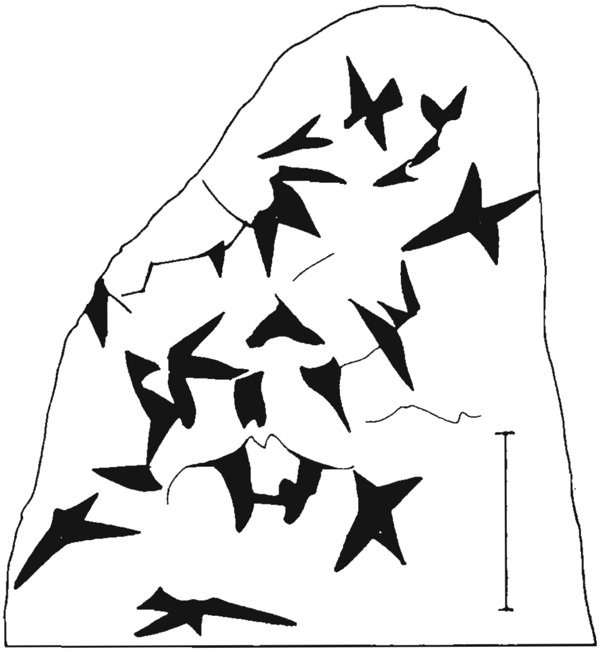
Pl. 4, figs 1-3; Pl. 8, fig. 5

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow—Specimen nos. 35959, 35961; Maithy, 1990, pl. 2, figs 1, 2. Maithy, 1990, pl. 1, fig. 8; Specimen no. not known.

Maithy (1990) reported the presence of Vendotaenid remains (in pl. 1, fig. 8) from Ghurma Shale Formation of Kaimur Group and Rohtas Limestone of Semri Group, Vindhyan Supergroup without providing a description. The other 'forms' reported by Maithy (1990, in pl. 2, figs 1, 2) have been briefly described as narrow, linear structures preserved compactly parallel to one another, 30 mm in length and 3 mm in width with rounded ends and fine transverse thickenings.

Remarks—The Vendotaenid remain (Maithy, 1990; pl. 2, fig. 7) was earlier considered a trace fossil by Maithy and Babu (1988, pl. 2, fig. 7). Specimen number has not been provided for the fossil described in both the papers (Maithy & Babu, 1988, pl. 2, fig. 7; Maithy, 1990, pl. 1, fig. 8). However, the fossil is available on specimen no. 36113 in the BSIP repository. The specimen which is a 3 cm thick fine grained sandstone has wavy structures on the top of the bedding surface showing irregular or radiating pattern sometime cross cutting each other. This feature is comparable to the subaqueous shrinkage cracks or synaresis cracks, a common feature in mud layers interbedded with sandstone (Collinson & Thompson, 1982; Hofmann, 1971). These structures reported by Maithy and Babu (1988, pl. 2, fig. 7) as trace fossil and later by Maithy (1990, pl. 1, fig. 8) as Vendotaenid remain are infact synaresis cracks.

The Vendotaenid form reported by Maithy, (1990, pl. 2, fig. 1, specimen no. 35959) is recorded in the BSIP Museum as *Katania singhi*. The specimen is a thin recrystallised limestone having a thin vener of fibrous calcite with typical transverse markings which have been considered as septa of *Vendotaenia*. These features are not the primary features as considered by Maithy (1990) but are the ones developed over the secondary calcite. The third fossil described as Vendotaenid form (Maithy, 1990, pl. 2, fig. 2) is now located on specimen no 35958 and does not stand on specimen no. 35961 as indicated by Maithy (1990). While the specimen located by us is from the Lower Kaimur Sandstone of Dabua as per records of the repository, the author reports this fossil from comparatively older sediments of Rohtas Formation of Murli Pahar. It is present on a small piece of a weathered silt stone and shows mineral veins with iron oxide staining which form cris-cross patterns. The vein-like feature has been considered as *Vendotaenia* by Maithy (1990). Being the 'Type specimen', it is not possible to break the specimen to test for mineral type. These veins may be made up of any of the known sesquioxides of iron and alumina, viz., limonite, goethite, hematite/magnetite. Goethite is commonly found as reniform, botryoidal or other colloform masses with an internal concentric or radial (or both) fibrous structure. Sometime the external forms of goethite suggest an original gel state (see Pettijohn, 1957, p. 138). The fossil under discussion appears to be a product of recrystallisation of an oxide. The divisions in the vein occurring uniformly which were considered as septa, are tensional cracks during crystallisation. Further, we have no knowledge or record of *Vendotaenia* of such large



Text-figure 66—*Ichnofossil* (Mukherjee *et al.*, 1987, figs. 1, 2), Scale = 14 cm. (Scale is same for figs 49, 50, 51, 56 & 57 as in fig. 50) (Scale is same for figs 31, 32, 35, 36, 39, 40, 43, 46 as in 21, 22, 28).

dimension (30 × 3 mm). We consider these reports of Vendotaenid remains (Maithy, 1990, pl. 1, fig. 8; pl. 2, figs 1, 2) as 'non-fossil'.

Tyrasotaenia

Pl. 4, fig. 8

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 25211/273; Shukla *et al.*, 1989, pl. 1, figs 5, 6; Shukla *et al.*, 1990, pl. 2, fig. 1.

Shukla *et al.* (1989) and Shukla and Sharma (1990) reported *Tyrasotaenia* as brown flattened carbonaceous film on buff coloured Suket Shale of Semri Group.

Remarks—Re-examination of specimen no. BSIP 25211/273 further supports the authors' observations (Shukla *et al.*, 1989, 1991). Maceration of associated samples yielded multicellular carbonaceous films which lack reproductive organs. It was not possible to macerate the type specimen recorded by the authors however, other similar specimens on maceration yielded organic films. These macroscopic films are considered 'true fossil' of *Tyrasotaenia*.

1. Dasycladaceae

Text-figures 37, 44

Repository—Not mentioned. Rao, 1943, fig. 1.

Rao (1943) reported a thallus of dasycladaceous algae having a central cavity with number of dark circular bodies arranged regularly along the periphery from the limestone of Cuddapah Formation.

Remarks—The photograph of the fossil published by Rao (1943, fig. 1) appears to be catagraphs or oncolites which are also known in the Upper Cuddapah (see Mandal *et al.*, 1983; pl. 1, figs 15, 16). These forms reported as multicellular dasycladaceous algae may be considered 'dubiofossil'.

2. Dasycladaceae

Text-figure 45

Repository—Not mentioned. Rao & Mohan, 1954, figs 2-5.

Rao and Mohan (1954) described a dasycladaceous algae from Dogra slates, Baramula. The fragmentary remains are considered as thallus and sporangia.

Remarks—Repository details are not provided. The illustrations are of poor quality. Hence, a proper assessment of these forms is not feasible. It is recommended that more material from the locality should be studied. For the purpose of present review it is kept under 'no comment' category.

1. *Epiphyton* Bornemann

Repository—Geology Department, Lucknow University, Lucknow, Specimen/Slide no. not known; Singh & Rai, 1983, pl. 2, figs 8-11, 13.

Singh and Rai (1983) reported the presence of *Epiphyton* from the upper part of Krol Formation in Mussoorie Hills.

Remarks—Evaluation of the illustrations of *Archaeocyatha, Renalcis* and *Epiphyton* indicates that they appear to be part of the same biotope which forms microstromatolite. Since detailed description is not available and photographs do not show all the characteristic features, these forms are considered here as 'dubiofossil'.

2. *Ephiphyton* Borneman

Text-figures 50, 51

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Slide nos. 8546, 8547; Shukla, 1984, pl. 1, figs 3, 4.

Shukla (1984) recorded calcareous algae *Epiphyton* from Calc-Zone of Pithoragarh. These are solid rod-like features, repeatedly branching at 25°-60° arranged in radial manner, length of individual rods 180-300 μm, breadth 3-5 μm at base and 6-10 μm at the point of branching and composed of black opaque microcrystalline calcite.

Remarks—Johnson (1966) has summarised the characteristics of 66 species. The fossil described by Shukla (1984) does not compare with any one of them besides the specimens under discussion did not exhibit a regular pattern of division in branching therefore it is concluded that the forms reported by Shukla (1984) are mineralic crystallite and hence are 'non-fossil'.

1. *Renalcis* Vologdin

Text-figures 56, 57

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Slide nos. 8544, 8545; Shukla, 1984, pl. 1, figs 1, 2.

Shukla (1984) described circular to subcircular oval or even irregular calcified grey-black to brown coloured structures under *Renalcis* from the Calc-Zone of Pithoragarh. These hollow structure range from 300-400 μm in size.

Remarks—Vologdin (1932, in Sokolov & Iwanowski, 1990) described this alga as microscopic, shapeless calcareous colonies. They occur as more or less globular or elongated calcified sheaths covering either the entire colony or only the peripheral portion. The central portion of the inner hollow is diverse and filled with light calcite. *Renalcis* reported from the Calc-Zone of Pithoragarh, though morphologically similar to the ones summarised by Johnson (1966), is smaller to any known species of *Renalcis*. The specimen reported from Calc-Zone of Pithoragarh is a 'true fossil' of *Renalcis* sp.

2. *Renalcis* Vologdin

Repository—Geology Department, Lucknow University, Lucknow, Slide no. not known; Singh & Rai, 1983, pl. 2, fig. 13.

Singh and Rai (1983) reported the presence of *Renalcis* from the upper part of the Krol E of Mussoorie Hills. It is characterised by irregular thallus, consisting of calcareous shell and an inner cavity, thickness of the shell is highly variable.

Remarks—Detailed descriptions are not provided by the authors. Evaluation of the illustrations indicates that *Renalcis* recorded and illustrated here is a part of a large calcareous algal biotope (see comments under Archaeocyatha & *Epiphyton*, p. 3, 12. Similar views have also been expressed by Brasier and Singh (1987). They are considered 'dubiofossil'.

Gansser (1974) also reported calcareous algae *Renalcis* and *Oleckmia* in the Krol B unit of Nainital hills without any description and photograph. So far it has not been photodocumented from Krol B unit of Nainital. They are placed under 'dubiofossil' pending proof of the reproducibility and detailed description.

Sajania Vologdin

Text-figure 49

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Slide no. 8548; Shukla, 1984, pl. 1, fig. 5.

Shukla (1984)reported ribbon-shaped structures from Calc-Zone of Pithoragarh which was 10-100 μm thick and branched irregularly. They are composed of opaque microcrystalline clacite.

Remarks—Re-evaluation is based on characteristics of *Sajania* given by Vologdin (1962, in Johnson, 1966). The genus is diagnosed as 'Thallus filamentous, irregularly branched. Composed of a single calcified thread which branches. Branches sometime alternate on one side than the other, but are commonly irregularly arranged. Some second order branches. Thickness of threads 100 μm or less". Comparison of thickness of thread and branching pattern show only partial similarity in diagnostic characters. Therefore we place this record under 'dubiofossil'.

SEKWIA EXCENTRICA

1. *Sekwia excentrica* Hofmann

Pl. 7, figs 1-3

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 35857; Maithy *et al.*, 1986, fig. 1; Maithy, 1990; pl. 1, figs 4, 5.

Maithy *et al.* (1986) described *Sekwia excentrica* from Rohtas Formation. No reasoning is put forward to assign the fossil to *Sekwia*. The report also does not mention the repository and specimen number. In a subsequent paper a specimen with almost similar features has been described (Maithy, 1990, pl. 1, figs 4, 5) as *Sekwia excentrica*, grouped in the category of 'Chuarid remains' and compared with encystment structures of *Nucellosphaeridium* Timofeev. This specimen (Maithy, 1990, pl. 1, fig. 4) bears the repository no. BSIP 35857.

Remarks—The grey coloured limestone sample bearing the fossils has circular markings on its one surface, which has been considered as *Sekwia excentrica* by Maithy *et al.* (1986, fig. 1) and Maithy (1990, pl. 1, fig. 4). These structures are present on a thin vener of fibrous calcite, which is secondary in origin and therefore any feature on it can not be considered syngenetic to the rock. We, however, could not observe any globular structures in the centre as mentioned by Maithy (1990, pl. 1, fig. 5, p. 24) to consider the fossil as an encystment structure or *Nucellosphaeridium.* These records (Maithy *et al.*, 1986, fig. 1; Maithy, 1990, pl. 1, fig. 4, are considered 'non-fossil'.

2. *Sekwia excentrica* Hofmann

Pl. 4, figs 4, 5; Pl. 7, figs 4, 5; Pl. 8, fig. 2

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen nos. 36106, 36107, 36108; Maithy & Babu, pl. 1, figs 7, 8; pl. 2, fig. 1.

Maithy and Babu (1988) reported circular to subcircular impressions of *S. excentrica* on a bedding plane of Rohtas Limestone Formation. They are 10-35 mm in diameter with distinct groove on margin and a small central area, on raised central portion without any radial striations.

Remarks—The diagnostic features of *Sekwia excentrica* are millimetric to centimetric sized discoidal impressions with annular groove and strongly eccentric coarse wrinkles whose centre of curvature lies near or beyond the margin of impressions (see Hofmann, 1981). The form described by Maithy and Babu (1988, pl. 1, fig. 7; specimen no. 36106) as *Sekwia excentrica* is a limestone clast which has assumed an ovoidal shape on the weathered bedding plane. This ovoidal structure is 11 mm in diameter and lacks marginal groove and radial/cresentric striations. Thus, it does not have any diagnostic characters to be assigned to *S. excentrica.* The other fossil also attributed to *S. excentrica* by Maithy and Babu (1988, pl. 1, fig. 8; specimen no. 36107) is an oblong structure on the weathered and rippled surface which is depressed in the limestone matrix. This structure appears to be a compressed concretion which is covered on the margin by projected host rock, radial striations and eccentric wrinkles are also not present. Hence, it would not be proper to assign the structure to *Sekwia excentrica.* Another oblong nodular structure of 5 mm size has also been described by Maithy and Babu (1988, pl. 2, fig. 1, specimen no. 36108) as *S. excentrica.* It is set in a matrix of limestone and not on the bedding plane as reported by Maithy and Babu (1988). The striations described by them are apparently the fractured surface of the limestone. Absence of diagnostic characters such as marginal groove, eccentric coarse wrinkles, etc. do not permit assignment of this form to *Sekwia excentrica.*

Hence, the specimens described by Maithy and Babu (1988, pl. 1, figs 7, 8; pl. 2, fig. 1) as *Sekwia excentrica* are 'non-fossil'.

SHELL-LIKE FORMS

Lamellibranchs etc.

Text-figure 30

Repository—Not mentioned. Iyengar, 1905; Gowda *et al.* 1978, pl. 1, figs A-D; pl. 2, figs a-d.

Iyengar (1905) and Gowda *et al.* (1978) reported numerous globular, oval and elongated forms from the rocks of Guddadarangavanahalli Formation (G. R. Formation), Dharwar Supergroup in Karnataka, which have an outer shell quite distinct from the inner one.

Remarks—These specimens could not be re-examined. The description and illustration too, are not convincing to assign biotic affinity. It is highly improbable that Lamellibranchs had appeared at a time when even shell forming tendency had not evolved. They are therefore considered here 'non-fossil'.

Shell-like forms

Text-figure 16

Repository—Not mentioned. Prakash, 1966, fig. 1.

Prakash (1966) reported a shell-like form from shaly limestone bed within the Kajrahat Limestone of Semri Group, north of Kajrahat Village. It is reported that the form has the appearance of a broken cast of a brachiopod shell. The convex side is placed towards the top of the bedding plane. Broken concentric fragments of stromatolites occur on the same plain. The chemical test of carbonate rock of the area gives positive signature for phosphatic material.

Remarks—In the absence of repository details the fossil could not be re-examined. The quality of illustration does not permit further evaluation. It is generally believed that mineralic shells of calcitic or phosphatic nature appeared only in Tommotian with a few exception in Vendian sediments. It is possible that the shell-like structure described by Prakash (1966) are crumpled and mud curled algal mats deposited along with fragments of stromatolites. Though possibly biogenic, these structures are not brachiopods and thus considered here 'dubiofossil'

Foraminifera ? or Porifera ? or *Obruchevella*

Text-figures 21, 22, 28

Repository—Author's collection, Ahluwalia, 1979, fig. 1a-c; Ahluwalia 1985; Ahluwalia & Bhargava, 1989.

Some biogenic structures comparable to *Archaediscus, Palaeobigenerina* and indeterminate form (? *Pachyphloia*) have been reported from cherts of Durmala, about five kilometers from Masrana situated on the Mussoorie-Tehri Road by Ahluwalia (1979, 1985) and Ahluwalia and Bhargava (1989). Comments of Dr Reitlinger, Prof. Conil and

Dr Vachard have been appended in the paper (Ahluwalia, 1979) to support the identifications and suggesting the age of foraminifera bearing beds to Carboniferous-Permian (?). However, the same author (Ahluwalia, 1985, 1989) later reassessed them as algal forms comparable to *Obruchevella* and suggested Vendian-Tommotian age for these beds.

Remarks—Our study of a single slide, made available to us by Dr Ahluwalia, confirms his latter view that the forms are *Obruchevella*. The difference in their shape is only due to their being sectioned along different planes. Hence, we consider these forms as 'true fossil' of *Obruchevella*.

Foraminifera and Gastropoda

Text-figures 31, 32, 35, 36, 39, 40, 43, 46

Repository—Author's collection. Kumar, 1979, pl. 1, figs 1-4; pl. 2, fig. 5.

Kumar (1979) reported the presence of foraminifera and gastropoda from the oolitic band of Krol D stage of the type area of Krol Formation, Krol Hill near Solan, in Himachal Pradesh. The foraminifera reported include *Novella* sp., *Nodosaria* sp., *Gourisina* (?) sp., *Lunucammina perforata* (large), *Lunucammina orientalis, Tetrataxis* sp., *Paraboultonia* sp. and *Diplotremina* sp.

Remarks—Singh (1981, p. 154) in his review considered these specimens to be only coated grains, Zhang *et al.* (1983) illustrated and explained the mechanism of formation of coated grains of sparry carbonate nucleus showing patchy recrystallisation subjected to varying degrees of diagenesis. The specimens attributed to foraminifera and gastropods by Kumar (1979) agree with the illustrations given by Zhang *et al.* (1983). Hence, they are considered 'non-fossil'.

1. Small shelly fauna

Repository—Not mentioned; Singh & Shukla, 1981. Not mentioned; Azmi & Pancholi, 1983. Geological Survey of India, Calcutta; Specimen nos. 20076-20122; Bhatt *et al.*, 1985, pl. 1, figs 1-17; pl. 2, figs 1-16; pl. 3, figs 1-14. Brasier & Singh, 1987. Kumar *et al.*, 1987.

There are a number of records of small shelly fossils from Chert-Phosphorite Member of Tal Formation reported from different localities of the Garhwal Syncline. Singh and Shukla (1981), Azmi and Pancholi (1983), Bhatt *et al.* (1985), Brasier and Singh (1987) and Kumar *et al.* (1987) reported—*Maldeotia bandalica, Protohertzina anabarica, Conotheca* sp., *Ovalitheca* cf. *multisulcatus* sp., *Barbitositheca ansata, Hexangulaconularia* cf. *formosa, Coleoloides* aff. *typicalis, Hyolithellus* aff. *insolatus, H.* cf. *insiticus, H. valdimirovae, Spirellus shankari, Olivooides trisulcatus, Protohertzina sciciformis, Protohertzina unguliformis, Hyolithes stylus, Circotheca* aff. *obessa, Circotheca dahaiensis, Turcytheca* aff. *praenguis, Anabarites* sp., *Coleoloides* sp., *Allatheca concinna, Circotheca longiconica, Circotheca* sp., *Turcutheca* sp., indet aff. *T. annae, Turcutheca lubrica, Turcutheca maldeotaensis, Protohertzina* sp., indet aff. *P. robusta, Gaulondina, Tikritheca* sp., *Maikhanella* sp., *Olivooides* sp., *Coleoloides* sp., *Spirellus*? sp., *Lapworthella*, etc. On the basis of this assemblage a Tommotian to Ordovician age has been suggested.

Remarks—The report of the small shelly fauna from Chert Member of the Tal Formation is very significant. The findings have been validated (Brasier & Singh, 1987). However, certain taxonomic reassignments have been suggested (see Cowie & Brasier, 1989, p. 52). We consider these fossils as 'true fossil'.

2. Small Shelly fauna

Repository—Geological Survey of India, Calcutta, Specimen no. not known; Das *et al.*, 1987, pl. 1, figs 1-11; pl. 2, figs 1-6.

An assemblage of shelly fauna consisting of *Olovooides* sp., *Hertzina*? sp., *Lapworthella*? sp., *Cambrotubulus.* sp., *Colooloides*? sp., specimens assigned to gen. et sp. indet 1, gen. et sp. indet 2, gen. et sp. indet 3 are recorded from the basal part of the Upper Krol dolomites near Baldiyakhan and Hanumangarhi on the Jeolikote—Nainital Road section (Das *et al.*, 1987). Shelly microfauna are claimed to be present in a large number but the authors identification are only provisional.

Remarks—The fossils illustrated by Das *et al.* (1987) are 'true fossil'. They need proper identification and description. The occurrence of *Anabarites, Circotheca* and *Protohertzina* assemblage (ACP assemblage) is important to mark the Precambrian/Cambrian boundary. Here the occurrence of some fossils of the ACP assemblage is significant to trace their antiquity.

3. Small Shelly fossils

Repository—Northern Region, Geological Survey of India, Lucknow, Specimen nos. PRF/5978, 5982, 5994 A-D & 6017; Bhatt & Mathur, 1990a, fig. 3a-g.

Small shelly fossils, including *Coleoloides typicalis* Walcott, *Olivooides multisulcatus* Qian, ?*Hyolithellus* sp. and ?*Turcutheca* sp., were recorded from phosphatic carbonates occurring at 7 km from Nainital on the Nainital-Kaladungi Road, near the village Chorkhet. On the basis of *Olivooides multisulcatus* and *Coleoloides typicalis* Bhatt and

Mathur (1990) inferred that the topmost 77 meters of Sherwood Member of Krol Formation and the basal 73 meters of the succeeding Giwalikhet Member of Tal Formation in the Nainital Syncline represents the same time span as the Chert Phosphorite Member of Tal Formation in Mussoorie and Garhwal Syncline.

Remarks—These forms are undoubtedly biogenic hence 'true fossil' and confirm the presence of SSF in Krol E.

Ostracoda

Text-figures 4, 5

Repository—Geological Survey of India, Calcutta, Specimen nos. 20306, 20307; Das *et al.*, 1990, pl. 1, figs 1, 2.

Two tiny carapaces having strong resemblance to Ostracoda are reported from the basal part of the Upper Krol Formation exposed 1 km north of Baldiyakhan toll gate on the Jeolikote-Nainital Road section. These specimens, obtained by maceration of thinly interbedded phosphorite and limestone, display platy appearance and are associated with shelly microfauna. The two valves bear few spines; eye tubercles are absent. The authors recommend its placement under Archaeocopida though they agree that the fossils do not show diagnostic characters of this group.

Remarks—The specimens are 600 μm in length and 350 μm in breadth. Their authentication requires further study under the Scaning Electron Microscope. Though, the specimens were available at the repository, we could not take up SEM studies due to non-availability of such facilities at the Calcutta repository. Therefore we refrain from offering comment on this record.

SPIRAL FORMS

Spiroichnus beerii Mathur

Text-figure 24

Repository—Geological Survey of India, Calcutta, Specimen no. not known; Beer, 1919, pl. 30, figs 1, 2; Mathur, 1983, pl. 2, figs 1, 2.

Beer (1919) reported small spiral groove of 13 × 11 mm from Vindhyan scarp at Sardainar near Rohtas. They could be caused by the impression left on the surface of the soft mud by the caracass of a coiled worm or may represent tracks of small burrowing animal. Mathur (1983) redescribed the same specimens as spiral grooved impression on the upper surface of the soft shaly layer (concave epirelief), and its cast on the sole of overlying slab of compact and hard limestone (convex hyporelief), whose inner termination has rounded and smooth margins and the outer pointed end broken. Mathur (1983) named this specimen as *Spiroichnus beerii.*

Remarks—The specimen was not available for our study. On the basis of published photographs (Beer, 1991; Mathur, 1983) we are of the opinion that the specimen is a biogenic structure and hence 'true fossil'.

Katnia singhi

Text-figures 48, 62, 63

Repository—Author's collection, Specimen no. LUTS-35; Tandon & Kumar, 1977, fig. 1.

Tandon and Kumar (1977) reported annelid remains from the ash-grey and white siltstone, shales and thinly laminated shaly brownish limestones of Rohtas Limestone Formation, Semri Group exposed in Katni, central India.

Remarks—Similar specimens from the same locality were made available by Dr S. Kumar to Prof. Glaessner and Dr Conway Morris for examination. According to Glaessner (1987, p. 354) "another somewhat similar fossil 'worm' has been described from the Lower Vindhyan of central India (Rohtas Formation of Semri Group, estimated age 900-1,000 Ma) as *Katnia singhi* Tandon & Kumar 1977. These fossils are compressions of tightly wound clusters, about 20 mm in diameter, of worm-like transversely annulated ribbons, just under 2 mm wide. Dr Kumar has kindly presented me with two specimens, one of which I have given to Dr Simon Conway Morris (Cambridge University) for further examination. In neither specimen could I ascertain the presence of head structures claimed by Dr Kumar for this species. They resemble illustrations of fossil oscillatorian cyanobacteria but are some 20-25 times larger". A similar view was expressed by Conway Morris (1989, fig. 2B, p. 85), wherein he has considered them flattened carbonaceous ribbons or sheets perhaps representing one or more eukaryotic groups such as brown algae.

Since, the holotype was not available for study, it is an *inaccessotype specimen.* One of us (Sharma), however, could see a photograph of another specimen which looks similar to oscillatorian filament (Text-figure 63). Thus, we agree with the assessment of Glaessner (1987) and C. Morris (1989). The fossils are 'true fossil' of plant affinity.

Vindhyavasinia nisrai

Text-figure 54

Repository—Author's collection, Specimen no. LUTS-34; Tandon & Kumar, 1977, figs 2, 3.

Tandon and Kumar (1977) reported a single laterally preserved specimen belonging to class Insecta in ash grey siltstone of Katni, Rohtas Formation, Semri Group, Vindhyan Supergroup, and designated it as *Vindhyavasinia misrai* with the following description: "In lateral view body elongate, subquadrate, differentiated into head, thorax, and abdomen, length 2.75 mm, height 1.42 mm; head broadly oval, probably hypognathus, broad dorsally, narrow ventrally, eye indistinct, below the middle of the antero-lateral margin of a head very short finely segmented, antena-like structure present just below it a short, narrow downwardly curved probosis." Besides, these major organs of an insect various other organs like leg, mouth, thorax were also discussed by the authors.

Maithy (1990, p. 26) considered *V. misrai* similar to *Krishnania* Sahni & Srivastava (1954). Maithy and Shukla (1984b) had earlier considered *Krishnania* a junior synonym of *Chuaria*.

Remarks—Since, the holotype of *V. misrai* was not available for restudy, it is an *inaccessotype specimen*. One of us (Sharma) had an opportunity on an earlier occasion to see the specimen and feel convinced that the specimen illustrated in Tandon and Kumar (1977, figs 2, 3) is a specimen of *Chuaria* preserved in fragments. Thus, we agree with Maithy (1990) that the fossil is not that of an insect but of *Chuaria (Krishnania)*. It is a 'true fossil' requiring reassessment of taxonomic affinity.

TRACE FOSSILS

Chordoichnus latouchei Mathur

Text-figure 55

Repository—Geological Survey of India, Calcutta, Specimen no. not known; La Touche, 1902; Vredenburg, 1908 (emended); Mathur, 1983, pl. 1, fig. 1.

La Touche (1902) reported a structure on red sandstone collected from Marwar Group exposed in Jodhpur area, Rajasthan and assigned a non-biological origin. Later, Vredenburg (1908) suggested an organic origin. Mathur (1983) after a restudy described and designated the specimen as *Chordoichnus latouchei*. It is a relief cast on the surface of a sandstone consisting of lobate swellings with finger-like terminations. No indication is given of its origin and affinity.

Remarks—The repository records of the specimen described by La Touche (1902) at GSI,. Calcutta bear a temporary number K1/963. It is presently misplaced and could not be examined. The specimen now designated as *Chordoichnus latouchei* has been figured in Vredenburg (1908), Pascoe (1958, vol. II, p. 516) and Mathur (1983, pl. 1, fig. 1). Its origin and affinity are not known. Thus, it is difficult to confirm it's biogenic nature untill further study of the specimen and place this form under "no comments" category.

1. Trace fossils

Pl. 10, figs 6, 7

Repository—Geological Survey of India, Calcutta, Specimen no. not known; Vredenburg, 1908; Mathur, 1983, pl. 2, fig. 3.

Vredenburg (1908) described hypichnal ridges probably casts of burrow in a slab of shaly sandstone from Lilgar in Raisen District, Madhya Pradesh. Mathur (1983) expressed a similar view for this and remarked that they are trace fossils.

Remarks—These structures are present on the specimen no. GSI-8968 which is a fine grained maroon coloured sandstone. On one surface of this specimen, number of structures are present. Some of these structures, present in thin vener of shaly material, have been reported as trace fossils by Vredenburg (1908) and Mathur (1983). These fine linear structures of few centimeters in length are 30 in number, mostly present on the bedding plane. Some of them are alligned with cracks in the sandstone. Some of the features which are not well preserved apparently resemble the cephalon and pygidium of an ?arthropod. Some other structures are circular to ovoidal with a thin filament like tail. The composition of mineral in the trails are different from the host rock. In all probability the rock slab holds evidence of extensive biogenic activity. The forms are not identifiable. Thus, they are 'true ichnofossils' whose taxonomic position is problematic.

2. Trace fossils

Pl. 5, figs 1-5

Repository—Geological Survey of India, Calcutta, Specimen nos. 18355, 18356, 18357; Verma & Prasad, 1968, figs 1-3; Misra & Misra, 1982; Das, 1987, figs 1-3.

Verma and Prasad (1968) described trace fossils in the Bhander Limestone of the Upper Vindhyans in Bankuiyan area, Rewa District, Madhya Pradesh. Three new species of trace fossils—*Bostrichophyton bankuiyanensis*, *Rouaulita rewanensis* (from Repachinia Group) and *Tasmanadia dasii* (from Pascichinia Group) proposed in this paper represent movement and grazing traces of organisms. The same specimens have been again described by Das (1987, figs 1-3) without any additional information.

Similar objects have also been reported by Misra and Misra (1982).

Remarks—Linear markings occuring on a weathered limestone slab (Specimen no. GSI 18355) were identified as trace fossil —***Bostrichophyton bankuiyanensis*** by Verma and Prasad (1968). In addition, the distinct linear markings, a second order of markings which are comparatively faint, are also present; unoriented cross laminations cut across these markings and are present at short intervals. These have sharp margins. Such features appear to be the crawling traces of worms and are placed in the 'true fossil' category.

A smooth bilobate trail (Specimen no. GSI-18356) is present on a black weathered limestone slab with some stylolite markings. Trail has maximum length of about 100 mm and width 15 mm and more close to be a biogenic drag made by some worm as supported by its wavy nature. There are also other trace movements (Specimen no. GSI 18357) on the weathered limestone. Significant ones are the linear traces on the smooth surface. The traces show non parallel pairs with pointed margins. They are suggestive of movements by animal in different directions as some times seen in the traces of arthropods.

Thus, even though, all the three traces are present on weathered surface and we do not know the top and bottom of these rock specimens on which the traces are present. Their morphological features suggest biogenic origin. Hence, all the three specimens are unquestionably 'true fossil'.

3. Trace fossils

Text-figure 23

Repository—Not mentioned. Shivarudrappa, 1981, pl. 1, fig. 1.

Shivarudrappa (1981) reported a few cresent-shaped structures which have been compared with *Fondinichnia*—feeding burrow from the upper bedding plane of the ripple marked quartzite near Dodguni in Karnataka. Each semicircular structure is slightly superimposed on the other and measures from 2 to 12 cm in width. The author considers that due to the absence of a central canal their comparsion with Zoophycus is not tenable, but still he considered them as trace fossil of evolved forms and consequently suggested an younger age for Dodguni chert.

Remarks—We could not examine the specimen. There are large number of stromatolites in the carbonate layers just above the quartzite in the Dodguni chert locality (Srinivasan *et al.*, 1989 and Venkatachala *et al.*, 1990) and the semicircular structures with superimposed layering described by Shivarudrappa (1981) could be parts of stromatolite. The stromatolite bearing dolomite has been silicified at places and similar structures can be observed on weathered surfaces of silicified dolomites. They are apparently broken algal mats. Besides, radiometric dates indicate that these beds are older than 2.6 billion years when even metazoa had not evolved, thus the occurrence of movement or resting traces of evolved forms cannot be explained. We consider these features as 'dubiofossil'.

4. Trace fossil

Pl. 8, figs 6, 8

Repository—Not mentioned. Maithy *et al.*; 1986, fig. 2.

Maithy *et al.* (1986) described 'trace fossil' from Murli Sandstone Formation (Kaimur Group) of Murlipahar. This is an elongated cylindrical structure measuring 5 cm in length with a central ridge and rows of deep furrows and circular on either side of the ridges. The trace fossil may be referred to as annelid traces.

Remarks—The authors have not mentioned any repository or specimen number. But this specimen

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PLATE 9

(Scale in figs 1-6, 1 div. = 1 cm & 7 = 5 cm and 8 = 1 mm)

1. *Medusinites* sp. cf. *M. asteroides* of Mathur & Shanker, 1990, note both the cast and mould of *M. asteroides* with outer ring, Specimen no. GSI-20310.

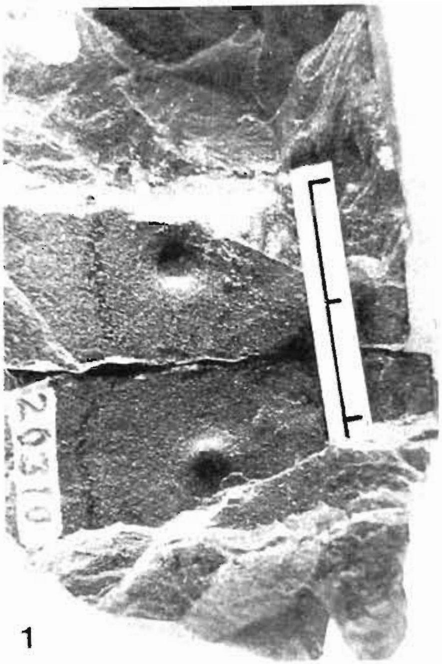
2, 4. *Tirasiana* sp. of Mathur & Shanker, 1990 note the characteristic tripartite organisation of specimens with small central tubercle, Specimen no. GSI-20308 and 20309.

3. *Beltanella* sp. cf. *B. gilesi* of Mathur & Shanker, 1990, note the smooth central disc with narrow rim preserved in convex hyporelief, Specimen no. GSI-20311.

5. *Beltanelliformis* sp. cf. *B. brunsae* of Mathur & Shanker, 1989, note the botton-shaped structure on the bedding plane with convex hyporelief, Specimen no GSI-20282.

6. *Gordia* sp. cf. *G. marina* of Mathur & Shanker, 1989. The ichnofossil is present in deepest portion of the trough of the folded specimen, note that this ichnofossil does not cross itself, Specimen no. GSI-20284.

7, 8. Commonly observable structure on the thin vener of clacite on Rohtas area. These structures are variously described as *Longfengshania chopanensis, Longfengshania stipitata* and Krishnanid forms. Infact all such features are 'non-fossil', Specimen no. BSIP-36794. Specimens marked with arrow are enlarged in fig. 8 showing characteristic feature.



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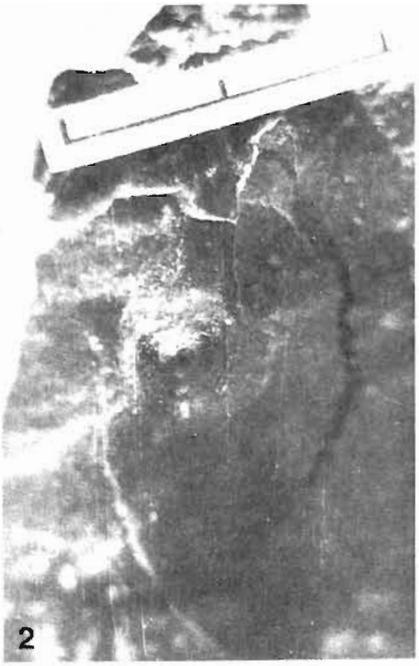
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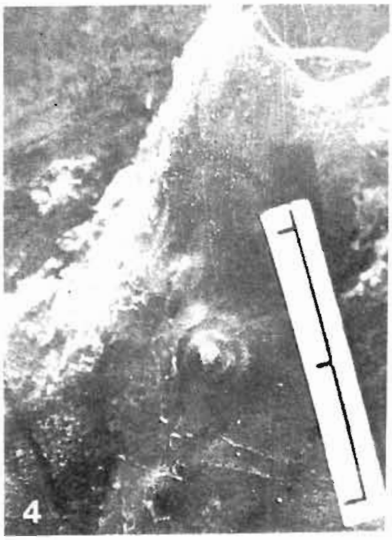
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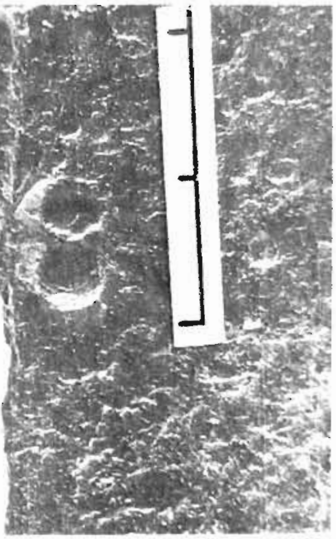
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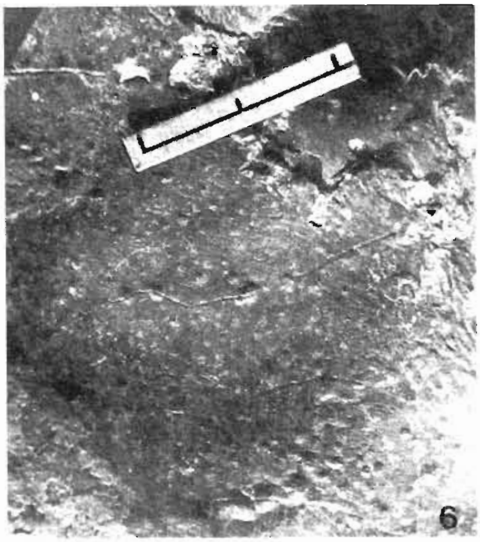
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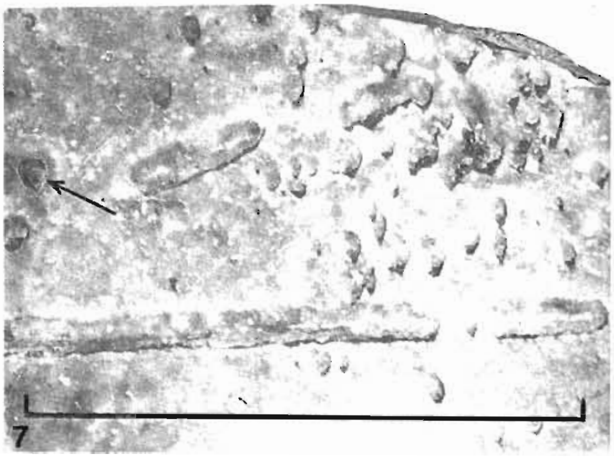
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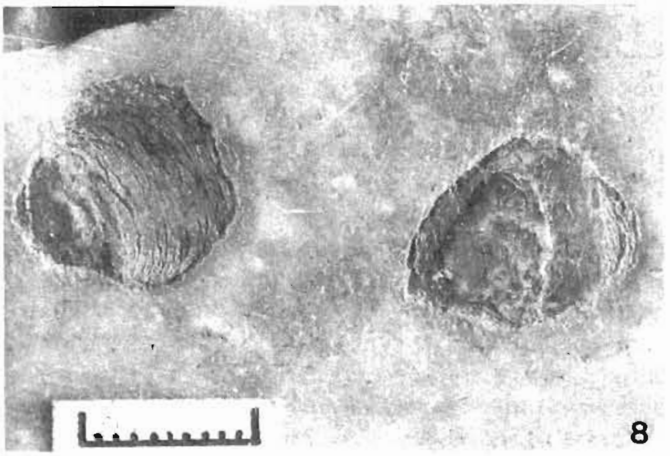
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PLATE 9

was located in BSIP repository and bears specimen no. 35858. It is a yellow coloured sandstone covered by a number of linear cylindrical structures. These structures with 'V'-shaped cross section are similar to cast of Sun cracks. We consider all these structures including the one illustrated by Maithy *et al.* (1986) as 'non-fossil'.

5. Trace fossils

Text-figures 1, 10, 13, 14, 34

Repository—Not mentioned. Das *et al.*, 1987, pl. 1, figs 1-3; pl. 2, figs 1-3.

Trace fossils *Acanthichnus* Hitchcock 1858, *Bostrichophyton* Squinabol 1890, *Onisocoidichnus* Brady 1949, *Protovirgularia* M'Coy 1850 and *Tasmandia* Chapman 1920 were reported by Das *et al.* (1987; pl. 1, figs 1-3; pl. 2, figs 1-3) without any description from Bankuiyan area, Rewa District, Madhya Pradesh.

Remarks—It was not possible to re-examine the assemblage in the absence of repository details. The illustrations are not of good quality and do not show the characters mentioned in the text. True trace fossils are known from the area (see Verma & Prasad, 1968; Das, 1987). A specimen from the same area exhibiting crawling traces was made available for examination by one of the authors (Moitra). It is possible that the trace fossils illustrated by Das *et al.* (1987) are of biogenic origin.

6. Trace fossils

Pl. 10, fig. 4

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 18/4031; Shukla & Sharma, 1990, pl. 2, figs 8, 9.

Shukla and Sharma (1990) described trace fossils from the contact of Suket shales and Morwan Sandstone Formation near Amarpura Ghat area on the Rampura-Gandhisagar Road. Since, the paper of Shukla and Sharma (1990) mainly dealt with the age implications of palaeobiological remains, no detailed account of trace fossil was given.

Remarks—Trace fossils (Ripichnia) are preserved in Morwan Sandstone, the lowermost part of the Kaimur Group in the area, with convex epirelief and exogenic in origin. Varied forms are reported such as meandering, straight, 'U' and 'C'-shaped tracks. Some of them have annulations. They form circular or crescent-shaped filling in the host lithology. While synaeresis cracks show a distinct 'V' shaped filling. Hence, we consider the structures described by Shukla and Sharma (1990, pl. 2, figs. 8, 9) as 'true fossil'.

1. Burrow

Text-figures 33, 38a, 38b

Repository—Not mentioned; Misra & Awasthi, 1962, figs 7, 8, 9, 10, 15

Misra and Awasthi (1962) described vertically aligned layered conical structures from Rohtas Limestone, Semri Group. These are triangular in cross section and have irregular to triangular lid. Discussing the two possible alternative origins, viz., wash out structures and organic burrow they favoured an organic burrow origin and cited the comments of Prof. F. Howell in support of their view. Prof. Howell (*In* Misra & Awasthi, 1962, p. 769) believed that they may be burrows of worms that were ancestors of Hyolithidae, some of which have triangular cross section.

Remarks—Absence of repository and specimen number permitted only evaluation based on photographs and the description available in the original paper. The conical, triangular structures are filled with coarser sediments which was later silicified (see Misra & Awasthi, 1962, p. 768, 769). It is possible that vertically-oriented tubular openings were produced by burrowing of soft sediments which were later filled with coarse sediments. The causative organism is yet to be known, still it's biogenecity is beyond doubt and we consider them authentic records of worm burrow.

2. Burrow

Text-figure 2

Repository—Not mentioned. Sarkar, 1974, figs 4A-D.

Sarkar (1974, figs 4A-D) reported different types of burrows from brown and grey laminated or massive limestone of Maihar and Satna areas. The burrows are slightly raised ridges, mostly sheet-like straight to sinuous, irregular to 'V'-shaped and in some cases haphazardly oriented.

Remarks—The original specimens were not available for study. Hence, the evaluation is based on photographic illustrations. The illustrations (Sarkar, 1974, pl. 4, fig. A) and text-figure (pl. 4, fig. D) show that these burrows have spindle-shaped structure in cross section. We do not know of any animal which would form such a burrow. They appear more similar to shrinkage cracks/crack fillings. Hence, we place them in the 'non-fossil' category.

3. Burrow

Text-figure· 27

Repository—Not mentioned. Sisodiya & Jain, 1984, pl. 1, figs 1, 2.

Dwelling traces (Domichnia) comparable to *Ophiomorpha* were recorded from Kaimur Sandstone exposed west of Besla in Mandsaur District, Madhya Pradesh by Sisodiya and Jain (1984, pl. 1, figs 1, 2). Burrows are up to 25 cm in length and 7 mm in diameter. These forms are supposed to have been formed by the borings of probably *Lithotrya*-type of Arthropoda, or belonging to the group of *Skolithos* (Sisodiya & Jain, 1984).

Remarks—Absence of repository details permitted evaluation only on the basis of photographs and description. The conical shape of structures proved by cross section, mineral filling of material other than the host rock, confirms the observation of Sisodiya and Jain (1984) that the structures belong to domichnia group and may have formed by animals probably belonging to the group of *Skolithos*. They are considered 'true ichnofossil'.

Burrows and bioturbations

Repository—Indian Institute of Technology, Kharagpur, Specimen nos. LBSM—99, 100, 101, 105, 107, 110, Chakrabarti, 1990, figs 3-10, 13-22.

Chakrabarti (1990) has recorded evidences of biogenic activity from the Bhander Group of rocks exposed near Maihar, central India. These signatures include burrows and bioturbations associated with long and curved scratch markings and 'bean-shaped' or 'Lozenge' shaped projections. The burrows are of Monocraterion and Diplocraterion types, the scratch markings and other features are considered as dubiotraces by Chakrabarti (1990).

Remarks—Chakrabarti (1990) studied burrows and bioturbations from the Bhander Group of rocks in petrographic thin sections, polished longitudinal sections and by radiography. This comprehensive study has helped to understand the biogenicity and syngenecity of these structures. The burrows and microburrows with large diameter are considered 'true fossils'. The affinity and biogenicity of the other structures such as drag or scratch markings, 'Lozenge' or 'bean-seed'-shaped bodies and 'mud volcano-like structures' can not be properly established and are considered 'dubiofossils'.

Worm tracks

Text-figure 6

Repository—Not mentioned. Misra & Awasthi, 1962, fig. 15.

Misra and Awasthi (1962) recorded worm tracks from Kaimur Quartzitic Sandstone of Rampura area and also in the Sirbu shales of Maihar area. Considering the poor state of preservation they are not assigned to any particular genus.

Remarks—In the absence of repository the material could not be examined. However, evaluation of figure of the object suggests more similarity with typical synaresis cracks rather than the worm tracks and burrows. Therefore, the record is considered here as 'non-fossil'.

Aulichnites

Pl. 10, figs 1, 2

Repository—Not mentioned. Banerjee & Narain, 1976, figs 3, 4a.

Two different trails occurring in positive epirelief are described as *Aulichnites* Fenton & Fenton. They occur on jointed and fractured thinly laminated sandy layers of a thickly bedded micaceous sandstone (subgreywacke of Psammite Member of Lower Tal Formation). One trail is 0.5-1 cm deep, 0.3 cm wide and 60 cm long, while the other is 3.75 cm wide, 1 cm deep and 40-75 cm long. Both these records of traces movement have been clubed into one group *Aulichnites*.

Remarks—Identification of *Aulichnites* (Banerjee & Narain, 1976, figs 3, 5) is based on field studies only, hence the specimens were not deposited in a repository. The fossils occur on jointed and fractured rock. Dr Banerjee (Pers. communication) also informed that the fragile nature of rock does not permit collection of more specimens. He kindly provided a photograph of the trail marking which is convincing and permits an evaluation of the habit, shape and size of the traces. We consider these structure as 'true trace fossil'.

Fusiform structures

Text-figure 18

Repository—Not mentioned. Bose, 1977, fig. 1.

Bose (1977, fig. 1) reported fusiform structures from Sullavai Sandstone occurring in the stream *Sudda vagu* 4 km north of Chelvai in the Warangal District, Andhra Pradesh. These are present on single bedding plane. He favoured a biogenic origin for these structures on the basis of the absence of (i) mud-crack in the vicinity of fusiform structures, (ii) pelitic layer at the bottom of the spindles, and (iii) easily separable spindles which occur as discrete bodies in the host quartzite and considered them sand filled worm burrows.

Remarks—Absence of repository details restricted us to evaluate these structures on the basis of photographic illustrations. Such structures which are common in Precambrian sedimentary sequences are often mistaken for trace fossils. Similar structures are also frequently present in younger sediments (see Collinson & Thomson, 1982, figs 9, 8b, p. 141). La Touche (1898) also recorded such structures from Vindhyan Sandstone near Jodhpur (available in GSI repository, Calcutta bearing temporary numbers K-1/963) and reproduced here in Plate 6, figure 7. The fusiform shape of these structures in planar view indicates possibilities of their being casts of typical synaeresis cracks. These structures are made up of rounded quartz grains which explain their easy separability from the host rocks. These are nonbiogenic structures. We consider them as 'non-fossil'.

Muniaichnus Kumar

Text-figure 12

Repository—Not mentioned. Kumar, 1978b, pl. 2, fig. 1.

Kumar (1978b) reported a specimen which is 16 cm long and 0.6-10 cm wide meandering structure with a broader end on one side and a tapering end on the other side under a new genus *Muniaichnus* from the glauconitic sandstone of Kheinjua Formation. He compared and considered these structures different from *Gordia* Emmons 1844 and *Cochlichnus* Hitchcock 1859.

Remarks—Evaluation of illustration of the form, in the absence of repository details, shows it's close similarity with weathered ripple mark or mud crack similar to the ones described as *Manchuriophycus* (Endo, 1933). In a personal discussion (with Sharma) Dr Kumar agreed that these structures may be the mud cracks and hence categorised as a 'non-fossil'.

Skolithos/Westites kymorensis Saxena

Text-figure 8

Repository—Geology Department, Sagar University, Specimen no. GNS-V/K. 101; Saxena, 1980, fig. 1.

Saxena (1980) described a trace fossil *Westites kymorensis* of class *Repichnia* from glauconitic sandstone of Kaimur Group from the foot-hills opposite A.C.C. factory, Kymore, Madhya Pradesh. It has a maximum length of 10 cm and a diameter of 0.8 cm. These horizontal traces have 'Y'-shaped branching which sometimes intersects, forming tunnels and channels, filled with other minerals, the burrows and channels are generally thickest in the middle of each branch, or at the point of intersections, they further gradually taper. The structures occur as ridges rising in relief on the sandstone with sharp relief.

Remarks—A perusal of the description by Saxena (1980) highlights their maximum length and diameter, 'Y' shaped branching and their presence as a relief on the sandstone slab. All these features indicate characteristics of a mud crack particularly the 'Y' shaped branching which in all probability suggest a typical 120° angle made by sun cracking of loosely consolidated sand. These cracks subsequently have widened due to weathering and filled with later sediments. It is a common knowledge that such Sun cracks start widening from the junction and taper toward the edge. Thus, the shape, size and branching pattern of these structures described by Saxena (1980) indicate their origin through mud cracking and hence considered 'non-fossil'.

Asteriradiatus karauliensis Mathur

Text-figure 17

Repository—Not mentioned. Mathur, 1982, fig. 2A.

'Mathur (1982, fig. 2A) named a new genus of trace fossil, *Asteriradiatus karauliensis* as a star-shaped trace fossil from Karauli Quartzite, Rewa Group, Panna District, Madhya Pradesh without any description or diagnostic features.

Remarks—The specimen was not available for restudy. The photographs are also of not adequate quality for fine assessment; diagnosis or description has not been given and the illustrated specimen has been named as the holotype. The genus is thus invalid. It could be possible that the structure is formed by cracking in the loosely packed sediments and may be lenticular and radiating shrinkage crack.

PLATE 10 →

(Scale in fig. 4 = 200 μm fig. 5 = 2 cm and fig. 7 = 1 cm)

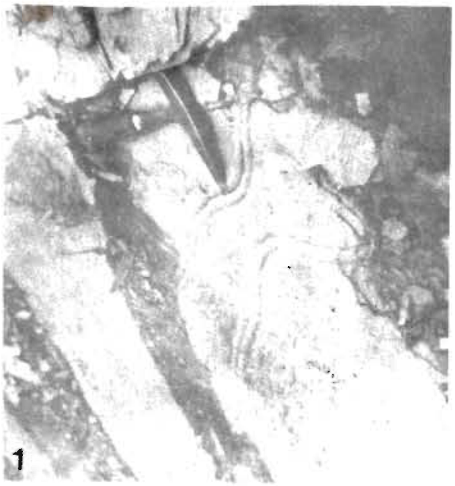
1, 2. *Aulichnites* sp. Banerjee & Narayan 1976, note the movement traces on thinly laminated sandy layers.

3. *Ramapuraea vindhyanensis* Maithy & Shukla 1984, Specimen no. BSIP-27341.

4. Trace fossil Shukla & Sharma 1990, note a meandering structure on the sandstone surface, Specimen no. BSIP-18/4031.

5. *Coleolella billingsi* Maithy & Shukla 1984a, a calcitic ring-shaped structure which is a by product of maceration and hence considered non-fossil, Specimen no. BSIP-8001.

6, 7. Trace fossils Vredenburg 1908, note the object marked with arrow in fig. 6 which is enlarged in fig. 7 giving the impression of probable arthropod, Specimen no. GSI-8968.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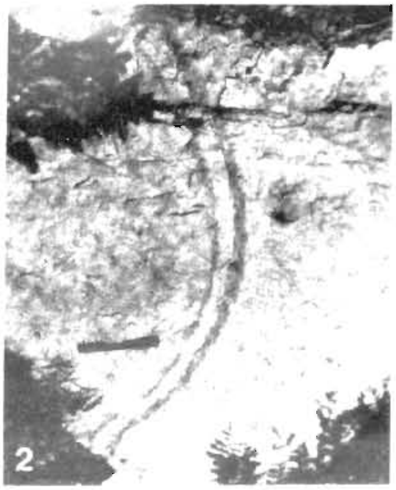
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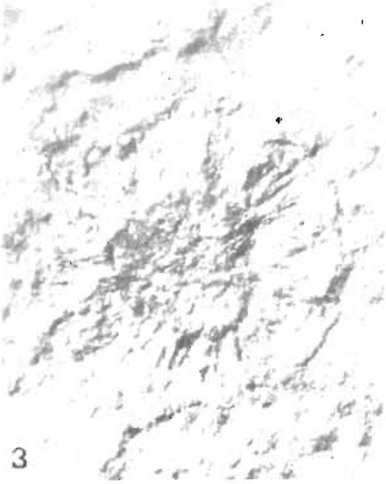
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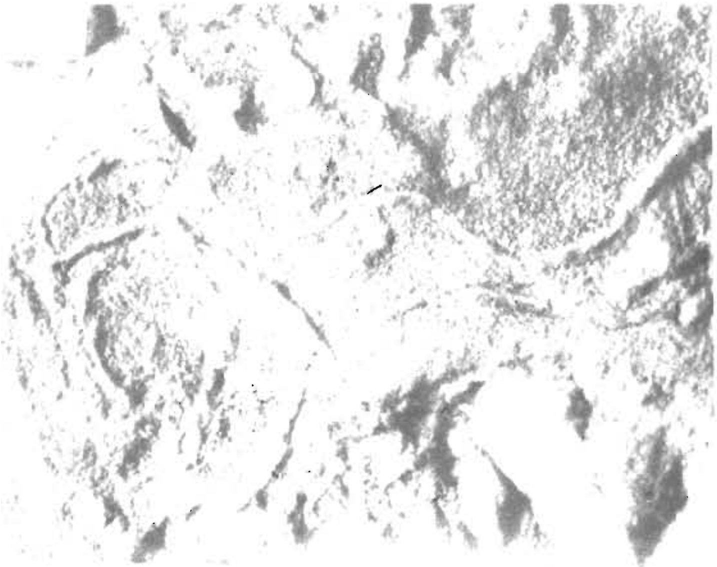
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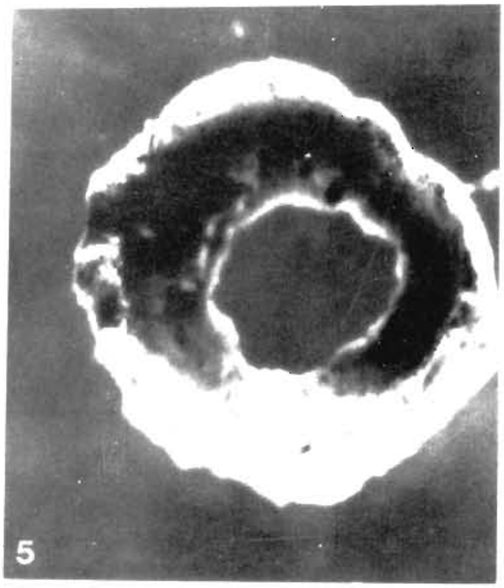
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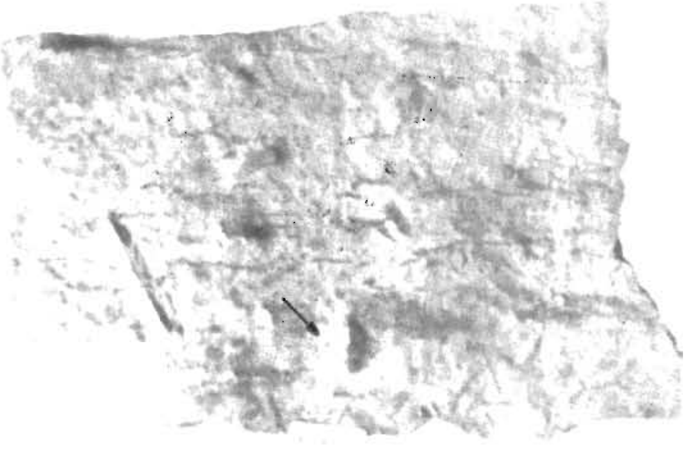
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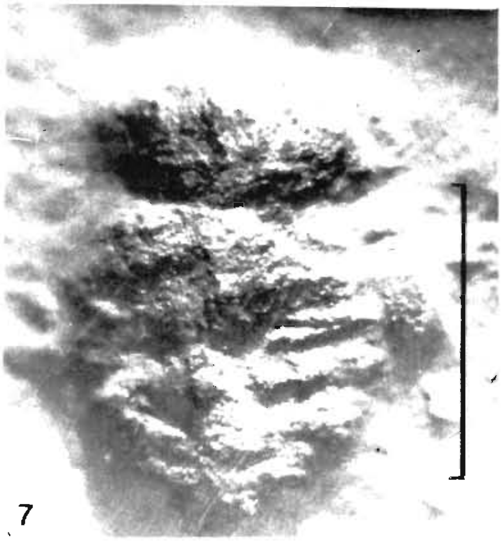
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PLATE 10

Sonjiwashmam basuhariensis **Mathur**

Text-figure 11

Repository—Not mentioned. Mathur, 1982, fig. 2B.

Mathur (1982) named *Sonjiwashmam basuhariensis* a new genus of trace fossil from Basuhari Sandstone, Semri Group, Mirzapur District, Uttar Pradesh without any description or diagnosis.

Remarks—The genus is invalid because of the lack of diagnosis and description. Evaluation of the photograph suggests that the meandering structures with smooth margin and uniform breadth could be the movement trace or *Manchuriophycus* Endo. Therefore, the structure described by Mathur (1982, fig. 2B) is considered as 'dubiofossil'.

Bhanrerichnus damohensis **Mathur & Verma**

Text-figure 9

Repository—Not mentioned. Mathur & Verma, 1983, fig. 1.

Mathur and Verma (1983) described an ichnofossil *Bhanrerichnus damohensis* from Maihar Quartzite Formation of Bhander Group, Vindhyan Supergroup in Damoh District, Madhya Pradesh. This form occurs on the slab of a very dusky red-purple quartz arenite which is ripple marked. This trace fossil has convex hyporelief which is reverse 'L'-shaped with four pairs of symmetrically placed lobes without any ornamentation or marking on any part of the structure. Its formation is attributed to resting and burrowing organisms of uncertain affinity.

Remarks—The form could not be re-examined due to absence of repository details. The illustration provided by the authors is also not clear. However, the complex nature of this (?) trace fossil is difficult to interpret. Its presence on rippled surface and the symmetrical nature of the lobes suggest that it is a 'problematic' fossil which can not be assigned to any known phylum, hence, considered 'dubiofossil'.

Puratanichnus bijawarensis **Mathur**

Text-figure 41

Repository—Geology Department, Sagar University, Specimen no. not known; Mathur & Chattri, 1986, pl. 1, fig. 1A, B.

Mathur and Chattri (1986, pl. 1, fig. 1A, B) reported trails of probable annelid worms on the Amronia quartzite of the Bijawar Group (~ 2,500 Ma) Both the trails are figured (pl. 1, fig. 1A, B), one of them belong to epichnial groove while the other to hypichnial ridge. Both the trails are about 10 cm long and 5-8 mm wide. In a communication to Mathur and Chattri (1986) Prof. Seilacher commented that these structures could be inorganic sedimentary features known as *Manchuriophycus* Endo. However, Mathur and Chattri (1986) still consider them biogenic.

Remarks—Two linear ridged corrugated structures are considered as *Puratanichnus bijawarensis* by Mathur and Chattri (1986). This is one of the few reports claiming the presence of metazoan trail from such an old sedimentary rock. Metazoan records are not known prior to Neo Proterozoic. It is difficult to explain records of Metazoan activity in 2,500 Ma old sediments. In a personal discussion with us, Dr Mathur informed that the specimen was lost when it was loaned to an Indian expert for re-examination.

Evaluation of photographs suggests that the ridge on these structure appear similar to 'Tool marks' of continuous category of Collinson and Thompson (1982, p. 42). Such tool marks can be formed when any material is carried by a flow on a soft surface leaving a mark either in the form of a groove or when filled in as a groove cast. In the present context the groove casts are preserved. We thus, infer that the structure described by Mathur and Chattri (1986) are 'non-fossil'.

Ichnofossils

Text-figure 66

Repository—Not mentioned. Mukherjee *et al.*, 1987, figs 1, 2.

Mukherjee *et al.* (1987) described a wide variety of ichnofossils from the Gulcheru Quartzite of Lower Cuddapah sequence. Particularly rich ichnocoenoses have been observed in a dirty brown quartzite occuring at 120 m from the base of the unit. Casts of horizontal burrows are most common. In the branching types, the horizontal burrows are commonly petal-shaped or spindle-shaped casts with minor grooves. In the cast portion horizontal burrows are 3-10 mm wide, 1-3.9 cm long and 2-6 mm high. A few petal-shaped casts show median depression of 1 mm width. In the groove portion the horizontal burrows are 3-9 mm wide, 1.2-2.9 cm long and 1-2 mm deep. The burrow fills are made up of coarser quartzite with a coating of cherry brown ferruginous clay. In higher horizons the assemblage gets diversified to successively include vertically paired burrows.

Remarks—These structures are closely comparable with the subaqueous shrinkage cracks discussed in Collinson and Thompson (1982, p-141). Such petal shaped/fusiform/or lobed structures are common on the basal face of the sandstone beds and often confused with trace fossils. The structures are considered 'non-fossil'

Ichnogenus Type 'A' & Type 'B'

Pl. 8, figs 5, 7

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 36113; Maithy & Babu, 1988, pl. 2, figs 6, 7.

Maithy and Babu (1988; pl. 2, figs 6, 7) described sinuous to meandering trails which are elongated structures with pointed ends. They are 1-2 mm wide (mainly from 1.5-2.0 mm) and up to 0.5 mm deep or raised, showing arcuately transverse annulated appearance with constrictions or septa, chiefly at 2-4 mm intervals. Occasionally a rounded circular scar is preserved in the centre of the septae.

Ichnofossil type B (Maithy & Babu, 1988; pl. 2; fig. 7) is paired structure with circular marks with a interspacing gap of 1-4 mm from one another, arranged over a length up to 10 cm in a linear fashion. The paired circular markings are less than 1 mm in dimension. Linear distance between two pairs is less than 2 mm.

Remarks—The meandering structures with negative relief (Maithy & Babu, 1988, figs 6, 7) can be observed on the three centimeter thick fine grained sandstone slab. The negative relief indicates that they are present on the upper bedding surface. The irregular or radiating patterns with trails sometimes cross cutting one another is also clearly observable. Neither the septae nor the circular scar in between the septae are noticed. These structures taper downward in the longitudinal section of the bed forming a 'V'-shape; which is a characteristic feature of mud cracking common in the mudstones interbedded with sandstone. Similar mud cracks/synaeresis cracks have been considered earlier also as trace fossils (see discussion in Cloud, 1968, p. 29; Glaessner, 1969, p. 370; Hofmann, 1971, pp. 36-39) and hence, the structure described by Maithy and Babu (1988, pl. 2, figs 6, 7) are considered synaeresis cracks and categorised as 'non-fossil'.

Gordia sp. cf. *G. marina* Emmons

Pl. 9, fig. 6

Repository—Geological Survey of India, Calcutta, Specimen no. 20284; Mathur & Shanker, 1989, pl. 1, fig. 3B.

Mathur and Shanker (1989) described few impressions on the bedding plane of shales of the Krol Formation of Nainital Syncline. These are horizontal long and slender burrows with no branching. Burrows are smooth with a diameter of approximately 1 mm. The biogenicity of *Gordia* has been questioned by Azmi and Tewari (1991), who considered them to be negative impression produced by the sharp axial hinge of the folds which appear as or the "median of *Pteridinium*" on one surface and as *Gordia* on the other.

Remarks—Examination of *Gordia* reported by Mathur and Shanker (1989, pl. 1, fig. 3B) shows that it is present in the deepest part of the trough of the folded specimen. But we did not find any *Pteridinium*-like structure on it's reverse or in the counter part which was also available. Therefore, we believe that the structures reported by Mathur and Shanker (1989) are different from those that Azmi and Tewari (1991) have discussed. The burrows reported by Mathur and Shanker (1989) do not cross itself and hence cannot be referred to *Gordia*. The closest comparison could be with *Helminthopsis* or *Helmintheidichnites* (G. M. Narbonne, In Pers communication G. Kumar also agrees with this interpretation). Hence, we consider *Gordia* reported by Mathur and Shanker (1989, pl. 1, fig. 3B) as an authentic movement trace representing metazoan activity at that time but its taxonomic position needs revision. This specimen is considered 'true fossil'.

TRILOBITID AND EURYPTERID FORMS

Repository—Not mentioned. Dubey, 1982.

Dubey (1982) reported the presence of Trilobitid and Eurypterid remains from the Ganurgarh shales and Nagod Limestone located about 5 km north of Rewa. Due to absence of any description, illustration or repository details, we are only listing this record without any comment. The record should be kept pending till more details are available. For the present review we include it under 'no comment category'.

ENIGMATIC FORMS

This category includes forms whose affinity is yet not firmly established.

Allatheca Missarzhevsky

Pl. 8, figs 3, 4

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 8001; Maithy & Shukla, 1984a, pl. 1, figs 5-8.

Maithy and Shukla (1984a) described four specimens of circular to subcircular calcitic bodies of 200-500 μm in size from the Suket Shale Formation of Vindhyan Supergroup around Ramapura, Madhya Pradesh. Their top is raised and bottom flattened, with smooth to reticulate surface; reticulation are pronounced and raised. Maithy and

Shukla (1984a) compared the specimen with *Allatheca* sp. of Tommotian age.

Remarks—These four specimens of *Allatheca* sp. are much smaller in size than the known species of *Allatheca* which are 20-30 times larger. A restudy indicates that they are siliceous rounded grains with brown coloured garnet or calcitic material attached to them. They appear as tubercles as illustrated in fig. 5 of Maithy and Shukla (1984a) and an attached brown covering in the illustration at fig. 7 of Maithy and Shukla (1984a). Since these grains are part of the original rock they could be of varying composition either silicious or calcitic. Monotonously arranged growth lines, folds, ribs and septa in the initial part of the shell which are diagnostic features of *Allatheca* are not recognised on these specimens. Hence, we consider them as 'non-fossil'

Coleolella billingsi Missarzhevesky

Pl. 10, fig. 5

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 8001; Maithy & Shukla, 1984a, pl. 1, fig. 9.

Maithy and Shukla (1984a) described a specimen recovered from Suket Shale, Semri Group, Ramapura, Mandsaur, Madhya Pradesh as a ring-like calcitic fossil, measuring up to 530 μm in dimension with a ± 450 μm central hollow area and a ± 30 μm broad border, whose surface is smooth to rugose. It was compared with Tommotian record of the operculum of *Coleolella billingsi*.

Remarks—The restudy indicates that this is a fragile, calcitic ring-shaped structure which is comparable, in over all morphology, to the discoid structures with asymmetrically placed opening, which were considered as the operculum of *Coleolella billingsi* by Missarzhevesky (1981). But it has a smaller diameter (530 μm) in comparison to *Coleolella billingsi* (1.8 mm) of Missarzhevesky (1981). Maithy and Shukla (1984a) have used sodium bicarbonate as a dispersing agent to pulverize the shale. The resultant product often assumes a ring shape. The fragile nature of the specimen further supports the conclusion that the ring-like structure is inorganic in origin and has been formed through the process discussed earlier. Hence, it is considered 'non-fossil'.

Beltanelliformis sp. cf. *B. brunsae*

Pl. 9, fig. 5

Repository—Geological Survey of India, Calcutta, Specimen no. 20282; Mathur & Shanker, 1989, pl. 1, figs 1, 3A; Shanker & Mathur, 1991, pl. 2, fig. 1.

Mathur and Shanker (1989) and Shanker and Mathur (1991) described *Beltanelliformis* from Krol Formation of Nainital syncline as a button-shaped circular to semicircular structure with convex hyporelief and 1.5 to 6 mm diameter. The specimens present vary from smooth, flat disc to more strongly convex forms with faint marginal grooves. The biogenicity, and the age of beds bearing these specimens have been doubted (Misra, 1990, p. 114; Bhatt & Mathur, 1990b, p. 117; Azmi & Tewari, 1991).

Remarks—Button-shaped structures similar to those reported by Mathur and Shanker (1989) are invariably found associated with Ediacaran fossils. Their phylogeny is still not known. Re-examination indicates that these structures are present sporadically and in clusters having two size maxima. Since, both negative as well as positive reliefs are present on the same specimen they do not appear to be rain prints. These forms may be related to *Chuaria* (Misra, 1992) as their size range compares with the size maxima of *Chuaria* in Iran. At present it is difficult to conclude on it's biogenicity and phyletic position. They are considered 'dubiofossil'

Beltanelloides Sokolov

Pl. 6, fig. 8

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 35956; Maithy, 1990, pl. 1, fig. 3.

Maithy (1990) recorded a specimen which has fine surface thickenings with raised portion in the centre. He assigned it to "Chuarid remains" and termed it *Beltanelloides* as recommended by Sokolov (1965 *in* Maithy, 1990) for such forms. No other details like diagnostic character, horizon or site of collection are given in the text.

Remarks—The specimen no. 35956 collected form Dabua locality, Rohtas Formation, Semri Group does not have any carbonaceous structure or impression similar to that described by Maithy (1990, pl. 1, fig. 3). Similar structures have been observed on a thin vener of fibrous calcite which is of secondary origin. This structure is similar to *'Longfengsahnia'* (*Longfengshania*) reported by Maithy and Babu (1988) which has already been considered 'non-fossil' in the present review. Hence, the structure described by Maithy (1990, pl. 1, fig. 3) is considered here as 'non-fossil'.

Krishnanid forms

Pl. 2, figs 5, 6

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen nos. 36109, 36919, 36576; Maithy, 1990, pl. 2, figs 3-5.

Oval to oblong structure with single stipe or appendage, from Rohtas Limestone Formation, Semri Group, were described by Maithy (1990, pl. 2, figs 3-5) as Krishnanid forms. The body has two distinct parts. The distal structure is foliate, circular-oval or elongate oval in shape, occasionally with a distinct border on the margin. Surface of the specimen may be smooth or with thickenings. Narrow stalk like structures emerge out from the contracted point of foliate structure. When the stalk gets detached it leaves a rounded scar on the proximal end of the foliate part indicating the point of attachment.

Remarks—This form (Maithy, 1990; pl. 2, fig. 4) has already been described by Maithy and Babu (1988, pl. 2, fig. 5) as '*Longfengsahnia*' (*Longfengshania*) *chopanensis* which has been considered as a 'non-fossil' (see discussion under heading *Longfengshania chopanensis*).

It was observed on the specimen no. 35919 instead of 36109 as mentioned in the text by Maithy (1990; pl. 2, fig. 3). The rock on which the ?fossils are found is a thinly bedded carbonate and the ?fossils are present on a thin vener of recrystallised calcite. Such structures are also described by Maithy and Babu (1988; pl. 2, fig. 4) as '*Longfengsahnia*' (*Longfengshania*) *chopanensis* and considered 'non-fossil' in the present review (see discussion under *Longfengshania chopanensis* specimen no. 36111).

It is present on the specimen no. 36516 instead of specimen no. 36576 as mentioned in the paper by Maithy (1990; pl. 2, fig. 5). This specimen is presently not available in the museum, hence could not be studied. Evaluation is based on photographic illustrations only. These forms look similar to other forms reported by Maithy (1990; pl. 2, fig. 3) and Maithy and Babu (1988; pl. 2, figs 4, 5) from the same locality. These later forms have been considered 'non-fossil' in the present review. Hence, the objects described by Maithy (1990; pl. 2, figs 3-5) as Krishnanid forms are considered as 'non-fossil'.

cf. *Podolithus* sp.

Pl. 4, figs 6, 7

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen no. 25222/273; Shukla & Sharma, 1990, pl. 2, figs 3-7.

Shukla and Sharma (1990) described two types of holdfast like structures from the buff coloured Suket shales of Semri Group. The specimen illustrated in Plate 4, figure 6 is compared with *Podolithus* sp. This fossil is characterised by a lobed appearance (or conical volcano shape) and is up to 2 mm large, the concave scar is interpreted as stem attachment point. The other type of holdfast (Pl. 4, fig. 7) is nearly flat with clearly demarcated central area and lobed outer margins. This form is compared to similar holdfast described as "Type 3" of Palmer and Palmer (1977).

Remarks—The characters observed by Shukla and Sharma (1990) are present in the specimens. The well organised morphology and close similarity with known holdfast-like structure lends support to it's biogenic nature. Though, their presence in such old sediments needs further explanation. This occurrence needs to be substantiated with more finds. These structures are presently classed under 'dubiofossil'.

Misraea

Pl. 7, figs 6-8

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow, Specimen nos. 35820-35825; Maithy & Babu, 1986, pl. 1, figs 1-7; Text-figure 1A-C.

Maithy and Babu (1986) described two species of *Misraea* from the Chopan Porcellanite Formation and Rohtas Limestone Formation, Semri Group exposed in Mirzapur, Uttar Pradesh. These structures are "triangular to subtriangular in outline, surface is convexly raised with an inner concave hollow depression with the body margin curved inward forming a rim; the rim area is either smooth or with transverse thickenings. The over all outline of the fossils smooth or with distinct perforations." On the basis of body margin two species of *Misraea* were recognised, viz., *M. vindhyanensis* and *M. psilata*.

Remarks—It is difficult to comment on these specimens which are preserved in formaldehyde. They have lost their characters and are fragile. The similar state of preservation in two different lithologies, viz., porcellanite and limestone needs explanation. To avoid breaking these fragile specimens we have refrained from rephotographing them and have used photographs prepared from the negatives available with the repository. At present we prefer not to comment on these specimens.

Organic plates

Organic plates have been recorded by Venkatachala and Rawat (1972, 1973) and Vishwanathaiah *et al.* (1975, 1976, 1977) from the Dharwar, Kaladgi and Bhima sediments. These are enigmatic fossils needing further study.

SUMMARY AND CONCLUSION

In all, 79 types of metaphyte and metazoan remains have been recorded from the Precambrian sediments of India. These records are often not accompanied with essential details, viz., lithology of the area, thickness, lateral extent and details about upper and lower contact of the fossil bearing litho-unit. New genera have been instituted without proper description and comparison, even photographs of the reported specimen is often replaced by sketches. Though, it is obligatory to deposit the holotype in a repository and provide details of the specimen number, etc. authors have also not followed this necessary practice.

Fossils are often reported in various symposia/conference abstracts without sufficient details. Pending publication of detailed account such reports can be considered only tentative. To eliminate such short comings, not only the authors, but also the referees as well as journals should insist on bare minimum facts, viz., "accurate location data, a measured section, sample collection levels, the name of the person collecting the sample, the time when the trip was undertaken and all such related matters which help in establishing the authenticity of material being reported" (Radhakrishna, 1989). The detailed account of palaeontological material should accompany the description of each reported form, viz., size, magnification of photograph, repository, number of samples analysed and how many of them proved to be yielding, frequency of the specimen/s, etc. Strict adherance to ICBN or ICZN and complete list of comparison with existing genera or species while reporting new genera or species is a necessary pre-requisite for establishing validity of the report.

Other aspects which will help to eliminate the inadvertent mistakes include discussions, on the age of the bed vis-a-vis the recorded fossil and on the palaeoecology and the depositional environment of fossil assemblage. These discussions would help to judge the fossil assemblage more critically and avoid reporting fossils merely on the basis of apparent morphological similarity.

In this review we have tried to reassess the taxonomic validity and biogenicity of the reported forms and hope that it will help future workers not only to know about all the records at one place but also provide them sufficient background to reassess their validity. This re-evaluation indicates that amongst the metaphyte and metazoan records from India 26 categorise as 'true fossil', 18 as 'dubiofossil', and 28 as 'non fossil'. It has not been possible to 7 records due to insufficient information available on them. Amongst the metaphyte/metazoa considered authentic the oldest records are from 1,000 Ma. Most of the remaining authentic fossil records are from Cryogenian (850-650 Ma) or younger age. Thus, we may conclude that organisms may have achieved multicellularity around 1,000 Ma ago but proliferation of multicellular organisms took place only at the Terminal Precambrian.

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Palaeobiology of Vindhyan

P. K. Maithy

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Biological remains and their activities, preserved in the form of ichnofossils and organosedimentary structures in the Vindhyan sediments are critically reviewed. The diversification of metaphytes and metazoans and their significance in biostratigraphy have also been discussed.

Key-words—Palaeobiology, Stromatolites, Metaphytes, Metazoans, Precambrian, Vindhyan, India.

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सारांश

विन्ध्य का पुराजैविक अध्ययन

प्रभात कुमार माइती

विन्ध्य अवसादों में इक्नोजीवाश्मों एवं कार्बनिक-अवसादी संरचनाओं के रूप में परिरक्षित जैविक अवशेषों तथा उनकी गतिविधियों की विवेचना की गई है। मेटाफ़ाइटीयों एवं मेटाजीवीयों में विभिन्नता तथा जैवस्तरविन्यास मे इनकी उपयोगिता की भी समीक्षा की गई है।

THE Vindhyan Supergroup of central India exhibits well developed stratified formations of sandstones, shales and limestones covering a thickness over ca. 4,200 meter of Middle to Late Proterozoic age (1,400-570 Ma). The Vindhyan Basin has an exposed area of 1,04,000 square kilometers from Sasaram and Rohtas in western Bihar to Chittorgarh on the Aravallis, with the exception of a central track in Bundelkhand, where a large area of Vindhyan rocks is covered by the Deccan trap and Gangetic alluvium. The maximum breadth of the outcrop is seen between Agra and Neemuch.

The Vindhyan Supergroup is composed of two distinct facies of deposits: a marine, calcareous and argillaceous, characteristically developed in the lower part and the other almost exclusively arenaceous of fluviatile or estuarine deposits forming the upper part. The shale, limestone and sandstone strata show very little structural displacement or disturbance of their primeval characters. They have preserved almost their original horizontality of deposition over wide areas. The shales have not developed cleavages nor have the limestones undergone any degree of crystallisation.

The Vindhyan sandstones throughout their thickness provide evidence of shallow water deposition in their often occurring ripple-marked and sun-cracked surfaces and their conspicuous current bedding or diagonal lamination characters which point shallow agitated water of the coast near the mouth of rivers and the constantly changing velocity and direction of its currents.

The Vindhyan geological succession, is as under

GROUP	FORMATION
	Dholpur Shale
	Balwan Limestone
	Maihar Sandstone
	Sirbu Shale
Bhander	Lower Bhander Sandstone
	Nagod Limestone
	Ganurgarh Shale
	Upper Rewa Sandstone
	Jhiri Shale
Rewa	Lower Rewa Sandstone
	Panna Shale
	Mangesar Sandstone

Four Decades of Indian Palaeobotany
Editors : B. S Venkatachala & H. P. Singh
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Kaimur	Bijaigarh Shale Gurma Sandstone Rohtas Limestone Basuhari Sandstone Bargawan Limestone
Semri	Kheinjua Shale Chopan Porcellanite Kajrahat Limestone Arangi Shale Patherwa Sandstone & Conglomerates

RADIOMETRIC DATES

On the basis of Potassium-Argon dates Vinograd *et al.* (1964) estimated the age of glauconitic sandstone as 1,110 ± 60 Ma. According to them, the age of the Lower Vindhyan (Semri) Group is between 1,100 to 1,400 Ma. Accordingly the Kaimur sequence has been estimated to range from 910 to 940 Ma by these authors. Rubidium-Strontium dates of the Vindhyan rocks by Crawford and Compston (1970) have revealed that the age of this unit extends over a very long period ranging from atleast 1,200 or possibly 1,400 Ma to perhaps 550 Ma or even later. According to these authors the base of Upper Vindhyans is about 1,150 Ma or more. Pichamuthu (1971) has indicated that the base of the Vindhyan is probably 1,400 Ma and the Upper Kaimur about 910 Ma. No dates are available for fixing the upper age limit of the Vindhyans. Recently dating of Vindhyan has been done by the fission-tracks on the surface of an authigenic mineral glauconite (Srivastava *et al.*, 1983). Systematic dating work has been carried out in the eastern part (Srivastava, 1985, 1987; Srivastava *et al.*, 1985, 1988), western part (Srivastava & Rajagopalan, 1986a, 1987, 1990) and central part (Srivastava, 1987; Srivastava & Rajagopalan, 1985, 1986b, 1989a, b) of the Vindhyan Basin. This study has indicated that the glauconitic sandstone bed in Chopan area is of 1,155 Ma age and belongs to Kheinjua Formation of the Lower Vindhyan. The Vindhyan deposits in Chitrakut area represent a condensed sequence with age ranging from 1,030 to 1,380 Ma and the pellet limestone forms the marker bed for this area indicating the age of 1,100-1,200 Ma. Glauconitic sandstone bed around Rawatbhata area, Rajasthan belonging to Upper Rewa Sandstone Formation is 740 Ma and that of Karauli area of Lower Bhander Sandstone Formation is 650 Ma.

BIOLOGICAL LIFE AND ITS ACTIVITIES

During the last four decades biological life and its relics of activities have been reported from the Vindhyan sequence from time to time. Most of these records are being reported only in the last two decades.

The evidences of the biological life are preserved as detailed below:

Structural biological remains
(i) Macrofossils
(ii) Organic-walled microfossils

Activities of biological life
(i) Ichnofossils
(ii) Organosedimentary structures, viz., stromatolites

Structural Biological Remains

The reported Vindhyan fossils mostly leaves an interpretation hurdle regarding their biologic origin. Living systems are identified by showing their capabilities for reproduction, mutation and reproduction of the mutation. These properties are not readily identifiable in most primitive fossils. Therefore, the under mentioned criteria are used jointly whenever possible for establishing biologic origin of the remains.

1. Evidences for the performance of vital functions: (a) fossilisation while performing a vital activity; for example, cell division. (b) morphologic or material evidence attributable to a biologic function.
2. Cellular differentiation combined with morphologic consistency
3. Similarities to living or known extinct forms
4. Morphological diversity in an assemblage
5. Chemical evidences.

These criteria are best applicable to higher biologic taxa, however, this facility is greatly reduced when dealing with the ancient biological remains of Vindhyan time. Not only the fossils are less abundant and little known, but they are also morphologically more primitive. We still have no unequivocal way of knowing whether the large impressions of discs or the micro-sized spheroids seen in a thin section or maceration represent the remains of reproducing mutating entities or are physiochemical structures. Therefore, the confirmation for the biologic origin is when we can observe a variety of associated, morphologically distinct remains resembling the modern. As such observations have not been possible in most of the Vindhyan remains, therefore, many of them still remain to be probably biogenic.

MACROBIOTA

Macrofossil records are tabulated below:

Year	Author	Macrofossils	Horizon & Locality
1950	Misra & Bhatnagar	Carbonaceous discs	Rohtas Limestone, Banjari
1954	Sahni & Shrivastava	*Krishnania*	Suket Shale, Ramapura
1966	Prakash	?Brachiopod	Kajrahat Limestone, Chopan
1977	Tandon & Kumar	*Katnia* & *Vindhyania*	Rohtas Limestone, Katni
1982	Sisodiya	? Jelly fish	Rohtas Limestone, Mandsor.
1982	Mathur	*Chuaria circularis* *Tawuia suketensis* *Vindhyania jonesi*	Suket Shale, Ramapura
1984	Maithy	Jelly fish	Suket Shale, Ramapura
1984a	Maithy & Shukla	*Chuaria minima*	Suket Shale, Ramapura
1984b	Maithy & Shukla	*Ramapuraea*	Suket Shale, Ramapura
1986	Maithy *et al.*	*Sekwia* & Trace fossil,	Rohtas Limestone, Rohtas
1986	Maithy & Babu	*Misraea*	Chopan Porcellanite, Chopan
1988	Maithy & Babu	*Tawuia, Chuaria* cf. *Sekwia* *Longfengsahnia*	Rohtas Limestone, Chopan
1989	Maithy	Middle Proterozoic & Ediacaran biota	Rohtas & Dholpura Shale

Pre-vendian Forms

Misraea Maithy & Babu 1986

Spongy body fossil, keel form, outline triangular to subtriangular, surface convexly raised with inner hollow dipression, body margin curved inwardly forming a rim, rim area smooth or with transverse thickenings.

Remarks—The affinities of this body fossil is debatable and with the present state of knowledge, it is extremely difficult to assign them to any known group of Metazoan. In their overall organisation it is speculated that they may be the portions of bivalved forms. If this is true, then these forms are the oldest Metazoan.

Misraea vindhyanensis Maithy & Babu 1986

Occurrence—Chopan Porcellanite, Chopan, Mirzapur District (Maithy *et al.*, 1986, p. 225, pl. 1, figs 1-6).

Misraea psilata Maithy & Babu 1986

Occurrence—Rohtas Limestone, east of Markundi (Maithy *et al.*, p. 225, pl. 1, fig. 7).

Chuaria Walcott 1899

Platyspermic carbonaceous discs, commonly solitary, rarely in pairs, circular or oval in outline, measuring 2-4 mm, surface smooth or with marginal thickenings; occasionally in some specimens a small central area is marked indicating possible opening. Isolated specimens show exine with fine puncta referable to *Orygmatosphaeridium* Timofeev.

Remarks—Though, these circular disc-like forms are known from the Proterozoic succession nearly a century ago, but their biological nature is still enigmatic. Recently Maithy and Shukla (1984) considered them to be the cyst structures belonging to algae. Contrary to this Sun (1986) expressed the view that they may be discs enclosing Cyanophyceae algae.

Chuaria minima Maithy & Shukla 1984

Synonymy

For list of synonymy, see Maithy and Shukla, 1984, pp. 146-147.

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1984); Rohtas Formation, Son Valley (Maithy & Babu, 1988, p. 586, pl. 1, figs 1-2).

Shoubsienia Xing 1979

Oval to dumbbell-shaped carbonaceous macrobiota, measuring 3-5 mm long and 2-3 mm broad, one end broader than the other, margin entire, surface smooth.

Remarks—*Shoubsienia* Xing (in Du Rulin, 1982) represents oval planktonic forms allied to *Chuaria*.

Shoubsienia shoubsiensis Xing 1979

Synonymy

1984 *Chuaria minima* emend. Maithy & Shukla, partim p. 148, pl. 1, fig. 5.

Occurrence—Suket Shale, Ramapura, Madhya Pradesh; Rohtas Limestone, Murlipahar, Rohtas District.

Ramapuraea Maithy & Shukla 1984 emend.

Synonymy

1989 *Cyclomedusa* sp., Sprigg *in* Shukla, Venkatachala & Sharma, p. 1012, figs 3-4.

Emended diagnosis—Circular carbonised impressions with a distinct central circular area with numerous small compactly packed globular structures; outer area with several closely spaced fine dichotomising radial thickenings.

Ramapuraea vindhyanensis Maithy & Shukla, 1984

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1984, p. 213, pl. 1, figs 1-3).

Remarks—*Ramapuraea* is found associated with *Chuaria* Walcott. It differs from *Chuaria* in possessing distinct central area, which is compactly packed with several small globular structures (Pl. 1, fig. 2). Presence of number of globular structures raises doubt about its jelly fish affinity. In all probability, it compares with the members of the family Chlorococaceae, viz., *Chlorococum,* *Neochloris, Pulchrasphaera* and *Neospongiococcum*. Shukla *et al.* (1989, p. 102, figs 3-4) suggested its comparison with *Cyclomedusa* Sprigg. *Ramapuraea* in its size is much smaller than *Cyclomedusa*. Moreover the concentric circular thickenings around central zone characteristic for *Cyclomedusa* are absent.

Amjohrea **gen. nov.**

Diagnosis—Carbonised impression, outline circular with a large structureless inner body, covering half to three fourth of the overall body dimension; concentric and radial thickenings absent.

Genotype—Amjohrea rohtaseae sp. nov.

Comparison—Amjohrea gen. nov. is found associated with *Chuaria* and is characterised by its large size and with large inner body. *Ramapuraea* Maithy & Shukla 1984 differs from *Amjohrea* in being smaller and in having fine branched radial thickenings. *Sekwia* Hofmann 1981 distinguishes itself in the presence of raised inner body with globular structures. Moreover *Sekwia* is known from the Vendian strata.

Amjohrea rohtasae sp. nov.

Synonymy

1950 Carbonaceous disc-like bodies, Misra & Bhatnagar, p. 88, fig. 1.
1984 *Chuaria minima* emend. Maithy & Shukla, partim, Pl. 1, fig. 2.
1986 *Sekwia excentrica* Hofmann *in* Maithy, Narain & Sarkar, p. 1029, fig. 1.
1988 *Sekwia excentrica* Hofmann *in* Maithy & Babu, p. 586, pl. 1, figs 7-8; pl. 2, fig. 1.

Diagnosis—Carbonaceous impressions, circular to sub-circular measuring 10-40 mm; central area circular, covering nearly one half to three fourth area of the body. Surface thickenings absent. Marginal thickenings often preserved.

Holotype—Specimen no. BSIP 36862.

Locality—Murlipahar, Rohtas District, Rohtas Formation (Semri Group); Vindhyan, ± 1,000 Ma.

Occurrence—Rohtas Formation, Murlipahar, (Maithy *et al.*, 1986); and Chopan (Maithy & Babu, 1988).

Remarks—Misra and Bhatnagar (1950) reported black (carbonaceous) disc-like bodies, measuring 26 mm with a prominent border from the carbonaceous limestone beds of Rohtas Formation exposed in Banjari Quarry, Rohtas District. They considered them to be the plant remains. Maithy *et al.* (1986) reported large discs with inner body from the Rohtas Formation of Amjohre and referred them to *Sekwia* Hofmann. Subsequently, Maithy and Babu (1988) also reported similar forms the Rohtas Formation of Chopan under *Sekwia*. As pointed above that these Rohtas forms do not fit in the generic circumscription of *Sekwia* due to flat inner body, therefore, the previously described forms from the middle Proterozoic of Vindhyan are now transferred here to a new genus *Amjohrea*.

Tawuia **Hofmann 1979**
(in Hofmann & Aitken, 1979)

Carbonaceous impressions and compression, sausage-shaped, both ends rounded, surface smooth.

Remarks—Maithy and Babu (1988) recorded *Tawuia* and *Chuaria* together on the same rock specimen supporting their planktonic nature.

Tawuia dalaensis Hofmann 1979

Synonymy

1954 'Filament-like structure' Sahni & Shrivastava, p. 40, fig. 2.
1975 'Filament-like structure' Sahni, p. 293, fig. 2.
1984 Megascopic algal remains, Maithy, p. 5, fig. 5.
1984 *Chuaria minima* emend. Maithy & Shukla, Partim, p. 148, pl. 1, fig. 5.

Occurrence—Suket Shale, Ramapura (Maithy & Shukla, 1984, p. 213, pl. 1, fig. 4); Rohtas Limestone, Chopan (Maithy & Babu, 1988, p. 585, pl. 1, figs 1, 2).

Katnia **Tandon & Kumar 1977 emend.**

Emended diagnosis—Carbonaceous impressions of sausage-shape forms with distinct transverse partitions, ends rounded or pointed.

Holotype—Katnia singhii Tandon & Kumar 1977.

Remarks—Tandon and Kumar (1977) considered *Katnia* to be an annelid remain due to the presence of transverse partitions. However, this Middle Proterozoic macrobiota does not exhibit any other character by which it can be considered that they are like annelids. However, Glaessner (1987) expressed the views that *Katnia* may be large oscillatorean Cyanobacteria. Maithy (1990) opined that *Katnia* may be episodic remains of plankton blooms of mass encystment structures, i.e., algal in nature. This opinion now seems to be more justifiable as the specimens show close morphological similarity with *Tawuia* Hofmann except for the presence of transverse thickenings.

Katnia singhi Tandon & Kumar 1977

Occurrence—Rohtas Limestone, Semri Group, Tikaria about 2 km SW of Katni.

Katnia attenuata sp. nov.

Synonymy

1988 Ichnogenus : Type 'A' Maithy & Babu, p. 588, pl. II, figs 6 & 7.

Diagnosis—Elongated structure with both the ends attenuated, measuring 20-50 mm in length and 15-30 mm wide, transverse thickenings at an interval of 2-4 mm, each partitioned area may have a faint circular dipression.

Holotype—Specimen no. BSIP 36113.

Locality—Railway cutting near Saikhan Hill, Ghurma Shale, Kaimur Group.

Comparison—*Katnia singhii* Tandon & Kumar 1977 from Rohtas Limestone, Semri Group differs from *Katnia attenuata* in having blunt ends.

Grypania Walter, Oehler & Oehler 1976

Carbonised impression of linear unbranched filament, evenly curved, ends broken, surface smooth to finely granulate, no transverse septa perceptible.

Grypania spiralis Walter, Oehler & Oehler 1976

Synonymy :

1919 Spiral impression, Beer, p. 120, fig. 30.
1983 *Spiroichnus beeri* Mathur, p. 112, figs 1, 2.

Occurrence—Rohtas Formation; Murlipahar and Amjohre, Rohtas District.

Daltaenia Hofmann 1985

Slender, broadly curvilinear, untwisted ribbon-like structures of uniform submilimetric to milimetric width and centimetric length, apparent infrequent lateral branching.

Daltaenia mackenziensis Hofmann 1985

Synonymy :

1989 Megascopic sheet algae cf. *Vendotaenia* Gnilovaskaya *in* Shukla, Venkatachala & Sharma, p. 1012, figs 5-6.
1990 *Tyrastaenia* sp. Shukla & Sharma, pl. 3, fig. 1.

Occurrence—Suket Shale, Ramapura, Madhya Pradesh.

Remarks—The carbonaceous film claimed to be cf. *Vendotaenia* described by Shukla *et al.* (1989) do not conform to the diagnosis of *Vendotaenia* as the authors failed to isolate cellular material. Subsequently, Shukla and Sharma (1990) have transferred this specimen to *Tyrasotaenia* sp. The original specimens of *Tyrasotaenia* are unbranched. The figured specimen by Shukla and Sharma (1990) shows distinct branching, therefore, it compares with *Daltaenia* Hofmann and is synonymous.

Krishnania Sahni & Shrivastava 1954 emend. Maithy 1991

Carbonaceous biota comprising a foliate part and a parstem appearing stalk-like. Foliate part oval to circular in shape, surface smooth to structured.

Krishnania acuminata Sahni & Shrivastava 1954 emend. Maithy 1991

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Sahni & Shrivastava, 1954, p. 40, figs 2, 3); Rohtas, Katni (Tandon & Kumar, 1977, p. 127, fig. 2b, c); Rohtas, Murlipahar, Rohtas District (Maithy, 1991, figs 1-4).

→

PLATE 1

1. *Shouhsienia shouhsiensis* Xing, Specimen no. BSIP 36538; Amjohre, Bihar; Rohtas Formation, Semri Group.
2. *Ramapuraea vindhyanensis* Maithy & Shukla, Specimen no. BSIP 27341; Ramapura, Madhya Pradesh; Suket Shale Formation, Semri Group. × 10.
3. *Amjohrea rohtaseae* gen. et sp. nov., Specimen no. BSIP 36862; Murlipahar, Bihar; Rohtas Formation, Semri Group.
4. *Katnia attenuata* sp. nov., Specimen no. BSIP 36113; in railway cuttings 2 km WNW of Agori Khas railway station; Ghurma Shale Formation, Kaimur Group × Nat. size.
5. *Krishnania acuminata* emend. Maithy, Specimen no. BSIP 35968; Murlipahar, Bihar; Rohtas Formation, Semri Group.
6. *Cyclomedusa davidi* Sprigg, Specimen no. BSIP 36388; Bhavpura, Rajasthan; Dholpura Shale Formation, Bhander Group. × 1.
7. *Medusinites asteroides* Glaessner & Wade, Specimen no. BSIP 36392; Bhavpura, Rajasthan; Dholpura Shale Formation, Bhander Group. × 1.
8. *Nuia tandoni* (Maithy & Gupta) n. comb., Slide no. BSIP 5950; Mhow, Madhya Pradesh; Hinaoti Limestone, Semri Group. × 50.
9. *Biocatenoides sphaerula* Schopf, Slide no. BSIP 6590; West of Baisa, Madhya Pradesh; Nagod Limestone, Bhander Group. × 1000.
10. *Gloeocapsomorpha karauliensis*, Maithy & Mandal, Slide no. BSIP 5993; Near wall of Ranipura, South-east of Karauli; Semaria Shale, Bhander Group. × 1000.
11. *Aphanocapsaopsis sitholeyii* Maithy & Shukla, Slide no. BSIP 6587; Jurmani, Madhya Pradesh; Baghwar Shale, Semri Group. × 500.
12. *Vindhyacapsiopsis bhanderensis* Maithy & Mandal, Slide no. BSIP 6254; North of Karauli; Upper Bhander Sandstone, Bhander Group. × 500.
13. *Vetronostocale amoenum* Schopf & Blacic, Slide no. BSIP 9784-J27; Badanpur Limestone Quarry; Rohtas Limestone, Semri Group. × 1000.
14. *Bavlinella faveolata* Shepeleva; Slide no. BSIP 9791 052/2; Lilji nala, Madhya Pradesh; Nagod Limestone, Bhander Group. × 1000.
15. *Protosphaeridium volkovae* Maithy & Shukla; Slide no. BSIP 9783-W42; Sharda Devi Hill, Madhya Pradesh; Sirbu Shale, Bhander Group. × 1000.
16. *Lophosphaeridium jainii* Salujha *et al.*; Slide no. BSIP 9766-I 29; Sharda Devi Hill, Madhya Pradesh; Sirbu Shale, Bhander Group. × 1000.

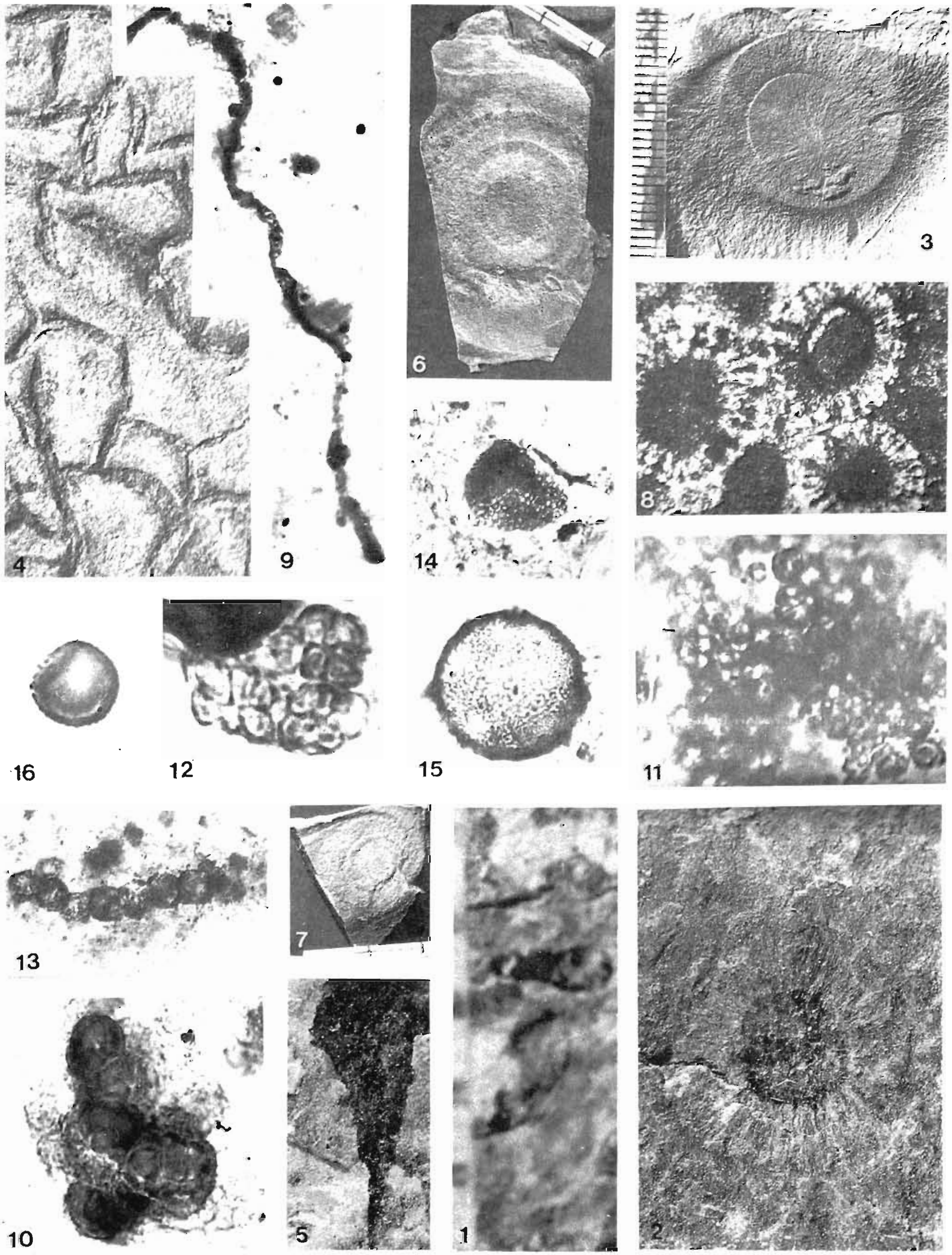

PLATE 1

Krishnania multistriata Maithy 1991

Occurrence—Rohtas, Baulia, Rohtas District (Maithy, 1991, figs 6-9).

Vendian Forms

Cyclomedusa Sprigg 1947

Outline subcircular, surface of disc with several to many concentric grooves separating slightly elevated area (rugae); their arrangement indicates an original conical shape at the center or in some species on most of the body. Many specimens show fine straight radial grooves.

Cyclomedusa davidi Sprigg 1947

Occurrence—Dholpura Shale, Bhavapura, Rajasthan (Maithy, 1989; Maithy *et al.*, 1992, figs 1-4).

Medusinites Glaessner & Wade 1966

Small, subcircular, discoidal bodies with central discs separated by deep circular groove from large outer ring with radius greater than central disc, there is a narrow marginal flange.

Medusinites asteroides (Sprigg) emend.
Glaessner & Wade 1966

Occurrence—Dholpura Shale, Bhavapura, Rajasthan (Maithy, 1989; Maithy *et al.*, 1991, figs 3-5).

Dickinsonia Sprigg 1947

Broad, flat with numerous short segments, anterior body, segments fused pre-orally along median line, segmental furrows depressed dorsally and ventrally.

cf. *Dickinsonia*

Occurrence—Dholpura Shale, Bhavapura, Rajasthan (Maithy 1989).

?Calcareous Algae

Nuia Maslov 1954

Remarks—According to Maslov (1954) *in* Johnson, 1966, p. 73) the thalli of *Nuia* develop calcareous cylinders with a distinct central duct. Numerous very fine calcareous plates or needles radiate in all directions from the central duct, giving a radial structure to the cylinders in cross section. The thalli may be straight or sinuous.

The systematic position of the genus is quite uncertain; superficially it looks like a small primitive dasyclad alga. However, the supposed primary branches consist of flattened blade-like plates of calcite instead of rounded needle-like or thread-like elements. Preservation is not characteristic of Dasycladaceae. Based on this character, Johnson (1966) suggested its structural closeness to *Microcodium* Glük, possibly a blue green algae.

Maithy and Gupta (1981) reported Archaeocyatha, *Ajacicyathus tandoni* from the Hinaoti Limestone Formation, Semri Group and *Tubocyathus vindhyanensis* from the Nagod Limestone Formation, Bhander Group. Zhuraleva (1986) has doubted their identification. The so-called reported forms of Archaeocyatha show similarity with *Nuia* Maslov, therefore, they have been transfered to this genus.

Nuia tandoni (Maithy & Gupta) n. comb.

Synonymy :
1981 *Ajacicyathus tandoni* Maithy & Gupta, p. 78, pl. 1, figs 1-3; text-fig. 1.

Emended diagnosis—Thalli develop as a very small calcareous cylinder (measuring up to 300 μm) with a distinct central duct. Numerous very fine calcareous plates or needles radiate in all directions from the central duct giving a radial structure to the cylinders in cross section. Thalli may be straight or sinuous.

Occurrence—1.4 km N, 46° W of Mhow (82° 38′ 00″ : 38° 23′ 80″); Hinaoti Limestone, Semri Group.

Nuia vindhyanensis (Maithy & Gupta) n. comb.

Synonymy :
1981 *Tubocyathus vindhyanensis* Maithy & Gupta, p. 79, pl. 1, figs 4-7; text-fig. 2.

Emended diagnosis—Thallus develops as a small calcareous cylinder (measuring up to 225 μm) with a distinct central duct. Numerous anastomosing very fine, calcareous plates or needles radiate in all directions from central duct giving a radial structure to cylinder in cross section. The thalli may be straight or sinuous.

Occurrence—1.1 km S, 55°E of Kulwarn (83°00′00″ : 38°08′00″); Nagod Limestone, Semri Group.

ORGANIC-WALLED MICROFOSSILS

Acid maceration and thin section have allowed the identification of organic-walled microfossils belonging to Sphaeromorphs (Acritarch), filamentous taxa (Nematomorphs), spherical cells arranged in colonies (Synaptomorphs) and vase-shaped microfossils. Their previous records from Vindhyans are summarised below:

Year	Author	Locality	Group
1953	Sitholey *et al.*	Ramapura	Semri
1968	Maithy	Ramapura	Semri
1971	Salujha, Rehman & Arora	Sidhi	Semri & Kaimur

1971	Salujha, Rehman & Rawat	Kota-Karauli	Rewa & Bhander
1972	Shrivastava	Ramapura	Semri
1974	Sarkar	Maihar	Bhander
1977	Maithy & Shukla	Ramapura	Semri
1978	Kumar	Chopan	Semri
1983	Maithy & Gupta	Chandrehi	Semri, Rewa & Bhander
1983	Maithy & Mandal	Karauli-Sapotra	Semri & Bhander
1983	McMenamin, Kumar & Awramik	Chopan	Semri
1983a	Nautiyal	Chopan	Semri
1983b	Nautiyal	Chopan	Semri
1984	Nautiyal	Sangrampur	Tirohan
1988	Maithy & Babu	Chopan	Semri & Kaimur
1989	Maithy & Meena	Satna, Maihar	Bhander

Biocatenoides Schopf 1968

Uniseriate, unbranched chains of rod-shaped coccoid cells, less than 1 μm, broad chains up to 200 μm long or more, straight or recurved.

Biocatenoides sphaerula Schopf 1968

Synonymy :

1989 *Gunflintia minuta* Barghoorn 1965 *in* Maithy & Meena, p. 181, pl. 1, figs 5-7, 10-19.

Occurrence—Nagod Limestone, Chandrehi, Madhya Pradesh (Maithy & Gupta, 1983, p. 158, pl. 1, fig. 1); Nagod Limestone, Satna, Madhya Pradesh (Maithy & Meena, 1989, p. 181, pl. 1, figs 5-7, 10-19).

Remarks—The specimens described by Maithy and Meena (1989) under *Gunflintia minuta* do not conform to the generic circumscription of *Gunflintia*. Rather it conforms to that of *Biocatenoides*.

Huronispora

Solitary cells, spherical, exine smooth to micro-reticulate, enveloping sheath absent.

Remarks—Sarkar (1974, figs 5B-E) recorded *Huronispora* sp. from the Bhander Limestone. The presence of biota in calcitic facies is questionable. Further, from the photographs it is possible to ascertain that the recorded biota are mineral crystals belonging to apatite. This can be best seen in fig. 5D, which she has claimed to be spheroids with double wall.

Huronispora microreticulata Barghoorn 1965

Synonymy

1982 *Kheinjuasphaera vulgaris* McMenamin, Kumar & Awramik, pp. 267-269, fig. 13C-E.

1982 *Melasmatosphaera media* Hofmann, 1986 in McMenamin, Kumar & Awramik, p. 261, fig. 10I.

Occurrence—Kanwari Shale and Chorhat Sandstone formations, Chandrehi, Madhya Pradesh (Maithy & Gupta, 1983, p. 159, pl. 1, figs 2, 3); Fawn Limestone, Kheinjua Formation, Salkhan, Mirzapur District (McMenamin *et al.*, 1983).

Remarks—McMenamin *et al.* (1983) instituted a new genus *Kheinjuasphaera* characterised by solitary cells-like unit without an enveloping sheath. This form in its organisation cannot be differentiated from *Huronispora microreticulata* Barghoorn 1965 (in Barghoorn & Tyler, 1965) except for the fact that in some cases the size of the cells are larger. The use of size criteria to institute a new genus is not justified. These authors have also mentioned that the smaller cells of *Kheinjuasphaera* cannot be differentiated from *Huronispora reticulata*. It is proposed to consider both the forms alike and synonymous.

The solitary specimen of *Melasmatopshaera magna* Hofmann described by McMenamin *et al.* (1985) in the Fawn Limestone is also like *Huronispora microreticulata*. Therefore, the same is also placed here under the synonymy list.

Huronispora psilata Barghoorn 1965

Occurrence—Kanwari Shale, Koldha, Ramapura Shale, Hinoti Limestone and Kokah Shale formations, Chandrehi, Madhya Pradesh (Maithy & Gupta, 1983, p. 159, pl. 1, fig. 4).

Eosynechococcus Hofmann 1976

Loosely associated group of cells, rod-shaped to ellipsoidal, occasionally slightly curved, cells lack individual sheath.

Eosynechococcus isolatus McMenamin, Kumar & Awramik 1983

Occurrence—Fawn Limestone, Salkhan, Mirzapur District (McMenamin *et al.*, 1983, p. 258, fig. 5E-G).

Sphaerophycus Schopf 1968

Cells solitary or in pairs, less frequently arranged in loosely associated groups, cells encompassed by sheath.

Sphaerophycus medium Horodyski & Donaldson, 1980

Occurrence—Panna Shale, Rewa Group, South of Sapotra (Maithy & Mandal, 1983, p. 131, pl. 2, figs 13-15).

Sphaerophycus parvum Schopf 1968

Occurrence—Baghwar Shale (Semri Group) and Nagod Limestone (Bhander Group), Chandrehi, Madhya Pradesh (Maithy & Gupta, 1983, p. 159, pl. 1, figs 5, 6); Nagod Limestone and Sirbu Shale, Satna, Maihar (Maithy & Meena, 1989, p. 181, pl. 1, fig. 30).

Gloeodiniopsis Schopf 1968

Spheroids and ellipsoids with single, double or multiple outlines, solitary or in groups of 2, 3, 4 or up to 8 individuals within a common envelope.

Gloeodiniopsis lamellosa (Schopf) Knoll & Golubic 1979

Occurrence—Panna Shale, Rewa Group, Bapoti Village, Rajasthan (Maithy & Mandal, 1983, p. 133, pl. 1, figs 5, 6; pl. 2, fig. 30).

Tetraphycus **Oehler 1977**

Cells spherical, psilate, arranged in planar tetrads, cross tetrads, diads and cluster of cells isolated or in groups surrounded by amorphous matrix.

Tetraphycus congregatus McMenamin, Kumar & Awramik 1983

Occurrence—Kheinjua Formation, Salkhan Hills, Mirzapur (McMenamin *et al.*, 1983, p. 265, fig. 13A, B).

Myxococcoides **Schopf 1968**

Colony of compactly arranged spheroidal cells, individual cells and colony ensheathed.

Myxococcoides ramapuraensis Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, p. 177, pl. 1, fig. 2).

Myxococcoides magnus Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, p. 178, pl.1, fig. 3).

Myxococcoides psilata Maithy & Mandal 1983

Occurrence—Panna Shale, Bapoti, Rajasthan (Maithy *et al.*, 1983, p. 131, pl. 1, fig. 1); Rohtas Limestone, Simirawal Shale, Nagod Limestone and Sirbu Shale, Satna-Maihar (Maithy & Meena, 1989, p. 181, pl. 1, fig. 21).

Palaeoanacystis **Schopf 1968**

Cells spheroidal, without sheath, clumped together to form a colony, colony enveloped by an organic sheath.

Palaeoanacystis suketensis Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977, p. 178, pl. 1. fig. 4).

Palaeoanacystis punctatus Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977, p. 178, pl. 1, fig. 5).

Palaeoanacystis verucosus Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977, p. 178, pl. 1, fig. 6).

Palaeoanacystis reticulatus Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977, p. 178, pl. 1, fig. 7).

Gloeocapsomorpha **Zalessky 1916**

Spheroidal cells aggregated in a colony, daughter colonies and cells within the colony ensheathed by a non-lamellated amorphous sheath, division of cells common and occurs in two directions.

Gloeocapsomorpha karauliensis Maithy & Mandal 1982

Occurrence—Semaria Shale, Bhander; Ranipura, Rajasthan (Maithy *et al.*, 1983, p. 133, pl. 1, fig. 4).

Glenobotrydion **Schopf 1968**

Cells with prominent circular small organic structure on inner surface of cell walls, cells loosely associated, groups of many hundred cells in pseudofilamentous organisation, enclosed in a sheath, sheath non-lamellated.

Glenobotrydion aenigmatis Schopf 1968

Synonymy :

1983 *Myxococcoides minor* Schopf 1968 *in* McMenamin, Kumar & Awramik, p. 258, fig. 5E-G.

Occurrence—Fawn Limestone, Salkhan, Mirzapur (McMenamin *et al.*, 1983, p. 260, fig. 5D-F).

Remarks—McMenamin *et al.* (1983, p. 260) have stated "Individual cells of *G. aenigmatis* and *Myxococcoides minor* are indistinguishable; we refer to cells organized into pseudofilaments as *C. aenigmatis*". The figured photograph and details of *Myxococcoides minor* by McMenamin *et al.* (1983, p. 258.) does not compare with the generic circumscription of *Myxococcoides*, i.e., cells organised in a globular colony and enclosed in a sheath. The Salkhan *Myxococcoides* described by McMenamin *et al.* (1983) is arranged in clustured groups and not in a globular colony, therefore, it is proposed here to transfer it to *Glenobotrydion*.

Nanococcus **Oehler 1977**

Cells spheroidal to ellipsoidal, generally loosely and randomly arranged, generally colony enclosed in formless organic matrix.

Nanococcus vulgaris Oehler 1977

Occurrence—Panna shale, Rewa Group near Bapoti, Rajasthan (Maithy & Mandal, p. 131, pl. 1, fig. 2).

Corymbococcus Awramik & Barghoorn 1977

Spheroidal or ellipsoidal cells aggregated in colonies, colonies enclosed in common unlamellated sheath; individual cells non-ensheathed.

Corymbococcus vindhyanensis Maithy & Mandal 1983

Occurrence—Upper Bhander Sandstone, Ranipura, Rajasthan (Maithy & Mandal, 1983, p. 131, pl. 1, fig. 3; pl. 2, fig. 12).

Corymbococcus sp. Maithy & Gupta 1983

Occurrence—Koldha, Chorhat Sandstone, Hinoti, Simrawal Shale, Chandrehi (Maithy & Gupta, 1983, p. 159, pl. 1, fig. 8).

Saccifera Maithy & Mandal 1983

Solitary or in group of 2-4 cells enclosed in a broad thick fibrilar amorphous envelope.

Saccifera tirohensis Maithy & Mandal 1983

Occurrence—Tirohan Limestone, Naroli Fort, Rajasthan (Maithy *et al.*, 1983, p. 135, pl. 2, figs 16-18).

Aphanocapsiopsis Maithy & Shukla 1977

Colony of loosely arranged spheroidal cells without any order.

Aphanocapsiopsis sitholeyii Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy & Shukla, 1977, p. 179, pl. 1, figs 8, 9); Bargawan Shale, Chandrehi (Maithy & Gupta, 1983, p. 159, pl. 1, fig. 7).

Aphanocapsiopsis ramapuraensis Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy & Shukla, 1977, p. 179, pl. 1, figs 10, 11).

Eoentophysalis Hofmann 1976

Oval cells enclosed in a mucilage sheath.

Eoentophysalis belcherensis Hofmann 1976

Occurrence—Fawn Limestone, Salkhan (McMenamin, Kumar & Awramik, 1983, p. 282, fig. 10A-C).

Eoentophysalis magna McMenamin, Kumar & Awramik 1983

Occurrence—Kheinjua Formation, Salkhan Hills (McMenamin *et al.*, 1983, pp. 262-263, fig. 10D-E).

Vindhyacapsiopsis Maithy & Mandal 1983

Cells clumped together in a rectangular colony, ensheathed within a gelatinous mass; 4-6 cells in each vertical row, arranged in opposite pairs, cells spherical, non-ensheathed.

Vindhyacapsiopsis bhanderensis Maithy & Mandal 1983

Occurrence—Upper Bhander Sandstone, Karauli, Rajasthan (Maithy *et al.*, 1986, p. 133, pl. 1, fig. 7).

Oscillatoriopsis Schopf 1968

Trichome with linearly arranged tetragonal cells, broader than longer, filament ensheathed.

Oscillatoriopsis psilata Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977, p. 179, pl. 2, fig. 12).

Neoscytonema Maithy 1980

Synonymy :
1977 *Palaeoscytonema* Maithy & Shukla, p. 179.

Filaments with thick sheaths, non-branched, cells broader than length, hetrocyst absent.

Neoscytonema srivastavae (Maithy & Shukla) n. comb. Maithy 1980

Occurrence—Suket Shale, Ramapura (Maithy & Shukla, 1977, p. 180, pl. 2, figs 13, 14).

Gunflintia Barghoorn 1965

Trichome multicellular, uniseriate and unbranched, septa distinct, cells elongated without any sheath.

Gunflintia sp. Maithy & Mandal 1983

Occurrence—Tirohan Limestone, Karisal Bandh, Sapotra, Rajasthan (Maithy & Mandal, 1983, p. 134, pl. 1, fig. 8).

Veteronostocale Schopf & Blacic 1971

Trichome multicellular, beaded in appearance, uniseriate, unbranched, septa points distinctly constricted; cells circular or ellipsoidal in shape, arranged in linear chain.

Veteronostocale amoenum Schopf & Blacic 1971

Occurrence—Rohtas Limestone, Badanpur, Madhya Pradesh (Maithy & Meena, 1989, p. 183, pl. 1, fig. 4).

Eomycetopsis Schopf 1968

Tubular sheath, empty and non-septate.

Eomycetopsis psilata Maithy & Shukla, 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977, p. 180, pl. 2, fig. 15).

Eomycetopsis pflugii Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977, p. 180, pl. 2, fig. 16).

Eomycetopsis reticulata Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy *et al.*, 1977; p. 180, pl. 2, fig. 17).

Eomycetopsis ?siberensis Lo 1980

Synonymy :

1983 *Gunflintia minuta* Barghoorn 1965, *in* McMenamin, Kumar & Awramik, p. 269, fig. 10F.

Occurrence—Fawn Limestone, Kheinjua Formation, Salkhan, Mirzapur (McMenamin *et al.*, p. 265, fig. 10G-H).

Remarks—*Gunflintia minuta* Barghoorn reported by McMenamin *et al.* (1965) from the Fawn Limestone, Salkhan does not show any septation, as such it also does not compare with the generic characters of *Gunflintia.* In the absence of septa it resembles *Eomycetopsis*, therefore, it is transferred here.

Eomycetopsis sp. Maithy & Meena 1989

Occurrence—Nagod Limestone and Sirbu Shale (Maithy & Meena, 1989, p. 183, pl. 1, fig. 3).

Eomycetopsis sp. Sarkar 1974

Remarks—Sarkar (1974, fig. 5A) reported tubular filaments 6-8 μm to 23.8 μm in diameter. From photographs it can be commented that the recorded forms are abiogenic structures, probably the apatite crystals have got themselves arranged in a row.

***Animikiea* Barghoorn 1965**

Non-septate, unbranched tubes with finely arranged grana in parallel row indicating transverse septa.

Animikiea septata emend. Mandal & Maithy 1984

Occurrence—Nagod Limestone and Sirbu Shale (Maithy & Meena, 1989, Mandal *et al.*, 1984, p. 183, pl. 1, figs 8, 9).

***Taeniatum* Sin & Liu 1973**

Broad non-septate, unbranched dark tubes with irregular surface thickenings.

Taeniatum sp. Maithy & Meena 1989

Occurrence—Nagod Limestone and Sirbu Shale (Maithy & Meena, 1989, p. 182, pl. 1, figs 1, 2).

***Heliconema* Schopf 1968**

Remarks—Sarkar (1974, fig. 5G) reported *Heliconema* sp. (?) long spiral, tubular, non-septate microfossils in the styolite seams of algal limestones of the areas around Maihar and Rewa. The diameter of these structures according to Sarkar (1974) ranges from 30 to 150 μm, i.e. about 7 to 40 times larger than the recorded specimens of *Heliconema.* Therefore, the reference of these forms to *Heliconema* is questionable.

***Archaeorestis* Barghoorn 1965**

Trichome slender, non-septate, non-tubular and branched.

Archaeorestis sp. Maithy & Mandal 1983

Occurrence—Sirbu Shale, Karisal Bandh, Sapotra, Rajasthan (Maithy & Mandal, 1983, p. 134, pl. 1, fig. 11).

ACRITARCHA

Sphaeromorphida

Spherical vesicles without any operculum.

***Protosphaeridium* Timofeev**

Vesicles smooth and small in size (commonly less than 30 μm).

Protosphaeridium diatretus Salujha,
Rehman & Rawat 1971a

Occurrence—Upper Rewa Quartzite Sandstone; Dalapura-Hanumanpura traverse, Rajasthan (Salujha *et al.*, 1971a, p. 73, pl. 1, figs 11-13); Semri Group, Son Valley (Salujha *et al.*, 1971b, p. 26, pl. 2, figs 8, 9); Panna Shale and Lower Bhander Sandstone, Karauli-Sapotra, Rajasthan (Maithy & Mandal, 1983, p. 136, pl. 2, fig. 23).

Protosphaeridium pristinum Salujha,
Rehman & Rawat 1971b

Occurrence—Basuhari Sandstone, Son Valley, Mirzapur District (Salujha *et al.*, 1971b, p. 26, pl. 3, figs 8, 9)

Protosphaeridium densum Timofeev 1966

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy & Shukla, 1977, p. 181, pl. 2, fig. 19); Panna Shale, Jhiri Shale and Lower Bhander Sandstone, Karauli-Sapotra (Maithy & Mandal, 1983,

p. 130, pl. 2, fig. 25); Nagod Limestone & Sirbu Shale, Satna, Maihar, Madhya Pradesh (Maithy & Meena, 1989, p. 183, pl. 1, figs 31, 32).

Protosphaeridium volkovae Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy & Shukla, 1977, p. 181, pl. 2, fig. 18); Sirbu Shale, Satna-Maihar (Maithy & Meena, 1989, p. 184, pl. 1, figs 28, 29).

Remarks—*Zonosphaeridium dignatum* described by Salujha *et al.* (1971a, p. 77, Pl. 1, figs 27-30) from the Sirbu Shale, Chambal Valley is identical to *Protosphaeridium densum* Timofeev 1966, therefore, it is considered here to be the junior synonym.

Protosphaeridium cambriense Timofeev 1959

Occurrence—Panna Shale, Karauli-Sapotra (Maithy & Mandal, 1983).

Remarks—Salujha *et al.* (1971a, pl. 1, figs 17, 18, 19) reported a new species of *Cymatiosphaera, C. compta* from the Maihar Sandstone of Mandral-Karauli traverse which compare morphologically with *Protoleiosphaeridium diatretus* (Salujha *et al.*, 1971a) described from the same area. Therefore, *Cymatiosphaera compta* is referred as a junior synonym of *P. diatretus*.

Likewise, *Tasmanites* sp. described by Salujha *et al.* (1971a, pl. 1, fig. 31) is similar to *Protosphaeridium densum* Timofeev and synonymous too. The same also holds true for the specimen described by Salujha *et al.* (1971b) under *Tasmanites* sp. A (pl. 2, fig. 23) and *Tasmanites* sp. B (pl. 2, fig. 2) from Son Valley.

***Leiosphaeridia* Eisenack 1958**

Vesicles thin-walled with smooth to shar green surface.

Leiosphaeridia vindhyana Salujha,
Rehman & Rawat 1971a

Occurrence—Maihar Sandstone, Mandral-Karauli traverse (Salujha *et al.*, 1971a, p. 72, pl. 1, figs 5-7).

Leiosphaeridia pellucida Salujha,
Rehman & Arora 1971b

Occurrence—Bijaigarh Shale, Son Valley (Salujha *et al.*, 1971b, p. 25, pl. 2, figs 1-3).

***Kildinosphaera* Vidal 1983**

Remarks—The forms described now under *Kildinosphaera* were earlier described under *Kildinella* Timofeev, 1963. Vidal (in Vidal & Knoll, 1983) pointed that the later name is preoccupied, therefore, the specimens described under *Kildinella* were transferred by him to a newly proposed name *Kildinosphaera*.

Kildinosphaera suketensis Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, p. 182, pl. 3, fig. 21).

Kildinosphaera sp.

Occurrence—Panna Shale, Karauli—Sapotra, Rajasthan (Maithy & Mandal, 1983, p. 136, pl. 2, fig. 26); Rohtas Limestone, Nagod Limestone and Sirbu Shale, Satna-Maihar (Maithy & Meena, 1989, p. 184, pl. 1, figs 23, 27).

***Orygmatosphaeridium* Timofeev 1959**

Vesicle thin, surface closely pitted, pits small.

Orygmatosphaeridium plicatum Maithy & Shukla
1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, p. 181, pl. 3, fig. 26); Koldha Shale (Semri) and Simrawal Shale (Bhander), Maithy & Gupta, 1983, p. 159, pl. 1, fig. 9); Semaria Shale (Bhander) Ranipura, Karauli (Maithy & Mandal, 1983, p. 136, pl. 2, fig. 27).

Orygmatosphaeridium vulgarum Maithy 1975

Occurrence—Nagod Limestone and Sirbu Shale (Maithy & Meena, 1989, p. 184, pl. 1, figs 24-25).

***Granomarginata* Naumova 1969**

Vesicle with grana-like structures.

Granomarginata primitiva Salujha, Rehman & Arora
1971b

Occurrence—Basuhari Sandstone, Son Valley (Salujha *et al.*, 1971b, p. 28, pl. 3, figs 18-20).

Granomarginata rotata Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, p. 181, pl. 3, fig. 23).

Granomarginata minuta Maithy 1975

Occurrence—Sirbu Shale, near Karisal Bandh, Sapotra, Rajasthan (Maithy & Mandal, 1983, p. 136, pl. 2, fig. 28).

Granomarginata prima Naumova 1969

Occurrence—Maihar Sandstone, north of Karauli (Maithy & Mandal, 1983, p. 136, pl. 2, fig. 29).

Remarks—*Archaeofavosinia venusta* Salujha *et al.* (1971b, p. 27, pl. 3, figs 2, 3) compares to *G. prima* due to presence of closely spaced grana and seems to be synonymous.

Granomarginata nagodensis Maithy & Gupta 1983 n. comb.

Synonymy :

1983 *Bavlinella nagodensis* Maithy & Gupta, p. 160, pl. 1, figs 10, 11.

Occurrence—Nagod Limestone Formation, west of Baisa, Madhya Pradesh.

Remarks—As per description the surface of the organic-walled microfossils has closely spaced grana, which compares with the generic circumscription of *Granomarginata*, therefore, *Bavlinella nagodensis* is transferred to *Granomarginata*.

Symplassosphaeridium **Timofeev 1959**

Vesicle spheroidal, body divided to several rounded areas.

Symplassosphaeridium bulbosum Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura (Maithy & Shukla, p. 181, pl. 2, fig. 20).

Symplassosphaeridium sp. A Salujha, Rehman & Rawat 1971a

Occurrence—Vindhyan, Rajasthan (Salujha *et al.*, 1971a, p. 72, pl. 1, fig. 9).

?*Symplassosphaeridium* sp. B, Salujha, Rehman & Rawat 1971a

Occurrence—Vindhyan, Rajasthan (Salujha *et al.*, 1971a, p. 73, pl. 1, fig. 10).

Remarks—The identification of *Symplassosphaeridium* sp. A Salujha *et al.*, 1971a, p. 72, pl. 1, fig. 9) and ?*Symplassosphaeridium* sp. B. Salujha *et al.*, 1971b, p. 73, pl. 1, fig. 10) seems to be doubtful as the photographs show that small globular cells are enclosed within a fine enveloping sheath. Accordingly, it shows morphological closeness to *Bavlinella* Shepleva 1962. Both the specimens also compare with recently figured specimens of *Bavlinella* by Hofmann (1984, pl. 32, figs A-G) from the latest Proterozoic of the Wernecke Mountains, Yukon.

Lophosphaeridium **Timofeev 1969**

Vesicle spherical, exine covered with bulbose processes.

Lophosphaeridium jainii Salujha, Rehman & Rawat 1971a

Occurrence—Kaimur Sandstone, Mandral-Karauli traverse, Rajasthan (Salujha *et al.*, 1971a, p. 74, pl. 1, figs 14-16).

Lophosphaeridium jainsoniusii Salujha, Rehman & Arora 1971a

Occurrence—Bijaigarh Shale, Son Valley, Mirzapur (Salujha *et al.*, 1971b, p. 26, pl. 2, figs 10-13).

Lophosphaeridium vetulum Salujha, Rehman & Arora 1971b

Occurrence—Rohtas Limestone, Son Valley, Sidhi District (Salujha *et al.*, 1971b, p. 27, pl. 3, figs 10, 11).

Remarks—The above named three species seem to be synonymous owing to their morphological similarity. They also overlap in the size range. As such *Lophosphaeridium jainii* has priority over the later two described species *L. jainsonusii* and *L. vetulum*.

Microhystridium sitholeyi Salujha *et al.* (1971b, p. 30, pl. 2, figs 15-17) has exine and broad processes with rounded tips. This character conforms to the generic identity of *Lophosphaeridium*. Further, the figured specimens also compare with the figured specimens of *L. jainii* Salujha *et al.* (1971a, pl. 1, figs 14-16).

Lophosphaeridium echinatum Salujha *et al.*, 1971 comb. nov.

Synonymy :

1971 *Priscogalea echinata* Salujha, Rehman & Rawat, p. 76, pl. 1, figs 23, 24.

Remarks—The species is transferred to *Lophosphaeridium* due to the presence of closely set spines, ± 2 μm long. The species differs from *L. jainii* Salujha *et al.* 1971 in being larger in size and pointed structures.

Vavosophaeridium **Timofeev 1956**

Vesicle spherical, exine covered with muri forming reticulations.

Vavososphaeridium bharadwajii Salujha, Rehman & Rawat 1971a

Synonymy :

1971a *Dictyotidium aerolatus* Salujha, Rehman & Rawat, p. 75, pl. 1, figs 21, 22.

Occurrence—Maihar Sandstone, Mandral-Karauli traverse, Rajasthan (Salujha *et al.*, 1971a, p. 75, pl. 1, figs 21, 22); Vindhyan, Son Valley (Salujha, Rehman & Arora, 1971b, p. 29, pl. 3, figs 24, 25); Nagod Limestone and Sirbu Shale; Satna-Maihar (Maithy & Meena, 1989, p. 184, pl. 1, fig. 26).

Remarks—Salujha *et al.* (1971a, p. 75, pl. 1, figs 21, 22) reported *Dictyotidium aerolatus*, a new species from the Maihar Sandstone, Mandral-Karauli traverse. These specimens in their gross morphology are like *Vavososphaeridium bharadwajii*.

Vavososphaeridium vindhyanensis
Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, pl. 4, fig. 27).

Archaeofavosina Naumova 1960

Vesicle with broad reticulum, reticulum free area pitted.

Archaeofavosina reticulata Maithy & Shukla 1977

Occurrence—Suket Shale Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, pl. 3, fig. 24).

Bavlinella Shepleva 1962

Spheroidal aggregates of dark brown organic material tightly packed isodiametric globular to subpolyhedral globular cell-like units, 0.3-1.0 μm in diameter.

Bavlinella faveolata (Shepleva, 1962) emend. Vidal 1976

Nucellosphaeridium Timofeev 1969

Vesicle sphaeroidal with inner body.

Nucellosphaeridium minimum Maithy & Shukla 1977

Synonymy :
1971b *Pterospermopsis typicanus* Salujha, Rehman & Arora, p. 30, pl. 2, figs 18, 19.
1971b *Baltisphaeridium scitulum* Salujha, Rehman & Arora, p. 30, pl. 2, fig. 26.

Occurrence—Suket Shale; Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, p. 182, pl. 4, figs 30, 31).

Remarks—*Pterospermopsis typicanus* Salujha, Rehman and Arora (1971b, pl. 2, figs 18, 19) compares closely to *N. minimum* Maithy & Shukla (1977, pl. 4, figs 30, 31). It does not compare with the morphological features of *Pterospermopsis*. Therefore, it is a synonym of *N. minimum*. The specimen described and figured by Salujha *et al.* (1971b, p. 30, pl. 2, fig. 26) shows a distinct circular body, therefore its assignment to *Baltisphaeridium scitulum* is not correct. In gross morphology it resembles *Nucellosphaeridium minimum* Maithy *et al.*, 1977 and is synonymous.

Nucellosphaeridium maithyi (Maithy & Shukla) emend. Fensome *et al.* 1990

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy & Shukla, 1977, p. 182, pl. 4, figs 30, 31).

Remarks—Fensome *et al.* (1990) pointed out that *N. zonatum* Maithy & Shukla 1977 is junior homonym of *N. zonatum* Maithy 1975, therefore, proposed *N. maithyi* for it.

Tasmanites (Newt.) Eisenack 1958

Large size vesicle, surface with numerous puncta or pores.

Tasmanites vindhyanensis Maithy & Shukla 1977

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1977, p. 182, pl. 4, figs 32, 33).

Tasmanites punctatum (Maithy & Shukla) emend. Fensome *et al.* 1990

Synonymy :
1977 *Zonosphaeridium punctatum* Maithy & Shukla, p. 182, pl. 4, fig. 28.

Occurrence—Suket Shale, Ramapura, Madhya Pradesh (Maithy *et al.*, 1971, p. 182, pl. 4, fig. 28).

Remarks—Fensome *et al.* (1990) pointed out that the genus *Zonosphaeridium* Timofeev is not validly published, therefore, they transferred the forms placed under *Zonosphaeridium* to *Tasmanites*, which is a senior synonym.

Leiovalia Eisenack 1965

Oval organic-walled microfossils, exine smooth.

Leiovalia sp. Salujha, Rehman & Rawat 1971a

Occurrence—Vindhyan, Karauli-Kotah (Salujha *et al.*, 1971a, p. 76, pl. 1, fig. 25).

Remarks—Most probably the reported specimen by Salujha *et al.* (1971a, p. 76, pl. 1, fig. 25) is a modern fungal spore. Similar fungal spores have also been reported in association of organic-walled microfossils from the Vindhyans of Son Valley by Salujha, Rehman and Arora (1971b, pl. 3, figs 21-23).

Vase-shaped microfossils

Melanocyrillium Bloesser 1985

Remarks—Vase-or flask-shaped microfossils are well known from the Precambrian rocks (Knoll, 1982). Bloesser (1985) put all of them under a new genus *Melanocyrillium* as encystment structures belonging to unidentified alga. *Melanocyrillium* was reported by Salujha *et al.* (1971a, p. 32, pl. 3, fig. 31) from the Vindhyan rocks of Son Valley and from the Upper Vindhyan rocks of Rajasthan by Salujha *et al.* (1971b, p. 70; pl. 1, fig. 35). Maithy and Babu (1989) recorded *Melanocyrillium fimbriatum* sp. in the Arangi Formation, Semri Group and Markundi Quartzite Formation, Kaimur Group exposed around Chopan, Mirzapur District, Uttar Pradesh.

ACTIVITIES OF BIOLOGICAL LIFE

Ichnofossils

Several markings were noted by early workers in the Vindhyan rocks, but were dismissed as of inorganic origin. Verma and Prasad (1968) reported the occurrence of three types of trace fossils in the Bhander Limestone in Bankuiyan area, Rewa District. *Bostricophyton bankuianensis* are large spiral thread-like markings, slightly broader in the middle, tapering ends with transverse ridges, thick, prominent, slightly arched and closely spaced. Marking appears to represent crawling tracks of a worm or an arthropod. *Rouaulita rewaensis* is a smooth bilobate crawling trail with two very distinct lateral furrows and one median furrow, body almost flat. *Tasmanadia dassi* has double rows of very sharp transverse foot-like imprints, longer axis of the imprint is slightly diagonal to the direction of movement; foot-like imprints, single, thick and varying in size. Sarkar (1974, p. 150) reported in brown and grey limestone outcrop sections of Lakheri Limestone the presence of slightly raised ridges mostly sheet-like, straight to sinuous or irregular, spindle-shaped, most of which wedge out peripherally. The length and breadth of the structures vary from 0.5 to 5 cm and 0.5 to 4 mm, respectively. Generally both the ends of these structures are tapering. Some forms are not tapering but simply rod-shaped. Some burrows show flat crescent U-shaped body with two arms-like projections. Kumar (1978c) described a horizontal trail *Muniaichnites* from glauconitic sandstone.

Mathur (1982, fig. 2A) reported *Asteriradtus karaulensis* in Karauli Quartzite of Panna. However, no details have been provided and as such it is *nomen nudum*. *Sonjiwashman basuharensis* claimed to be a trace fossil by Mathur (1982, fig. 2B) from the Basuhari Sandstone is actually a drag mark. Mathur and Verma (1983, fig. 1) reported *Bhanderichnus damohensis* in the Maihar Quartzite Formation, Sagoni, Madhya Pradesh. The specimen is a trail with lobe-like structure, placed symmetrically on either side of the main trail. Four pairs of such lobes are seen.

Trails with paired circular marks with a inter-spacing gap of 1-4 mm from one another are arranged in a linear fashion up to 8-10 cm; circular markings nearly less than 1 mm in dimension. Linear distance between two pairs less than 2 mm was reported by Maithy *et al.* (1986, fig. 2) in the Murli Sandstone Formation (Kaimur) of Murlipahar, Bihar and Maithy and Babu (1988, pl. 2, fig. 7) in the Ghurma Shale (Kaimur) of Chopan.

Chakrabarti (1990) recorded traces and dubiotraces from the Lower Bhander Sandstone exposed around Maihar, Madhya Pradesh. Burrows have been detected on exposures as small sand lump exposures in rippled or plane bedding surface. Two groups of burrows were found (a) large diameter burrows with diameters varying between 0.5 and 4.5 cm, and (b) micro-burrows with diameter 1.5 mm. Burrow discloses two different patterns in the nature of burrow fill (i) staggered concave upward internal laminae showing 'V'- in 'V' or broad-based 'U'- in 'U' structures resembling *Monocraterion*, and (ii) an ill-defined arrangement of the upward laminae of the burrow fill, the stubby thumb-like burrow being bordered by clay lining on the burrow wall. Dissection of the 'bean-shaped' forms reveal that these represent the lower part of *Diplocraterion* burrows.

ORGANOSEDIMENTARY STRUCTURES

The principal organosedimentary structures of Vindhyan are stromatolites These records of stromatolites have been summarised by Kumar (1984). Incidentally, in most of earlier works the identification of stromatolites is based on field data and three dimensional reconstructions for the taxonomic identification were not prepared. Further, in many cases the descriptions are also incomplete. Kumar (1984) identified three distinct stratigraphical assemblage zones. Of these, two assemblages are recognised within the Semri Group, the older is *Kussiella-Colonella* Assemblage of the Early Riphean age and the younger is *Conophyton garganicus-Colonella* Assemblage of Middle Riphean age. The Bhander Group assemblage is dominated by *Baicalia-Tungussia* Assemblage of Late Riphean age. The stromatolite records are tabulated below.

CONCLUDING REMARKS

The paper indicates that very little evidences of the Vindhyan life were available before 1970. All the earlier reports are poorly documented. Since 1970, proper attention was given to record various biological remains from the Precambrian rocks.

Macrofossils—Presence of *Chopania* in the rock as old as ± 1,300 Ma suggests that the lineage separation between Metaphyte and Metazoan began sometimes during the early part of Middle Proterozoic. The younger bed of Semri and the older beds of Kaimur preserve characteristic macrofossil assemblages dominated by the planktonic forms—*Chuaria* alongwith *Tawuia* and the benthic form *Krishnania*. This association also includes elongated

Semri Group

HORIZON	LOCALITY	AUTHOR	FORMA
Rohtas	Mirzapur	Kumar, 1976b	*Collenia clappii* Poorly developed stromatolite
Bargawan	Mirzapur	Valdia, 1969	*Colonella columnaris* *Conophyton garganicus* *Colenia clapii*
		Kumar, 1982	*Conophyton garganicus* *C. garganicus, Colonella columnaris*
	Dabua	Maithy, 1990	*Newlandia minuta*
Bhagwanpura Limestone	Hatipura Rajasthan	Raja Rao & Mahajan 1965	*Collenia frequence, Conophyton indinatum, Cryptozoan accidentale* and *Weedia.*
		Prasad, 1975	*Collenia columiaria* *C. kussiensis, Conophyton cylindrica, Cryptozoan accidentale, Weedia*
	Chainpur Rajasthan	Prasad, 1975	*Collenia columnaris* *C. frequence* *C. baicalica, C. spissa* *C. kussiensis, C. oompaeta* *Cryptozoan accidentale,* *Conophyton cylindricus* *C. inelinatum, Weedia*
	Bhojenda Rajasthan	Barman & Verma 1975	*Conophyton cylindricus, Collenia* sp., *Collenia baicalica, C. frequence, Weedia*
		Prasad, 1976, 1978	*Collenia columnaris, C. baicalica* *C. kussiensis, Gymnosolen* *Cryptozoan accidentale,* *Conophyton cylindricus,* *Weedia* sp.
Kajrahat Limestone	Mirzapur	Kumar, 1976a, b, c, 1982	*Kussiella kussiensis, Kussiella kussiensis, K. dalaensis,* *Conophyton vindhyaensis,* *Colonella symmetrica,* *C. kajrahatensis*
Tirohan Limestone	Chitrakoot	Valdia, 1969 Kumar, 1976b 1977b, 1982	*Colonella lodwarensis, C. columnaris, Collenia symmetrica, Kussiella kussiensis*
Tirohan Limestone	Sapotra Karauli	Maharajasingh & Banerji, 1980	*Conophyton cylindricus,* *Collenia kussiensis,* *C. baicalica*

Rewa Group

HORIZON	LOCALITY	AUTHOR	FORMA
Jhiri Shale	Barwas, Akher	Prasad, 1984	*Baicalia baicalica,* *Gymnosolen ramasayi*

Bhander Group

HORIZON	LOCALITY	AUTHOR	FORMA
Balwan Limestone	Balwan	Prasad, 1984	*Baicalia baicalica, Linella*
Upper Bhander Limestone	Sawai-Madhopur	Prasad & Ramaswamy, 1980	*Collenia baicalica*
	Lakheri	Prasad, 1984	*Collenia* (*Baicalia*) *baicalica* & *Linella*
Sirbu-Shale (Megardha Member)	Satna	Rao, Lal & Ghosh, 1977	*Stratifera*
Nagod-Limestone	Maihar	Kumar, 1978	*Maiharia maiharensis*
	Sawai-Madhopur	Prasad & Ramaswamy, 1980	*Collenia baicalica* & *C. collumnaris*
	Bundi	Prasad, 1984	*Collenia baicalica, C. buricata* & *Oncolites*
	Maihar	Valdiya, 1969	*Collenia baicalica*
	Maihar	Misra & Awasthi 1962	*Collenia*
	Maihar, Satna Nagod & Rewa	Sarkar, 1974	*Baicalia baicalica, Colonella, Cryptozoan, Collenia undosa, Stratifera* & *Weedia*
	Maihar	Kumar, 1978	*Baicalia baicalica* & *Colonella columnaris*
	Satna	Kumar, 1978	*Baicalia satanensis* (? *Tungussia*)
	Satna	Rao, Lal & Ghosh, 1977	*Collenia = (Colonella) Baicalia, Boxonia* identical to *Baicalia) Tungussia, Stratifera* & Oncolite
	Rewa	Rao, Rao & Ghosh, 1977	*Colonella, Collenia, Symmetrica, Baicalia, Kussiella* & *Anaberia*
Samaria Limestone	Sawai-Madhopur	Prasad & Ramaswamy, 1980	*Collenia (Baicalia) baicalica*
	Satur, Lonaba Naygoan Singlore	Prasad, 1984	*Weedia, Stratifera, Collenia (Baicalica)*

tubular types—*Grypania* and *Daltaenia*, planktonic sphaeroid with inner body, viz., *Amjohrea, Ramapuraea* and elongated-oval forms *Katnia* and *Shouhsienia*. *Krishnania* is the oldest benthic form. The assemblage suggests extensive shallow seas on a peneplained landscape for the Vindhyans. Most of the Middle Proterozoic forms seem to be Eucaryotic due to their large size, though affinities of many of them are still uncertain. This assemblage is known world wide from the equivalent strata, i.e., 800-1,000 Ma of China (du Rulin, 1982; Duan, 1982) and north-west Canada (Hofmann, 1985). Considering this, Maithy and Babu (1988) indicated that this is a time marker assemblage and therefore denoted this time period as "Chuarian Period".

The youngest bed of the Vindhyan-Dholpura Shale preserves Ediacaran biota, comprising mainly of Vendian Radialia medusoids dominated by oligocytic forms of 'Cyclomedusa complex'. This type of biotic composition is now known from Australia, China, Europe and Canada. The presence of Ediacaran biota in the youngest beds of the

Vindhyan indicates the uppermost limit of Vindhyan is restricted to Vendian.

Organic-walled microfossils—In the past, doubts have been raised concerning synsedimentary deposition of the organic-walled microfossils in the rocks. Workers have also questioned the authenticity of the macerated organic residues. Many of them tried to call them organic contaminants of modern vegetation. In recent years this point is over-ruled by the methodology of study suggested by Pflug and Maithy (1977). According to them synsedimentary deposition of biota can be well proved by studying them first in thin sections and later by maceration.

Identification of organic-walled microfossils too, is problematic due to ill preservation. The Precambrian organic-walled microfossils are black to dark-brown in colour and the original wall structure also gets altered due to diagenetic changes in the course of fossilisation. Therefore, probability remains that the identified forms under different species and generic names may be the preservation variants. In view of the same, due caution is now needed while instituting new forms.

The study indicates that relationship exists between the biota and preserved rock. The stromatolite bearing rocks preserve distinct biotic composition in comparison to non-stromatolitic ones. The stromatolitic beds preserve Synaptomorphs (colonial forms) and the Nematomorphs (tubular forms) indicate lagoonal deposit while non-stromatolitic beds preserve Cryptarchs (including Acritarcha) indicating open shelf deposit.

Organic-walled microfossils particularly Cryptarch-Sphaeromorphs play significant role in biostratigraphy. The available data indicates that Semri Group Cryptarch shows dominance of *Protosphaeridium, Orygmatosphaeridium* and *Leiosphaeridia* and the Bhander Group is characterised by the presence of large-sized sphaeromorphs—*Nucellosphaeridium, Vavosphaeridium, Micryhystridium, Cymatopshaeroides* associated with *Bavlinella.*

Trace fossils—Ichnofossil evidences from the Vindhyan are scanty in comparison to the Late Precambrian records. However, the ichnofossil records indicate the existence of metazoan in the early part of Upper Proterozoic. The preserved traces indicate the presence of vagile benthos. In sedimentary strata, these organisms moved owing to persistaltic changes in the shape of entire body (in the same way living nemertines, annelids, etc.) passing through their digestive canal, a residue rich in organic matter. Proterozoic Metazoa moved by persistaltic waves, passing through the ventral parts of body, like living planarians, chitons, etc. The ichnofossil records indicate that metazoan life possibly developed sometimes in the early part of Middle Proterozoic.

Organosedimentary structures—The Vindhyan stromatolites indicate that non-branched and domal forms (*Conophyton*) dominate the Semri Group and the branched stromatolites are characteristic of the Bhander Group. The branched forms indicate Upper Riphean to Vendian age for the Bhander Sequence.

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Changing patterns of the Permian Gondwana vegetation

Shaila Chandra

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Floristics, ecology and vegetation through Permian of peninsular India are summarised. Palynological, sedimentological and faunal data are also utilized in this study. The Permian vegetation of India, known as the *Glossopteris* flora, comprises fungi, bryophytes, lycophytes, arthrophytes, Filicales and gymnosperms. Some of the important plant types are reconstructed on the basis of available information. Five reconstructions are made depicting Talchir, Karharbari, Barakar, Kulti and Raniganj vegetation.

Key-words—Floristics, Ecology, Vegetation, Reconstructions, Permian Gondwana, India.

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सारौंश

परमी गोंडवाना वनस्पति के बदलते स्वरूप

शैला चन्द्रा

प्रायद्वीपीय भारत के परमी कल्प के वनस्पतिजात, पारिस्थितिकी एवं वनस्पति की विवेचना की गई है। इस अध्ययन में परागाणविक, अवसादीय एवं जन्तुजात के आँकड़ों का भी उपयोग किया गया है। भारत के परमी कल्प के वनस्पतिजात में, जो कि ग्लॉसॉप्टेरिस वनस्पतिजात के नाम से विख्यात है, कवकीय, ब्रायोफ़ाइटी, आर्थ्रोफ़ाइटी, फिलीकेली एवं अनावृतबीजी अवयव विद्यमान हैं। उपलब्ध जानकारी के आधार पर कुछ मुख्य पौधों की पुनर्रचना की गई है। तलचीर, करहरबारी, बराकार, कुल्टी एवं रानीगंज की वनस्पति प्रदर्शित करते हुए पाँच पुनर्रचना प्रस्तावित की गई हैं।

OUR knowledge of the Permian flora of India has rapidly increased over the last four decades. Studies of the Glossopteris flora representing Permian vegetation in India was initiated by O. Feistmantel between 1879-86. Later Arber (1905) published the British Museum Catalogue of the Glossopteris flora, covering much wider geographical area. Since then a lot of new data has accumulated and many review and compilations have appeared on the Glossopteris flora of India (Sahni, 1939; Surange, 1966, 1975; Lele, 1976; Surange & Lele, 1977; Maithy, 1974a; Maheshwari, 1976; Pant, 1977; Bose *et al.*, 1990).

The first step for reconstructing the vegetation through Permian time has been to observe and understand the distribution of plant remains belonging to various plant groups in different sedimentary facies. The next step involves interpretation of the depositional environments and likely the transport history of plants. As few fossil plants are found *in situ*, their distribution within the rock strata is controlled by transport and depositional processes. The reconstruction of the original plant communities is therefore dependent upon the understanding of transport history and depositional environment interpreted from the sedimentological evidences. It is also true that the entire flora is not preserved. Therefore information on preservational environment is also very important as we know far less about the original vegetation.

An ideal situation would have been to reconstruct the changing vegetational scenarios of a particular basin but for want of adequate information it is not presently possible. Therefore, data from various basins have been put together to reconstruct the vegetation of different formations in the peninsular India. A number of changes in the floras and plant communities have been related to climatic and evolutionary factors. The effect of climate on plants through Permian has been detailed by Chandra and Chandra (1987). Faunal records, known meagerly from peninsular India, have also played a

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major role in understanding the environment. This aspect is also dealt with.

Reconstructing vegetation of any particular period requires vast information from several sources, which is usually not adequately available. The present effort is made to recreate Permian vegetation scenarios as precisely as possible. Papers published during the past decades mostly deal with descriptive accounts and floristics. A very few papers are on record which throw light on the origin and development of the past vegetation. Similarly, reconstructions of the Indian Permian vegetational scenarios have not been attempted. Seward (1941, fig. 74), Plumstead (1966), Rigby (1969) and Rayner and Coventry (1985) reconstructed the Lower Gondwana vegetation and viewed it as a single scene depicting a span of more than 50 million years. Recently, Pant (1985) wrote an article in Hindi which mentions several forest types of the past.

PERMIAN OF PENINSULAR INDIA

The Glossopteris flora is richly preserved in the Lower Gondwana formations of India, which include Talchir, Karharbari, Barakar, Barren Measures (also known as Kulti Formation) and Raniganj formations in ascending order (Table 1). The continental deposits of the Lower Gondwana formations are developed in a series of basins in the Damodar, Son Mahanadi and Narmada grabens. The Lower Gondwana formations in different basins of peninsular India are usually referred to by local names. The Lower Gondwana deposits have a glacigene unit at their base which is recognisable in all the intracratonic basins of the country It is believed that the Talchir glacial deposits were spread almost all over the peninsula, however, the outcrops are present in the form of erosional relicts. After the ice cap receded the glacial event was followed by deposition of sands, shales and coals in subsiding back swamps, marshes and lacustrine environments for about 40 million years. There were occasional incursions of the sea which left behind intermittent thin marine deposits.

GLOSSOPTERIS FLORA OF PENINSULAR INDIA

The Glossopteris flora of peninsular India includes few characteristic plants, most of them are largely restricted to the Gondwana countries. The botanical relationship of most of the fossil forms is tentative as few are known with their fructification. Majority of the forms occurs as detached parts and it is a rare instance if they are found attached, so as to provide us information regarding their phyllotaxy and mode of attachment on the parent plant. Therefore, the habit of different plants is not adequately known. So far very few reconstructions of the Permian plants have been made. In the following account Permian fossil finds from the peninsular India are assessed for their character states to reconstruct the individual plants, wherever possible. This information has been used to visualize the Permian vegetation of India.

Bryophyta

Till now this group was thought to be almost non-existing during Permian of India as all previous records were discarded. The latest findings (Chandra, M.S.) have proved beyond doubt that both hepatics and musci are very well represented in the

Table 1—Lower Gondwana Formations of India in different basins

			LITHOSTRATIGRAPHIC UNITS					
STANDARD SCALE			DAMODAR VALLEY	SATPURA BASIN	SON VALLEY	RAJMAHAL REGION	WARDHA-GODAVARI VALLEY	MAHANADI VALLEY
PERMIAN	TATARIAN		RANIGANJ FORMATION	BIJORI FORMATION	PALI FORMATION	RANIGANJ FORMATION	KAMTHI FORMATION	KAMTHI FORMATION
	KAZANIAN		KULTI FORMATION	MOTUR FORMATION			KULTI FORMATION	KULTI FORMATION
	ARTINSKIAN	UPPER	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION
		LOWER	KARHARBARI FORMATION	KARHARBARI FORMATION	KARHARBARI FORMATION			KARHARBARI FORMATION
	SAKMARIAN		TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION
LOWER GONDWANA FORMATION OF INDIA								

Talchir flora from the South Rewa Gondwana Basin. Their absence in other Permian formations of India is intriguing as they are well represented in the Nidpur beds considered to be Triassic in age (Pant & Basu, 1978, 1981). It is expected that future finds will fill the gaps in understanding this group. The bryophytic plants are diminutive and they grow near marshy wet places.

Lycophyta

Lycopods too are rarely represented in the Permian sediments of peninsular India. Majority of them are known from the Extra-peninsular region and a few from peninsular region. The oldest authentic record of *Cyclodendron leslii* (Seward) Kräusel is from the Middle Permian (Iron Stone Shale Formation; Kar, 1968). It is represented by fragments of stems bearing a number of spirally arranged eye-shaped leaf scars. Surprisingly they are well-represented in other Gondwana countries, viz., South Africa, South America and Australia forming conspicuous part of the vegetation in the Early Permian. It is premature to infer whether the Indian lycopods during Permian were small plants or attained a considerable height. So far there is no evidence to prove that the Gondwana lycopods were arborescent plants. Based on present information it is considered that they were small plants which grew near marshy places forming an undercover of the vegetation.

While the lycopsid fossil remains are scanty in the Permian sequence of India; a large number of micro-and mega-spores have been recorded (Bharadwaj & Tiwari, 1970; Maheshwari & Tewari, 1987). This indicates the likely possibility of the presence of more lycopsid plants in the Permian than presently known by the megafossil records.

Arthrophyta

This group includes two orders. The order Equisetales forms a significant part of the Permian vegetation, the plants being represented by vegetative shoots with leaflets. In the absence of anatomical details and fruiting bodies of the plant types of the group, their relationship and affinities are imperfectly known. Well known form genera assigned to this group are *Phyllotheca, Schizoneura, Lelstotheca* and *Raniganjia*. Other less known forms of localised occurrence are *Barakaria, Gondwanophyton* and *Bengalia*. Ribbed jointed stem impressions commonly occur in virtually all the Lower Gondwana formations indicating the presence of equisetalean plants.

***Schizoneura* Schimper & Mougeot**

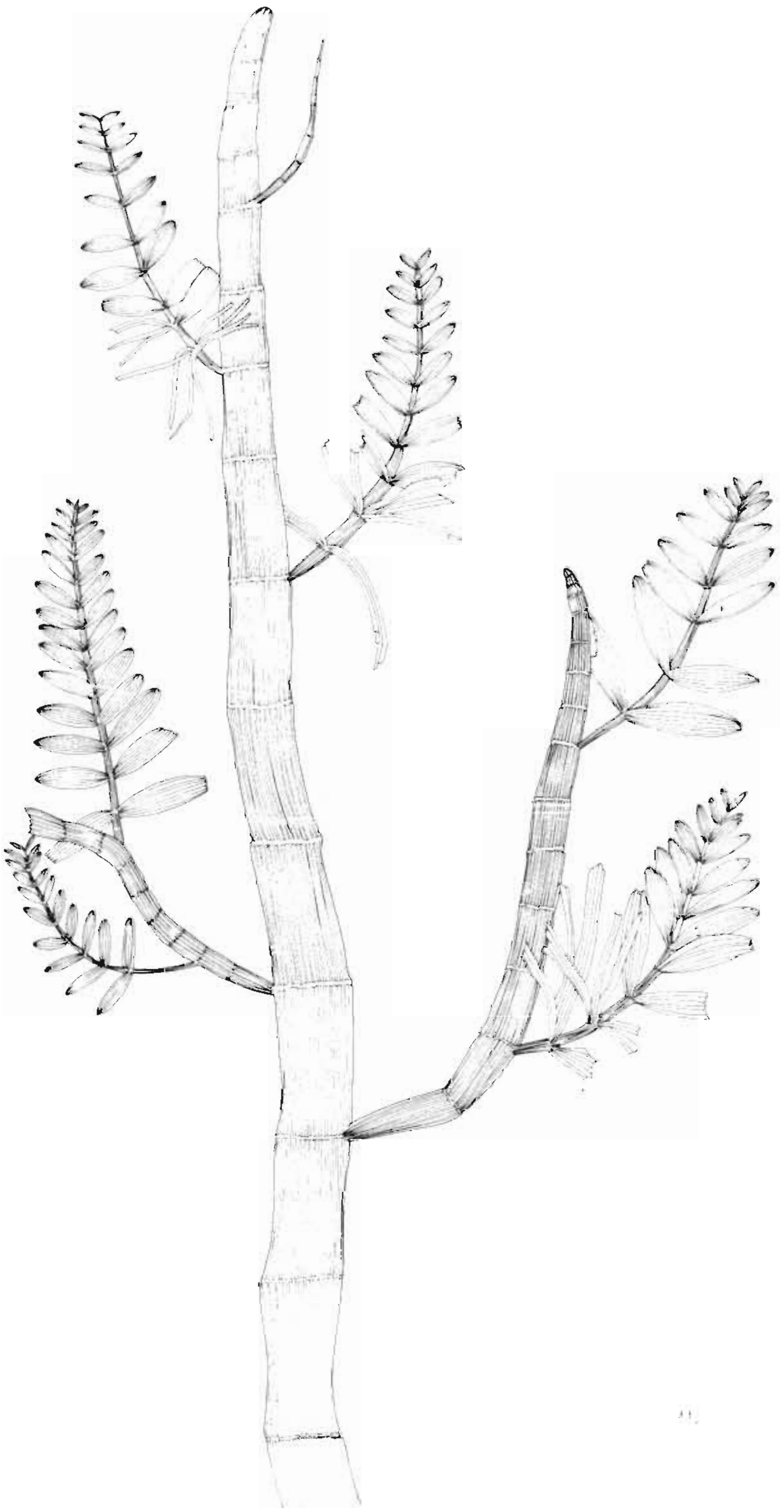
This appears to be a plant of considerable height reaching up to few meters as evidenced by the specimens reported by Feistmantel (1880, 1881) and others. The herbaceous plant had a main stem giving out alternate branches which were also branched sometimes and ultimately possessing opposite leaflets on finer branches (Text-figure 1). Generally the fossils of stem and finer branches with leaflets are found separately. The older leaflets tear along the veins to form long narrow, strap-shaped leaflets hanging out from the nodes. The reconstruction of the plant shows main axis with its branches and leaflets on finer branches. In India, the genus is recognized by two species, in which *S. gondwanensis* Feistmantel is common in occurrence and has a wide vertical and horizontal distribution.

***Phyllotheca* Brongniart**

It is known by 15 species from all over Gondwana countries. In India, the genus makes its first appearance in the Early-Middle Permian and continues up to Late Triassic. The most complete specimen is reported by Surange and Kulkarni (1968) from Barakar Formation of South Karanpura Coalfield. The plant appears to be smaller than the *Schizoneura* plant. The main stem gives out lateral branches which in turn give out finer branches bearing leaf-sheaths (Text-figure 2). Identification of the species is made on various shapes and sizes of the cups formed by the leaf-sheaths. The complete plant could have been up to a meter high. The cuticular details of the leaf-sheaths are like those of modern *Equisetum* and therefore it is presumed that the *Phyllotheca* plant also had similar habit and habitat. It is likely that *Phyllotheca* too had xerophytic as well as hygrophytic characters like that of modern *Equisetum* and perhaps had the ability to grow in both the habitats. The genus is recognised by five species in Lower Gondwana of India.

***Lelstotheca* Maheshwari**

This genus has been reported from India only and is recognised by a single species. So far it was known from the Barakar Formation. Presently its occurrence has been recognised in the Kamthi Formation of Handapa beds as well. The herbaceous plants of *Lelstotheca* appear to be quite small in size (Text-figure 3). The stems of the plant are quite thin as compared to the leaflet size. It is quite likely that the plant had a trailing habit and was growing with the support of other plants. Maithy and Mandal (1978), on the contrary, believe that the plant was erect and herbaceous.



Text-figure 1—Reconstruction of the plant of *Schizoneura gondwanensis* Feistmantel.

Raniganjia Rigby

It is mostly found in the Late Permian, i.e., Raniganj and Kamthi formations and is well known in other Gondwana countries. Pant and Nautiyal (1968) reported quite complete specimens of the genus and gave details of other characters. The thin stems bore umbrella-shaped leaf-sheaths at the nodes (Text-figure 4). Generally the leaf-sheaths are preserved in flattened condition. It is likely that

Text-figure 2—Reconstruction of the plant of *Phyllotheca indica* Bunbury.

Raniganjia plant too had a trailing habit. The plant was smaller than the plants of *Schizoneura* and *Phyllotheca* but was bigger than *Lelstotheca*. The genus is recognised by two species.

The order Sphenophyllales is represented in India by vegetative shoots of commonly found form genera *Sphenophyllum* and *Trigygia*. *Benlightfootia* and *Parasphenophyllum* are of rare and localized in occurrence. All the forms have slender stem axis and swollen nodes bearing leaflets of varying size and shape.

Trizygia Royle

The southern forms having three sets of leaflets are recognised as *Trizygia*. Some authors in India have preferred to retain the name *Sphenophyllum*. Maithy (1978) has wrongly reconstructed the plant of *Sphenophyllum* growing vertically attached to the horizontally lying *Vertebraria* axes. These two form genera have nothing in common. One for sure belongs to pteridophytes and the other to gymnosperms. *Trizygia* or *Sphenophyllum* were small plants having slender unbranched stem axis with leaflets on the swollen nodes (Text-figure 5). It is quite likely that they were growing upright and needed the help of arborescent plants for support.

It is presumed that the Permian Arthrophytes were aquatic or semiaquatic plants growing in shallow waters or marshy places around lakes and rivers. All of them had green stem and the photosynthetic activities were carried out by both stem and leaflets.

Filicophyta

Most of the Indian Permian ferns and fern-like plants were placed under the northern hemisphere

Text-figure 3—Reconstruction of the plant of *Lelstotheca robusta* (Feistmantel) Maheshwari.

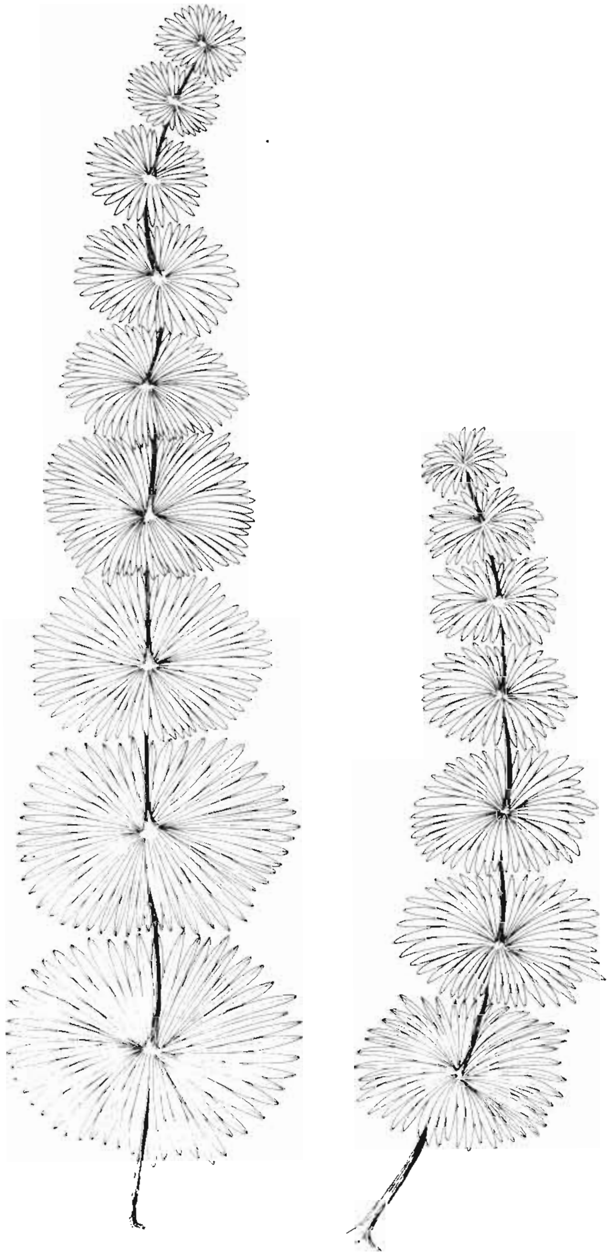
generic names till late. Now several of them have been assigned to new genera and species (Maithy, 1974b, 1975, 1977; Pant & Khare, 1974; Pant & Misra, 1976, 1977, 1983). *Neomariopteris* and *Damudopteris* (former *Sphenopteris*), *Dizeugotheca* (former *Alethopteris*), *Asansolia, Damudosorus, Trithecopteris* and *Cuticulatopteris* are the names given to the Lower Gondwana ferns. They have been classified by Pant and Misra (1977) under two families—Damudopteridaceae having free sporangia and Asterothecaceae having synangia. The oldest fern-like frond from the Karharbari Formation is *Gondwanidium* (*Botrychiopsis*) *valida* (Feistmantel) Archangelsky & Gamerro. It is considered as marker species of the Early Permian.

Most of the Permian fern fronds are believed to be small 'plants having usual habit (Text-figure 6) but it is likely that some of the species could be tree ferns as evidenced by the huge fronds of *Neomariopteris khanii* Maithy 1977 from the Late Permian beds. In Australia the tree ferns are represented by Osmundaceae, no such evidences are available in India. Recently, some huge fronds still attached to quite wide branches from the Kamthi beds of Talchir Coalfield have been found, leading to believe that there were atleast a few ferns with a tree habit in the Late Permian.

So far there is no evidence to prove the presence of true Pteridosperms having seeds on fern fronds as in northern forms. Therefore, with the present state of our knowledge all the fern fronds are placed under Filicales. Mostly ferns grow in cool temperate shady places with high humidity. It is assumed that the Indian Permian ferns also grew under shady places beneath the *Glossopteris* trees and developed in variety in the Late Permian as the humidity increased.

Gymnospermophyta

Gymnosperms are the most dominant group of plants of the Permian of India. Generally they are referred to Cordaitales, Cycadales, Coniferales, Ginkgoales and Glossopteridales. The assignment of



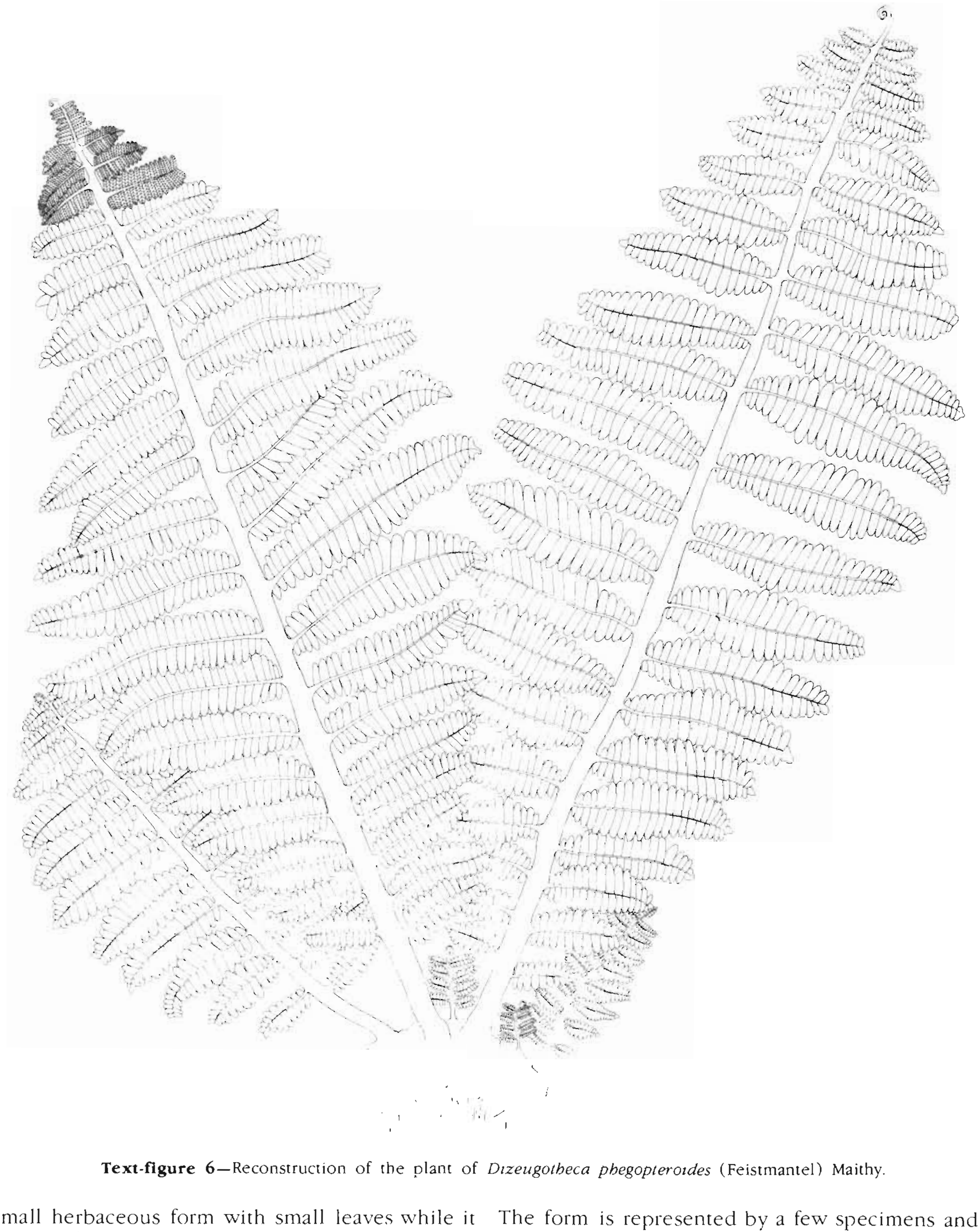
Text-figure 4—Reconstruction of the plant of *Raniganjia bengalensis* (Rigby) Pant & Nautiyal.

fossil plants to these groups is mostly tentative as most of them are known by their vegetative parts and the fertile organs are rarely found attached to them. There are divergent views on the classification of gymnospermous remains and their affiliation but this aspect is not considered in this paper. General consensus is followed to classify gymnospermous remains of the Glossopteris flora of India.

Cordaitales—Simple leaves known from the Early Permian beds are generally referred to *Noeggerathiopsis* having typical venation pattern. Though the genus was first recognised from the Kamthi beds, it is generally found in the Karharbari and Talchir formations and sometimes in the Early Barakar. The leaves are very much similar to the northern genus *Cordaites* and some authors have preferred to place the Indian forms under this genus. Others believe that both the *Noeggerathiopsis* and *Cordaites* forms were present in the Permian of India.

Inclusion of *Noeggerathiopsis* under Cordaitales is also not free from doubts in the absence of definite reproductive structures and typical discoid pith in the wood. Ovule bearing *Arberia* fructifications have been correlated with *Noeggerathiopsis* but there is no direct evidence. The genus is assigned to five species of morphographic characters and several species based on cuticular studies are also instituted. The plant of *Noeggerathiopsis* during Talchir time must have been

Text-figure 5—Reconstruction of the plant of *Trizygia speciosa* Royle.



Text-figure 6—Reconstruction of the plant of *Dizeugotheca phegopteroides* (Feistmantel) Maithy.

a small herbaceous form with small leaves while it attained a good size of a small tree in the Karharbari period and formed a major constituent of the forest vegetation.

Rather imperfectly known genus *Euryphyllum* Feistmantel has been identified in the Karharbari beds and is placed under Cordaitales (Lele, 1976). The form is represented by a few specimens and is of localised occurrence.

Coniferales—Conifers or conifer-like plants from the Permian of India are relatively few The well known examples are *Buriadia heterophylla* (Seward & Sahni) Pant & Nautiyal 1967 and

Walkomiella indica Surange & Singh 1953. *Buriadia florinii* Maithy 1970, *Walkomiella australis* (Feistmantel) Florin 1944, *Paranocladus? indica* Surange & Lele 1956, *P dusenii* Florin 1940, *P? fallax* Florin 1940 and *Searsolia oppositifolia* Pant & Bhatnagar 1975 are other forms assigned to this group. All these forms possess spirally disposed linear or squamiform leaves except *Searsolia* where the leaves are two ranked and inserted in opposite pairs.

The genus *Paranocladus* is known from the Talchir beds as vegetative shoots without reproductive structures. *Buriadia* and *Walkomiella* with their typical coniferalean fertile structures are known from Karharbari and Barakar formations. *Searsolia*, though imperfectly known with its fertile structure, is recorded from the Raniganj Formation. All these Lower Gondwana conifers are distinct from those of Northern Hemisphere forms.

The plants of *Paranocladus* appear to be very small while those of *Buriadia* and *Walkomiella* attain a bushy appearance. Doubtfully placed *Searsolia* within the conifers could be a small tree with profuse branching.

Cycadales—The order Cycadales is poorly represented by the foliage of the form genera *Pseudoctenis balli* (Feistmantel) Seward & Sahni 1920, *Senia reticulata* Khan 1969 and *Pteronilssonia gopalii* Pant & Mehra 1963. The authors have preferred to place *P gopalii* under Pteridosperms. According to others there was no need to designate *Pteronilssonia* as this could be easily placed under *Pseudoctenis*, perhaps with a separate specific epithet. The genus *Pseudoctenis* is well recognised in Barakar, Raniganj and Kamthi formations while *Senia reticulata* is reported so far from the Handapa beds. The reports suggest that the cycadalean plants appeared during the Middle Permian times as there are no authentic records from the Early Permian.

Consideration of all these forms under Cycadales is tentative on the basis of look-alike fronds and there is no solid reason for their inclusion in the group. Since the fossil remains are included in Cycadales it can be presumed that their habit could also be similar to present day cycads which generally do not form conspicuous vegetation in the forests.

Ginkgoales—Inclusion of some of the fossil remains from the Lower Gondwana formations under Ginkgoales is also on the basis of their general resemblance to *Ginkgo*-type leaves. Consideration of such leaves under this group is also tentative as there are no reproductive structures or cuticular details to support their identification. Such ginkgoalean remains are more common in the extra-peninsular region than in the peninsular region, where their occurrence is sporadic The fossil remains of *Ginkgophyllum, Platyphyllum, Gondwanophyton* and *Handapaphyllum* (Chandra & Singh, 1989) are reported from the Barakar and the Kamthi formations of the peninsular India.

With the present state of knowledge, it is very difficult to comment on the habit of the plants of this group. It can only be summarized on the basis of their sporadic occurrence that they grew in pockets and never formed a conspicuous vegetation of the forest in any formation.

Glossopteridales—Under this order we generally include most common leaf genera *Glossopteris* and *Gangamopteris*, less common *Palaeovittaria, Rhabdotaenia* and *Belemnopteris* and rarely found *Rubidgea* and *Surangephyllum*. Some authors prefer to include *Euryphyllum* and *Pteronilssonia* with this group while others retain them with Cordaitales and Cycadales. Inclusion of these leaf form genera with *Glossopteris* is merely on the basis of similarities in their form, general pattern of venation and cuticular structures. *Glossopteris* and *Rhabdotaenia* have single midrib, while *Gangamopteris, Rubidgea* and *Euryphyllum* are midribless forms. *Belemnopteris* and *Surangephyllum* possess two more midveins in addition to the midrib while *Palaeovittaria* is distinguished by having midrib up to half leaf length In *Glossopteris, Gangamopteris, Belemnopteris* and *Surangephyllum* cross connections are present so as to form anastomoses and reticulation, while *Palaeovittaria, Euryphyllum* and *Rhabdotaenia* lack them. At times it is difficult to assign some specimens to these genera because the distinguishing characters intergrade with each other so much that their distinction becomes obscure. Epidermal features of all these genera are very similar and it is impossible to distinguish them based on cuticular evidences.

Unlike the compound leaved gymnospermous remains of the Carboniferous and Permian rocks of Europe and North America most of the Indian forms seem to be simple leaved. Inclusion of all these similar looking forms under one head is only for convenience and no genetic relationship is implied.

Glossopteris Brongniart

It is the best known, most common member of the group. The leaf remains in India are known from the base to the top of the Permian and also perhaps in the Triassic. The leaves mostly occur in the form of impressions and a few as compressions. To date, there are no reports of petrified leaves from India, though they are known from Australia and Antarctica. The genus has the largest number of species, well over seventy from the peninsular region. Some species are characteristic of a particular formation and they could be useful for stratigraphic purposes (Chandra & Surange, 1979).

The size of the leaves is variable from very small (*G. taeniensis, G. senii*) to very big (*G. major, G. karanpurensis, G. sahnii*) having very narrow (*G. taenioides, G. gondwanensis*) to very broad lamina (*G. musaefolia, G. damudica*). Most of them appear to be sessile while quite a few with distinct petioles (*G. longicaulis, G. maculata*). Variety of midrib types are known with different kinds of reticulations as displayed by several species. Depending upon the shape of the leaf, variety of apices and bases are recognised. Surprisingly the epidermal features of the leaves are uniformly similar. The leaves are typically hypostomatic, epidermal cells straight to sinuous-walled and the stomata are haplocheilic and irregularly dispersed between the veins. The cells are usually papillate and the guard cells are sunken in a shallow pit.

Most of the leaves of *Glossopteris* are found in detached, dispersed conditions but there are few instances where they are preserved in attached condition to the axis. Stem attached leaves of *Glossopteris* have been reported by Bunbury (1861), Feistmantel (1881), Etheridge (1904), Zeiller (1896), Oldham (1897), Seward (1910), Du-toit (1927), Walton and Wilson (1932), Thomas (1952), Dolianiti (1954), Plumstead (1958), Pant (1967), Pant and Singh (1974) and Chandra and Srivastava (1981). Pant and Singh (1974) have shown that instances of actual attachment to the axes are rare. According to them some have *Vertebraria*-like shoots while others have no rectangular areas but have longitudinal striations and still others show spirally arranged leaf bases. Few of them have alternately attached leaves (*G. pandurata*), few are with oppositely attached leaves (*G. angustifolia*), and a majority have leaves in apparent whorls (*G. sastrii, G. maculata*). Some believe that the leaves were attached to short shoots as all hitherto reported foliage shoots have slender axes with only a few leaves attached thereto. In fact, all whorled arranged examples of leaves are close or tight spirals and in flattened condition during fossilisation they appear to be whorls. It is also possible that alternate and oppositely attached examples are also loose spirals of which some leaves have been shed.

Pant (1977) considers that *Vertebraria* definitely represents an axes of *Glossopteris* on the basis of similar anatomical structures. On the contrary, there are views that *Vertebraria* represents root system of the *Glossopteris* plant (Gould & Delevoryas, 1977; Schopf, 1965). Pant (1977) also described the roots of *Vertebraria* under the name *Lithorhiza tenuiirama.* It is quite likely that *Glossopteris* plant had similar anatomical system in stem and root at that stage of evolution and both the views could be valid but presently the evidences strongly favour that *Vertebraria* to be the root system of the plant. Irrespective of its being root or stem it certainly belongs to some of the species of *Glossopteris* and has a distinctive stelar structure.

In recent years, several fertile genera have been discovered and described from India, some of them are attached to the *Glossopteris* leaves. *Dictyopteridium feistmantelli* are attached to *Glossopteris tenuinervis, Plumsteadiostrobus ellipticus* to *G. gondwanensis, Jambadostrobus pretiosus* to *G. contracta, Venustostrobus diademus* to *G. ghusikensis, Scutum sahnii* to *G. maculata, Senotheca murulidihensis* to *G. syaldihensis* and *Ottokaria bengalensis* to *G. indica.* All other fertile organs referred to *Glossopteris* are based on the basis of their close association with the leaf in the same sediment. The fertile organs are found generally attached to the midrib of the leaves and the fertile organ-bearing leaves are found intermingled with the vegetative leaves. The arrangement of these fertile and vegetative leaves on the axis or branch is not known. Chandra and Surange (1977) have visualized the attachment of fertile organs to the parent plant in some of the genera.

It is also not known whether the plant was monoecious or dioecious, though there is some evidence that the ovules belonging to some of the *Glossopteris* plants were pollinated by bisaccate pollen (Chandra & Surange, 1977).

Surprisingly, except *Ottokaria bengalensis* all other attached fructifications are recorded from the Late Permian strata of India. Infact, most of the fructifications assignable to *Glossopteris* and reported from other Gondwana countries are also

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PLATE 1

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Reconstruction of Late Talchir vegetation:

1. Stunted form of *Glossopteris*
2. *Gangamopteris*
3. *Noeggerathiopsis*
4. *Paranocladus*
5. Equisetalean plant
6. Ice free land
7. Still ice covered land
8. Melted icy water.
9. Boulders
10. Floating ice.

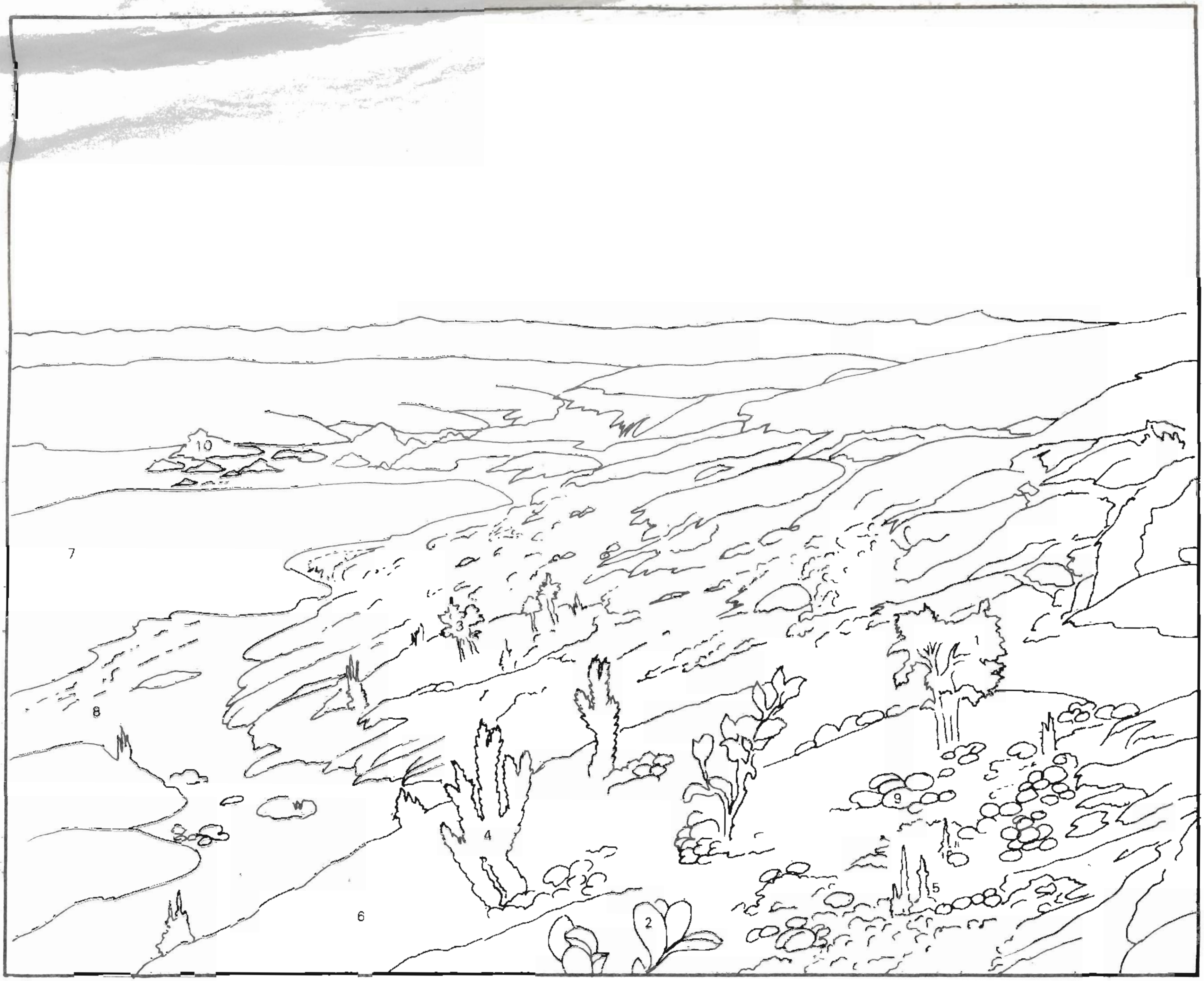
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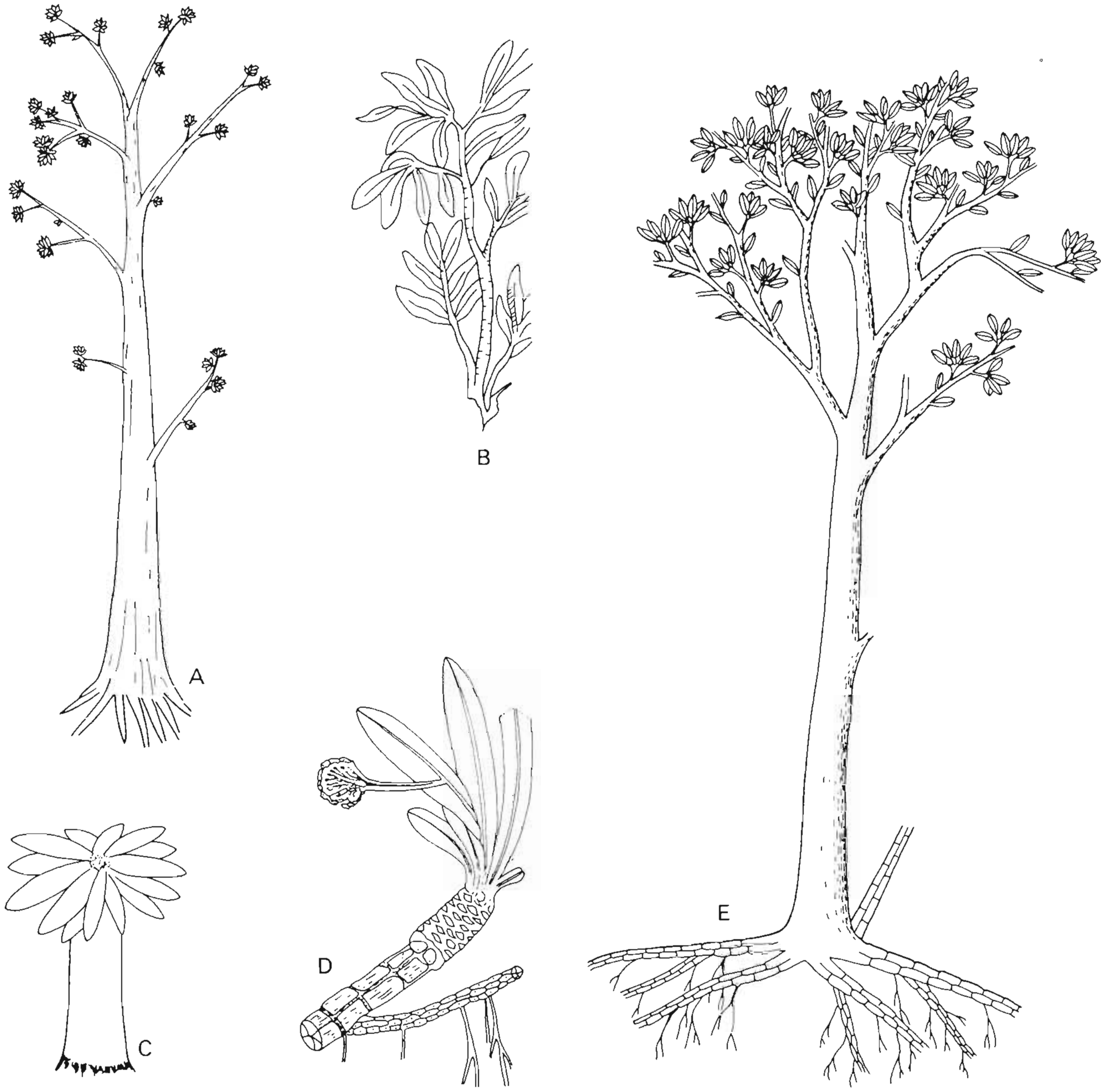
PLATE 1



Text-figure 7—Reconstructions of plant of *Glossopteris* as suggested by various authors. **A** and **C**—by Rigby, **B**—by Seward, **D**—by Pant, and **E**—by Pant and Singh.

from the Late Permian beds. The attachment of seemingly diverse fructifications to the leaves of *Glossopteris* suggests that the form genus *Glossopteris* is an unnatural genus and represents an assortment of a number of natural genera. As mentioned by Plumstead (1958) the occurrence of apparently similar fructifications in *Glossopteris, Gangamopteris* and *Palaeovittaria* may suggest that the boundaries

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PLATE 2

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Reconstruction of Karharbari vegetation:

1. *Glossopteris*
2. Variety of *Gangamopteris* species
3. *Noeggerathiopsis*
4. *Phyllotheca*
5. *Gondwanidium*
6. Usual fern plant
7. *Buriadia*
8. *Schizoneura*
9. Tree trunk
10. Site for deposition of vegetal matter.


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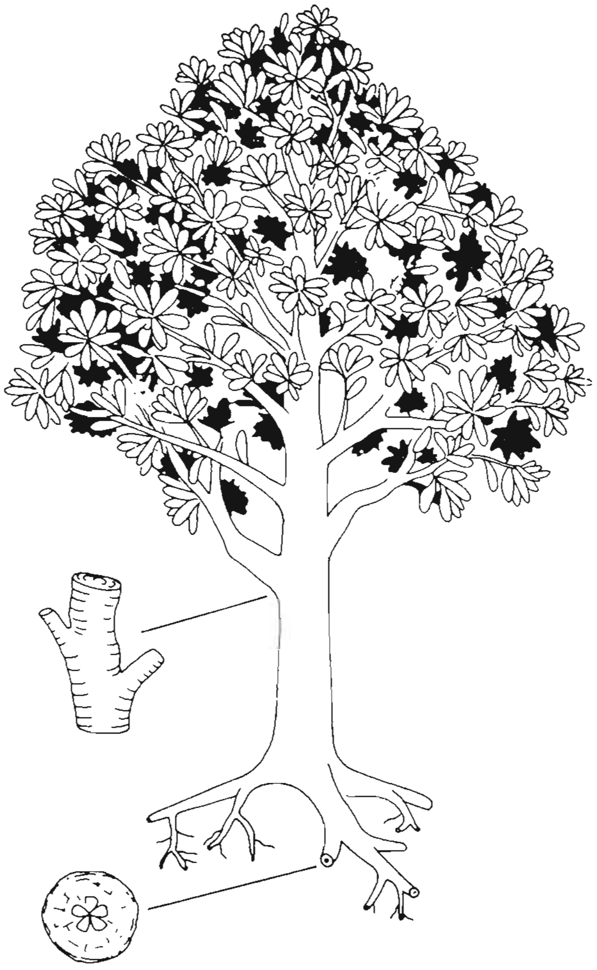

Text-figure 8—Reconstruction of the plant of *Glossopteris* as suggested by Gould & Delevoryas.

between these form genera include leaves of number of natural genera, though they might be interrelated. It has already been suggested (Surange & Chandra, 1975; Maheshwari, 1990) that these various fructifications belong to two rather different groups of plants. The author contemplates more than two orders, perhaps four, on the basis of the organization of ovules. Under such conditions the form genus *Glossopteris* will have to be split into various separate organ genera in future with the advancement of knowledge and data. Accordingly the plant of *Glossopteris* should not be viewed as representing one particular habit or reconstruction but may represent a variety of plant habits.

Plant of Glossopteris—Seward (1941) was the first to reconstruct the plant of *Glossopteris* as a small shrub (Text-figure 7B). Later Plumstead (1958, 1967) talked about the plant of *Glossopteris* on the basis of factual and circumstantial evidences. She concluded that "Glossopteridae were mainly deciduous woody plants of arborescent habit and that the leaves, flowers and fruits grew as short shoots, at fairly wide intervals from the woody stem and also terminally and that they represented a new experiment in plant evolution in Palaeozoic times". Rigby (1964) reconstructed the plant as an unbranched tree trunk bearing a crown of *G. browniana* leaves (Text-figure 7C). Later he depicted *Glossopteris* as a tall tree with whorled small leaves occurring in tufts (Text-figure 7A) in his reconstruction of the Lower Gondwana scene (Rigby, 1969). Gould and Delevoryas (1977) reconstructed the *Glossopteris* plant and opined that "*Glossopteris*, probably a deciduous arborescent gymnosperm, is considered to be a distinct type of pteridosperm" (Text-figure 8).

Pant and Singh (1974) on the study of Indian fossils thought that the *Glossopteris* plant had terminally or laterally attached leaves which belonged to two kinds of shoots (Text-figure 7D, E). Those which had short shoots with short internodes and those whose short shoots had long internodes. Alternatively shoots with terminal clusters may be assumed to be short shoots and the shoots with laterally attached leaves may be taken to represent long shoots. The authors compared the habit of *Glossopteris* with that of modern *Ginkgo biloba*. The shoots of *Glossopteris* which show terminal clusters and those which have laterally attached leaves may be compared, respectively, with the short and long shoots of *Ginkgo*. The authors further mentioned that the leafy short shoots might lend some support to the views about the arborescent nature of the plants.

With the advancing knowledge of reproductive biology of *Glossopteris* it can be assertively and conclusively said that *Glossopteris* is no more a form genus, genus, super genus, family or order but represents a unique class unparalleled in the present day Plant Kingdom. It will be wrong to visualize one type of plant habit for all the species of *Glossopteris*.

PLATE 3

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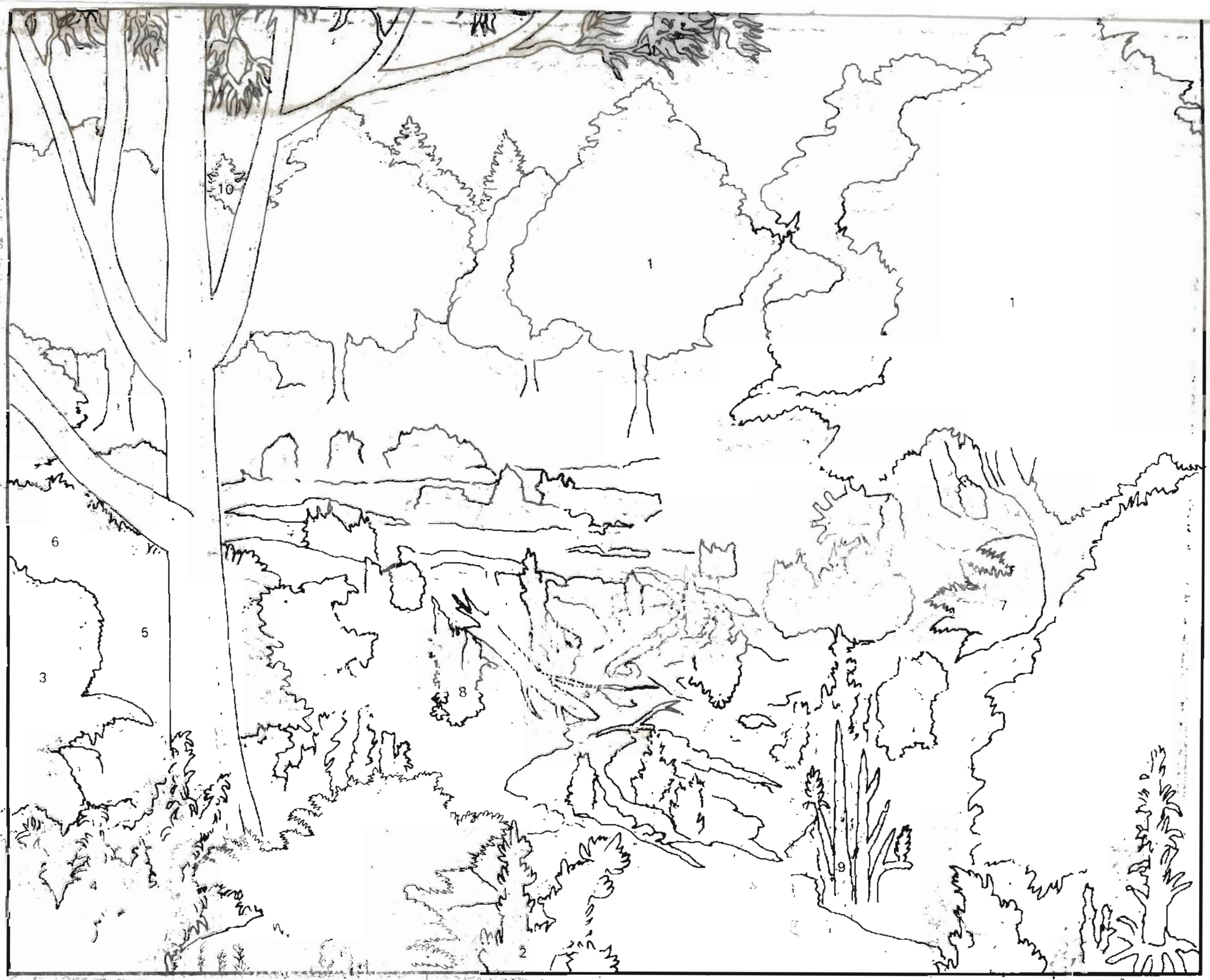
Reconstruction of Barakar vegetation:

1. *Glossopteris*
2. *Phyllotheca*
3. Usual fern plant
4. *Lelstotheca*
5. *Macrotaeniopteris*
6. *Rhabdotaenia*
7. *Pseudoctenis*
8. Log of *Glossopteris* plant
9. *Schizoneura*
10. *Walkomiella*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Plants of *Glossopteris* during Talchir time were perhaps very stunted forms attaining a height of a small shrub. This can be explained by the fact that we have no knowledge of woody stems from this period from India or any other Gondwana country The plant here is at the lowest level of evolution as it made its first appearance in the Talchir Formation in India. We have no knowledge about its origin or parent stock. In the Karharbari time some of the species attained a height of big trees while others remained as small bushy plants. In the Barakar or Raniganj times most of them acquired an arborescent habit but some species could as well have retained a herbaceous habit. Some believe that big leaves are borne by small trees while the smaller leaves by bigger trees.

Pant and Nautiyal (1987) consider that *Diphylloptelis verticillata* from the Barakar Formation of Auranga Coalfield is the seedling of *Glossopteris*, preserved vertically compressed in growth position.

Gangamopteris McCoy

The genus is regarded as the most primitive of the glossopterids and is generally found in the Early Permian strata of India. In comparison to *Glossopteris* it has fewer number of species. The form genus is known in the form of impressions or compressions and no definite fructification is reported from India.

Pant and Singh (1974) reported one specimen of *Gangamopteris* cf. *Cyclopteroides* var *cordifolia* with two nearly complete leaves attached in opposite manner to the axis. Rigby (1967) reported many spirally arranged tufts of *G. walkomii* from New South Wales. Plumstead (1966) visualised *Gangamopteris* as a small herbaceous plant, while Rigby (1969) reconstructed it as a tall tree with whorled small leaves growing in tufts. He made *Glossopteris* and *Gangamopteris* as having similar habit. Pant and Singh (1974) imagined *Gangamopteris* as an arborescent tree having leafy short shoots.

Reports of *Gangamopteris* leaves are mostly from the Karharbari and Talchir formations and indefinite stray records from other formations. In Talchir time the plant of *Gangamopteris* was very small like *Glossopteris*. It attained its maximum development in the Karharbari period showing varied habits. Most of the vegetal matter for Karharbari coal is formed by *Gangamopteris* plant. It is presumed that some of the species were small shruby plants while others attained the habit of a large tree.

Palaeovittaria Feistmantel

The genus is distinguished from other Lower Gondwana spatulate leaves by its simple or forked veins, running parallel or sub-parallel to each other and by having an ill-defined midrib only in the basal part of the leaf. The genus has been recognised only in the Late Permian beds of Raniganj Coalfield by two species. Feistmantel's specimen of *Palaeovittaria kurzii* shows nine very perfect fronds arranged as if springing from the common point of attachment. Now it appears that the plants of *Palaeovittaria* are of localized occurrence and do not form conspicuous vegetation like *Glossopteris* or *Gangamopteris*.

Petrified woods and their affinities

A large number of petrified woods have been reported from the Barakar, Raniganj and Kamthi formations of India. Their affinities are mostly unknown. Earlier most of the woods were placed under the name *Dadoxylon* but later they have been assigned to a number of genera on the basis of pith, secretory cells, primary and secondary xylem, medullary rays, ray field pits and tracheidal pits. In the absence of any association of these woods with foliage shoots, it is not possible to assign them to any particular group. It is also difficult to assign most of these woods to any particular gymnosperm of that time. Presently it can only be said that these woods belong to gymnospermous plants of the Permian period.

ANCESTORS AND ORIGIN OF GLOSSOPTERIS FLORA

Who were the ancestors of *Glossopteris* plant or other plants of the flora? This aspect is still not well understood as there are no significant records prior to Permian. The ancestors of this flora and their geographical situation are still controversial. Plumstead (1967) believed that the Protoglossopterideae, whose remains were found from the Carboniferous beds of South Africa, were the ancestors of glossopterids of the post glacial coal-bearing Gondwana strata. The idea was discarded by many workers as these Protoglossopterid plants were actually smaller forms of *Glossopteris* and were recovered from the same beds as others. Sahni (1939) believed that almost sudden and enigmatic arrival and spread of the Glossopteris flora is deeply rooted in the glacial episode itself which presumably might have triggered genetic changes of rapid evolutionary significance. Accordingly there might have been mass mutational changes in the then existing flora giving rise to *Glossopteris* and allied forms. The general consensus favours this explanation.

PRE-PERMIAN VEGETATION OF INDIA

The knowledge of Early Palaeozoic flora of India is meagerly known. There are several gaps in the earliest plant-bearing strata of Silurio-Devonian period as land conditions prevailed in very few restricted area. In the Lower Carboniferous, fossil plants are known only from one area, the basal part of the PO Series of Spiti. The fossil plants include *Rhacopteris* and other characteristic elements of the Northern Hemisphere Lower Carboniferous period. Towards the end of the Carboniferous, however, an extensive glaciation prevailed which wiped out most of the older vegetation. In the wake of this climatic revolution in the South there appeared an almost entirely new type of vegetation which is named after its predominant genus *Glossopteris*. This flora flourished throughout the Permian Period and eased out in the Lower Triassic by a new flora.

PERMIAN VEGETATION OF INDIA

Talchir Formation, vegetation and forest type

The Talchir Formation starts with the Gondwana glaciation in India and occupies a special place in Lower Gondwana stratigraphy. The formation rests directly on the Precambrian and is conformably overlain by the coal-bearing Damuda Group. The wide spread glaciation during Talchir is evidenced by the boulder beds, tillites and varvites at the base. The Boulder Bed is overlain by Needle Shales and higher up by siltstones and sandstones.

There is evidence of plant life at the beginning of the Gondwana Era in the Boulder beds by the recovery of spores and pollen (Lele & Karim, 1971; Lele & Chandra, 1973). Higher up in the Talchir Needle Shales a fairly good plant assemblage has been recovered near Goraia in the Johilla Coalfield of South Rewa Gondwana Basin (Surange & Lele, 1957). The assemblage is represented by *Gangamopteris cyclopteroides, G. angustifolia, Gangamopteris* sp., *Noeggerathiopsis hislopi, Cornucarpus furcata, Samaropsis goraiensis, Paranocladus ?indica, Arberia umbellata* and Equisetaceous stems. Reports of *Paranocladus* from India by Lele (1976) was interesting as this plant was considered to be restricted to Brazil. Lele and Chandra (1973) later on found megaspores and seed cuticles from Chada Village of Johilla Coalfield. In the adjoining Chirimiri, Anupur and Singrauli coalfields well-preserved remains of *Gangamopteris, Noeggerathiopsis, Glossopteris* and seeds were reported.

Surange and Lele (1956) reported stunted forms of *Gangamopteris* and *Noeggerathiopsis* from the Needle Shale of the Talchir Formation from 3 meter above the Boulder Bed in the Giridih Coalfield. Earlier, Feistmantel (1879) had reported *Schizoneura*, an equisetaceous stem, *Gangamopteris cyclopteroides, Noeggerathiopsis hislopi* from Deogarh area and *Gangamopteris ?angustifolia, Gangamopteris* sp., a specimen of *Glossopteris* and a few equisetaceous stems from the Karanpura Coalfield.

The palynological assemblages of the Talchir are even richer as evidenced by the monosaccate rich mioflora from the matrix of the Boulder Bed (Lele & Karim, 1971; Lele & Chandra, 1973). The assemblage is characterised by the prevalence of monosaccate pollen associated with a few disaccate pollen, simple trilete spores and monocolpate pollen. The entire assemblage is rather distinct and can serve to demarcate the Talchir Formation. Tiwari (1975) suggested three tentative zones in the Talchir Formation, however, this can not be substantiated by megafossil studies.

Faunal records from Talchir Needle Shales consist of conchostracans, fragments of small winged insects and other arthropods.

Talchir plant community, climate and landscape

The Talchir plant community consists of glossopterids, conifers and Equisetales. The plants of *Gangamopteris* and *Noeggerathiopsis* are well-represented in most of the basins while *Glossopteris* appeared late in some of the basins. If we consider equisetalean stems as representative of the group some of the forms appeared almost in every basin. Regarding the presence of conifers, represented locally by *Paranocladus*, doubts have been expressed about the identification. It can safely be concluded that *Gangamopteris* and *Noeggerathiopsis* are the oldest and most ancient of the plants of Glossopteris flora to have appeared first on the scene.

The vegetation was very scanty during Talchir time (Plate 1). The leaves of all the plants were strikingly small, sometimes fleshy, curled or folded up in sediments and the venation mostly very fine and crowded. The plants bearing these leaves were also very small and stunted growing in small hospitable places (Plate 1).

In the early phase of Talchir deposition the Indian Peninsula was presumably a land surface of high elevation ice covered and nearly barren of vegetation (Lele, 1976; Chandra & Chandra, 1987). The Early Talchir basins were embryonic without any diastrophic control (Ghosh & Mitra, 1975). The glacial sedimentation in several basins indicate a cyclic pattern governed by advancing and retreating ice fronts. Records of fossils are poor everywhere in the Lower Talchir. Towards the end of the Talchir the flora shows definite improvement. The plants continued to occupy the land as more and more space became available by melting of ice. The climatic situation seems to have improved considerably with the increased sunlight and temperature and improved size of the leaves (Surange, 1966; Lele, 1976; Chandra & Chandra, 1987). It seems appropriate that the *Glossopteris* flora had already come into existence before the land was ice free (Sahni, 1939). This also indicates that some of the hardy plants could survive even under an ice cover.

The Talchir landscape shows the scene (Plate 1) with *Gangamopteris, Noeggerathiopsis, Glossopteris, Paranocladus* and some equisetaceous plants growing on ice free pockets of land. All the plants are small in size and represent stunted forms. Most of the land is shown still covered with ice.

Karharbari Formation, vegetation, forest type

Lithologically Karharbari Formation is a distinct unit in the Giridih Coalfield and is well-recognized in the Johilla and Chirimiri coalfields of the South Rewa Gondwana Basin, Manendragarh area and coalfields of Hutar, Auranga, Karanpura and Mohpani. The formation consists of grey to brown mottled carbonaceous sandstones, grits and conglomerates with occasional coal seams and fire clays.

Palaeobotanically this formation is interesting as *Gangamopteris* and *Noeggerathiopsis*, both midribless leaf forms, attained their maximum development here. Some new plants like *Gondwanidium, Euryphyllum, Rubidgea, Ginkgophyton, Palmatophyllites, Dolianitia* and *Buriadia* appear for the first time in this formation, though few of them are of localized occurrence. The flora of the Karharbari Formation has been worked out by Maithy (1966), Pant and Gupta (1968) and Pant and Nautiyal (1968).

The well known Giridih flora comprises *Schizoneura* 2 spp., *Phyllotheca* 2 spp., *Gondwanidium* 2 spp., *Neomariopteris* 1 sp., *Gangamopteris* 17 spp., *Glossopteris* 17 spp., *Noeggerathiopsis* 11 spp., *Rubidgea* 2 spp., *Euryphyllum* 2 spp., *Buriadia* 1 sp., *Cordaicarpus* 2 spp., *Samaropsis* 6 spp., *Ottokaria* 1 sp., *Arberia* 2 spp., *Ginkgophyton, Palmatophyllites* and *Dolianitia* each with one species.

The Karharbari plants from South Karanpura Coalfield are represented by *Gangamopteris* 4 spp., *Glossopteris* 4 spp., *Vertebraria* and *Phyllotheca* (Kulkarni, 1971) and from Auranga Coalfield by *Neomariopteris, Noeggerathiopsis, Samaropsis, Euryphyllum* and *Vertebraria.*

Palynologically the formation is well recognised with distinct biozones. The monosaccates of the Talchir Formation continue to dominate and are associated with a trilete genus *Callumispora.* Nonstriate-disaccates and *Sulcatisporites* are typically present in the Upper Karharbari. Faunal remains are neorachitomous amphibians, different reptiles and large neuropteroid insects.

Karharbari plant community, climate and landscape

It appears that the Karharbari Formation marked a definite time period in which unfavourable climatic condition of the Talchir began to grow milder favouring the growth of new plants. The plant assemblage is distinct in many ways and can easily be differentiated from the Talchirs below and the Barakar above.

Preponderance of *Gangamopteris* and *Noeggerathiopsis* is observed and true fern allies appeared for the first time on the scene and the same hold true for Equisetales as shown in the landscape. Tree habit of the plants could also be visualized (Plate 2) by the presence of fossil woods from this formation. It is expected that some of the species of *Gangamopteris* attained small tree habit forming major constituent of the Karharbari forest.

Noeggerathiopsis attained maximum diversity and development in this formation. The plants of *Glossopteris* were represented by narrow meshed, small-sized leaves bearing multiovular *Ottokaria* fructifications. Much of the peat for coal formation was provided by *Gangamopteris, Noeggerathiopsis* and *Glossopteris* plants. The marker plants like *Buriadia* and *Gondwanidium* were also growing intermingled with dominant plant groups but did not form conspicuous vegetation. Equisetales and ferns growing near water logged places formed the under cover of the forest. Overall assessment of the flora makes the plant community of the Karharbari distinct from the underlying Talchirs and overlying Barakars. This can be assessed by the fact that the climatic conditions of the Talchirs improved in the Karharbari. The glaciers had completely disappeared from the ground leaving ample space for luxuriant plant growth. Substantial deposits of Karharbari coals also suggest proliferation of vegetation in coal basins. Bisaccate pollen indicate pollination by wind and presence of winged seeds indicate dispersal by strong winds.

Barakar Formation: vegetation and forest type

During Barakar sedimentation the peninsular Gondwana basins witnessed its acme of development. The restricted basins particularly of Damodar, Godavari and Pench Valley assumed wide geographical extent in Karharbari time. The sedimentation regime in the Gondwana grabens expanded and the fluvial regime encroached on the adjacent area. The present day distribution of Barakar Formation is an erosional remnant of far more widespread deposits. The formation includes the principal coal-bearing strata in India and displays vertical alterations of sandstones and finer sediments. The Barakar sandstones are generally coarser than those of the underlying Karharbari and the overlying Kulti Formation. These are gray, white to yellow or brownish gritty or pebbly sandstones which are frequently cross bedded. Interbedded with the sandstones are siltstones and shales, fire clays and coal seams. The formation is well represented in Damodar Valley, Satpura area, Godavari Valley and the South Rewa Gondwana Basin. The Barakar vegetation is dominated by *Glossopteris* plants having mostly with narrow meshed leaf forms. *Gangamopteris* and *Noeggerathiopsis* plants which were dominant in the Karharbari are nearly absent though they might be present in the Early Barakars in some coal basins.

Pteridophytic remains are few in the Barakars as compared to the Raniganj Formation but are well represented by various genera. The equisetaceous genera are *Phyllotheca* (5) spp., and *Lelstotheca, Schizoneura* and *Trizygia* represented by one species each. Some have recognized the presence of *Sphenophyllum* as well. The fern-like plants are represented by *Neomariopteris* species.

The other gymnosperms of the Barakar vegetation include *Pseudoctenis balli, Rhabdotaenia danaeoides, Macrotaeniopteris feddeni, Gondwanophyton indicum* and *Barakaria dichotoma.* The only conifer known from the Barakar is *Walkomiella indica.* Fossil plants of all these forms are of sporadic nature and not of uniform occurrence in all the Barakar assemblages. Few glossopterid fructifications like *Eretmonia* are known but they are of rare occurrence. A large number of wood genera are reported but their affinities are mostly uncertain.

The plant assemblages of Barakar Formation were recorded from South Karanpura, Auranga, Singrauli, Raniganj coalfields and South Rewa Gondwana Basin.

The Barakar palynoflora comprising more than 50 genera has been divided into Lower, Middle and Upper zones characteristically correlatable to Lower, Middle and Upper Barakars. The Lower Barakar is distinguished as Zonate-singulate Zone, the Middle as *Scheuringipollenites/Vesicaspora* Zone and the Upper Barakar as *Podocarpites* Zone. In later years, palynologists have recognized finer zones. Megafossil studies do not support or corroborate the palynological zones in Barakar. Faunal records are virtually the same as that from the Karharbari Formation.

Barakar plant community, climate, landscape

The vegetation during the Barakar time was lush green dominated by arborescent *Glossopteris* plant community with secondary wood. The forests were very dense swampy in low lying river valleys as shown in the landscape (Plate 3). The climatic conditions during Barakar were warm temperate, in general, with appreciable amount of humidity. Intermittent spells of hot and cold seasons were also recorded with abundant rainfall. The Barakar is an important period exhibiting maximum development of coal of our country. 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 mineral matter is found intergrown with the coals (Basu, 1964).

It is further observed that during Middle Barakar, the vegetal matter might have possibly been 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.

Kulti Formation, vegetation, forest type

After the end of Barakar sedimentation, the peninsular basins witnessed deposition of a varied array of lithofacies. In Chanda-Wardha Valley a hiatus is recorded at the top of the Barakar Formation which denotes either a period of erosion or of non-depositional phase of overlying unit. In Damodar Valley, the Barakars are succeeded by Barren Measures which are devoid of economically exploitable coal seams sandwitched between the Barakar and Raniganj coal formations. In the Raniganj Coalfield it is known as the Ironstone Shale Formation because of the preponderance of ironstone bands.

In the Satpura-Kamptee belt, the Motur Formation has been correlated with the Kulti Formation. In the Damodar Valley, it is represented by thick micaceous shales with ferruginous bands and medium to coarse grained sandstones. This formation is devoid of any workable coal in any of the basins.

Floral records from the Barren Measures are meagre and are reported from Raniganj and Jharia coalfields. Feistmantel (1881) reported *G. damudica, G. musaefolia, G. communis (G. raniganjensis)* and *G. ?stenoneura* from Kulti, Raniganj Coalfield. Kar (1968) reported *Cyclodendron leslii, Neomariopteris hughesii* and three species of *Glossopteris* from the Jharia Coalfield. Chandra and Surange (1979) suggested that only four species, viz., *G. damudica, G. raniganjensis, G. indica* and *G. stenoneura* are represented in Kulti. Surprisingly, most of the *Glossopteris* species reported are large-sized leaves; some of the doubtful records of *Rhabdotaenia, Gangamopteris* and *Noeggerathiopsis* need revision for correct identification.

Rich palynological assemblages have been reported from several coalfields. The records reveal the dominance of striate-disaccate pollen alongwith *Densipollenites* and a few trilete spores. Three zones have been recognized on the basis of variable percentage of *Densipollenites*.

Megafossil and palynological studies present varying results. Chandra and Chandra (1987) have adduced reasons for the paucity of megafossils. The forest during Kulti time were sparse and not as dense as they were in Barakar and Raniganj times, though the vegetation, in general, was the same and continuous. The forests were dominated by mediumly built arborescent trees of *Glossopteris* with secondary wood.

Kulti plant community, climate, landscape

It was generally believed that the climate during Kulti Formation was arid but the present state of evidences indicate warm, humid, temperate climate (Chandra & Chandra, 1987). The plant community in general is represented by *Glossopteris* species, ferns and lycopods. Presence of lycopods and ferns indicates appreciable amount of humidity necessary for their growth. It can safely be presumed that the climate was favourable for plant growth but unfavourable for their deposition and preservation. The absence of coal, paucity of flora and occurrence of ferruginous bands in Kulti indicate destruction of vegetal matter due to oxidation.

The background of the landscape shows the abundance of *Glossopteris* trees. However, ferns and lycopods are seen in the foreground inhabiting the open area around small ponds or lakes in front (Plate 4).

The deposition of Barren Measures appears to be restricted to a limited area. The plants which flourished in Barakars continued to grow in an uninterrupted manner in most of the areas and extended into the Raniganj Formation. Some species continued to live in areas away from the Barakar swamps in Damodar Valley during the Barren Measure interval and when the conditions became favourable they invaded the swamps. In other areas of peninsular India the plant life continued uninterruptedly until the end of the Raniganj Period.

Raniganj Formation, vegetation and forest type

Since the Barren Measures times onwards, there is notable reduction in the coal-bearing areas on the one hand as in Raniganj and Jharia coalfields and the rapid expansion of the noncarbonaceous, ferruginous, arenaceous, variegated sediments Kamthi facies on the other.

The Raniganj Formation is mainly developed in Damodar Valley coalfields and is the major coal-bearing horizon. The formation is chiefly composed of thick massive cross bedded to laminated fine to medium grained sandstones with interbedded siltstones, shales and coal seams.

The Glossopteris flora is best developed in the Raniganj Formation represented by the maximum number of leaf forms, fructifications and woods. Pteridophytes and gymnosperms reached their maximum development both in quantity as well as variety.

Articulates are well represented by *Trizygia, Raniganjia, Phyllotheca* and *Schizoneura* mostly by a single species in each genus. Fern and fern-like plants are represented by *Neomariopteris, Damudopteris, Dizeugotheca, Dichotomopteris, Damudosorus, Leleopteris, Asansolia, Trithecopteris* and *Cuticulatopteris*. Some of these genera are synonyms and are formulated on not sufficient grounds.

Gymnosperms are represented by a high

PLATE 4 →

Reconstruction of Kulti vegetation:
1. *Glossopteris*
2. Fern plant
3. *Cyclodendron*

PLATE 4

number of *Glossopteris* species which are distributed uniformly in all the coalfields of peninsular India. Large-sized leaves with broad meshed forms of *Glossopteris* plants are well represented. *Gangamopteris* and *Noeggerathiopsis* are totally absent though doubtful records are reported. Some new forms assigned to *Glossopteris* also make their appearance, viz., *Palaeovittaria, Belemnopteris* and *Surangephyllum*. Interestingly multiovular fructifications like *Scutum, Jambadostrobus, Venustostrobus, Plumsteadiostrobus* and *Dictyopteridium* are best developed in the Raniganj Formation but the other types of fructification with scales and branching pattern are totally absent.

Non-glossopterid gymnosperms are represented by *Macrotaeniopteris feddeni, Rhabdotaenia daneoides, R. fibrosa, Pseudoctenis balli, Pterophyllum burdwanense Pteronilssonia gopalii* and *Rhipidopsis densinervis* and their distribution is localized. They are not uniformly present in all the beds of the formation. The conifer-like shoots are represented only by *Searsolia oppositifolia*.

Palynological assemblages in general show quantitative increase in trilete and monolete spores. The Lower Raniganj assemblage is dominated by striate-disaccate pollen and is subdominated by trilete and monolete spores. The Middle and the Upper Raniganj assemblages are recognized by the relatively high percentage of striate-disaccates and triletes.

The faunal records of the Raniganj Formation are: palaeonisceds, xenacanthodian sharks and ?diphoans ecologically related to Euramerian faunas of warm humid climate (Satsangi, 1987; Shah & Schneider, 1988).

Raniganj plant community, climate and landscape

Restoration of Raniganj plants envision lush green dense vegetation with variable habits and habitats. *Glossopteris* plants were mostly arborescent trees and also were the major constituents of the forest. Some species could be small trees or shrubs attaining considerable height, though shrubby and herbaceous habits are rare for the gymnospermous plants. The venation pattern of the *Glossopteris* plants also diversified and species with open mesh forms show preponderance over narrow mesh forms and intermediate mesh forms. Open mesh type of reticulation is another indicator of warm and humid climate. The epidermal characters of any gymnosperm are also indicative of mesophytic conditions. Plants like *Trizygia* were small delicate plants and might have been trailing on some bigger plants. *Phyllotheca* and *Schizoneura* like *Equisetum* were perhaps growing in semiaquatic conditions. There were marshy places suitable for plants having ribbed stems. The stems and leaves were succulent in nature as indicated by their way of preservation and were also green carrying out photosynthetic activities for the plant.

Ferns inhabit places with diffused sunlight and the shade was provided by high trees of *Glossopteris* (Plate 5). Some ferns were delicately built forming the undercover of the Raniganj forest as evidenced by slender rachis and dainty pinnules. Others attained small tree-like habit as evidenced by big pinnules with prominent veins attached to wide and strong rachis which is often winged. Some ferns possessed open branching system. Most of the Permian ferns bore marattiaceous sporangia favouring warm and humid environment for their luxurient growth. Fossil woods represented by several form genera also indicate that they belong to tree plants. The secondary wood with well-developed growth rings suggests seasonal variability in a year.

Kamthi Formation, vegetation and forest type

The Kamthi Formation, equivalent to Raniganj Formation was first recognized in the Wardha-Godavari Valley. It is characterised by the red and grey argillaceous sandstones and conglomerates with interstratified red shales. The sandstones vary greatly in colour and character. In the type area the Kamthi Formation overlies the Barakar unconformably.

Plant fossils of the Kamthi Formation were initially reported by Bunbury (1861) and Feistmantel (1881). In recent years the knowledge of the Kamthi Formation was greatly advanced by Chandra and Prasad (1981). The assemblage is recognized by typical species of *Glossopteris*, viz., *G. musaefolia, G. stricta* and *G. leptoneura*. Other plant types are

PLATE 5

Reconstruction of Raniganj vegetation:
1. *Glossopteris*
2. *Palaeovittaria*
3. *Pseudoctenis*
4. *Trizygia*
5. *Raniganjia*
6. *Schizoneura*
7. *Phyllotheca*
8, 9, 10. Usual fern type plants
11. Tree like fern plant
12. Logs of *Glossopteris* plant
13. Vegetal matter.

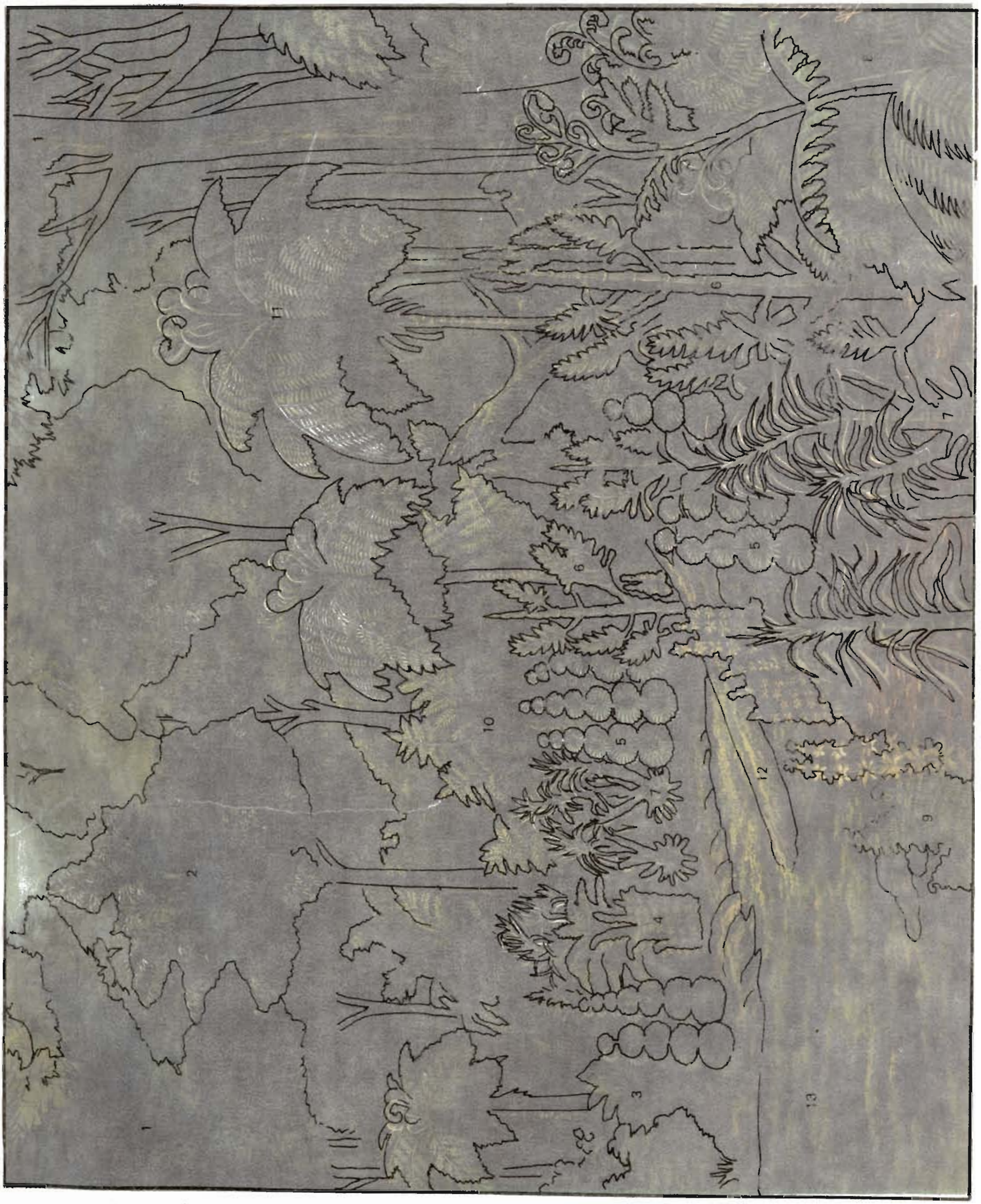


PLATE 5

PLATE 5

common to the Raniganj flora except that a large number of fossil woods belonging to several genera are also reported from Chandrapur area. Several tree trunks, more than a meter in diameter, were found from this area. One of the fossil tree measuring almost ten meters in length was seen lying in the forest of Bazargaon Village in Chandrapur District of Maharashtra. These tree trunks are believed to be belonging to *Glossopteris* plant as no other gymnosperm is recorded from the location. This is perhaps the only Permian record of *in situ* occurrence of tree trunks of *Glossopteris* plant from India.

Five palynological zones have been recognized in the Kamthi Formation of Godavari Graben.

In recent years a locality rich in plant fossils has been discovered near Handapa Village in Hinjrida Ghati of Dhenkanal District, Orissa. The flora, mainly studied at the Institute, comprises lycopod—*Cyclodendron leslii;* articulates—*Trizygia speciosa, Phyllotheca indica, Raniganjia bengalensis, R. etheridgei, Schizoneura gondwanensis, Lelstotheca robusta, Sphenophyllum crenulatum, S. churuliensis, S. utkalensis*; ferns—*Dizeugotheca phegopteroides, Neomariopteris hughesi, N. polymorpha, N. khanii, Pantopteris gracilis, Damudopteris bengalensis, Asansolia* cf. *phegopteroides*; Cycads—*Pseudoctenis ballii, Senia reticulata*; Ginkgoales—*Handapaphyllum indicum* and *Glossopteris* represented by 41 species. The complete flora is being published elsewhere. The *Glossopteris* species exhibit various types of venation (Singh & Chandra, 1987) and forms of different shapes and sizes. Many male and female fructifications are found from these beds only. So far they have not been reported from other equivalent formations and localities. Some of the typical forms are *Glossotheca, Partha, Denkania, Utkalia, Khania, Indocarpus* and *Lidgettonia*.

Kamthi plant community, climate and landscape

The forests of Kamthi times were dominated by huge trees of *Glossopteris* of considerable height belonging to several species. Dense leaf cover of the trees provided shade for the fern plants. The arthrophytes and lycopods grew around the ponds or lakes. The Kamthi forest scenario is being published elsewhere and therefore is not included here. Most of the vegetation of Kamthi forest is similar to Raniganj forest. Unlike the Raniganj forests, the Kamthi forests perhaps grew on uplands. The climatic conditions of Kamthi times were very suitable for the luxuriant plant growth, i.e., warm and humid. The red bed facies of the ferruginous sandstones indicate seasonal variability of dry spells. This could be one of the reasons for non-formation of coal in Kamthi times in spite of the presence of enormous vegetal matter.

CONCLUDING REMARKS

The sequence of plant remains in the Permian peninsular basins of India reveals a clear succession of ancient floras. They have been related to palynological and faunal records, sedimentary environments and palaeoclimates to reconstruct a detailed vegetational history, thereupon depicting changing scenarios through Permian time. In the foregoing account, all the inter-related aspects are discussed in detail. In general three major interconnected ecosystems may be construed: (i) lacustrine, (ii) terrestrial, and (iii) marshy.

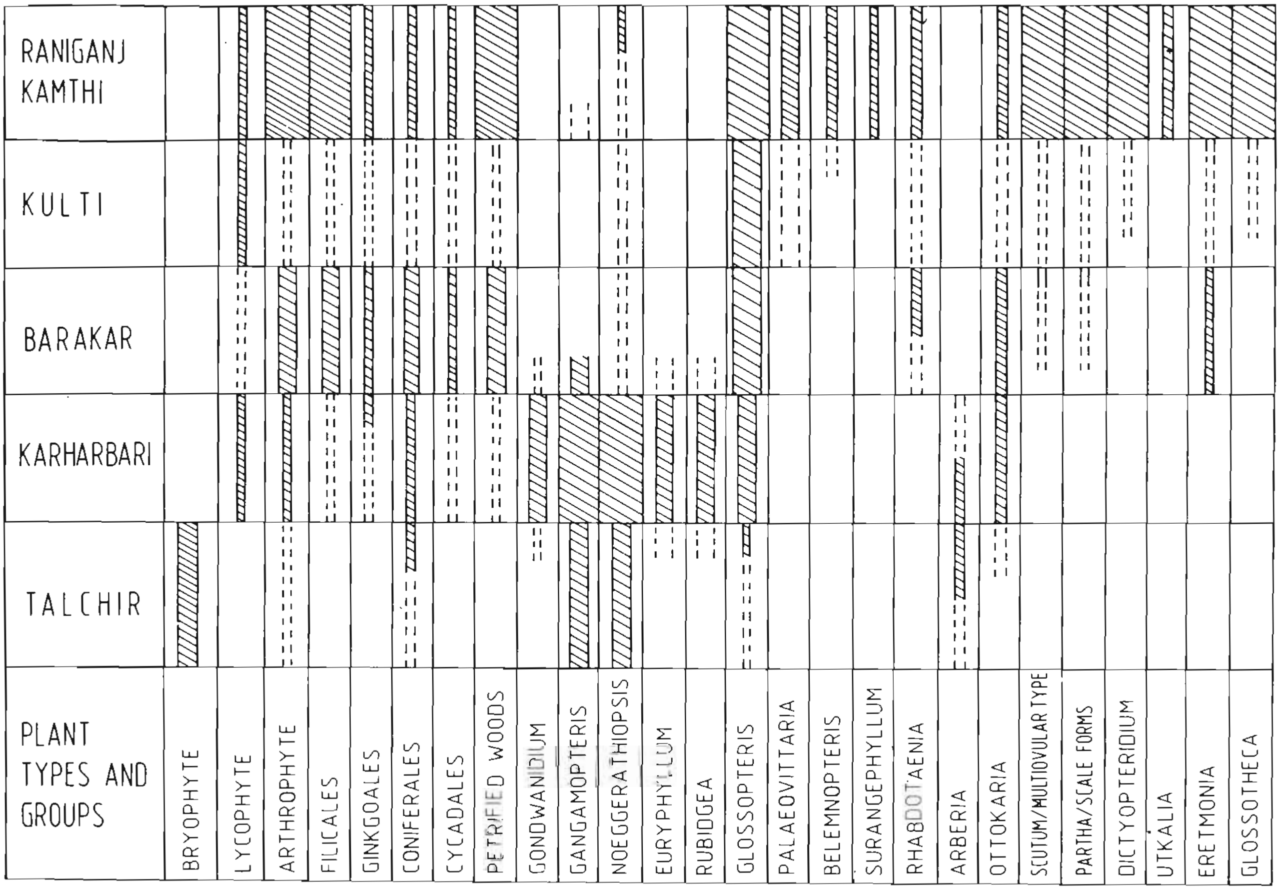
Lacustrine system—This is generally the site for sediment and biomass deposition. Most data concerning fauna could be obtained here. Algae, bacteria and some arthrophytes compose this system.

Terrestrial system—Most of the Lower Gondwana plants belonging to pteridophytes and gymnosperms form this important system which provide organic detritus for peat formation.

Marshy system—Majority of the ferns, lycopods, bryophytes and arthophytes growing in and around form this system. All the three ecosystems are distinctly well represented in Karharbari, Barakar and the Raniganj scenes.

Although the data is incomplete, the evidences suggest that the basic ecological associations of plants belonging to various groups adopted in the Early Permian continued with some evolution and diversification throughout the rest of the Permian. There are still very important gaps in our knowledge as some of the missing links are yet to be found, even then we can trace the evolution and development of some of the important plants and groups through Permian of India (Table 2). Recent observations prove the existence of bacteria, algae and fungi which have played an important role in the formation of coal. The bryophytes appeared quite early in the Permian but their absence in the Middle and Late Permian is intriguing as they reappear in the Lower Triassic beds. The lycopods appeared in the Karharbari and existed right up to the uppermost Permian. Rarity of the lycopods is generally attributed to their delicate nature unfit for preservation, though they are expected to have been well represented throughout the Middle and Late Permian as indicated by the presence of appreciable records of megaspores.

Table 2—Relative occurrence of various plant groups in the Permian Formation of India



PLANT TYPES AND GROUPS	BRYOPHYTE	LYCOPHYTE	ARTHROPHYTE	FILICALES	GINKGOALES	CONIFERALES	CYCADALES	PETRIFIED WOODS	GONDWANIDIUM	GANGAMOPTERIS	NOEGGERATHIOPSIS	EURYPHYLLUM	RUBIDGEA	GLOSSOPTERIS	PALAEOVITTARIA	BELEMNOPTERIS	SURANGEPHYLLUM	RHABDOTAENIA	ARBERIA	OTTOKARIA	SCUTUM/MULTIOVULAR TYPE	PARTHA/SCALE FORMS	DICTYOPTERIDIUM	UTKALIA	ERETMONIA	GLOSSOTHECA
RANIGANJ KAMTHI		▨	▨	▨	▨	▨	▨	▨		┆	▨ ┆			▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨
KULTI		▨	┆	┆	┆	┆	┆	┆			┆			▨	┆	┆		┆		┆	┆	┆	┆		┆	┆
BARAKAR		┆	▨	▨	▨	▨	▨	▨	┆	▨	┆	┆	┆	▨				▨ ┆		▨	┆	┆			▨	
KARHARBARI		▨	▨	┆	▨ ┆	▨	┆	┆	▨	▨	▨	▨	▨	▨					┆ ▨	▨						
TALCHIR	▨		┆			▨ ┆			┆	▨	▨	┆	┆	▨ ┆					▨ ┆	┆						

▨ Occurrence of Plant

Arthrophytes seem to be an ancient group persistently and uniformly represented by stems and spores throughout the Permian and by a variety of forms in the Middle and Late Permian exhibiting maximum development both in quality and quantity. Fern and fern-allies also developed in the same pattern as arthophytes, showing their maximum development in the Late Permian.

The class Gymnosperm with its several orders evolved steadily throughout the Permian. Conifers appeared quite early on the scene but they never formed conspicuous vegetation. Cordaitales represented by *Noeggerathiopsis* and allied forms show steady development in Early and Late Permian but they were altogether absent in the Middle Permian. Cycads and Ginkgoales appeared much later in the Permian almost in the later part of Middle Permian and never formed a uniform or conspicuous vegetation. *Gangamopteris* of the Glossopteridopsida appeared first in the Early Permian and formed the major constituent of the forest vegetation. *Glossopteris* appeared on the scene later than the *Gangamopteris* and *Noeggerathiopsis* but quickly occupied the major part of land forming conspicuous vegetation of the forest of the Middle and Late Permian time and almost lingered up to the Triassic.

The basic pattern of the Glossopteris flora was laid in the Talchir time as patchy non-forest like vegetation in pockets under cold deglaciated conditions. The first lowland, coal swamp, deciduous forest dominated by *Gangamopteris/Noeggerathiopsis* trees developed during Karharbari period under not so cold but humid conditions. *Glossopteris* dominated dense deciduous lowland, coal swamp forest appeared during Barakar time under warm and humid conditions. The first upland floras appeared in the Kulti time as not so dense forest under warm but not so humid climatic conditions. Again there was shift of floras in the low lying river valleys in the Raniganj time to give rise to very dense, swampy vegetation dominated by *Glossopteris* and allied forms under very warm and humid conditions. At the same time some of the *Glossopteris* dominated deciduous forests developed in upland areas under warm but not so humid climate represented the Kamthi forest. The general patterns of change in the plant ecology were controlled in parts by broad climatic changes.

Finally the present synthesis has brought to light the following thoughts which might stimulate further investigations in evolutionary biology of Lower Gondwana plants in order to understand squarely the how and why of:

1. The development of arborescence or tree habit of plants.
2. Production of spore/pollen and development of dispersal mechanism for fertilization.
3. Biological strategies adapted by vascular plants in production of seeds and their dispersal mechanism, enabling plants to grow in far flung areas.
4. Development of wide varieties of plant communities to enable them to grow under varied ecological conditions.

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Provincialism in Gondwana floras

Hari K. Maheshwari

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The Gondwana sediments of India, ranging from Asselian to Rhaetian in age, contain remnants of a unique flora that in general composition is uniform all over. Two basic floral assemblages, i.e., *Glossopteris*-Assemblage and *Dicroidium*-Assemblage, can be recognized through Permian and Triassic, respectively. A synthesis of data on distribution of plant fossils in different formations of the Gondwana Supergroup brings out an incipient provincialism throughout, particularly in the Barakar Formation. It is not yet understood if this provincialism is apparent or real.

Key-words—Gondwana Supergroup, Glossopteris Flora, Dicroidium Flora, Provincialism, Biostratigraphy, Phytogeography, India.

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सारांश

गोंडवाना वनस्पतिजातों में प्रान्तीयता

हरिकृष्ण माहेश्वरी

अँसेलियन से रिहेँटियन आयु के भारतीय गोंडवाना अवसादों में एक विशेष वनस्पतिजात के पादप-अवशेष मिलते हैं जो कि संरचना की दृष्टि से एक जैसे हैं। क्रमशः परमी एवं त्रिसंघी कल्पों में वस्तुतः दो वनस्पतिजातीय समुच्चय—**ग्लॉसॉप्टेरिस** समुच्चय एवं **डाइक्रोइडियम** समुच्चय, अभिनिर्धारित किये जा सकते हैं। गोंडवाना महासमूह के विभिन्न शैल-समूहों में अश्मित पौधों के वितरण से सम्बद्ध आँकड़ों के संश्लेषण से प्रान्तीयता की स्पष्ट झलक मिलती है विशेषतया बराकार शैल-समूह में। अभी तक यह स्पष्ट नहीं हो पाया है कि यह प्रान्तीयता वास्तविक है अथवा आभासी।

THE term Gondwana floras relates to the succession of remnants of a vegetation that have been recorded from the Gondwana sediments of India. The unit Gondwana was originally proposed for a group of sediments laid down in a primarily fresh-water environment (Medlicott, 1872—unpublished). In subsequent years three distinct floral associations were recorded from the Gondwana group of sediments, within a time slice of Late Carboniferous to Early Cretaceous (see Lele, 1976). The composition of the contained floras led to the inclusion of certain coastal marine sedimentaries of Cretaceous age, and also a group of sediments of Early Permian age from western Himalayan region within the purview of the Gondwana. The concepts, limits and extension of the Indian Gondwana have been debated in recent years. One of the proposals fixes the status of the Gondwana as a supergroup comprising an almost continuous sequence of essentially terrigenous sediments, the deposition of which was preceded and followed by large hiatuses. The time slot of the Gondwana Supergroup in India has now been fixed between earliest Permian and latest Triassic (Venkatachala & Maheshwari, 1991) The Gondwana sediments were deposited in the three major grabens, viz., Damodar, Son-Mahanadi and Pranhita-Godavari, besides several smaller basins.

The Gondwana Supergroup in the Damodar Graben is classified as follows:

	hiatus	
Mahadeva Group	T_3 T_2	Supra Panchet Formation[1]
Panchet Group	T_1	Hirapur Formation[2] Maitur Formation[3]

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Damuda Group	P_2	Raniganj Formation[4]
		Kulti Formation[5]
	P_1	Barakar Formation[6]
Talchir Group	P_1	Talchir Formation
	hiatus	

1) Equivalent formations—Dubrajpur (Rajmahal Basin), Tiki and Parsora (Son Graben), Pachmarhi and Denwa (Satpura Graben), and Dharmaram, Maleri and Bheemaram (Pranhita-Godavari Graben).
2) Equivalent to top of 'Kamthi' (Godavari Graben).
3) Equivalent to Upper 'Kamthi' (Godavari Graben) and Upper Hinjir (Mahanadi Graben).
4) Equivalent formations—Pachwara (Rajmahal Basin), Pali (Son Graben), Hinjir (Mahanadi Graben), Kamthi (Wardha Coalfield), Bijori (Satpura Graben).
5) Also known as Barren Measures (Damodar Graben) or Motur (Satpura Graben). May also include basal part of the 'Kamthi' (Godavari Graben).
6) Basal part sometimes known as Karharbari 'Formation'. Equivalent formations are Nishatbagh and Mamal (Kashmir Valley, Pir Panjal and Parauthochtone), Khelong/Rilu (eastern Himalaya).

After the initial report of plant fossils from the Raniganj Coalfield (Brongniart, 1828), mega- and micro-fossils have been reported from almost all the horizons (see Lakhanpal, Maheshwari & Awasthi, 1976; Chandra & Singh, 1989; Maheshwari, Singh & Bajpai, 1989; Bajpai, 1990; Bajpai & Tewari, 1990; Chandra, Srivastava & Singh, 1990; Prasad & Maithy, 1990; Singh & Bajpai, 1990; Singh & Chandra, 1990; Bajpai & Maheshwari, 1991; Chandra & Tewari, 1991; Srivastava, 1991; Kapoor, Bajpai & Maheshwari, 1992; Maheshwari & Bajpai, 1992, etc.).

Table 1 lists plant megafossils known so far from different formations of the Gondwana Supergroup. Tables 2-15 list plant megafossils for each important formation and show their areal distribution.

In recent years a few papers have analysed the palaeobotanical implications or rather palaeobotanical evidences on the northern limits of the Indian Plate during the Gondwana period. Use of palaeobotanical data for phytogeographic considerations one can understand. But to demarcate plate boundaries on the basis of elements of a land flora involves two assumptions or surmises:

(i) One particular type of plant association could not transcend plate boundaries, and
(ii) More than one plant association could not thrive on each palaeoplate.

These surmises seem to be natural corollaries of long held belief that the Gondwana Supercontinent had a uniform vegetation all over. The area of the Gondwana Supercontinent comprising all the continents of the Southern Hemisphere and India should total to some millions of square kilometres, with a south-north extent from the South Polar Region to Tropic of Cancer atleast. If the accretion of Turkey, Afghanistan, Tarim Basin, etc. as a part of the Indian Plate is also accepted, the northern margin of this plate may well have reached the Permian equator. It seems improbable that such a huge landmass had a uniform vegetation cover, a vegetation that did not show any provincialism even at micro-level. One would rather expect some degree of provincialism in floral composition in an area, much smaller than that covered by Gondwanan India.

The distribution of the vegetation undoubtedly is an active attribute of land-sea distribution, and climatic thermometry, i.e., palaeolatitudes. It does not seem plausible that each taxon of land plants could have thrived simultaneously both in cool-temperate and subtropical-tropical areas and that each taxon would have populated the Gondwana Supercontinent all over, at the same time.

The concept of the so-called mixed floras seems to have complicated our understanding of the phytogeography of the Permian period. For example, the genus *Glossopteris* established for certain tongue-shaped leaves with reticulate venation and a midrib is the most characteristic element of the Permian flora of Gondwana Supercontinent. In the 1930s similar leaves were recorded in the Angaran Flora. Zimina (1967) reported similar leaves from Permian of Siberia. I have examined these specimens, and had I not known from where these specimens have come, I would have unhesitatingly accepted their placement under the Gondwanan *Gangamopteris* and *Glossopteris*. However, hardly any palaeobiogeographer accepts that these leaves are same as the Gondwanan ones, probably because such an acceptance would not fit in with the concept of Continental Drift. But, reports of *Glossopteris* from Turkey or Indonesia are accepted even though there is no evidence to show that the *Glossopteris*-like leaves from these areas belong to the same lineage as the Gondwanan *Glossopteris* (see Maheshwari & Bajpai, 1988). A leaf from the Jurassic of Oaxaca, Mexico, that has all the morphographical characters of a Gondwanan *Glossopteris* is not accepted as a record of this genus, because the genus is not 'expected' to have continued into the Jurassic. There is a recent veiw that the genus *Lesleya* from the

Table 1—Distribution of plant megafossils through Indian Gondwana

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARÁ	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Mesembrioxylon malerianum															....
Cladophlebis indica															....
Noeggerathiopsis sp.											?				
Spermatites orbicularis														cf	
Baiera sp.														....	
Baieroxylon cicatricum														....	
Dicroidium coriaceum														....	
Dicroidium giarensis														....	
Dicroidium zuberi														....	
Heidiphyllum singhii														....	
Lepidopteris madagascariensis														....	
Lepidopteris stormbergensis														....	
Pagiophyllum bosei														....	
Rissikia denticulata														....	
Rissikia raoi														.	
Sphenobaiera janarensis														.	
Xylopteris sp.														....	
Yabiella indica														....	
Diplasmiophyllum hughesii													....	....	
Dicroidium odontopteroides											?		....	cf	
Baiera indica													....		
Cordaicarpus chichariensis													....		
Dicroidium sahnii											?		....		
Ginkgoites goiraensis													....		
Heidiphyllum taeniatum													....		
Lycopodites sahnii													.		
Marattiopsis sp.													....		
Neocalamites foxii													....		
Parsorophyllum indicum													....		
Pterophyllum sahnii													....		
Samaropsis srivastavae													....		
Cladophlebis shensiensis													cf		
Dicroidium feistmantelii													cf		
Dicroidium sp.												?			
Heidiphyllum sp.											....				
Lepidopteris sp.											....				
Pecopteris concinna											....				
Taeniopteris stenoneura											....				
Kendostrobus sp.											?				
Pantopteris gracilis										....			....		
Denkania indica										....					
Eretmonia hinjridaensis										....					
Eretmonia ovata										....					
Eretmonia utkalensis										....					
Glossopteris acuminata										....					
Glossopteris dhenkanalensis										....					
Glossopteris hinjridaensis										....					
Glossopteris inaequalis										....					
Glossopteris kamthiensis										....					
Glossopteris maheshwarii										....					
Glossopteris utkalensis										....					
Glossotheca immanis										....					
Glossotheca orissiana										....					
Glossotheca utkalensis										....					

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Handapaphyllum indicum										....					
Indocarpus elongatus										....					
Khania dhenkanalensis										....					
Lidgettonia indica										....					
Lidgettonia mucronata										....					
Neomariopteris khanii									cf	....					
Raniganjia etheridgei										....					
Scutum elongatum										....					
Scutum indicum										....					
Scutum sahnii										....					
Senia reticulata										....					
Sphenophyllum utkalensis										....					
Surangephyllum elongatum										....					
Utkalia dichotoma										....					
Anthrophyopsis sp.										....					
Lelstotheca robusta									....	....					
Dichotomopteris bansloiensis									....						
Dichotomopteris ovata									....						
Glossopteris parallela									....						
Glossopteris wilkinsonii									....						
Glossopteris gopadensis								....	....						
Samaropsis raniganjensis								....	....						
Algacites oogonifera								....							
Chakrea papillosa								....							
Cordaicarpus ovatus								....							
'Dicroidium' gopadensis								....							
'Dicroidium' nidpurensis								....							
'Dicroidium' papillosum								....							
Glossopteris formosa major								....							
Glossopteris nilssonioides								....							
Glossopteris papillosa								....							
Glossopteris rewaensis								....							
Glossopteris senii								....							
Glossopteris sidhiensis								....							
Glottolepis glabrosa								....							
Glottolepis ovata								....							
Glottolepis rugosa								....							
Glottolepis sidhiensis								....							
Glottolepis tuberculata								....							
Gopadia coriacea								....							
Gopadia papillata								....							
Hapaticites foliata								....							
Hapaticites metzgerioides								....							
Hepaticites nidpurensis								....							
Hepaticites riccardioides								....							
Lelestrobus pennatus								....							
Lepidopteris indica								....							
Nidia ovalis								....							
Nidispermum glabrosum								....							
Nidistrobus harrisiana								....							
Nidpuria problematica								....							
Marhwaseaphyllum hastatum								....							
Pantiaspermum cristatum								....							
Pterophyllum karkatiensis								....							
Pteruchus gopadensis								....							

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Pterucbus indicus								....							
Pterucbus nidpurensis								....							
Pterucbus thomasii								....							
Pyriformispermum elongatum								....							
Rewapbyllum nidpurensis								....							
Rotundaspermum mucronatum								....							
Rugapites spherica								....							
Rugaspermum insigne								....							
Rugaspermum media								....							
Rugaspermum obscura								....							
Rugatbeca nidpurensis								....							
Samaropsis menisca								....							
Samaropsis surangei								....							
Satsangia campanulata								....							
Savitrispermum crateriformis								....							
Sidipbyllites flabellatus								....							
Spbagnopbyllites triassicus								....							
Taeniopteris spatulata								?					?		
Dicksonia sp.							....								
Rbipidopsis densinervis						....					....				
Araucarioxylon kotbariensis						....									
Araucarioxylon latbiense						....									
Araucarioxylon lobarense						....									
Araucarioxylon nandoriense						....									
Araucarioxylon surangei						....									
Arauspiropitys indicum						....									
Australoxylon kanbargaoense						....									
Australoxylon longicellularis						....									
Australoxylon wejgaoense						....									
Baieroxylon multiseriale						....									
Dadoxylon adbariense						....									
Dadoxylon cbandrapurense						....									
Dadoxylon mabarasbtraensis						....									
Dadoxylon spp.						....									
Filicites sp.						....									
Glossopteris musaefolia						....									
Glossopteris surangei						....									
Glossopteris venustus						....									
Kamtbioxylon adbariensis						....									
Kaokoxylon pseudotrimedullaris						....									
Nandorioxylon saksenae						....									
Planoxylon indicum						....									
Prototaxoxylon gondwanense						....									
Prototaxoxylon mababalei						....									
Prototaxoxylon maitbyi						....									
Prototaxoxylon uniseriale						....									
Rbizoctonia nandoriense						....									
Sclerospiroxylon marguerierae						....									
Taxopitys indica						....									
Taxopitys surangei						....									
Trigonomyelon kamtbiensis						....									
Zalesskioxylon lepekbinae						....									
Zalesskioxylon simplexum						....									
Gangamopteris bugbesii			?		cf	....									

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Dadoxylon chandaensis						?									
Glossopteris stenoneura					....	....		....			....				
Dichotomopteris ovata					....				....						
Raniganjia bengalensis					....				....	....					
Glossopteris divergens					....				....						
Glossopteris formosa					....			....	....						
Neomariopteris lobifolia					....				....		?				
Phyllotheca griesbachii					....			....	....						
Glossopteris spatulata					....			....							
Dichotomopteris lindleyii					....		....								
Gangamopteris whittiana					....		cf								
Glossopteris arberi					....	....									
Glossopteris lanceolatus					....	....									
Glossopteris mohudaensis					....	....									
Glossopteris tenuifolia					....	....									
Arberiella vulgaris					....										
Araucarioxylon bradshawianum					....										
Araucarioxylon kumarpurense					....										
Araucarioxylon ningahense					....										
Araucarioxylon parbeliense					....										
Araucarioxylon robertianum					....										
Araucarioxylon semibiseriatum					....										
Australoxylon ranaensis					....										
Bankolaea raniganjensis					....										
Belemnopteris pellucida					....										
Belemnopteris sagittifolia					....										
Belemnopteris woodmasoniana					....										
Bengalia raniganjensis					....										
Catervoxylon raniganjensis					....										
Chapmanoxylon indicum					....										
Chapmanoxylon raniganjensis					....										
Cornuspermum pennatus					....										
Cuticulatopteris polymorpha					....										
Dadoxylon jamudhiense					....										
Damudopteris bengalensis					....										
Damudosaurus raniganjensis					....										
Damudosaurus searsolensis					....										
Damudoxylon jamuriense					....										
Damudoxylon lepekhinae					....										
Damudoxylon waltonii					....										
Dichotomopteris asansolioides					....										
Dichotomopteris falcata					....										
Dichotomopteris major					....										
Dictyopteridium feistmantelii					....										
Eretmonia emarginata					....										
Gangamopteris anthrophyoides					....										
'Gangamopteris' flexuosa					....										
Gangamopteris indica					....										
Glossopteris acaulis					....										
Glossopteris acuta					....										
Glossopteris anthrophyoides					....										
Glossopteris bengalensis					....										
Glossopteris brongniartii					....										
Glossopteris clarkei					....										
Glossopteris contracta					....										

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Glossopteris cordiformis					....										
Glossopteris euryneura					....										
Glossopteris frondosa					....										
Glossopteris ghusikiensis					....										
Glossopteris gigas					....										
Glossopteris gondwanensis					....										
Glossopteris isolateralis					....										
Glossopteris longifolia					....										
Glossopteris maculata					....										
Glossopteris major					....										
Glossopteris nautiyalii					....										
Glossopteris obscura					....										
Glossopteris oldhamii					....										
Glossopteris orbicularis					....										
Glossopteris petiolata					....										
Glossopteris pseudocommunis					....										
Glossopteris radiata					....										
Glossopteris reticulata					....										
Glossopteris retusa					....										
Glossopteris rhabdotaenioides					....										
Glossopteris sahnii					....										
Glossopteris sastrii					....										
Glossopteris searsolensis					....										
Glossopteris shailae					....										
Glossopteris srivastavae					....										
Glossopteris subtilis					....										
Glossopteris taeniopteroides			?		....										
Glossopteris tenuinervis					....										
Glossopteris tortuosa			?		....										
Glossopteris transversalis					....										
Glossopteris varia					....										
Glossopteris verticillata					....										
Glossopteris vulgaris					....										
Glossopteris waltonii					....										
Gondwanolepis lanceolata					....										
Gondwanolepis linearis					....										
Gondwanolepis oblongovata					....										
Jambadostrobus pretiosus					....										
Kaokoxylon zalesskyi					....										
Kendostrobus cylindricus					....										
Kendoxylon fissilis					....										
Leleopteris ovata					....										
Leleopteris srivastavae					....										
Lithangium indicum					....										
Lithangium ovoides					....										
Lithangium surangei					....										
Mahudaea senii					....										
Megaporoxylon kraeuselii					....										
Ottokaria raniganjensis					....										
Palaeospiroxylon heterocellularis					....										
Palaeovittaria raniganjensis					....										
Paracatervoxylon biseriatum					....										
Paracatervoxylon raniganjensis					....										
Parapalaeospiroxylon burmundiaensis					....										
Pecopteris affinis					....										

Contd.

Table 1—Contd.

	TALCHIR B	KARHARBARI C	BARAKAR D	KULTI E	RANIGANJ F	KAMTHI G	BIJORI H	PALI I	PACHHWARA J	HINJIR K	MAITUR L	HIRAPUR M	PARSORA N	TIKI O	MALERI P
Platycardia bengalensis					....										
Plumsteadia indica					....				?						
Plumsteadia lanceolata					....										
Plumsteadiostrobus ellipticus					....										
Polytheca elongata					....										
Protophyllocladoxylon indicum					....										
Pterophyllum burdwanense					....										
Pteronilssonia gopalii					....										
Pterygospermum raniganjense					....										
Ranoxylon bengalensis					....										
Rhabdotaenia fibrosa					....										
Samaropsis raniganjensis					....										
Scirroma angusta					....										
Scirroma ventilebra					....										
Scutum draperium					....										
Scutum dutoitides					....			....							
Scutum leslium					....										
Scutum stowanum					....										
Senotheca murulidihensis					....										
Searsolia oppositifolia					....										
Stephanostoma crystallinum					....										
Trithecopteris gondwanensis					....										
Venustostrobus ghusikensis					....										
Venustostrobus indicus					....										
Vertebraria raniganjensis					....										
Vertebraria myelonis					....										
Zalesskioxylon gondwanensis					....										
Zalesskioxylon raniganjensis					....										
Zalesskioxylon uniseriatum					....										
Glossopteris fibrosa					cf										
Dadoxylon ghorawariense				....											
Cyclodendron leslei				....					....						
Trizygia speciosa			....		....		....	....	....	?					
Dadoxylon barakarense			....						....						
Dictyopteridium sporiferum			....		....			....		....					
Glossopteris conspicua		?	....	....	....	....	....			....	....				
Glossopteris elongata			....	....	....		....	....	....	....	?				
Neomariopteris polymorpha			....		....			....		....					
Pseudoctenis ballii			....					....		....					
Glossopteris leptoneura			....		....	....	....				?				
Asansolia phegopteroides			....		....	....			....						
Glossopteris emarginata			....		....				....						
Glossopteris feistmantelii			....					....	....						
Rhabdotaenia danaeoides		?	....	....	....	....		....	....						
Glossopteris intermittens			....		....			....							
Glossopteris stenoneura			....		....			....							
Glossopteris stricta			....		....	....		....							
Squamae gymnospermarum			....					....							
Glossopteris raniganjensis			....	....	....	....	....								
Alethopteris spp.			....			....									
Damudoxylon parenchymosum			....			....									
Pterophyllum spp.			....			....									
Sphenophyllum churulianum			....			....									
Sphenophyllum crenulatum			....		....	....									
Glossopteris ampla			....	....	....										

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSOṚA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Glossopteris ingens			....		....										
Glossopteris intermedia			....		....					?					
Glossopteris linearis			....		....										
Glossopteris nimishea			....		....										
Glossopteris pandurata			....		....										
Palaeovittaria kurzii			....		....										
Glossopteris barakarense			....	....											
Alatocarpus indicus			....												
Angiopteridium infarctum			....												
Araucarioxylon kharkhariense			....												
Barakaria dichotoma			....												
Birbalsahnia divyadarshanii			....												
Dadoxylon bengalense			....												
Eretmonia karanpuraensis			....												
Gangamopteris chatterjei			....												
Ginkgoites buraensis			....												
Ginkgoites veekaysinghii			....												
Glossopteris bargoensis			....												
Glossopteris churiensis			....												
Glossopteris fuchsii			....												
Glossopteris karanpuraensis			....												
Glossopteris ornatus			....												
Glossopteris parallela			....												
Glossopteris saksenae			....												
Gondwanophyllites dissectus			....												
Gondwanophyton indicum			....												
Gondwanophyton sp.			....												
Indoxylon canalosum			....												
Kashmiropteris meyenii			....												
Kawizophyllum dunpathriensis			....												
Lepidostrobus kashmirensis			....												
Lobatannularia ensifolia			....												
Lobatannularia lingulata			....												
Lobatannularia sinensis			....												
Lelstotheca striata			....												
Lidgettonia sp.			....												
Neomariopteris barakarensis			....												
Ottokaria bihariensis			....												
Parapalaeoxylon ghorawariense			....												
Parapalaeoxylon gondwanense			....												
Platyphyllum bokaroensis			....												
Polysolenoxylon jhariense			....												
Psygmophyllum haydenii			....												
Psygmophyllum hollandii			....												
Psygmophyllum sahnii			....												
Rajahia mamalensis			....												
Pterygospermum spiculatum			....												
Rhipidopsis densinervis			....												
Rhipidopsis gondwanensis			....												
Samaropsis johillensis			....												
Saportaea nervosa			....												
Saportaea reniformoides			....												
Scutum sp.			....												
Spermatites indicus			....												
Sphenophyllum thonii			....												

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Taeniopteris kashmirensis			....												
Trizygia maithyiana			....										cf		
Veekaysinghia durgavatiae			....												
Walkomiella indica			....												
Walkomiellospermum indicum			....												
Cyathea tchihatcheffi			cf		cf										
Gangamopteris kashmirensis			cf												
Glossopteris angustifolia		....	....	....	....	....	....	....	....	....	?	....			
Schizoneura gondwanensis		....	....		....	....	....	....	....	....	....	....			
Glossopteris communis		....	....	....	....	....	....	....	....	....	?				
Glossopteris browniana		....	....	....	....	....	....	....	....	....	?		?		
Neomariopteris hughesii		....	....	....	....		....	....	....	....					
Phyllotheca australis		....	....		....	....			?	....					
Glossopteris damudica		....	....	....	....		....	....	....	cf		?			
Squamae integerrima		....			....			....							
Rhipidopsis gondwanensis		....	....			....									
Glossopteris decipiens		....	....	?	....										
Glossopteris taenioides		....	....		....										
Neomariopteris talchirensis		....	....		....										
Alatocarpus johillensis		....	....												
Cordaicarpus zeilleri		....	....												
Euryphyllum whittianum		....	....												
Glossopteris angusta		....	....												
Glossopteris giridihensis		....	....												
Glossopteris karharbariensis		....	....												
Glossopteris longicaulis		....	....								?				
Rubidgea obovata		....	....												
Sphenophyllum gondwanensis		....	....												
Dadoxylon indicum		....	cf												
Buriadia sewardii		....	?		?			?							
Arberia indica		....													
Arberia surangei		....													
Birsinghpuria indica		....													
Botrychiopsis valida		....													
Bulbospermum surangei		....													
Buriadia florinii		....													
Buriadia fragilis		....													
Capsulites gondwanensis		....													
Cardiocarpus indicus		....													
Caulophyllites indica		....													
Cheirophyllum lacerata		....													
Cordaicarpus karharbariense		....													
Cordaicarpus zeilleri		....													
Cordaites stoliczkanus		....													
Dolianitia karharbariense		....													
Euryphyllum obovatum		....													
G. cyclopteroides auriculata		....													
Gangamopteris fibrosa		....													
Gangamopteris gondwanensis		....													
Gangamopteris hispida		....													
Gangamopteris karharbariensis		....													
Gangamopteris kashmirensis		....													
Gangamopteris media		....													
Gangamopteris mucronata		....													
Gangamopteris oblanceolata		....													

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI •	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Gangamopteris obtusifolia		....													
Gangamopteris papillosa		....													
Gangamopteris srivastavae		....													
Ginkgophyton sp.		....													
Giridia indica		....													
Glossopteris jayantiensis		....													
Glossopteris nishatbaghensis		....													
Glossopteris recurva		....													
Glossopteris spathulocordata		....													
Glossopteris zeilleri		....													
Karharbariospermum surangei		....													
Maheshwariella bicornuta		....													
Maheshwariella spinicornuta		....													
Noeggerathiopsis bunburyana		....													
Noeggerathiopsis conspicua		....													
Noeggerathiopsis fibrosa		....													
Noeggerathiopsis gondwanensis		....													
N. hislopii subrhomboidalis		....													
Noeggerathiopsis indica		....													
Noeggerathiopsis minor		....													
Noeggerathiopsis papillosa		....													
Noeggerathiopsis spathulata		....													
Noeggerathiopsis whittianum		....													
Noeggerathiopsis zeilleri		....													
Otofeistia milleri		....													
Ottokaria bengalensis		....													
Ottokaria zeilleri		....													
Palaeocarpus birsinghpurensis		....													
Palispermum ovalis		....													
Palmatophyllites debilis		....													
Palmatopteris furcata		cf													
Phyllotheca ampla		....													
Phyllotheca angusta		....													
Phyllotheca crassa		....													
Phyllotheca sahnii		....													
Platycardia jugus		....													
Retortistoma crystallina		....													
Rotundocarpus ovatus		....													
Rotundocarpus striatus		....													
Rubidgea lanceolatus		....													
Rubidgea emarginata		....													
Samaropsis feistmantelii		....													
Samaropsis ganjrensis		....													
Schizoneura wardii		....													
Shivacarpus johillensis		....													
Shivacarpus latus		....													
Vertebraria gondwanensis		....													
Samaropsis parvula		cf	cf		cf		cf	cf							
Nummulospermum bowense		cf													
Schizoneura merianii		cf													
Equisetalean stems	....	....	....	....	....	....	....	....	....	....	....		....		
Glossopteris indica	....	....	....	....	....	....	....	....	....	....	....	?	?		
Vertebraria indica	....	....	....	....	....	....	....	....	....	....	....		....		
Gangamopteris cyclopteroides	....	....	....	....	?		?		?		?				
Pantophyllum spatulata	....	....	....	....	?	?		?	?				?		

Contd.

Table 1—Contd.

	TALCHIR	KARHARBARI	BARAKAR	KULTI	RANIGANJ	KAMTHI	BIJORI	PALI	PACHHWARA	HINJIR	MAITUR	HIRAPUR	PARSORA	TIKI	MALERI
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Gangamopteris angustifolia	....	....	....		?										
Gangamopteris intermedia	....	....	....												
Gangamopteris major	....	....	....												
Cordaicarpus spp.	....	....											?		
Gangamopteris buriadica	....	....			?										
Gangamopteris clarkeana	....	....													
G. cyclopteroides areolata	....	....													
G. cyclopteroides attenuata	....	....													
G. cyclopteroides subauriculata	....	....													
Gangamopteris obliqua	....	....													
Maheshwariella furcata	....	....													
Samaropsis goraiensis	....	....													
Arberia umbellata	....	cf													
Gangamopteris spathulata	cf	....	?												
G. cyclopteroides acuminata	....														
Paranocladus? indica	....														
G. cyclopteroides cordifolia	....														
G. cyclopteroides crassinervis	....														
Samaropsis sp.	cf										cf				
Talchirospermum indicum	....														

Table 2—Geographical distribution of plant fossils in the Talchir Formation

TAXA/AREA	KARANPURA	GIRIDIH	AURANGA	SINGRAULI	CHIRIMIRI	PALI	TALCHIR
Arberia umbellata						•••	
Cordaicarpus spp.			•••		•••		
Cordaites (Pantophyllum) spatulata	•••	•••	•••	•••		•••	•••
Gangamopteris angustifolia		•••					•••
Gangamopteris buriadica	•••						
Gangamopteris clarkeana					•••		
Gangamopteris cyclopteroides	•••	•••	•••	•••	•••	•••	
G. cyclopteroides acuminata	•••		•••				
G. cyclopteroides areolata	•••						
G. cyclopteroides attenuata	•••		•••	•••		•••	
G. cyclopteroides cordifolia	•••		•••				
G. cyclopteroides crassinervis	•••						
G. cyclopteroides subauriculata	•••		•••				
Gangamopteris intermedia					•••		
Gangamopteris major	•••			•••	•••	•••	
Gangamopteris obliqua	•••						
Gangamopteris spathulata						cf	
Glossopteris indica	•••						
Maheshwariella furcata						•••	
Paranocladus? indica						•••	
Samaropsis goraiensis				cf		•••	
Samaropsis sp.						•••	
Talchirospermum indicum						•••	
Vertebraria indica						•••	

Table 3—Geographical distribution of plant fossils in Karharbari Formation

TAXA/AREA	GIRIDIH	DEOGARH	KARANPURA	RANIGANJ	JHARIA	AURANG	HUTAR	DALTONGANJ	PALI	SINGRAULI	UMARIA	MOHPANI	CHRIMIRI	KASHMIR	ARUNACHAL
Alatocarpus jobillensis									****	****					
Arberia indica	****														
Arberia surangei									****						
Arberia umbellata	cf														
Birsinghpuria indica									****						
Botrychiopsis valida	****	****	****	??							cf				
Bulbospermum surangei									****						
Buriadia florinii	****														
Buriadia fragilis								****							
Buriadia sewardii	****		****	****	****					??					
Capsulites gondwanensis									****						
Cardiocarpus indicus	****														
Caulophyllites indica	****														
Cheirophyllum lacerata	****								****						
Cordaicarpus karharbariense	****														
Cordaicarpus zeilleri	****	****						****			****				
Cordaites spatulata	****	****	****	****		****		****	****		****	****	****		
Cordaites stoliczkanus	****														
Dolianitia karharbariensis	****														
Euryphyllum obovatum	****														
Euryphyllum whittianum	****				****	****									
Gangamopteris angustifolia	****	****			****				****		****				
Gangamopteris buriadica	****		??		****										
Gangamopteris clarkeana	****					****							****		
Gangamopteris cyclopteroides	****	****	****	****	****	****	****	****	****	??	****	****	****		****
G. cyclopteroides areolata	****														
G. cyclopteroides attenuata	****				****		****	****			****				
G. cyclopteroides auriculata	****														
G. cyclopteroides subauriculata	****							****	****						
Gangamopteris fibrosa	****														
Gangamopteris gondwanensis	****	??													
Gangamopteris hispida	****												****		
Gangamopteris intermedia	****		??												
Gangamopteris karharbariensis	****								****						
Gangamopteris major	****								****						
Gangamopteris media													****		
Gangamopteris mucronata	****							****							
Gangamopteris oblanceolata	****														
Gangamopteris obliqua	****							****							
Gangamopteris obtusifolia													****		
Gangamopteris papillosa													****		
Gangamopteris spathulata			??						****						
Gangamopteris srivastavae									****						
Ginkgophyton sp.	****														
Giridia indica	****														
Glossopteris angusta	****		??								****				
Glossopteris angustifolia	****								****				****	****	****
Glossopteris browniana	****							****							
Glossopteris communis	****					****		****	****		****		****		****
Glossopteris conspicua															****
Glossopteris damudica	****														****
Glossopteris decipiens	****							****	****						
Glossopteris giridihensis	****														
Glossopteris indica			??					****	****		****		****	****	****
Glossopteris jayantiensis		****													

Contd.

Table 3—Contd.

TAXA/AREA	GIRIDIH	DEOGARH	KARANPURA	RANIGANJ	JHARIA	AURANGA	HUTAR	DALTONGANJ	PALI	SINGRAULI	UMARIA	MOHPANI	CHRIMIRI	KASHMIR	ARUNACHAL
Glossopteris karharbariensis			****								****				
Glossopteris longicaulis	****													****	****
Glossopteris nishatbaghensis														****	
Glossopteris pandurata	****														
Glossopteris recurva	****														
Glossopteris spathulocordata	****														
Glossopteris taenioides									****						
Glossopteris zeilleri													****		
Maheshwariella bicornuta	****														
Maheshwariella furcata	****														
Maheshwariella spinicornuta									****						
Neomariopteris hughesii						****									
Neomariopteris talchirensis								****							
Pantophyllum bunburyana		****						****							
Pantophyllum conspicua		****													
Pantophyllum fibrosa									****						
Pantophyllum gondwanensis									****						
Pantophyllum indica									****						
Pantophyllum minor									****				****		
Pantophyllum papillosa									****						
Pantophyllum zeilleri	****														
Nummulospermum bowense	cf													??	
Otofeistia milleri	****								****						
Ottokaria bengalensis	****														
Ottokaria zeilleri	****														
Palaeocarpus birsinghpurensis									****						
Palispermum ovalis									****						
Palmatopteris furcata														cf	
Phyllotheca ampla			****												
Phyllotheca australis	****												****		??
Phyllotheca crassa								****							
Phyllotheca sahnii	****								****	****					
Platycardia jugus								****							
Psygmophyllum haydenii														****	
Retortistoma crystallina									****						
Rhipidopsis gondwanensis				****		****									
Rotundocarpus ovatus	****														
Rotundocarpus striatus	****														
Rubidgea emarginata	****														
Rubidgea lanceolatus	****														
Rubidgea obovata	****														
Samaropsis feistmantelii	****	****													
Samaropsis ganjrensis	****					****			****						
Samaropsis goraiensis	****	****						****							
Samaropsis parvula								cf	cf						
Schizoneura merianii	cf														
Schizoneura wardii	****														
Shivacarpus jobillensis									****						
Shivacarpus latus									****						
Squamae integerrima									****						

Euramerican Flora is the ancestor of *Glossopteris* (Leary, 1991). It all seems to be very subjective thinking which does not allow clear demarcation of macro- or micro-palaeophytogeographical provinces.

It is thus axiomatic that for palaeophytogeographic or palaeoclimatic interpretations for the Gondwana period, one should critically assess systematic and taxonomic position of each taxon of

Table 4—Geographical distribution of plant fossils in Barakar Formation

TAXA/AREA	HURA	PACHWARA	RANIGANJ	JHARIA	KARANPURA	BOKARO	DEOGARH	AURANGA	HUTAR	DALTONGANJ	RAMKOLA	SINGRAULI	PALI	UMARIA	CHIRIMIRI	TALCHER	KASHMIR
Alatocarpus indicus												****					
Alatocarpus jobillensis												****					
Angiopteridium infarctum			****														
Araucarioxylon barakarense				****													
Araucarioxylon kharkhariense				****													
Asansolia phegopteroides		****															
Barakaria dichotoma								****									
Birbalsahnia divyadarshanii	****																
Buriadia sewardii												??					
Cordaicarpus zeilleri															??		
Cordaites spatulata			****														***
Cyathea tchihatcheffi																cf	
Dadoxylon bengalense				****													
Dadoxylon indicum							****										
Damudoxylon parenchymosum				****													
Dictyopteridium sporiferum			****													****	
Eretmonia karanpuraensis					****												
Euryphyllum elongatum			****														
Gangamopteris chatterjei								****									
Gangamopteris cyclopteroides		??	****					****				****	****		****		****
Gangamopteris hughesii								****									
Gangamopteris kashmirensis																	***
Gangamopteris major																	***
Gangamopteris rajaensis			****														
Gangamopteris spathulata													****				
Giridia barakarensis			****														
Glossopteris ampla						****											
Glossopteris angusta			****														
Glossopteris angustifolia			****			****		****			****		****		****		***
Glossopteris bansloiensis		****															
Glossopteris barakarensis			****		****			****									
Glossopteris bargoensis		****															
Glossopteris browniana		****	****					****			****		****			****	
Glossopteris churiensis			*****					****									
Glossopteris communis	****	****	****		****			***			****	****	****		****	****	***
Glossopteris conspicua			****														***
Glossopteris damudica		****	****					****	****		****		****			****	***
Glossopteris decipiens																****	
Glossopteris elongata		****						****									

Contd.

Table 4—Contd.

TAXA/AREA	HURA	PACHWARA	RANIGANJ	JHARIA	KARANPURA	BOKARO	DEOGARH	AURANGA	HUTAR	DALTONGANJ	RAMKOLA	SINGRAULI	PALI	UMARIA	CHIRIMIRI	TALCHER	KASHMIR
Glossopteris emarginata		****	****														
Glossopteris feistmantelii		****						****									
Glossopteris indica		****	****	****	****	****		****	****		****	****			****	****	
Glossopteris ingens			****														
Glossopteris intermedia																****	
Glossopteris intermittens			****														
Glossopteris karanpuraensi		****			****												
Glossopteris linearis								****									
Glossopteris longicaulis																****	***
Glossopteris nimishea			****					****									
Glossopteris ornatus			****														
Glossopteris parallela		****															
Glossopteris saksenae			****														
Glossopteris stenoneura			****		****												
Glossopteris stricta			****			****		****									
Glossopteris taenioides			****										****				
Glossopteris taeniopteroides		****										cf					
Glossopteris tortuosa			****		****			****									
Gondwanophyllites dissectus			****														
Gondwanophyton indicum			****														
Indoxylon canalosum				****													
Kashmiropteris meyenii																	***
Kawizophyllum dunpathriensis																	***
Lelstotheca robusta	cf	****	****														
Lelstotheca striata			****														
Lepidostrobus kashmirensis																	***
Lidgettonia sp.			****														
Lobatannularia ensifolia																	***
Lobatannularia lingulata																	***
Lobatannularia sinensis																	***
Maheshwariphyllum indicum			****														
Neomariopteris barakarensis								****									
Neomariopteris hughesii		****	****		****												
Neomariopteris polymorpha			****					****								****	
Neomariopteris talchirensis										****						****	
Ottokaria bihariensis								****									
Palaeovittaria kurzii			****														
Palasthalia indica			****														
Parapalaeoxylon ghorawariense															****		

Contd.

Table 4—Contd.

TAXA/AREA	HURA	PACHWARA	RANIGANJ	JHARIA	KARANPURA	BOKARO	DEOGARH	AURANGA	HUTAR	DALTONGANJ	RAMKOLA	SINGRAULI	PALI	UMARIA	CHIRIMIRI	TALCHER	KASHMIR
Parapalaeoxylon gondwanense				****													
Partha raniganjensis			****														
Phyllotheca australis			****	****											****		
Phyllotheca griesbachii													****				
Platyphyllum bokaroensis						****											
Polysolenoxylon canalosum				****													
Polysolenoxylon jhariense				****													
Polysolenoxylon kraeuselii				****													
Pseudoctenis ballii								****									
Psygmophyllum haydenii																	***
Psygmophyllum hollandii																	***
Psygmophyllum sahnii																	***
Rajahia mamalensis																	***
Pterophyllum spp.								****									
Pterygospermum spiculatum			****														
Rhabdotaenia danaeoides		****						****									
Rhipidopsis gondwanensis			****					****									
Samaropsis jobillensis													****				
Samaropsis parvula													cf				
Schizoneura gondwanensis		****				****		****					****		****	****	
Scutum barakarensis			****														
Spermatites indicus						****											
Sphenophyllum churulianum			****														
Sphenophyllum crenulatum			****														
Sphenophyllum gondwanensis		****															
Squamae gymnospermarum			****														
Trizygia maithyiana			****														
Trizygia speciosa						****		****								****	
Veekaysinghia durgavatiae	****																
Vertebraria indica		****	****	****	****	****		****	****		****		***		****	****	
Walkomiella indica																	
Walkomiellospermum indicum																	

Table 5—Geographical distribution of plant fossils in Kulti Formation

TAXA/AREA	RANIGANJ	JHARIA	KARANPURA	AURANGA	CHIRIMIRI
Boldihadendron raniganjensis	****				
Cordaites spatulata			****		
Cyclodendron leslei	****	****			
Dadoxylon ghorawariense					****
Gangamopteris cyclopteroides	****		cf	****	
Glossopteris ampla	****	****			
Glossopteris angustifolia			****		
Glossopteris browniana		****		****	
Glossopteris communis	****	****	****		
Glossopteris conspicua			****		****
Glossopteris damudica	****		****		
Glossopteris decipiens		****			
Glossopteris elongata			****		
Glossopteris indica		****	****		****
Neomariopteris hughesii		****			
Rhabdotaenia danaeoides			****		

Table 6—Geographical distribution of plant fossils in Raniganj Formation

TAXA/AREA	RANIGANJ	JHARIA	KARANPURA	BOKARO	AURANGA	HUTAR	RAMKOLA
Araucarioxylon bradshawianum	****						
Araucarioxylon kumarpurense	****	****					
Araucarioxylon ningahense	****						
Araucarioxylon parbeliense	****						
Araucarioxylon robertianum	****						
Araucarioxylon semibiseriatum	****						
Arberiella vulgaris	****						
Asansolia phegopteroides	****				??		
Australoxylon ranaensis	****						
Bankolaea raniganjensis		****					
Belemnopteris pellucida	****						
Belemnopteris sagittifolia	****						
Belemnopteris woodmasoniana	****						
Bengalia raniganjensis	****						
Buriadia sewardii	??						
Catervoxylon raniganjensis	****						
Chapmanoxylon indicum	****						
Chapmanoxylon raniganjensis	****						
Cordaites (Pantophyllum) spatulata	??						
Cornuspermum pennatus		****					
Cuticulatopteris polymorpha	****						
Cyathea tchihatcheffi			****				
Dadoxylon jamudhiense		****					
Damudopteris bengalensis	****						
Damudosaurus raniganjens							
Damudosaurus searsolensis	****						
Damudoxylon jamuriense	****						
Damudoxylon lepekhinae	****						
Damudoxylon waltonii	****						
Dichotomopteris asansolioides	****						
Dichotomopteris falcata	****						
Dichotomopteris lindleyii	****						
Dichotomopteris major	****						
Dichotomopteris ovata	****						
Dictyopteridium feistmantelii	****						
Dictyopteridium sporiferum	****		??		??		
Fretmonia emarginata	****						
Gangamopteris angustifolia	??						

Contd.

Table 6—Contd.

TAXA/AREA	RANI-GANJ	JHARIA	KARAN-PURA	BOKARO	AURANGA	HUTAR	RAMKOLA
Gangamopteris anthrophyoides	••••		••••				
Gangamopteris buriadica					••••		
Gangamopteris cyclopteroides	??				??		
Gangamopteris flexuosa	••••						
Gangamopteris hughesii	??						
Gangamopteris indica	••••						
Gangamopteris whittiana	••••						
Glossopteris acaulis	••••						
Glossopteris acuta	••••						
Glossopteris ampla	??						
Glossopteris angustifolia	••••		••••		••••	••••	
Glossopteris arberi	••••						
Glossopteris bengalensis							
Glossopteris brongniartii		••••					
Glossopteris browniana	••••						
Glossopteris clarkei	••••	••••					
Glossopteris communis	••••		••••		••••		
Glossopteris conspicua	••••		••••	••••	••••		
Glossopteris contracta	••••						
Glossopteris cordiformis	••••						
Glossopteris damudica	••••		••••		••••		••••
Glossopteris decipiens	••••			••••	••••		
Glossopteris divergens	••••				••••		
Glossopteris elongata	••••		••••	••••	••••		
Glossopteris emarginata	••••						
Glossopteris euryneura	••••						
Glossopteris fibrosa	••••						
Glossopteris formosa	••••		••••				
Glossopteris frondosa	••••						
Glossopteris ghusikiensis	••••						
Glossopteris gigas	••••						
Glossopteris gondwanensis	••••			••••			
Glossopteris indica	••••		••••	••••	••••		••••
Glossopteris ingens	••••						
Glossopteris intermedia	••••						
Glossopteris intermittens	••••						
Glossopteris isolateralis	••••						
Glossopteris ianceolatus	••••						
Glossopteris leptoneura					••••		••••
Glossopteris linearis	••••						
Glossopteris longifolia	••••						
Glossopteris macutata	••••						
Glossopteris major	••••						
Glossopteris nautiyalii	••••						
Glossopteris obscura	••••						
Glossopteris oldhamii	••••						
Glossopteris orbicularis	••••						
Glossopteris pandurata	••••						
Glossopteris petiolata	••••						
Glossopteris pseudocommunis	••••						
Glossopteris radiata	••••						
Glossopteris reticulata	••••						
Glossopteris retusa	••••						
Glossopteris rhabdotaenioides	••••						
Glossopteris sahnii	••••						
Glossopteris sastrii	••••						
Glossopteris searsolensis	••••						
Glossopteris shailae	••••	••••					
Glossopteris singularis	••••						
Glossopteris spatulata	••••						

Contd.

Table 6—Contd.

TAXA/AREA	RANI-GANJ	JHARIA	KARAN-PURA	BOKARO	AURANGA	HUTAR	RAMKOLA
Glossopteris srivastavae	••••						
Glossopteris stenoneura	••••						
Glossopteris stricta					••••		
Glossopteris subtilis					••••		
Glossopteris taenioides	••••						
Glossopteris taeniopteroides	••••	••••					
Glossopteris tenuifolia	••••						
Glossopteris tenuinervis	••••						
Glossopteris tortuosa	••••						
Glossopteris transversalis	••••						
Glossopteris varia		••••					
Glossopteris verticillata	••••						
Glossopteris vulgaris	••••						
Glossopteris waltonii	••••						
Gondwanolepis lanceolata		••••					
Gondwanolepis linearis		••••					
Gondwanolepis oblongovata		••••					
Jambadostrobus pretiosus	••••						
Kaokoxylon zalesskyi	••••						
Kendoxylon fissilis	••••						
Kendrostrobus cylindricus	••••						
Leleopteris ovata	••••						
Leleopteris srivastavae	••••						
Lithangium indicum	••••						
Lithangium ovoides	••••						
Lithangium surangei	••••						
Mahudaea senii		••••					
Megaporoxylon kraeuselii	••••						
Neomariopteris hughesii	••••	••••					
Neomariopteris lobifolia	••••						
Neomariopteris polymorpha	••••			••••			
Neomariopteris talchirensis	••••						
Ottokaria raniganjensis	••••						
Palaeospiroxylon heterocellularis	••••						
Palaeovittaria kurzii	••••						
Palaeovittaria raniganjensis	••••						
Paracatervoxylon biseriatum	••••						
Paracatervoxylon raniganjensis	••••						
Parapalaeospiroxylon burmundiaensis	••••						
Pecopteris affinis	••••						
Phyllotheca australis	••••	••••					
Phyllotheca griesbachii	••••						
Platycardia bengalensis	••••						
Plumsteadia indica	••••						
Plumsteadia lanceolata							••••
Plumsteadistrobus ellipticus	••••						
Polytheca elongata	••••						
Protophyllocladoxylon indicum	••••						
Pteronilssonia gopalii	••••						
Pterophyllum burdwanense	••••						
Pterygospermum raniganjense	••••						
Raniganjia bengalensis	••••						
Ranoxylon bengalensis	••••						
Rhabdotaenia danaeoides	••••	••••			••••		
Rhabdotaenia fibrosa	••••						
Samaropsis parvula	••••						
Schizoneura gondwanensis	••••	••••	••••	••••	••••	••••	••••
Scirroma angusta	••••						
Scirroma ventilebra	••••						
Scutum draperium	••••						

Contd.

Table 6—Contd.

TAXA/AREA	RANI-GANJ	JHARIA	KARAN-PURA	BOKARO	AURANGA	HUTAR	RAMKOLA
Scutum dutoitides		****					
Scutum leslium		****					
Scutum stowanum		****					
Searsolia oppositifolia		****					
Senotheca murulidihensis	****						
Sphenophyllum crenulatum		****					
Squamae integerrima		****					
Stephanostoma crystallinum		****					
Trithecopteris gondwanensis	****						
Trizygia speciosa	****						
Venustostrobus ghusikensis	****						
Venustostrobus indicus	****						
Vertebraria myelonis	****						
Vertebraria raniganjensis	****						
Zalesskioxylon gondwanensis	****						
Zalesskioxylon raniganjensis	****						
Zalesskioxylon uniseriatum	****						

Table 7—List of plant fossils from the Bijori Formation, Satpura Basin

Dichotomopteris lindleyii
Dicksonia sp.
Gangamopteris cyclopteroides
Gangamopteris whittiana
Glossopteris angustifolia
Glossopteris browniana
Glossopteris communis
Glossopteris conspicua
Glossopteris damudica
Glossopteris elongata
Glossopteris indica
Glossopteris leptoneura
Glossopteris raniganjensis
Neomariopteris hughesii
Samaropsis parvula
Schizoneura gondwanensis
Trizygia speciosa
Vertebraria indica

Table 8—List of plant fossils from Pachwara Formation, Rajmahal Basin

Asansolia phegopteroides
Cordaites (Pantophyllum) spatulata
Dichotomopteris bansloiensis
Dichotomopteris ovata
Gangamopteris cyclopteroides
Glossopteris angustifolia
Glossopteris browniana
Glossopteris communis
Glossopteris conspicua
Glossopteris damudica
Glossopteris divergens
Glossopteris elongata
Glossopteris emarginata
Glossopteris feistmantelii
Glossopteris formosa
Glossopteris gopadensis
Glossopteris indica
Glossopteris parallela
Glossopteris wilkinsonii
Lelstotheca robusta
Neomariopteris hughesii
Neomariopteris lobifolia
Pachwarophyllum santhalensis
Phyllotheca australis
Phyllotheca griesbachii
Plumsteadia indica
Raniganjia bengalensis
Rhabdotaenia danaeoides
Samaropsis raniganjensis
Schizoneura gondwanensis
Scutum dutoitides
Trizygia speciosa
Vertebraria indica

plant fossils, whether based on a leaf, wood or, pollen. Look-alike plant fossils from disjointed areas do not necessarily mean that they belong to the same plant. For example, the pollen genus *Striatopodocarpites* is known from Euramerican, Angaran,' Cathaysian and Gondwanan floras, yet so far we have no evidence to show that any gymnosperm was common to all these floras. Similarly the pollen genus *Potonieisporites* referred to the conifers was originally reported from the Zechstein of Germany (Bharadwaj, 1964), and at the same time it is an important and characteristic constituent of Early Permian floras of the Gondwana Supercontinent. Again we have no evidence if there

Table 9—Geographical distribution of plant fossils in Pali Formation

TAXA/AREA	PALI	SOHAGPUR	GOPAD-R	NIDHPURI
Chakrea papillosa				****
Cordaicarpus ovatus	****			
'Dicroidium' gopadensis				****
'Dicroidium' nidpurensis			****	****
'Dicroidium' papillosum				****
Dictyopteridium sporiferum	****			
Glossopteris angustifolia	****	****	****	****
Glossopteris browniana	****	****	****	****
Glossopteris communis	****	****	****	
Glossopteris conspicua			****	
Glossopteris damudica	****	****	****	
Glossopteris elongata	****		****	
Glossopteris emarginata			****	
Glossopteris feistmantelii		****		
Glossopteris formosa			****	
Glossopteris formosa major	****		****	
Glossopteris gigas			****	
Glossopteris gondwanensis			****	
Glossopteris gopadensis			****	
Glossopteris indica	****	****	****	
Glossopteris intermedia			****	
Glossopteris leptoneura			****	
Glossopteris linearis			****	
Glossopteris nilssonioides				****
Glossopteris papillosa				****
Glossopteris senii			****	****
Glossopteris sidhiensis				****
Glossopteris spatulata			****	
Glossopteris stenoneura			****	
Glossopteris stricta	****			****
Glossopteris tenuifolia			****	
Glossopteris varia			****	
Glossopteris zeilleri			****	
Glottolepis glabrosa				****
Glottolepis ovata				****
Glottolepis rugosa				****
Glottolepis sidhiensis				****
Glottolepis tuberculata				****
Gopadia coriacea				****
Gopadia papillata				****
Hapaticites foliata				****
Hapaticites metzgerioides				****
Hepaticites nidpurensis				****
Hepaticites riccardioides				****
Lelestrobus pennatus				****
Lepidopteris indica			****	****
Marhwaseaphyllum hastatum				****
Neomariopteris hughesii		****	****	
Neomariopteris polymorpha	****			
Nidia ovalis				****
Nidispermum glabrosum				****
Nidistrobus harrisiana				****
Nidpuria problematica				****
Pantiaspermum cristatum				****
Phyllotheca griesbachii		****		
Pseudoctenis ballii	****			
Pterophyllum karkatiensis	****			
Pteruchus gopadensis				****
Pteruchus indicus				****
Pteruchus nidpurensis				****
Pteruchus thomasii				****

Contd.

Table 9—Contd.

TAXA/AREA	PALI	SOHAGPUR	GOPAD-R	NIDHPURI
Pyriformispermum elongatum				****
Rewaphyllum nidpurensis				****
Rhabdotaenia danaeoides	****			
Rostrumaspermum venkatachalae				****
Rotundaspermum mucronatum				****
Rugapites spherica				****
Rugaspermum insigne				****
Rugaspermum media				****
Rugaspermum obscura				****
Rugatheca nidpurensis				****
Samaropsis menisca	****			
Samaropsis parvula	****			
Samaropsis raniganjensis	****			
Samaropsis surangei	****			
Satsangia campanulata				****
Savitrispermum crateriformis				****
Schizoneura gondwanensis	****	****	****	
Scutum sahnii			****	
Sidiphyllites flabellatus				****
Sphagnophyllites triassicus				****
Squamae gymnospermarum		****		
Squamae integerrima		****		
Taeniopteris spatulata	****			
Trizygia speciosa		****	****	
Vertebraria indica	****	****	****	

was any conifer that was common to Laurasia and Gondwana Supercontinent during Permian. Thus, at macro-level the boundaries between major floristic provinces become blurred due to subjective taxonomic approaches and/or misidentifications.

At the micro-level, for example, during the Gondwana time slice on the Indian subcontinent, the limited spatial distribution of certain elements reflects an incipient to decipherable provincialism. For this one has to consider time slices of reasonable durations only. A phytogeographic reconstruction, say for the Permian Period has no meaning because it would assume that for 40 million odd years there was a uniform distribution of vegetation all over India. Of course, one has also to take into account the fact that a complete sequence of floral succession is yet to be established. As finer stages of Permian are yet to be identified in the Indian Gondwana, a few examples are taken from different formation level units.

Talchir Formation—The formation represents the basal portion of the Indian Gondwana and is usually taken as equivalent of Asselian and Sakmarian stages. The flora of this period was not much diversified and is poorly known. Leaves of the genera *Gangamopteris* and *Pantophyllum* (= *Noeggerathiopsis*) are major components of the flora. No visible provincialism is seen.

Barakar Formation—The Barakar Formation conformably succeeds the Talchir Formation and is equivalent of Artinskian Stage. Some authors classify the lower part of the formation as an independent formation—the Karharbari. This unit does have a distinct floral association and hence here it is considered as a biozone.

The Karharbari biozone is reported from a number of coalfields (Table 3). The common elements of the flora are leaves of the genera *Pantophyllum* (= *Noeggerathiopsis*), *Gangamopteris* and *Glossopteris*. The biozone is best developed in the Giridih Coalfield, where the characteristic elements are *Botrychiopsis*, *Rubidgea* and *Buriadia*. The first two genera have not been found so far from any other place in India. *Botrychiopsis* is known from Australia and Argentina, and *Rubidgea* from South Africa. The synchroneity of these records with the Giridih record is yet to be established. The genus *Buriadia* is known from the Pali and Ib-River coalfields, as also from the Raniganj Formation of Raniganj Coalfield. The latter record is doubtful. Thus for the Karharbari time slice, the flora of Giridih Coalfield does show a decipherable provincialism.

In the Barakar Formation *sensu stricto*, the genera *Pantophyllum* (= *Noeggerathiopsis*) and *Gangamopteris* became almost extinct; the former genus has recently been recorded from the lower

Table 10—Geographical distribution of plant fossils in 'Kamthi' Formation

TAXA/AREA	GODA-VARI	CHAND-RAPUR	NAGPUR
Alethopteris spp.	****		
Araucarioxylon kothariensis		****	
Araucarioxylon lathiense		****	
Araucarioxylon loharense		****	
Araucarioxylon nandoriense		****	
Araucarioxylon surangei		****	
Asansolia phegopteroides			****
Australoxylon kanhargaoense		****	
Australoxylon longicellularis		****	
Australoxylon wejgaoense		****	
Baieroxylon multiseriale		****	
Cordaites spatulata			****
Dadoxylon adhariense		****	
Dadoxylon chandaensis		****	
Dadoxylon chandrapurensis		****	
Dadoxylon maharashtraensis		****	
Filicites sp.			****
Gangamopteris hughesii			****
Glossopteris angustifolia		****	
Glossopteris arberi			****
Glossopteris browniana			****
Glossopteris communis			****
Glossopteris conspicua			****
Glossopteris indica		****	****
Glossopteris lanceolatus		****	
Glossopteris leptoneura		****	****
Glossopteris mohudaensis		****	
Glossopteris musaefolia		****	****
Glossopteris raniganjensis		****	
Glossopteris stricta		****	****
Glossopteris surangei		****	
Glossopteris tenuifolia		****	
Glossopteris venustus		****	
Kamthioxylon adhariensis		****	
Kaokoxylon pseudotrimedullaris		****	
Nandorioxylon saksenae		****	
Phyllotheca australis			****
Planoxylon indicum		****	
Prototaxoxylon mahabalei		****	
Prototaxoxylon maithyi		****	
Prototaxoxylon uniseriale		****	
Pterophyllum spp.	****		
Pseudoctensis ballii		****	
Rhabdotaenia danaeoides			****
Rhipidopsis gondwanensis			****
Rhizoctonia nandoriense		****	
Schizoneura gondwanensis		****	
Sclerospiroxylon marguerierae		****	
Taxopitys indica		****	
Taxopitys surangei		****	
Trigonomyelon kamthiensis		****	
Vertebraria indica		****	****
Zalesskioxylon lepekhinae		****	
Zalesskioxylon simplexum		****	

seams of the Raniganj Coalfield (Srivastava, 1992). In general, the flora is dominated by species of the genus *Glossopteris* (Table 4). Three floral provinces

Table 11—Geographical distribution of plant fossils in 'Hinjir' Formation

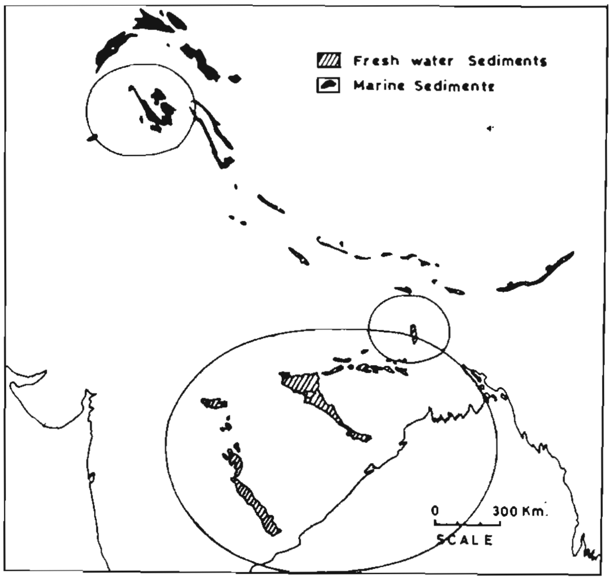
TAXA/AREA	IB-RIVER	MADHU-PUR	HAND-APPA
Anthrophyopsis sp.			****
Asansolia phegopteroides			****
Cyclodendron leslei			?
Denkania indica			****
Dicroidium sp.		****	
Dictyopteridium sporiferum			****
Eretmonia hinjridaensis			****
Eretmonia ovata			****
Eretmonia utkalensis			****
Glossopteris acuminata			****
Glossopteris angustifolia			****
Glossopteris browniana			****
Glossopteris communis		****	****
Glossopteris conspicua			****
Glossopteris damudica			****
Glossopteris dhenkanalensis			****
Glossopteris elongata			****
Glossopteris gigas		****	
Glossopteris hinjridaensis			****
Glossopteris inaequalis			****
Glossopteris indica			****
Glossopteris kamthiensis			****
Glossopteris maheshwarii			****
Glossopteris tenuifolia		****	
Glossopteris utkalensis			****
Glossotheca immanis			****
Glossotheca orissiana			****
Glossotheca utkalensis			****
Handapaphyllum indicum			****
Indocarpus elongatus			****
Khania dhenkanalensis			****
Lelstotheca robusta			****
Lepidopteris sp.		****	
Lidgettonia indica			****
Lidgettonia mucronata			****
Neomariopteris hughesii			****
Neomariopteris khanii			****
Neomariopteris lobifolia		****	****
Neomariopteris polymorpha			****
Pachwarophyllum santhalensis	****		
Pantopteris gracilis			****
Phyllotheca australis			****
Pseudoctenis ballii		****	****
Raniganjia bengalensis			****
Raniganjia etheridgei			****
Samaropsis sp.		****	
Schizoneura gondwanensis			****
Scutum elongatum			****
Scutum indicum			****
Scutum sahnii			****
Senia reticulata			****
Sphenophyllum churulianum			****
Sphenophyllum crenulatum			****
Sphenophyllum utkalensis			****
Surangephyllum elongatum			****
Trizygia speciosa		****	****
Utkalia dichotoma			****
Vertebraria indica		****	****

Table 12—Geographical distribution of plant fossils in Maitur Formation

TAXA/AREA	RANI-GANJ	AURA-NGA	RAM-KOLA
Dicroidium odontopteroides			****
Dicroidium sahnii		****	
Gangamopteris cyclopteroides		****	
Glossopteris angustifolia	****	****	****
Glossopteris browniana	****		
Glossopteris communis	****	****	****
Glossopteris conspicua	****		
Glossopteris elongata	****		****
Glossopteris indica		****	****
Glossopteris intermedia	****		
Glossopteris leptoneura			****
Glossopteris longicaulis			****
Heidiphyllum sp.	****		
Kendostrobus sp.	****		
Lepidopteris sp.	****	****	****
Neomariopteris lobifolia			****
Noeggerathiopsis sp.		****	
Pecopteris concinna	****		
Rhipidopsis densinervis		****	
Samaropsis sp.	****		
Schizoneura gondwanensis	****	****	****
Taeniopteris stenoneuron	****		
Trizygia speciosa		****	
Vertebraria indica		****	

Table 13—Geographical distribution of plant fossils in Hirapur/'Upper Kamthi' formations

TAXA/AREA	RANIGANJ	TALCHER
Dicroidium sp.	****	****
Glossopteris angustifolia	****	
Glossopteris damudica	****	
Glossopteris indica	****	
Lepidopteris sp.		****
Neomariopteris hughesii	****	****
Schizoneura gondwanensis	****	



Map 1—The three apparent floristic micro-provinces during the period when Barakar and equivalent formations were deposited.

Table 14—Geographical distribution of plant fossils in Tiki/Upper Kamthi formations

TAXA/AREA	SINGRA-ULI	TALCHER
Baiera sp.	****	
Baieroxylon cicatricum	****	
Dicroidium coriaceum	****	
Dicroidium giarensis	****	****
Dicroidium odontopteroides	****	
Dicroidium superbum		****
Dicroidium zuberi	****	****
Diplasmiophyllum hughesii	****	
Heidiphyllum singhii	****	****
Lepidopteris madagascariensis	****	
Lepidopteris stormbergensis	****	****
Pagiophyllum bosei	****	
Rissikia denticulata	****	
Rissikia raoi	****	
Spermatites indicus	****	
Spermatites orbicularis	****	
Sphenobaiera janarensis	****	
Xylopteris sp.	****	
Yabiella indica	****	****

are apparent, though not necessarily of the same age (Map 1). These provinces are:

(i) Perigondwana (Mamal Formation), with *Lobatannularia*, *Sphenophyllum*, *Rajahia* (= *Pecopteris*) and *Kashmiropteris*. All these genera are important constituents of the Cathaysian Flora, and except for the genus *Sphenophyllum* are not known from the Gondwanan flora.

(ii) Northern Rajmahal Basin (Hura Coalfield), with *Sphenophyllum* (dimorphic leaves), *Dactylophyllum digitata*-type, *Saportaea*, *Psygmophyllum*, *Rhipidopsis*, *Ginkgoites*, *Veekaysinghia*, *Birbalsahnia*, etc. Leaves resembling those of the genus *Saportaea* have recently been discovered in the fireclays of Auranga Coalfield. The genus is also known from Permian ,of China and United States of America. On the Gondwana Supercontinent, it has been reported from the Triassic of South Africa (Anderson & Anderson, 1989). *Dactylophyllum digitata* is known only from the Late Carboniferous of Australia (Morris, 1975). A *Potonieisporites*-*Hamiapollenites* palynological association has also been recorded from the Hura Coalfield. These two genera normally are not expected to occur

Table 15—List of plant fossils from Parsora Formation, Son Basin

Baiera indica
Cladophlebis shensiensis
Cordaicarpus chichariensis
Cordaites spatulata
Dicroidium feistmantelii
Dicroidium odontopteroides
Dicroidium sahnii
Diplasmiophyllum hughesii
Ginkgoites goiraensis
Glossopteris browniana
Glossopteris indica
Heidiphyllum taeniatum
Lycopodites sahnii
Marattiopsis sp.
Neocalamites foxii
Pantopteris gracilis
Parsorophyllum indicum
Pterophyllum sahnii
Samaropsis srivastavae
Taeniopteris spatulata
Vertebraria indica

together; in India, *Potonieisporites* is confined to Early Permian, and *Hamiapollenites* to Late Permian.

(iii) Main Gondwana country, including Damodar, Son-Mahanadi and Pranhita-Godavari grabens, and probably also eastern Himalaya. The genera *Barakaria* and *Diphyllopteris* are endemic to the Auranga Coalfield. The only other known record of the genus *Barakaria* is from the Angaran flora (Meyen, 1969).

Raniganj Formation—The flora of the Raniganj and 'equivalent' formations (Table 6-11) is relatively more diversified. Here, too, an incipient provincialism is decipherable. The flora of this formation in the Raniganj Coalfield, where it is best known, has a characteristic element, *Palaeovittaria*, which is not known from any other equivalent bed. The genus has recently been reported from the Barakar Formation of Raniganj Coalfield (Srivastava, 1992), and the Mamal Formation of the Perigondwana (Pant *et al.*, 1991). Alongwith certain other genera, such as, *Belemnopteris, Rhabdotaenia*, the flora of Damodar Graben has a decipherable compositional difference as compared to equivalent floras from other areas. For example, the Hinjir Formation of the Mahanadi Valley has yielded fossils referable to the family Eretmoniaceae (Maheshwari, 1990), which are restricted to this area. The fossils of this family are known only from Queensland in Australia and Natal in South Africa. The upper part of the Pali Formation (Nidhpuri Plant beds) in the Son Graben also contains certain endemic elements, such as the genera *Nidia, Nidistrobus, Satsangia*, etc. The beds also contain 'Thinnfeldia' callipteroides-type of leaves, which in literature have been named as species of the genus *Dicroidium*. The genus *Lelstotheca* is restricted to the Pachwara Formation of Pachwara Coalfield, though it possibly occurs in the Barakar Formation of Hura Coalfield also.

The few examples discussed above reveal that at certain points of time some of the plant taxa had a restricted geographical distribution, and on the basis of such occurrences few incipient or apparent micropalaeophytogeographical provinces can be delineated. However, much more work needs to be carried out as most of the regions are underexplored, and a complete sequence of floral succession is yet to be established for all the Gondwanan areas.

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Morphological trends in Gondwana plants

Usha Bajpai

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The term Gondwana has recently been redefined to include the group of terrestrial rocks in the Indian Craton, that was initiated with a basal Permian glacigene epoch and terminated with the large hiatus at the top of the Triassic. The Gondwana Supergroup as redefined now comprises Talchir, Damuda, Panchet and Mahadeva groups and ranges in age from the earliest Permian to latest Triassic or earliest Jurassic (Venkatachala & Maheshwari, 1991).

The vegetational scenario of Gondwana shows mixture of plants belonging to quite distinct habitats. The morphological adaptations of plants that thrived at all levels on land, in continental water, upland and in environments of exeeding dryness are significant. Leaf size varies from small to large with variety of apex and base, midribless to prominent midrib, non-petiolate to petiolate, veins loosely arranged, narrow mesh type of venation to open mesh and narrow mesh type. Leaf cuticle of glossopterids also shows variations.

Most of the Gondwana woods show variation in pith and primary xylem and secondary xylem. Pith varies from homo- to hetero-cellular. Primary xylem shows variation from endarch to mesarch. The secondary xylem is pycnoxylic, homoxylous. Secondary xylem shows well-marked growth rings. There is a great variation in the pitting of secondary tracheids. Xylem rays vary from uni- to multi-seriate. The ray field-pits also show diversity.

Wide diversities are also seen in the morphology of pteridophytic megaspores and of reproductive organs of gymnosperms. The exosporium of megaspore is either smooth or variously ornamented. The mesosporium is with or without cushions. Reproductive organs are known only for the glossopterid group and are of two types.

The changing patterns in leaves, woods, megaspores and reproductive organs of Gondwana plants may provide significant data for charting of morphotrends in these organs. It can probably also be established if these morphotrends were ecologically controlled temporary and transient phase or were genetically controlled leading to evolution of new types.

Key-words—Gondwana, Lycopodophyta, Megaspores, Arthrophyta, Glossopteridopsida, Morphotrends.

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सारॉश

गोंडवाना पौधों में आकारिकीय प्रवृत्तियाँ

ऊषा बाजपेयी

भारतीय क्रेटॉन में विद्यमान स्थलजात चट्टानों के समूह को सम्मिलित करने के लिए गोंडवाना शब्द को अभी हाल में पुन: परिभाषित किया गया है। इस क्रेटॉन का आधारी भाग परमी हिमानी कल्प का तथा उपरितम भाग त्रिसंघी कल्प की चट्टानों का निरूपण करता है। पुन: परिभाषित गोंडवाना महासमूह में अब तलचीर, दमुदा, पंचेत एवं महादेवा समूहों को सम्मिलित किया गया है तथा आयु में ये पूर्वतम् परमी से उपरितम् त्रिसंघी अथवा प्रारम्भिकतम् जूराई (वेंकटाचाला व माहेश्वरी, 1991) तक विस्तृत हैं।

गोंडवाना वनस्पति में विभिन्न जलवायु से सम्बद्ध पौधों का मिश्रण है। भूमि, पानी, ऊँचे स्थल तथा शुष्क वातावरण के अनुसार इन सभी पौधों का आकारिकीय अनुकूलन अत्यन्त महत्वपूर्ण है। पत्ती के आकार में अनेक विभिन्नतायें हैं कुछ पत्ती छोटी, कुछ बड़ी, कुछ मध्यशिराविहीन तो कुछ पूर्ण विकसित मध्यशिरा तथा चौड़े शिरान्यास एवं काफी सघन शिरान्यास से युक्त हैं। ग्लॉसॉप्टेरिडी पौधों की पत्तीयों की उपचर्म में भी विभिन्नताऐं हैं।

गोंडवाना से प्राप्त अधिकतर काष्ठों में मज्जा तथा प्राथमिक एवं द्वितीयक दारु में भी विभिन्नता प्रेक्षित की गई हैं। द्वितीयक वाहिनिकीयों के गर्तन्यास में भी विभिन्नता विद्यमान है। दारु किरणें एक अथवा बहुक्रमी हैं। किरण क्षेत्र-गर्त्त भी विविधता प्रदर्शित करते हैं।

यही नहीं अपितु टेरीडोफाइटी गुरुबीजाणु तथा अनावृतबीजीयों के जननांगों में भी विविधता प्रेक्षित की गई हैं। गुरुबीजाणुओं की बाह्यउपचर्म या तो चिकनी होती है अथवा विभिन्न प्रकार से अलंकृत। मध्यउपचर्म तल्पहीन अथवा किसी-किसी में तल्पयुक्त होती है। अभी तक जननाँग केवल ग्लॉसॉप्टेरिडी

Four Decades of Indian Palaeobotany
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समूह में ही विदित हैं तथा दो प्रकार के होते हैं।

गोंडवाना पौधों की पत्तीयों, काष्ठों, गुरुबीजाणुओं एव जननांगों में उक्त विविधता से महत्वपूर्ण आँकड़े उपलब्ध हो सकते हैं। यह भी संभव है कि ये विविधता अस्थायी रूप से पारिस्थिति के कारण हो गई हैं अथवा स्थायी रूप से आनुवंशिक गुणों द्वारा निर्यत्रित नये प्ररूपों के विकास के फलस्वरूप हुई हैं।

MORPHOLOGY implies the study of form. The adult form and structure of plants seems to be the outcome of a series of evolutionary changes extending over hundreds of million years. Most fossils represent the fragments of plants. The reconstructions of whole plants are made on the basis of morphology and anatomy. However, due to break in sequence of sediments and also due to uneven distribution of plant fossils in the sediments, usually it is very difficult to trace morphotrends which depict evolutionary tendencies and patterns. This is also true for the vegetation that thrived during the time when the Gondwana Supergroup of sediments was deposited in India and countries of the Southern Hemisphere. Available data being imperfect, there are several gaps in our knowledge which need to be investigated further.

LYCOPSIDA

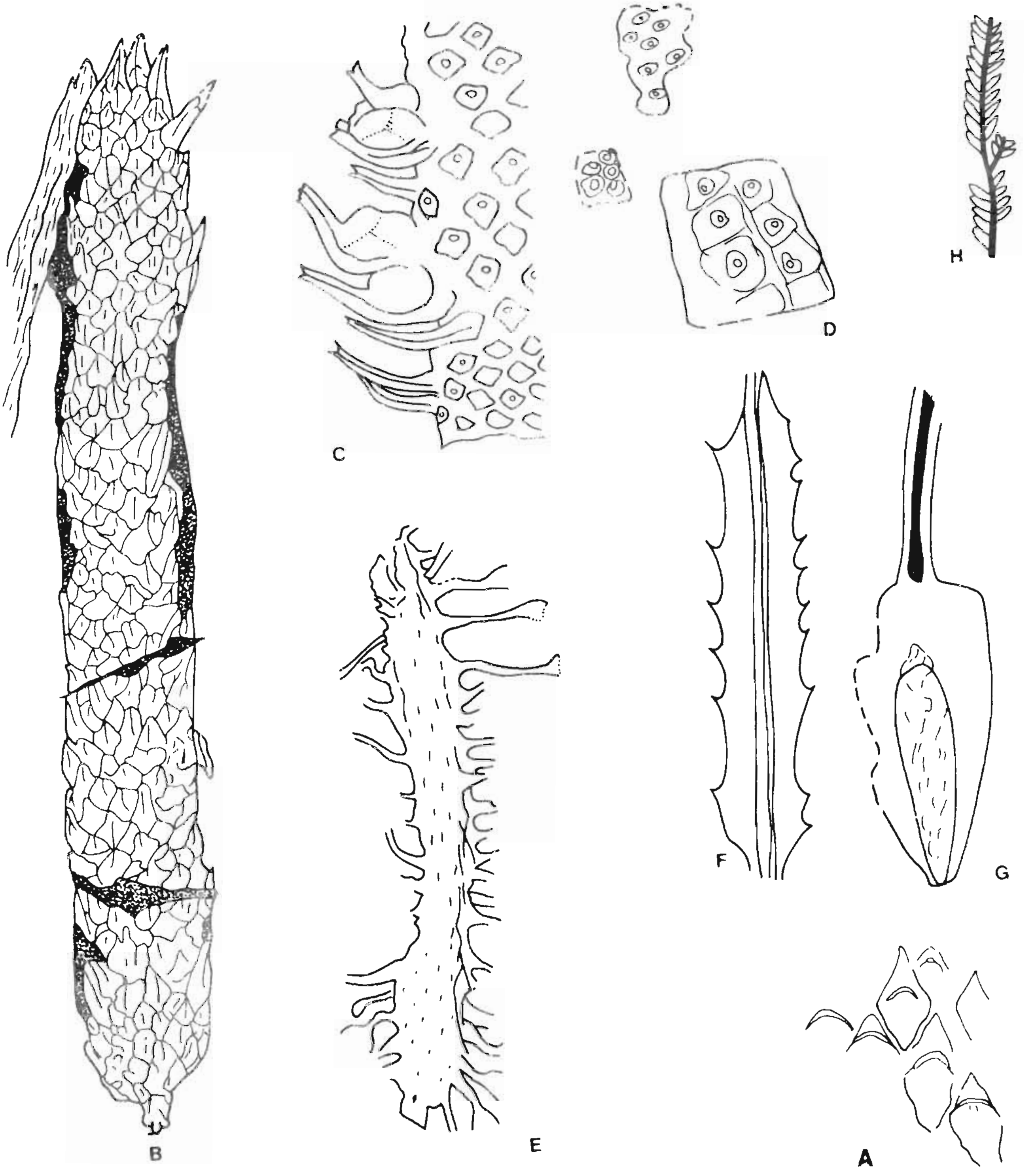
The Lycopodophyta, that appeared in the Upper Devonian, and constituted a major part of Carboniferous vegetation of the Northern Hemisphere, are meagrely represented in the contemporary and younger floras of the Gondwana Supercontinent, particularly so in India. In India, the oldest record of lycopsid megafossils is from the Early Permian *Gangamopteris* beds of Zewan Spur, Kashmir (Kapoor, 1968). The incomplete specimen shows crescentic ligular scars inside spirally disposed rhomboid leaf cushions (Text-figure 1A). Srivastava and Kapoor (1967) reported a lycopsid cone, *Lepidostrobus kashmirensis* from equivalent beds of the Liddar Valley, Kashmir (Text-figure 1B). Not many details are seen in this specimen, and hence its exact taxonomic position is yet to be decided.

In the Gondwana of the Peninsula, the oldest definite lycopsid megafossil has been reported from the Kulti Formation (Ironstone Shale/Barren Measures, ?late Early Permian) of Jharia Coalfield (Kar, 1968). The solitary species, *Cyclodendron leslii* (Seward) Kräusel is represented only by fragments of stems, which bear a number of spirally arranged, eye-shaped leaf scars (Text-figure 1C). Each leaf-scar has a more or less circular boss which perhaps indicates the position of vascular supply to the leaf. The ligular pit or the parichnos scars have not been found. Better preserved specimens of this species are known from other Gondwana provinces, which are heterosporous, the sporophylls being distributed on normal leafy shoots, without any organized cone (Kräusel, 1961). A specimen described as *Bothrodendron* sp. by Seward and Sahni (1920, pl. 2, figs 28 a-c) from the Kulti Formation of the Raniganj Coalfield, probably also represents *C. leslii* (Text-figure 1D). The species possibly persisted into the Early Triassic Mangli beds, from where a somewhat similar specimen was described as *Lepidodendron* by Hislop (1856) and later as "*Stigmaria*" by Bunbury (1861) from the Kamthi Formation.

From the Late Triassic another lycopsid species, *Lycopodites sahnii* is known (Lele, 1962). The fragmentary axis bears spirally disposed linear delicate leaves almost at right angles to the axis. The leaf scars show a centrally situated minute depression that probably represents the vascular trace to the leaf (Text-figure 1E). The genus *Lycopodites* continues into the Cretaceous where it is represented by the species *L. gracilis* (Oldham & Morris) Seward & Sahni. From the Early Cretaceous Bhuj Formation of Kutch Basin, Bose and Roy (1964) and Bose and Banerji (1984) have reported lycopsid taxa *Isoetites serratifolius* (Text-figure 1F), *I. indicus* (Text-figure 1G), and *Selaginellites* sp. (Text-figure 1H)

Evidently, lycopsid megafossils are meagrely known from the Indian Gondwana, yet the presence of lycopsid megaspores in almost all the sediments is indicative of their existence all through the Gondwana period. This indicates that many more species of lycopsids flourished than is evident from the megafossil record. The paucity of lycopsid megaplant remains may probably be due to the delicate nature of plants and their suppression by an overwhelming preponderance of gymnospermic megaplant remains (Maheshwari, 1974, p. 52).

The mesosporium in all the megaspore taxa, except in *Srivastavaesporites indicus* (Singh) Bharadwaj & Tiwari, recorded from the Early Permian Talchir Formation shows characteristic biseriately arranged, more or less rounded, projections or cushions in the inter-ray areas. In the succeeding Barakar Formation (Early Permian), the arrangement of cushions on the mesosporium changes and becomes irregularly organized, but the cushions remain confined within the inter-ray areas. However, in the ?late Early Permian Kulti Formation, the biseriate arrangement of cushions on the inner body reappears (e.g., *Duosporites congoensis*) and



Text-figure 1—**A.** Lycopsid stem; **B.** *Lepidostrobus kashmirensis*, **C.** *Cyclodendron leslii*, **D.** *Bothrodendron* sp., **E.** *Lycopodites sahnii*; **F.** *Isoetites serratifolius*; **G.** *Isoetites indicus*; **H.** *Selaginellites* sp. (Figure **B** redrawn from Srivastava & Kapoor, 1969, figure **C** redrawn from Kräusel, 1961; figure **D** redrawn from Seward & Sahni, 1920; figure **E** redrawn from Lele, 1962, figures **F-H** redrawn from Bose & Banerji, 1984).

exists alongwith irregular arrangement of the cushions (Text-figure 2A). This arrangement continues into the Late Permian and Early Triassic (Bharadwaj & Tiwari, 1970; Maheshwari & Banerji,

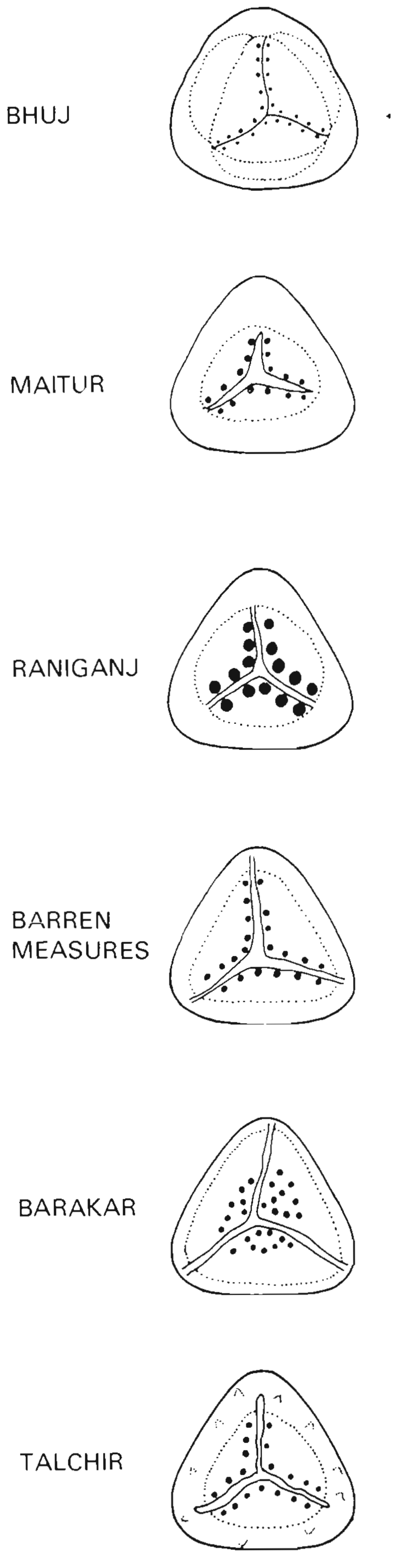
1975) but becomes associated with a megaspore type that is circular in polar view. One of the taxa, i.e., *Talchirella densicorpa* Bharadwaj & Tiwari, has massive cushions. Mesosporium with cushions is not known from younger horizons except for in three species of the genus *Minerisporites*, a zonate megaspore from the Bhuj Formation of Kutch Basin (Singh, Srivastava & Roy, 1964, Banerji, Jana & Maheshwari, 1984).

The sculptural elements on the megaspore sporoderm show a trend towards becoming more pronounced and robust in time (Text-figure 2B). The exine ornamentation in all the taxa of megaspores of Talchir Formation is from granulate to fine verrucate, except in *Trilaevipellites talchirensis* (Lele & Chandra, 1974), which is laevigate. The megaspore genus *Srivastavaesporites* continued into the Early Triassic without any significant change in the ornamentation pattern Megaspores assigned to the genus *Bokarosporites* are almost similar except that the sporoderm sculpture is psilate. Pronounced sculptural elements appear for the first time in the Barakar Formation. The megaspore genus *Jhariatriletes* with baculate exine also extended into the Early Triassic, different species having differentially baculate, closely baculate, and sparsely baculate elements. The baculae probably changed into ribbose pattern of *Singhisporites* in late Early Permian. Baculate elements reappear in *Bacutriletes* recorded from Late Triassic to Early Cretaceous (Text-figure 2C). The megaspore genera *Nathorstisporites* and *Paxillitriletes* seem to belong to this line. In Early Triassic megaspores appear with reticulate exosporium, e.g., *Maiturisporites*. Late Triassic megaspores of the genus *Hughesisporites* with finger-like interwoven projections could have been derived from *Maiturisporites* (Text-figure 2D).

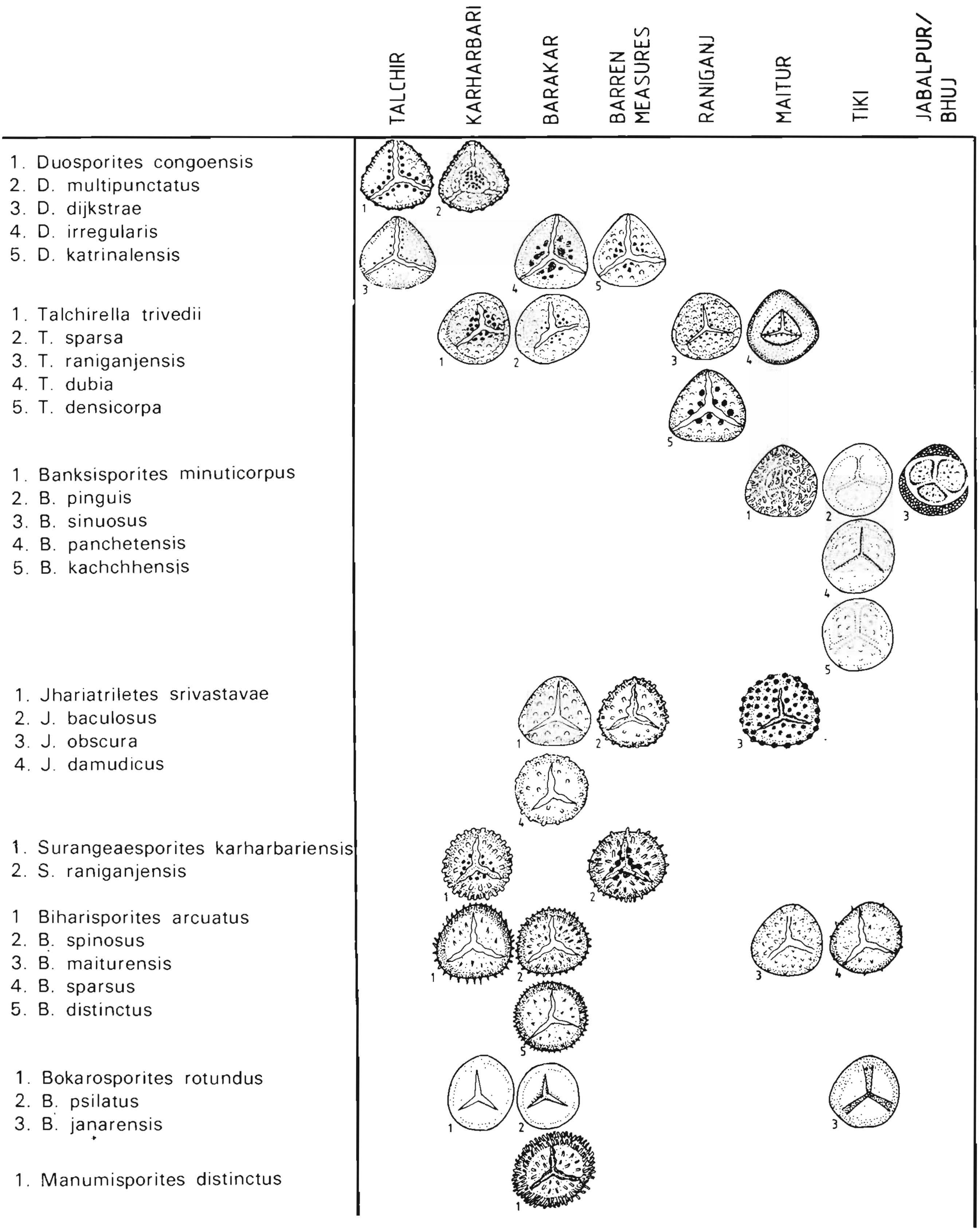
ARTHROPHYTA

The group is largely known through vegetative shoots. In the absence of well-preserved fertile parts, except for *Giridia indica* (Text-figure 3A; Pant *et al.*, 1981), the plant remains can only provisionally be assigned to two orders, viz., Equisetales and Sphenophyllales.

The equisetalean stems are all similar in being jointed and ribbed, the ribs continuing through successive nodes (Surange, 1971). Adpressed leaf sheaths are known in the genera *Phyllotheca* Brongniart (Text-figure 3B) and *Schizoneura* Schimper & Mougeot (Text-figure 3C). Both appear simultaneously in the Early Permian (Lower Barakar Formation) and continue almost into the Early



Text-figure 2A—Schematic drawing showing arrangements of cushions on the mesosporium.



Text-figure 2B—Schematic drawing showing sculptural pattern on megaspore sporoderm.

Contd.

1. Singhisporites surangei
2. S. radiales

1. Maiturisporites indicus
2. M. distinctus
3. M. spinotriletus

1. Erlansonisporites triassicus
2. E. indicus

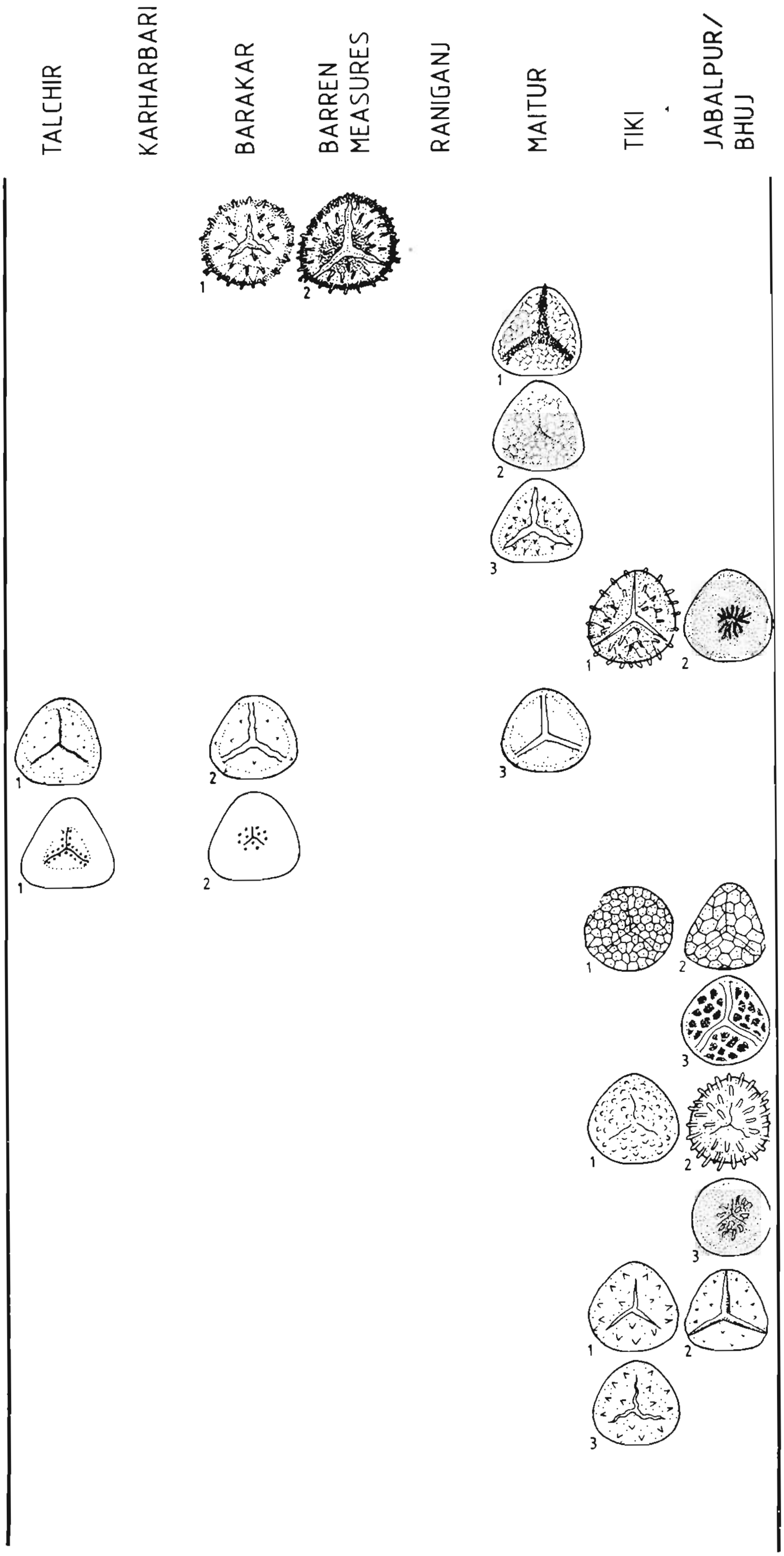
1. Srivastavaesporites indicus
2. S. utkalensis
3. S. panchetensis

1. Trilaevipellites talchirensis
2. T. multipulvinatus

1. Horstisporites areolatus
2. H. semireticulatus
3. H. biswasii

1. Hughesisporites variabilis
2. H. rajnathaii
3. H. singhii

1. Verrutriletes minuticorpus
2 V. obscura
3. V. royii



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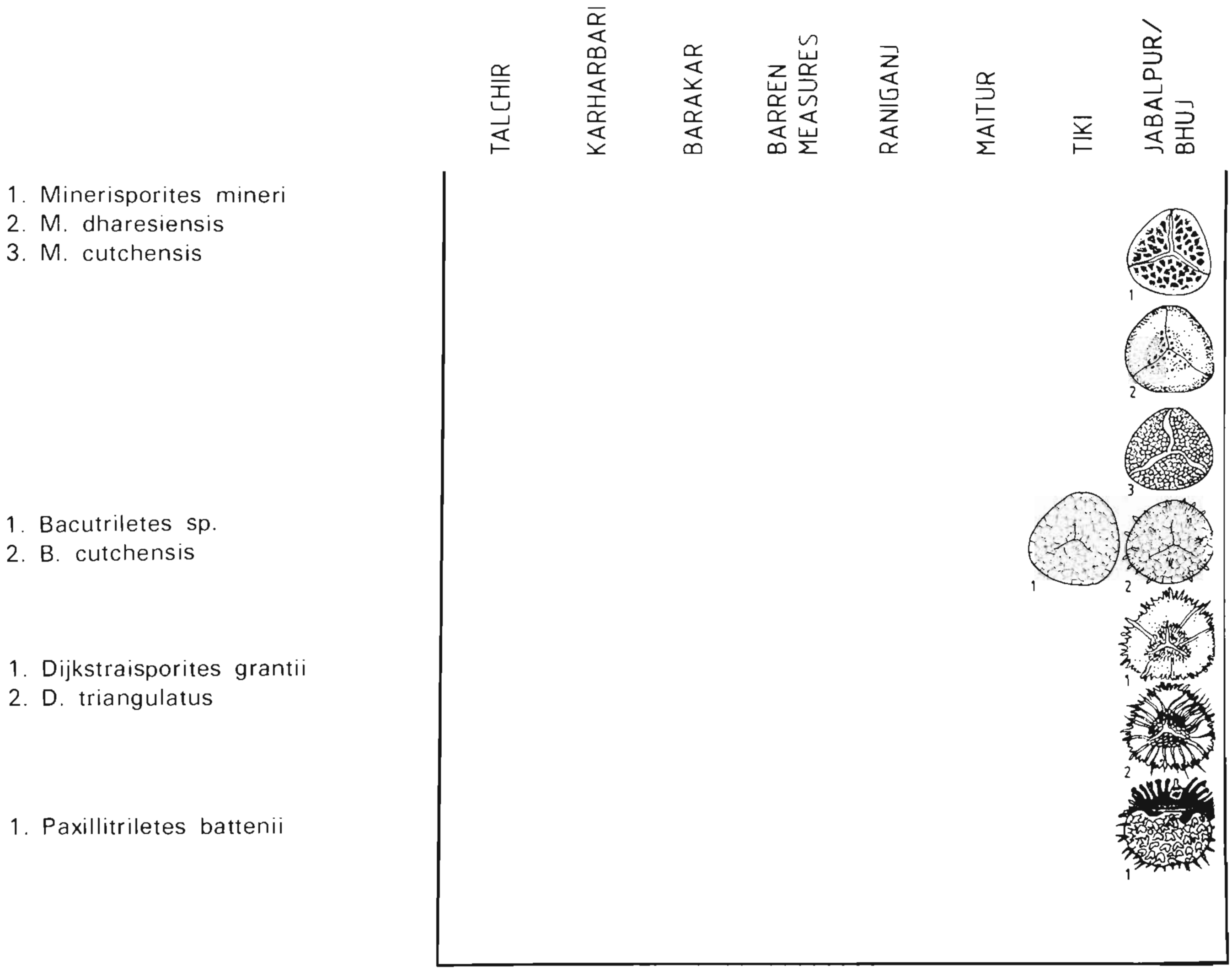
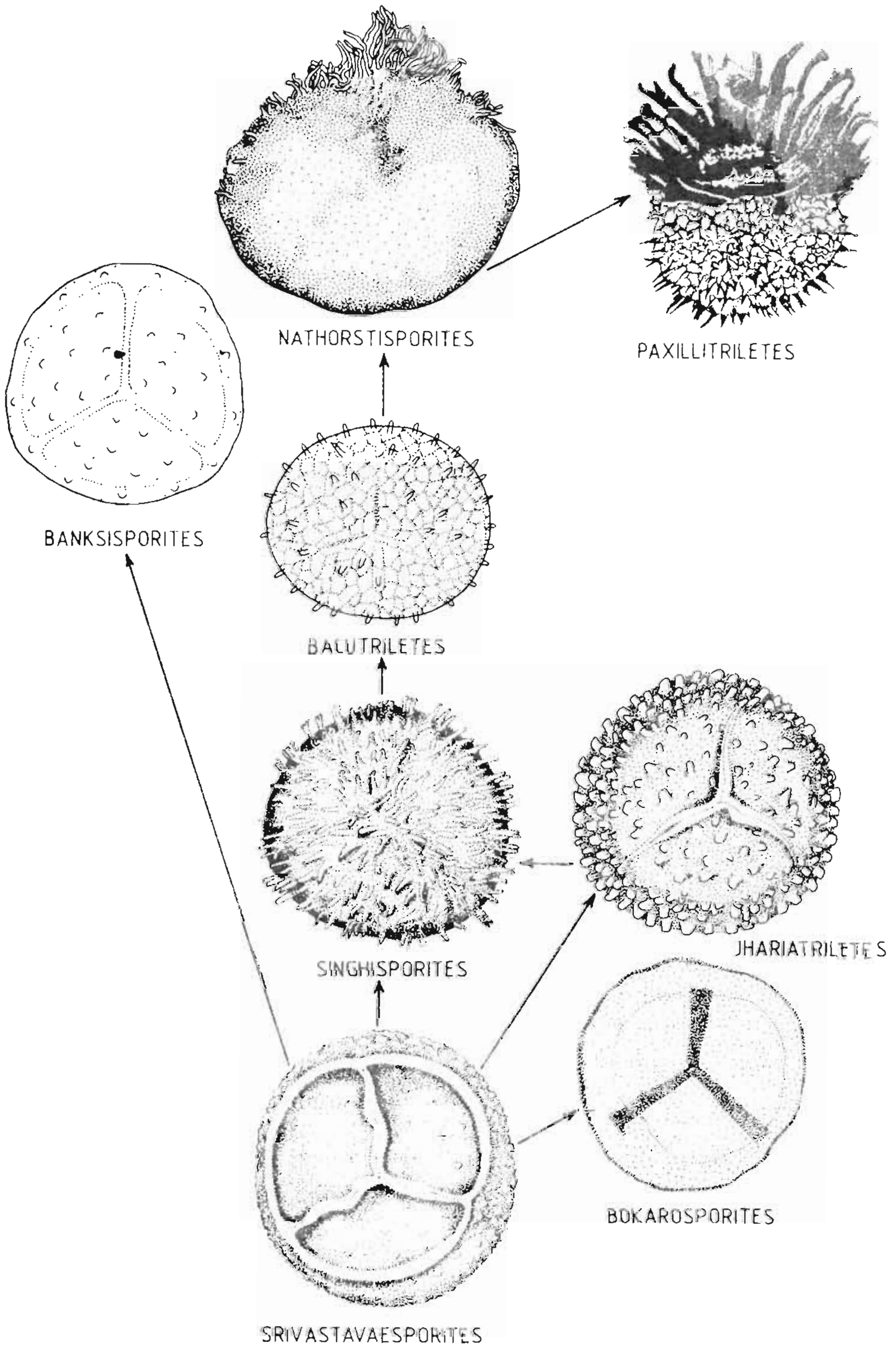


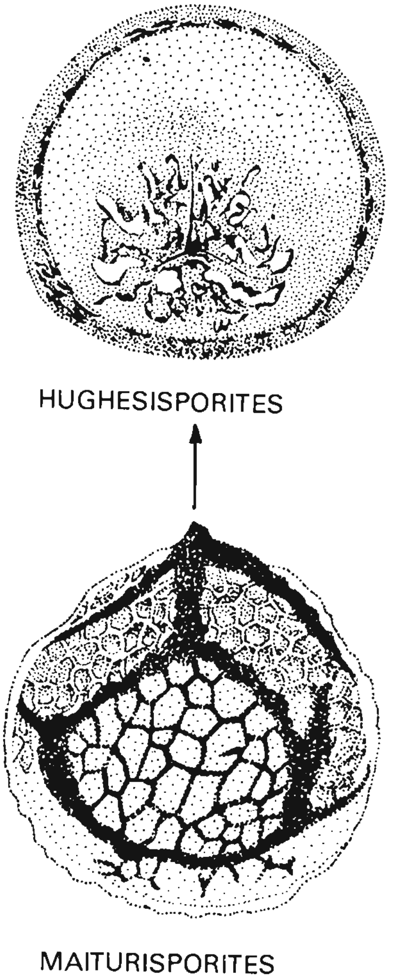
Triassic. The genus *Lelstotheca* Maheshwari (Text-figure 3D) apparently resembles shoots of the genus *Phyllotheca*, but is distinguished by the absence of an adpressed leaf sheath. The genus appears later than *Phyllotheca* and is so far known only from the Barakar Formation (Maheshwari, 1971; Srivastava & Maheshwari, 1986). The genus *Barakaria* Seward & Sahni (Text-figure 3E) has a restricted distribution and is a very rare form, having been reported only once (Feistmantel, 1881, 1886; Seward & Sahni, 1920). *Raniganjia* Rigby (Text-figure 4A), a characteristic form of the Late Permian (Raniganj Formation), has a typical disc-like leaf whorl which may have arisen from the leaf-whorl of *Lelstotheca* through an increase in number of segments, and in length of continuity of margins. *Bengalia raniganjensis* Maheshwari, Singh & Bajpai from the Late Permian Raniganj Formation (Text-figure 4B), probably is also related to *Lelstotheca robusta* (Feistmantel) Maheshwari. In the epidermal features of most of the genera of the Equisetales there is hardly any difference (Meyen, 1969; Pant & Nautiyal, 1968). In *Raniganjia bengalensis* (Feistmantel) Rigby, the guard cells show radiating striations (Pant & Nautiyal, 1968) like those on the leaf-segment and stems of some of the modern Equisetums (Pant & Kidwai, 1968). This feature, however, is not known in the cuticle of *Schizoneura* (Srivastava, 1954) and *Barakaria* (Meyen, 1967). Leaf segments of the genera *Barakaria, Lelstotheca, Raniganjia* and *Bengalia*, all have transverse running striations that simulate lateral veins, and mucronate apices. These characters are lacking in leaf segments of *Phyllotheca* and *Schizoneura*.

The Sphenophyllales are represented by two genera, viz., *Trizygia* Royle (Text-figure 4C) and *Sphenophyllum* Koenig (Text-figure 4D). The former, represented by a single species, *T. speciosa* Royle, is the most common form and continues unchanged from the Early Permian Barakar Formation into the



Text-figure 2C—Schematic drawing showing changes in ornamentation pattern in time.

Early Triassic Maitur Formation (Bose & Banerji, 1984). The genus *Sphenophyllum* is comparatively rare in the Indian Gondwana. Fragments have been reported from Barakar and Hinjir formations of the Raniganj and Talcher coalfields, respectively A characteristic heterophyllous *Sphenophyllum* has been reported from the Early Permian Barakar Formation of the Rajmahal Hills (Singh, Srivastava & Maheshwari, 1986) The two genera are distinguished on the basis of the difference in the nature of leaf whorls at the nodes; there is no difference in the epidermal features of the leaves



Text-figure 2D—Schematic drawing showing changes in ornamentation pattern in time.

(Pant & Mehra, 1963; Boureau, 1964). Recently, Prasad and Maithy (1990) have reported a new genus of fossil leaves from the Barakar Formation of the Bansloi Valley Coalfield in the Rajmahal Basin. The epidermal features of this leaf, *Pachwarophyllum santhalensis* (Text-figure 4E) which is morphologically indistinguishable from leaves of the genus *Benlightfootia* Lacey & Huard-Moine (Text-figure 4F), qualify for the placement of this taxon also under the Sphenophyllales. So far, no fructification has been assigned to the Gondwana taxa of Sphenophyllales; the genus *Kendostrobus* Surange & Chandra, with its monolete spores, probably belongs here.

PTEROPHYTA

The oldest fern-like foliage from the Indian Gondwana is *Botrychiopsis* (*Gondwanidium*) *valida* (Feistmantel) Archangelsky & Gamerro. The fronds, known only from the early Early Permian (Lower Barakar Formation), are long and bear two rows of large and more or less deeply lobed leaflets. Reproductive biology of this 'fern' is not known.

However, there are other genera of fern-like foliage that are known both as fertile and sterile forms. The Permian forms are species of the genera *Asansolia, Trithecopteris, Damudosorus* and *Damudopteris*. The sterile foliage ranges throughout the Permian but the fertile foliage is known only from the Late Permian Raniganj Formation. All the known ferns are exindusiate, some forms are characterized by free eusporangia with a transverse annulus, while the others have synangia. The forms with synangia (i.e., *Asansolia, Trithecopteris*) are referred to the family Asterothecaceae while forms with free eusporangia constitute the family Damudopteridaceae. The latter family could have been the progenitor of gleichenaceous forms. The spores of these ferns do not show any major trend. They are a mixed lot, except that all have a surface sculpture (Lele, Maithy & Mandal, 1981) that ranges from grana to bacula (Text-figure 5A-D).

The records of Triassic ferns in India are poor, and therefore their relationship with the Permian forms is uncertain. In the Early Triassic, two types of sphenopterid foliage, viz., *Sphenopteris polymorpha* and *Sphenopteris* spp. are found. Two new ferns, viz., *Marattiopsis* and *Danaeopsis* appear in the Late Triassic (Parsora Formation) of South Rewa Basin. These forms are again found in the Early Cretaceous (Rajmahal Formation) of Rajmahal Hills. There being a sedimentary hiatus, as well as geographical discontinuity, intervening story is not known, except that the pinnules of *D. rajmahalensis* Feistmantel are larger and more linear than those of *D. gracillis* Lele.

GLOSSOPTERIDOPSIDA

The most dominant and important group of plants that thrived during the Permian times in India is the Glossopteridopsida. This group appeared almost simultaneously with the Gondwana sedimentation. Due to non-deposition of older, Ordovician to Carboniferous sediments in the peninsular basins, forms ancestral to the glossopterids are not known. Five genera based on leaves, viz., *Rubidgea* Tate (Text-figure 6F), *Gangamopteris* McCoy (Text-figure 6D), *Maheshwariphyllum* Srivastava (Text-figure 6B), *Glossopteris* Brongniart (Text-figure 6A) and *Palaeovittaria* Feistmantel (Text-figure 6E) are definitely assigned to this group. The leaf genus *Belemnopteris* Feistmantel (Text-figure 6C) probably also belongs here.

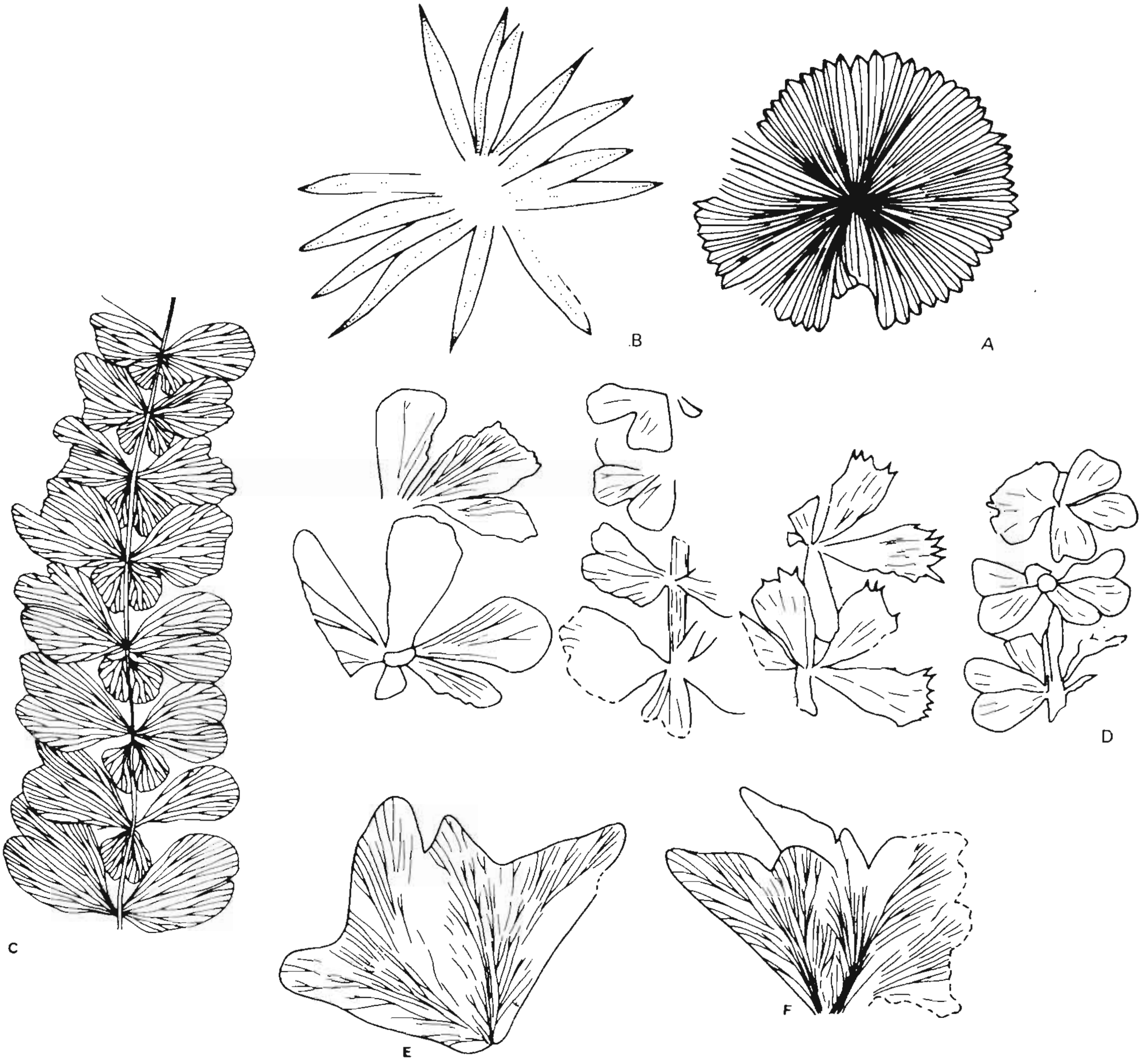
Text-figure 3—A. *Giridia indica*; **B.** *Phyllotheca australis*; **C.** *Schizoneura gondwanensis*; **D.** *Lelstotheca robusta*; **E.** *Barakaria dichotoma* (Figure **A** redrawn from Pant *et al.*, 1981; figure **B** redrawn from Pant & Kidwai, 1968).

The most important genus is *Glossopteris* which has tongue-shaped leaves with a midrib that gives off dichotomizing and anastomosing secondary veins. *Palaeovittaria* leaves have a midrib only in basal part. Leaves of the genera *Gangamopteris* and *Rubidgea* are devoid of a midrib. Anastomoses are present only in *Gangamopteris* and *Glossopteris*, and also in *Belemnopteris*.

The glossopterid group when put in a stratigraphic perspective reveals that leaves without a midrib were probably the first to appear. Alongwith the earliest forms, occurs a Cordaite-type of leaf, *Pantophyllum spatulata* (Dana) comb. nov. (Basionym: *Noeggerathia spatulata* Dana 1841; earlier known as *Noeggerathiopsis hislopii* (Bunbury) Feistmantel/*Noeggerathiopsis spatulata* (Dana) Rigby, Maheshwari & Schopf). The name *N. hislopii* should be restricted only to latest Permian forms from the Kamthi Formation (Bunbury, 1861), and which may have ginkgopsid, rather than cordaitalean affinities. The leaves of *Pantophyllum* were strap-shaped, lacked the midrib and the veins ran straight from the base to the apical region dichotomizing once or twice and never anastomosing.

An almost similar leaf is *Euryphyllum* Feistmantel (Text-figure 6G) which appeared slightly late, i.e., in basal Barakar Formation (Feistmantel, 1879) and is so far known only from the Giridih Coalfield (Lakhanpal, Maheshwari & Awasthi, 1976). Alongwith *Euryphyllum* also appears *Rubidgea* where too the leaves lack a midrib and anastomoses. The genus *Rubidgea* is also known only from the basal Barakar Formation of the Giridih Coalfield.

It is presumed that sometimes in the earliest Permian, the Cordaite-type of leaf gave rise both to *Euryphyllum* and *Rubidgea* (Text-figure 7). Morris (1975), however, believes that certain aphlebiae found alongwith leaves of *Dactylophyllum digitata* in the Late Carboniferous of New South Wales, Australia could have been precursors of the glossopterid lineage. From *Rubidgea* could then have arisen leaves of *Gangamopteris* which though lack a midrib, yet have a well-defined central strand of

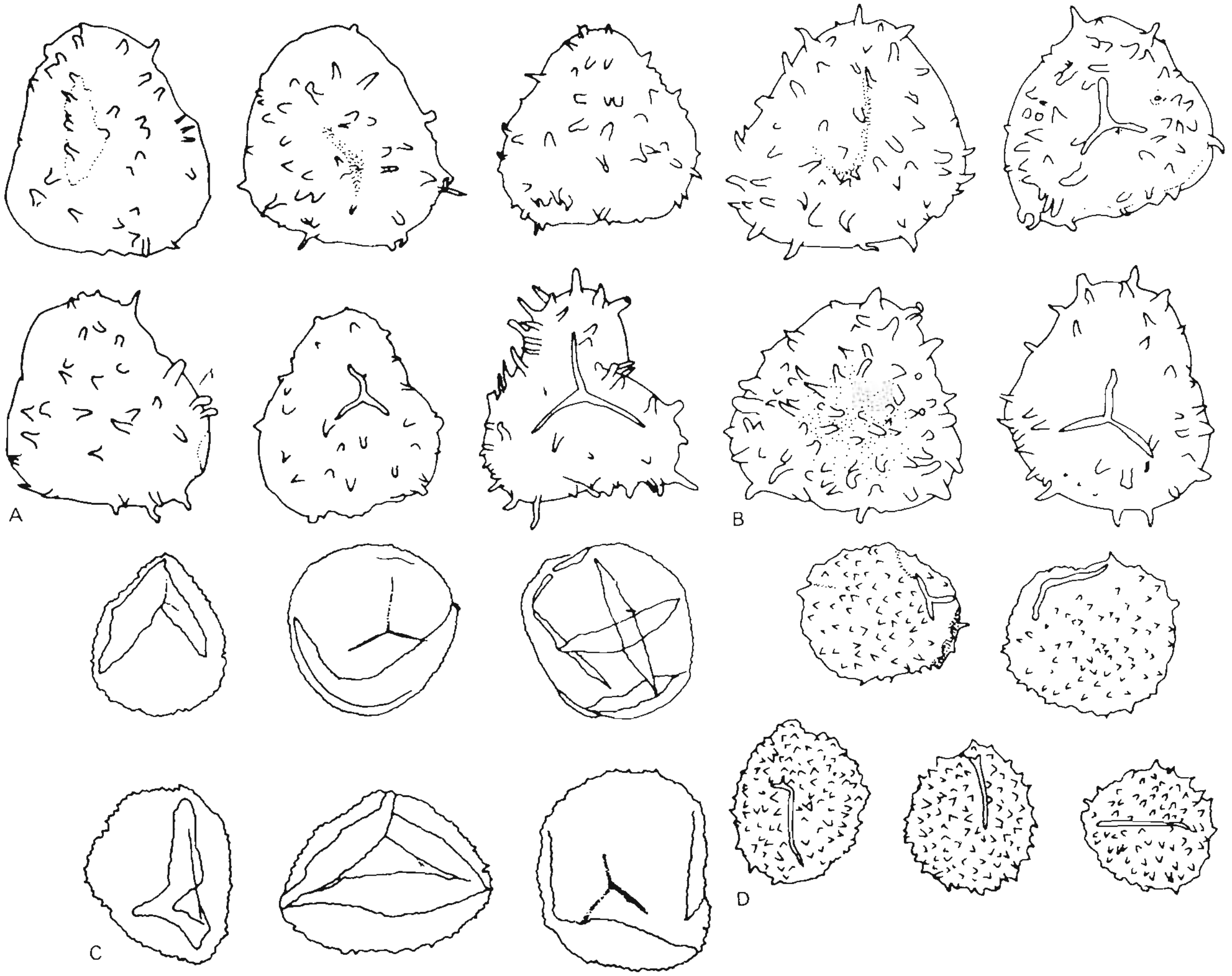


Text-figure 4—A. *Raniganjia bengalensis*; **B.** *Bengalia raniganjensis*; **C.** *Trizygia speciosa*; **D.** *Sphenophyllum gondwanensis*; **E.** *Pachwarophyllum santhalensis*; **F.** *Benlightfootia*. (Figure **A** redrawn from Pant & Nautiyal, 1968; figure **C** redrawn from Pant & Mehra 1963; figure **D** redrawn from Maheshwari *et al.*, 1986, figure **E** redrawn from Prasad & Maithy, 1990; figure **F** redrawn from Singh & Chandra, 1990).

straight veins. For the first time, anastomoses of veins appear. *Maheshwariphyllum*, a leaf with definite midrib recently discovered from the Barakar Formation (Srivastava, 1992), probably also had its origin in the earliest Permian. Slightly later appeared *Glossopteris* leaves having both a midrib and anastomosing veins, combining characters of *Maheshwariphyllum* and *Gangamopteris*. All this must have happened within a very short span of time in the earliest to Early Permian. The Maheshwariphyllum-line continued into the Late Permian (Raniganj Formation) as *Palaeovittaria*, a leaf with midrib reduced in length, running only up to 1/2-3/4 of lamina.

The leaves of many plants are characterized by distinctive leaf forms. The blade or lamina is most important and conspicuous part of the leaf. But as an adaptation to extreme climate, it may be reduced, modified or even absent; the leaves directly interact with the atmosphere and adapt themselves accordingly.

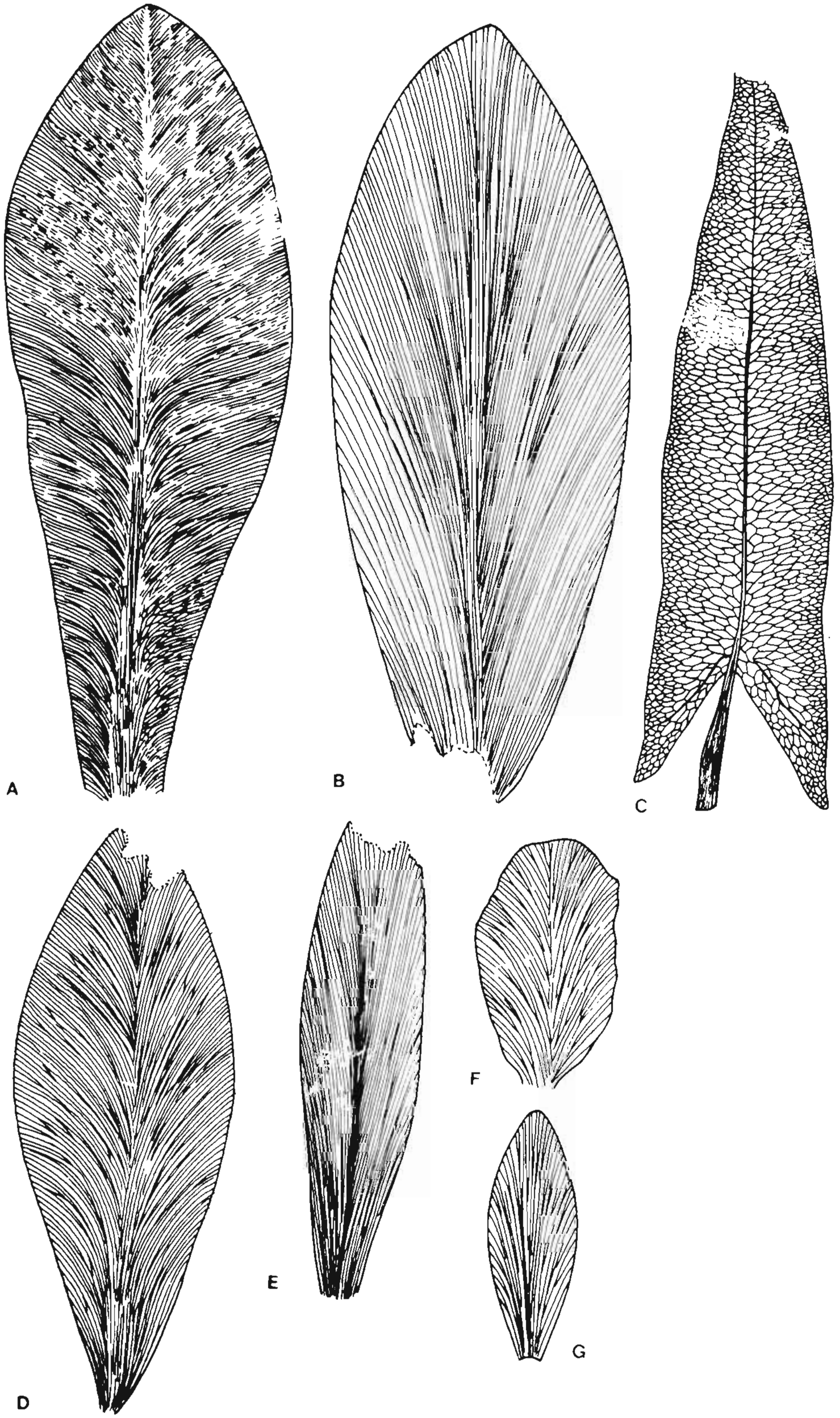
After the pioneering efforts of Sahni (1923) in



Text-figure 5—Showing variation in surface ornamentation of microspores in Late Permian ferns: **A.** *Dichotomopteris major* **B.** *Neomariopteris hughesii*; **C.** *Dichotomopteris lindleyii*; **D.** *Dizeugotheca phegopteroides* (All redrawn from Lele *et al.*, 1981).

chemically isolating cuticles from a *Glossopteris* leaf, much work has been done in recent years. A number of new species has been established under the belief and observation that cuticular morphology is taxon specific. Latest study on certain leaves of *Glossopteris* from the Barakar Formation of the Raniganj Coalfield (Maheshwari & Tewari, 1992) shows that this may not always be true. These authors have found that some morphographically different leaves show similar cuticular features.

The cuticle covers the aerial parts of the plants and plays an important role. The deposition of cuticle can be affected by light intensity and availability of water. In plants under continuous water stress twice as much cuticle is laid down as compared to plants growing under optimal water conditions (Martin & Juniper, 1970). The development of wax is also affected by light, being greater at higher light intensities. In leaves stomata may occur on both the surfaces or on one surface only. In temperate climate with an adequate water supply, stomata are more frequent on the abaxial surface. In aquatic plants stomata may be absent, or in floating leaves restricted to the upper or lower surface. In many xerophytes, plants which usually have a restricted water supply, the stomata may be deeply sunken. Therefore, these are the adaptive characters which develop in a plant depending on the ecological niches not necessarily genetic characters. However, one thing is certain that the syndetocheilic stomata did not appear in the Indian flora prior to the Early Cretaceous and there too are confined to a single order, the Bennettitales. Similarly development of trichomes and frequency of stomata are also governed by the environment. A trichome is formed by the outgrowth of an epidermal cell; it is protective in function and may prevent undue water loss. Therefore, these are the



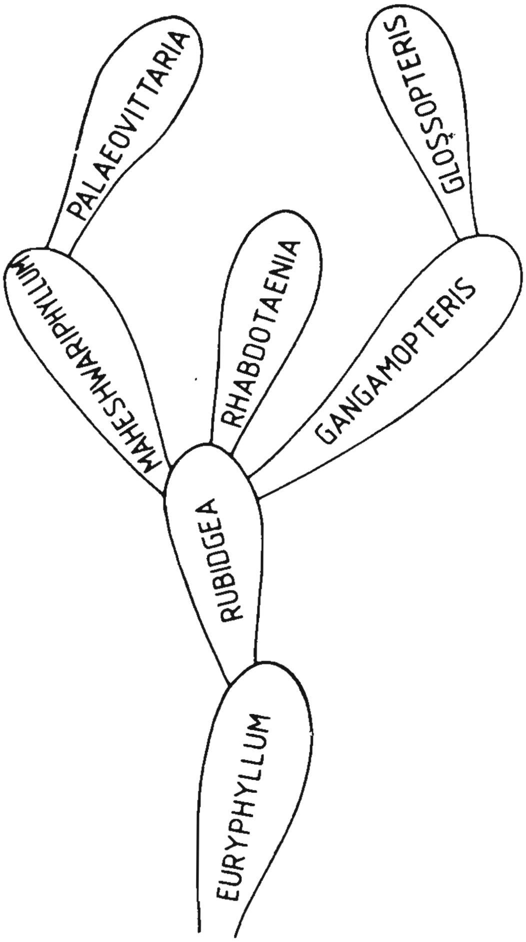
Text-figure 6—A. *Glossopteris*; **B.** *Maheshwariphyllum*, **C.** *Belemnopteris*; **D.** *Gangamopteris*; **E.** *Palaeovittaria*; **F.** *Rubidgea*; **G.** *Euryphyllum* (Redrawn from Pant, 1982).

characters which develop in the plant as a reflection of its surrounding environment and, hence are not necessarily indicators of phylogenetic relationships or morphological trends within a group of plants.

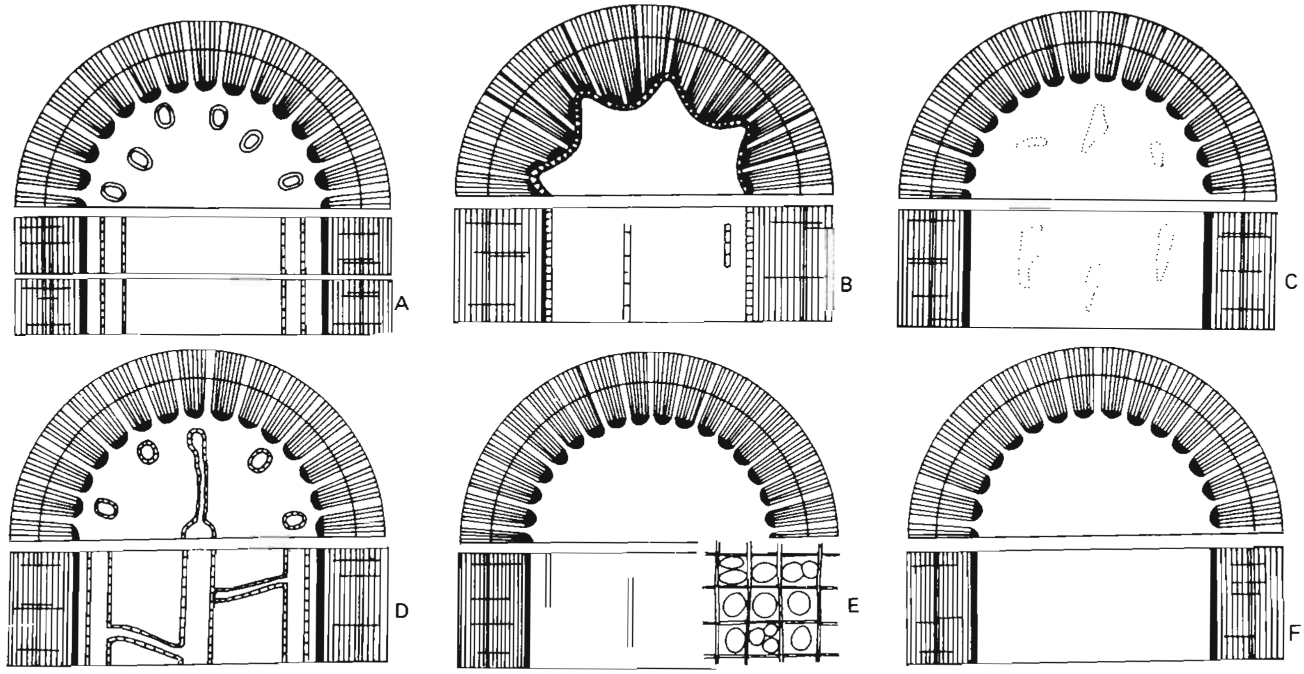
In most of the Gondwana woods, comparatively more delicate tissues like pith, primary xylem, phloem and cortex are not preserved. The taxa are usually known through pieces of secondary wood only. The secondary xylem in Gondwana woods is relatively uniform, but it may be combined in different arrangements with the pith and primary xylem. The wood taxa with pith and primary xylem known from the Permian Gondwana of India are *Trigonomyelon* Walton, *Damudoxylon* Maheshwari, *Megaporoxylon* Kräusel, *Kaokoxylon* Kräusel, and *Polysolenoxylon* Kräusel & Dolianiti.

In India, the oldest record of wood with heterogeneous pith and primary xylem is from the Early Permian Barakar Formation. The pith in this wood, viz., *Solenoxylon* (Text-figure 8A) and *Polysolenoxylon* (Text-figure 8D) is solid but with well-distributed 'secretory' cells and vertical running canals, supposed to have had some undefined secretory function. The primary xylem is endarch and the secondary xylem is with araucaroid and mixed pitting. This type of pith is restricted only to the Barakar Formation. Elsewhere, it is known from Brazil (Kräusel & Dolianiti, 1958) and Antarctica (Maheshwari, 1972). In the same horizon is also found wood with homogeneous pith, usually referred to the genus *Dadoxylon*. No woods have so far been reported from the Kulti Formation or equivalent beds.

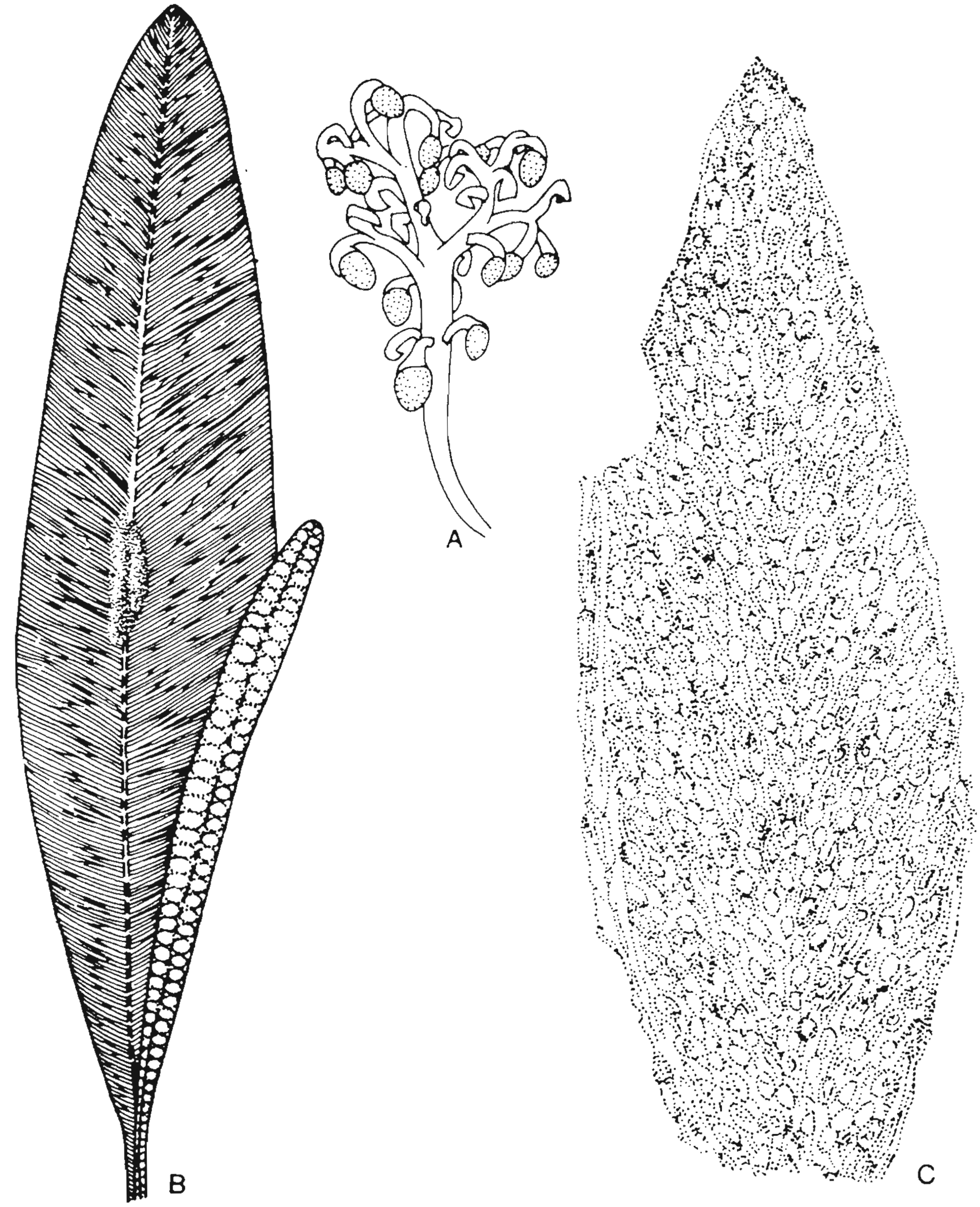
Fossil woods found in the Late Permian Raniganj Formation also have a solid pith which is heterogeneous. It may contain 'secretory' cells as in *Damudoxylon* Maheshwari (Text-figure 8C), *Trigonomyelon* Walton (Text-figure 8B), and



Text-figure 7—Sketch delineating assumed origin of glossopterid foliage.



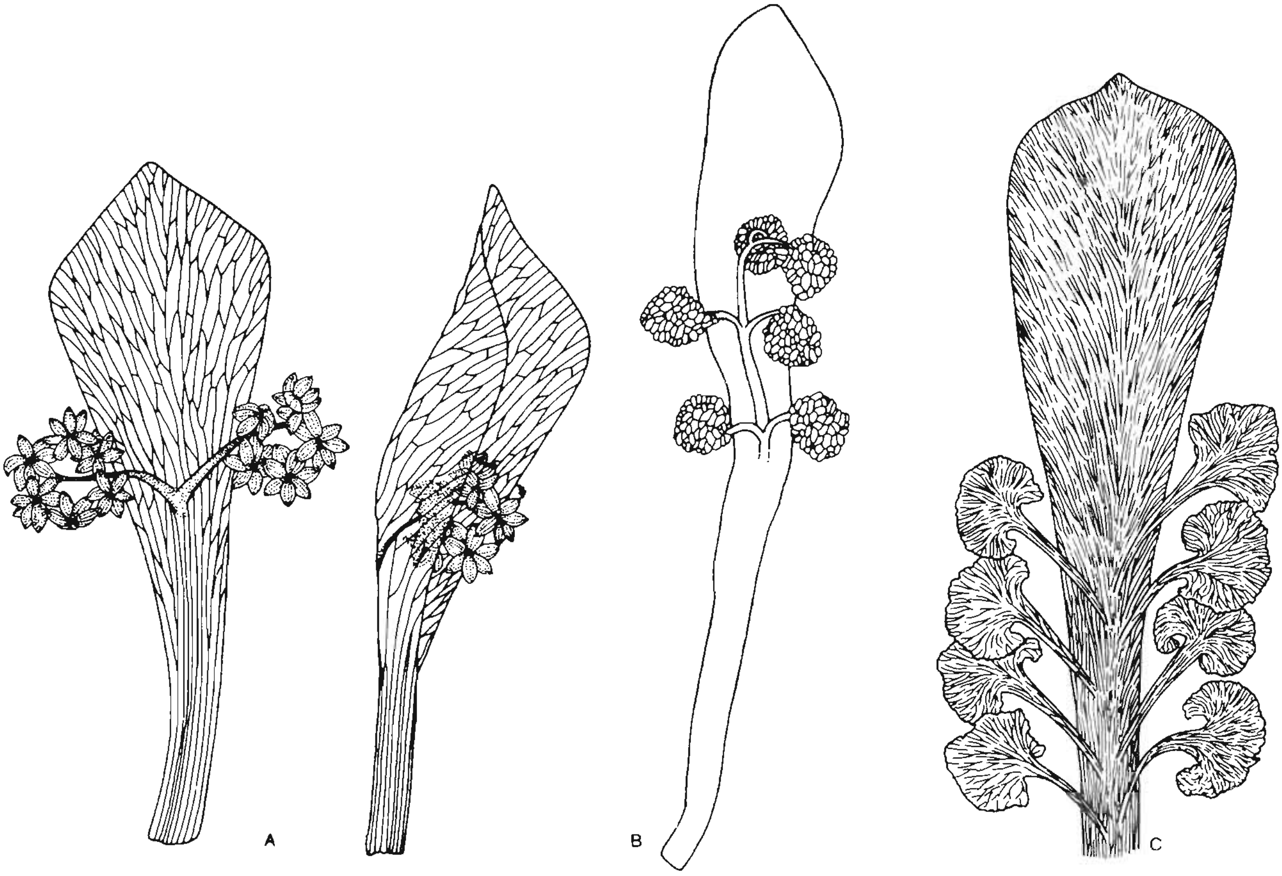
Text-figure 8—Schematic transverse sections through various taxa of fossil wood. **A.** *Solenoxylon* sp.; **B.** *Trigonomyelon raniganjense*; **C.** *Damudoxylon* sp.; **D.** *Polysolenoxylon canalosum*; **E.** *Megaporoxylon kraeuselii*; **F.** *Kaokoxylon zalesskyii* (Redrawn from Kräusel *et al.*, 1961).



Text-figure 9—A. *Senotheca murulidihensis*; **B.** *Arberia umbellata*; **C.** *Dictyopteridium sporiferum* (Figure **A** redrawn from Banerjee, 1980, figure **B.** from Rigby, 1972; figure **C.** from Surange & Chandra, 1973).

Megaporoxylon Kräusel (Text-figure 8E), or sclerenchyma as in *Kaokoxylon* Kräusel (Text-figure 8F). The pith is lobed in the genus *Trigonomyelon*, originally reported from South Africa (Walton, 1925). Most of the Gondwana woods show endarch protoxylem. The secondary xylem is pycnoxylic, homoxylous and shows well-marked growth rings. The presence of growth rings in the wood is generally regarded as indicative of a response to climatic fluctuations and periodicity as against lack of growth rings which is believed to be indicative of equitable climate. Pitting in the secondary wood tracheids of Gondwana woods is generally araucaroid but many of them show dual combination of araucaroid and abietoid pits or araucaroid pits with taxinean tertiary spirals or triple combination of araucaroid and abietoid pits with taxinean tertiary spirals.

The xylem rays of these woods are always homogeneous and one to many cells high. They are usually uniseriate or partly biseriate; rarely a xylem ray is multiseriate. The cross-field pits may be one to



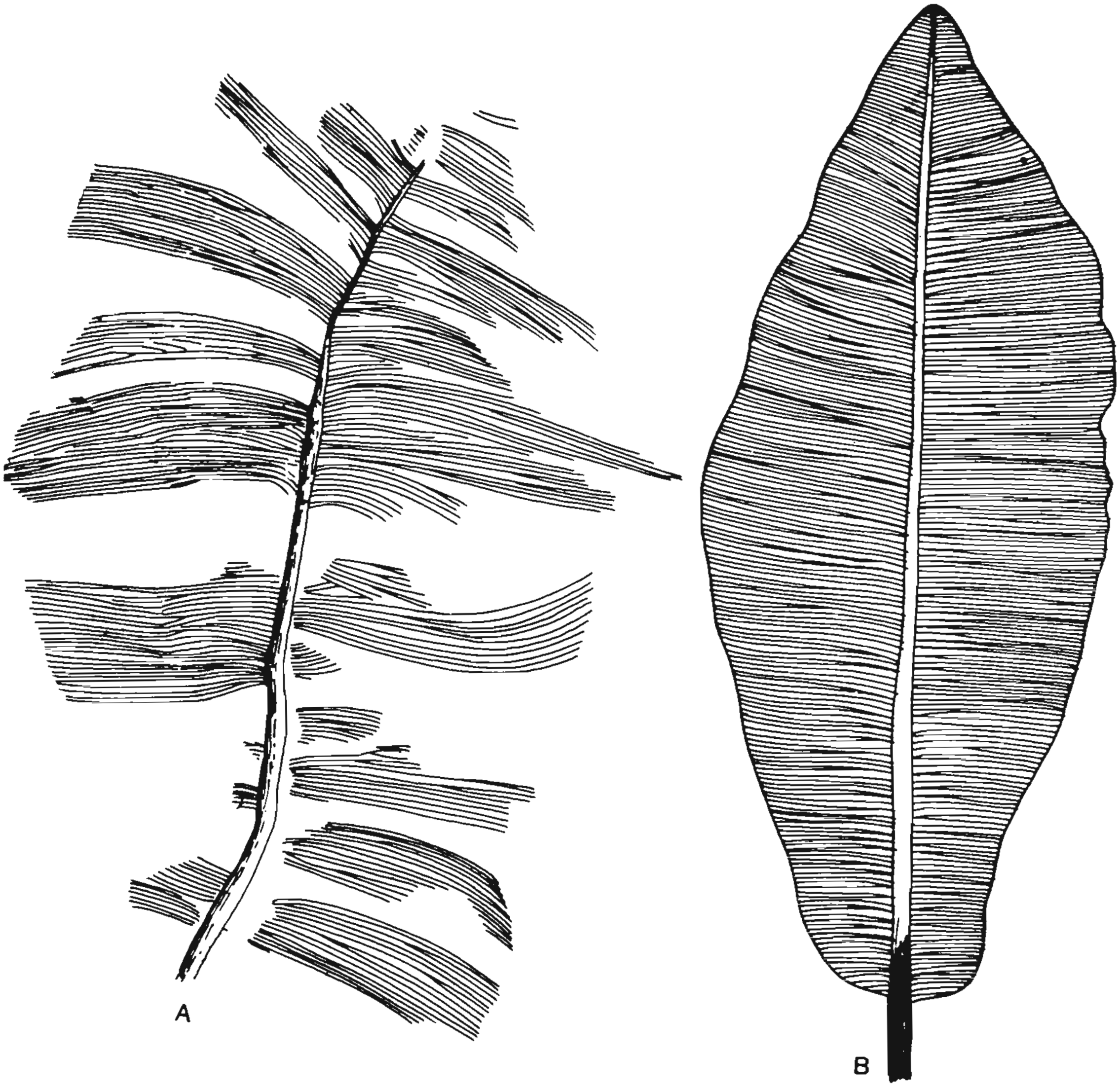
Text-figure 10—A. *Eretmonia*; **B.** *Glossotheca utkalensis*; **C.** *Lidgettonia indica* (Figure **A** redrawn from Surange & Maheshwari, 1971; figure **B** from Surange & Chandra, 1974).

many in number, simple or single dacrydiod or pinoid, simple or multiple bordered araucaroid, piceoid, cupressiod and taxadiod, podocarpoid or of intermediate types. The shape of cross-field pits may be circular, oval or elongated oval, may be isolated or contiguous.

On the basis of organisation of the fructification and the nature of subtending leaf, the glossopterids are grouped under two families, viz., Dictyopteridiumaceae and Eretmoniaceae (Maheshwari, 1990). The family Dictyopteridiumaceae includes the fructification genera *Dictyopteridium, Ottokaria, Scutum, Senotheca, Satsangia*, and probably *Vannus*. The family Eretmoniaceae includes the fructification genera *Eretmonia, Lidgettonia, Glossotheca* and probably *Denkania*.

The fructifications of the family Dictyopteridiumaceae are simple, dorsiventral and foliose (Text-figures 9B-C). A large number of ovules are borne on the abaxial surface. On the basis of an indepth analysis of all the characters, it is visualised that the basic structure of the dictyopterid ovule-bearing fructification is represented by the genus *Arberia* Rigby (Text-figure 9A) where the ovules are present on terminal branches of an axis subtended by a sporophyll. Through overtopping and syngenesis the Dolianitia-type of fructification could have given rise to the basic identity of the dictyopterid fructification. The dichotomies became unequal and eventually gave rise to a pinnate arrangement through syngenesis, where the photosynthetic area increases and ovules become transferred to the adaxial surface.

In the family Eretmoniaceae the fructifications are pinnately branched, axillary to a leaf; the subtending leaf is modified and looks like a scale leaf (Text-figures 10A-C). The fructification has 1-4 pairs of branches, each branch terminating in a fertile head. In the female fructification each fertile head is dorsiventral and bears 1-7 ovules on abaxial surface. In the male fructification each fertile head bears a large number of pollen-sacs, in a manner not yet clearly known. These fructifications show a superficial resemblance to the peltaspermaceous fructification—*Antevsia*. The *Eretmonia-Glossotheca*



Text-figure 11—A. *Pteronilssonia gopalii*, and **B.** *Rhabdotaenia danaeoides* (Redrawn from Pant, 1982).

complex probably resulted in the androclad *Pteruchus* (Pant & Basu, 1973) found in the Tiki Formation of terminal Permian age.

Birbalsahnia divyadarshanii Bajpai & Maheshwari is an incompletely known pollen-sac bearing organ. The main axis of the androclad is dichotomously branched, and subsequent branches are lateral and alternate to one another. No pollen grain was recovered from the pollen-sacs. This form alongwith pinnately branched gynoclads *Utkalia dichotoma* Chandra and *Veekaysinghia durgavatiae* (Bajpai & Maheshwari, 1991) are without any subtending scale leaf. These possibly do not belong to the glossopterid lineage.

CYCADOPHYTA

The group is poorly represented in the Gondwana. In the Early Permian it is represented by a frond which is pinnately divided, and the segments are of unequal width and attached at right angles or obliquely to a slender rachis. The veins are generally forked near the point of emergence and show a few cross connections. The leaf type, i.e., *Pseudoctenis balli* (Feistmantel) Seward reappears in the Early Cretaceous, e.g., *Pseudoctenis footeana* (Feistmantel) Seward & Sahni. *Pterophyllum sahnii* reported from the Late Triassic Parsora Formation (Lele, 1956) may also be a *Pseudoctenis* as the veins in the specimens show a few cross connections. *Pterophyllum burdwanense* (McClelland) Feistmantel and *Pteronilssonia gopalii* Pant & Mehra (Text-figure 11A) probably also belong here alongwith leaves of the genus *Rhabdotaenia* Pant (Text-figure 11B) as evidenced by the cuticular morphology. *Pteronilssonia* probably belonged to the same plant that bore *Rhabdotaenia* leaves.

GINKGOPHYTA

Definite records of the ginkgopsid group are mostly from the Early Cretaceous sediments of India (Lakhanpal, Maheshwari & Awasthi, 1976). In recent years Ginkgo-like leaves have also been recorded from older formations (Maheshwari & Banerji, 1978; Bajpai, 1991; Maheshwari & Bajpai, 1991). Most of these leaves have been assigned to the genus *Ginkgoites* and have the same morphology as the younger forms. However, definite ginkgoalean ovules are known only from the Early Cretaceous Rajmahal Formation (Bano, Maheshwari & Bose, 1979). A number of Early Permian leaves, e.g., *Saportaea, Psygmophyllum* and *Rhipidopsis* have also been assigned to the ginkgopsids (Maheshwari & Bajpai, 1991).

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Alien elements in the Gondwana Flora of India

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Srivastava AK 1992. Alien elements in the Gondwana flora of India. *Palaeobotanist* **40** : 147-156.

The occurrence of northern hemispheric taxa in Gondwana is considered as alien to the Glossopteris and Dicroidium floras of Southern Hemisphere. The morphology, evolutionary lineages, and stratigraphic distribution of Euramerian, Cathaysian and Angaran forms in the Gondwana flora of India are examined in view of their latest discoveries in the Permian and Triassic sequences. The study indicates that some of the elements of contemporaneous floras possess characteristic affiliation with the Gondwana flora, likewise some of the Gondwana elements exemplify the comparative characters of northern forms. Possible linkages, association, existence and ancestry of the Gondwana flora *vis a vis* Northern floras are discussed.

Key-words—Alien elements, Evolutionary linkage, Gondwana flora.

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सारांश

भारत के गोंडवाना वनस्पतिजात में अन्यदेशीय अवयव

अश्विनी कुमार श्रीवास्तव

गोंडवाना में उत्तरी गोलार्द्ध के वर्गकों की उपस्थिति दक्षिणी गोलार्द्ध के ग्लॉसॉप्टेरिस एवं डाइक्रोइडियम वनस्पतिजातों में अन्यदेशीय अवयवों के समान मानी गई है। परमी एवं त्रिसंघी अनुक्रमों में भारत के गोंडवाना वनस्पतिजात में यूरामेरिकन, कैथेसियन एवं अंगारन प्ररूपों की आकारिकी, विकासीय श्रृंखलाओं तथा स्तरिकीय वितरण का अध्ययन किया गया है। इस अध्ययन से व्यक्त होता है कि समकालीन वनस्पतिजातों के कुछ अवयव गोंडवाना वनस्पतिजात से समानता प्रदर्शित करते हैं और इसी प्रकार कुछ गोंडवाना अवयव उत्तरी प्ररूपों के लक्षण व्यक्त करते हैं। गोंडवाना वनस्पतिजात तथा उत्तरी वनस्पतिजातों के मध्य सम्भाव्य श्रृंखलाओं, साहचर्य तथा पूर्वजता की विवेचना की गई है।

THE Indian Gondwana flora makes its appearance in the Early Permian strata and develops as the Glossopteris flora and in the Triassic Period it succeeds as the Dicroidium flora. Earlier, the Ptilophyllum flora considered as Jurassic in age was recognized as the uppermost flora of the Indian Gondwana (Lele, 1964, 1976a) but recent investigations suggest that continental Jurassic deposits are absent in India and the Ptilophyllum flora in all probability belongs to Lower Cretaceous (Garg *et al.*, 1988; Krishna, 1988; Acharyya & Lahiri, 1991; Venkatachala & Maheshwari, 1991).

It is believed that there was a uniformity in the Carboniferous flora of northern and southern hemispheres before Glossopteris flora came into existence (Seward, 1903; Sahni, 1939; Halle, 1937; Jongmans, 1954; Edwards, 1955; Archangelsky, 1970, 1971; Chaloner & Meyen, 1973). The wide spread Gondwana glaciation resulted into the differentiation of world floras and by the close of Carboniferous and beginning of Permian there existed four more or less well-defined botanical provinces. The Glossopteris flora occupies the southern land-mass, i.e., Gondwana including India, Australia, South America, South Africa and Antarctica. The Euramerian flora dominated by lepidodendrids, calamites, sphenophylls and pteridosperms flourished in the North America and Europe. The Angara flora characterised by Cordaitales and pteridosperms covered the Siberian region from the Petchora Basin, north-west of Urals to the Pacific Coast of the USSR and south into the north-west China. The Cathaysian flora, commonly known as Gigantopteris flora developed in China and extended to the south of Sumatra. Chaloner and Lacey (1973) sorted out characteristic genera of each floral provinces as follows: North American floral

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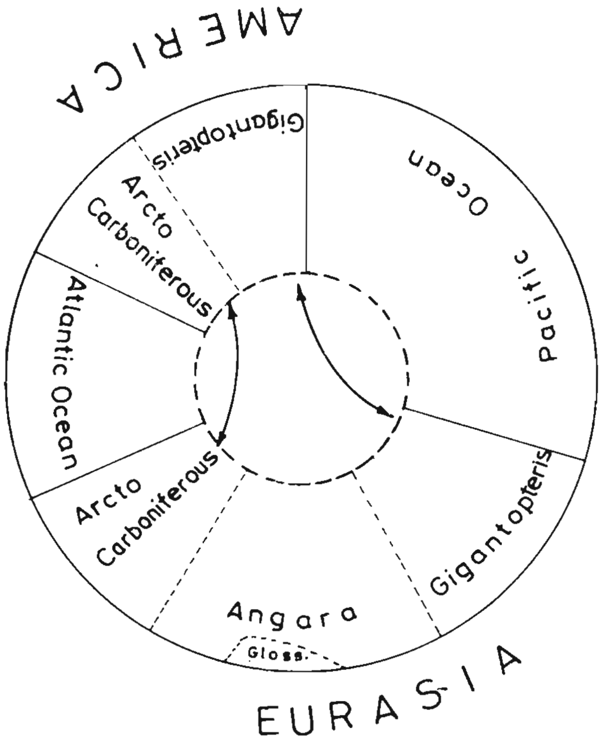
province, referred by them as fifth flora, is considered here under Euramerian flora for broader comparison of floras:

	Euramerian	Angara	North America	Cathaysia	Glossopteris
Alethopteris	+				
Calamites	+				
Sigillaria	+				
Cordaites	+	+	+	+	
Pecopteris	+	+			
Callipteris	+	+	+		
Neuropteris/Odontopteris	+	+			
Sphenophyllum	+	+	+	+	
Annularia	+	+			
Walchia	+	+	+		
Taeniopteris	+		+	+	
Intia					
Tschernovia		+			
Annulina		+			
Viatscheslavia		+			
Angaridium		+			
Paragondwanidium		+			
Rufloria		+			
Vojnovskya		+			
Supaia			+		
Glenopteris			+		
Russellites			+		
Giganotopteris			+	+	
Protoblechnum			+	+	
Tingia			+		
Lobatannularia			+		
Gondwanidium					+
Noeggerathiopsis					+
Gangamopteris					+
Glossopteris					+
Trizygia					+
Lycopodiopsis/Cyclodendron					+
Schizoneura					+

Sahni (1935) explained the distribution of each flora by viewing the globe from the Arctic Pole (Text-figure 1).



Text-figure 1

While discussing the Permo-Carboniferous floral provinces with special reference to India, he indicated that the floras of Northern Hemisphere, i.e., Euramerian, Cathaysian and Angara are more in common than any one of them has with the Gondwana flora. The compilation of the floras by Chaloner and Lacey (1973) also reflects such association with certain reservation.

PERMIAN GONDWANA FLORA VIS A VIS NORTHERN HEMISPHERIC FLORAS

Morphology, affinities and distribution of the flora in different formations, i.e., Talchir, Karharbari, Barakar, Barren Measures and Raniganj have earlier been discussed by many workers (Surange, 1975; Lele, 1976b; Maheshwari, 1976; Srivastava, 1986) and they strongly favoured the idea of endemism in the Gondwana flora. However, during the last ten years, the knowledge of the Indian Gondwana palaeobotany has increased rapidly and the discoveries of newer elements having comparative similarities with the northern hemispheric forms provide evidence to consider the Gondwana flora in a broader perspective rather than conservative flora of its own domain.

There are several limitations to know the exact affinities of Gondwana plants because most of them are known only by their sterile foliage characters, however, the organization and venation pattern of leaves demonstrate their positive affiliation with different groups of plants. Discovery of male and female fructifications of glossopterid has enabled us to identify it as a distinct plant group of the Gondwana flora. Its unequivocal affinity with pteridosperms and other groups of gymnosperms signifies a unique position in the taxonomy of plants.

Earlier investigators considered the Gondwana records of *Phyllotheca, Schizoneura, Noeggerathiopsis, Cordaites, Sphenophyllum, Pecopteris, Sphenopteris, Alethopteris, Ptychocarpus* as the representatives of northern hemispheric flora (Zeiller, 1896, 1902; Feistmantel, 1879-90; Arber, 1905; Srivastava, 1955; Surange, 1964). Later, many of them proved to be gondwanic in nature. The fern like pinnules have been considered to be true pteridophytes and accordingly they are placed into several new genera—*Neomariopteris, Damudopteris, Dichotomopteris, Asansolia, Dizeugotheca, Santhalea* and *Leleopteris* (Maithy, 1974a, b, 1975; Pant & Khare, 1974; Pant & Misra, 1976, 1977; Srivastava & Chandra, 1982). The forms placed under *Phyllotheca robusta* have been transferred to a new genus *Lelstotheca* Maheshwari (= *Stellotheca* Surange & Prakash 1962) and *Sphenophyllum* like foliage have been identified as *Trizygia* (Maheshwari, 1968).

Latest discoveries of plant fossil assemblages from Rajmahal, Raniganj, South Rewa Gondwana basins and Handapa areas indicate that the flora is much more diversified and contains many forms showing morphological similarity with the northern floras (Singh, Srivastava & Maheshwari, 1986; Chandra, 1984; Chandra & Singh, 1988; Bajpai & Maheshwari, 1991; Maheshwari & Bajpai, in press).

Critical assessment of the plant fossil assemblages amply demonstrates the fair representation of northern form in the Indian Gondwana flora. The following genera of Eurameria, Cathaysia and Angara floras are known in the Permian flora of Indian Gondwana:

	Eurameria	Angara	Cathaysia	Glossopteris
Schizoneura			+	+
Phyllotheca	+	+	+	+
Barakaria		+		+
Sphenophyllum	+	+	+	+
Trizygia			+	+
Psygmophyllum	+	+	+	+
Rhipidopsis	+	+	+	+
Saportaea	+		+	+
Ginkgoites	+	+	+	+
Cordaites	+	+	+	+

Meyen (1969, 1971, 1982), a strong believer of parallel evolution, suggested that similar looking sterile remains may not necessarily bear the same botanical affinity and cites the example of *Phyllotheca*, a common genus, where we find *Tschernovia* type of fructification in Angara but similar looking foliage axis bears another type of fertile structure known as *Gondwanostachys* in Gondwana (= *Giridia* Pant, Nautiyal & Misra 1981). *Manchuriostachys*, a fertile structure of Cathaysian *Schizoneura* (Konno, 1960) is an additional example which shows its differentiation with the fructification of Gondwana schizoneur (Srivastava, 1952; Surange, 1964). The occurrence of different types of fructification favours the idea of similar leaf morphology in two botanically distinct identities. But when we are dealing with a fraction or part of plant, it is very difficult to get associated or attached fertile specimens and the problem is much more serious in the Gondwana flora of India where we lack permineralized fossils and preserved fertile structures. Even the nature and affinities of dominant genus *Glossopteris* could be established only after a lapse of about 120 years since its first discovery by Brongniart (1828-1830). Though, Feistmantel in a series of monographs (1879-1890) described many glossopterid leaf assemblages from India and Australia but did not find sufficient fertile specimens. It was only in the year 1952 that Plumstead (1952-1958) discovered a large number of fertile specimens enabling us to understand the distinct taxonomic status of *Glossopteris*. Now many types of glossopterid fructifications are known in the Indian Gondwana flora (Surange & Chandra, 1978; Maheshwari, 1990 and references cited therein). However, the Indian Gondwana flora is devoid of fructifications of plants belonging to other groups and in such state of knowledge if we restrict our interpretation to the availability of fertile structures, almost all the groups of plant excepting glossopterid and pteridophyte, remain without a fair deal.

Paucity of fertile specimens do not necessarily warrant us to correlate the leaf or other parts of plant fossils and one is obliged to derive maximum information from available fossil specimens (Paul, 1982; Pant, 1982). Ignorance of such elements in the floral scene of Indian Gondwana would prove detrimental to draw complete knowledge of flora. In fact, qualitatively and quantitatively better specimens in the floras of northern hemisphere provide us sufficient information about their morphology but their poor occurrence and lack of fertile structures restrict us to decide their exact affinity in the Gondwana flora and as a matter of convenience we call them northern elements.

Sahni (1926, 1935) termed such "Northern" records (Table 2) in the Indian Gondwana flora as remnants or descendants of the pre-existing southern flora of Carboniferous age and emphasised that "at least some of them are hardy survivors (and in part descendants) of the cosmopolitan life of pre-Gondwana time".

Ancestry

The discovery of Lepidodendropsis flora from the Lower Carboniferous beds of Extra-peninsular India favours similarity in northern and southern floras (Pal & Chaloner, 1979; Singh *et al.*, 1982). Pre-Gondwana Late Carboniferous flora is not known in

India but this flora has been recorded in other Gondwana countries, e.g., Australia, South America and South Africa.

Earlier workers like Edwards (1952) and Krausel (1961) believe that the Carboniferous lycopods of Southern Hemisphere were distinct as compared to the northern forms. However, Archangelsky (1970) has observed similarity between Northern and southern lycopods. While transferring all the records of *Rhacopteris* from Southern Hemisphere, i.e., Argentina, Peru and Kashmir, Rigby (1985) considers *Lepidodendron* and *Pseudorhacopteris* as the diagnostic genera for New South Wales flora ranging from Namurian to Westphalian in age. In South America, South Africa and Australia it has been observed that *Botrychiopsis* (= *Gondwanidium*)—a Gondwana form, came into existence in the Late Carboniferous sequence alongwith the elements of Early Carboniferous flora (Plumstead, 1976; Rigby 1973; Archangelsky, 1986). *Nothorhacopteris, Botrychiopsis* and *Ginkgophyllum* (NBG) association has been found to be characteristic in South America. The reports of Gondwana forms, e.g., *Gondwanidium, Buriadia, Glossopteris* in the Upper Carboniferous flora of Tubarao Series and Santa Catarina of the Parana Basin of Brazil and in San Juan Province of Argentina (Fossa-Mancini, 1940; Dolianiti, 1953, 1954; Archangelsky & Sota, 1966) and the discovery of northern elements in the Early Permian Sequence of Patagonia, Paganzo Basin, Lubeckense flora of Argentina (Archangelsky & Sota, 1960; Archangelsky & Arrondo, 1975; Archangelsky, 1984, 1986), Brazil (Rosler, 1975) and Kashmir (Singh *et al.*, 1982) alongwith typical Gondwana flora clearly demonstrate that both Northern and southern floras were in some sort of agreement to each other at some stage. Such association was disturbed due to onset of Gondwana glaciation and the resultant climatic imbalances must have favoured a large scale mutation towards the appearance of Glossopteris flora and disappearance of major pre-Gondwana plants (Sahni, 1937, 1939; Pant, 1988). However, the catastrophic event did not destroy all the elements, some of them could have sustained the lethal conditions and continued their occurrence in hospitable pockets. The occurrence of the so-called northern elements and incoming records of plant fossils having comparative significance with northern elements in the Gondwana flora, e.g., *Polyspermophyllum* Archangelsky & Cuneo 1990 (Dicranophyllalean leaves in Argentina) and ginkgopsid leaves in India (Maheshwari & Bajpai, 1992) and near definite records of glossopterid leaves with other forms outside Gondwana countries (as discussed on p. 14) suggest such a phenomenon. Similar type of viability is evident in the flora of Upper Cretaceous, where we find sudden dominance of angiosperms alongwith earlier elements of Bennettitales, Cycadales, Leptostrobales and Ginkgoales (Meyen, 1987, p. 323).

Affiliation

Time and again, the comparative relationship and affinities of different plant groups of the Gondwana flora are discussed with the floras of Northern Hemisphere. On the contrary, some of the northern forms were viewed in relation to characteristics of Gondwana flora (Meyen, 1969, 1982, 1987).

The morphographic similarity of some of the genera of the Indian Gondwana flora belonging to different plant groups with their northern counterparts is examined. The plant groups represented in the Glossopteris flora are: ?Bryophyta, Lycopodophyta, Arthrophyta, Pterophyta, Glossopteridophyta, Cycadophyta, Ginkgophyta and Coniferophyta.

Lycopodophyta—Seward and Sahni (1920) placed lycopodaceous stem axes under *Bothrodendron lesli* Seward. Later, Krausel (1928, 1961) reallocated all southern lycopods into three genera, *Lycopodiopsis* Renault, *Lycopodophlois* Krausel and *Cyclodendron* Krausel in possessing eligulate leaf scars pattern. However, presence of eligulate lycopod stem in the Upper Carboniferous flora of Angara, e.g., *Angaraphlois* (Meyen, 1982) demonstrates the ancestry of such character in northern hemispheric flora (Archangelsky & Arrondo, 1969).

Arthrophyta—Most of the genera belonging to Equisetales and Sphenophyllales, e.g., *Phyllotheca, Schizoneura, Barakaria, Trizygia, Sphenophyllum,* are known to occur in the flora of Angara, Cathaysia and Eurameria. Unfortunately, the fructifications of these genera are not known in the Indian Gondwana flora.

Sphenophyll has long been considered as distinct in having asymmetrical trizygoid leaf pattern, e.g., *Trizygia speciosa* (Maheshwari, 1968) but recent discoveries of symmetrically arranged leaf whorls in *Sphenophyllum churulianum* (Srivastava & Rigby, 1983) and heterophyllous leaf whorls with dentate to smooth margin in *Sphenophyllum gondwanensis* (Singh, Srivastava & Maheshwari, 1986) indicate the presence of typical northern hemispheric form in the Indian Gondwana flora.

Articulated leaves united or free near the nodal axes in *Lelstotheca* and *Bengalea* are comparable with the foliage pattern of *Annularia/Asterophyllites* (Maheshwari & Srivastava, 1987; Maheshwari, Singh

& Bajpai, 1989). Leafless stem axes of *Phyllotheca* and *Schizoneura* described under Angaran genus, *Paracalamites* Zalessky by Rigby (1966) and the records of *Barakaria* in the Indian and Angara floras (Meyen, 1969) having possible affinity with autophyllites of Boureau (1964) supports the existence of such forms beyond the limits of Gondwana.

Surange and Prakash (1962) observed distinction in Gondwana phyllothecs and transferred the forms described under *P. robusta* to a new genus, *Stellotheca* (= *Lelstotheca* Maheshwari, 1972). Meyen (1971) while revising Angaran phyllothecs considered that Gondwanan and Angaran forms possess different types of fertile structure, i.e. *Tschernovia* in Angara and *Gondwanostachys* in Gondwana, hence both the forms are botanically distinct. But Meyen's (1982) noteworthy derivation of such fertile structures from the Lower Carboniferous Euramerian genera *Pothocites* (for Tschernoviaceae) and *Protocalamostachys* (for Gondwanostachyaceae) suggests possible northern ancestry for Gondwana phyllothecs—*Sakoarata polyangiata* Appert 1970. Madagascaran Gondwana phyllothec fructification showing mega- and micro-sporangiate organs separately demonstrate that *Phyllotheca* like plants had varied mode of fructification, a case similar with glossopterid where sometimes similar looking leaves possess different type of fructifications (Plumstead, 1958). Such explanation seems to be plausible for the occurrence of *Schizoneura* in Gondwana and Cathaysia floras (Konno, 1960; Asama, 1966).

Pterophyta—The oldest fern-like form from the Gondwana of India is *Botrychiopsis* (= *Gondwanidium*) *valida* Archangelsky & Arrondo. The genus has been found to be the earliest element of Glossopteris flora in the Late Carboniferous of Australia, Argentina and Brazil (Rigby, 1973; Archangelsky, 1986). Its exact taxonomic position is still not clear but Seward (1910) and Plumstead (1973, 1976) have compared the nature of its pinnules with northern hemispheric pteridosperms.

Recent investigations of sterile and fertile fronds recovered from the Barakar and Raniganj formations suggest that they are distinct from northern hemispheric forms of *Alethopteris, Cladophlebis, Cyclopteris, Merianopteris, Pecopteris, Sphenopteris,* etc. The Indian forms are now known as *Asansolia, Dichotomopteris, Damudosorus, Damudopteris, Dizeugotheca, Leleopteris, Neomariopteris, Santhalea* and *Trithecopteris.*

Pant and Khare (1974) and Pant (1976) grouped the ferns into two families, viz., Damudopteridaceae characterized by free eusporangia with a transverse annulus, and Asterothecaceae which includes the synangiate ferns apparently closer to northern ferns.

Glossopteridophyta—This is the dominant group of the Gondwana flora and is represented by simple leaf genera having reticulate or non-reticulate venation pattern with or without midrib, e.g., *Belemnopteris, Euryphyllum, Gangamopteris, Glossopteris, Palaeovittaria, Rhabdotaenia* and *Rubidgea.* Srivastava (1991) has observed an evolutionary tendency in the venation pattern of glossopteridalean leaves. Different types of male and female fructifications have been found attached or in association with such leaves (Surange & Chandra 1978; Maheshwari, 1990, and references cited therein).

Glossopterids are essentially the Gondwana forms and their records in other floral provinces have often been doubted in the absence of associated fertile structure (Edwards, 1955; Alvin & Chaloner, 1970; Chaloner & Crebe, 1983; Li Xingxue, 1986; Maheshwari & Bajpai, 1988). However, finding of *Vertebraria* alongwith *Glossopteris* leaves in New Guinea flora (Visser & Hermes, 1962) and my observation of type specimens of *Glossopteris anatolica* Archangelsky & Wagner 1983 at the British Museum suggest the probable occurrence of glossopterid leaves in association with northern floras. Meyen (1969) discussed the authenticity of glossopterid leaves in Angara flora and after careful scrutiny states, "It does not mean, however, that *Glossopteris* is completely absent from Angara flora. V. G. Zimina (1967) described typical *Glossopteris* leaves from the Upper Permian of the Far East".

The Late Carboniferous flora of Southern Hemisphere lacks any positive evidence to demonstrate the ancestry of glossopterids. However, noteworthy distribution and similarity of Northern and Southern forms in South America (= Lubeckense flora, Archangelsky & Arrondo, 1965, 1975) during Early Permian invite our attention to look into certain non-gondwanic forms to find the character affiliation of glossopterids.

The external morphological features of Angara genus *Zamiopteris* are similar to the glossopterid genus *Euryphyllum* and that too, to some extent with *Rubidgea* in having non-anastomosing, dichotomising veins, whereas Late Carboniferous Euramerian genus *Lesleya* is comparable with the leaves of *Palaeovittaria* and *Maheshwariphyllum* in having midrib only up to 1/2 or 3/4 of leaf lamina with dichotomizing veins. Cuticular features of *Zamiopteris* and *Lesleya* are also similar with *Palaeovittaria* (Pant & Verma, 1964; Remy & Remy, 1975, 1978; Meyen, 1982). On the basis of such similarities Leary (1991) considers *Lesleya* as the possible ancestor of Permian glossopterids.

Meyen (1982) and Maheshwari (1990) have correlated the female fructification, *Krylovia* of Angara flora with the glossopterid fructification *Arberia*. Possible relationship of *Arberia/Dolianitia*-plan with cordaitean fructification—*Cordaitanthus*, as suggested by Schopf (1976) also demonstrates the probable ancestry of glossopterids in Euramerian flora. The chances of getting glossopterid fructifications are rare even in the Gondwana flora, however, different types and varied modes of male and female fertile organs (Surange & Chandra, 1978; Maheshwari, 1990) do not rule out the possibility of getting their comparative forms in non-gondwanic countries. Likewise seed-bearing fructifications—*Veekaysinghia* and *Birbalsahnia*, recovered from the Permian strata of India enhances the existence of northern hemispheric pteridosperms in Gondwana flora (Bajpai & Maheshwari, 1991).

Cycadophyta—Pant (1958) while studying the cuticular features of *Taeniopteris* leaves from the Permian Gondwana found that they are similar with glossopterid leaves and transferred them to a new genus, *Rhabdotaenia*. Similarly the leaves of *Pteronilssonia* Pant & Mehra 1963 is now considered to belong to glossopterid (Pant, 1982). Forms such as *Pseudoctenis* and *Pterophyllum* are apparently similar with the northern floras.

Ginkgophyta—Ginkgoalean fructifications are not known but leaves apparently similar with *Ginkgo* leaves are well recorded in the Gondwana flora. Such leaves are very much similar with the northern forms and recent discovery of *Saportaea*-like leaves alongwith previously known records of *Psygmophyllum, Rhipidopsis* and *Ginkgoites* in Lower Permian flora of Rajmahal Hills (Maheshwari & Bajpai, 1992) reflects a close association of ginkgopsid leaves in northern and southern floras.

Coniferophyta—Coniferales are poorly known from the Lower Permian strata by one species each of *Buriadia, Paranocladus* and *Walkomiella*. Pant and Bhatnagar (1975) have described conifer-like foliage shoot under *Searsolia* from the Upper Permian sequence but its affinity is still not clear. The genus *Buriadia* is known by its sterile and fertile structure and is distinct in having single ovule on ordinary shoots among the leaves. However, the form is comparable with the Northern genus—*Walchia* in cuticular features and hairs on shoots. Archangelsky and Cuneo (1987) consider Buriadiales as the primitive conifers and suggest parallel line of evolution in Southern Hemisphere which led to Voltziales. While studying the female shoot of *Walkomiella indica* Surange & Singh 1953 have observed its similarity with Northern forms and remarked "*Walkomiella* therefore has a female "flower" on a seed scale complex of essentially the same type as in *Lebachia* (Florin, 1951)"

Cordaitales—The genus *Noeggerathiopsis* having strap-shaped parallel veined leaves are common in the Talchir and Karharbari formations. Their closest similarity with northern hemispheric cordaite leaves has led many workers to transfer leaves of *Noeggerathiopsis* under *Cordaites* (Rigby, Maheshwari & Schopf, 1980, and references cited therein). But recent investigation of Lower Permian flora from Raniganj Coalfield demonstrates that two forms are distinguishable from each other in the absence and presence of interstitial veins/fibres in between major veins. Accordingly *Cordaites* and *Noeggerathiopsis* leaves are described in the Gondwana flora (Srivastava, 1988, 1992).

RELATIONSHIP OF TRIASSIC GONDWANA AND NORTHERN FLORAS

The Triassic sequence of India is mostly arenaceous, ferruginous and devoid of coal. Plant fossil assemblages are poorly known and have been recorded from Panchet of Raniganj and Auranga Coalfields, Bihar; Parsora Formation and Nidpur beds of South Rewa Gondwana Basin and Maleri beds of Andhra Pradesh (Lele, 1964; Bose, 1974).

The incoming of *Dicroidium* in this sequence makes it distinct from the Glossopteris flora; however, Permian plant remains, viz., *Glossopteris, Rhabdotaenia, Schizoneura, Trizygia* and *Neomariopteris* continue in the Lower Triassic flora.

TRIASSIC	PANCHET FORMATION (LOWER TRIASSIC)	PARSORA FORMATION (UPPER TRIASSIC)
LYCOPODOPHYTA		
Lycopodites	+	
Stigmaria?	+	+
ARTHROPHYTA		
Neocalamites		+
Trizygia	+	+
Shizoneura	+	
Phyllotheca	+	
PTEROPHYTA		
Sphenopteris	+	
Pecopteris		+
Cyclopteris		+
Marattiopsis		+
Danaeopsis		+
Parsarophyllum		+
Cladophlebis		+
PTERIDOSPERMOPHYTA		
Lepidopteris	+	+

Bosea	+	
Dicroidium	+	+
Pteruchus	+	
Nidia	+	
Nidistrobus	+	
Satsangia	+	
Sagenopteris	+	
CYCADOPHYTA		
Anomozamites		+
Pseudoctenis		+
Pterophyllum		+
Taeniopteris		+
GINKGOPHYTES		
Baiera		+
Ginkgoites		+
CONIFEROPHYTA		
Noeggerathiopsis	+	+
Podozamites		+
Desmiophyllum		+
Araucarites		+
GLOSSOPTERIDOPHYTA		
Rhabdotaenia	+	
Glossopteris	+	
Glottolepis	+	
Vertebraria	+	
INCERTAE SEDIS		
Marwasophyllites	+	
Sidhiphyllites	+	
Rewaphyllum	+	

Newer elements, viz., *Lycopodites, Cladophlebis, Parsarophyllum, Marattiopsis, Danaeopsis, Pterophyllum, Pseudoctenis, Taeniopteris, Baiera, Desmiophyllum* and *Araucarites* show their appearance in the Upper Triassic flora as under:

The floral change from Permian to Triassic corresponds with a climatic shift. Poverty of floral assemblages and the xerophytic characters in some forms indicate the existence of adverse conditions which affected the survival of Glossopteris flora. The plants belonging to lycophytes, pteridophytes, glossopterids and cordaites also started receding from the floral scene of Early Triassic Period (Lele, 1964). On the contrary, new gymnosperm rich assemblage having affinity with cycadophytes, ginkgophytes, alongwith conifers, pteridosperms and ferns appeared on the scene in the later part of Triassic indicating return of favourable conditions for the development of plants loving warm humid climate (Lele, 1976a).

The common occurrence of *Ginkgoites, Psygmophyllum, Rhipidopsis, Taeniopteris, Pseudoctenis, Pterophyllum, Ctenis, Araucarites*, etc. in Northern and Southern floras demonstrates the uniformity of Triassic flora. However, *Dicroidium*—a characteristic genus of the Gondwana, is still open to question about its real affinity. Schopf (1976) postulates its Northern ancestry while Lele (1976a) states "*Dicroidium* is also rather polymorphous and some workers treat it in a more comprehensive sense including several other plants like *Xylopteris, Johnstonia, Stenopteris, Displasiophyllum, Zuberia, Protoblechnum* etc.".

CONCLUSION

The available examples and comparative significance of the Indian Gondwana flora *vis a vis* contemporaneous northern floras suggest that in all probability the elements of Glossopteris flora had its ancestry in the Late Carboniferous flora and the change in climatic set up resulted to evolve a glossopterid rich assemblage in Gondwana countries, whereas pteridosperms, cordaites, conifers and ginkgopsids continued to flourish in Northern Hemispheric floras.

Floristic analysis suggests that the plant groups other than glossopterid in Gondwana flora owe their character affiliation with Northern floras, however, at times they did change themselves in comparison to their Northern counterparts but still retained their lineage with them. The so-called "Alien" elements or "Northern" elements might not be alien but they bring out the uniform nature of Northern and Southern floras. Northern Hemispheric genera, e.g., *Lesleya, Zamiopteris* and *Krylovia* having affinity with Gondwana flora probably conceived the characters of glossopterids in Late Carboniferous flora. However, such elements did not get enough chance for their survival and development in the contemporaneous floras, whereas they succeeded into the development of Glossopterid-like forms in Southern Hemisphere.

The occurrence of uniform floral composition towards the end of Triassic in Northern and Southern floras signifies the viability of contemporaneous elements in Gondwana flora. They underscore themselves in Permian because of the super dominance of Glossopteris flora and as soon as this flora started disappearing from the scene, they succeeded in outplaying the Glossopteris flora.

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Morpho-evolutionary biohorizon stratigraphy and cladistics in saccate pollen through Gondwana Sequence of India

Vijaya and R. S. Tiwari

Vijaya & Tiwari RS 1992. Morpho-evolutionary biohorizon stratigraphy and cladistics in saccate pollen through Gondwana Sequence of India. *Palaeobotanist* **40** : 157-193.

The morphographic characters of fossil saccate pollen and their evolutionary sequence through the span of Gondwana formations play a vital role in the biohorizon stratigraphy. Based on evolutionary changes in the morphology of the pollen group, their FADs (First Appearance Datums) and LADs (Last Appearance Datum) and the cluster levels, eleven biohorizons and ten inter-biohorizon Zones (Interval-zones) have been identified. The model of alliance among the prime morphographies has been acquired through simple character state analysis. By extrapolation of lineages, four unique monosaccate and one simple disaccate organizations could be identified to have their origin in the early Upper Carboniferous stock of Australia, which, in turn, were related with the Devonian progymnospermopsida complex. The five outgroup stocks continued as such into the late Early Asselian Talchir Formation of India and sprouted in the subsequent Permian time. A gap in the sequence has been identified during Upper Carboniferous of Australia and the lowermost Permian in India. The sixth major lineage of striate pollen branched off from the simple disaccate pollen lineage to appear in the Late Asselian. Cladistic analysis supports the applicability of the proposed biohorizons as important stratigraphic parameter. The congruence of derived and ancestral states of internally compatible and persimonically harmonious characters in pollen organizations has been used in drawing relationship trees. Thus, the cladograms and stratograms (nested diagrams of stratigraphic occurrences) together depict the maximum diversification at the lower Upper Talchir and the P/Tr boundary. The major extinction of monosaccates at the Lower Permian-Upper Permian boundary and that of the striate-disaccates in the basal Triassic have also been brought to light. The reasons of such a behaviour is attributed to environmental stresses caused by massive glaciations during Early Permian Talchir Formation, climatic changes towards warmer-drier situation at Lower/Upper Permian passage and global cooling and regression at the permo-Triassic level. Pollen features, like striations, taeniae, girdling monosaccus, clefts and remnant of germinal marks, etc. of the Permian and Triassic have perished completely by the end of Triassic. Most of the Jurassic palyno-assemblages contain the fag-end organizations of simple disaccate lineages; the experimentation seems to have attained a more simple state in the morphography of saccate pollen which continued thereafter.

Key-words—Evolution, Biostratigraphy, Saccate pollen, Cladistics, Gondwana (India).

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सारौंश

भारत के गोंडवाना अनुक्रम में कोष्ठीय परागकणों में क्लेडिस्टिक तथा आकार-विकासीय जैवमंडलन स्तरविन्यास

विजया एवं रामशंकर तिवारी

गोंडवाना शैल-समूहों में अश्मित कोष्ठीय परागकणों के आकारिकीय लक्षणों तथा उनके वैकासिक अनुक्रम की जैवमंडलीय स्तरविन्यास में महत्वपूर्ण भूमिका है। परागकण समूह की आकारिकी में विकासीय परिवर्तनों, इनके एफ-ए-डी० एवं एल-ए-डी० तथा समूह-स्तरों पर आधारित 11 जैवसंस्तर तथा 10 अंतरजैवसंस्तर मंडल अभिनिर्धारित किये गये हैं। सामान्य लक्षण-विश्लेषण के आधार पर सम्बद्ध मॉडल बनाये गये हैं। आस्ट्रेलिया के प्रारम्भिक उपरि कार्बनीफ़री कल्प में इनकी उत्पत्ति सुनिश्चित करने के लिए श्रृंखलाओं के बाह्यकलन के द्वारा चार विशेष एककोष्ठीय तथा एक सरल द्विकोष्ठीय संरचनायें अभिनिर्धारित की जा सकी हैं जो डिवोनी कल्प के प्रोजिम्नोस्पर्मोप्सिड् समूह से सम्बद्ध किये गये थे। ये पाँच बाह्य-समूह अर्नतिम प्रारम्भिक अँसेलियन तलचीर शैल-समूह में वैसे ही विद्यमान रहे तथा परमी कल्प में इनका प्रादुर्भाव हुआ। भारत के अधरितम् परमी कल्प में तथा ऑस्ट्रेलिया के उपरि

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कार्बनीफ़री कल्प में विद्यमान अनुक्रम में रिक्तता अन्वेषित की गई है। अनंतिम अँसेलियन में विकसित होने हेतु रेखीय परागकणों की छठी मुख्य श्रृंखला सरल द्विकोष्ठी परागकणों की छठी मुख्य श्रंखला से अलग हो गई। क्लेडिस्टिक विश्लेषण प्रस्तावित जैवसंस्तरों के महत्वपूर्ण स्तरिकीय परिसीमन हेतु उपयोगी सिद्ध हुआ है। परागकण संरचनाओं के व्युत्पादित एवं पूर्वजी लक्षणों का उपयोग सगोत्रता-वृक्ष बनाने में किया गया है। अतः क्लेडोग्राम एवं स्ट्रेटोग्राम संयुक्त रूप से अधरि उपरि तलचीर एवं परमी/त्रिसंघी सीमा पर सबसे अधिक विभिन्नता प्रदर्शित करते हैं। अधरि परमी उपरि परमी सीमा पर एककोष्ठीयों तथा आधारी त्रिसंघी कल्प में रेखीय-द्विकोष्ठीयों के बहत्विलुप्तीकरण पर भी विवेचना की गई है। इस तरह का विलुप्तीकरण वातावरण में अत्याधिक परिवर्तनों के कारण हुआ है। इन परिवर्तनों का मुख्य कारण हिमनदन अथवा जलवायु में काफी उतार-चढ़्व हैं। परागकणों के कई लक्षण जैसे रेखीयन, टीनी, मेखलन आदि त्रिसंघी कल्प के अन्त तक बिल्कुल समाप्त हो गये थे। जूराई कल्प के परागाणु-समुच्चयों में अधिकतर सरल द्विकोष्ठी श्रृंखलाओं के कुछ ही अंश शेष हैं। यह अध्ययन कोष्ठीय परागकणों की आकारिकी में अधिक सरल प्रतीत होता है, ये परागकण इसके बाद के कल्पों में भी मिलते हैं।

SPORES and pollen are unique entities in the life cycles of plants, because of their being complete units in themselves, beset with fine exinal characters and individualistic organizations. The building substance of the exine—the sporopollenin, a suitable material for preservation manifests into the structures, sculptures and modes of layer separation according to the blue-print of the genetic code in the mother cells (Heslop-Harrison, 1973). The large number in which they occur theoretically in all types of sediments (facies independent), adds a great value to the study of fossil spores and pollen. These assets make them more suitable than several other types of plant fossils for character analysis in time. When morpho-organizations of dispersed pollen and spores are tagged with stratigraphy, they could be effectively utilized in determination of evolutionary lineages, bench-mark events delineated by turnovers or by major innovations of organizations, genealogical pattern of descendence, and identification of major biohorizons and interbiohorizon zones for stratigraphic resolution (Hedberg, 1976; Levinton, 1988).

In the Indian Gondwana Sequence, extensive investigations in the field of palynofloral stratigraphy have been done (Lele & Makada, 1972; Bharadwaj & Srivastava, 1973; Tiwari, 1973; Bharadwaj, 1975b; Lele, 1975, 1984; Chandra & Lele, 1980; Vijaya & Tiwari, 1987; Tripathi *et al.*, 1990, and references cited therein). However, so far little has been done on the lines of morphographic character analysis in search of evolutionary trends. Lele (1964) and Lele and Shukla (1978) established morpho-variant lines in *Potonieisporites* and *Plicatipollenites* in the Lower Permian succession and derived composite variation trends; however, no biostratigraphic events were ascertained in this analysis. Although Bharadwaj (1975a) proposed a scheme to derive character lineages in spore-pollen groups mainly based on the nature of tenuitas, the generalized temporal reference made this proposal less useful for biostratigraphy. Kumar (1984) has attempted to evaluate the character variants in polysaccate pollen but again precise stratigraphic tagging could not be accomplished.

The present paper deals with the appearance of major morphographic building-plans of saccate pollen (Tiwari, 1975; Lele, 1975) at the beginning of Early Permian in the Indian peninsula, their diversification, multiple proliferation and declination through Permian, Triassic, Jurassic and Lower Cretaceous periods. During such a vast span of time passing through several changing climatic patterns (Lele, 1976; Kar, 1976; Shah, 1976; Tiwari & Tripathi, 1988; Banerji & D'rozario, 1990), the saccate pollen have undergone definitive experimentation due to severe stresses, in their saccus body architecture at several horizons. These biohorizons could be further tested for their compatibility with stratigraphic datums, using cladogram and stratogram (Fortey & Jefferies, 1982) of the stock lineage-trees, which are structured around similar organizations.

The saccate pollen have a remarkable edge over the trilete and monolete pteridophytic (incl. lycopsidean) spores and asaccate pollen of other types in respect of dispersal and subsequent preservation in synchronous sediments of varied lithofacies. The saccus is the most effective instrument for spatial dispersal of pollen by the mechanism of wind floating, while the non-saccate pollen and spores are handicapped for wider scattering; they are almost locally concentrated after shedding, and if carried away by waterflows they have a current biased distribution. Since the numerical abundance has not been taken as a criterion for datums, the saccate pollen have the best chance of representation in the widely separated regions at a given time. Their dispersal record is analogous to fragrance which could be detected in the same time plane in distant areas, may be that the degree of intensity varies. The FADs of innovation in character states in saccate pollen have, thus, a better prospect to provide control-lines for dating and correlation than that of the non-saccate morphos.

EVOLUTIONARY TRENDS AND BIOSTRATIGRAPHY

Speciation is the key event in evolution. The evolutionary trends are regarded as either variation in the rate of speciation or selective extinction of species in a biased morphological direction (Gould & Eldredge, 1977). The saccate pollen species are not the true biological species. They are morphographic groups of dispersed pollen specimens, based around a morpho-type which share similar characters amongst themselves. The circumscription of such morphographic taxa may not include, at times, the naturally affiliated forms; the ecological variants could be included into the group because of the apparent form similarity; or, inversely, the variants of a form can be mistaken for entirely separate species. Such a practice of identifying the non-statistically founded pollen species leads to the problem of biased identification. In a system where form-species could be sometimes arbitrarily defined, the incompleteness of geological record further adds to the difficulty of tracing ancestral or descendent lines, or character state (specific features) alliance (Joysey & Friday, 1982).

In order to circumvent these problems, the *gross organization and basic exine character* (morphos)—rather than the narrow quantitative parameters used for circumscription of pollen species—have been taken for the assessment of the character state relationship. The term "morphos" (singular and plural both, morphos) has been used in the text to denote the morphographic unit of characteristic building-plan and specified characters linked with it (morph, Gr., morphe, form); it is a supraspecific category of pollen—could be suprageneric or of a infraturma group. The supraspecific categories might give a very generalized picture in case where a whole fossil organism is dealt, but in case of palynotaxa they minimize the blurring effect of the taxonomic artifacts. The choice of the category "genus" for cladistic analysis has been rated as more effective than the "more-or-less species". It is more so when the "genus" is taken in terms of fundamental morpho-organizations. Such an approach has resulted into cohesive group patterns in pollen morphographies. And because the sequence of fossil occurrence is related with the time, the inter-connections of morphographic groups could be established by the criteria of relationship of descent and compatibility of derived characters.

The morphos have also followed definitive paths of innovation, diversification and extinction. It is not speculated here that one pollen group has given rise to another, but it is asserted that the phenomenon of evolutionary forces had always been in the backdrop which geared the morphological characters to alter in a certain direction, for better adaptation under changing conditions.

The biostratigraphic classification of strata is mainly based on the criterion of various distinguishable fossil assemblages. The morphological features of the fossils and their evolutionary sequence that had occurred, play a vital role in the development of fossil-based stratigraphy. The innovation of a mode in body-sac attachment, a novel character on body exine, or an unusual feature of the sulcus are remarkable character states, employed in the search of event datums. The consistent first appearance and the steady last appearance of a unique character or of a morpho-organization, or both, in a given population demarcate the major level of change in evolutionary flow, and referentially such FADs and LADs have important relation with the biochronology (Gradstein, 1983).

Through time, the gradual change within a character produces variants, but the mutational changes in genome contribute to speciation and such characters are reflected as apparent discontinuity in the chain of lineages. Although pure phyletic analysis cannot be advocated for pollen taxa dispersed in sediments of the geological past, such a discontinuity of characters had been generally observed in the run of lineages. The gross offsets in groups indicate rampant mutational changes that produced newer morphos, and refers to a catastrophy which exterminated the older ones.

CLADISTIC ANALYSIS

During the course of present study, the first occurrences of distinctive morphographic organizations were plotted along the stratigraphic span of Gondwana Sequence, and the range-line of occurrence for each form was drawn. Now the question was whether the clusters of these forms should be based intuitionally, or they be grouped in the light of their maximal character relationship. To adapt the latter approach, a simple cladistic analysis (Henning, 1966) has been done and its results are incorporated in the distribution chart (Text-figure 1). The cladistic approach (Greek *clade*, meaning a branch or younger shoot) for analysis of lineage in morphography deals with the relationship amongst a series of taxa grouped on the basis of their uniquely shared and evolutionarily derived similarities. The cladograms (branching pattern diagrams) based on fossils are not necessarily phylogenetic expression, unless the sequence of record in temporal aspect is continuous. But, if the trends of changes in group morphology through geological section are established, the broad phylogenetic sequence could be interpreted (Fortey & Jefferies, 1982; Hill & Crane, 1982). By the fixation of ancestral and derived character states in each pair of characters of a taxon, a further closeness with history of evolutionary connections can be achieved through cladistics. Such an attempt has been made here for saccate pollen through Gondwana Sequence.

The list of taxa, each representing a morphographic organization, is given in Table 1. Forty-four distinct morphographies (A to Z and AA to AV) were selected from amongst various genera. After repeated attempts for choosing the polarity of characters for outgroup comparisons, 28 character-pairs were finally enlisted (Table 2). In the list the italicised character represents the ancestral state, while the roman stands for derived state.

Table 1—Palynotaxa considered for morpho-evolutionary analysis

CODE NO.	PALYNOTAXA
A	*Potonieisporites* Bhardwaj emend. Bharadwaj 1964
B	*Plicatipollenites* Lele 1964
C	*Parasaccites* Bharadwaj & Tiwari 1964
D	*Virkkipollenites* Lele 1864
E	*"Pityosporites"* Seward emend. Manum 1960
F	*Caheniasaccites* Bose & Kar 1966
G	*Vestigisporites* Balme & Hennelly emend. Tiwari & Singh 1984
H	*Gondwanopollis* Lele & Maithy 1969
I	*Rimospora* Lele & Maithy 1969
J	*Rugasaccites* Lele & Maithy 1969
K	*Divarisaccus* Venkatachala & Kar 1966
L	*Crescentipollenites* Bharadwaj, Tiwari & Kar 1974
M	*Faunipollenites* Bharadwaj 1962
N	*Stellapollenites* Lele 1964
O	*Crucisaccites* Lele & Maithy 1964
P	*Circumstriatites* Lele & Makada 1972
Q	*Vesicaspora* Schemel emend. Wilson & Venkatachala 1963
R	*Pachysaccus* Lele & Maithy 1969
S	*Scheuringipollenites* Tiwari 1973
T	*Tuberisaccites* Lele & Makada 1972
U	*Parastriopollenites* Maheshwari 1967
V	*Rhizomaspora* Wilson 1962
W	*Sahnites* (Mehta) Mehta emend. Tiwari & Singh 1984
X	*Striatopodocarpites* Soritsch & Sedova emend. Bharadwaj 1962
Y	*Verticipollenites* Bharadwaj 1962
Z	*Striomonosaccites* Bharadwaj 1962
AA	*Barakarites* Bharadwaj & Tiwari 1964
AB	*Densipollenites* Bharadwaj 1962
AC	*Lueckisporites* Potonié & Klaus 1954
AD	*Corisaccites* Venkatachala & Kar 1968
AE	*Guttulapollenites* Goubin emend. Venkatachala, Goubin & Kar 1967
AF	*Schizopollis* Venkatachala & Kar 1964
AG	*Distriomonosaccites* Bharadwaj 1962
AH	*Klausipollenites* Jansonius 1962
AI	*Playfordiaspora* Maheshwari & Banerji 1975
AJ	*Alisporites* Daugherty emend. Jansonius 1971
AK	*Satsangisaccites* Bharadwaj & Srivastava 1969
AL	*Lunatisporites* Leschik emend. Scheuring 1970
AM	*Kamthisaccites* Srivastava & Jha 1986
AN	*Goubinispora* Tiwari & Rana 1981
AO	*Podocarpidites* Cookson *ex* Couper 1953
AP	*Minutosaccus* Mädler 1964
AQ	*Brachysaccus* Mädler 1964
AR	*Infernopollenites* Scheuring 1970
AS	*Staurosaccites* Dolby 1976
AT	*Samaropollenites* Goubin 1965
AU	*Podosporites* Rao emend. Kumar 1984
AV	*Callialasporites* Dev 1961

Taxa considered under discussion but not included in Table 1

Tiwariasporis Maheshwari & Kar 1967
Distriatites Bharadwaj 1962
Distriamonocolpites Bharadwaj & Sinha 1969
Hamiapollenites Wilson 1962
Aurangapollenites Srivastava 1977
Trochosporites Wilson 1962
Tumoripollenites Bharadwaj 1962
Platysaccus Naum. ex Potonié & Klaus 1954
Podocarpeaepollenites Thiergart 1949

Since we are dealing with the detached, exclusively fossil components of the plants which existed during Late Palaeozoic and Mesozoic eras, it is difficult to get clues for determination of character polarity in their living counterparts. It is more so, because almost none of the prime characters, viz., striations, taeniae, alveolae, endoreticulae, protosaccus, trilete or monolete marks, etc. is found in the extant saccate pollen. Therefore, we are left with two parameters, one—the stratigraphic levels of characters, and the other—the *in situ* pollen characters and their primitive or advance nature rated on the basis of parent plants. The little-known latter aspect is again syndromically tagged with stratigraphy, hence of no major consequence. The stratigraphical parameter is significantly authentic and irreversible in deciding the polarity in character

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Text-figure 1—Composite figure of Cladogram and Stratogram, showing character states relationship of morphos and their stratigraphic occurrence through Gondwana Sequence of India. Lower segment in the figure exhibits the primaeval stock level in Carboniferous (C1, C2) in Australia and their outgroup relation in Devonian (D), and the upper segment of the figure illustrates the sprouting and branching pattern of main six trees identified in the oldest strata of Indian Gondwana. *Solid-circle*—FAD's of each morphos; *thick lines*—main trunk of morphos-trees; *Dotted lines*—branching pattern of tree showing relationship amongst cladistically grouped morphos; *Continuous thinline*—consistent stratigraphic range of each morpho-organization; *Broken line*—inconsistent occurrence; *Cardinal numbers* are Morphos Index Numbers (MIN). Stratigraphic column not drawn proportionately, Permian sequence inflated.

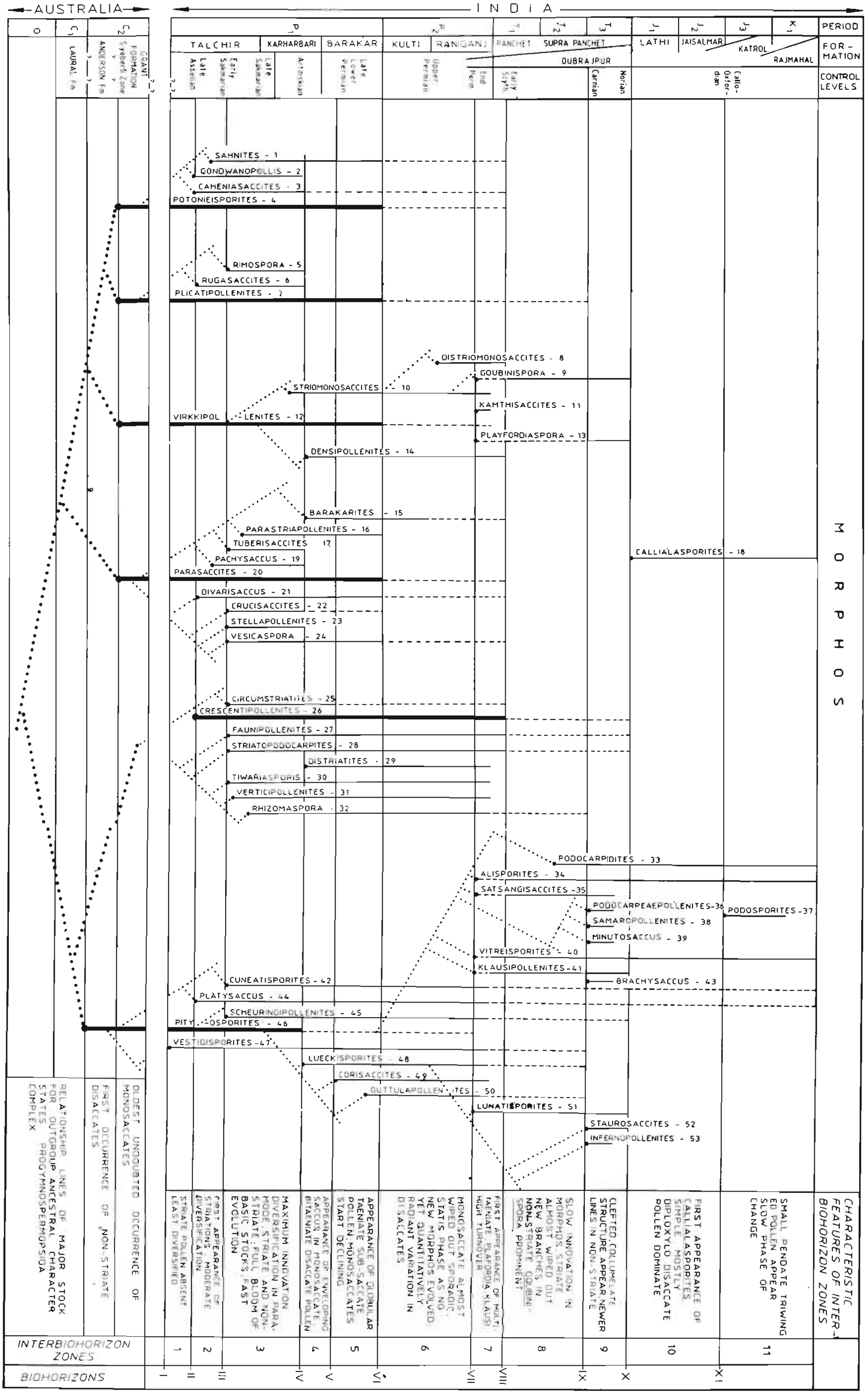

AUSTRALIA
INDIA
O
C1
C2
P1
P2
T1
T2
T3
J1
J2
J3
K1
PERIOD
FORMATION
CONTROL LEVELS
LAURAL Fm
ANDERSON Fm
GRANT FORMATION Stephenzone
TALCHIR
KARHARBARI
BARAKAR
KULTI
RANIGANJ
PANCHET
SUPRA PANCHET
DUBRAJPUR
LATHI
JAISALMAR
KATROL
RAJMAHAL
Late Asselian
Early Sakmarian
Late Sakmarian
Artinskian
Late Lower Permian
Upper Permian
End Perm
Early Scyth.
Carnian
Norian
Callo-Oxfordian
SAHNITES - 1
GONDWANOPOLLIS - 2
CAHENIASACCITES - 3
POTONIEISPORITES - 4
RIMOSPORA - 5
RUGASACCITES - 6
PLICATIPOLLENITES - 7
DISTRIOMONOSACCITES - 8
GOUBINISPORA - 9
STRIOMONOSACCITES - 10
KAMTHISACCITES - 11
VIRKKIPOLLENITES - 12
PLAYFORDIASPORA - 13
DENSIPOLLENITES - 14
BARAKARITES - 15
PARASTRIAPOLLENITES - 16
TUBERISACCITES 17
CALLIALASPORITES - 18
PACHYSACCUS - 19
PARASACCITES - 20
DIVARISACCUS - 21
CRUCISACCITES - 22
STELLAPOLLENITES - 23
VESICASPORA - 24
CIRCUMSTRIATITES - 25
CRESCENTIPOLLENITES - 26
FAUNIPOLLENITES - 27
STRIATOPODOCARPITES - 28
DISTRIATITES - 29
TIWARIASPORIS - 30
VERTICIPOLLENITES - 31
RHIZOMASPORA - 32
PODOCARPIDITES - 33
ALISPORITES - 34
SATSANGISACCITES - 35
PODOCARPEAEPOLLENITES - 36
PODOSPORITES - 37
SAMAROPOLLENITES - 38
MINUTOSACCUS - 39
VITREISPORITES - 40
KLAUSIPOLLENITES - 41
CUNEATISPORITES - 42
BRACHYSACCUS - 43
PLATYSACCUS - 44
SCHEURINGIPOLLENITES - 45
PITYOSPORITES - 46
VESTIGISPORITES - 47
LUECKISPORITES - 48
CORISACCITES - 49
GUTTULAPOLLENITES - 50
LUNATISPORITES - 51
STAUROSACCITES - 52
INFERNOPOLLENITES - 53
MORPHOS
RELATIONSHIP LINES OF MAJOR STOCK FOR OUTGROUP ANCESTRAL CHARACTER STATES PROGYMNOSPERMOPSIDA COMPLEX
FIRST OCCURRENCE OF NON-STRIATE DISACCATES
OLDEST UNDOUBTED OCCURRENCE OF MONOSACCATES
STRIATE POLLEN ABSENT LEAST DIVERSIFIED
FIRST APPEARANCE OF STRIATIONS MODERATE DIVERSIFICATION
MAXIMUM INNOVATION DIVERSIFICATION IN PARA-MODE, STRIATE AND NON-STRIATE; FULL BLOOM OF BASIC STOCKS, FAST EVOLUTION
APPEARANCE OF ENVELOPING SACCUS IN MONOSACCATE, BITAENIATE DISACCATE POLLEN
APPEARANCE OF GLOBULAR TAENIATE SUB-SACCATE POLLEN MONOSACCATES START DECLINING
MONOSACCATE ALMOST WIPED OUT SPORADIC STATIS PHASE AS NO NEW MORPHOS EVOLVED YET QUANTITATIVELY RADIANT VARIATION IN DISACCATES
FIRST APPEARANCE OF MULTI-TAENIATE PLAYFORDIA KLAUSI HIGH TURNOVER
SLOW INNOVATION IN MORPHOS STRIATE ALMOST WIPED OUT NEW BRANCHES IN NON-STRIATE GOUBINISPORA PROMINENT
CLEFTED COLUMELLATE STRUCTURE APPEAR NEWER LINES IN NON-STRIATE
FIRST APPEARANCE OF CALLIALASPORITES SIMPLE MOSTLY DIPLOXYLO DISACCATE POLLEN DOMINATE
SMALL PENDATE TRIWINGED POLLEN APPEAR SLOW PHASE OF CHANGE
CHARACTERISTIC FEATURES OF INTER-BIOHORIZON ZONES
INTERBIOHORIZON ZONES
1
2
3
4
5
6
7
8
9
10
11
BIOHORIZONS
I
II
III
IV
V
VI
VII
VIII
IX
X
XI

Table 2—Ancestral (in italics) and derived character states, selected for cladistic analysis of Gondwana saccate pollen

CHARACTER CODE	CHARACTER STATES
I.	Symmetry *Radial*/Bilateral (radial symmetry is the basic plan).
II.	Tetrad mark *Present*/Absent (remainié of primitive pteridophytic group).
III.	Tetrad mark *Trilete*/Monolete (tetrahedral tetrad had primitive configuration).
IV.	Body exine *Sculptured*/Structured (reference point pteridophytic exine).
V.	Proximal face of the body *Simple*/with Elevations (sexine forming islands, strips or discrete protuberances (result of secondary evolution in sexine).
VI.	*Non-striate*/Striate (striations are later development in evolutionary course).
VII.	Cleft on proximal face of body *Absent*/Present (Dolby & Balme, 1976; p. 150).
VIII.	Striations *Linear*/Reticuloid (tagged with stratigraphic occurrence).
IX.	Striations on *One face*/Both the faces of body (radiation in character as advance state).
X.	Striations *Loose-ended*/Joined-ended (Lele & Karim, 1972; p. 61).
XI.	*Non-striate*/Taeniate (Vijaya, 1990; p. 90; secondary evolution, a response to seasonality of climate).
XII.	*Taeniae two*/More in number (adaptation during course of evolution).
XIII.	*Monosaccate*/Disaccate (conservation of material and adaptation for better bouyancy).
XIV.	*Monosaccate*/Tri- or polysaccate.
XV.	Saccus *Sculptured*/Structured (general lineage of exine structure).
XVI.	Saccus *Infrapunctate*/Infrareticulate (exinal evolution lineage).
XVII.	Saccus *Infrapunctate*/Infracolumellate (further advancement in exinal evolution lineage).
XVIII.	Saccus *fully inflated*/little inflated.
XIX.	Saccus *Enveloping*/Non-enveloping (Pteridophytic spores and prepollen are reference points).
XX.	Distal attachment *Radial*/Bilateral (linked with basic lineage of radial symmetry).
XXI.	Distal attachment *Differential*/Para-mode.
XXII.	Para-mode *Circular*/Cruciform.
XXIII.	Para-mode *Circular*/Stellate (experiments in body-sac attachment relationship).
XXIV.	Sacci *Terminal*/Pendate (experimental line).
XXV.	Central body—Defined with *Haploxylon sacci*/Diploxylon sacci.
XXVI.	Central body—Ill-defined with *Haploxylon sacci*/Diploxylon sacci (reference point monosaccate as ancestral state).
XXVII.	In disaccates folds at root *Present*/Absent.
XXVIII.	In monosaccates folds at root *Present*/Absent (reduction in area of distal surface in central body—a conservation of material).

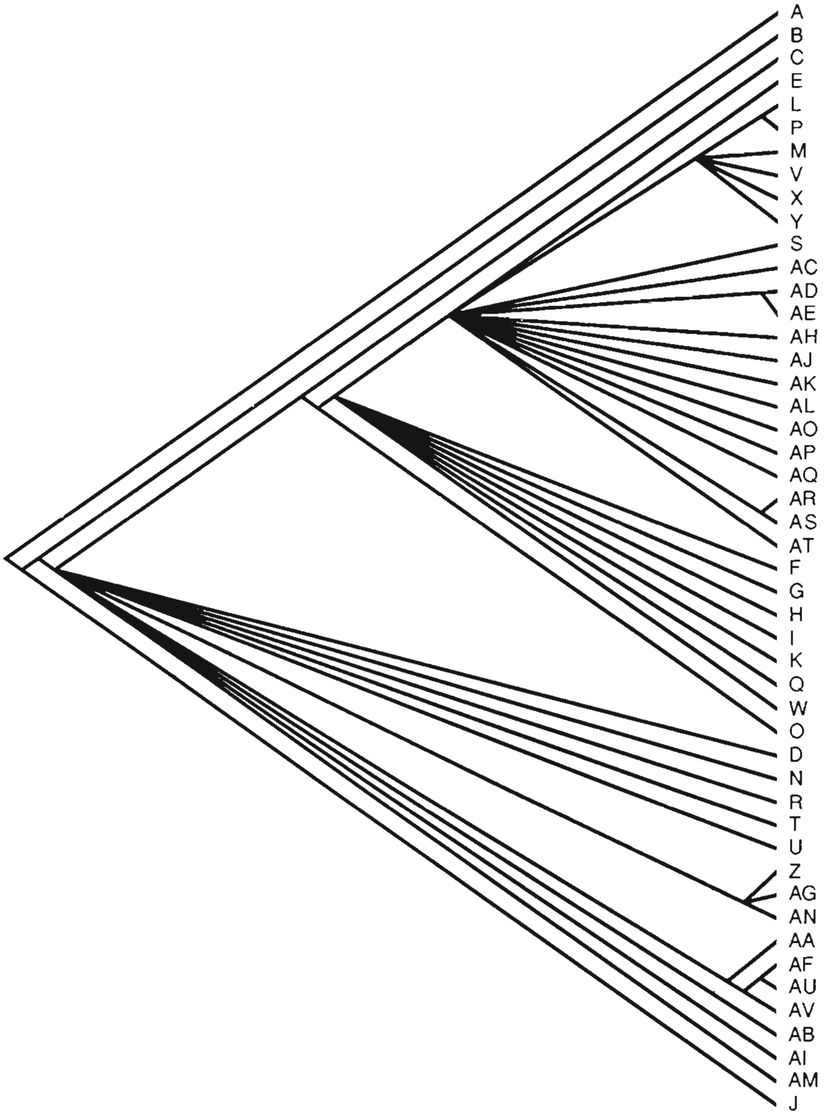
states of fundamental nature in a morphos. Stratigraphy, evolution and polarity in characters are linked with time, hence there can be no better parameter than stratigraphy for fixing the polarity of characters. However, the recurrence of primitive character in younger horizon may create problems in such considerations but they can be detected in conjunction with the entirety of characters; thus retrogressive trends or effect of parallel evolution can be sorted out on the basis of character compatibility.

The cladogram patterns are constructed from a matrix of taxa versus characters. In Table 3, the characters are taken along X-axis and the taxa on Y-axis. In Table 4, this arrangement has been reversed in order to project the result of different combinations. Table 3 depicts the outcome of sorting of taxa by taking monosaccate/disaccate (i.e., character XIII) as the primary key and striate-nonstriate (i.e., character VI) as the secondary key. Table 4 illustrates the results of sorting based on Column B representing *Plicatipollenites* as an outgroup for radiosymmetric monosaccate stock. The whole data was handled employing LOTUS software.

For the matrix, symbol-"1" is taken as ancestral (plesiomorphic) and "3" as derived (apomorphic) character state. The transitionary and mixed state is represented by symbol-"2". The root of each cladogram sector has been assumed to possess most ancestral character state. No numerical algorithms are employed here to generate cladograms as given in Text-figure 1. The correlation of simple cladistic pattern with the broad-frame stratigraphy reinforces the significance of various event-planes in saccate pollen through Gondwana Sequence.

To achieve a more compact picture of character state distribution in the matrix, the characters as well as taxa were shortlisted. As the parsimony demands, the majority set of internally consistent characters were chosen (Levinton, 1988). Such an arrangement (Tables 5, 6) reflects the alliance of character states which are based on minimum changes required for plotting the cladograms. Various segments of cladogram (see dotted lines in Text-figure 1) represent morphographic relationship lines, rather than the phyletic lines. It is our opinion that such an approach will considerably reduce the problem of homoplasy. No pollen morphos has been derived from the other but their basic similarities are suggested, hence the branching is not drawn in a direct manner, as in a typical cladogram.

In order to assess the results obtained by the above described method, an analysis was performed through the courtsey of Dr M. Muller of Florida Museum of Natural History. This analysis (Text-figure 2) was attempted on Apple MacIntosh IIci computer applying "Phylogenetic Analysis Using



Text-figure 2—Showing the results of Nelson algorithm analysis measuring evolutionary "cost" between character states. A supplementary figure to Text-figure 1 (MIN as in Text-fig. 1; courtsey D. Dilcher and M. Muller).

Parsimony (PAUP)" ver 3.0 (Swofford, 1990). The characters are ordered and reversible. An ordered character sequence is one which measures the evolutionary "cost" of acquiring a character as the absolute value of the difference between character states. Through this analysis, 1000 trees of length 132 were retained, and consensus tree (Text-figure 2) was drawn using the Nelson algorithm. This analysis provides a chance to compare the results of cladistic analysis done by us using a simple method (Text-figure 1) and by the algorithm method (Text-figure 2).

BIOHORIZON AND EVOLUTIONARY EVENTS

The analysis of data on appearances of new morphographies in saccate pollen through Gondwana Sequence of India has thrown light on several aspects of biostratigraphy. The advent level of derived features as well as termination or attenuation of lineages has been termed here as Biohorizon. In strict sense, a biohorizon is a surface (or distinctive bed) of biostratigraphic change, or a plane of distinctive characters. The identification of biohorizons is generally based on first appearance, last occurrence, change in frequency, evolutionary change, or change in character of individual taxon (Hedberg, 1976). In the present context, for recognising biohorizons emphasis is laid on the evolutionary changes in organizations and important characters which implicitly incorporate their FADs or LADs.

The second important natural outcome of the present analysis is the interbiohorizon-zones (or

Table 3—Elaborated data matrix of character states (1. Ancestral, 2. Transitionary, 3. Derived) and morphos; character codes are on X axis and morphos on Y axis. For morphos A-Av see Table 1, and for character states see Table 2

MORPHOS CODE	CHARACTER CODE													
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
AF	1	3		1	3	1	1							3
AU	1	3		1	1	1	1				1			3
AV	1	1	1	1	1	1	1				1			2
AN	1	3		3	3	3	1	1	1	1				2
R	1	1	1	3	1	1	1				1		1	1
O	2	1	3	3	1	1	1				1		1	1
A	2	1	2	3	1	1	1				1		1	1
N	1	3		3	1	1	1				1		1	1
AB	1	3		3	1	1	1				1		1	1
J	1	1	3	1	1	1	1				1		1	1
C	2	1	1	3	1	1	1				1		1	1
AM	1	3		3	1	1	1				3	3	1	1
B	1	1	1	3	1	1	1				1		1	1
T	1	3		3	3	1	1				1		1	1
AI	1	1	1	3	1	1	1				1		1	1
D	1	1	1	3	1	1	1				1		1	1
U	1	1	1	3	1	3	1	3	1				1	1
AG	1	3		3	1	3	1	1	3	1			1	1
AA	1	1	1	3	1	3	1	3	1				1	1
Z	1	3		3	1	3	1	1	1	1			1	1
K	3	3		3	1	1	1				1		2	
H	3	3	3	3	1	1	1				1		2	
F	3	1	3	3	1	1	1				1		2	
W	3	1	3	3	1	1	1				1		2	
G	3	1	3	3	1	1	1				1		2	
Q	3	3		3	1	1	1				1		2	
V	3	3		3	1	3	1	3	1				2	
I	3	1	3	3	1	3	1	3	3				2	
AT	3	3		3	1	1	1				1		3	
AD	3	3		1	3	1	1				3	1	3	
AQ	3	3		3	1	1	1				1		3	
AK	3	3		3	1	1	1				1		3	
AC	3	2	3	3	3	1	1				3	1	3	
AH	3	3		3	1	1	1				1		3	
AR	3	3		3	3	1	3				3	3	3	
AE	3	3		3	3	1	1				3	3	3	
S	2	3		3	1	1	1				1		3	
AL	3	3		3	3	1	1				3	3	3	
AS	1	3		3	3	1	3				3	1	3	
AO	3	3		3	1	1	1				1		3	
AJ	3	3		3	1	1	1				1		3	
AP	3	3		3	1	1	1				1		3	
E	3	3		3	1	1	1				1		3	
Y	3	3		1	1	3	1	1	1	1			3	
X	3	3		3	1	3	1	1	1	1			3	
P	3	3		3	1	3	1	1	1	3			3	
M	3	3		3	1	3	1	1	1	1			3	
L	3	3		3	1	3	1	1	1	1			3	

interval-zones), which by definition are the intervals between two distinctive biostratigraphic horizons (Hedberg, 1976). These zones represent a sequence between two identifiable biohorizons, and since the biohorizons are demarcated on the basis of morpho-evolutionary datums in the present work, the significance of interbiohorizon-zones is enhanced as a parameter for correlation and dating.

The earliest palynoassemblages from the Indian Gondwana are mainly constituted by radiosymmetric and bilateral monosaccates, and a few monosaccoid nonstriate-disaccate forms. Through time, during Late Permian and the Mesozoic, varied types of disaccates have evolved. The synthesis of data has

Table 3—Contd.

MORPHOS CODE	CHARACTER CODE													
	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
AF	3	1	1	3	3	2	1							3
AU	3	1		3	3	1				3	1			3
AV	1			3	1									3
AN	3	3		1	3	1	1							3
R	3	1	1	1	3	1	3	1	1					3
O	3	3		1	3		3	3						2
A	3	3		1	3	1	1							1
N	3	3		1	3		3		3					3
AB	3	3		1	1									3
J	3	3		1	3	1								1
C	3	3		1	3	1	3	1	1					3
AM	3	3		1	3	1	1							3
B	3	3		1	3	1	1							1
T	3	3		3	3	3	3	1	1					3
AI	3	3		1	1									3
D	3	3		1	3	1	1							3
U	3	2		1	3	1	3	1	1					3
AG	3	3		1	3	1	1							3
AA	3	1	1	3	3	1	1							3
Z	3	3		1	3	1	1	3						3
K	3	3		1	3	3	3						3	
H	3	3		1	3	3				1	1		1	
F	3	3		1	3	3					1		3	
W	3	3		1	3	3	3			1	1		1	
G	3	3		1	3	3				1	1		3	
Q	3	3		1	3	3				1	1		3	
V	3	3		1	3	3				1	3		3	
I	3	3		1	3	3				1	1		1	
AT	3	3		1	3	3				3	1		3	
AD	3	1	1	3	3	3				2	1		3	
AQ	3		3	3	3	3				1	1		3	
AK	3	3		1	3	3				1	1		3	
AC	3	3		1	3	3				1	3		3	
AH	3	3		1	3	3				1	1		3	
AR	3		3	3	3	3				1	1		3	
AE	3	1	1	3	3					2	1		3	
S	3	3		1	3	3				1		1	3	
AL	3	3		1	3	3				1	2		1	
AS	3		3	3	3	3				1	1		3	
AO	3	3		1	3	3				1	3		3	
AJ	3	3		1	3	3				1	2		3	
AP	3	3		3	3	3				3	1		3	
E	3	3		1	3	3				1	1		3	
Y	3	3		1	3	3				1	3		3	
X	3	3		1	3	3				1	3		3	
P	3	3		1	3	3				1	1		1	
M	3	3		1	. 3	3				1		1	3	
L	3	3		1	3	3				1	3		1	

revealed 11 major episodes, each of which is diagnostic as a FAD for new organisations which could be linked for their relationship with an older plan of construction; similarly, LADs of characters were also demarcated for identification of their extinction.

Biohorizon-I : *Potonieisporites—Plicatipollenites* Phase

In terms of evolution, the earliest Talchir palynoflora is in a conspicuous primitive state of composition because it comprises less diversified

Table 4—Elaborated data matrix of character states (1. Ancestral, 2. Transitionary, 3. Derived) and morphos; Morphos are on X axis and character codes on Y axis. For morphos A-Av see Table 1, and for character states see Table 2

CHARACTER CODE	MORPHOS CODE																									
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
XXVI													1						1							
XII																										
XXVII					3	3	3	1	1		3	1	3			1	3		3			3	1	3	3	
XXIII			1											3				1		1	1					
VIII									3			1	1			1					3	3		1	1	1
IX									3			1	1			1					1	1		1	1	1
X												1	1			3								1	1	1
XXIV					1		1	1	1			1	1			1	1		1			1	1	1	1	
XVII																		1								
XXII			1												3			1		1	1					
XXV					1	1	1	1	1			3				1	1					3	1	3	3	
XIII	1	1	1	1	3	2	2	2	2	1	2	3	3	1	1	3	2	1	3	1	1	2	2	3	3	1
XVIII	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1
XX	1	1	1	1	3	3	3	3	3	1	3	3	3			3	3	1	3	1	1	3	3	3	3	1
XIV	1	1	1	1						1				1				1		1	1					1
XXI	1	1	3	1							3			3	3			3		3	3					1
VII	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
XXVIII	1	1	3	3						1				3	2			3		3	3					3
V	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1
III	2	1	1	1		3	3	3	3	3					3			1			1		3			
I	2	1	2	1	3	3	3	3	3	1	3	3	3	1	2	3	3	1	2	1	1	3	3	3	3	1
XI	1	1	1	1	1	1	1	1		1	1			1	1		1	1	1	1			1			
VI	1	1	1	1	1	1	1	1	3	1	1	3	3	1	1	3	1	1	1	1	3	3	1	3	3	3
II	1	1	1	1	3	1	1	3	1	1	3	3	3	3	1	3	3	1	3	3	1	3	1	3	3	3
XIX	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
XVI	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3	3	3
XV	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
IV	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3

type of organizations, e.g., *Plicatipollenites, Potonieisporites, Parasaccites, Virkkipollenites* and *"Pityosporites"* (Figures 2-6). The *Vestigisporites*-type of pollen are also recorded at the Biohorizon-I but they are closely related in character states with *Pityosporites* stock (see Tiwari, 1975; the older assemblage of Dudhi River section *in* Lele, 1975; assemblage of Talchir Needle Shale, Athgarh Basin *in* Tiwari *et al.*, 1987). It could be, that in some isolated localities (viz., Jamunia River section, Jharia Coalfield) all the five basic morphos are not recorded. This phenomenon appears to be related with the ecological conditions where the vegetation could have been very scanty, or with taphonomy hence the total representation is not reflected.

Now the question arises as to how and from where the girdling monosaccate organization has evolved? It is a known fact that several groups of Late Carboniferous seed plants, viz., Cordaitales, Callistophytales and Coniferales, produced monosaccate pollen. Although there are no Carboniferous sediments on the Indian Peninsula, the other regions of Gondwana contain Carboniferous palynoassemblages in which the monosaccate pollen have been generally assigned to *Feleixipollenites* and *Potonieisporites* (Balme, 1988). In Australia, Lower Carboniferous Laural Formation exclusively contains small trilete spores with incipient cingulum, and no saccate pollen are on record (Balme, 1960; Kemp *et al.*, 1977). In the subsequent Anderson Formation, the first appearance of a non-striate disaccate pollen resembling *Pityosporites westphaliensis* is recorded (Balme, 1960; pl. 5, fig.35). This *"Pityosporites"* is taken here to represent an old stock of simple disaccate pollen with laterally separated sacci and probably with a thinner, linear area—an incipient scar, at the centre of the cappa. In all probability, this oldest occurrence of non-striate disaccate pollen has morphographical connections with similar forms in the lowermost Talchir palynoassemblage in India (Lele, 1975, pl. 1, fig. 15; Tiwari *et al.*, 1987, fig. 2d).

In Australia, the oldest undoubtedly saccate pollen comprising bilateral and radiosymmetric organizations (*Potonieisporites, Parasaccites*), found at the base of *Spelaeotriletes* (*Anabaculites*) *yberti* assemblage (Early Namurian; Kemp *et al.*, 1977, p. 182; Playford, 1985; Cooper, 1991), are in

Table 4—Contd.

CHARACTER CODE	MORPHOS CODE																					
	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV
XXVI																						
XII			1	1	3							3	3					3	1			
XXVII			3	3	3			3		3	3	1		3		3	3	3	3	3		
XXIII																						
VIII	3						1							1								
IX	1						3							1								
X					1									1								
XXIV			1	2	2			1		1	1	1			1	3	1	1	1	3	3	
XVII	1			1	1	1											3	3	3			
XXII																						
XXV			3	1	1			1		2	1	2			3	1	1	1	1	1	1	
XIII	1	1	3	3	3		1	3	1	3	3	3	1		1	3	3	3	3	3		
XVIII	3	1	1	3	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	1	3	3
XX	1		3	3		2	1	3		3	3	3	1	1	3	3	3	3	3	3	1	
XIV	1	1				3	1		1				1	2							3	2
XXI	1					1	1						1	1								
VII	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1
XXVIII	3	3				3	3		3				3	3							3	3
V	1	1	3	3	3	3	1	1	1	1	1	3	1	3	1	1	1	3	3	1	1	1
III	1		3						1													1
I	1	1	3	3	3	1	1	3	1	3	3	3	1	1	3	3	3	3	1	3	1	1
XI		1	3	3	3			1	1	1	1	3	3		1	1	1	3	3	1	1	1
VI	3	1	1	1	1	1	3	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1
II	1	3	2	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	1
XIX	3	1	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	1
XVI	1	3	3	1	1	1	3	3	3	3	3	3	3	3	3	3				3	1	
XV	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1
IV	3	3	3	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1

association with lycopsoid and apiculate trilete forms. This zone also contains nonstriate-disaccate pollen, but no striate pollen has been recovered (Text-figure 3). In Biohorizon-I, the striate-disaccate pollen are absent (Lele, 1975; Tiwari *et al.*, 1987). In this repsect it resembles the Stage 1 of Australia (lower part of *Potonieisporites* assemblage, in Kemp *et al.*, 1977; Playford, 1985). However, Biohorizon-I is relatively younger than the latter because of the dominance of *Plicatipollenites-Parasaccites* (instead of *Potonieisporites*).

At this level the prominence of well-organized tetrad mark in monosaccates has a bearing on the phenomenon of continuance of a primitive character of a prepollen. Although the polarity for germination had shifted to the distal surface by this time, yet the distal saccus-free-area remained non-sulcoid in nature as it shows distinct infra-reticulate structure, and there is no thinning of sexine. The trilete mark appears to have functioned as an emergency exit for pollen tube. This is a case of conservation of a primitive character which continued through time for providing better chance of survival. This contention is supported by the fact that in subsequent time, although radiosymmetric monosaccates continued to occur till the Permian end, the tetrad mark lost its prominence to become a vestigial imprint. The bipolar germination mechanism appears to be an important evolutionary character at this biohorizon.

Stratigraphically, these stocks are the oldest in the Indian Peninsula. They are found in the lowermost beds of the Talchir Formation (Text-figure 1). Biohorizon-I is dated as Asselian but older in relation to the *Eurydesma*-bearing Manendragarh beds (Shah & Sastry, 1975) which are of Late Asselian age. The latter contains a much diversified palynoflora including striate-disaccate pollen types.

Biohorizon-II : *Crescentipollenites-Rugasaccites* Phase

The FAD for striate-disaccate (Figure 30) is identified in Penganga assemblage (Lele, 1984). In terms of symmetry, the bilateral construction of monosaccate pollen starts gaining ground at this datum plane (*Gondwanopollis, Caheniasaccites, Rugasaccites,* bilateral forms of *Parasaccites* as *P.*

Table 5—Selected and short-listed data matrix of character states and morphos; character codes are on X axis and morphos on Y axis. For morphos A-AV see Table 1, and for character states see Table 2

	II	IV	V	VI	VII	VIII	XI	XIII	XIV	XV	XVI	XVII	XIX
AU	3	1	1	1	1		1		3	3	1		3
AV	1	1	1	1	1		1		2	1			1
AB	3	3	1	1	1		1	1	1	3	3		1
D	1	3	1	1	1		1	1	1	3	3		3
AI	1	3	1	1	1		1	1	1	3	3		1
C	1	3	1	1	1		1	1	1	3	3		3
B	1	3	1	1	1		1	1	1	3	3		3
A	1	3	1	1	1		1	1	1	3	3		3
Z	3	3	1	3	1	1		1	1	3	3		3
AA	1	3	1	3	1	3		1	1	3	1	1	3
W	1	3	1	1	1		1	2		3	3		3
AQ	3	3	1	1	1		1	3		3		3	3
AL	3	3	3	1	1		3	3		3	3		3
AR	3	3	3	1	3		3	3		3		3	3
E	3	3	1	1	1		1	3		3	3		3
AD	3	1	3	1	1		3	3		3	1	1	3
AC	2	3	3	1	1		3	3		3	3		3
L	3	3	1	3	1	1		3		3	3		3

Table 6—Selected and short-listed data matrix of character states and morphos: character codes are on Y axis and morphos on X axis. For morphos A-AV see Table 1, and for character states see Table 2

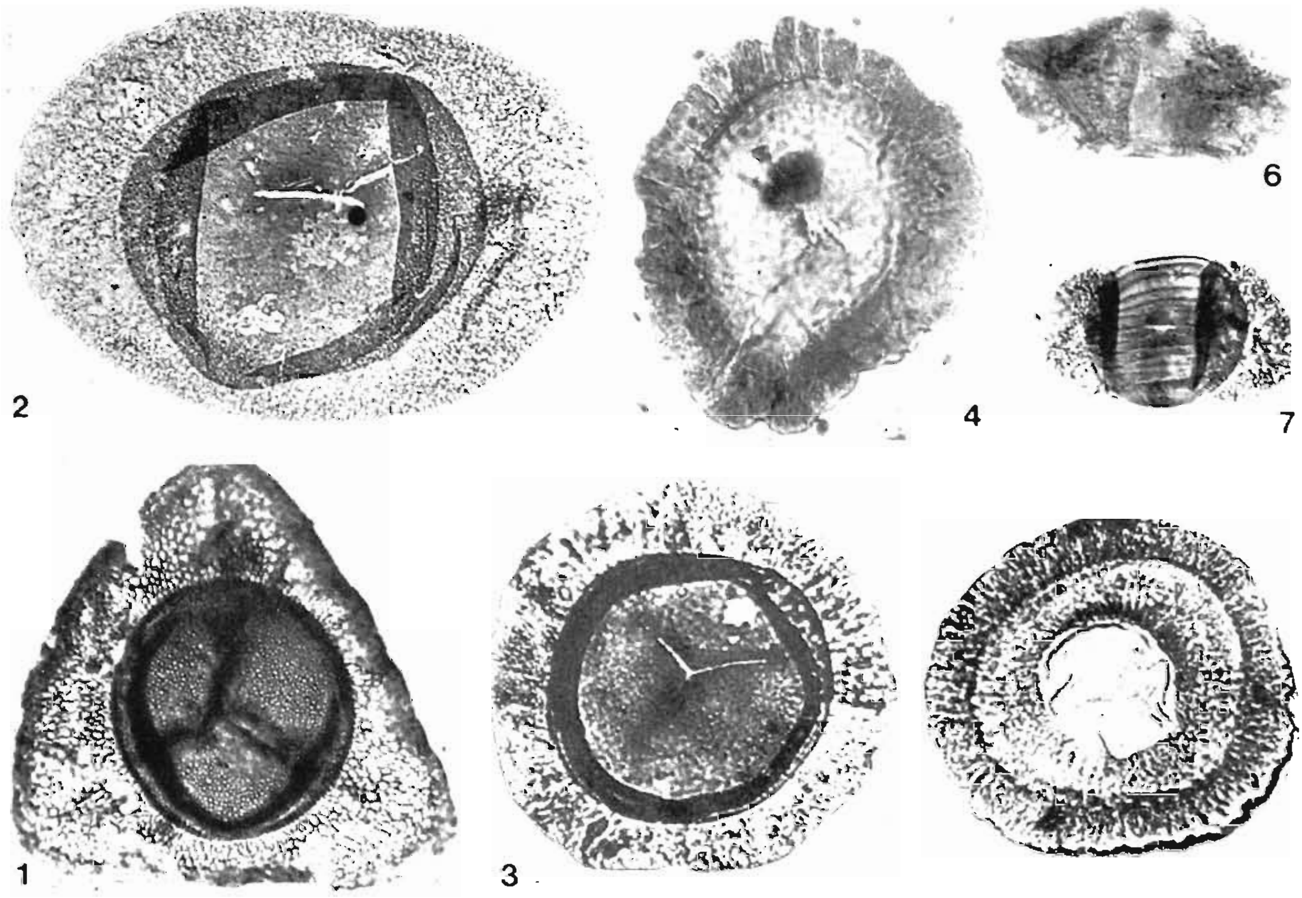
	A	B	C	D	E	L	W	Z	AA	AB	AC	AD	AI	AL	AU	AR	AU	AV
VIII						1		1	3									
XVII									1			1			3	3		
XI	1	1	1	1	1		1			1	3	3	1	3	1	3	1	1
VII	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
XIV	1	1	1	1				1	1	1			1				3	2
VI	1	1	1	1	1	3	1	3	3	1	1	1	1	1	1	1	1	1
II	1	1	1	1	3	3	1	3	1	3	2	3	1	3	3	3	3	1
V	1	1	1	1	1	1	1	1	1	1	3	3	1	3	1	3	1	1
XIII	1	1	1	1	3	3	2	1	1	1	3	3	1	3	3	3		
XV	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1
XVI	3	3	3	3	3	3	3	3	1	3	3	1	3	3	3	3	1	1
IV	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	1	1
XIX	3	3	3	3	3	3	3	3	3	1	3	3	1	3	3	3	3	1

bilateralis). With the bilateral monosaccate lineage (i.e., *Potonieisporites*) the morphologies of *Cabeniasaccites* and *Gondwanopollis* are closely related. Such a trend flows from typical monosaccate towards the disaccoid organization with a tendency of reduction in the lateral spreads of the saccus. Thus *Gondwanopollis*-type of organizations are intimately related with *Sahnites*-kind of morphos (Figures 8-11). In natural sequence of incidences it also appears logical that from radial monosaccate having para-mode of body-sac attachment (*Parasaccites*) such steps might have led to derivation of ovoidal, nonstriate-disaccate bilateral forms (Figures 21-23) assigned to *Vesicaspora* and *Divarisaccus* (Venkatachala & Kar, 1966; Lele & Shukla, 1978; Meyen, 1987).

The basic nature of body exine is infra-reticulate in monosaccates. The appearance of vermiculate or rugose sculpture at this biohorizon (*Rugasaccites*; Figure 13) is an example of re-appearance of an ancestral character state of exine.

The earliest occurrence of striate-disaccate equates this biohorizon with the part of *Potonieisporites* assemblage (base of Stage 2) in Australia (Kemp *et al.*, 1977). The sequence of FADs suggests that striate-disaccates had their fore-bearers in the older sequence which were closely related with the simple disaccate stock of "*Pityosporites*" type; the latter precedes the striate forms on temporal scale (Text-figures 1, 3). These are considered to have a remote ancestral relationship (Figures 6, 7).

This biohorizon has been established by incorporating the Penganga and Manendragarh



Figures 1-7—Oldest mother stock complex represented by **1.** *Teichertospora* McGregor & Playford 1990, and the morphos of six basic lineages which share ancestral character states of the stock in different combinations, i.e., prominent germinal mark, non-sulcoid distal saccus-free-area and body-in-fold system, as seen in fig. **2.** *Potonieisporites*, in Kemp *et al.*, 1977; **3.** *Plicatipollenites*; **4.** *Parasaccites*, **5.** *Virkkipollenites*; **6.** *"Pityosporites"*, in Balme, 1960; **7.** *Crescentipollenites*, in Kemp *et al.*, 1977.

palynoassemblages (Lele, 1984; Lele & Chandra, 1972; Chandra & Lele, 1980). The age of Manendragarh beds is Late Asselian. It has been indicated by the occurrence of *Eurydesma* fauna (Shah & Sastry, 1975).

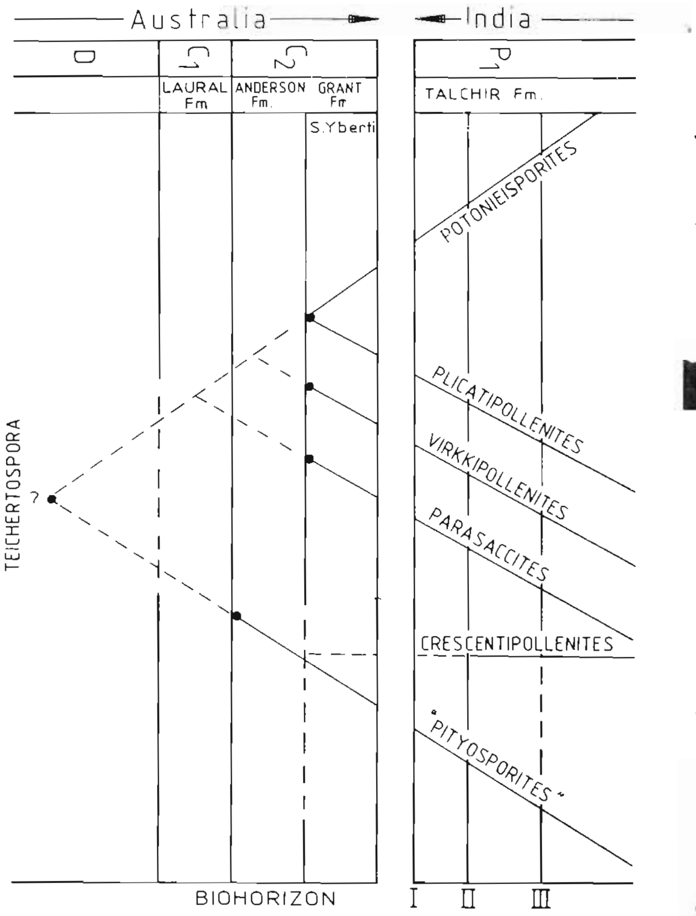
Biohorizon-III : *Crucisaccites-Tuberisaccites* Phase

This level of morphographic evolution in saccate pollen qualifies for a unique status in the Indian Gondwana. Many new characters derived from the preceding stock branch-off from three main organizations—monosaccate, non-striate-disaccate and striate-disaccate, including six basic lineages.

The composition at Biohorizon-III comprises diversified striate-disaccate pollen (such as *Circumstriatites, Striatopodocarpites, Faunipollenites,* Figures 31, 34, 33), nonstriate (*Scheuringipollenites*; Figure 45; *Platysaccus*) and monosaccates (*Tuberisaccites*, Figure 28; *Crucisaccites, Stellapollenites*; Figures 26, 25) and *Rimospora*, Figure 14). Subsequently, the reticuloid pattern of striations in mono- and disaccates also appears. The pitcher-shaped saccus develops both in striate and nonstriate-disaccates (*Verticipollenites, Aurangapollenites*). Furthermore, a unique variability is observed in a pseudo-striate form where extreme reduction of sacci has taken place (*Tiwariasporis*, Figure 37).

The basic bauplan of circular para-condition of saccus attachment is manifested in stellate, cruciform and amphi-saccate organizations at this biohorizon. By way of character state matching, these morphos appear to have been derived from the circular para-mode of body-sac attachment, as in *Parasaccites* (Figures 23-26).

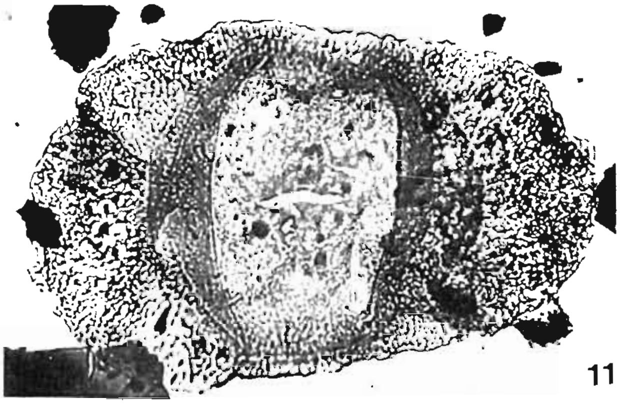
In the radiosymmetric para-mode lineage, further manifestation in the sexinal distribution has



Text-figure 3—Cladogram showing relationship of stock morphos based on congruence of parsimonically compatible character states. Out-group presumably located in Progymnospermous group of Devonian in Australia.

occurred by development of conspicuous protuberances and reticuloid pattern of grooves on the body (*Tuberisaccites, Parastriopollenites;* Figures 28, 29). This seems to be the starting plane for subsequent reticuloid striation-bearing monosaccates (*Barakarites*). The humble start of striate-disaccate line in Biohorizon-II has branched-off radiantly giving rise to a complex of combinations in striation pattern (Vijaya, 1990).

In the wake of sprouting of newer morphography at several levels, some trisaccate and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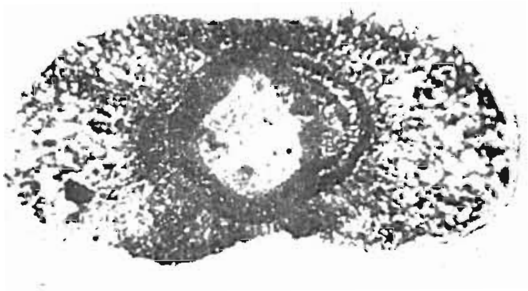
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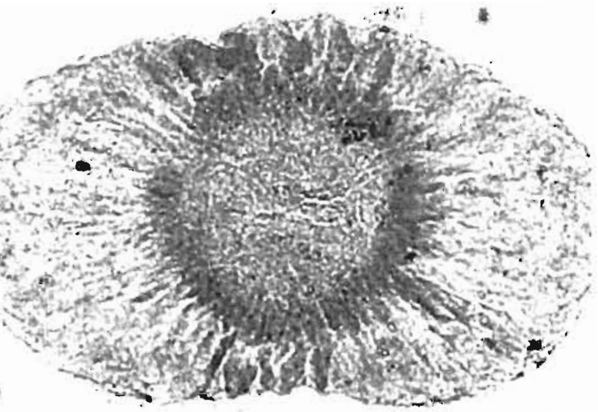
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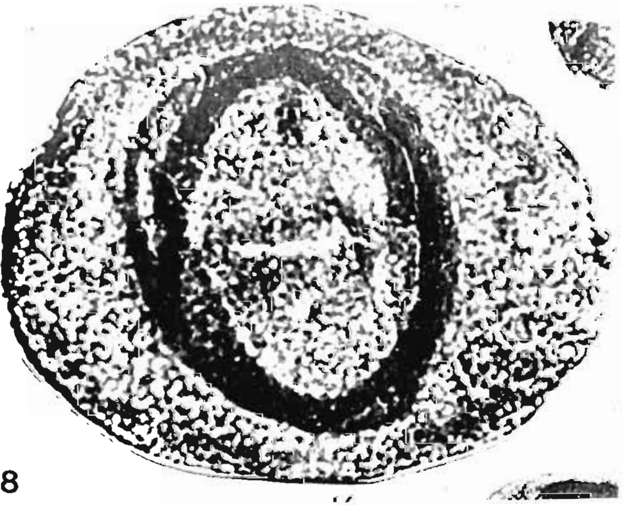
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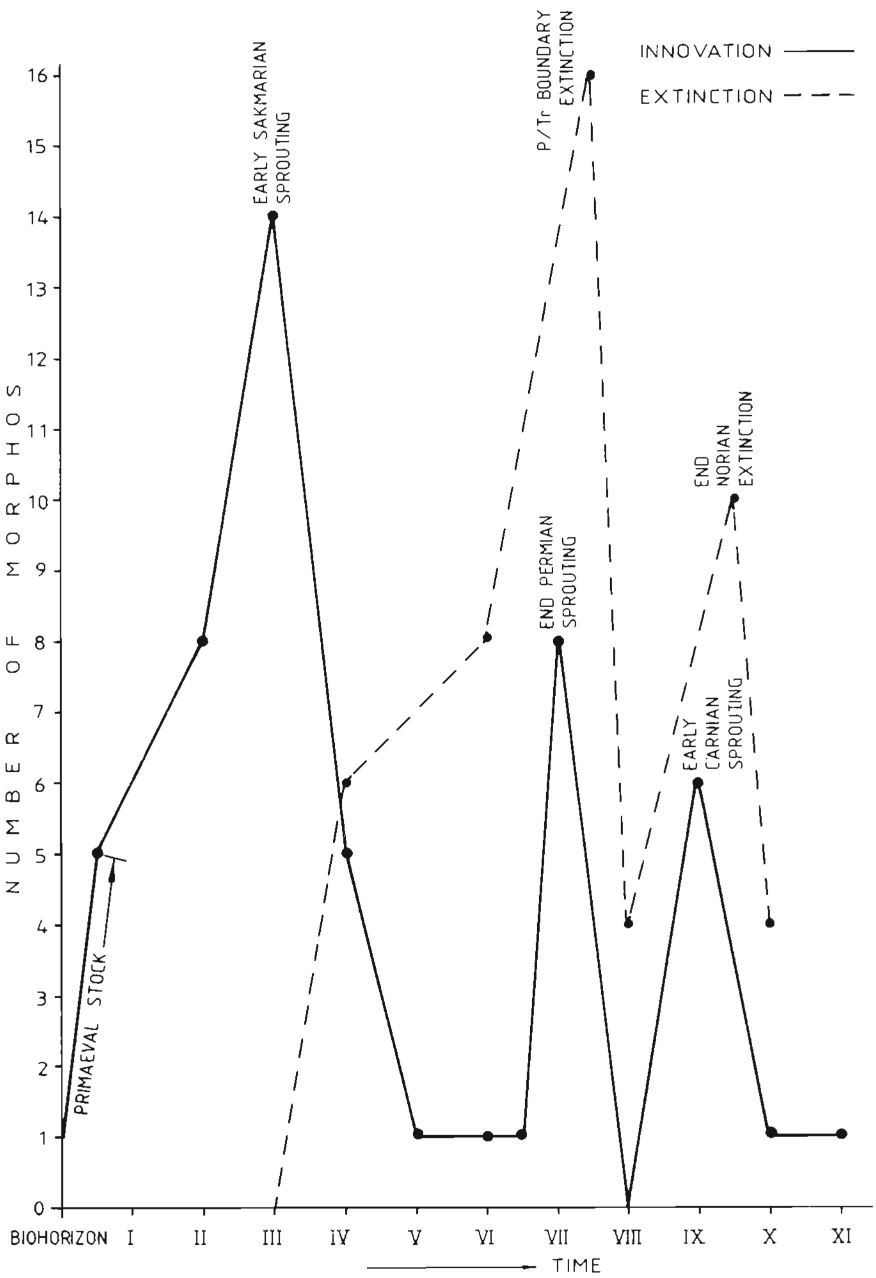
Figures 8-11—Showing morphos of *Potonieisporites* lineage in sequence of evolutionary states. The derived character state in each morphos is the resultant of changes. **8.** *Potonieisporites*, the stock of this tree possessing mainly ancestral character states of prominent germinal aperture, distal non-sulcoid saccus-free-area and double body-in-fold system; **9.** *Caheniasccites* and **10.** *Gondwanopollis* are the morphos which acquired derived state in the characters of having reduced body-in-fold and also attaining bilateral symmetry; **11.** *Sahnites* showing retained prominent nature of germinal aperture and represents ultimate derived character state of the lineage.

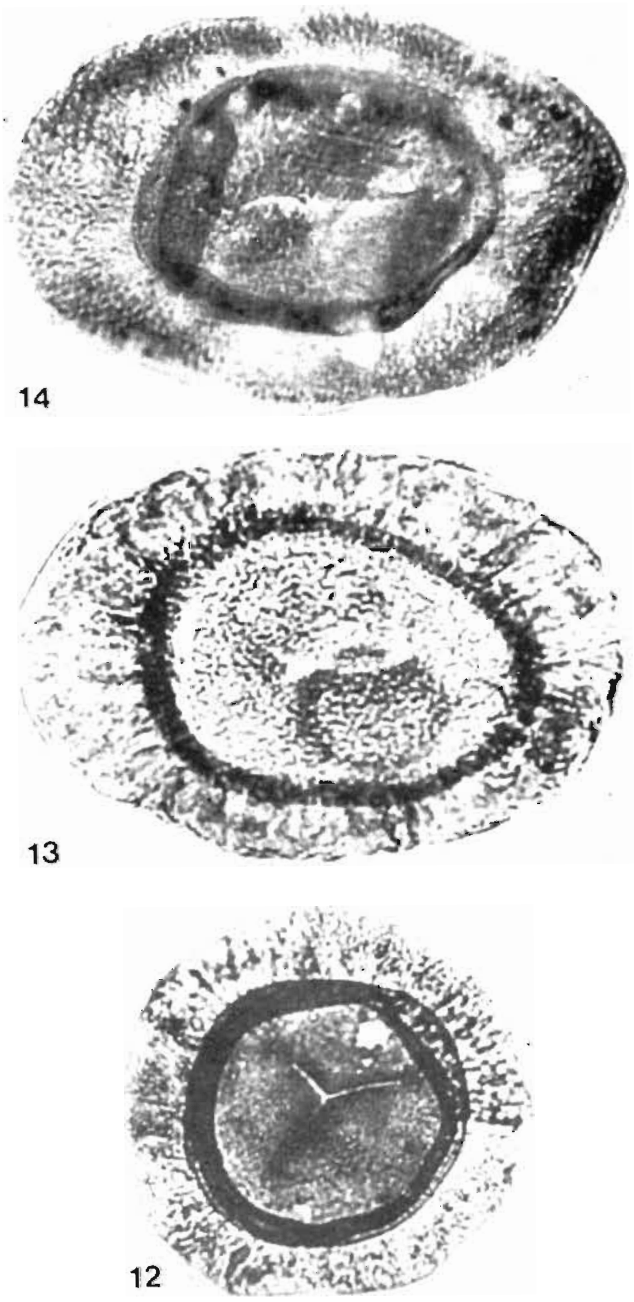


Text-figure 4—Graphic representation of mode of *innovation* (solid lines) and *extinction* (broken lines) in number of morphos through Gondwana Sequence of India; only the incoming and outgoing morphos are depicted at each biohorizon, and not their total sum. Stratigraphic succession represented by *Biohorizon numbers* from I to XI. This represents three innovation events and two extinction events. The high turnover of morphographies at P/Tr transitional zone as well as Carnian/Norian level are well-projected. The Early Sakmarian sprouting represents the highest innovation in saccate pollen.

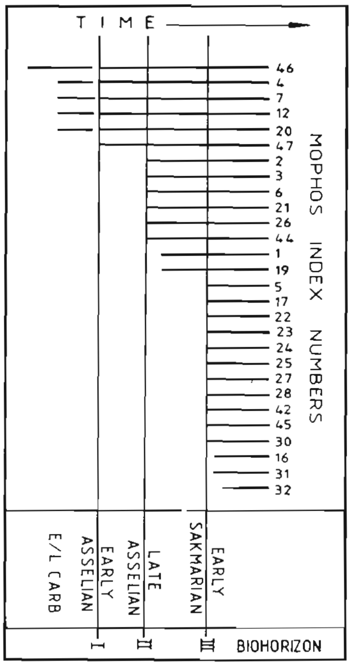
tetrasaccate forms (Figure 65) also occur but without any special exine characters (i.e. striations, islands, taeniae or a tetrad-mark). Their sporadic inconsistent incidences and anomalous features suggest that they are morpho-variants of disaccates rather than naturally affiliated groups in themselves (viz., *Trochosporites* in Lele, 1975; *Tetrasaccus* in Maithy, 1969; Tripathi *et al.*, 1990; Vishnu-Mittre, 1954; Sukh-Dev, 1980). Also a trisaccate pollen specimen with indistinct thin striation-like grooves has been assigned to *Crustaesporites* sp. by Lele and Karim (1971) from the younger beds of Talchir Formation.

The experimentation of nature to produce new and unusual combinations of building plans in pollen in the lower part of Upper Talchir Formation is well documented (Text-figures 1, 5).

Biohorizon-III derives the data from the



Figures 12-14—Morphos of *Plicatipollenites* lineage: **12.** *Plicatipollenites*, the out-group stock of this lineage is characterised by prominent germinal aperture and the body-in-fold system. The aperture becomes vestigial in subsequent time; **13.** *Rugasaccites*; and **14.** *Rimospora*, the morphos although appear at younger level than *Plicatipollenites* (with structured body exine) yet possess sculptured exine which is an ancestral character state.



Text-figure 5—A spread diagrame of sequential distribution of morphos through Biohorizons-I, II and III with respect to Australian primaeval stock in L/U Carboniferous (MIN as in Text-figure 1).

palynoassemblages studied from the younger horizon in Dudhi River Section (Lele, 1975) and Jayanti Coalfield (Lele & Karim, 1971; Lele & Makada, 1972; Chandra & Lele, 1980). The Umaria Marine bed assemblage (Lele & Chandra, 1972) is relatively younger to Manendragarh assemblage. The Umaria bed overlies the Talchir boulder bed and passes upward into the Karharbari rocks without any visible break (Sastry *et al.*, 1977). The productids make predominating elements of Umaria bed where *Eurydesma* are very rare, hence dated as Late Sakmarian. By these parameters, Biohorizon-III is assigned an Early Sakmarian age.

Biohorizon-IV : *Densipollenites-Barakarites* Phase

This biohorizon is recognised by the first appearance of four distinct morphographies in saccate pollen. In one group, the saccus envelops the body from all sides and is attached at one point (*Densipollenites*). This new organizational architecture is a remarkable episode in which the saccus is filled with endoreticulate alveolae to make it a protosaccus. It provides better protection to the central body which nurtures the genetic material. In other group, the body-sac attachment is a girdling kind, and a circumsulcus develops at the equatorial region of the body which bears reticuloid striations (*Barakarites*). The singular morphos having an enveloping saccus (*Densipollenites*) although does not possess any haptotypic mark, in most of the character state comparability this organization comes closest to *Virkkipollenites* (Figures 18, 19).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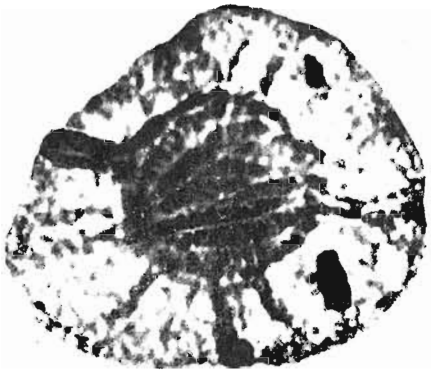
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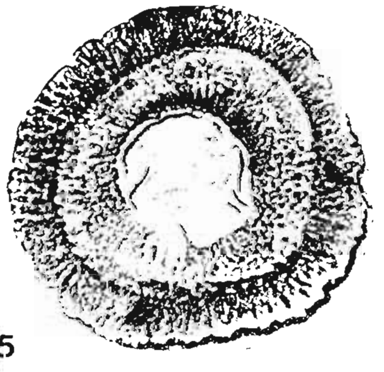
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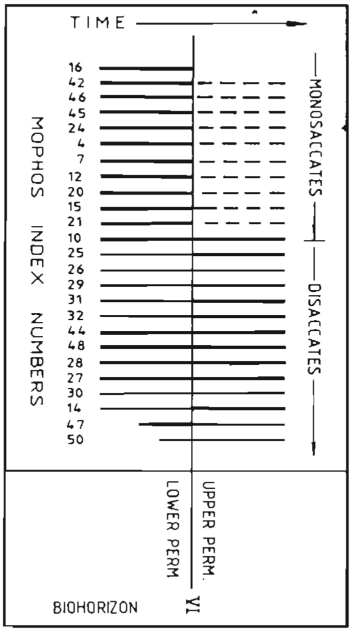
Figures 15-17—Morphos of *Virkkipollenites* lineage: **15.** *Virkkipollenites*, definitely a line of experimentation from the mother stock, lacking body-in-folds. Simple linear grooves develop on one of the faces of the body as seen in **16.** *Striomonosaccites*, and in another direction the sexinal islands also develop on other face of the body as in **17.** *Goubinispora*, a derived character state of out-group stock.



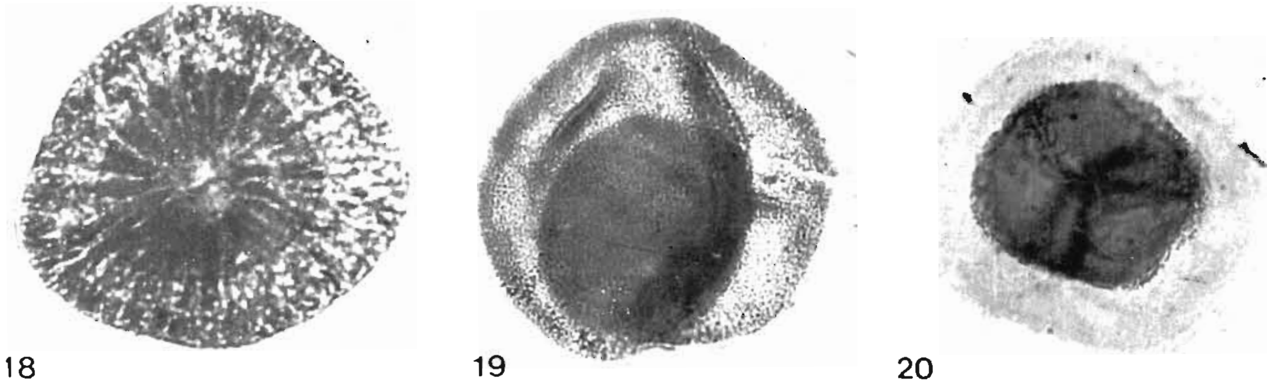
Text-figure 6—Sequential distribution of morphos across Lower/Upper Permian boundary at Biohorizon-VI to depict the major declination in monosaccate lineages at beginning of Upper Permian. Line thickness is indicative of relative prominence; broken line for inconsistent occurrence (MIN as in Text-figure 1).

The relationship derivation of the former from the latter can be traced through *V. densus* (Lele, 1964; pl. 2, fig. 19) and *Virkkipollenites* sp. (*in* Venkatachala & Kar, 1968; pl. 2, fig. 21).

The reticuloid striations-bearing monosaccate has its linkage in the comparable forms of older Biohorizon-III (i.e., in *Parastriopollenites, Tuberisaccites*). Similarly, the simple monosaccate pollen (*Virkkipollenites*) has relationship with the striate-monosaccate (*Striomonosaccites*) which occurs at slightly older level than the Biohorizon-IV.

The FAD for taeniate pollen (*Lueckisporites*) is also identified at the Biohorizon-IV. This bilateral bitaeniate, disaccate pollen has a greater degree of similarity in character states with nonstriate-disaccate "*Pityosporites*" stock in which the two sexinal bands could have developed on the proximal face of the body, presumably in response to the climatic changes. Such a derivation of relationship is simple, without involving many steps and in tune with the stratigraphic occurrence. The occurrence of striations on both the faces of the central body in disaccates is also recorded at this phase (*Distriatites*, incl. *Hamiapollenites*; Kar, 1973). This marks the diversification trends at their peak in the disaccate pollen.

The other important event which took place at this juncture is the extinction of unique lineage of monosaccate stellate body-sac attachment and also that of the monosaccate forms with tuberculoid sexinal protuberances, rugulate or reticuloid



Figures 18-20—Morphos, thought to be remotely allied with *Virkkipollenites* tree (**18.** *Virkkipollenites* sp.) but retaining a primitive state of saccus attachment which could give rise to a total covering as in **19.** *Densipollenites*, and almost total covering of the body as in **20.** *Playfordiaspora*.

sculpture on body surface (*Tuberisaccites, Pachysaccus, Rugasaccites* and *Rimospora*). The cruciform body-sac organization also loses it impact. All these events contributing to a high morphographic turnover correspond with the change of palynoflora at the Artinskian/Kungurian transition (Text-figure 1).

In the Australian Gondwana sediments, the earliest record of alete enveloping monosaccate organization and that of morphos with the circumsulcus and reticuloid striations are from *Acanthotriletes* Assemblage-Zone dated as Early Artinskian (High-cliff Sandstone Formation; Segroves, 1970). However, with reference to Umaria Marine bed, the Biohorizon-IV occurs at a higher level than the Early Artinskian, and hence is dated as early Late Artinskian. The Biohorizon-IV is identified at the uppermost Karharbari Formation represented in several sections (Tiwari, 1973; Lele & Makada, 1974; Bharadwaj & Srivastava, 1973).

Biohorizon-V : *Corisaccites* Phase

The FAD of globular taeniate form (*Corisaccites*) is the characteristic feature of this phase. The taeniate line of relationship appears to branch-off from older, simple nonstriate-disaccate. This new character has an alliance with a more complex unit of similar morphography (*Guttulapollenites*) in Late Permian, at a level slightly younger to Biohorizon-V. Parsimonically, *Lueckisporites, Corisaccites* and *Guttulapollenites* (Figures 60; 57 61) represent important character states. In some of the localities (South Rewa Gondwana Basin; Tiwari & Ram-Awatar, 1988) multitaeniate-disaccate pollen with massive sexinal bands have also been recorded, which exhibit gross similarity with *Lueckisporites*. However, this line does not survive in the subsequent horizons and hence seems to be a stage of experimentation at this level. After a gap represented by Kulti and Lower Raniganj formations the morphos with multi-taeniate body make their entry again at the Biohorizon-VII which is the derived state from the older stock of this group.

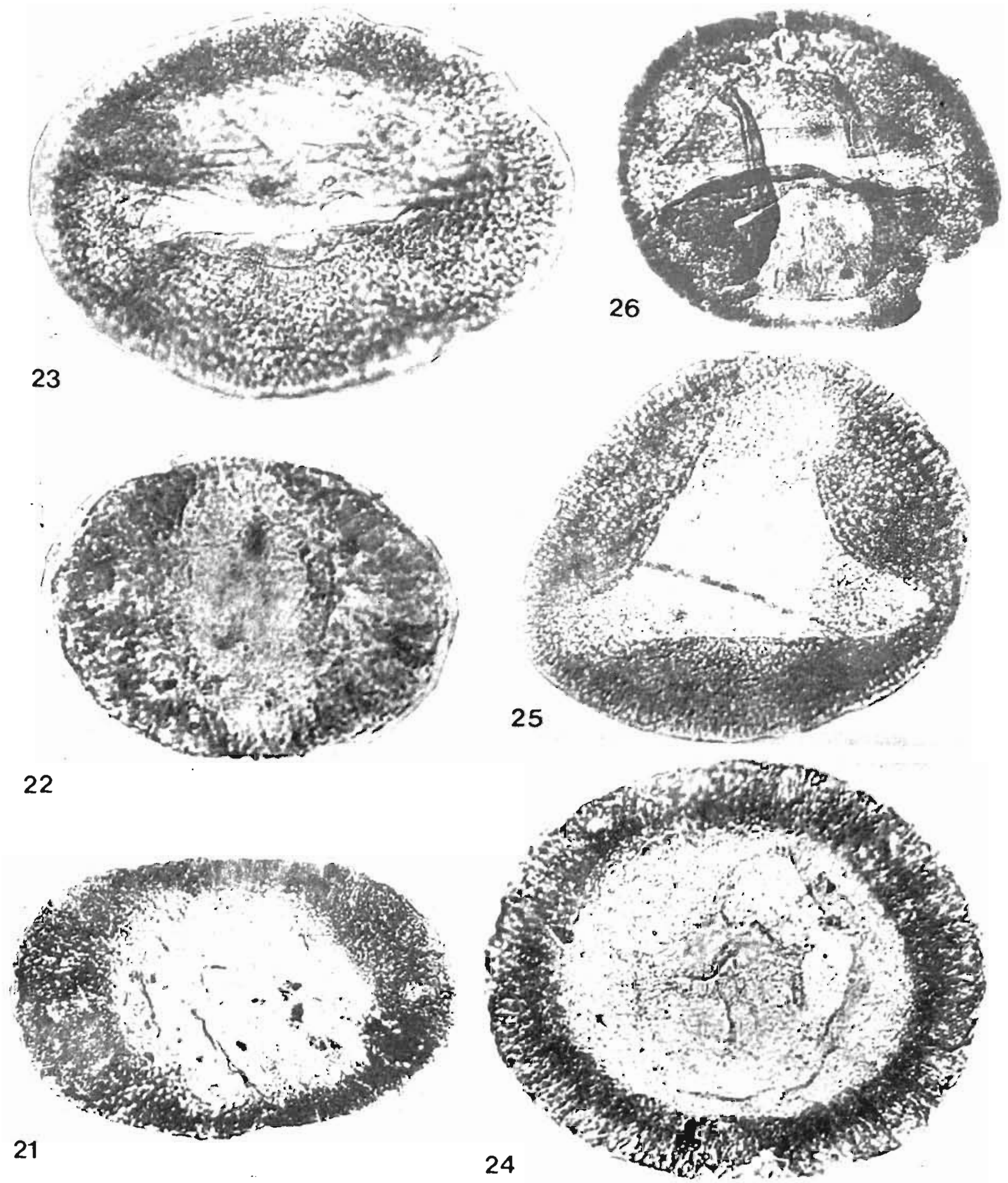
In globular taeniate form *Corisaccites*, the body exine is finely microverrucose (Venkatachala & Kar, 1966b) which makes a deviation from the generally found infra-structured exine of the body. This apparently represents homoplasy in a character, showing retrogressive evolutionary trend. The saccus is also indistinctly structured, rather than having well organized endo-reticulation. The indistinct structure of saccus is an ancestral character state. FADs of these morphos are identified by Kar (1973) and Bharadwaj and Srivastava (1973).

Distriamonocolpites, a unique pollen with oval configuration and striations on both the faces and a sulcus-like saccus-free-area, also appears at this level (identified in Bharadwaj & Dwivedi, 1981). It demonstrates the trend of specialization in striate pollen with non-expression of sacci.

In Australian sediments, the earliest globular forms with taeniate organization (*Corisaccites*) are recorded from *Quadrisporites* Assemblage dated as Late Sakmarian (Segroves, 1970). On the face value of data available the Australian record of *Corisaccites* is much earlier than the Biohorizon-V.

Biohorizon-VI : Monosaccate extinction Phase

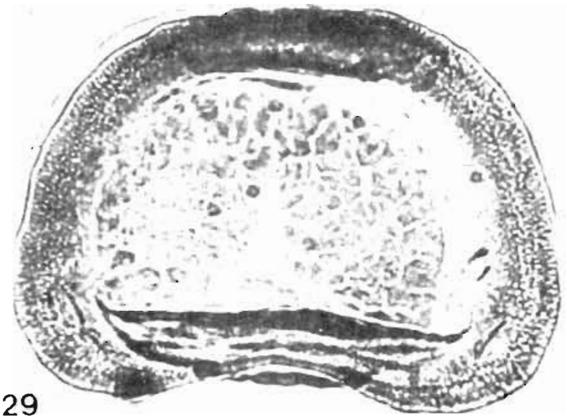
It is evident from Text-figure 1 that no new morphographical feature has appeared at this level. On the contrary, most of the singular monosaccate organizations either became extinct or almost disappeared (Text-figure 6). At the same time, the



Figures 21-26—*Parasaccites*-lineage is variously diversified in terms of derived character states of body-sac attachment as well as symmetry. **21.** *Parasaccites bilateralis*—the derived character state from radial symmetry, **22.** *Vesicaspora* is the other morphos of this state. The amphi-saccate, cruciform and stellate modes of body-sac attachment, as in **23.** *Divarisaccus*, **26.** *Crucisaccites*, and **25.** *Stellapollenites*, again are derived character states of para-mode (**24.** *Parasaccites*)

striate-disaccates exhibit immense proliferation in quantitative characters resulting into an array of form-species. The characters in striations, central body and the sacci follow multivariant paths at this biohorizon (Kar, 1973; Lele & Shukla, 1978; Tiwari, 1973; Srivastava & Jha, 1988).

This is considered as a great event for the extinction or landslide decline of monosaccate



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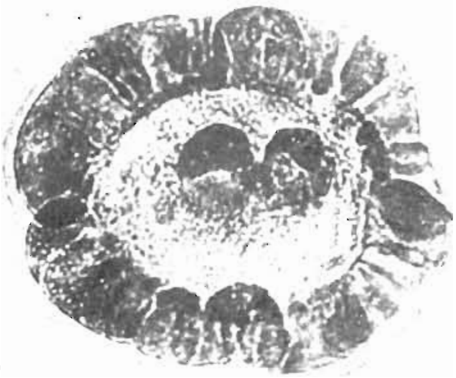

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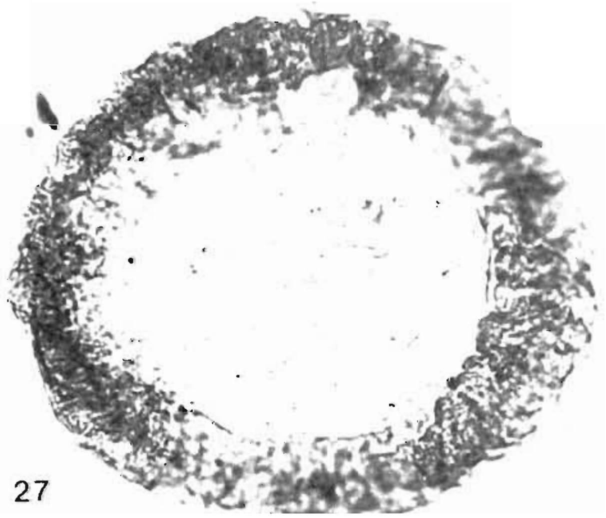

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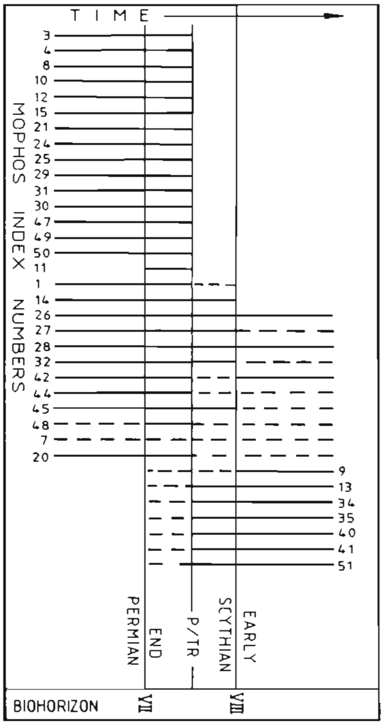
Figures 27-29—The branched-off morphos of **27.** *Parasaccites* out-group showing manifestations in the development of newer features in the exine character as seen in **28.** *Tuberisaccites*; and **29.** *Parastriopollenites* but the para-mode in body-sac attachment is retained.

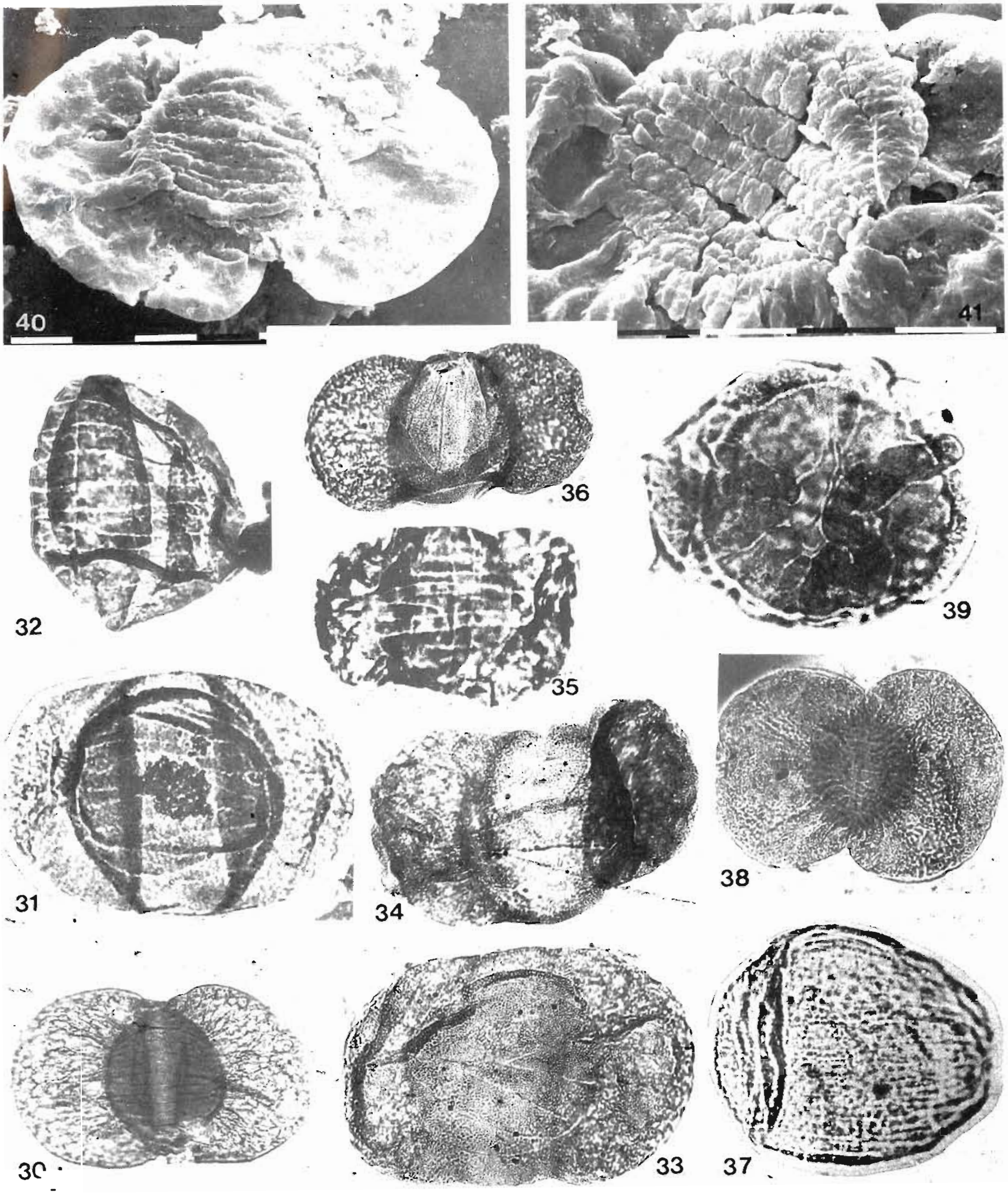
which dominated the Early Permian scenario. Virtually, the quantitative acme-zones of monosaccate pollen taxa cease at the end of Karharbari Formation (i.e., Biohorizon-IV), thus bracketing the Talchir and Karharbari palynofloras into one package, but the qualitative occurrence of monosaccates continues into the Barakar, whereafter they record a major decline (at Biohorizon-VI) and disaccates dominate the pupulation. The shift from monosaccate to disaccate domain and termination of several lineages of older sequence markedly denote a major change in the floral components delineating the Early and Late Permian epochs. The morpho-evolutionary trends in pollen group support the demarcation of Barakar and Kulti interformational boundary and also denote the Lower Permian-Upper Permian boundary.

Biohorizon-VII : *Lunatisporites-Playfordiaspora* Phase

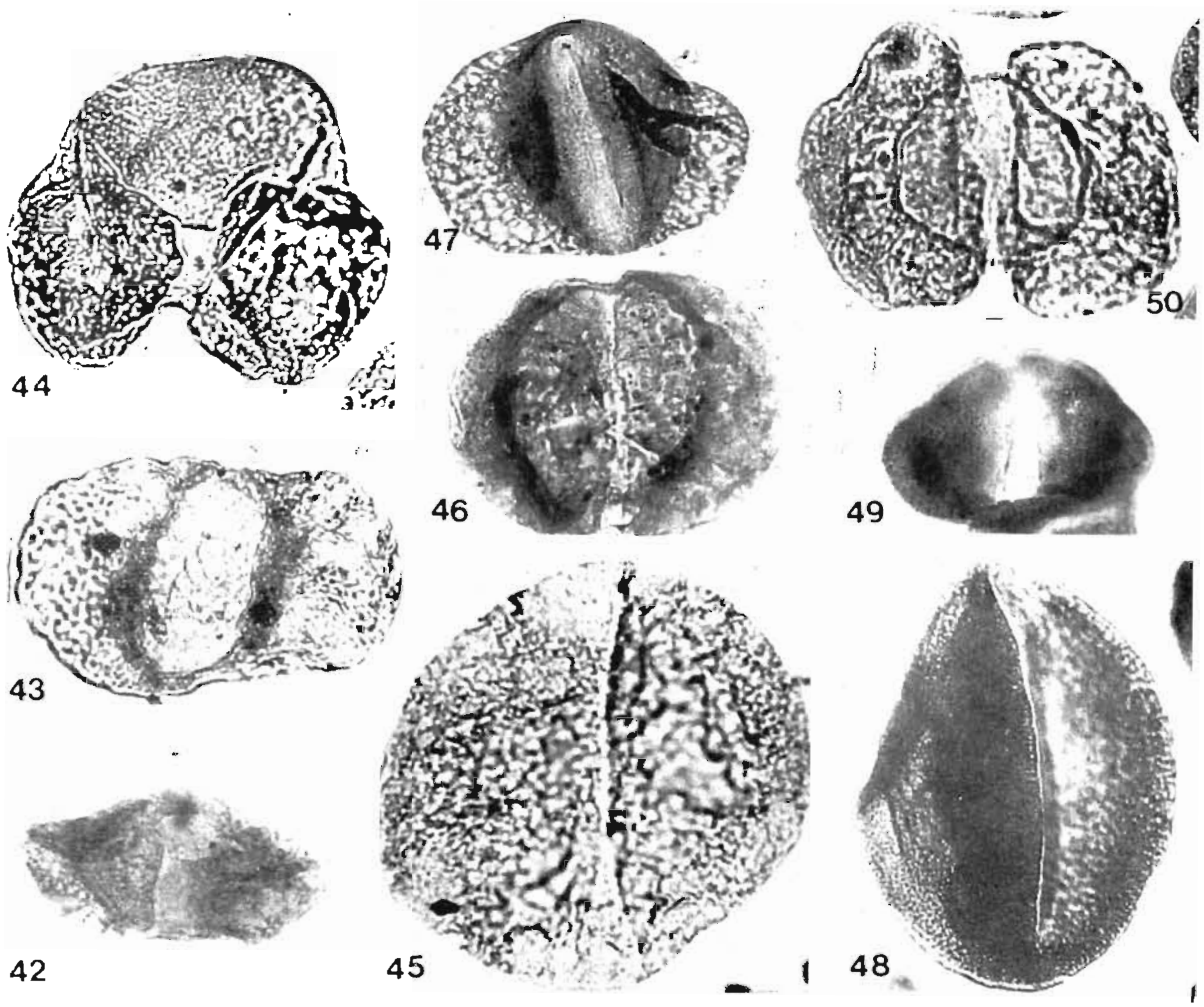
This biohorizon is identified by FAD of typical multi-taeniate pollen (Figures 58, 59). This new lineage has its form-relationship with bitaeniate stock of the Biohorizon-IV (Text-figure 1). Other entrants at this level are the monosaccates with several sexinal elevations on the cappa (*Goubinispora, Kamthisaccites*). Cladistically, *Goubinispora*-kind of morphos have their alliance with *Striomonosaccites*. The taeniate monosaccate organization has its maximum nearness to the *Virkkipollenites* stock; by way of minimum steps



Text-figure 7—Distribution of saccate morphos from end Permian (Biohorizon-VII) to Early Triassic (at Biohorizon-VIII) revealing the high degree of turnover at P/Tr boundary. Solid lines—consistent occurrence; broken lines—inconsistent and sporadic occurrence (MIN as in Text-figure 1).



Figures 30-41—*Crescentipollenites*-lineage (Fig 30) with its allied morphos The possible closely affiliated morphos of this tree is **31.** *Circumstriatites* experimenting a step towards joining the striation-ends to form a circum-striate pattern. Other morphos with varying combinations of ancestral and derived character states are: **32.** *Striasulcites*, **33.** *Faunipollenites*, **34.** *Striatopodocarpites*, **35.** *Distriatites*, **36.** *Striapollenites* Beside the horizontal and vertical grooves on body surface, a new line of experimentation, i.e. the non-linear pattern of the grooves is also observed which gives rise to a reticuloid pattern or its derived state, as seen in—**37.** *Tiwariasporis*, **38.** *Rhizomaspora*, and **39.** *Schizopollis*. Specimens under SEM to evaluate the nature of horizontal grooves in fig. **40** and vertical partitions in between the horizontal striations as in fig. **41**, bar 10 μm



Figures 42-50—Morphos of "*Pityosporites*" lineage: **42.** "*Pityosporites*", a stock for the out-group of disaccate pollen which has adapted diversified lines in morphography of nonstriate-disaccates as well as taeniate and clefted kind of patterns in exine character; **43.** *Vestigisporites*, first step from the out-group morphos in terms of evolution; **45.** *Scheuringipollenites*, the most simplified morphos—a combination of primitive (indistinct nexine) and advanced (absence of germinal mark and thinning of saccus-free-area) character states. Further adaptations in shape, size of sacci and their attachment with body is illustrated in Figures **46.** *Alisporites*, and **47.** *Satsangisaccites*. In **48.** *Brachysaccus*—the derived character state in exine structure having reticulate-columellate nature is a much advanced situation. In other characters, however, it seems to be distantly allied with *Scheuringipollenites* morphos. **50.** *Podocarpidites* shows a state adapted towards bigger size; the uniquely changed orientation of sacci is seen in figures **44** and **49**—*Samaropollenites* group of morphos, where the sacci become small and pendate.

these derivations can be achieved (Figures 15-17).

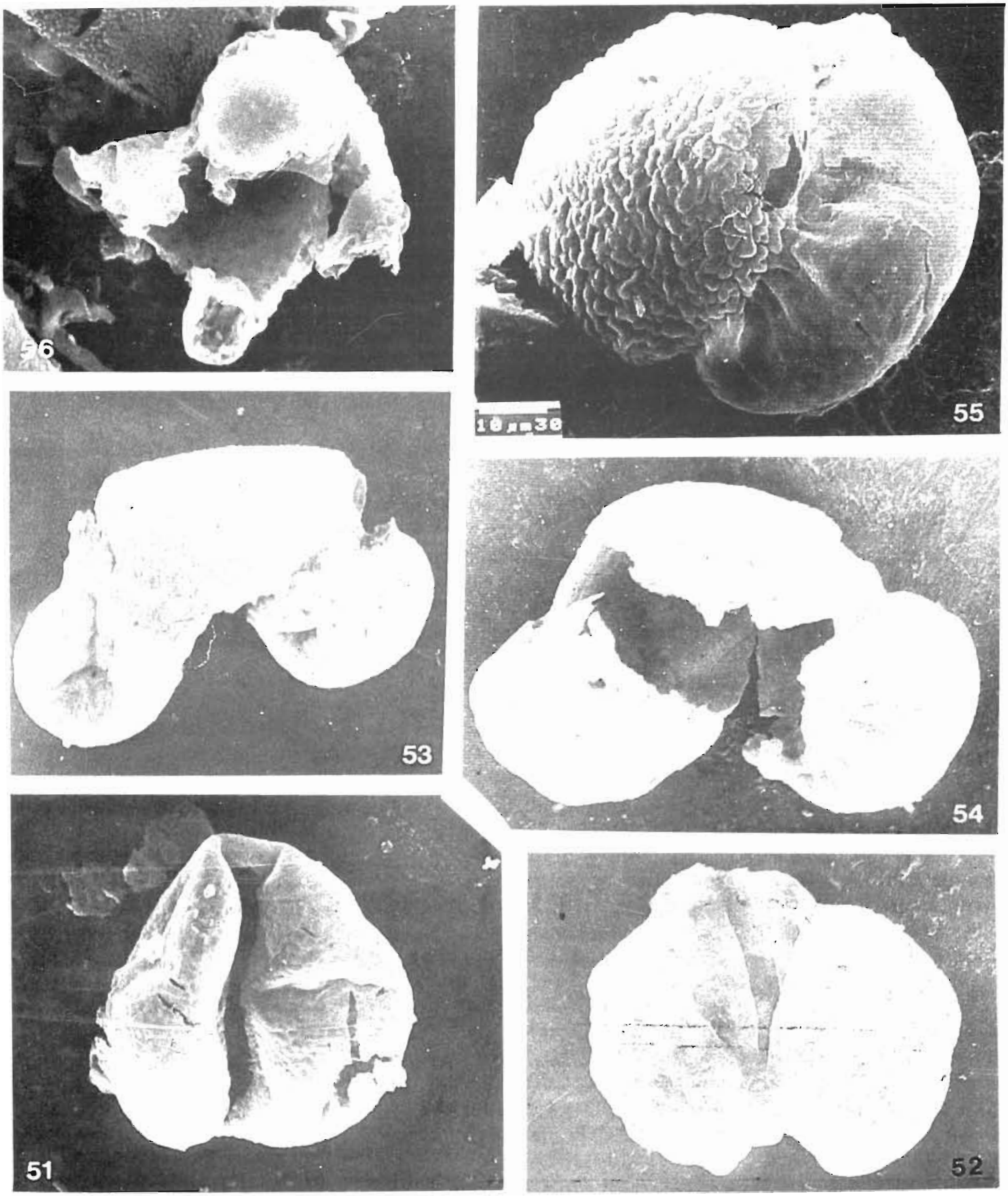
A unique organization, recorded for the first time at Biozone-VII, is represented in monosaccate pollen (*Playfordiaspora*, Figure 20) which does not have any intermediate linkage for its correlation with the older stock. The nature of saccus structure, its coverage over the body, and the presence of trilete mark may reflect a remote ancestral relationship with trilete monosaccate pollen of pre-Permian. The reappearance of such character states is baffling. Nevertheless, by way of comparison its affinity lies with *Virkkipollenites* (Figure 18).

Simple, disaccate, nonstriate pollen with individualistic features also appear at this line (*Klausipollenites, Satsangisaccites, Alisporites*; Figures 51, 46, 47). Cladistically the alete, nonstriate-disaccate lines of the Early Permian are the possible outgroups which are related at different temporal levels, with this group of pollen. The Biohorizon-VII is demarcated at the end of Permian horizon in the Indian Gondwana (Vijaya & Tiwari, 1987).

Biohorizon-VIII : Striate-disaccate extinction Phase

Between Biohorizon-VII and VIII several characters and some organizations of long-standing

Permian history met their extinction gradually (Text-figure 7). At the level of Biohorizon-VIII, forms with striations on both the faces of body, vertical partitions between horizontal striations, reticuloid striations, and pitcher-shaped saccus terminated completely from the scenario. The character state of



Figures 51-56—Morphos of *"Pityosporites"* stock under SEM showing modified nature of sacci in relation to their attachment to the body in disaccate as well as trisaccate forms **51.** *Klausipollenites*; **52.** *Satsangisaccites*; **53, 54.** *Samaropollenites*; **55.** *Podocarpidites*; **56.** *Podosporites*. Bar represents 10 µm in each figure

enveloping saccus, para-attachment of body-sac, and the monosaccate with reticuloid striations and circumsulcus also vanished from the population of saccate pollen. Thus, all radially and bilaterally symmetrical monosaccate or monosaccoid forms which had their spread in Early Permian disappeared at Biohorizon-VIII. Evidently the morpho-organizational turnover (sum total of dying-out and incoming forms) is very high at this level of time (Text-figures 1, 4).

The span of time between Biohorizon-VII and VIII has been identified as Permo-Triassic transition; based on many other parameters as well (Vijaya & Tiwari, 1987; Tiwari & Vijaya, 1992) the P/Tr boundary has been recognized between these biohorizons, precisely at the Raniganj-Panchet interformational boundary where steady occurrence of taeniate pollen and cavate spores begins.

The Biohorizons-VII and VIII resemble in several aspects of FADs and LADs with *Protohaploxypinus microcorpus* Assemblage-Zone (Late Permian) and the *Lunatisporites pellucidus* Assemblage-Zone (Griesbachian) of Australia, respectively (Helby *et al.*, 1987).

Biohorizon-IX : *Staurosaccites-Brachysaccus* Phase

There is a considerable gap in the data from the Indian Peninsula between the Biohorizon-VIII and IX, as sequential palynofloras are not yet known. However, the singularity of this zone is reflected in the record of some unusual organizations.

In nonstriate-bisaccate forms small sacci attached to a relatively bigger body (e.g., *Minutosaccus*; Figure 49) are recorded. A related disaccate with moderately developed distally inclined and laterally joint sacci (*Samaropollenites*; Figure 44) is also found. In another disaccate, the sacci are least inflated and remain adhered with the body inclining distally to mark a narrow sulcus (*Brachysaccus*, Figure 48). The transitionary stage of saccus structure in between the infrareticulate to infracolumellate nature is also reported in the latter two pollen groups (Dolby & Balme, 1976).

Another new lineage of disaccate pollen includes forms with cappa which is finely columellate and dissected into two equal halves by a sharp cleft, and little inflated sacci having similarity in structure with cappa (*Staurosaccites*, Figure 63). Further diversity is seen in the forms having two clefts but more inflated sacci resulting into diploxylonoid construction (*Infernopollenites*, Figure 62). By way of comparison, the clefted pollen share many character states with taeniate forms of older lineage. Therefore, cladistically this is the only probable relationship, but the clefted form had acquired a derived character of columellate structure in body exine as well as saccus. This is a significant step in the evolutionary sequence of exine characters observed at this datum which could have acted as progenitor of angiospermoid trends in sexinal structure.

The disaccates with small, pendate sacci are morpho-organizationally related with *Klausipollenites* stock. The *Brachysaccus* organization had its outgroup in *Scheuringipollenites* stock of nonstriate-disaccates but with a derived character of columellate structure in the sacci. Some radio-symmetric alete monosaccate pollen of indeterminate organization (referred to *Enzonalasporites* and *Pseudoenzonalasporites*) are reported from this biohorizon (Kumaran & Maheshwari, 1980). They could have some linear development in the younger strata also, but no evidence of well-studied forms is available.

In Australia, the FAD of *Staurosaccites* is at the latest Anisian level on the top of *Triplexisporites playfordi* Oppel Zone while that of *Infernopollenites* is at the earliest Ladinian level (*Staurosaccites quadrifidus* Oppel Zone). The assemblage containing the organizations typical of Biohorizon-IX in the Indian Peninsula makes its beginning at early Late Carnian and continues up to Early Norian (Kumaran & Maheshwari, 1980; Tiwari *et al.*, 1984).

Biohorizon-X : *Callialasporites* Phase

At this level a very significant morphography, viz., *Callialasporites* Complex, appeared in the lineages of saccate pollen representing an assembly of close-knit forms generally described as *Callialasporites, Tsugaepollenites, Cerebropollenites* and *Triangulopsis*—a group of subsaccate pollen (Sukh-Dev, 1961; Dettmann, 1963; Singh & Kumar, 1969). The sporadic but marked record of these subsaccate morphos, generally with granulose microsculpture on exoexine extended to form frilled or flat, continuous to tri-notched, vestigial or uninflated saccus, characterises this biohorizon (Figures 64, 67). No other significant morphology in the saccate pollen has made its beginning. On the contrary, a large number of organizations record their extinction; the older disaccates with striations, taeniae and clefts do not show at this level, so also the simple disaccate (*Klausipollenites*) group. The *Goubinispora* and *Playfordiaspora* lineages also disappear. However, the diploxylonoid disaccate simple nonstriate pollen group (*Alisporites, Podocarpidites*) continues to survive. Evidently, the *Callialasporites* phase is remarkable in recording the extinction of the saccate pollen morphography of long standing which started at Biohorizon-VII.

The FAD of *Callialasporites* from the Indian Mesozoic sequence is from *Gliscopollis* Zone dated as Lower Jurassic, which overlies the *Taeniaesporites* Zone (Koshal, 1975; Ramanujam, 1987). In Australia, the definite FAD of *Callialasporites* is recorded in *Corolina torosa* Zone and dated as Hetinginian (Lowermost Jurassic).

Biohorizon-XI : *Podosporites-Dacrycarpites* Phase

Small pollen with three sub-hemispherical, distally subequatorially attached, pendate sacci and micro-granulate microrugulate to microverrucose sculpture on the body appear at the Callo-Oxfordian level represented by the Biohorizon-XI (Figures 55, 68; Text-figure 1). No other significant saccate pollen morphology has appeared. The *Callialasporites* and the simple non-striate-disaccate (*Podocarpidites, Alisporites*) type of organizations continue to prevail. The triwinged pollen complex makes its FAD at the Callo-Oxfordian level (Srivastava, 1966; Lukose, 1972). It has a form-similarity with triwinged pollen, generally identified as *Podocarpeaepollenites* (Figure 66), of the Upper Triassic (Kumaran & Maheshwari, 1980).

In Australia, *Murospora florida* Oppel Zone exhibits the first appearance of *Microcachrydites* group of triwinged pollen (Helby *et al.*, 1987); hence equation of this level to Middle Callovian is corroborated. There is no distinct alteration in the saccate pollen organization after the Biohorizon-XI, a trend which continues from Upper Jurassic to Lower Cretaceous.

INTERBIOHORIZON ZONES

The recognition of 11 Biohorizons leads to the delimitation of 10 Interbiohorizon Zones (Biointerval Zones, Biostratigraphic Interval-Zones, or Interval-Zones; Hedberg, 1976). In accordance with ISG, the names of these zones have been given after a taxon (distinctive morpho-organization in the present context), typical of the zone. It is not obligatory that designated taxon is confined to a particular zone.

Following is the brief characterization of each Interbiohorizon-Zone proposed here and illustrated in Text-figures 1 and 8.

1. *Potonieisporites* Interbiohorizon Zone

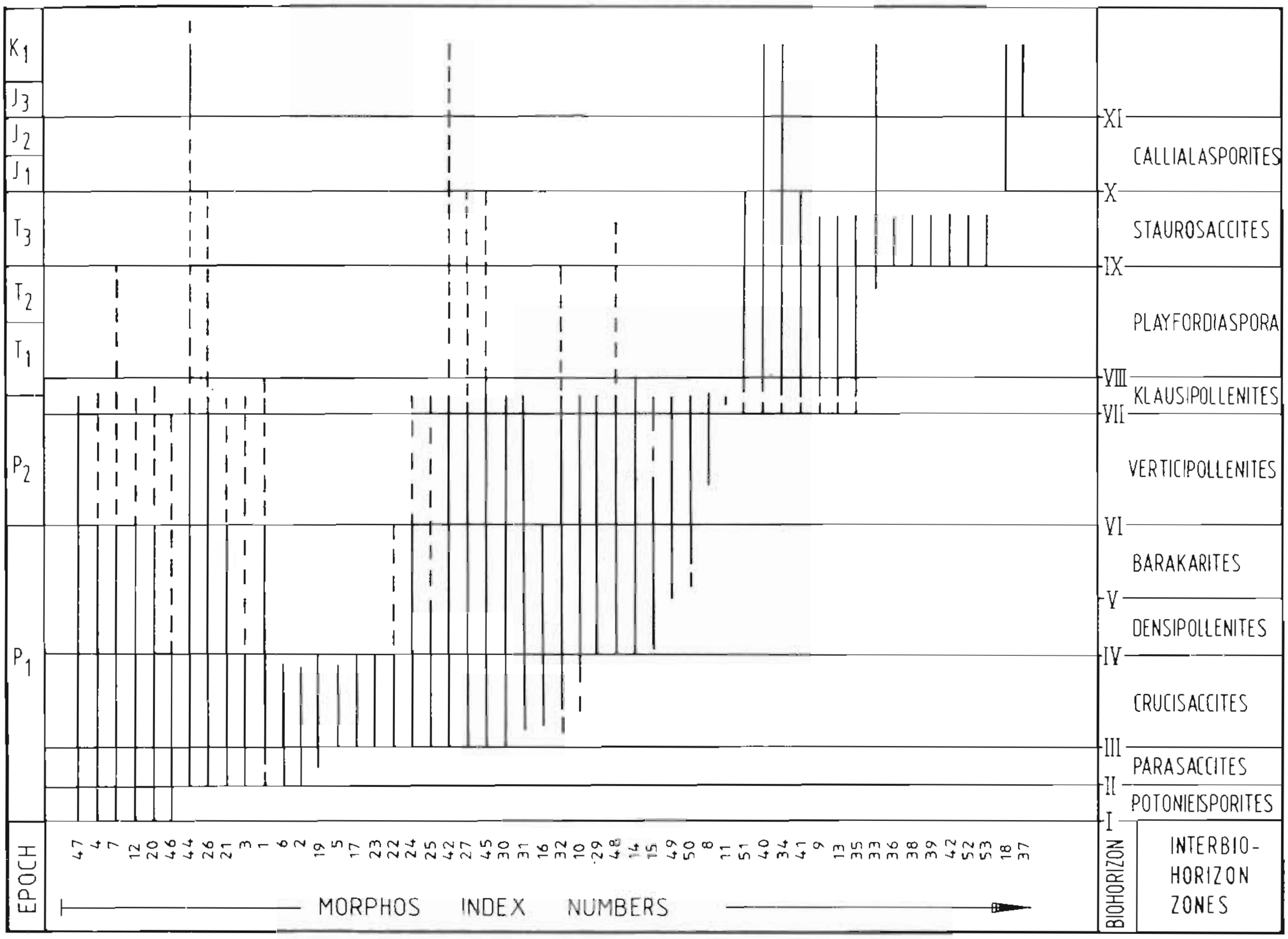
It is the oldest as well as the least diversified zone (between Biohorizon I and II) in the Indian Gondwana. It is represented by four elements of basic stock having monosaccate organization (*Potonieisporites, Plicatipollenites, Parasaccites* & *Virkkipollenites*), and a simple disaccate (*Pityosporites*). The forms with a vestigial monolete mark are also recorded but they make a related auxilliary group to "*Pityosporites*" (Text-figures 3, 5). The absence of striate-disaccate pollen is diagnostic for this zone. The subsequent younger Interbiohorizon-zones are progressively complex in their components. The present zone is equated with the lowest part of Lower Talchir Formation having Early to early Late Asselian age relationship.

2. *Parasaccites* Interbiohorizon Zone

The first appearance of striations on the body cappa of disaccate pollen marks the identity of this zone, i.e., between Biohorizon-II and III. *Parasaccites* is numerically dominated and diversified in organizations in the next younger zone. The striate group progressively diversifies at the top of this zone. Also, the new trends of evolution in the reduction of body curvature on distal face are seen; thus the double body-fold system in the body of monosaccate pollen *Potonieisporites* of older lineage has a morpholinkage with *Gondwanopollis* which has a single fold system in the same pattern; this circular body-fold system further acquires bilateral convex arrangement alongwith lateral axis indicating further change in distal surface area. The width of lateral continuations of saccus also reduces considerably. These lines are major trends of bilateralism with a path line towards the monosaccoidal bisaccate form (*Sahnites*) in having narrow lateral continuity, which in time disappears to give such a form with perfect disaccate configuration. From the preceding *Potonieisporites* Interbiohorizon-Zone, the present zone is distinguished in having the FAD of striate pollen and increased complexity in the morphos. The lithological sequence of Lower Talchir to lower part of the Upper Talchir Formation is represented in the *Parasaccites* Interbiohorizon Zone. In age relationship, this zone ranges from Late Asselian to Early Sakmarian.

3. *Crucisaccites* Interbiohorizon Zone

It is a zone between Biohorizon-III and IV. In this zone, maximum innovation and inflexion in the characters have been recorded among the basic group characters of the older stock. This zone spans from lower Upper Talchir Formation to the Upper Karharbari Formation, short of Karharbari-Barakar boundary. This means that in terms of morphographic evolution in saccate pollen there is a consistency of lineages from lower Upper Talchir Formation through most of the Karharbari Formation



Text-figure 8—Summary diagram to depict Inter-relationship of Biohorizons, Interbiohorizon-zones and stratigraphic distribution of morphos. Permian sequence inflated out of proportion (MIN as in Text-figure 1).

without appearance of any significant new morphography. The age relationship for this zone is indicated with Early Sakmarian to late Late Artinskian.

4. *Densipollenites* Interbiohorizon Zone

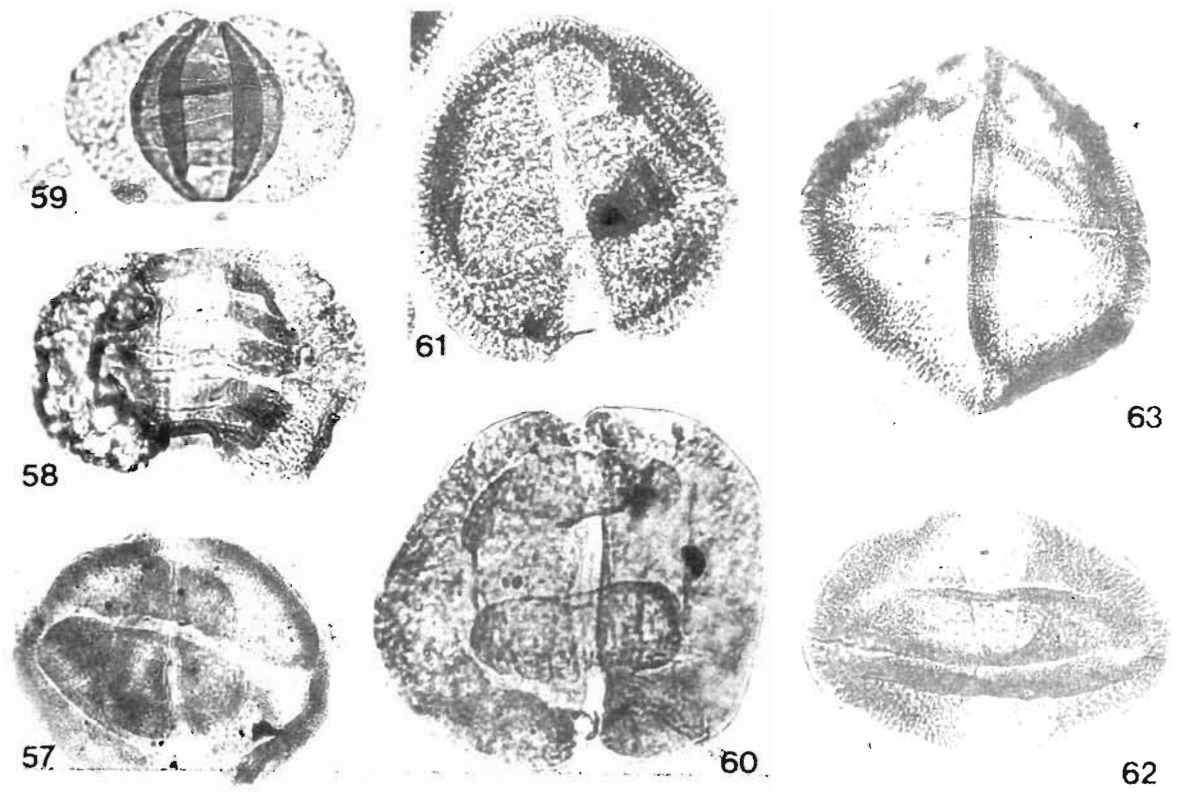
This zone is delimited by Biohorizon-IV at the base and V at the top. In the lithostratigraphic sequence, it represents a narrow span of the uppermost Karharbari Formation and the lowermost Barakar Formation. This is a significant transitional zone for demarcating the Karharbari-Barakar boundary and represents the Artinskian-Kungurian passage. The age relationship is suggested on the basis of lithostratigraphic comparisons with the control, levels. The absence of *Rimospora, Rugasaccites, Tuberisaccites, Pachysaccus, Stellapollenites, Distriomonosaccites, Corisaccites* and *Guttulapollenites* qualifies this zone to be distinguished from the adjacent lower and upper zones. The continuity of occurrence of several older morphos, particularly the monosaccates, characterize this zone.

5. *Barakarites* Interbiohorizon Zone

It encompasses most of the late Early Permian Barakar Formation and lies between Biohorizon-V and VI. The palynoassemblages contain a number of monosaccate lineages struggling from the preceding zones, which suddenly decline or become extinct at its top. The non-striate disaccates with simple organization (*Cuneatisporites, Platysaccus, Ibisporites* Group) also diversify within this zone. Qualitative sproutings have not been observed but quantitatively the characters have immensely diversified.

6. *Verticipollenites* Interbiohorizon Zone

This zone is demarcated by Biohorizon-VI at the base and Biohorizon-VII at the top. Except for the appearance of a rarely recorded character of sexinal protuberances on body surface (*Tumoripollenites*)



Figures 57-63—A line of experimentation in the off-shoot morphos of *"Pityosporites"* stock, is seen in **57.** *Corisaccites* possessing a combination of ancestral and derived character states, i e. exine sculptured but having thick sexinal bands, respectively The other morphos with micro-intrareticulate sexine but bi-taeniate; **60.** *Lueckisporites*, and the globular multi taeniate state in figure **61.** *Guttulapollenites* The most advanced state of multi-taeniate organization is represented by Figures **58** and **59.** *Lunatisporites* Other morphos illustrated here in Figures **62.** *Infernopollenites* and **63.** *Staurosaccites* represent mainly the congruence of derived character states in body exine nature (clefted and columellate).

in the later half of the zone, no new morphogrpahy in saccate pollen appears during the span of this zone. The entire zone represents Kulti Formation and most of the Raniganj Formation, except for the uppermost part of the latter. The older monosaccate stock dies out or declines considerably at the bottom of this zone. The younger elements of Triassic affinity mark the upper limit of this zone. This interbiohorizon-Zone represents most of the Upper Permian period and terminates at its end.

7. *Klausipollenites* Interbiohorizon Zone

This zone is a transitional passage between upper reaches of the Raniganj Formation (Biohorizon-VII) and the Lower Panchet Formation (Biohorizon-VIII). It encompasses the events which took place at the Permo-Triassic boundary. Striate-disaccates continue in this zone, but most of them disappear at its top level. The progressive increase in the newer types of nonstriate as well as taeniate disaccate morphos is the characteristic feature of this zone.

When viewed in totality of events in Gondwana Sequence, the *Klausipollenites* Interbiohorizon-Zone represents a period when major shift of organizations have been towards newer type of nonstriate-disaccates, in contrast to the monosaccates and striate-disaccates of the Permian time. Thus, the offset of lineage trees is the characteristic feature of P/Tr boundary.

8. *Playfordiaspora* Interbiohorizon Zone

The interval zone between Biohorizon-VIII and IX is regarded as a unique zone encompassing upper part of the Lower, the Middle and beginning of the Upper Triassic formations. The paucity of data does not allow a detailed analysis but morpho-evolutionary trends suggest a continuation of saccate forms which appeared at the P/Tr boundary. This is a phase of slow evolutionary alterations in morphographies of saccate pollen. From the older Interbiohorizon Zone, the present zone differs in the absence of major lines of the Permian lineages. So also in the younger Interbiohorizon Zone where several new lines appear

9. *Staurosaccites* Interbiohorizon Zone

It is a zone between Biohorizons-IX and X. The Upper Triassic (excl. Early Carnian of which data is not known) palynoassemblage is represented in the span of this interval zone. New morphographies, including clefted body and columellate exine structure, appear for the first time at the base of this zone. On the basis of available data it appears that the Rhaetic assemblage does not contain several of the forms which otherwise mark the Carnian assemblage (Koshal, 1975; Tripathi *et al.*, 1990).

10. *Callialasporites* Interbiohorizon Zone

This is an Interval-Zone between Biohorizon-X and XI. The singular organization of *Callialasporites* defines the starting point of this zone, while the appearance of triwinged *Podosporites* group demarcates its upper limit. Most of the saccate forms of this zone are simple nonstriate-disaccates, generally having diploxylon construction of sacci; they continue from the earlier Interbiohorizon Zone. The offshoot lineage of nonstriate-disaccate pollen of Biohorizon VII is wiped out from its base line. A complex unit of sub-saccate forms has been on record within this Interbiohorizon Zone. Random occurrence of striate-disaccates seems to be an indication of recycling.

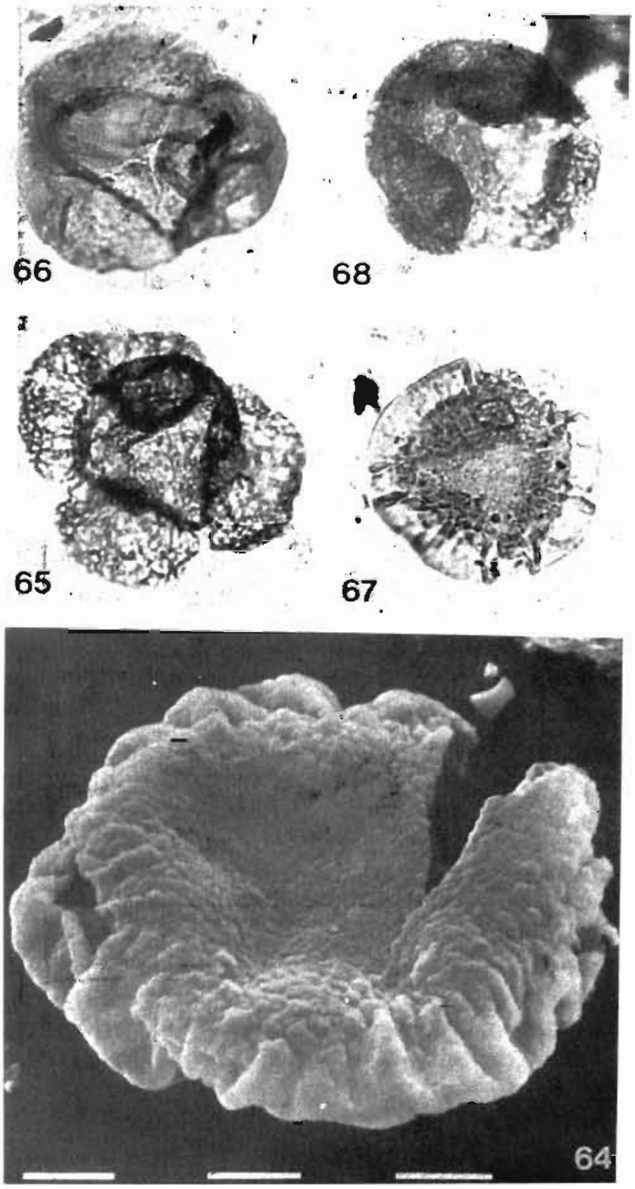
MORPHO-ORGANISATIONAL ALLIANCE : CLADOGRAMS AND STRATOGRAMS

The outcome of cladogenesis has been interpolated with the stratigraphic occurrence of each character states through Gondwana Sequence. After such a synthesis of cladograms and stratograms (stratigraphically arranged morphos forming the trees) the final picture crystalizes the biostratigraphic events.

Six basic organizations considered as the oldest stocks are discussed below for their morpho-evolutionary relationships. These stocks are subsequently represented in the form of individual tree, structured on the basis of data matrix given in Tables 3 to 6, which evidence the degree of morpho-evolutionary allinace among the ancestral and derived character states. The placement of related morphographies in these trees is made in terms of stratigraphic occurrences as well as synapomorphy (relative akinness).

Pre-Permian Lineage

The character state matrices given in Tables 3 and 4 clearly indicate that the ancestral character states are shared by six major lineages (Figures 2-7), as given in Text-figure 3. At the level Biohorizon-III, with reference to *Potonieisporites* type of organisations as the oldest lineage, the radiosymmetric monosaccate pollen with body-fold system (*Plicatipollenites*) are closer to it; while others (e.g., *Virkkipollenites, Parasaccites*) are



Figures 64-68—Morphovariants of mono-and di-saccate organizations, probably the transforming states to tri- as well as tetrasaccate forms having microreticulate exine structure as in **65.** *Tetrasaccus* and **66.** *Podocarpeaepollenites.* The morphos with retrogressive step in the character of exine and nature of saccus is represented by Figure **67.** *Callialasporties.* **64.** SEM of *Callialasporites* to evaluate granular pattern on body surface as well as non-structured state of the saccus; bar—10 μm. A triwinged morphos with shifted sacci root from the body equatorial position towards the distal body face as in Figure **68.** *Podosporites.*

relatively and progressively distant in relationship. The disaccates are still remotely related to the monosaccate block. They could have had a common origin because stratigraphically the simple disaccate morphos is older than the monosaccates—as per the present data.

The definite stratigraphic occurrences of these lineages (solid circles in Text-figure 3) indicate their relationship in Pre-Permian horizons of Australia and South America (Kemp *et al.*, 1977; Archangelsky & César, 1986). The oldest occurrence of *Potonieisporites, Plicatipollenites, Virkkipollenites* and *Parasaccites* organizational groups is from Early Namurian (base of *S. yberti* zone; Playford, 1985, p. 125) while that of "*Pityosporites*" is recorded in the assemblage of Anderson Formation; this assemblage is closely related with that of Lower Carboniferous Laural Formation (Balme, 1964, p. 56). The segment of cladogram (Text-figures 1, 3) in Carboniferous is incomplete and hence less parsimonious. Still the congruence of character states as well as their stratigraphical incidences support the topology proposed here.

On the basis of relationship pattern it is presumed that the oldest mother stock of saccate pollen was in existence in the Progymnospermopsida complex and through *Teichertospora*-type of organization (Figure 1) in Devonian (Balme, 1988; Mc-Gregor & Playford, 1990), various lineages might have arisen during the Lower Carboniferous. The palynofossils normally included under the Suprasubturma *Pseudosaccititriletes* Richardson 1965 seem to be the ancestral stock for the monosaccate pollen. Such a complex of diverse suite of trilete cavate miospores of this group, such as—*Auroraspora, Grandispora, Endosporites*, etc. in Lower Carboniferous (Viséan) of the Bonaparte Gulf Basin, north-western Australia, has been recorded by Playford and Satterthwait (1988).

The progymnosperms are a group of vascular plants intermediate in morphology and age between Early Devonian pteridophytes and seed plants of Late Devonian and later ages (Stein & Beck, 1987). The prominent nature of the tetrad mark in these basic lineages up to the level of Asselian-Sakmarian is a continuation of prepollen character of pteridosperms (in broad sense including Glossopteridales) and Cordaitales. It is interesting to note that the trilete mark in the same group of pollen becomes almost vestigial in the younger strata.

Potonieisporites-lineage

Taking this lineage as a trunk of the morphostratigraphic tree in the form of a stratogram at Biohorizon-II, the maximum character states of this stock are shared by three forms (Figures 8-11; Text-figure 1). The possible branching of *Potonieisporites* tree has occurred with in the time span of Late Asselian to Early Sakmarian and its flourishing period lasted only up to the end of Lower Permian Barakar Formation.

The palynomorphs normally included under the Suprasubturma *Pseudosaccititriletes* Richardson 1965 seem to be the ancestral stock for radiosymmetric building plan of *Parasaccites, Plicatipollenites* and *Virkkipollenites* trees; the *Potonieisporites* lineage is a branched-off line from the original plexus (Figures 1, 2).

Plicatipollenites-lineage

By way of determining the assembly of comparable character states, two forms (*Rugasaccites* and *Rimospora*) appear to have close relationship with the *Plicatipollenites* trunk. Although *Rugasaccites* is a closely related branch with the main lineage, it shows one primitive character state of rugate exine sculpture which is a retrogressive step in the course of evolution. *Rimospora*, on the other hand, is a step ahead in having derived character states of bilateral symmetry and incipient grooving on the body surface. This corroborates with the stratigraphically younger appearance of this form (Figures 12-14; Text-figure 1).

The branching of the *Plicatipollenites* tree has taken place during the Late Asselian to Early Sakmarian period and lasted up to the early Late Artinskian; however, the elements of *Plicatipollenites* continued impressively up to the top of Lower Permian Barakar Formation, thereafter it dwindled and disappeared at P/Tr boundary.

Virkkipollenites-lineage

With *Virkkipollenites* as out-group morphos, this lineage seems to have branched off into affiliated comparable forms with derived character states. The deviations in characters took place later in the sequence. The important shoots of relationship are connected with the forms having striations (Figures 15-17). The futuristic organization of enveloping saccus also seems to be linked with the main trunk of the tree. These events have taken place at transition phase encompassing Late Artinskian to the earliest Kungurian time (Figures 18, 19).

The next event, supposed to be allied with this tree, had occurred at the latest Permian (Biohorizon-VII) where newer characters of body and saccus have come into being, although the basic organization remained the same. A 'singular form

(*Playfordiaspora*) with zona-like thin reticulate saccus, a trilete mark and the coverage of saccus on body could be remotely connected with the main tree, as some characters had ancestral affinity in this taxon. Parsimonically, the *Virkkipollenites*-lineage seems to be the best suited stock of relationship for *Playfordiaspora*. The organizations which sprouted from this lineage at P/Tr boundary transition continued up to Upper Triassic (Figures 18-20; Text-figure 1).

Parasaccites-lineage

The tree of *Parasaccites* affinity attains a maximum diversification of new morphographies among all groups of monosaccates. The para-condition of saccus attachment remaining a principal character state, eight new forms have branched-off from this lineage, most of which appear in Early Sakmarian (Biohorizon-III). This tree flourishes with its branches up to the end of Artinskian where four of the unique lines disappeared; the other continued up to the close of Early Permian. The only trend which persisted into Late Permian is that of the monosaccoid bisaccate configuration—a derived character state (Figures 21-29; Text-figure 1). The *Parasaccites* tree is the most dominating factor in the Lower Permian Sequence; it loses its grip by the end of Lower Permian Barakar Formation, although stray branches struggle to continue up to P/Tr boundary.

Crescentipollenites-lineage

The above described four trees, comprising monosaccate organization stand apart from the two trees of the disaccate pollen. The first occurrence of striate-disaccate, with lunar folds at the sacci roots on distal face of the body, at Biohorizon-II, heralds an event of great significance of a distinctive morphology.

At Early Sakmarian Biohorizon-III, most of the relation-branching in this lineage had sprouted. Subsequently, this complex ramifies to give rise to some more evolutionary lines up to Biohorizon-IV. In totality, the striate complex predominates the scenario from Early Kungurian to P/Tr boundary. The major thrust of *Crescentipollenites* tree gets denuded by Scyathian (Tiwari & Singh, 1986) yet few straddlers continue till Liassic (Koshal, 1975)—see Figures 30-41 and Text-figure 1.

Pityosporites-lineage

The term "*Pityosporites*" used here has no conservative taxonomic connotation in the present context; it represents a stock of simple disaccate pollen architecture without striations. The genus *Vestigisporites*, also recorded from the lowermost Talchir is considered to be the branched-off lineage from the *Pityosporites* main tree at an older level. The suspected vestigial scar in the *Pityosporites* recorded from Anderson Formation (Balme, 1960; pl. 5, fig. 35) supports this contention. The FAD of this morphos predates the occurrence of monosaccate stocks. Analysis of the data reveals that there seems to be a convergent point of relationship between simple disaccate and the monosaccate organizations in the Lower Carboniferous, as shown in Text-figure 3.

The tree with "*Pityosporites*"-type of organization in a broader aspect of construction and in course of time has given rise to a line of relationship at Biohorizon-I (late Early Asselian) into a pollen with monolete slit on the proximal face of the body. As stated earlier, the "*Pityosporites*" form of Carboniferous (Figure 42), in all probability, possesses a vestigial linear thinning, which could be an outgroup character of ancestral state in this lineage.

The alterations in sacci shape towards haploxylon and indistinct nexinal differentiation define a group (*Faunipollenites, Scheuringipollenites*) at the base of *Crucisaccites* Interbiohorizon-Zone, which had maximum characters sharing with the main trunk (Figure 43; Text-figure 1). The origin of taeniae is an event of great morpho-stratigraphic significance. By assembly of character states, the taeniate pollen have a close relationship bondage with the nonstriate-disaccate tree. Such forms make their appearance at Late Artinskian-Early Kungurian. The further manifestation of these derived characters had taken place at the close of Permian where multiple taeniate forms are recorded for the first time (Figures 57-61).

The clefted and columellate character states (*Infernopollenites, Staurosaccites*) which are much advanced with relation to the taeniate pollen of this tree, appear at late Early Carnian. Cladistically, however, these forms share maximum character relationship with bitaeniate pollen (Figures 62, 63; Text-figure 1).

The main trunk of the simple disaccate morphos is further related with a prime group of similar forms with, of course, variable individualistic features, which appeared at the Permian-Triassic transition zone. This complex persisted during the whole span of Triassic. The other allied forms which joined these branching pattern at the late Early Carnian acquired some of the advance character states in their morphography (e.g. reduction of size and transitional columellate structure in sacci.

During Jurassic and into the Lower Cretaceous, only a few of the nonstriate-disaccate morphos—mainly diploxylonoid, continued to occur. At Callo Oxfordian time plane, a triwinged organization with a shift of sacci roots on distal side from the equator and a recurrence of ancestral character states (sculptured body) emerges (Figures 64, 67, 68). In view of common trend in character states, these younger triwinged morphos had a relationship with *Podocarpeaepollenites* type of forms (Figure 66) of Carnian age (Kumaran & Maheshwari, 1980; pl. 9, fig. 13).

From a glance at the "*Pityosporites*" lineage it becomes evident that except for taeniate branching no new morphographies had appeared up to the latest Permian. The tree of striate-disaccate complex flourished during Permian while the nonstriate-disaccate lineage offsets it in prominence at the P/Tr datum and continued till close of the Gondwana.

DISCUSSION

Primaeval outgroups

The oldest six morphographic stocks of saccate pollen in the Gondwana Sequence of India, when cladistically extrapolated for their lineages, anchor their primaeval outgroup in the Carboniferous of Australia (Text-figures 1, 3). But evidences and opinions differ regarding the dating of various palynological zones in the Upper Carboniferous of Australia (Balme, 1964; Kemp *et al.*, 1977; Playford, 1985; Gilby & Foster, 1988; Foster & Waterhouse, 1988; Cooper, 1991).

The Lower Carboniferous assemblage from Po-Formation of Tethys Himalaya (Khanna & Tiwari, 1983) does not contain any saccate pollen so also the Viséan assemblage of Australia. The *Grandispora maculosa* Zone (Kemp *et al.*, 1977) of Late Viséan to earliest Namurian age (brachiopod control) contains exclusively Early Carboniferous palynotaxa (*Grandispora, Auroraspora, Anabaculites yberti, Raistrickia, Hymenozonotriletes*). No such palynoflora is on record from the Indian Peninsula. In the subsequent younger zone, i.e., *Spelaeosporites (Anabaculites) yberti* Zone (Early Namurian), additionally nonstriate-disaccate pollen make their humble appearance. However, Foster and Waterhouse (1988) recorded striate pollen as well, and if this be accepted, the absence of striate-disaccate in Stage 1 of Australia still remains intriguing because Stage 1 is younger to the *S. yberti* Zone. The arguments putforth by Foster and Waterhouse (1988, p. 143) that Stage 1 is probably a facies controlled palynoflora and hence the striate-disaccates are absent; this needs further verification because similar situation has been recorded in *Potonieisporites* Interbiohorizon proposed here.

The Stage 1 Assemblage has more akinness with the Early Asselian Talchir palynoflora (*Potonieisporites* Interbiohorizon) rather than with the Early Namurian *S. yberti* assemblage. Yet the pattern of diversity of forms in Stage 1 suggests that the monosaccates might have their ancestry in Late Viséan/Early Namurian time-transition. Obviously, Stage 1 has a greater bond of age relationship with Early Permian rather than the Carboniferous. In view of this Permian affinity of Stage 1, it is indicated that in Australia the succession between uppermost Namurian to Asselian could be incomplete.

Biostratigraphy and cladistics

The record of sedimentary deposition is, no doubt, incomplete and recognised or inferred hiatuses exist at several levels in the Gondwana Sequence. In order to minimize the blurring effect of discontinuity of strata on the changes that had occurred in pollen morphography, the gross organizations and basic exine characters (morphos) have been taken as units for alliance determination. The major innovations and appearance of newly derived character states tagged with stratigraphic sequence have revealed eleven definite datum lines—termed as Biohorizons. These levels, in terms of saccate pollen morphography, represent important events. At places these morpho-evolutionary biohorizons precede the lithostratigraphic boundaries as if they foreshadow the incoming change in the whole set-up (e.g. Karharbari/Barakar, Raniganj/Panchet boundaries). Ten Interbiohorizon Zones delimited on the basis of eleven Biohorizons record the floral changes in the Gondwana Sequence. These zones and the biohorizons are important reference units for correlation. The FADs, LADs and diversification of characteristically identifiable morpho-evolutionary groups in saccate pollen are implicitly reliable parameters of precision in correlation and age connotation.

The viability of the proposed zonations and biohorizons in stratigraphy is reinforced by cladistic analysis. The character polarity is based on primitive (ancestral) and advanced (derived) states in each pair. These terms are relative expressions and could have a stratigraphic bias. Nontheless, stratigraphy has been taken to be a dependable guide in deciding the character states because the richness of sequential palynological data available for Gondwana of India has lessened the pit-falls of stratigraphically biased polarity.

In terms of polarity of a character state, the present observations have revealed that distinct proximal germinal aperture (trilete, monolete) and lack of distal sexinal thinning (sulcus) are the ancestral character states. This fact is collated with the older stratigraphic occurrence of these features in comparison to the vestigial mark and thinning of distal sexine in younger sequences, which are derived characters. At Biohorizons I, II and III, the forms *Plicatipollenites, Potonieisporites, Parasaccites* and *Sahnites* possess prominent proximal aperture with well-defined labra and vertex, suggesting their functional nature for germination. This character transforms into a vestigial imprint in the subsequent biohorizons. Similar is the behaviour of the distal saccus-free-area in these pollen; it is a structured sexinal layer in the older sequences. In younger horizons it ultimately becomes unstructured.

The distinct germinal mark and clearly structured distal sexine of the body are the prepollen characters (Mapes & Rothwell, 1984; Kerp *et al.*, 1990). As other Late Palaeozoic conifers produced prepollen (Clement-Westerhof, 1984), it is probable that most of the early saccate pollen with a prominent proximal aperture, were prepollen as well as zoidogamous rather than siphonogamous.

Innovation, evolution and extinction

The massive glaciation of early Lower Permian, the time of Talchir sedimentary deposits, had its history in the Carboniferous glaciation of Australia. The wide-spread ice sheets generated intensive cooling and left little open space for the growth of vegetation during Lower Talchir. In this climatic set-up the five types of stock organizations in saccate pollen were found, which vouch for reduced diversity in the organizational architecture at Biohorizon-I.

The lower part of Talchir experienced a sustained period of refrigeration resulting into extremely stressing condition. This invoked the force of evolution to generate enormous newer morphographies in younger horizons by the level of Biohorizon-III (Text-figure 5). Although the glaciers had yet not completely retreated, as recorded in Jayanti and West Bokaro coalfields, they had melted away to a greater extent to leave wider habitat areas for plants. It provided a platform for radiation in morphography and inflation in species output at the close of Tālchir, at Biohorizon-III. It was a great event in the evolution of morphography of pollen, which is collated with Early Sakmarian (Text-figures 4, 5). The climate continued to ameliorate in the subsequent time, and the morpho-lineages flourished. There is an evidence of cooling down of the climate at the proximity of Biohorizon-IV (Bharadwaj, 1975; Mitra, 1988). There is no evidence of mass extinction at second cooling phase of Upper Karharbari but definitely some bizarre organizations (*Rugasaccites, Rimospora, Stellapollenites, Gondwanopollis, Crucisaccites*) met their extinction. Thus it may be termed as a regional extinction, as defined by Donovon (1988), in terms of episodic and fast termination of few morphos in a broad area.

This event is again followed by incoming of new organisations (*Barakarites, Densipollenites, Lueckisporites, Distriatites*) which provide evidences for one more step in the course of evolution; the Biohorizon-VI again experienced a regional termination of long standing lineages (*Potonieisporites, Caheniasaccites, Parastriopollenites* and *Divarisaccus*).

The cool-loving morphos of older sequence are either terminated or their overall impact is highly attenuated, and this event is connected with a change in climate which was warmer and drier during the Kulti Formation (Text-figure 6). The seasonality in climate is apparent in the latter because striate disaccates immensely diversify.

In the Upper Permian, from the Lower Permian-Upper Permian boundary till the end Permian, the process of evolution has been slow as no new organizations have come into being. The statis nature of evolutionary changes during this vast period is reflected in the monotony of assemblages in the coalseams of Barakar and Raniganj formations.

Two important phenomena were observed during the Upper Permian—one, protracted and gradual extinction of straddling monosaccates and two—increase in the numerosity of striate disaccate pollen. The influence of warm and increasingly humid climate during most of the Upper Permian is thus reflected in the morpho-evolutionary trends of saccate pollen.

The end Permian Biohorizon-VII marks the innovation of new characters (Text-figures 4, 7), which continued into the Triassic; this event is followed by a line of episodic, fast extinction of numerous morpho-lineages (Biohorizon-VIII) so that most of the major trees terminated and only few new offshoots captured the scenario in younger horizon, till Biohorizon-IX. The P/Tr boundary lies between the closely placed Biohorizon-VII and VIII (*Klausipollenites* Interbiohorizon-Zone). The turnover of forms is very high at this level as depicted in spread diagram (Text-figure 7). But the end Permian mass extinction, the greatest crisis to effect the marine biota for which several causes have been discussed (Maxwell, 1989), is not reflected in the patterns of saccate pollen occurrence. The extensive regression of Late Permian sea must have caused the greater continentality which induced drier climate than the Permian resulting into the high turnover of plant species.

Recently Stanley (1984, 1988) has emphatically suggested that the frigid condition of poles resulting into the cooling of continental margins must have spread the cool temperatures from high latitudes towards the equator in Upper Permian. Such a situation could have triggered a high degree of extinction of forms in the end of Permian. Palynologically there are indicative evidences of cooling of climate in the Upper Permian, more so in Godavari Graben (Srivastava & Jha, 1988). This is concluded on the basis of increased frequency of *Parasaccites*, a cool-loving taxon primarily associated with glacigene sediments of Early Permian Talchir Formation. The continuance of this cooling effect is indicated across Permo/Triassic transition as reflected by the fair occurrence of *Callumispora* (Bharadwaj, 1975; Bharadwaj & Tiwari, 1977). The subsequent time in Upper Panchet (Biohorizon-VIII onwards) has again experienced warmer and drier climatic condition which is reflected in red bed formations. The proposition of Stanley (1988), in general, supports the pattern of spore-pollen extinctions due to cooling at P/Tr boundary and thereafter by an immense warming.

At Biohorizon-IX again the post P/Tr lineages modified to give rise to several new morphos (Text-figure 1) with totally novel characters which reflect a relationship to the angiospermoid characters in sexine structure (incipient columellae). These Carnian-Norian off-shoots remained on scene for a short time and were out at the end of Norian. This could be correlated with Triassic-Jurassic boundary (Norian event, Orth, 1989, p. 61). With regard to various saccate pollen, the end Norian event is a high extinction level in which all the nonstriate-disaccates, taeniates and monosaccates of P/Tr origin and the weakened branches of striate-disaccate of the Permian affinity die out. Although the clefted and columellate forms of the Carnian also vanish from the scenario but they seem to have given rise to newer branches of columellate morphos.

At Lower Jurassic Biohorizon-X the amazing start of *Callialasporites* group is noteworthy because the recurrence of several ancestral character states (trilete mark, saccus covering on body, zona-like flattened saccus) are identified. Similarly at the *Podosporites-Dacrycarpites* phase, Biohorizon XI, the primitive character state of sculptured body exine reappears, which is a reversal of features in stratigraphically younger morphos.

The summary diagram of innovation and extinctions (Text-figure 4) reveals that there have been three peaks of maximum incoming of new morphos and two of extinctions. The Early Sakmarian sprouting is the most prominent maximal in the whole of Gondwana Sequence. The end Permian and Early Carnian sprouting maximals are immediately followed by extinctions, thus raising the turnover values of mophos at these two levels.

Biohorizons—the tie-points of stratigraphy

The morphographic organizations in pollen tagged with singular characters, i.e., morphos, are as good indicators of datums in terrestrial sequence as the faunal remains are in the marine strata. The pollen have additional credentials of numerosity, wider distribution leading to facies-independence and miracle material sporopollenin which make them "omnipresent" and suitable for preservation of finer characters. In effect, spore-pollen make a more practical and authentic tool than the other types of fossils. Generally, the long range of occurrences are taken as negetive point for dating reliability of pollen as compared to very short range in majority of animal fossils. This may be true for certain groups of palynofossils but, as is clear from the present study, there are several forms which have relatively short stretch of incidences, viz., *Stellapollenites, Crucisaccites, Rimospora, Rugasaccites, Tuberisaccites, Kamthisaccites, Brachysaccus, Staurosaccites*, etc.

When precisely identified and objectively determined the short-ranging taxa could be of great value. Above all, the FAD for morpho-organization groups in pollen are most effective parameters in stratigraphy, so also the mass extinction plane and high turnover datum can be easily demarcated with the help of the morphos. The major episodes in the evolutionary sequence of saccate pollen are discussed for their synchroneity with biochronological and lithostratigraphic datums.

The Biohorizon-II is a reliable datum as it is tagged with the Manendragarh palynoassemblage. Manendragarh marine fauna consists of well-studied bryozoa, brachiopods, lamellibranchs and gastropods. It is dominated by *Eurydesma* and its age is suggested to be late Early Asselian (Shah & Ghosh, 1977; Shah & Sastry, 1975). Recent studies of a rich fauna from Calytrix, in marine glaciogene sequence of Grant Formation, Australia (Foster & Waterhouse, 1988) have brought out a Mid to Late Asselian age for the strata, but the palynoassemblage of the same is highly diversified and it compares closely with the Biohorizon-III level identified here and dated as Early Sakmarian. However, in the

Calytrix palynoflora the lowermost sample (354 m) which is 50 m above the basal line of Grant Formation, yielded a least diversified assemblage mainly having apiculate trilete and monosaccates with *Protohaploxypinus* spp.; this level could be equated with Biohorizon-II of the present study.

The second important datum is Umaria Marine bed which is dated as Late Sakmarian (Sastry *et al.*, 1977) on the basis of productids dominance. However, no new morphos in saccate pollen have appeared at this level, hence no line of biohorizon could be identified. But in the sequence of Jayanti and West Bokaro coalfields, the Biohorizon-III has been demarcated. By comparison of totality in pollen-spore assemblages and on stratigraphic grounds (Chandra & Lele, 1980) the Umaria beds are taken to be younger to the Jayanti beds; hence Biohorizon-III represents a definite Early Sakmarian level.

The palynofloral assemblages recorded from the Intertrappean beds of Abor Volcanics from various localities in Arunachal Pradesh (Prasad *et al.*, 1989) are comparable to that of Upper Talchir, resembling to Biohorizon-III. The first volcanic flow in the Agglomerate Slate sequence in Kashmir also represents Sakmarian level (Kapoor & Shah, 1979) which is followed by an Artinskian flow below the Nishatbagh beds. These episodes of north-west and north-east India have apparently no deteriorating effect on the flora of the peninsula, because no mass extinction, as could be expected, has been recorded in the morpho-evolutionary sequence presented here (Text-figure 4).

The Permo-Triassic event is very well documented between Biohorizon-VII and VIII. The changing pattern of the sequence records innovation of forms at the end Permian level, extinction of older lineages at P/Tr boundary (Text-figure 7) and radiation of newer forms at Early Scythian level. There has been a high degree of extinction but newer forms have also come into being. The palaeontological datums (palynofossils, plant megafossils, estheriids) almost conicide with the Raniganj-Panchet interformational boundary (Tiwari & Vijaya, 1992). Thus with higher degree of confidence, the entrance of *Goubinispora, Playfordiaspora, Klausipollenites, Lunatisporites* and exit of *Densipollenites, Corisaccites, Distriatites* and *Verticipollenites* can be taken as biochronologic datum for P/Tr boundary.

The Biohorizon-IX stands for the well-dated Carnian. The assemblage from Tiki Formation is linked with the fauna consisting of *Unio, Tihkia* and reptilian remains like *Hyperodapedon, Parasuchus,* etc. In the present study well delineated Biohorizon-IX is characterised by the pollen having columellate exine structure and clefted body. The appearance of these morphos makes an event of evolution in itself.

The FADs of *Callialasporites* and *Podosporites* complex are linked with the Lower and Middle Jurassic sequence. The tie-point for these data is linked with the well known fauna of Lathi and Jaisalmer formations. Although the former is poor in vertebrates, the latter formation has rich and diverse bivalves, ammonoids, etc. (Krishna, 1987).

CONCLUSIONS

1. The events in evolutionary sequence of morphographies of saccate pollen found in the Gondwana formations are definite indicators of biochronological datums.
2. The FADs of new organizations, or LADs of older lineages, have led to identify eleven Biohorizons and consequently ten Interval-Zones through the wide span of Gondwana Sequence.
3. The cladistic analysis, based on ancestral and derived character states, has carved out the relationship clusters of morphos and the stratogram patterns which have emerged into a mosaic of morpho-organizational trees with their patterns of sprouting as well as off-sets through time.
4. The saccate pollen groups are more reliable for time plane identity than the nonsaccate spore-pollen because of their wider dispersal capabilities, and the stratigraphically linked character polarity is highly authentic since the Gondwana flora is intensively studied from oriented profiles representing wide geographic areas.
5. The Upper Talchir Formation experienced the peak activity of radiation in morphos because the intensive climatic stresses invoked the forces of evolution.
6. The P/Tr boundary zone was the biggest episode in terms of turnover of forms during the whole Gondwana Sequence.
7. The rate of evolution during Upper Permian was slow and so also in the post P/Tr boundary phase of the Triassic.
8. The congruence of character states and sequence of stratigraphic occurrences suggest that the glossopterid palynoassemblages of Early Permian in India had their roots in the Lower Carboniferous of Australia. The least diversified palyno-morphographies of earliest available strata of India had only six stocks which branched-off and sprouted into the

plexus of organizations in the subsequent Permian Period.

9. The Upper Carboniferous-Lower Permian gap in stratigraphy is indicated by the comparative assessment of palynodata and their outgroup relationship.
10. Morphographically, the prominence of well organized trilete and monolete mark, and that of a non-sulcoid distal saccus-free area on body in the monosaccate pollen of Talchir Formation make them probable candidate for prepollen representative, even at the Lower Permian level. The monosaccates could have had their main root of origin in the progymnospermopsida—mainly with a trilete mark and flabby flange characters which appeared during the Upper Devonian-Lower Carboniferous time.

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Marker Assemblage-Zones of spores and pollen species through Gondwana Palaeozoic and Mesozoic sequence in India

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Tiwari RS & Tripathi A 1992. Marker Assemblage-Zones of spores and pollen species through Gondwana Palaeozoic and Mesozoic sequence in India. *Palaeobotanist* **40** : 194-236.

Most of the palynozonation schemes so far proposed for the Gondwana Sequence of India are based on quantitative representation of spore-pollen genera. These proposals have limited value for interbasinal correlation. The present synthesis deals with a model for species-based stratigraphy. Palynologically well studied Permian and Triassic sequences in the Damodar Graben and Permian, Triassic and Cretaceous sequences in the adjacent Rajmahal Basin have been taken as key regions to establish the zonation scheme. Based on the FADs and LADs and totality of composition of selected species, twenty Species Assemblage-Zones have been recognised. The reorganisation of this data through computer has also resulted into the identification of thirty Species Acme-Zones.

Key-words—Palynology, Palynozonation, Stratigraphy, Palaeozoic-Mesozoic, Gondwana, India.

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साराँश

भारत के गोंडवाना पुराजीवी एवं मध्यजीवी अनुक्रम में बीजाणु एवं परागकण जातियों के सूचक समुच्चय मंडल

राम शंकर तिवारी एवं अर्चना त्रिपाठी

भारत के गोंडवाना अनुक्रम हेतु अभी तक प्रस्तावित परागाणुमंडल योजनाओं में से अधिक्तर बीजाणु-परागकण प्रजातियों के परिमाणात्मक निरूपण पर आधारित हैं। इन प्रस्तावों का अन्तरद्रोणीय सहसम्बन्धन मूल्यांकन सीमित है। प्रस्तुत संश्लेषण जातियों पर आधारित स्तरविन्यास के मॉडल से सम्बद्ध है। दामोदर द्रोणी में परमी एवं त्रिसंघी अनुक्रमों तथा राजमहल द्रोणी में परमी, त्रिसंघी एवं क्रीटेशी अनुक्रमों के परागाणविक अध्ययन के आधार पर मंडलन योजना विकसित की गई है। एफ-ए-डी० एवं एल-ए-डी० तथा छाँटी गई जातियों की समग्र संरचना के आधार पर 20 जाति समुच्चय मंडल बनाये गये हैं। इन्हीं आँकड़ों को कम्प्यूटर द्वारा पुनर्व्यवस्थित करके 13 जाति-एक्मॅ-मंडल प्रस्तावित किये गये हैं।

THE study of spores and pollen, dispersed in the Gondwana Sequence of India, dates back to nineteen-thirties (Virkki, 1937). During the last five decades enormous data has been generated on morphotaxonomy and palynostratigraphy (Venkatachala & Kar, 1970; Venkatachala *et al.*, 1972; Venkatachala, 1974; Lele, 1974; Tiwari, 1974a, b; Maheshwari *et al.*, 1978; Maheshwari & Jana, 1988; Tiwari & Tripathi, 1988). Identification of distinctive organizations and exine characters in spores and pollen has established the identity of Gondwana palynoflora (Tiwari & Vijaya, 1988). However, it is evident that the splitter syndrome in morphological delineation of species has resulted in the unwieldy growth of morphotypical population. Statistically based taxa could check this explosion. The former approach, to some extent, has added subjectivity to the application of palyno-species in stratigraphy.

For Indian Gondwana Sequence, the collage of distribution patterns of palynotaxa in temporal dimension had been proposed from time to time (Bharadwaj, 1970; Venkatachala, 1972, 1974; Chandra & Lele, 1980; Tiwari & Tripathi, 1988), but most of these zonation schemes are genus-based. These proposals had their importance in deciphering the increasing diversity and totality of vegetational changes through time. The epiboles of supra-specific taxa and the assembly of total constituents in palynoflora are bimodal expressions,

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the former representing an acme-zone and the latter an assemblage-zone. Such syntheses had their utmost value in depicting the changing palynological compositions through time and implicitly in stratigraphy. Nevertheless, the existing schemes in India have their limitations because the importance of percentage frequency of supra-specific taxa has been over-emphasized as a stratigraphic parameter. Such numerical abundance could have an ecological bias. So also, the generic assemblage-zones generally formulated for Indian stratigraphy could be useful as an environmental indicators but their value for inter-basinal correlations is limited. So far no effective analysis of spatial behaviour of these taxa has been attempted. Therefore application of generic epiboles as well as generic assemblages in stratigraphy needs a concerted effort for refinement.

The present attempt is a synthesis designed towards achieving species-based stratigraphy of the Indian Gondwana. This palynological model deals with the well-studied profiles of the Permian and Lower Triassic sequences of Damodar Graben for plotting the species occurrences, and the Upper Gondwana data from the adjacent Rajmahal Basin has been added to complete the span of time up to Lower Cretaceous. For comparative assessment of palynozones, the Mesozoic data from marine-tagged sequences of Kachchh, Rajasthan and Cauvery Basin have also been taken into account. The materials taken for the synthesis are listed in Table 1.

DATABASE

The basal datum for Gondwana Sequence is the classical Talchir Formation with marine fauna comprising eurydesma-productus-connularia groups. These glacial and fluvio-glacial deposits are dated as Early Permian (Asselian; Sastry *et al.*, 1977). The megaplant assemblage and the palynoflora support a Permian affinity rather than the Carbo-Permian aspect for the Talchir Formation (Venkatachala & Tiwari, 1988).

The history of the subsequent sequence is well documented in the thick series of terrestrial, fluviatile and lacustrine sediments (about 7 km in thickness) which span from Early Permian to the end of Early Cretaceous. The Glossopteris flora dominates the scene during the Permian Period. It declines considerably at the Permo-Triassic boundary wherein a new flora, viz., the Dicroidium flora, makes its appearance. The latter datum has been identified at the Raniganj-Panchet interformational boundary. This conclusion is supported by estheriids and palyno-stratigraphic studies (Ghosh *et al.*, 1988; Tiwari & Vijaya, 1992). The flora, fauna and lithology have been the major parameters for defining the stratigraphic units of the Mesozoic. Recent K-Ar dates (105 ± 5 Ma) for the Rajmahal traps have provided an anchor line of Aptian-Albian age (McDougall & McElhinny, 1970; Agrawal & Rama, 1976; Baksi *et al.*, 1987). This necessitated a revision of the earlier views. The

Table 1—The details of profiles/outcrops considered as database for the present study (also see Map 1)

HORIZON	COALFIELD/AREA	SECTION/BORE HOLE	REFERENCES
Talchir	West Bokaro Coalfield, Bihar	Dudhi River Section	Lele, 1975
Talchir	Hutar Coalfield, Bihar	Section in Deori Nala, Koel River, Behra Nala, Saphi Nala, Jhapidhora Nala	Lele & Shukla, 1980
Talchir	Jayanti Coalfield, Bihar	Section in Patharjore Nala	Lele & Karim, 1971
Talchir	Jayanti Coalfield, Bihar	Patharjore Nala section, Barisari Village	Lele & Makada, 1972
Talchir	Giridih Coalfield, Bihar	Suknid River, Karharbari Village	Lele, 1966
Talchir	Jayanti Coalfield, Bihar	Section in tributary of Patharjore Nala, Misra Village	Lele & Makada, 1974
Karharbari		Banskupi Colliery samples	
Karharbari Barakar	W. Raniganj Coalfield, Bihar	Sections along Sonbad Nala, Pusai Nala and Khudia Nala, Pusai Shampur area	Tiwari, 1973b
Karharbari	Auranga Coalfield, Bihar	Section in Gowa Nala, Gowa Village	Lele & Srivastava, 1980
Barakar		Sukri River Section, near Gurtur Village	
Kulti		Sukri River Section, near Rajbar Village	
Raniganj		Sukri River Section, near Tubed Village	
Karharbari	Giridih Coalfield, Bihar	Colliery samples and stream cuttings	Maithy, 1965
Barakar	West Bokaro Coalfield, Bihar	Colliery samples	Tiwari, 1965
Barakar	North Karanpura Coalfield, Bihar	Section in rivulet, at Badam Village	Venkatachala & Kar, 1968a
Barakar		Section in rivulet, near Pukra-Buruadeeh Colliery, Lungatoo	Venkatachala & Kar, 1968c
Barakar	South Karanpura Coalfield, Bihar	Colliery samples	Bharadwaj & Dwivedi, 1981

Contd.

Table 1—Contd.

HORIZON	COALFIELD/AREA	SECTION/BORE HOLE	REFERENCES
Barakar	Pachwara Coalfield, Bihar	Exposures along Bansloi River, near Bargo and Alubera, Bansoli Valley	Maheshwari, 1967
Kulti Raniganj Panchet	E. Raniganj Coalfield, West Bengal	B.H. RNM3 (23°35'45" : 87°13'55"), up to 930.00 m, Burdwan District	Rana & Tiwari, 1980
Kulti Raniganj	E. Raniganj Coalfield, West Bengal	B.H.RNM2 (23°35'30" : 87°12'30"), up to 657.00 m, Burdwan District	Tiwari & Rana, 1984
Panchet Mahadeva		B.N.RNM4 (23°34'30" : 87°13'03"), up to 107-135 m depth, Burdwan District	
Kulti	Jharia Coalfield, Bihar	B.H.JK5 (23°44'86"; 29'28"), 3,926 ft. deep, Dhanbad	Kar, 1968a
Kulti	North Karanpura Coalfield, Bihar	B.H.K5, 337.30 m deep, Baral-Raniganj-Kevendai area, Hazaribagh District	Kar, 1969a
Raniganj	W. Raniganj Coalfield, Bihar	Colliery samples	Bharadwaj, 1962
Raniganj			Bharadwaj & Salujha, 1964, 1965
Raniganj	North Karanpura Coalfield, Bihar	B.H.K2,352.57 m deep, Raniganj-Kavendai area, Hazaribagh District	Kar, 1969b
Raniganj		Section in river running across Lungatoo, Bukragaon Village	Kar, 1968b
Raniganj Panchet	E. Raniganj Coalfield, West Bengal	B.H. NCRD 660.00-352.40 m depth in Disergarh, Asansol Region	Bharadwaj & Tiwari, 1977
Raniganj Panchet	E. Raniganj Coalfield, West Bengal	Section in a tributary of Damodar River, near Saturbandh Village	Tiwari & Rana, 1981
Panchet Mahadeva		B.H.RD1, 532.48-600.58 m depth, near Durgapur, Burdwan District	
Panchet	East Bokaro Coalfield, Bihar	Dhardharia Nala Section, West of Jurwa Village	
Raniganj	Brahmani Coalfield, Bihar	Road section, Chaipani Village	Tiwari & Tripathi, 1984
Raniganj	Pachwara Coalfield, Bihar	Bansloi River section, near Tattitola Village	Mandal & Maithy, 1981
Panchet	Raniganj Coalfield, West Bengal	B.H.RE9 (23°40' : 87°20') 31.00-84.05 m deep, in Laudoha area	Kar, 1970
Panchet	Raniganj Coalfield, West Bengal	Section along north western branch of Nonia Nala, Burdwan District	Maheshwari & Banerji, 1975
Panchet		Section at Junction of Junat and Damodar River	Banerji & Maheshwari, 1975
Panchet	Auranga Coalfield, Bihar	Sukri River Section, 0.8 km from Kaima and 1.6 km South-west of Tubed	Banerji & Maheshwari, 1977
Dubrajpur Rajmahal	Rajmahal Basin, Bihar	B.H.RJR2, 884.25 m deep, near Kazigaon	Tripathi, Tiwari & Kumar, 1990
Rajmahal		Section exposed at Sakrigali Ghat and Basko	Sah & Jain, 1965
Rajmahal		Well Section near Mandro	Maheshwari & Jana, 1983
Lathi	Rajasthan	Well near Jaisalmer (26°54'30"; 70°57'00"), 1,257 ft deep	Srivastava, 1966
Jaisalmer		Well near Barragoan (26°51'30" : 70°11'00"), 965 ft deep	
Lathi Jaisalmer	Rajasthan	Well at Chhor Village (11°9'9" : 27°45'49"), Jaisalmer District	Lukose, 1972
Jhurio Jhamara Jhuran Bhuj	Kachchh	B.H. in Banni South of Paccham Island, 618.00-1,760 mm depth	Koshal, 1975
Jhuran	Kachchh	Pur River and Khari River Section, near Bhuj	Venkatachala, Kar & Raza, 1969
Bhuj	Kachchh	Pur River Section, near Trambau; Pat Section, near Bhuj	Venkatachala, 1969
	Kachchh	Section exposed in a pond, near Dayapar Village	Venkatachala & Kar, 1972

absence of Jurassic sediments from most of the terrestrial Gondwana has been advocated (Datta, Mitra & Bandyopadhaya, 1983).

The basic units of stratigraphy in the Indian Gondwana were initially identified on the basis of distinctive lithology, rich floras and sporadic faunas (Sastry *et al.*, 1977). In due course of time the biostratigraphic zones were identified and consistent efforts were made to tag them with lithostratigraphic units, particularly in the Lower Permian. However, in the younger sequence, the megafloral assemblages exercised main control for

Map 1—Map of India showing various basins from where data has been incorporated for the present study. **1**, Damodar; **2**, Koel; **3**, Deogarh; **4**, Rajmahal; **5**, Jaisalmer; **6**, Kachchh; **7**, Cauvery.

stratigraphy till the sixth decade of the present century. Thereafter, palynology was employed as an effective parameter for refining biostratigraphy.

In view of the differential history of deposition for each graben, and because of the lack of marine controls, chronostratigraphy on a precise international scale could not be established with a high degree of confidence. Nevertheless, the biostratigraphic zones have been fairly well-defined, some of which are regionally persistent and have broader time connotation. The megafloral biostratigraphy has limitations of preservation and numerosity of specimens. Therefore, palynology is a suitable discipline which can play a significant role in refining the biostratigraphy and in establishing a biochronological scheme for the Indian Gondwana.

Damodar Graben

The Raniganj, Jharia, Bokaro, Karanpura, Auranga and Hutar basins of the main Damodar Valley and Giridih and Jayanti basins of subsidiary parallel belt provide rich information on the distribution of spore-pollen species. These areas show classic development of basal glacigene Talchir Formation and subsequent Karharbari, Barakar, Kulti and Raniganj formations. The Karharbari Formation grossly resembles the Barakar Formation in its lithological attributes having substantial coal facies, although the former contains specks of needle shales in its sandstone units reworked from the underlying Talchir Formation. Floristically, the Talchir and Karharbari formations are bracketted together. In the post-Talchir succession the continuous pile of deposition having mostly coal-shale-sandstone suites, ranges up to uppermost Permian. The intervening Kulti Formation although contains coals, but the seams are not thick enough for exploitation, hence earlier it was termed as Barren measures. The beginning of Triassic Period is marked by the deposition of the coal-less Panchet Formation which in most areas conformably overlies the Raniganj Formation.

The Panchet Formation is characterised by khaki-green and red beds containing Dicroidium flora and vertebrate fauna of Early Triassic age (Sastry *et al.*, 1977). The deposition of Panchet Formation has witnessed a break in the Middle Triassic Period, followed by Supra-Panchet Formation of coarse conglomerate, ferruginous sandstone and red shales, which is supposed to extend up to Upper Triassic. After this sequence, the deposition ceased in the Damodar graben.

Rajmahal Basin

The data for the present study has been obtained mainly from subsurface of Rajmahal Basin (Table 1). The Permian and Lower Triassic history of Rajmahal Basin closely compares with that of the Raniganj Basin—except for some lithological variations and reduced thickness in the former. Following the deposition of Barakar Formation the litho-sequence was conventionally recognised as Dubrajpur Formation which was interrupted by the volcanic activity at its upper reaches. However, the Dubrajpur Formation has been now proved to range from Upper Permian to Lower Cretaceous (Tiwari *et al.*, 1984; Sengupta, 1988; Tripathi, 1989) both by palynological and plant fossil assemblages.

Kachchh

The Mesozoic Sequence in Kachchh is classified as Jhurio, Jhumara, Jhuran and Bhuj formations, ranging in age from Middle Jurassic (Bathonian) to Early Cretaceous (Albian—?Santonian). These formations are tagged with the marine fauna for their age (Biswas, 1977). The palynological details which are considered for comparison in the present study are from various outcrop sections representing, in part, Jhuran (Katrol) and Bhuj formations. Additionally, the data from wells in Banni and Nirona areas provide a complete reference succession from Late Triassic (Rhaetic-Liassic) to Early Cretaceous (Table 1).

Rajasthan

In Rajasthan, the Mesozoic sedimentary package has been defined as Lathi Formation and the overlying Jaisalmer Formation to which Early to Middle Jurassic age is assigned. The Lathi sediments are mainly arenaceous representing deltaic environment, while Jaisalmer sequence was deposited under marine environment (Narayanan *et al.*, 1961 *in* Lukose, 1972). Palynological details from two records (Srivastava, 1966; Lukose, 1972) provide the data-base for the Lower and Middle Jurassic which constitutes a reference succession for comparison with the main data.

BIOSTRATIGRAPHIC UNITS AND SPORE-POLLEN SPECIES

The International Subcommission on Stratigraphic Classification (1971, 1972, *in* Hedberg, 1976) defined the zone as a commonly used term to denote a minor stratigraphic interval in any category of stratigraphic classification. There are many types of zones depending on stratigraphic parameter. The biozone is one of such zones which represents the basic unit of biostratigraphic classification, it encompasses a body of rock defined or characterized by its fossil contents.

The biozones, in general, include four types of zones—Assemblage-Zone, Range-Zone, Acme-Zone, and Interval-Zone (Hedberg, 1976). For achieving high resolution in biostratigraphy these four major zones should be used in conjunction with each other. In other words, same strata can be handled in terms of more than one type of biozones. It may be more effective identification of datum if more than one zones coincide for the same succession in their lower and upper limits.

The present synthesis attempts to identify spore-pollen species assemblage zones (not in terms of species range-zones) based on the data available from one key region (Damodar-Rajmahal depositional domain). Presently, the range-zones have not been determined because of the geographically limited scope of the area covered under study. Also, the numerical abundance of each species is not yet known and hence the acme-zones of species cannot be objectively identified at the present juncture.

The utility of any system of biozonation is related with the number of events recognized in the given sequence of sediments. The more such levels are established in geographically wide area, the higher is the stratigraphic resolution. This is all the more important because each kind of zonation system has some lacunae (Schoch, 1989). Keeping this in view, the same data on species distribution in the Permian, Triassic, Jurassic and Lower Cretaceous has been handled here in two different combinations to sift maximum information for recognition of datum planes, viz., species assemblage-zones and epibole of number of species in individual genus. The presently proposed assemblage zones, based on the occurrence of spore-pollen species, have been identified after a multi-tier sieving and reshufling of data. To start with a thorough scanning of the published literature from the areas under consideration was done and all the species in each area were listed according to their stratigraphic occurrences. After scrutiny of synonymy and nomenclatural validity the species were shortlisted. Those morphotypes which were based on poorly preserved specimens or possessed little distinctive characters were rejected. Further sieving of the composite data was done to discard most common and very long-ranging species and apparent variants.

The zone-types which now emerge from the stair-case arrangement of species against the lithostratigraphic column, as achieved by sorting through LOTUS package, are the Assemblage Zones. They represent distinctive natural assemblages of most of the principal spore-pollen species. The practicability of the assemblage zone lies in the fact that for any particular zone it is not essential that all the defined elements need be present in order to assign the strata to the assemblage zone. As mentioned earlier in the text, an assemblage zone is largely an indicator of environment but at the same time it is also a general pointer of geological age. The species-assemblage-zone has a defined age connotation as compared to the generic assemblage zones because the species change faster than the genera on the evolutionary path. As depicted in Table 2, the name of each assemblage zone is derived from the prominent and diagnostic constituent species normally found in the said zone. Although the stratotype designation is not mandatory, it has been cited here, as far as possible, in accordance with the recommendations of the International Stratigraphic Guide.

From the rearrangement of the same data, another type of zones—the acme-zones, have emerged in which case the species are grouped together according to their generic affiliation (Table 3). Normally the acme-zones are defined to be based on abundance or development of certain forms. There are two ways to define the abundance or development, one in which the frequency of specimens of a certain species is the highest, and the other in which the number of species within a genus reaches the maximum. As stated above, since the percentage frequency of individual species is not known, the maximum proliferation of species represented by their number within a genus has been taken as a criterion for acme-zone. It may be mentioned that the generic acme-zone known so far in the Gondwana Sequence are different from the acme-zone being proposed in this paper. The former are based on generic abundance and the latter are defined on epibole in the number of species of a particular genus along the stratigraphic column. To differentiate the two, the names have been given in different ways, e.g., *Parasaccites* Acme-Zone and *Parasaccites* spp. Acme-Zone, respectively.

In Table 2, the first and the last occurrences of species are depicted. The Last Appearance Datum (LAD) may be distorted by reworking of taxa and thus affect the authenticity of the ranges, particularly when their record is not continuous in time prior to the last appearance, and the specimens are very scantily and inconsistently found. The First Appearance Datum (FAD) is a very useful parameter for stratigraphy, but has also certain limitations in the long range spatial correlation. Any given species normally can not make its first appearance simultaneously at several geographically widely separated regions, particularly in different latitudinal belts. This is because of time factor involved in migration from its original first appearance site. nevertheless, the FADs are useful parameters to demarcate a zone in a particular region. If the FADs and LADs are defined at the steady first appearance and last appearance levels, respectively, these datums gain considerable weightage. In the present synthesis, a mere record of a species—one specimen in more than four slides with large coverslips of 20 × 40 mm size, or its sporadic rarest occurrence at any level has not been taken for FAD or LAD as suggested by Gradstein (1983).

SPORE-POLLEN SPECIES ASSEMBLAGE-ZONES

The basic units of biostratigraphy, identified and described below are the species Assemblage Zones which represent lithologic strata. The spore-pollen species contained in the strata constitute the natural assemblage of distinctive characters.

The list of principal spore-pollen species in each assemblage zone is depicted in the stair-case diagram (Table 2). For the reference section, original works are cited or described in brief, wherever possible. The earlier proposed comparable zones have been compared or equated with the present zones, or if the earlier propositions are in wide use and conventionally accepted to be effectively useful, they have been adapted after redefinition. The top and bottom limits of each assemblage zone proposed here are defined by the

Table 2 — Spore-pollen species-based assemblage-zone through Gondwana Sequence of Damodar-Rajmahal basins. For comparative assessment Mesozoic palyno-sequence from Jaisalmer, Kachchh and Cauvery basins also intercalated. J=Jaisalmer, JH=Jhumara, JHUR=Jhuran, DUBR=Dubrajpur.

Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded, >> inconsistent presence

		Period	L. Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L.-Cretaceous			J/C	L.-Cretaceous	
	Palyno-species	Formation	Talchir		Karhar-bari		Barakar		Kulti	Raniganj		Panchet		Supra-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHUR	Katrol	Siv-ganga	Bhuj	DUBR contd.	Raj-mahal	
		Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
1	Verrucosisporites cf. donarii in Lele 1975		1 ••																							
2	Parassacites densicorpus Lele 1975		2 ••	••																						
3	Potonieisporites crassus Lele & Ch.1973		3 ••	••																						
4	Potonieisporites magnus Lele & Karim 1971		4 ••	••	••																					
5	Potonieisporites neglectus Pot.& Lele 1961		5 ••	••	••	••																				
6	Plicatipollenites gondwanensis (Balme & Henn.) Lele 1964		6 ••	••	••	••	••	••																		
7	Parasaccites obscurus Tiw.1965		7 ••	••	••	••	—	••	••	••																
8	Plicatipollenites indicus Lele 1964		8 ••	••	••	••	—	••	••	—	••	••														
9	Jayantisporites cf. conatus in Lele 1975		9	••																						
10	Striatoparvisaccites circularis Lele 1975		10	••																						
11	Striatoparvisaccites indicus Lele 1975		11	••																						
12	Caheniasaccites densus Lele & Karim 1971		12	••	••																					
13	Rugasaccites obscurus Lele & Maithy 1969		13	••	••																					
14	Sahnites elongatus (Lele & Karim) Tiw. & Singh 1984		14	••	••																					
15	Tuberisaccites tuberculatus (Mah.) Lele & Mak.1972		15	••	••																					
16	Plicatipollenites densus Sr.1970		16	••	••	••																				
17	Plicatipollenites trigonalis Lele 1964		17	••	••	••																				
18	Parasaccites bilateralis Tiw.1965		18	••	••	••	••	••																		
19	Sahnites thomasi Pant em. Tiw.& Singh 1984		19	••	••	••	••	••																		
20	Crescentipollenites fuscus (Bh.) Bh. et al.1974		20	••	••	••	••	••	••	••	••	••	••	••												
21	Faunipollenites perexiguus Bh.& Sal.1965		21	••	••	••	••	••	••	••	••	••														
22	Callumispora gretensis (B.& H.)Bh.& Sr. em. Tiw.et al.1989		22	••	••	••	••	••	••	—	••	••	••	••												
23	Caheniasaccites decorus Lele & Mak.1972			23	••	••																				
24	Caheniasaccites ovatus Bose & Kar 1966			24	••	••																				
25	Crucisaccites latisulcatus Lele & Maithy 1964			25	••	••																				
26	Tuberisaccites lobatus Lele & Mak.1972			26	••	••																				
27	Faunipollenites varius Bh. em. Tiw.et al.1989			27	••	••	••	••	••	••	••	••	••	••												
28	Scheuringipollenites maximus (Hart) Tiw.1973a			28	••	••	••	••	••	••	••	••	••	••	••											
29	Microbaculispora tentula Tiw.1965			29	••	••	—	••																		
30	Vestigisporites novus Tiw.1965			30	••	••	—	••																		
31	Parasaccites korbaensis Bh.& Tiw.1964			31	••	••	—	••	••	••	••	••	—	••												
32	Microfoveolatispora foveolata Tiw. em. Tiw.& Singh 1981			32	••	••	—	••	—	••	••	—	••													
33	Lacinitriletes badamensis Venk.& Kar em. Tiw.& Singh 1981			33	••	—	••	••	••	••	••															
34	Ginkgocycadophytus novus Sr.1970			34	••	—	—	••																		
35	Divarisaccus lelei Venk.& Kar 1966a			35	••	—	—	••	••	—	••															
36	Caheniasaccites distinctus Lele & Mak.1972			36	••																					
37	Circumstriatites obscurus Lele & Mak.1972			37	••																					
38	Circumstriatites talchirensis Lele & Mak.1972			38	••																					

39	Cyclogranisporites plicatus Allen 1965	39	**							
40	Jayantisporites indicus Lele & Mak.1972	40	**							
41	Jayantisporites pseudozonatus Lele & Mak.1972	41	**							
42	Parastriopollenites indicus Lele & Mak.1972	42	**							
43	Parastriopollenites segmentatus Lele & Mak.1972	43	**							
44	Plicatisporites distinctus Lele & Mak.1972	44	**							
45	Striasulcites sp. in Lele & Mak.1972	45	**							
46	Tuberisaccites varius Lele & Mak.1972	46	**							
47	Vestigisporites nigratus Lele & Karim 1971	47	**							
48	Vestigisporites notus (Lele & Karim) Tiw. & Singh 1984	48	**							
49	Barakarites gondwanensis Maithy 1965		49	**						
50	Callumispora barakarensis Bh.& Sr. em. Tiw. et al.1989		50	**						
51	Crescentipollenites limpidus (Balme & Henn.) Lele & Sr.1977		51	**						
52	Crescentipollenites rhombicus in Lele & Mak. 1974		52	**						
53	Crucisaccites monoletus Maithy em. Tiw. et al.1989		53	**						
54	Distriamonocolpites circularis Sinha 1972		54	**						
55	Tiwariasporis gondwanensis (Tiw.) Mah. & Kar 1967		55	**						
56	Welwitschiapites magnus Maithy 1965		56	**						
57	Stellapollenites talchirensis Lele 1965		57	**	**	**				
58	Verrucosisporites donarii Pot.& Kr.1955		58	**	**	**	**	**	**	
59	Densipollenites indicus Bh.1962		59	**	**	**	**	**	**	**
60	Scheuringipollenites barakarensis (Tiw.) Tiw.1973a		60	**	**	**	**	**	**	**
61	Sahanites barrelis (Tiw.) Tiw.& Singh 1984		61	**	—	**				
62	Laevigatosporites colliensis Venk.& Kar 1968a		62	**	—	**	**	**	**	
63	Ginkgocycadophytus cymbatus (Balme & Henn.) Pot.& Lele 1961		63	**	—	**	**	—	**	
64	Marsupipollenites triradiatus Balme & Henn.1956		64	**	—	—	—	—	—	**
65	Brevitriletes communis Bh.& Sr. em. Tiw.& Singh 1981			65	**	**				
66	Corisaccites vanus Venk.& Kar 1966b			66	**	**				
67	Dentatispora gondwanensis Tiw.1965			67	**	**				
68	Distriatites distinctus Sinha 1972			68	**	**				
69	Indotriradites korbaensis Bh.& Tiw.1964			69	**	**				
70	Paravesicaspora indica (Tiw.) Bh.& Dwi.1981			70	**	**				
71	Primuspollenites levis Tiw.1964			71	**	**				
72	Faunipollenites singrauliensis Sinha 1972			72	**	**	**			
73	Platysaccus densus Kar 1968a			73	**	**	**			
74	Striasulcites tectus Venk.& Kar 1968b			74	**	**	**			
75	Indotriradites korbaensis Tiw.1964			75	**	**	**	**		
76	Ibisporites diplosaccus Tiw.1968			76	**	**	**	**	**	
77	Rhizomaspora indica Tiw.1965			77	**	**	**	**	**	
78	Scheuringipollenites ovatus (B.& H.) Bh.& Dwi.1981			78	**	**	**	**	**	
79	Striatites notus Bh.& Sal.1964			79	**	**	**	**	**	
80	Verticipollenites gibbosus Bh.1962			80	**	**	**	**	**	
81	Striatites communis Bh.& Sal.1964			81	**	**	**	**	**	**
82	Weylandites lucifer (Bh.& Sal.) Foster 1976			82	**	**	**	—	**	
83	Lophotriletes rectus Bh.& Sal.1964			83	**	**	—	**	**	**
84	Barakarites indicus Bh.& Tiw.1964				84	**				

Contd.

Table 2 — *Contd.*

Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded, >> inconsistent presence

	Period	L. Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L.-Cretaceous			J/C	L.-Cretaceous	
Palyno-species	Formation	Talchir			Karharbari	Barakar		Kulti	Raniganj		Panchet		Supra-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHUR	Katrol	Sivganga	Bhuj	DUBR contd.	Rajmahal	
	Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
85 Cyclofoveolatispora minutus Venk.& Kar 1968c						85	**																		
86 Didecitriletes horridus Venk.& Kar 1965						86	**																		
87 Ginkgocycadophytus vetus (B.& H.) Tiw.1965						87	**																		
88 Insignisporites barakarensis Bh.& Dwi.1977						88	**																		
89 Lueckisporites crassus Sinha 1972						89	**																		
90 Maculatasporites indicus Tiw.1964						90	**																		
91 Microbaculispora indica Tiw. em. Tiw.& Singh 1981						91	**																		
92 Microbaculispora villosa (B.&H.) Bh.1962						92	**																		
93 Microfoveolatispora bokaroensis Tiw.1965						93	**																		
94 Paravesicaspora distincta (Tiw.) Bh.& Dwi.1981						94	**																		
95 Potonieitriradites barakarensis Bh.& Sinha 1969						95	**																		
96 Striatites naditoliensis Bh.& Dwi.1981						96	**																		
97 Tiwariasporis flavatus Mah.& Kar 1967						97	**																		
98 Vestigisporites rudis Balme & Henn.1955						98	**																		
99 Vittatina permagna Tiw.1965						99	**																		
100 Welwitschiapites simplex Tiw.1965						100	**																		
101 Weylandites dubius (Venk.& Kar) Bh.& Dwi.1981						101	**																		
102 Lahirites lungatooensis Venk.& Kar 1968c						102	**	**																	
103 Schizopollis disaccoides Venk.& Kar 1964						103	**	**																	
104 Schizopollis wodehousei Venk.& Kar 1964						104	**	**																	
105 Vittatina lata Wils.1962						105	**	**																	
106 Indospora clara Bh.1962						106	**	**	**	**															
107 Praecolpatites sinuosus (B.& H.) Bh.& Sr.1969						107	**	**	**	**															
108 Striatites multistriatus (B.& H.) Tiw.1965						108	**	**	**	**															
109 Densipollenites invisus Bh.& Sal.1964						109	**	**	**	**	**														
110 Horriditriletes curvibaculosus Bh.& Sal.1964						110	**	**	**	**	**														
111 Lahirites rarus Bh.& Sal.1964						111	**	**	**	**	**														
112 Striomonosaccites ovatus Bh.1962						112	**	**	**	**	**														
113 Cyclogranisporites gondwanensis Bh.& Sal.1964						113	**	**	**	**	**	**	**												
114 Striatopodocarpites decorus Bh.& Sal.1964						114	**	**	—	**	**	—	—	—	—	**									
115 Corisaccites alutas Venk.& Kar 1966b						115	**	**	—	**															
116 Guttulapollenites hannonicus Goubin 1965						116	**	**	—	**															
117 Rhizomaspora costa Venk.& Kar 1968b						117	**	**	—	**															
118 Welwitschiapites tenuis Bh.& Sal.1964						118	**	**	—	**															
119 Microfoveolatispora raniganjensis Bh. em. Tiw. & Singh 1981						119	**	—	**																
120 Microbaculispora gondwanensis Bh.1962						120	**	—	**	**															
121 Corisaccites distinctus Venk.& Kar 1968c						121	**	—	—	**															
122 Hennellysporites diversiformis Tiw.1968						122	**	—	—	**															
123 Lahirites angustus Venk.& Kar 1968a						123	**	—	—	**															
124 Striatopodocarpites tiwarii (Tiw.) Bh.& Dwi.1981						124	**	—	—	**															
125 Bharadwajipollis striatus Kar 1969a							125	**																	
126 Praecolpatites biplicatus (Kar) Bh.& Dwi.1981							126	**																	
127 Verrucosisporites ambiplicatus Kar 1968a							127	**																	
128 Densipollenites brevis Lele & Sr.1977							128	**	**	**															
129 Gondisporites raniganjensis Bh.1962							129	**	**	**															

130 Hindipollenites indicus Bh.1962	130	••	••	••						
131 Striatopodocarpites ovatus (Mah.) Tiw.& Rana 1980	131	••	••	••						
132 Verticipollenites crassus Bh.& Sal.1964	132	••	••	••						
133 Densipollenites magnicorpus Tiw.& Rana 1981	133	••	••	••						
134 Densipollenites densus Bh.& Sr.1969	134	••	••	••	••					
135 Striatopodocarpites rotundus (Mah.) Bh.& Dwi.1981	135	••	••	••	••					
136 Platysaccus fuscus Goubin 1965	136	••	••	••	••	—	—	••		
137 Cyclobaculisporites minimus Kar 1968a	137	••	—	••						
138 Didecitriletes ericianus (B.& H.) Venk.& Kar 1965		138	••							
139 Lophotriletes rarus Kar 1968		139	••							
140 Vestigisporites disectus Hart em. Tiw.& Singh 1984		140	••							
141 Distriamonocolpites ovalis Bh.& Sinha 1969		141	••	••						
142 Distriatites bilateris Bh.1962		142	••	••						
143 Distriomonosaccites ovalis Bh.& Sal.1964		143	••	••						
144 Lahirites singularis Bh.& Sal.1964		144	••	••						
145 Verticipollenites oblongus Bh.1962		145	••	••						
146 Crescentipollenites gondwanensis Bh.et al.1974			146	••						
147 Crescentipollenites sellingi (Sal.) Tiw.& Rana 1980			147	••						
148 Cyclobaculisporites indicus Bh.& Sal.1964			148	••						
149 Gondisporites reticulatus Tiw.& Ram-Awatar 1989			149	••						
150 Indospora macula Bh.& Sal.1964			150	••						
151 Marsupipollenites striatus (B.& H.) Foster 1975			151	••						
152 Striatites rhombicus Bh.& Sal.1964			152	••						
153 Thymospora gondwanensis Bh.& Sal.1964			153	••	••					
154 Verrucosisporites gondwanensis Sr.1970			154	••	••					
155 Weylandites indicus Bh.& Sr.1969			155	••	••					
156 Crescentipollenites bengalensis (Mah.& Ban.) Tiw.& Rana 1981			156	••	••	••	••			
157 Densoisporites complicatus Balme 1970			157	>>	••					
158 Lunatisporites diffusus Bh. & Tiw. 1977			158	>>	••					
159 Osmundacidites senectus Balme 1963			159	>>	••					
160 Alisporites asansoliensis Mah.& Ban.1975			160	>>	••	••				
161 Indotriradites cuspidus (B.) Bh.& Tiw.1977			161	>>	••	••				
162 Lunatisporites ovatus (Goubin) Mah.& Ban. 1975			162	>>	••	••				
163 Alisporites damudicus Tiw.& Rana 1981			163	>>	••	••	••			
164 Densoisporites playfordii Balme 1970			164	>>	••	••	••			
165 Lundbladispora brevicula Balme 1970			165	>>	••	••	••			
166 Lundbladispora microconata Bh.& Tiw.1977			166	>>	••	••	••			
167 Callumispora fungosa (Balme) Bh.& Tiw.1977			167	>>	••	••	••	••		
168 Inaperturopollenites nebulosus Balme 1970			168	>>	••	••	••	••		
169 Alisporites landianus Balme 1970			169	>>	••	••	••	••	••	
170 Goubinispora morondavensis (Goubin) Tiw.& Rana 1981			170	>>	••	••	••	••	••	••
171 Klausipollenites schaubergeri (Pot.& Kr.) Jans.1962			171	>>	••	••	••	••	••	••
172 Playfordiaspora cancellosa Mah.& Ban.1975			172	>>	••	••	••	••	••	••
173 Rhizomaspora triassica Tiw.& Rana 1981			173	>>	••	—	••			
174 Densoisporites contactus Bh.& Tiw.1977			174	>>	••	—	••	••		
175 Aratrisporites fischeri Kl.1960				175	••					
176 Biretisporites sp. in Kar 1970				176	••					
177 Granuloperculatipollis flavatus Kar 1970				177	••					
178 Convertubisporites contactus Ban.& Mah.1975				178	••	••				
179 Verrucosisporites triassicus Bh.& Tiw.1977				179	••	••	••			
180 Pretricolpipollenites bharadwajii Balme 1970				180	••	••	••	••		
181 Verrucosisporites narmianus Balme 1970				181	••	••	••	••		
182 Lunatisporites pellucidus (Goubin) Mah.& Ban.1975				182	••	••	••	••	••	

Contd.

Table 2 — *Contd.*

Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded, >> inconsistent presence

Period	L. Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L.-Cretaceous			J/C	L.-Cretaceous	
Palyno-species Formation	Talchir		Karhar-bari		Barakar		Kulti	Raniganj		Panchet		Supra-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHUR	Katrol	Siv-ganga	Bhuj	DUBR contd.	Raj-mahal	
Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
183 Cyathidites australis Coup.1953									183	**	**	**	—	—	—	—	++	++	++	—	—	**		
184 Cycadopites follicularis Wils.& Webst.1946									184	**	**	**	—	—	—	—	—	—	—	—	—	**		
185 Indotriradites mammilatus Bh.& Tiw.1977										185	**													
186 Indotriradites wargalensis (Balme) Bh.& Tiw.1977										186	**													
187 Lundbladispora baculata Bh.& Tiw.1977										187	**													
188 Lundbladispora densispinosa Bh.& Tiw.1977										188	**													
189 Lundbladispora warti Tiw.& Rana 1981										189	**													
190 Ringosporites ringus Tiw.& Rana 1981										190	**													
191 Guttatisporites ambiguus Tiw.& Rana 1980										191	**	**												
192 Lunatisporites noviaulensis (Lesch.) Scheuring 1970										192	**	**												
193 Novitasporites triassicus Tiw.& Rana 1981										193	**	**												
194 Triplexisporites playfordii (de Jer.& Hamilt.) Foster 1979										194	**	**												
195 Verrucosisporites densus Bh.& Tiw.1977										195	**	**	—	—	**									
196 Orbella indica Tiw.& Rana 1981										196	**	—	**											
197 Osmundacidites pilatus Tiw.& Rana 1981										197	**	—	**											
198 Araucariacites australis Cooks.1947										198	**	—	—	—	—	—	—	—	++	\\	++	**	**	**
199 Carnisporites raniganjensis Tiw.& Rana 1980											199	**												
200 Lundbladispora reticulata Tiw.& Rana 1981											200	**												
201 Lundbladispora willmotti Balme 1963											201	**												
202 Nevesisporites vallatus de Jer.& Patten 1964											202	**												
203 Playfordiaspora annulata Tiw.& Rana 1980											203	**												
204 Ringosporites fossulatus (Balme) Tiw.& Rana 1980											204	**												
205 Vitreisporites pallidus (Reiss.) Nils.1958											205	**	—	—	—	—	—	—	—	—	—	**		
206 Chordasporites minutus Kar et al. 1972												206	**											
207 Converrucosisporites lunzensis Bh.& Singh 1964												207	**											
208 Foveosporites mimosae de Jer.& Hammil.1967												208	**											
209 Polycingulatisporites sp. in Tripathi et al.1990												209	**											
210 Rajmahalispora reticulata Tiw. et al.1984												210	**											
211 Rajmahalispora rugulata Tiw. et al.1984												211	**											
212 Rajmahalispora triassica Tiw. et al.1984												212	**											
213 Falcisporites minutosaccus Kum.& Mah.1980												213	**	**										
214 Klausipollenites staplinii Jans.1962												214	**	**										
215 Nidipollenites monoletus Bh.& Sr.1969a												215	**	**	**									
216 Satsangisaccites triassicus Bh.& Sr.1969a												216	**	**	**									
217 Foveosporites triassicus Kum.& Mah.1980												217	**	—	**									
218 Conbaculatisporites baculatus Bh.& Singh 1964													218	**										
219 Convolutispora perfecta Kum.& Mah.1980													219	**										
220 Infernopollenites claustratus Dolby & Balme 1976													220	**										
221 Staurosaccites densus Kum.& Mah. em. Tripathi et al.1990													221	**										
222 Staurosaccites tharipatharensis Mah.& Kum.1979													222	**										
223 Brachysaccus indicus Kum.& Mah.1980													223	**	**									
224 Brachysaccus ovalis Maedler 1964													224	**	**									
225 Gabonisporis papillosus Tripathi et al.1990													225	**	**									
226 Gabonisporis vigourouxii Boltenhagen 1967													226	**	**									

227 Guttatisporites elegans Visscher 1966	227	••	••									
228 Guttatisporites guttatus Visscher 1966	228	••	••									
229 Staurosaccites marginalis Kum.& Mah. 1980	229	••	••									
230 Staurosaccites quadrifidus Dolby in Dolby & Balme 1976	230	••	••									
231 Striatopodocarpites dubrajpurensis Tripathi et al.1990	231	••	••									
232 Podocarpidites grandis Sah & Jain 1965	232	••	••	—	—	—	++	—	++	—	—	••
233 Podocarpidites typicus Sah & Jain 1965	233	••	—	—	—	—	—	—	—	—	—	••
234 Converrucosisporites jenensis Reinh.1984		234	••									
235 Dictyotriletes aulius Rigby in Rigby & Heckel 1977		235	••									
236 Dubrajisporites bulbosus Tiw.& Tripathi 1987		236	••									
237 Dubrajisporites triassicus Tiw.& Tripathi 1987		237	••									
238 Podocarpidites rarus Singh et al.1964		238	••									
239 Verrucosisporites carnarvonensis de Jer.& Hamilt.1967		239	••									
240 Podocarpidites alareticulatus Sah & Jain 1965		240	••	—	—	—	—	—	—	—	••	
241 Aequitriradites minor Maedler 1964			241	++								
242 Alisporites sp. in Koshal 1975			242	++								
243 Concavisporites sp. in Koshal 1975			243	++								
244 Convolutispora microrugulata in Koshal 1975			244	++								
245 Dictyophyllidites sp. in Koshal 1975			245	++								
246 Klausipollenites sp. in Koshal 1975			246	++								
247 Klausipollenites cf. vestitus in Koshal 1975			247	++								
248 Lunatisporites sp. in Koshal 1975			248	++								
249 Lundbladispora sp. in Koshal 1975			249	++								
250 Podocarpidites sp. in Koshal 1975			250	++								
251 Rhaetipollis germanicus Schulz 1967			251	++								
252 Verrucosisporites sp. in Koshal 1975			252	++								
253 Vitreisporites sp. in Koshal 1975			253	++								
254 Podocarpidites sp. In Koshal 1975			254	++								
255 Spheripollenites sp. in Koshal 1975				255	++							
256 Staplinisporites sp. in Koshal 1975				256	++							
257 Callialasporites barragaonensis Sr.1966				257	++	++						
258 Cingulatisporites lathiensis Sr.1966				258	++	++						
259 Dictyotriletes crateris (Balme) Sr.1966				259	++	++						
260 Ginkgocycadophytus deterius (B.) Dev 1961				260	++	++						
261 Monosulcites couperi Dev 1961				261	++	++						
262 Triangulatisporites mathurii Sr.1966				262	++	++						
263 Trilobozonosporites verrucatus (Lantz) Sr.1966				263	++	++						
264 Classopollis minor Pocock & Jans.1961				264	++	++	++					
265 Matonisporites cooksonii Dettm.1963				265	++	++	++					
266 Callialasporites triletes Singh et al.1964				266	++	++	++	\\				
267 Callialasporites dampieri (Balme) Dev 1961				267	++	++	++	\\	++	••	••	
268 Callialasporites segmentatus (Balme) Dev 1961				268	++	++	++	\\	++	••	••	
269 Callialasporites trilobatus (Balme) Dev 1961				269	++	++	++	\\	—	••	••	
270 Classopollis classoides Pfl. em. Pocock & Jans.1961				270	++	++	++	—	++			
271 Callialasporites granulatus Venk. & Kar 1972					271	++	++					
272 Callialasporites monoalasporus Dev 1961					272	++	++	\\				
273 Callialasporites lenticularis (Doering) Venk. & Kar 1969					273	++	++	—	++			
274 Cicatricosisporites sp. in Koshal 1975					274	++						
275 Contignisporites sp. in Koshal 1975					275	++						
276 Klukisporites sp in Koshal 1975					276	++						

Contd.

Table 2 — *Contd.*

Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded, >> inconsistent presence

Palyno-species Period	L. Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L.-Cretaceous			J/C	L.-Cretaceous	
Formation	Talchir			Karharbari	Barakar		Kulti	Raniganj		Panchet		Supra-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHUR	Katrol	Sivganga	Bhuj	DUBR contd.	Rajmahal	
Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
277 Alsophyllidites bellus Venkatach. et al.1969																		277	++					
278 Biretisporites potoniaei Delc. & Sprum.1955																		278	++					
279 Boseisporites praeclarus Dev em. Singh et al.1964																		279	++					
280 Concavisporites crassus Venk. et al.1969																		280	++					
281 Concavissimisporites crassatus (Del.& Spr.) Del. et al.1963																		281	++					
282 Concavissimisporites variverrucatus (Coup.) Singh 1964																		282	++					
283 Concavissimisporites verrucosus (Del.& Spr.) Del. et al.1963																		283	++					
284 Contignisporites cooksonii (Balme) Dettm.1963																		284	++					
285 Contignisporites kutchensis Venk. et al.1969																		285	++					
286 Coptospora sp. in Venk. et al.1969																		286	++					
287 Foveotriletes foveolus Venk. et al.1969																		287	++					
288 Foveotriletes triangulus Venk. et al.1969																		288	++					
289 Impardecispora uralensis (Bolk.) Venk. et al.1969																		289	++					
290 Klukisporites apunctus Venk. et al.1969																		290	++					
291 Klukisporites kutchensis Venk.in Venk. et al.1969																		291	++					
292 Klukisporites scaberis (Cooks.& Dettm.) Dettm.1963																		292	++					
293 Matonisporites kutchensis Venk.1969																		293	++					
294 Trilobosporites sp. in Venk. et al.1969																		294	++					
295 Contignisporites glebulentus Dettm.1963																		295	++	\\				
296 Podocarpidites ellipticus Cooks.1947																		296	++	\\	++	**		
297 Podocarpidites multesimus (Bolkho.) Pocock 1962																		297	++	\\	++	**		
298 Cicatricosisporites australiensis (Cooks.) Pot.1956																		298	++	\\	—	**	**	**
299 Retitriletes austroclavatidites (Rouse) Doring et al.1963																		299	++	\\	—	**	**	
300 Classopollis torosus (Reiss.) Coup.1958																		300	++	—	++			
301 Microcachryidites antarcticus Cookson 1947																		301	++	—	++			
302 Podosporites tripakshi Rao em. Kumar 1984																		302	++	—	++	**	**	
303 Podocarpidites cristiexinus Sah & Jain 1965																		303	++	—	++	**	**	**
304 Impardecispora trioreticulosa (Cooks.& Dettm.) Venk.et al.1969																		304	++	—	++	—	**	
305 Concavissimisporites penolaensis Dettm.1963																		305	++	—	—	**		
306 Coptospora kutchensis Venk.1969																		306	++	—	—	**		
307 Todisporites minor Couper 1958																		307	++	—	—	**		
308 Alsophilidites exilis Sah & Jain 1965																		308	++	—	—	—	—	**
309 Cyathidites trilobatus Sah & Jain 1965																		309	++	—	—	—	**	
310 Impardecispora purverulentus (Verbits.) Venk. et al.1969																		310	++	—	++			
311 Ceratosporites equalis Cooks. & Dettm. 1958																			311	\\				
312 Contignisporites multimuratus Dettm.1963																			312	\\				
313 Retitriletes reticulmsporites Doering et al.1963																			313	\\				
314 Baculatisporites comaumensis (Cooks.) Pot.1956																			314	\\	—	**		
315 Cicatricosisporites ludbrooki Dettm.1963																			315	\\	—	**	**	**
316 Stereisporites antiquasporites (Wils.& Webs.) Dettm.1963																			316	\\	—	—	—	**
																				317	++			

317 Acquitriradites indicus Singh et al.1964					
318 Aequitriradites triangulatus Singh et al.1964	318	++			
319 Alsophyllidites densus Singh et al.1964	319	++			
320 Concavissimisporites subverrucosus Venk.1969	320	++			
321 Cooksonites minor Venk.1969	321	++			
322 Cyathidites ghuneriensis Singh et al.1964	322	++			
323 Deltoidospora pseudoreticulata Singh et al.1964	323	++			
324 Deltoidospora rhytisima Rouse 1957	324	++			
325 Impardecispora apiverrucata (Coup.) Venk. et al.1969	325	++			
326 Leptolepidites sp. in Venk.& Kar 1972	326	++			
327 Staplinisporites caminus (B.) Pocock 1962	327	++			
328 Trilobosporites bemissartensis (Del.& Sprum.) Pot.1956	328	++			
329 Trilobosporites triangularis Venk. et al. 1969	329	++			
330 Podosporites microsaccatus Dettm.1963	330	++	••	••	
331 Araucariacites cooksonii Singh et al.1964	331	++	••	••	••
332 Callialasporites circumplectus Kumar 1973		332	••		
333 Callispora potoniei Dev em. Bh.& Kumar 1972		333	••		
334 Contignisporites dettmannii Singh & Kumar 1966		334	••		
335 Cooksonites rajmahalensis Tripathi et al.1990		335	••		
336 Foraminisporis sp. in Tripathi et al.1990		336	••		
337 Klukisporites varigatus Couper 1958		337	••		
338 Klukisporites venkatachalae Tripathi et al.1990		338	••		
339 Leptolepidites major Couper 1958		339	••		
340 Leptolepidites verrucatus Couper 1953		340	••		
341 Murospora florida Balme em. Dettm.1963		341	••		
342 Santhalisporites bulbosus Tripathi et al.1990		342	••		
343 Aequitriradites verrucosus (C.& D.) Cooks.& Dettm. 1961		343	••	••	
344 Callialasporites lametaensis Kumar 1973		344	••	••	
345 Aequitriradites spinulosus (C.& D.) Cooks.& Dettm. 1961		345	••	—	••
346 Classopollis indicus Mah. 1974		346	••	—	••
347 Coptospora verrucosa Tripathi et al.1990		347	••	—	••
348 Labiipollis granulatus Maedler 1964		348	••	—	••
349 Santhalisporites baskoensis (Sah & Jain) Tripathi et al.1990		349	••	—	••
350 Triporoletes reticulatus (Pocock) Playf.1971		350	••	—	••
351 Dictyophyllidites haradensis Kum.1973			351	••	
352 Alisporites baskoensis Sah & Jain 1965				352	••
353 Cicatricosisporites hallei Del.& Sprum.1955				353	••
354 Cingulatisporites notaclarus Sah & Jain 1965				354	••
355 Concavissimisporites minor Sah & Jain 1965				355	••
356 Converrucosisporites santalensis Sah & Jain 1965				356	••
357 Converrucosisporites sinuotectus Sah & Jain 1965				357	••
358 Dacrycarpites australiensis Cooks.& Pike 1953				358	••
359 Densoisporites mesozoicus Singh et al.1964				359	••
360 Divisisporites ovalis Sah & Jain 1965				360	••
361 Foraminisporis cf. asymmetricus Sah & Jain 1965				361	••
362 Impardecispora purverulenta (Verb.) Venk. et al.1969				362	••
363 Ischyosporites irregularis Sah & Jain 1965				363	••
364 Osmundacidites minutus Sah & Jain 1965				364	••

Table 3 — Spore-pollen species sorted on generic affiliation to define the species Acme-zones. J=Jaisalmer, JH=Jhumara, JHU=Jhuran, DUBR=Dubrajpur. Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded.

	Period	L.Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L.-Cretaceous			J/C	L.-Cretaceous	
Palyno-species	Formation	Talchir			Karhar-bari	Barakar		Kulti	Raniganj		Panchet		S.-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHUR	Katrol	Siv-ganga	Bhuj	DUBR contd.	Raj-mahal	
	Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
1 Araucariacites australis											1	**	—	—	—	—	—	—	—	++	\\	++	**	**	**
2 Araucariacites ghoshii																					2	++			
3 Araucariacites cooksonii																			3	++	—	++	**	**	
4 Araucariacites ghuneriensis																					4	++	**		
5 Barakarites gondwanensis				5	**																				
6 Barakarites crassus						6	**																		
7 Barakarites decorus						7	**																		
8 Barakarites densicorpus						8	**																		
9 Barakarites glabrus						9	**																		
10 Barakarites implicatus						10	**																		
11 Barakarites indicus						11	**																		
12 Barakarites triquetrus						12	**																		
13 Barakarites dubius						13	**	**	—	**															
14 Caheniasaccites densus		14	**	**																					
15 Caheniasaccites distinctus			15	**																					
16 Caheniasaccites decorus			16	**	**																				
17 Caheniasaccites ovatus			17	**	**																				
18 Caheniasaccites flavatus				18	**																				
19 Caheniasaccites granulatus				19	**																				
20 Caheniasaccites indicus				20	**																				
21 Callialasporites barragaonensis																	21	++	++						
22 Callialasporites jaisalmerensis																	22	++	++						
23 Callialasporites dampieri																	23	++	++	++	\\	++	**	**	**
24 Callialasporites trilobatus																	24	++	++	++	\\	++	**	**	**
25 Callialasporites granulatus																		25	++	++	—	++			
26 Callialasporites lenticularis																		26	++	++	—	++			
27 Callialasporites monoalasporus																		27	++	++	\\	++			
28 Callialasporites ovatus																			28	++	—	++			
29 Callialasporites punctatus																			29	++	—	++			
30 Callialasporites triletes																			30	++	\\	++			
31 Callialasporites lucidus																			31	++	—	++			
32 Callialasporites segmentatus																			32	++	\\	++	**	**	**
33 Callialasporites circumplectus																						33	**		
34 Callialasporites lametaensis																						34	**		
35 Callialasporites grandis																			35	++	—	++	**	**	
36 Circumstriatites obscurus			36	**																					
37 Circumstriatites ovatus			37	**																					
38 Circumstriatites talchirensis			38	**																					
39 Circumstriatites cf. obscurus				39	**																				
40 Crescentipollenites talchirensis		40	**	**																					

41 Crescentipollenites ampulus		41	••	••	—	—	••	••	••						
42 Crescentipollenites globosus			42	••											
43 Crescentipollenites rhombicus			43	••											
44 Crescentipollenites limpidus			44	••											
45 Crescentipollenites brevis				45	••	••									
46 Crescentipollenites fuscus				46	••	••	••	••	••	••	••	••			
47 Crescentipollenites notabilis					47	••									
48 Crescentipollenites karii						48	••								
49 Crescentipollenites hirsutus						49	••	—	••						
50 Crescentipollenites implicatus							50	••	••						
51 Crescentipollenites gondwanensis								51	••						
52 Crescentipollenites sellingi								52	••						
53 Crescentipollenites santhalensis								53	••	••					
54 Crescentipollenites bengalensis								54	••	••	••	••			
55 Densipollenites indicus				55	••	••	••	••	••	••					
56 Densipollenites invisus					56	••	••	••	••	••					
57 Densipollenites minimus					57	••	••	••	••						
58 Densipollenites brevis						58	••	••	••						
59 Densipollenites densus						59	••	••	••						
60 Densipollenites magnicorpus						60	••	••	••						
61 Dubrajisporites bulbosus														61	••
62 Dubrajisporites isolatus														62	••
63 Dubrajisporites triassicus														63	••
64 Dubrajisporites unicus														64	••
65 Hindipollenites oblongus					65	••									
66 Hindipollenites formosus					66	••	••								
67 Hindipollenites sp.					67	••	—	—	••						
68 Hindipollenites globossus						68	••	••	••						
69 Hindipollenites indicus						69	••	••	••						
70 Hindipollenites rajmahalensis								70	••						
71 Hindipollentites oblongus								71	••						
72 Horriditriletes novus		72	••	—	—	••									
73 Horriditriletes bulbosus					73	••									
74 Horriditriletes pseudoseptatus					74	••									
75 Horriditriletes rampurensis					75	••									
76 Horriditriletes curvibaculosus					76	••	••	••	••	••					
77 Horriditriletes brevis								77	••						
78 Horriditriletes cf. ramosus								78	••						
79 Jayantisporites cf. conatus	79	••													
80 Jayantisporites conatus		80	••												
81 Jayantisporites indicus		81	••												
82 Jayantisporites pseudozonatus		82	••												
83 Lahirites singularis		83	••	—	—	—	—	••	••						
84 Lahirites rhombicus			84	••	—	••									
85 Lahirites parvus				85	••	••	••	••	••						
86 Lahirites rotundus				86	••	••	—	—	••						
87 Lahirites bokaroensis					87	••									
88 Lahirites fractus					88	••									
89 Lahirites karanpuraensis					89	••									
90 Lahirites levicorpus					90	••									
91 Lahirites lungatooensis					91	••	••								

Contd.

Table 3 — *Contd.*

Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded.

Palyno-species	Period	L. Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L. Cretaceous			J/C	L. Cretaceous	
	Formation	Talchir		Karhar-bari		Barakar		Kulti	Raniganj		Panchet		S.-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHU	Katrol	Siv-ganga	Bhuj	DUBR contd.	Raj-mahal	
	Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
92 Lahirites navicula						92	**	**																	
93 Lahirites alutas						93	**	**	**	**															
94 Lahirites incertus						94	**	**	**	**	**														
95 Lahirites raniganjensis						95	**	**	**	**	**														
96 Lahirites rarus						96	**	**	**	**	**														
97 Lahirites angustus						97	**	—	—	**															
98 Lahirites minutus						98	**	—	—	**															
99 Lahirites kajoraensis							99	**	**	**															
100 Lahirites lepidus							100	**	**	**															
101 Lahirites levistriatus										101	**														
102 Lahirites triassicus										102	**														
103 Lahirites sp.															103	**									
104 Lunatisporites asansoliensis										104	**														
105 Lunatisporites damudicus										105	**														
106 Lunatisporites diffusus										106	**	**													
107 Lunatisporites ovatus										107	**	**													
108 Lunatisporites sp.										108	**	**													
109 Lunatisporites noviaulensis										109	**	**	**												
110 Lunatisporites pellucidus										110	**	**	**	**	—	—	—	**							
111 Lundbladispora brevicula										111	**	**	**												
112 Lundbladispora baculata										112	**														
113 Lundbladispora densispinosa										113	**														
114 Lundbladispora raniganjensis										114	**	**													
115 Lundbladispora warti										115	**	**													
116 Lundbladispora microconata										116	**	**	**												
117 Lundbladispora obsoleta										117	**	**	**												
118 Lundbladispora reticulata												118	**												
119 Lundbladispora willmotti												119	**												
120 Microbaculispora tentula				120	**	—	**																		
121 Microbaculispora indica						121	**																		
122 Microbaculispora villosa						122	**																		
123 Microbaculispora gondwanensis								123	**	**															
124 Microfoveolatispora foveolata			124	**	**	—	**	—	**	**	—	**													
125 Microfoveolatispora bokaroensis						125	**																		
126 Microfoveolatispora raniganjensis						126	**	—	**																
127 Microfoveolatispora sp.							127	**																	
128 Parasaccites densicorpus	128	**	**																						
129 Parasaccites obscurus	129	**	**	**	**	—	**	**	**																
130 Parasaccites perfectus		130	**	**																					

131 Parasaccites bilateralis		131	••	••	••	••	••																		
132 Parasaccites korbaensis			132	••	••	—	••	••	••	••	••	—	••												
133 cf.Parasaccites radiplicatus				133	••																				
134 Parasaccites ovatus							134	••																	
135 Plicatipollenites gondwanensis	135	••	••	••	••	••	••																		
136 Plicatipollenites indicus	136	••	••	••	••	—	••	••	—	••	••														
137 Plicatipollenites maculatus		137	••	••																					
138 Plicatipollenites stigmatus			138	••																					
139 Plicatipollenites diffusus			139	••	••																				
140 Plicatipollenites trigonalis		140	••	••	••																				
141 Plicatipollenites densus		141	••	••	••																				
142 Plicatipollenites cf.magnus				142	••																				
143 Plicatipollenites densicorpus					143	••	••																		
144 Plicatipollenites plicatus					144	••	••																		
145 Plicatipollenites ovatus						145	••	••																	
146 Plicatipollenites giganticus							146	••																	
147 Plicatipollenites gondwanensis							147	••																	
148 Plicatipollenites reticulatus									148	••															
149 Plicatipollenites triangularis									149	••															
150 Podocarpidites rarus																						150	••		
151 Podocarpidites grandis														151	••	••	—	—	—	++	—	—	••	••	••
152 Podocarpidites alareticulatus															152	••	—	—	—	—	—	—	—	••	
153 Podocarpidites typicus															153	••	—	—	—	—	—	—	••		
154 Podocarpidites canadensis																			154	++					
155 Podocarpidites densus																			155	++	—	++			
156 Podocarpidites minisulcus																			156	++					
157 Podocarpidites ornatus																			157	++					
158 Podocarpidites multesimus																			158	++	\\	++	••		
159 Podocarpidites cristiexinus																			159	++	—	—	••	••	••
160 Podocarpidites ellipticus																			160	++	\\	++	••		
161 Potonieisporites crassus	161	••	••	••																					
162 Potonieisporites magnus	162	••	••	••																					
163 Potonieisporites monosaccoides	163	••	••	••																					
164 Potonieisporites mutabilis	164	••	••	••																					
165 Potonieisporites neglectus	165	••	••	••	••																				
166 Potonieisporites densus			166	••																					
167 Potonieisporites jayantiensis			167	••	••																				
168 Potonieisporites lelei		168	••	••	••	—	••																		
169 Potonieisporites elegans				169	••																				
170 Potonieisporites cf. novicus				170	••																				
171 Potonieisporites triangulatus				171	••	—	••																		
172 Potonieisporites sp.					172	••	••	••																	
173 Potonieisporites barrelis						173	••																		
174 Potonieisporites concinnus						174	••																		
175 Potonieisporites raniganjensis									175	••															
176 Primuspollenites dicavus					176	••	••																		
177 Primuspollenites levis					177	••	••																		
178 Primuspollenites obscurus					178	••	••																		
179 Primuspollenites brevicorpus						179	••																		
180 Primuspollenites densus						180	••																		
181 Primuspollenites distinctus						181	••																		

Contd.

Table 3 — *Contd.*

Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded.

Palyno-species	Period	L. Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L.-Cretaceous			J/C	L.-Cretaceous	
	Formation	Talchir		Karhar-bari		Barakar		Kulti	Raniganj		Panchet		S.-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHU	Katrol	Siv-ganga	Bhuj	DUBR contd.	Raj-mahal	
	Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
182 Primuspollenites linterus						182	**																		
183 Primuspollenites ovatus						183	**																		
184 Primuspollenites singrauliensis						184	**																		
185 Rhizomaspora singula			185	**	—	—	**	**																	
186 Rhizomaspora sp.				186	**	—	**	—	—	**															
187 Rhizomaspora indica					187	**	**	**	**	**															
188 Rhizomaspora costa						188	**	**																	
189 Rhizomaspora fimbriata						189	**	—	**	**															
190 Rhizomaspora costa									190	**															
191 Rhizomaspora biharia									191	**	**	**													
192 Rhizomaspora triassica									192	**	**	—	**												
193 Rhizomaspora divaricata										193	**	**													
194 Sahnites cf. congoensis			194	**																					
195 Sahnites elongatus			195	**																					
196 Sahnites cf. hexagonalis			196	**																					
197 Sahnites cf. methoris			197	**																					
198 Sahnites thomasi			198	**	**	**	**																		
199 Sahanites barrelis				199	**																				
200 Sahnites gondwanensis				200	**	**	**																		
201 Scheuringipollenites barakarensis			201	**	**	**	**	**	**	**	**														
202 Scheuringipollenites tentulus			202	**	**	**	**	**	**	**															
203 Scheuringipollenites maximus			203	**	**	**	**	**	**	**	**	**	**	**											
204 Scheuringipollenites ovatus					204	**	**	**	**	**															
205 Staurosaccites densus													205	**											
206 Staurosaccites marginalis													206	**											
207 Staurosaccites quadrifidus													207	**											
208 Staurosaccites tharipatharensis													208	**											
209 Striatites densus				209	**																				
210 Striatites medius				210	**																				
211 Striatites karharbarensis				211	**	**	**																		
212 Striatites incirus				212	**	—	**																		
213 Striatites tentulus				213	**	—	**	**	**	**															
214 Striatites alius					214	**	**	**	**	**															
215 Striatites barakarensis					215	**	**	**	**	**															
216 Striatites notus					216	**	**	**	**	**															
217 Striatites rhombicus					217	**	**	**	**	**															
218 Striatites subtilis					218	**	**	**	**	**															
219 Striatites communis					219	**	**	**	**	**	**														

Contd.

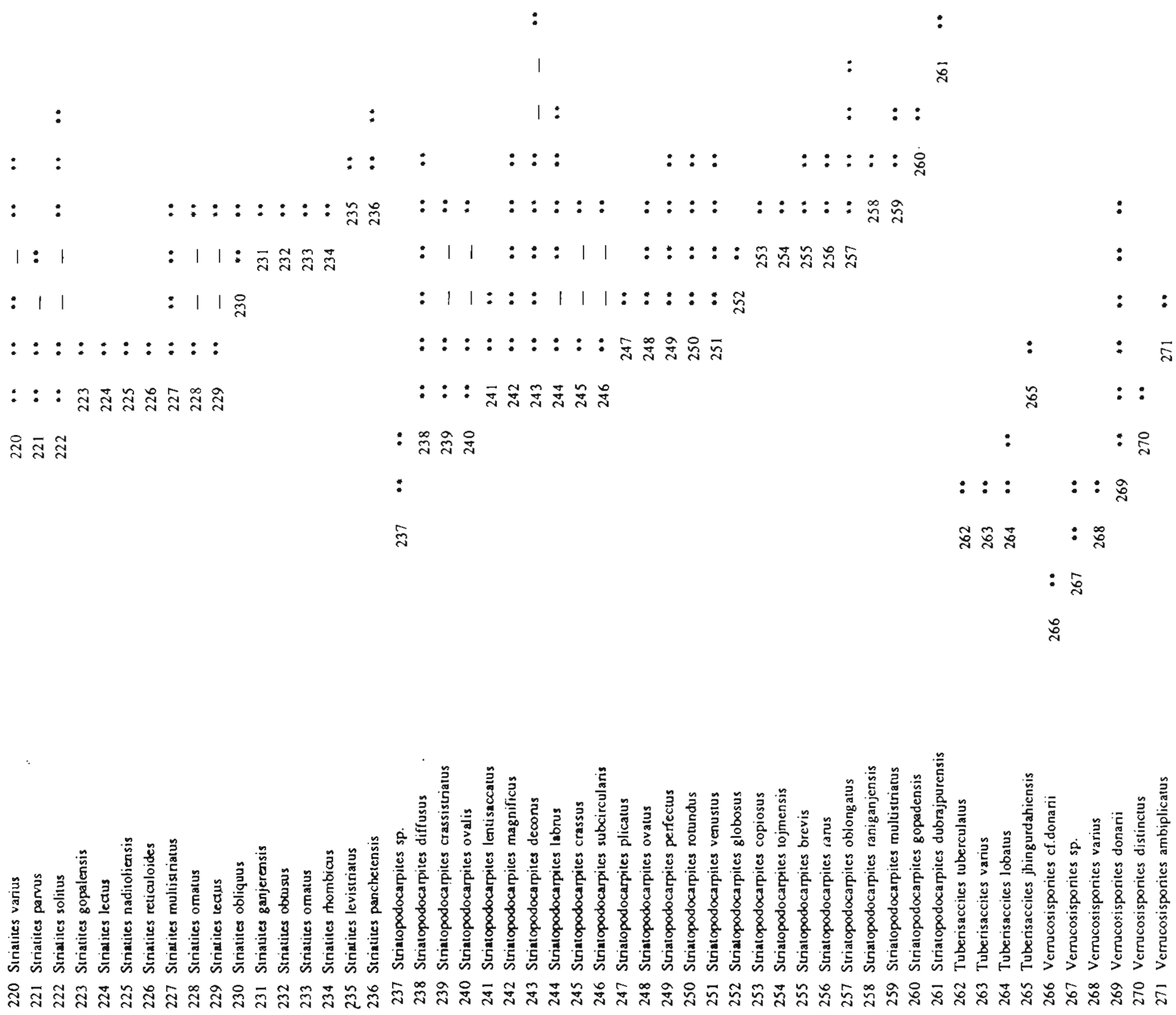
220 Striatites varius
221 Striatites parvus
222 Striatites solitus
223 Striatites gopalensis
224 Striatites lectus
225 Striatites nadiolensis
226 Striatites reticuloides
227 Striatites multistriatus
228 Striatites ornatus
229 Striatites tectus
230 Striatites obliquus
231 Striatites ganjerensis
232 Striatites obtusus
233 Striatites ornatus
234 Striatites rhombicus
235 Striatites levistriatus
236 Striatites panchetensis
237 Striatopodocarpites sp.
238 Striatopodocarpites diffusus
239 Striatopodocarpites crassistriatus
240 Striatopodocarpites ovalis
241 Striatopodocarpites lentisaccatus
242 Striatopodocarpites magnificus
243 Striatopodocarpites decorus
244 Striatopodocarpites labrus
245 Striatopodocarpites crassus
246 Striatopodocarpites subcircularis
247 Striatopodocarpites plicatus
248 Striatopodocarpites ovatus
249 Striatopodocarpites perfectus
250 Striatopodocarpites rotundus
251 Striatopodocarpites venustus
252 Striatopodocarpites globosus
253 Striatopodocarpites copiosus
254 Striatopodocarpites tojmensis
255 Striatopodocarpites brevis
256 Striatopodocarpites rarus
257 Striatopodocarpites oblongatus
258 Striatopodocarpites raniganjensis
259 Striatopodocarpites multistriatus
260 Striatopodocarpites gopadensis
261 Striatopodocarpites dubrajpurensis
262 Tuberisaccites tuberculatus
263 Tuberisaccites varius
264 Tuberisaccites lobatus
265 Tuberisaccites jhingurdahiensis
266 Verrucosisporites cf.donarii
267 Verrucosisporites sp.
268 Verrucosisporites varius
269 Verrucosisporites donarii
270 Verrucosisporites distinctus
271 Verrucosisporites ambiplicatus

Table 3 — *Contd.*

Index : ** Damodar and Rajmahal, ++ Jaisalmer and Kachchh, \\ Cauvery, — not recorded.

Palyno-species	Period	L. Permian						U. Permian			L. Triassic		M. Triassic	U. Triassic				L. Juras	M-U. Juras	L.-Cretaceous			J/C	L. Cretaceous	
	Formation	Talchir			Karhar-bari	Barakar		Kulti	Raniganj		Panchet		S.-Panchet	Dubrajpur			Pre-Lathi	Lathi	J, JH, JHU	Katrol	Siv-ganga	Bhuj	DUBR contd.	Raj-mahal	
	Assemblage-zone	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	"XIX"	XIX	XX	XX "D-E"	XX "F"	XX "G"
272 Verrucosisporites diversus									272	**															
273 Verrucosisporites gondwanensis									273	**	**														
274 Verrucosisporites narmianus									274	**	**	**	**	**											
275 Verrucusisporites warti										275	**														
276 Verrucosisporites cf. conatus										276	**	**													
277 Verrucosisporites morulae										277	**	**													
278 Verrucosisporites triassicus										278	**	**	**												
279 Verrucosisporites densus										279	**	**	**	**											
280 Verrucosisporites bosei										280	**	**	—	**											
281 Verrucosisporites racemus													281	**											
282 Verrucosisporites camarvonensis													282	**											
283 Verrucosisporites kazgigaonensis													283	**											
284 Verrucosisporites dubius																						284	**		
285 Verticipollenites mineosus					285	**	**	**																	
286 Verticipollenites finitimus					286	**	**	**	**	**															
287 Verticipollenites gibbosus					287	**	**	**	**	**															
288 Verticipollenites subcircularis					288	**	**	**	**	**															
289 Verticipollenites debilis						289	**	**	**	**															
290 Verticipollenites secretus						290	**	**	**	**															
291 Verticipollenites crassus							291	**	—	**															
292 Verticipollenites oblongus								292	**	**															

first and last occurrences of some species in the Damodar-Rajmahal depositional domain, and it is envisaged that these limits can be identified by one or more species cited here.

Some of the important species pertaining to various zones are illustrated in Plates 1 to 10; for other species citations of original authors are given in Table 2.

I. *Potonieisporites neglectus* Assemblage-Zone

This is the lowermost assemblage zone found in the basal beds of Talchir Formation. The least diversified flora contains mainly girdling radial and bilateral monosaccate pollen. The striate-disaccates are not recorded.

The earliest palynoflora of Permian in India is marked by this zone. The top of this assemblage zone is defined by the oldest occurrence of *Crescentipollenites fuscus* (= *C. talchirensis*) and several first appearances, e.g., *Faunipollenites perexiguus, Tuberisaccites tuberculatus, Sahnites thomasi, Jayantisporites* sp., *Parasaccites bilateralis.*

Composition—Plicatipollenites gondwanensis, P indicus, Parasaccites densicorpus, P. obscurus, Potonieisporites neglectus, P. crassus, and *P. magnus* constitute the major population, *Verrucosisporites*—type of spores are very sporadic in occurrence.

Horizon—Talchir Formation.

Remarks—This assemblage zone is recognised by the absence of striate-disaccate pollen and preponderance of *Plicatipollenites, Parasaccites* and *Potonieisporites.* When compared with the generic acme-zones already known from Lower Permian, the *Potonieisporites neglectus* Assemblage-Zone constitutes a part of the oldest segment of Composition-I: *Plicatipollenites-Parasaccites* Zone-A, of Tiwari and Tripathi (1988).

Reference section—Lele, 1975 (text-figure 1, p. 220), Dudhi River Section; Sample nos. B 17/662, B 19/662; Siltstone units above the first boulder bed at the metamorphic basement, West Bokaro Coalfield, Bihar.

II. *Plicatipollenites gondwanensis* Assemblage-Zone

At this level the palynoflora suddenly diversifies qualitatively. A variety of striate-disaccates, monosaccates and zonate spore-pollen taxa make their appearance. The distinction from the *Potonieisporites neglectus* Assemblage-Zone is sharp. At generic level, *Parasaccites* and *Plicatipollenites* continue to dominate the population.

The base of this assemblage zone is defined by the oldest occurrence of *Crescentipollenites fuscus, Tuberisaccites tuberculatus* and *Caheniasaccites densus* (and FAD of several other species shown in Table 2). First occurrence of *Microbaculispora tentula* and *Microfoveolatispora foveolata* and LAD of *Parasaccites densicorpus* and *Potonieisporites crassus* (Table 2) mark the top of this assemblage zone.

Composition—Plicatipollenites gondwanensis, Callumispora gretensis, Parasaccites bilateralis, Caheniasaccites densus, Crescentipollenites fuscus (= C. talchirensis), Jayantisporites cf. *conatus, Tuberisaccites tuberculatus, Potonieisporites magnus.*

Horizon—Talchir Formation.

Remarks—With reference to the generic acme-zone, the *Plicatipollenites gondwanensis* Assemblage-Zone is a part of Composition-I : *Plicatipollenites-Parasaccites* Zone-A, of Tiwari and Tripathi (1988). The species acme-zone defined by the epiboles of number of species in the genera *Plicatipollenites* and *Potonieisporites* are recorded in this zone (Table 3).

Reference section—Lele, 1975 (text-fig. 1, p. 220), Dudhi River Section, Sample no. B 9/662, Siltstone below the last boulder bed in the section; West Bokaro Coalfield, Bihar.

III. *Parasaccites korbaensis* Assemblage-Zone

This zone represents a level of further diversification in having several new entries, such as pteridophytic apiculate and lycopsid spores, ginkgo-cycadoid pollen, and several monosaccates. First occurrence of *Divarisaccus lelei* and those of several other species (Table 2) define the base, and the oldest occurrence of *Crucisaccites monoletus* marks the top of this assemblage zone.

Composition—Parasaccites korbaensis, Callumispora gretensis, Jayantisporites indicus, J. pseudozonatus, Tuberisaccites indicus, Circumstriatites obscurus, C. talchirensis, Divarisaccus lelei, Ginkgocycadophytus novus, Plicatipollenites spp., *Parasaccites* spp. (as shown in Table 2).

Horizon—Talchir Formation.

Remarks—As regards the generic acme-zone, the Composition-I : *Parasaccites-Plicatipollenites* Zone-B of Tiwari and Tripathi (1988) encompasses the *Parasaccites korbaensis* Assemblage-Zone since the monosaccate group still continues to dominate numerically. The *Parasaccites, Sahnites, Tuberisaccites, Jayantisporites* and *Circumstriatites* spp. acme-zones are documented in this assemblage zone (Table 3). This incidence is a characteristic feature.

Reference section—Lele and Makada, 1972 (pp. 62, 63), section exposed in Patharjore Nala, Jayanti Coalfield, Bihar.

PERIOD	EPOCH	FORMATION	ZONE NUMBERS	SPORE-POLLEN SPECIES ASSEMBLAGE-ZONE	SPP. ACME-ZONE (Epibole of species no. in the genus.)	COMPOSITION BASED ON GENERIC DOMINANCE		
CRETACEOUS	LOWER	RAJMAHAL	XX	*Microcachryidites antarcticus*	*Araucariacites, Podocarpidites*	[7] *Assemblage from Basko and Sakrigali ghat* [4] *Assemblage F* [4] *Assemblage D, E*		
			XIX	*Callialasporites segmentatus*	*Callialasporites, Podocarpidites*	[6] *Callialasporites segmentatus Zone*		
JURASSIC	U. M.	JHURAN JHUMARA JAISALMER	XVIII	*Callialasporites trilobatus*		[5] *Callialasporites trilobatus Zone*		
	L.	LATHI	XVII	*Classopollis minor*		[5] *Classopollis-Gliscopollis Zone*		
TRIASSIC	UPPER	PRE-LATHI	XVI	*Rhaetipollis germanicus*		[5] *R. germanicus Assemblage IX*		
		PANCHET S.PANCHET DUBRAJPUR	XV	*Dubrajisporites triassicus*	*Dubrajisporites*	[4] *Assemblage C*		
			XIV	*Brachysaccus ovalis*	*Brachysaccus*	[4] *Assemblage B*		
			XIII	*Rajmahalispora rugulata*	*Rajmahalispora*	[4] *Assemblage A*		
	M.		XII	*Goubinispora morandavensis*		[3] *Goubinispora Zone*		
	LOWER		XI	*Playfordiaspora cancellosa*	*Lunatisporites, Lundbladispora*	[1] VI *Lundbladi.-Densoi. Zone (D)* *Lunati.-Verrucosi. Zone (C)* *Verrucosi.-Callumi. Zone (B)*	[2] P IV [2] P III [2] P II	[8] *P. cancellosa Assemblage II*
			X	*Klausipollenites schaubergerii*	*Verrucosisporites*	*Striato.-Klausi. Zone (A)*	[2] P I	[8] *K. schaubergeri Assemblage I*
PERMIAN	UPPER	RANIGANJ	IX	*Densipollenites magnicorpus*	*Crescenti., Striatopodo., Vertici., Densipoll.*	[1] V *Striato.-Crescenti. Zone (D)* *Striato.-Densi. Zone (C)*	[2] R I A [2] R I B	
			VIII	*Gondisporites raniganjensis*	*Densipollenites, Verticipollenites, Scheuringipollenites*	*Striato.-Gondi. Zone (B)* *Striato.-Fauni. Zone (A)*	[2] R II A [2] R II B	
		KULTI	VII	*Densipollenites indicus*	*Densipollenites, Verticipollenites, Scheuringipollenites*	[1] V *Densipollenites-Striatopodo. Zone (A)*		
	LOWER	BARAKAR	VI	*Faunipollenites varius*	*Faunipollenites, Barakarites, Microbaculispora, Scheuringi.*	[1] III *Faunipollenites-Scheuringi. Zone (B)*		
			V	*Scheuringipollenites barakarensis*	*Scheuringipollenites*	*Scheuringi.-Faunipollenites Zone (A)*		
		KARHAR-BARI	IV	*Crucisaccites monoletus*	*Caheniasaccites*	[1] II *Parasaccites-Callumispora Zone (B)* *Callumispora-Parasaccites Zone (A)*		
		TALCHIR	III	*Parasaccites korbaensis*	*Parasaccites, Tuberisaccites, Jayantisporites, Circumstriatites*	[1] I *Parasaccites-Plicatipollenites Zone (B)*		
			II	*Plicatipollenites gondwanensis*	*Plicatipollenites, Potonieisporites*	*Plicatipollenites-Parasaccites Zone (A)*		
			I	*Potonieisporites neglectus*				

Text-figure 1—Composite Table depicts the correlation between spore-pollen Species Assemblage Zones and Generic Acme-Zones. The sequence of formations has been compositely structured on the basis of sequences in Damodar Graben, Rajasthan and Kachchh and Rajmahal Basin to represent a complete span of Gondwana Sequence. For tagging with chronostratigraphic scale, a conventional scheme is followed (GSI Lexicon, 1977). The ordinal number in the last column refers to the original references for various compositions, as follows: **1.** Tiwari & Tripathi, 1988; **2.** Tiwari & Singh, 1986; **3.** Tiwari & Rana, 1980; **4.** Tiwari, Kumar & Tripathi, 1984; **5.** Koshal, 1975; **6.** Venkatachala, Sharma & Jain, 1972; Venkatachala, 1974; **7.** Sah & Jain, 1965; **8.** Maheshwari, Kumaran & Bose, 1978.

IV. *Crucisaccites monoletus* Assemblage-Zone

This zone is related with *Parasaccites korbaensis* Assemblage-Zone by virtue of the continuing abundance of the monosaccate pollen but it aquires new character by the first appearance of several and varied striate-nonsaccate, striate-disaccate and apiculate trilete species. The base of this assemblage zone is marked as FAD of

Tiwariasporis gondwanensis, Marsupipollenites triradiatus, Welwitschiapites magnus, and *Stellapollenites talchirensis*, while the oldest records of *Rhizomaspora indica, Indotriradites korbaensis* and *Dentatispora gondwanensis* defines the top.

Composition—Crucisaccites monoletus, C. latisulcatus, Callumispora gretensis, C. barakarensis, Caheniasaccites decorus, Parasaccites obscurus, P. korbaensis, Crescentipollenites rhombicus, C. limpidus, Verrucosisporites donarii, Tiwariasporis gondwanensis, Distriamonocolpites circularis, Stellapollenites talchirensis.

Horizon—Karharbari Formation.

Remarks—In relation to the generic acme-zone, the *Crucisaccites monoletus* Assemblage-Zone compares with the Composition II of Tiwari and Tripathi (1988). However, two subdivisions of Composition II : *Callumispora-Parasaccites* Zone-A and *Parasaccites-Callumispora* Zone-B were identified but it is not, as yet, possible to define these units on the basis of species occurrence. The present zone is also characterised by the *Caheniasaccites* spp. Acme-Zone.

Reference section—Lele and Makada, 1974 (p. 82), Section along tributary of Patharjore Nala, Jayanti Coalfield, Bihar; Tiwari, 1973b (map 1, p. 168), Section along Sonbad Nala, Sample no. 17-35 and Section along Pusai Nala Sample no. 8, Raniganj Coalfield, Bihar.

V. *Scheuringipollenites barakarensis* Assemblage-Zone

A marked change is recorded in this assemblage zone in relation to the preceding *Crucisaccites monoletus* Assemblage-Zone; the abundance of monosaccate pollen is replaced by the nonstriate disaccate taxa *Scheuringipollenites* spp. The base of this assemblage zone is marked by the oldest record of *Rhizomaspora indica, Indotriradites sparsus, Striatites communis, Verticipollenites gibbosus* and *Densipollenites indicus*, while the top is demarcated by the oldest occurrence of *Corisaccites alutas, Horriditriletes curvibaculosus* and *Barakarites indicus.*

Composition—Scheuringipollenites barakarensis, S. maximus, Faunipollenites varius, Corisaccites vanus, Striasulcites tectus, Weylandites lucifer, Paravesicaspora indica, Primuspollenites levis.

Horizon—Lower Barakar Formation.

Remarks—The *Scheuringipollenites barakarensis* Assemblage-Zone compares with the Composition III : *Scheuringipollenites-Faunipollenites* Zone-A of Tiwari and Tripathi (1988) in respect of the generic acme-zone. The epibole of species in the genus *Scheuringipollenites* begins in this zone and continues in the next three succeeding assemblage zones (Table 3).

Reference section—Tiwari, 1973b, (map 1; p. 168); Section along Pusai Nala, Sample No. 10-46/5, Raniganj Coalfield, Bihar.

VI. *Faunipollenites varius* Assemblage-Zone

Qualitatively, a diverse array of species by way of new appearances (FAD) of several striate-saccates and nonsaccates, colpates and apiculate triletes (zonates and azonates) is recorded at this level. The oldest occurrence of *Didecitriletes horridus, Striatopodocarpites tiwarii, Horriditriletes curvibaculosus, Schizopollis disaccoides* and *Cyclogranisporites gondwanensis* defines the base of the assemblage zone. The oldest occurrence of *Verticipollenites crassus, Densipollenites densus, Striatopodocarpites ovatus, Cyclobaculisporites minimus* and *Gondisporites raniganjensis* delimits the top line (Table 2).

Composition—Barakarites indicus, Microbaculispora tentula, M. gondwanensis, M. indica, Brevitriletes communis, Cyclogranisporites gondwanensis, Striatites communis, Lahirites rarus, Corisaccites alutas, Striomonosaccites ovatus, Schizopollis disaccoides, Vittatina lata, Praecolpatites sinuosus (Table 2).

Horizon—Upper Barakar Formation.

Remarks—This zone relates with the generic acme-zone described as Composition-III : *Faunipollenites-Scheuringipollenites* Zone-B by Tiwari and Tripathi (1988). This zone is also diagnosed by the epiboles of the number of species in *Barakarites, Lahirites, Microfoveolatispora, Horriditriletes, Faunipollenites, Microbaculispora, Primuspollenites* and *Striatites*. The *Scheuringipollenites* spp. Acme-Zone which started in the preceding zone also continues.

Reference section—Tiwari, 1973b (map 1; p. 168); Section along Khudia Nala, Sample no. 47, 67a-81, Raniganj Coalfield, Bihar.

VII. *Densipollenites densus* Assemblage-Zone

This zone is identified on the basis of several first occurrences of species (Table 2). The oldest occurrence of *Densipollenites densus* defines the base while the oldest occurrence of *Didecitriletes ericianus, Verticipollenites oblongus* and *Distriatites bilateris* marks the top of this zone.

Composition—Striatites notus, S. communis, Densipollenites invisus, D. densus, D. brevis, D. indicus, Striatopodocarpites ovatus, S. decorus, Verticipollenites crassus, Gondisporites raniganjensis, Bharadwajipollis striatus, *Verrucosisporites ambiplicatus.*

Horizon—Kulti Formation.

Remarks—Beside the continuing epibole of species in *Scheuringipollenites,* the begining of species Acme-Zone of genera *Densipollenites* and *Verticipollenites* is recorded here (Table 3), which continues into the next younger assemblage zone. With regard to the generic acme-zone, the *Densipollenites densus* Assemblage-Zone relates well with the Composition IV: *Densipollenites-Striatopodocarpites* Zone-A, delimited by Tiwati and Tripathi (1988).

Reference section—Tiwari *et al.* (1981, map 1, p. 221): palynological composition studied in Jamunia River section from levels at sample nos. JMR-1 to JMR-26, Jharia Coalfield, Bihar. The strata is identified by being devoid of major coal seams, which are otherwise present in the underlying Barakar Formation and overlying Raniganj Formation. With these formations the contact of the reference strata is faulted (Fox, 1930, pp. 77-89).

VIII. *Gondisporites raniganjensis* Assemblage-Zone

The oldest occurrence of *Distriomonosaccites ovalis, Distriatites bilateris* and *Verticipollenites oblongus* defines the base and sporadic as well as unsteady first occurrence of *Lundbladispora brevicula, Playfordiaspora cancellosa. Lunatisporites diffusus* marks the top of the zone.

Composition—Several of the disaccate pollen species found in the preceding assemblage zone continue to prevail in the present zone. A further diversification is evident in this assemblage; additionally, *Indospora clara, Cyclobaculisporites minimus, Microfoveolatispora gondwanensis, Gondisporites raniganjensis* occur significantly (Table 2).

Horizon—Raniganj Formation (Late Permian).

Remarks—In the terms of generic acme-zone, *Gondisporites raniganjensis* Assemblage-Zone is related with the Composition V : *Striatopodocarpites-Faunipollenites* Zone-A, and *Striatopodocarpites-Gondisporites* Zone-B delimited by Tiwari and Tripathi (1988), and with the Assemblage R-II, A and B of Tiwari and Singh (1986). However, such subdivisions are possible only on the basis of generic percentage frequency. *Gondisporites raniganjensis* Assemblage-Zone exhibits the continuity of *Verticipollenites, Scheuringipollenites* and *Densipollenites* spp. acme-zones.

Reference section—Rana and Tiwari, 1980 (pp. 113, 114); Bore hole RNM-3, (23°35′45″ : 87°13′55″), 912 to 481 m depth; Raniganj Coalfield, Bihar.

IX. *Densipollenites magnicorpus* Assemblage-Zone

The basic nature of this assemblage zone continues to be broadly similar as in *Gondisporites raniganjensis* Assemblage-Zone. However, sporadic appearance of *Lundbladispora brevicula, L. microconata, Lunatisporites diffusus* and *Klausipollenites schaubergeri* marks the identity of this assemblage zone.

The prominence of *Densipollenites magnicorpus* and the first appearance of *Gondisporites reticulatus, Klausipollenites schaubergeri* and *Lunatisporites diffusus* define the base and LADs of *Gondisporites raniganjensis* and *Densipollenites magnicorpus* marks the top of this assemblage zone.

Composition—*Crescentipollenites gondwanensis, C. sellingi, C. bengalensis, C. fuscus, Densipollenites densus, D. magnicorpus, D. indicus, D. invisus, Welwitschiapites tenuis, Indospora macula, Klausipollenites schaubergeri, Lundbladispora brevicula, Gondisporites reticulatus.*

Horizon—Raniganj Formation (latest Permian).

Remarks—On the ground of generic dominance the *Densipollenites magnicorpus* Assemblage-Zone corresponds to the Composition V : *Striatopodocarpites-Densipollenites* Zone-C and *Striatopodocarpites-Crescentipollenites* Zone-D of Tiwari and Tripathi (1988), and Zone-RI, A and B of Tiwari and Singh (1986). The epiboles of number of species in the genera *Crescentipollenites* and *Striatopodocarpites* appear in this assemblage zone, while *Densipollenites* and *Verticipollenites* spp. acme-zones

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PLATE 1 →

(All photomicrographs are × 500)

Lower Permian palynotaxa.

1. *Potonieisporites neglectus*
2. *Plicatipollenites gondwanensis*
3. *Tuberisaccites tuberculatus*
4. *Parasaccites bilateralis*
5. *Plicatipollenites trigonalis*
6. *Parasaccites densicorpus*
7. *Plicatipollenites indicus*
8. *Callumispora gretensis*
9. *Sahnites thomasi*
10. *Jayantisporites conatus.*

Species in 1, 2, 6, 7 signify *Potonieisporites neglectus* Assemblage-Zone, FAD of species in 3-5, 8-10 define *Plicatipollenites gondwanensis* Assemblage-Zone.

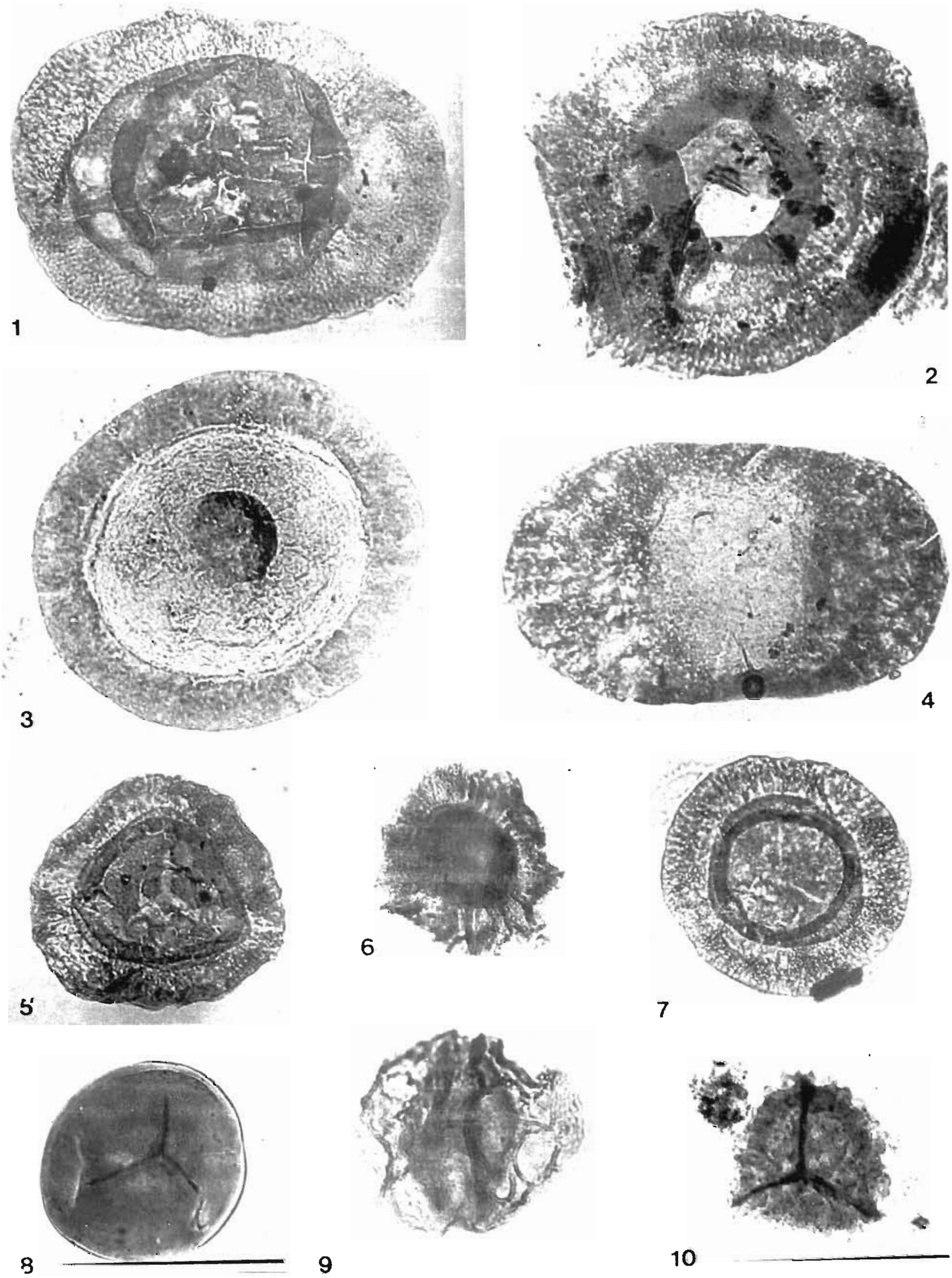

PLATE 1

continue from the preceding zone.

Reference section—Bharadwaj and Tiwari, 1977 (map 1; pp. 27, 28); Bore-hole NCRD-6, depth 358.40 to 287.30 m, Raniganj Coalfield, Bihar; Rana & Tiwari, 1980 (pp. 113, 114); Bore-hole RNM-3 (23°35'45" : 87°30'55"), depth 422 to 218 m, East Raniganj Coalfield, West Bengal.

X. *Klausipollenites schaubergeri* Assemblage-Zone

(*Klausipollenites schaubergeri* Assemblage-I, Maheshwari *et al.*, 1978).

This assemblage zone shows the continuation of several species, particularly of striate disaccates, from the preceding assemblage zone. The cavate cingulate-zonate spores, non-striate disaccate and taeniate pollen species which made their sporadic appearance in *Densipollenites magnicorpus* Assemblage-Zone become consistent and diversified in the *Klausipollenites schaubergeri* Assemblage-Zone.

The base of the present zone is marked by the consistent appearance of *Verrucosisporites triassicus, V. narmianus* and *Lunatisporites pellucidus*. The oldest occurrence of *Indotriradites mamillatus, Verrucosisporites densus, Lundbladispora baculata, L. densispinosa* defines the top of this assemblage zone.

Composition—Crescentipollenites fuscus, Striatopodocarpites decorus, Callumispora fungosa, Densipollenites densus, Lundbladispora brevicula, Densoisporites playfordii, Playfordiaspora cancellosa, Alisporites asansoliensis, Klausipollenites schaubergeri, Lunatisporites diffusus and *L. ovatus* (Table 2).

Horizon—Lower Panchet Formation (Early Scythian).

Remarks—The definition of *Klausipollenites schaubergeri* Assemblage-I of Maheshwari, Kumaran and Bose (1978) is elaborated here. This assemblage zone encompasses the generic acme-zone Composition VI : *Striatopodocarpites-Klausipollenites* Zone-A delimited by Tiwari and Tripathi (1988) and Assemblage-PI of Tiwari and Singh (1986). The *Verrucosisporites* spp. Acme-Zone is also recorded in the present assemblage zone (Table 3).

Reference section—Bharadwaj and Tiwari, 1977 (map 1; pp. 27, 28); Bore-hole NCRD-6, 215 m depth; Raniganj Coalfield, Bihar.

XI. *Playfordiaspora cancellosa* Assemblage-Zone

(*Playfordiaspora cancellosa* Assemblage-II, Maheshwari *et al.*, 1978).

This assemblage zone reveals further proliferation of species which appeared for the first time in *Klausipollenites schaubergeri* Assemblage-Zone. A decline in the prominence of striate disaccate species is also recorded. Several new entries of taeniate disaccate, cavate-zonate and apiculate trilete species are documented (Table 2).

The base of this assemblage zone is marked by the oldest common occurrence of *Lunatisporites pellucidus, L. ovatus* and several species of *Lundbladispora* and *Densoisporites* as shown in Table 3. At present, it is rather difficult to define the top of this assemblage-zone as the Middle Triassic flora is poorly known; however, the dominance of *Goubinispora morondavensis* and *G. indica* in the subsequent assemblage zone identifies the top.

Composition—Crescentipollenites fuscus, Lunatisporites pellucidus, L. ovatus, L. noviaulensis, Lundbladispora warti, L. densispinosa, L. microconata, Convertubisporites contactus, Triplexisporites playfordii, Verrucosisporites narmianus, Densoisporites playfordii, Playfordiaspora cancellosa, Ringosporites ringus, etc. (Table 2).

Horizon—Panchet Formation (Scyathian).

Remarks—The definition of *Playfordiaspora cancellosa* Assemblage-II of Maheshwari, Kumaran and Bose (1978) is revised and enlarged here. It also incorporates the *Decisporis variabilis* Assemblage-III of Maheshwari *et al.* (1978) as their delimitation is not feasible at present. This assemblage zone compares well with the Composition VI : *Verrucosisporites-Callumispora* Zone-B, *Lunatisporites-Verrucosisporites* Zone-C and *Lundbladispora-Densoisporites* Zone-D delimited by

→

PLATE 2

(All photomicrographs are × 500)
Lower Permian palynotaxa.

1. *Parastriopollenites segmentatus*
2. *Divarisaccus lelei*
3. *Microbaculispora tentula*
4. *Stellapollenites talchirensis*
5. *Jayantisporites pseudozonatus*
6. *Cabeniasaccites decorus*
7. *Circumstriatites talchirensis*
8. *Tuberisaccites lobatus*
9. *Parasaccites korbaensis*
10. *Crucisaccites monoletus*
11. *Cabeniasaccites distinctus*.

FAD of species in 1-9, 11 define *Parasaccites korbaensis* Assemblage-Zone and FAD of species in 10 marks *Crucisaccites monoletus* Assemblage-Zone.

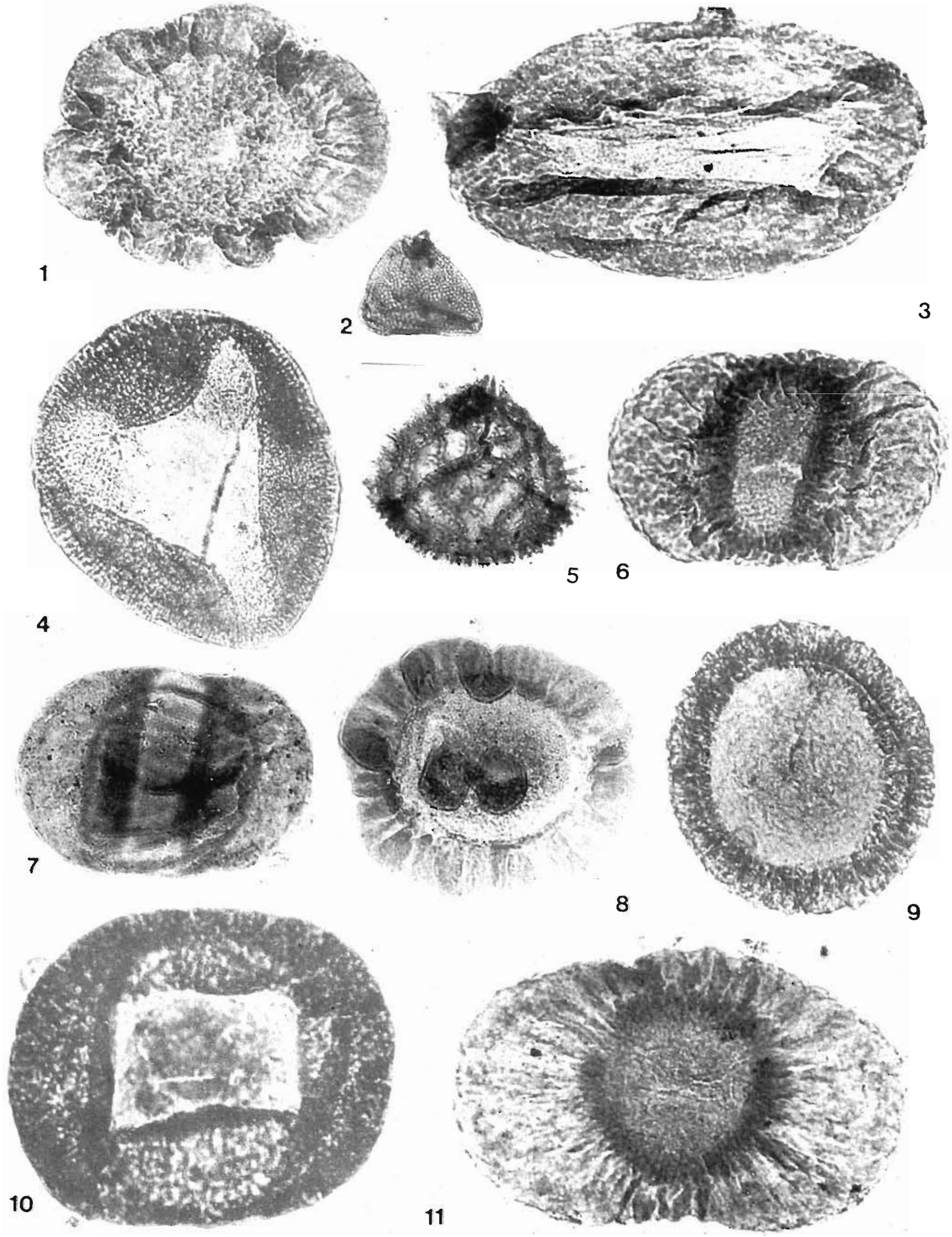

PLATE 2


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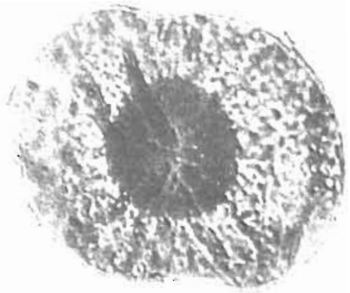
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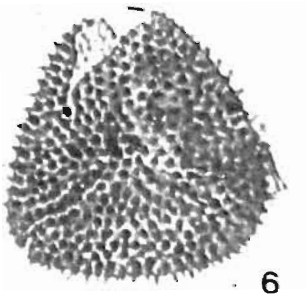
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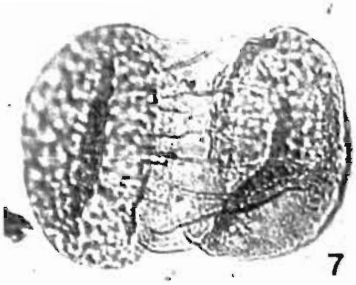
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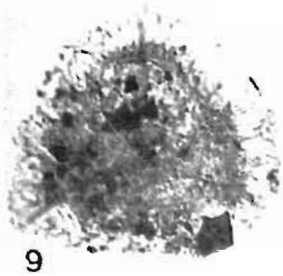
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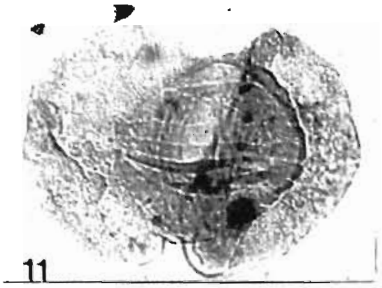
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PLATE 3

(All photomicrographs are × 500)

Lower Permian spore-pollen species

1. *Scheuringipollenites barakarensis*
2. *Rhizomaspora indica*
3. *Microbaculispora gondwanensis*
4. *Striatites communis*
5. *Brevitriletes communis*
6. *Didecitriletes horridus*
7. *Striatopodocarpites decorus*
8. *Verticipollenites gibbosus*
9. *Indotriradites korbaensis*
10. *Schizopollis wodehousei*
11. *Striatites solitus*
12. *Faunipollenites varius*
13. *Striasulcites tectus*
14. *Distriatites distinctus*

FAD of species in 1, 2, 4, 9, 12 marks *Scheuringipollenites barakarensis* Assemblage-Zone and FAD of species in 3, 6, 8, 10, 11, 13, 14 define the *Faunipollenites varius* Assemblage Zone

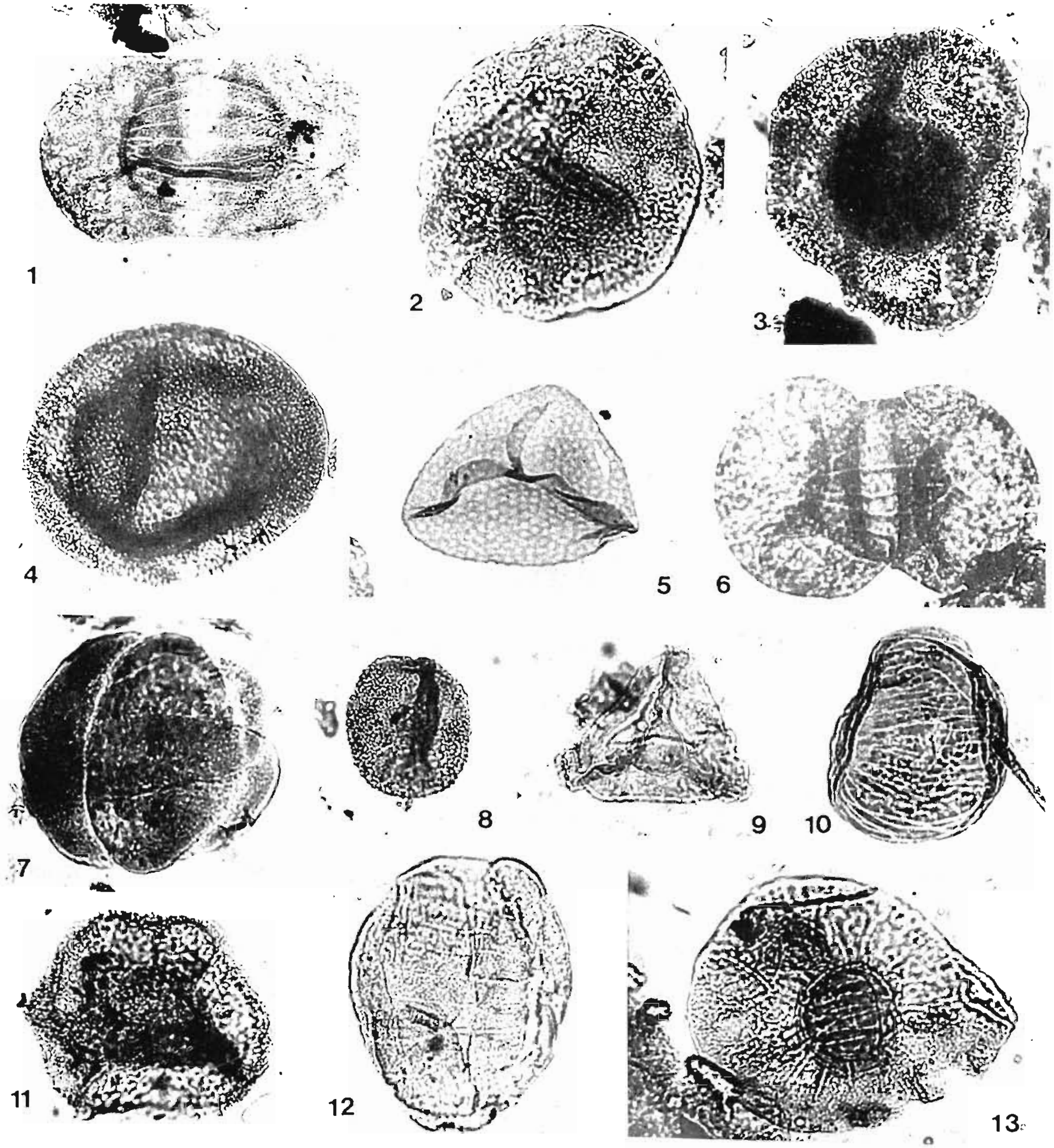

PLATE 4

(All photomicrographs are × 500)
Characteristic Upper Permian palynotaxa.

1. *Striatopodocarpites magnificus*
2. *Densipollenites indicus*
3. *Densipollenites densus*
4. *Densipollenites magnicorpus*
5. *Microfoveolatispora raniganjensis*
6. *Crescentipollenites fuscus*
7. *Gutullapollenites hannonicus*
8. *Cyclobaculisporites minutus*
9. *Indospora clara*
10. *Marsupipollenites striatus*
11. *Gondisporites raniganjensis*
12. *Distriamonocolpites ovalis*
13. *Distriamonosaccites ovalis*

Tiwari and Tripathi (1988) based on generic acme-zone.

The compositions delimited by Tiwari and Singh (1986) as P-II, P-III and P-IV also equate with the present assemblage zone. The distinctive nature of the *Playfordiaspora cancellosa* Assemblage-Zone is further corroborated with the record of *Lunatisporites* and *Lundbladispora* spp. acme-zones (Table 3) during the same span.

Reference sections—A complete representation of this assemblage zone is not recorded in one section, hence three sequences are cited: Bharadwaj and Tiwari, 1977 (map 1; pp. 27, 28); Bore-hole NCRD-6, depth 123 to 86 m; Raniganj Coalfield, Bihar; Singh and Tiwari, 1982 (p. 181), Bore-hole RAD-2, depth 460-260 m, Raniganj Coalfield, West Bengal; Tiwari and Singh, 1983 (p. 228), Bore-hole RAD-5; depth 481-455 m; East Raniganj Coalfield, West Bengal.

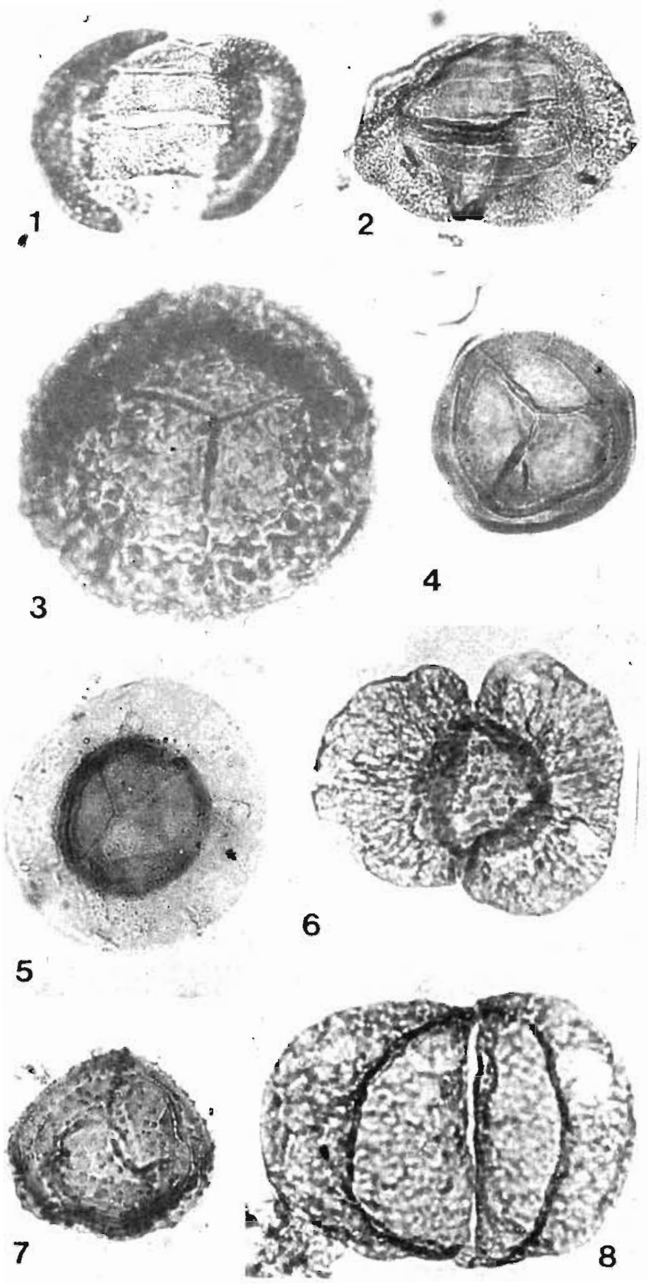

PLATE 5

(All photomicrographs are × 500)

Lower Triassic spore-pollen species defining *Klausipollenites schaubergeri* Assemblage-Zone.

1. *Lunatisporites pellucidus*
2. *Lunatisporites diffusus*
3. *Verrucosisporites narmianus*
4. *Densoisporites playfordii*
5. *Playfordiaspora cancellosa*
6. *Rhizomaspora biharia*
7. *Lundbladispora microconata*
8. *Alisporites asansoliensis*

XII. *Goubinispora morondavensis* Assemblage-Zone

The dominance of *Goubinispora* has been identified to be individualistic for this assemblage zone. From the *Playfordiaspora cancellosa* Assemblage-Zone the present zone is differentiated on the basis of restricted species—*Lundbladispora reticulata, L. willmotti, Playfordiaspora annulata, Carnisporites raniganjensis.*

The general composition, beside the above species, is marked by the presence of *Lunatisporites noviaulensis, L. pellucidus, Lundbladispora microconata, Verrucosisporites densus, Guttatisporites ambiguus, Nevesisporites vallatus, Novitasporites triangulus* and *Ringosporites fossulatus.* Certain species which are present in *Playfordiaspora cancellosa* Assemblage-Zone are absent from the present zone, viz., *Lundbladispora baculata, L. densispinosa, Ringosporites ringus, Lunatisporites damudicus, L. ovatus.*

The next younger assemblage-zone (i.e., *Rajmahalispora rugulata* Assemblage-Zone) recognised in the present account from the Rajmahal Basin can be differentiated by the presence of *Foveosporites, Polypodiisporites, Verrucosisporites racemus, Converrucosisporites* and *Rajmahalispora.* However, so far these two zones have not been found in a single sequence.

Horizon—Supra-Panchet, *pars* (Early Middle Triassic).

The palynological details studied from bore-hole RNM-4 (23°34′30″ : 87°13′03″); depth 59 m, East Raniganj Coalfield, West Bengal is considered for reference (Tiwari & Rana, 1984).

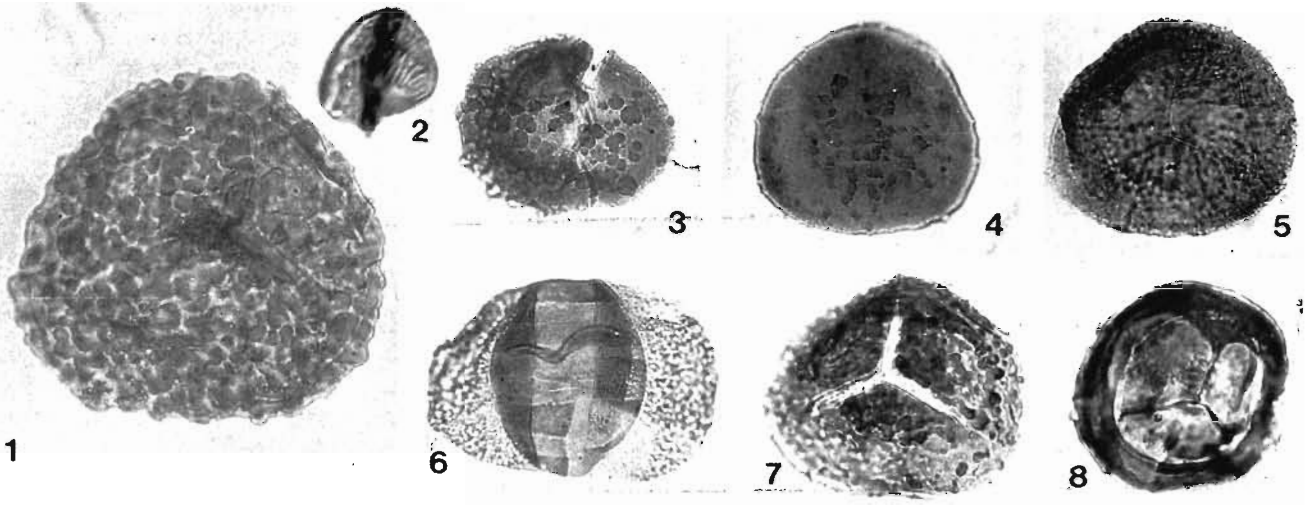

PLATE 6

(All photomicrographs are × 500)

Lower Triassic palynotaxa characterising *Playfordiaspora cancellosa* Assemblage-Zone.

1. *Verrucosisporites densus*
2. *Triplexisporites playfordii*
3. *Verrucosisporites warti*
4. *Lundbladispora densispinosa*
5. *Lundbladispora raniganjensis*
6. *Lunatisporites noviaulensis*
7. *Convertubisporites contactus*
8. *Ringosporites ringus*. × 750.

XIII. *Rajmahalispora rugulata* Assemblage-Zone

The unique trilete spore *Rajmahalispora* represented by the species *R. triassica, R. rugulata* and *R. reticulata* characterises this assemblage zone. Besides, *Foveosporites mimosae, F. triassicus, Converrucosisporites lunzensis, Chordasporites minutus, Orbella indica, Playfordiaspora cancellosa, Lunatisporites pellucidus*, etc. contribute to the composition.

From the next younger assemblage zone—*Brachysaccus ovalis* Assemblage-Zone, recognised in the present account, the present zone can be differentiated by the absence of the genera *Convolutispora, Conbaculatisporites, Staurosaccites* and *Brachysaccus*, etc. On the basis of epibole of species the *Rajmahalispora* spp. Acme-Zone is also recorded in this assemblage zone.

Horizon—Dubrajpur Formation, *pars* (Carnian).

The palynological details studied from Bore-hole RJR-2, Rajmahal Basin, Bihar, depth 842-671.05 m (Tiwari *et al.*, 1984, map 1; pp. 208, 212-214) is considered here for reference.

XIV. *Brachysaccus ovalis* Assemblage-Zone

The genera *Staurosaccites* and *Brachysaccus* are abundantly represented in this zone, although the species of non-striate disaccates (*Satsangisaccites, Klausipollenites*) continues to occur.

composition—*Lunatisporites pellucidus, Goubinispora morondavensis, Playfordiaspora cancellosa, Conbaculatisporites baculatus, Infernopollenites claustratus, Staurosaccites quadrifidus, S. tharipatharensis, S. densus, Brachysaccus indicus, B. ovalis, Guttatisporites elegans.* The number of species in the genus *Staurosaccites* show an epibole which defines the *Staurosaccites* spp. Acme-Zone (Table 3).

Horizon—Dubrajpur Formation, *pars* (Early Norian).

Palynological details recorded from Bore-hole RJR-2, Rajmahal Basin, Bihar, depth 441.90 to 441.40 m (Tiwari *et al.*, 1984; map 1, pp. 208, 211) is considered as reference data.

XV. *Dubrajisporites triassicus* Assemblage-Zone

A continuation of elements of the previous assemblage zone prevails but the genus *Dubrajisporites* with its four species characterise the present zone, and the species of non-striate disaccate—*Brachysaccus, Satsangisaccites, Falcisporites* and *Klausipollenites* are also abundantly recorded (Table 2).

Composition—*Foveosporites triassicus, Playfordiaspora cancellosa, Staurosaccites quadrifidus, Brachysaccus ovalis, Striatopodocarpites dubrajpurensis, Gabonisporis papillosus,* *Guttatisporites elegans, G. guttatus, Dictyotriletes aulius, Podocarpidites typicus, P. alareticulatus* and *P. rarus*, etc. (Table 2). *Dubrajisporites* spp. Acme-Zone is recorded at this level as indicated by the epibole of number of species in this genus (Table 3).

Horizon—Dubrajpur Formation, *pars.* (Early Norian).

Remarks—The presence of *Podocarpidites alareticulatus, P. rarus* and *P. typicus* together with the species of *Dubrajisporites* gives an younger aspect to this assemblage zone than the Assemblage defined by Maheshwari, Kumaran and Bose (1978) from Janar Nala, South Rewa Gondwana Basin. This assemblage zone is recorded by Tiwari, Kumar and Tripathi (1984, map 1, pp. 208, 211) in bore-hole RJR-2, 398.20-398.99 m depth, Rajmahal Basin, Bihar.

The following 4 assemblage zones are described as reference zones only for comparative assessments of the subsequently described zones found in the Rajmahal Basin.

XVI. *Rhaetipollis germanicus* Assemblage—Zone

Rhaetipollis germanicus Assemblage-IX : Maheshwari *et al.*, 1978—This assemblage zone is characterised by the presence of *Rhaetipollis germanicus, Aequitriradites minor* and *Classopollis* and the dominance of non-striate disaccate pollen species.

The composition records the taxa *Dictyophyllidites, Klausipollenites, Lunatisporites* (incl. *Taeniaesporites*), *Verrucosisporites, Scheuringipollenites, Podocarpidites, Vitreisporites, Striatisaccus, Klausipollenites* sp., cf. *K. vestitus, Lundbladispora, Concavisporites* and *Convolutispora.* This assemblage zone is recorded from a well in Banni, South of Patcham Island, Kachchh, 1,620-1,760 m depth (Koshal, 1975, p. 79), which is considered as reference material. Koshal has dated it as Rhaetic-Liassic.

XVII. *Classopollis minor* Assemblage-Zone

(*Gliscopollis-Classopollis* Zone Koshal, 1975)

The palynoflora is characterised by the abundance of *Classopollis* and *Spheripollenites*

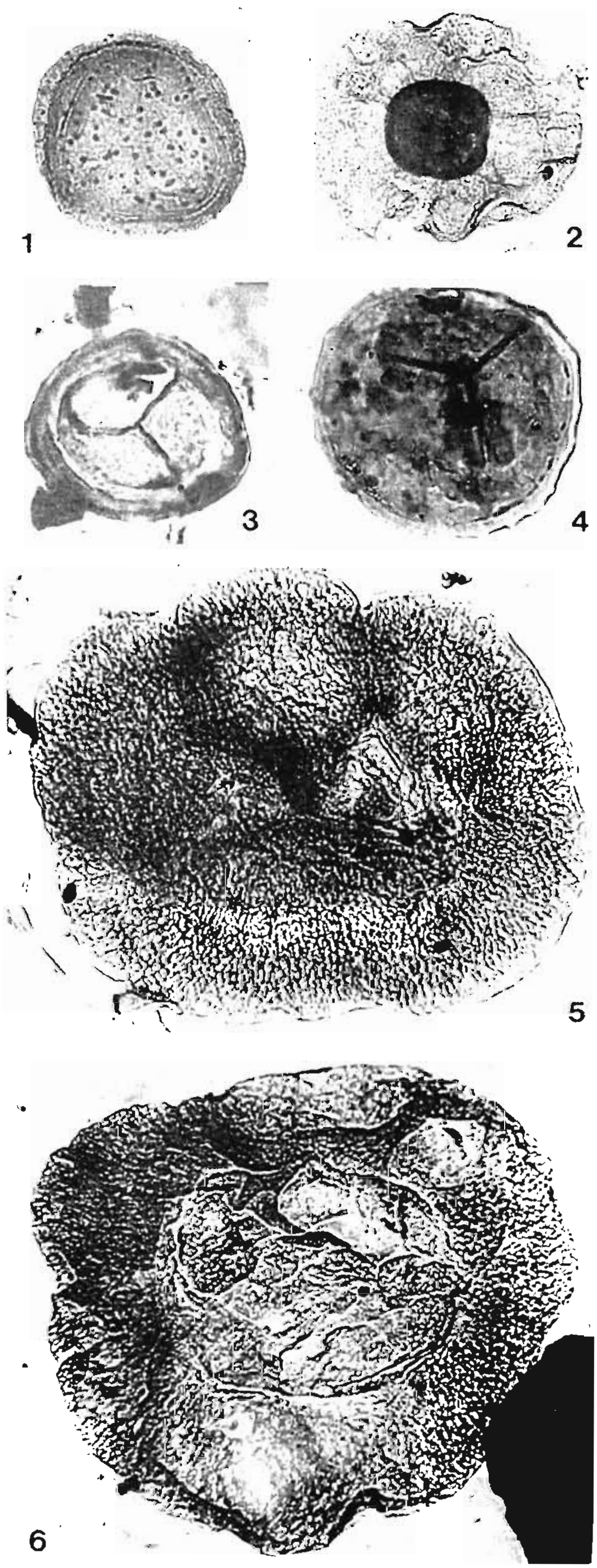

PLATE 7

←

(All photomicrographs are × 500 unless otherwise stated)

Middle Triassic spore-pollen species signifying *Goubinispora morondavensis* Assemblage-Zone.

1. *Lundbladispora willmotti*
2. *Playfordiaspora annulata*
3. *Ringosporites fossulatus* × 750
4. *Guttatisporites ambiguus*
5. *Goubinispora morondavensis*
6. *Goubinispora indica*

species. The other significant forms present are *Cyathidites, Gleichenidites, Verrucosisporites, Callialasporites trilobatus. C. triletes, C. segmentatus, Staplinisporites, Classopollis minor, C. classoides, Podocarpidites* spp. and *Matonisporites cooksonii.* The palynological details of this zone are recorded from a well (1,620-1,161 m depth) in Banni, South of Patcham Island, Kachchh (Koshal, 1975) to which an Early Jurassic age has been assigned. A comparable assemblage is also recorded from a well drilled in Lathi Formation near Chhor Village (71°9′9″ : 27°45′49″), south-east of Jaisalmer (Lukose, 1972, p. 156).

XVIII. *Callialasporites trilobatus* Assemblage-Zone

(*Callialasporites trilobatus* Zone; Koshal, 1975)

The status of various assemblages known at present from Middle to Upper Jurassic is not very clear. However, for comparing the data of Rajmahal Basin, which concerns the subject of the present communication, the assemblages from Kachchh basin are considered.

From Kachchh three comparable assemblages are known—one *Callialasporites trilobatus* Zone (Koshal, 1975: Banni; South of Patcham Island, 1,161-833 m depth, Middle to Upper Jurassic); and two assemblages from Jhuran Formation (± Katrol Formation, Kimmeridgian to Valaginian, Biswas, 1971); one by Venkatachala and Kar (1970) and another by Maheshwari and Jana (1988).

It is important to note that the *Callialasporites trilobatus* Assemblage-Zone makes a segment of continuous sequence in Banni well, delimited at its base by *Classopollis minor* Assemblage-Zone of Early Jurassic age. The abundance of several species of *Callialasporites* and the presence of *Densoisporites, Gleicheniidites, Klukisporites, Cicatricosisporites, Araucariacites, Classopollis (C. minor, C. classoides, C. itunensis)* characterise this zone. This zone has been dated as Middle to Late Jurassic by Koshal (1975); although he has not equated this sequence with the lithostratigraphic units, the data suggests that the assemblage belongs to Jhumara-Jhuran formations.

The species composition (Zone "XIX", Table 2) in the assemblage described by Venkatachala, Kar and Raja (1969) and Venkatachala and Kar (1970)

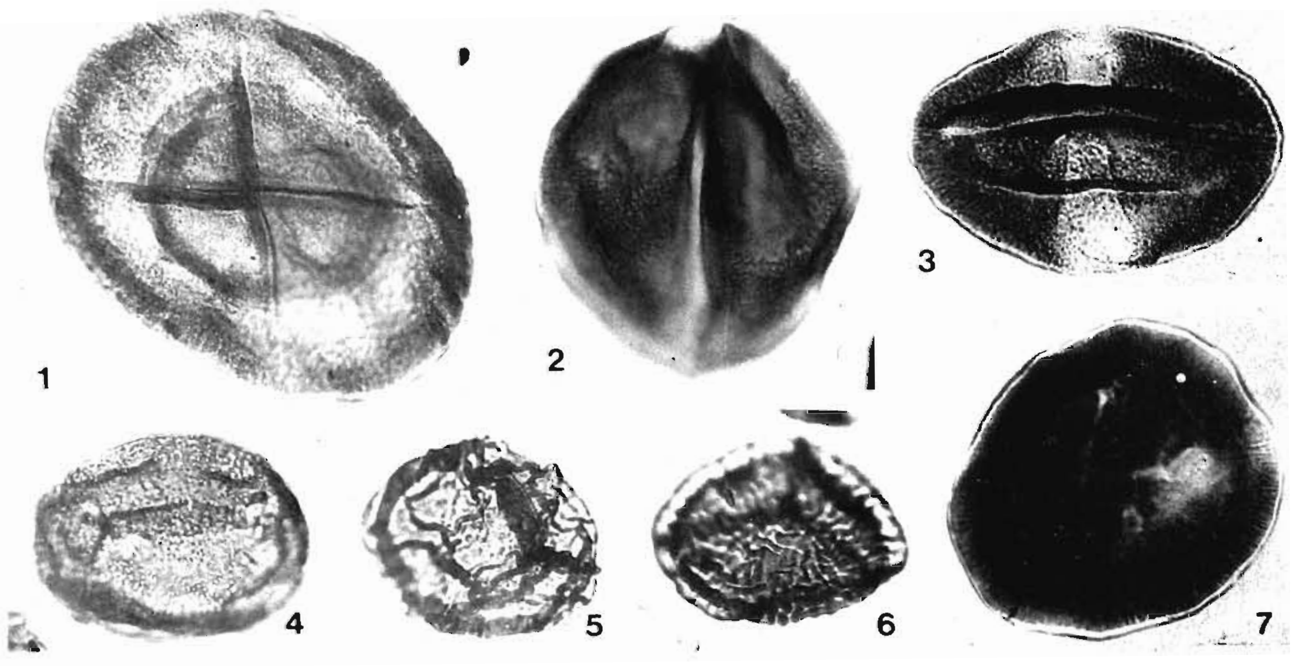

PLATE 8

(All photomicrographs are × 500)

Upper Triassic palynotaxa.

1. *Staurosaccites densus*
2. *Brachysaccus triassicus*
3. *Infernopollenites claustratus*
4. *Foveotriletes triassicus*
5. *Rajmahalispora reticulata*
6. *Rajmahalispora rugulata*
7. *Staurosaccites quadrifidus*

FAD of species in 4-6 characterise *Rajmahalispora rugulata* Assemblage-Zone and FAD of species in 1-3, 7 define *Brachysaccus ovalis* Assemblage-Zone.

suggests a broader correlation with the next zone—i.e., *Callialasporites segmentatus* Assemblage-Zone (Zone XIX, Table 2). Maheshwari and Jana (1988) described the generic composition of the palynoassemblage from Jhuran Formation as Palynozone-I; in totality of forms it is closely comparable with Zone-I of Venkatachala and Kar (1970). The presence of the taxa *Cicatricosisporites, Klukisporites, Contignisporites, Boseisporites, Coptospora* and *Aequitriradites* is significant.

XIX. *Callialasporites segmentatus* Assemblage-Zone

(*Callialasporites segmentatus* Zone; Venkatachala, Sharma & Jain, 1972)

Venkatachala, Sharma and Jain (1972, text-fig. 3) and Venkatachala (1974, text-fig. 1) recognised *Callialasporites segmentatus* Zone from Karaikal well-D (3,055-3,060 m depth), Cauvery Basin which is characterised by the presence of following species (Zone-XIX, Text-figure 1): *Araucariacites australis, Ceratosporites equalis, C. acutus, Stereisporites antiquasporites, Classopollis classoides, Podocarpidites ellipticus, P. multesimus, Contignisporites glebulentus, C. multimuratus, Cicatricosisporites ludbrooki, C. australiensis, Baculatisporites comaumensis, Callialasporites dampieri, C. monoalasporus, C. segmentatus, C. trilobatus, C. triletes, Retitriletes austroclavatidites, R. reticulumsporites,* etc. This assemblage zone was originally dated as Tithonian. However, recently it has been reassigned to Early Cretaceous (Barriasian) because of the presence of *Cicatricosisporites australiensis* (*see* Sastry *et al.*, 1981; Singh & Venkatachala, 1988).

XX. *Microcachryidites antarcticus* Assemblage-Zone

(*Microcachryidites antarcticus* Assemblage : Venkatachala, Sharma & Jain, 1972)

This assemblage zone has been defined originally from Cauvery Basin by Venkatachala, Sharma and Jain (1972) and Venkatachala (1974, text-fig. 1, p. 482, Karaikal Well-D. 2,420-2,860 m depth). It is in continuation of the *Callialasporites segmentatus* Assemblage-Zone. The diagnostic species are *Microcachryidites antarcticus, Podosporites tripakshi, P. microsaccatus, Spheripollenites scabris, Leptolepidites major, Klukisporites scaberis, Cooksonites variabilis, Aequitriradites verrucosus, Staplinisporites caminus, Trilobosporites triangulus, Impardecispora apiverrucata, I. uralensis* and *Appendicisporites distocornitatus.*

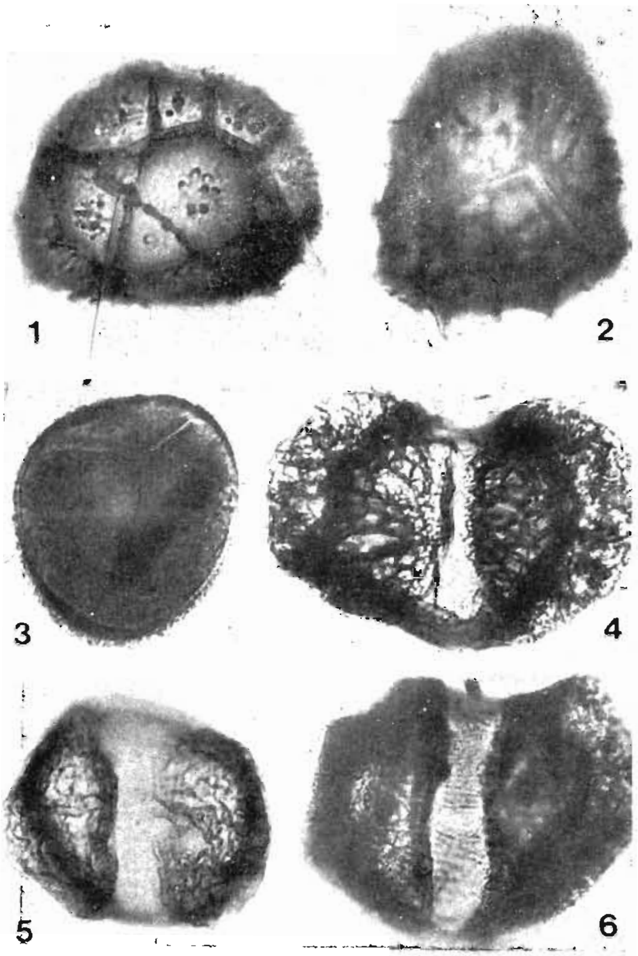

PLATE 9

(All photomicrographs are × 500)

Characteristic spore-pollen species of *Dubrajisporites triassicus* Assemblage-Zone.

1. *Dubrajisporites unicus*
2. *Dubrajisporites triasscus*
3. *Gabonisporis vigrauxii*
4. *Podocarpidites rarus*
5. *Podocarpidites alareticulatus*
6. *Striatopodocarpites dubrajpurensis*

In broader connotation the palynoassemblages so far known from Dubrajpur and Rajmahal formations, assignable to Jurassic/Cretaceous and Lower Cretaceous (Sah & Jain, 1965; Maheshwari & Jana, 1983; Tiwari *et al.*, 1984) are placed under the *Microcachryidites antarcticus* Assemblage-Zone. This is considered as a working model at present for the sequential positioning of the Rajmahal assemblages because they still need detailed study.

The following informal zones, recognised in Rajmahal Basin, are included in *Microcachryidites antarcticus* Assemblage-Zone.

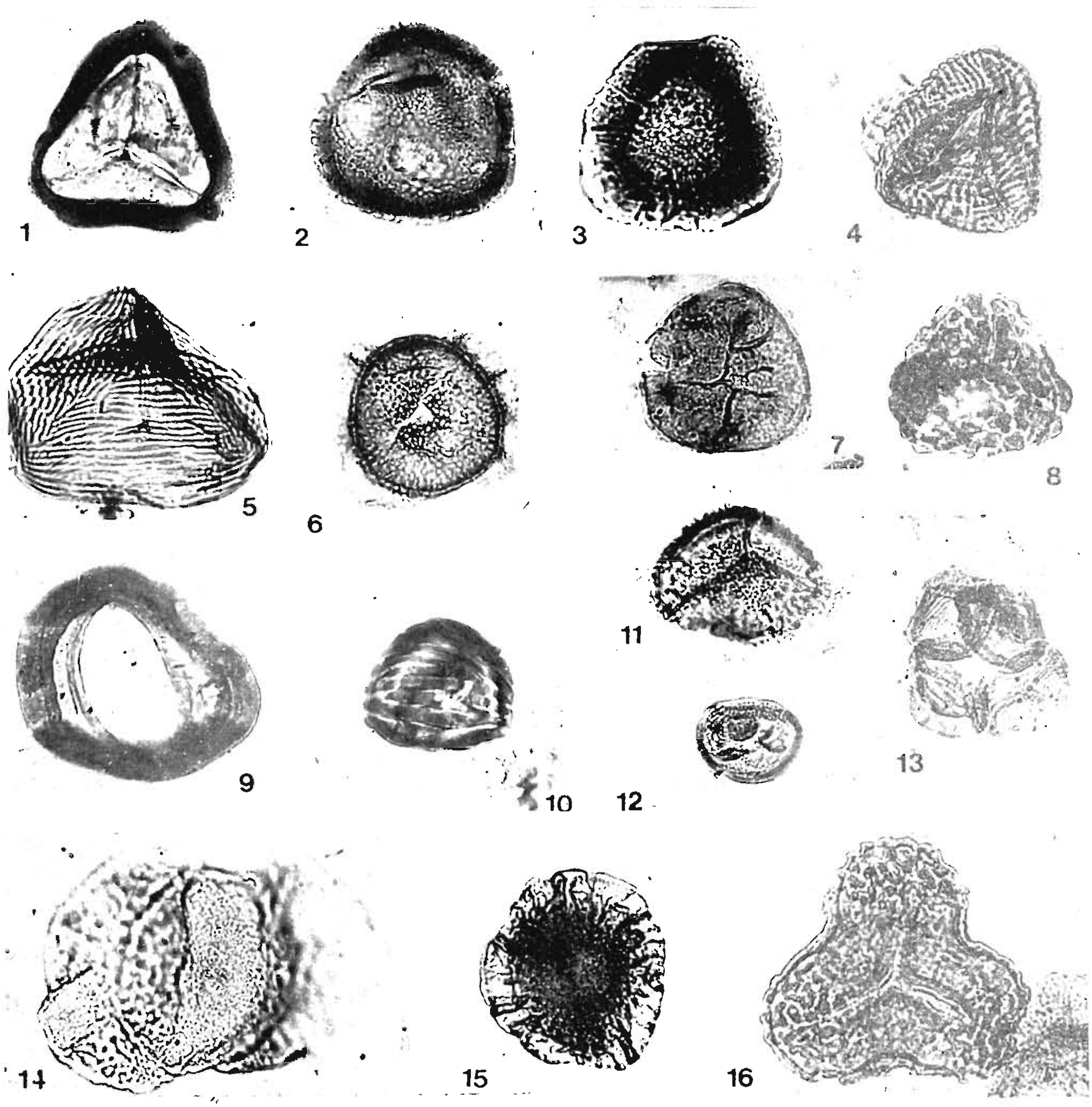

PLATE 10

(All photomicrographs are × 500)

Characteristic palynotaxa of *Microcachryidites antarcticus* Assemblage-Zone.

1. *Murospora florida*
2. *Coptospora verrucosa*
3. *Cooksonites rajmahalensis*
4. *Cicatricosisporites hallei*
5. *Cicatricosisporites australiensis*
6. *Aequitriradites spinulosus*
7. *Triporoletes reticulatus*
8. *Leptolepidites verrucatus*
9. *Coptospora kutchensis*
10. *Contignisporites dettmanni*
11. *Santhalisporites bulbosus*
12. *Podosporites tripakshi*
13. *Classopollis classoides*
14. *Podocarpidites ellipticus*
15. *Callialasporites segmentatus*
16. *Impardecispora trioreticulosa*

Assemblage-Zone D and E (Zone XX "D-E" in Table 2)—This includes Assemblage D and E of Tiwari *et al.* (1984, text-fig. 2, bore-hole RJR-2, Rajmahal Basin, 102.76-91.00 m) where the distinction was based on the percentage frequency of the genera *Callialasporites* and *Podocarpidites.* A further search of species in these materials has revealed that on the basis of species occurrence the Assemblage-Zone D and E cannot be separated.

The assemblages as such are dominated by the coniferous pollen grains *Podocarpidites/Araucariacites.* The significant constituents present are *Concavissimisporites penolaensis, Santhalisporites bulbosus, Klukisporites varigatus, Matonisporites dubius, Coptospora kutchensis, C. verrucosa, Aequitriradites spinulosus, Contignisporites dettmanni, Leptolepidites verrucatus, L. rimatus, L. major, Triporoletes reticulatus, Cicatricosisporites australiensis, C. ludbrooki, Araucariacites* spp., *Callialasporites* spp., *Podocarpidites* spp., *Labiipollis mesozoicus, L. granulatus* and *Podosporites tripakshi* (Table 2). The *Callialasporites, Podocarpidites* and *Araucariacites* spp. Acme-Zones are clearly observed in this assemblage zone (Table 3).

Various assemblage zones from the Kachchh Basin have been plotted (marked as + in Table 2) for the comparative assessment of the "Assemblage-Zones D and E" which remarkably share several of the characteristic elements with the *Callialasporites trilobatus* Assemblage-Zone, viz., *Callialasporites trilobatus, C. dampieri, C. segmentatus, Coptospora kutchensis, Cicatricosisporites australiensis, Concavissimisporites penolaensis, Podosporites microsaccatus* and *P. tripakshi* (Table 2).

There is a similar situation when the *Callialasporites segmentatus* zone of Venkatachala (1974) is compared. In addition to the above mentioned species, however, a few first appearances of the species having an younger affiliation, are also recorded, e.g., *Aequitriradites spinulosus, Leptolepidites major, Podosporites tripakshi, P. microsaccatus, Cicatricosisporites australiensis, Contignisporites dettmanni, Foraminisporis* sp., *Coptospora kutchensis* and *Baculatisporites comaumensis.*

Most of these species are considered to be age determinant for the beginning of cretaceous (Venkatachala, 1974). But some of these supposedly marker of the Neocomian (*Aequitriradites spinulosus, Cicatricosisporites australiensis* and *Contignisporites dettmanni* have been recorded from the Tithonian as well (Singh & Venkatachala, 1988; Maheshwari & Jana, 1988; Helby *et al.*, 1987; Burger, 1988). The consistent occurrence of these species has been definitely located at the base of *Microcachryidites antarcticus* Assemblage from the Cauvery Basin (Venkatachala, 1974) which qualify for Early Cretaceous. But, inspite of this valuable data, it cannot be ascertained that this assemblage marks the beginning of the Early Cretaceous because there is a gap of about 195 m of sediments between *Callialasporites segmentatus* and *Microcachryidites antarcticus* Assemblages.

In view of these facts, the Late-Jurassic/Early Cretaceous age given to these assemblages by Tiwari *et al.* (1984) is corroborated by the observations made by Singh and Venkatachala (1988) that the floral changes which occurred at the Late Jurassic level continue into the Early Cretaceous. However, the lack of data on continuous sequence from Upper Jurassic to Lower Cretaceous does not permit to define the species which can demarcate the FAD for the base of Lower Cretaceous.

Assemblage-Zone F (Zone XX "F" in Table 2)—This assemblage is not rich in palynofossils, and its close similarity is observed with "Assemblage-Zones D and E" analysed above. The new entrant *Dictyophyllidites haradensis* (Table 2) is recorded as a solitary example. This Assemblage-Zone F is recorded from Bore-hole RJR-2, Rajmahal Basin, Bihar, 69.75-40.65 m depth (Tiwari *et al.*, 1984) representing the Rajmahal Formation (Early Cretaceous).

Assemblage-Zone G (Zone XX "G" in Table 2)—This assemblage zone is recorded from the Intertrappean sediments of Rajmahal Formation at Sakrigalighat and Basko, Rajmahal Basin, Bihar (Sah & Jain, 1965, p. 264). The basic species composition indicates a relationship with the "Assemblage-Zone F". However, a number of additional new elements are documented in "Assemblage-Zone XX G", viz., *Concavissimisporites minor, Osmundacidites minor, Trilobosporites purverrulentus, Cingulatisporites notaclarus, Podosporites (= Trisaccites) microsaccatus, Dacrycarpites australiensis, Converrucosisporites santalensis* and *C. sinuotectus,* etc. (Table 2). The assemblage from a well near Mandro (Maheshwari & Jana, 1983) records *Densoisporites mesozoicus* and *Cicatricosisporites hallei* as new entrants.

Besides, in the Intertrappean sediments of Rajmahal Formation in bore-hole RJNE-32 near Kirtanya (Tripathi & Tiwari, 1991; Tripathi, 1991), some angiospermous pollen with reticulate columellate exine and monocolpate, trichotomosulcate and tricolpate aperture-types have been recorded together with typical Early Cretaceous palynomorphs.

DISCUSSION

The synthesis of the data discussed in the preceding pages recognises 12 assemblage zones based on spore-pollen species (Column I-XII) in the Damodar Graben, spanning through the sequence from Talchir to Supra-Panchet formations. In the Rajmahal Basin four assemblage zones (column XIII, XIV, XV & XX) are recognised to represent the Upper Triassic, Jurassic/Cretaceous and Lower Cretaceous sequences (Text-figure 1). In order to structure comprehensive model of successive assemblage zones, the data from Rajasthan, Kachchh and Cauvery basins has been intercalated where 4 assemblage zones (XVI-XIX) have been recognised. This arrangement provides an opportunity of direct comparison amongst the various assemblage zones in Rajmahal Basin with reference to their placement in the temporal scale.

Conventionally the epibole zones are based on the dominance in percentage frequency of the taxa. For the first time, in the present analysis the species acme-zones have been identified on the number of species in various genera. Such an approach has resulted into a very significant parameter which reinforces the individuality of the species assemblage zones. It is evident from Text-figure 1 that in some assemblage-zones several genera show the epiboles of the number of their species.

The composition of palynoassemblages based on generic dominance is fairly well established in the Gondwana Sequence; some of these updated assemblage zones have been tagged with the spore-pollen species assemblage zones proposed here.

The distribution pattern of selected species has revealed events of stratigraphic significance (Table 2).

Lower Permian

The impoverished assemblage (total 9 species; 2 pteridophytic, 1 alete, rest gymnospermous) of the lowest Talchir level (Zone-1) successively diversifies into a rich flora by the beginning of Karharbari Formation. The three assemblage zones (Zone I to III) identified in the Talchir Formation are indicative of gradual and continuous amelioration of the climate where the vegetation has flourished to its maximum by the time the glaciers retreated completely. The Karharbari assemblage (Zone-IV) shows a major continuation of elements from the underlying Talchir Formation except that some species are mutually exclusive in their occurrence.

The advent of Barakar flora witnesses the incoming of several new species which continue to flourish in the subsequent younger horizons; on the other hand many of the species belonging to the radial monosaccate group which flourished during Talchir and Karharbari also continue to occur. The clear cut demarcation between the Lower Barakar (Zone V) and Upper Barakar (Zone VI) are very well depicted in their species distribution (Table 2).

Upper Permian

In the two fold system of classification of the Permian the boundary between Lower Permian and Upper Permian is drawn between the Barakar and Kulti formations. In qualitative aspect of genera and species, however, the demarcation of the two is not very well defined. The differences in species distribution indicate a subtle change (Table 2). Nonetheless, the species acme-zones provide a useful parameter for identification of this level (Table 3). In Barakar the epibole of number of species in the genera *Scheuringipollenites, Faunipollenites, Barakarites* and *Microbaculispora,* etc. are recorded, while in Kulti Formation the species acme-zone of the genera *Densipollenites, Verticipollenites* and *Scheuringipollenites,* etc. are well documented.

The palynoassemblage of Kulti Formation (Zone-VII) forms a more or less monotonous continuum to the Raniganj assemblage (Zone-VIII). The most significant change has occurred at the close of the Raniganj Formation (Zone IX) and at the beginning of the Panchet Formation (Zone X) which is taken as the Permo-Triassic transition. At this level 175 spore-pollen species (39 pteridophytic) are on record at the close of Permian. Out of these, only 38 species (6 pteridophytic) continue into Triassic while 84 species appear as new entrants in Early Triassic; the pteridophytic spores constitute the major part by being 48 species in number. The behaviour pattern of the species distribution at P/Tr boundary thus signals one of the most outstanding changes in the history of Gondwana floristics.

Triassic

The Early Triassic Panchet Formation is the stage for termination of several Permian species. Progressively numerous new sets of species appear which diversify through the Lower and Middle Triassic (Table 2). The Upper Triassic (Upper Carnian, Lower Norian) again experiences an influx of entirely new species although these assemblages, in general, had a close relationship with the Lower (Zone X, zone XI) and Middle Triassic (Zone XII) groups of species. The new entrants in Zone XIII, XIV and XV of Late Triassic (species of *Staurosaccites, Barchysaccus, Infernopollenites, Dubrajisporites, Rajmahalispora,* etc.) had obviously a short history of existence as they do not occur in the Lower Jurassic sediments.

Jurassic/Cretaceous

The area of study concerns with the Rajmahal Basin but the Jurassic and Lower Cretaceous assemblages Zones XVI to XX from Rajasthan and Kachchh basins have been interpolated for comparison and assessment of the Infra- and Intertrappean asemblages in this basin. It is very clear from Table 2 that the Jhuran (= Katrol Assemblage (Zone "XIX") is distinguished from the Bhuj assemblage (Zone XIX) by having several species of restricted distribution in both (see details in Venkatachala & Kar, 1970, pp. 83, 84). The distinction between the two are very sharp. The Assemblages D and E of Bore-hole RJR-2 (Zone XX "D-E", Table 2) stand apart from the Katrol and Bhuj Assemblages except for the long ranging species (*Podocarpidites, Callialasporites* and *Araucariacites*).

The Assemblage F of Bore-hole RJR-2 (Zone XX "F", Table 2) is impoverished. The Sakrigalighat, Basko and Mandro assemblages, together considered here as Zone XX "G", are again highly diversified; most of its components were unknown in the older zones and hence they stand apart from the Zone XX (Bhuj) and Zone XX "D-E" (Rajmahal). Inspite of distinct offset mode between the Katrol (Zone "XIX"), Bhuj (Zone XX) and Rajmahal (Zone XX "D-E") there are certain trends of comparison between Katrol and Rajmahal assemblages; the common presence of *Coptospora kutchensis, Concavissimisporites penolaensis, Cicatricosisporites australiensis, Retitriletes austroclavatidites, Podosporites tripakshi*, etc. which points out important linkage between the Katrol assemblage and Assemblage D-E of Rajmahal. On the other hand, the latter are remotely related with the Sakrigalighat which is dated as Early Cretaceous (Singh & Venkatachala, 1988). On the face value, the Lower Cretaceous Bhuj assemblage (Zone XX) and the Assemblage D-E of Rajmahal cannot be clubbed together intimately. Tiwari, Kumar and Tripathi (1984) placed the Infratrappean Assemblage D-E at Upper Jurassic/Lower Cretaceous level. However, there are several gaps yet to be filled to complete the story of the Jurassic-Cretaceous transition span. The sequence of evidences depicted in Table 2 reveals that the succession of palynofloral assemblages from Upper Jurassic to Lower Cretaceous had been at low pace. But the Neocomian palynoflora has changed at a faster rate and the isolated areas had an ecology bias for the growth of various species; hence the matching of synchronous assemblages which are distantly apart may not suggest the real age bracket.

CONCLUSIONS

For achieving the goal of species based palynostratigraphy through the span of Indian Palaeozoic and Mesozoic Sequence, a model based on data from the Damodar Graben and Rajmahal Basin has been constructed. The following main conclusions are drawn:

1. Based on the FADs and LADs of selected species, and also the totality of species composition twenty Species Assemblage Zones have been identified which demarcate various datums.
2. The authenticity of Species Assemblage Zone is reinforced by the recognition of thirty Species Acme-Zones based on the epiboles of number of species in various genera. These epiboles either coincide with one assemblage zone or encompass more than one.
3. The least diversified spore-pollen flora of the earliest Talchir horizon enormously radiates by the end of Talchir Formation and continues to flourish during the rest of the Permian time.
4. The behaviour pattern of species distribution evidences for the most outstanding change at the Permian/Triassic boundary in the history of Gondwana floristics.
5. During Upper Triassic a marked change is recorded by the influx of several new species having short stratigraphic range which result into a distinct alteration in the species pattern at the Late Triassic/Early Jurassic level.
6. At the Late Jurassic/Early Cretaceous datum major event in the species change-over is not represented. The continuum of flora is reflected by spores/pollen; however, there are gaps in information for precise location of the change.

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Permian palynological assemblages in the Godavari Graben

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Palynological investigations carried out in the Godavari Graben during the last three decades have led to suggest the existence of nine palynozones from the Talchir to Kamthi formations. The Talchir Formation palynological assemblage, though dominated by the presence of radial monosaccate pollen grains, exhibits evidences of fluvio-glacial and lacustrine environment of deposition alongwith periodical influence of marine incursions. The presence of Karharbari and Barren Measures (Kulti) as distinct formations has been substantiated with palynological data. The occurrence of *Corisaccites-Guttulapollenites* palynozone and *Densipollenites* palynozone in the Middle Member of the Kamthi Formation represents the uppermost Permian palynoflora in Godavari Graben.

Key-words—Palynology, Permian, Godavari Graben (India)

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सारॉश

गोदावरी द्रोणिका में परमी युगीन परागाणविक समुच्चय

सुरेश चन्द्र श्रीवास्तव

पिछले तीन दशकों में गोदावरी द्रोणिका में किये गये परागाणविक अन्वेषण से तलचीर से कामथी शैल-समूहों तक में नौ परागाणुमंडलों की उपस्थिति व्यक्त हुई है। हालाँकि तलचीर शैल-समूह अरीय एककोष्ठीय परागकणों से प्रभावी हैं, नदीय हिमानी एवं सरोवरी निक्षेपणीय वातावरण की विद्यमानता करते हैं। ये अवसाद समय-समय पर समुद्री अतिक्रमण से प्रभावित रहे हैं। परागाणविक आँकड़ों के आधार पर करहरबारी एवं बेरन मेज़र्स (कुल्टी) की उपस्थिति विभिन्न शैल-समूहों के रूप में प्रस्तावित की गई है। कामथी शैल-समूह के मध्य सदस्य में **कोरिसेक्काइटिस-गुट्टुलापोलिनाइटिस** तथा **डेन्सीपोलिनाइटिस** नामक परागाणुमंडलों की उपस्थिति से गोदावरी द्रोणिका में उपरितम् परमी परागाणुवनस्पतिजात की विद्यमानता इंगित होती है।

THE Godavari Graben bounded by latitudes 16°38′ and longitudes 79°12′ and 79°39′ is a major graben trending NNW-SSE and covers an area of about 17,000 sq km. This graben is unique in the sense that it is the major coal producing area, south of Narmada River and there is a geological continuity of the Gondwana sediments from one extremity to the other having a well-defined constriction in the Paluncha-Kothagudem sector. Few outliers exist beyond this basin, viz., Yellandu, Kamaram and Tallada/Tiladru.

The Permian sediments in the main Godavari Graben are exposed along both the margins while the overlying sequence covers the axial portions. Archean rocks form the basement mainly in the northern part of the basin, while the Pakhal and Sullavai group of rocks constitute the basement north of the Mailaram High. However, the Archean rocks occur in faulted contact in the northern part around Ramagundam and east of Sirpur. Except for a limited exposure of the Permian sediments, major part of the sequence lies concealed below the surface as a result of which the lithostratigraphy in Godavari Graben has remained a matter of discussion. The transition between older to younger formations is gradational and it is difficult to draw inter-formational boundaries.

The geological set up of the Permian sequence initially defined by King (1881) has been later modified by various authors but the most commonly accepted one is that of Raja Rao (1982) which has

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been followed in the present review. The lithostratigraphic set up described by Raiverman *et al.* (1985) covers the entire Pranhita-Godavari Valley extending further north to the Wardha Valley coalfields and includes a number of new formations whose relationship with the known lithostratigraphic units is not clearly defined. Kutty *et al.* (1988) prefered to restrict the term Kamthi Formation to the lithologically distinct Upper Member of the Kamthi Formation (*sensu strictu* Raja Rao, 1982). They designated Infra-Kamthi to accommodate the strata between Barakar Formation and the Middle Member of the Kamthi Formation which is a well-defined lithostratigraphic unit. Recently, Lakshminarayana and Murty (1990) have proposed the stratigraphic set up for the Chintalpudi sub-basin which almost agrees with that described by Ramanamurty (1985) from Ramagundam area. However, he has overlooked the presence of Barren Measures (Kulti) and Raniganj equivalent sediments, which may possibly exist in Chintalpudi sub-basin.

TALCHIR FORMATION

This forms the lowermost unit of the Permian sediments and is exposed in narrow strips along the western margin near Mandaram to Lingala, while on the eastern margin they occur near Cherla-Manuguru sector besides a few small occurrences within the basin. Near Mancherial, these rocks are exposed in Chintala stream and railway cutting leading to Mandamari Power Station. The basal tillite beds comprise polymictic clasts in a fabric of mixed grain size and are overlain by siltstone, khaki green splintery shale and sandstone. These tillites suggest ancient glaciated moraines. Recurrence of tillite bed is also reported (Raja Rao, 1982). The siltstone gets coarser in the younger part of the sequence and exhibit cross laminations. In few bore-holes in Ainapallam area grey black splintery shales containing *Gangamopteris* leaf-impressions have been observed.

BARAKAR FORMATION

The sediments pertaining to Barakar Formation are exposed to a very limited extent and occur as discontinuous patches along the basin margins. It has been divided into two members:

1. *The Lower Member*—It is characterised by coarse-grained sandstone including lenses of conglomerates, carbonaceous shales and coal seams.
2. *The Upper Member*—It constitutes a large scale cross stratified sandstone with inter-bedded carbonaceous shales and coal seams. The present mining of coal is largely confined to this horizon.

BARREN MEASURES (KULTI) FORMATION

Sengupta (1970) demarcated the Barren Measures within the basal part of the Kamthi Formation and it was later established as a persistent horizon overlying the Barakar and underlying the Kamthi Formation. It is characterised by cross bedded medium to coarse-grained, greenish to grey white sandstone, variegated clays, etc. These sandstones turn brown when exposed on the surface. Kutty *et al.* (1988) included it as a basal unit of the Infra-Kamthi Formation.

KAMTHI FORMATION

The sediments overlying the Barren Measures (Kulti) and underlying the Maleri Formation are now referred to as the Kamthi Formation (Raja Rao, 1982) and form the thickest horizon in this coalfield. Based on lithologic attributes it has been divided into three members: (i) *The Lower Member* is marked by grey white sandstone which gets calcareous at intervals. These sandstones are interbedded with thick to thin coal seams. The Sondila Seam near Sondila Village corresponds to this member. The occurrence of this member has been proved in Ramakrishnapuram, Mantheni, Ramagundam, Manuguru, Mailaram, Budharam and Ainapallam-Gompana areas and contain coal seams; (ii) *The Middle Member* contains a cyclic sequence of grey-white cross-bedded sandstone, shale, variegated clays which exhibit greenish tint at places. These sandstones sometime show erosional surfaces at their bases. The shales often contain calcareous nodules/concretions; (iii) *The Upper Member* is distinguished by coarse-grained sandstone and brick-red siltstone, clays, etc. This member often overlaps all the other older formations at places.

PALYNOLOGY

Palynological studies in the Godavari Graben started as early as 1962 when Thiergart and Frantz (1962) recorded some pollen and spores from the Kothagudem Coalfield. Ghosh (1968) worked out the vertical and lateral variations of spores and pollen in Ross and Salarjung seams from Tandur area. Subsequently Tiwari and Moiz (1971) described five new taxa. Ramanamurty (1979) while reporting the occurrence of a coal seam in the

Kamthi Formation from Ramagundam area mentioned some trilete spores and striate and nonstriate pollen.

During the past decade systematic work has been carried out at the Birbal Sahni Institute of Palaeobotany and considerable data has accumulated relating to Permian and Permian-Triassic sediments of the Godavari Graben. Occurrence of megaspores (Jha & Srivastava, 1984) and a new taeniate-monosaccate pollen *Kamthisaccites* (Srivastava & Jha, 1986) have been recorded from the Permian sediments. Recently Rama Rao *et al.* (1990) have also dated the Permian sediments of the Chintalpudi sub-basin on the basis of palynological studies. Palynological assemblages recorded from different levels are summarised in Table 1.

Table 1—Permian palynozones in Godavari Graben, Andhra Pradesh

LITHOZONE		PALYNOZONES				STANDARD
FOR-MATION	MEMBER	PALYNO-ZONE	DOMINANT TAXA	SUBDOMINANT TAXA	QUALITATIVELY IMPORTANT TAXA	PALYNO-ZONE
Kamthi	Middle	10	*Striatopodocarpites* *Faunipollenites*	*Densipollenites*	*Crescentipollenites* *Marsupipollenites* *Chordasporites* *Lunatisporites* *Falcisporites* *Klausipollenites*	Raniganj
		9	*Striatopodocarpites* *Faunipollenites*	*Corisaccites* *Guttulapollenites*	*Densipollenites* *Lunatisporites* *Falcisporites* *Vitreisporites*	
		8	*Striatopodocarpites*	*Parasaccites*	*Densipollenites* *Corisaccites* *Guttulapollenites*	
		7	*Faunipollenites*	*Striasulcites*	*Densipollenites* *Falcisporites* *Polypodiidites* *Osmundacidites*	
	Lower	6	*Faunipollenites* *Striatopodocarpites*	*Labirites* *Verticipollenites*	*Distriatites,* *Hindipollenites* *Hamiapollenites* *Lueckisporites* *Gondisporites* *Weylandites* *Marsupipollenites*	
Barren Measures (Kulti)		5	*Faunipollenites* *Striatopodocarpites*	*Densipollenites* *Scheuringipollenites*		Kulti
Barakar	Upper	4	*Scheuringipollenites* *Brevitriletes*	*Indotriradites* *Hennellysporites* *Horriditriletes*	*Primuspollenites* *Striatites* *Tiwariasporis* *Latosporites*	Lower Barakar
	Lower	3	*Parasaccites*	*Scheuringipollenites*	*Brevitriletes*	Upper Karharbari
		2	*Callumispora*	*Parasaccites*	*Brevitriletes* *Indotriradites*	Lower Karharbari
Talchir		1	*Parasaccites*	*Plicatipollenites*	*Leiosphaeridia* *Vestigisporites* *Virkkipollenites* *Caheniasaccites* *Jayantisporites*	Talchir

Talchir Formation

The Talchir Formation palynological assemblage is dominated by the presence of radial monosaccate pollen. This assemblage has been recovered from siltstone, banded shale, etc. In bore-hole GRK-1 (825-807 m) and GRK-24 (853.55-826.65 m) from Ramakrishnapuram area *Leiosphaeridia* occurs in higher percentages alongwith monosaccate pollen. Rawat and Jain (1985) reported similar assemblage alongwith *Botryococcus* and foraminifers from Chandrapur area. The leiosphaerid associated assemblage has been considered to indicate marine influence during the deposition of Talchir sediments in Palar Basin and Bap Formation, Rajasthan (Venkatachala & Rawat, 1973, 1984, respectively). In Manendragarh area (Bharadwaj, Srivastava & Anand-Prakash, 1979) *Leiosphaeridia* and spinose acritarchs (*Micrhystridium*) occur together in *Eurydesma-Counularia* associated sediments. The grey-black splintery shale present at the top of the Talchir Formation in bore-hole GAG-1 from Ainapallam-Gompana area which contains well preserved *Gangamopteris* leaf impressions (personal observation) is lithologically comparable to the black needle shale of the Talchir Formation from Manendragarh which contain invertebrate marine fossils. In Mohpani Coalfield Bharadwaj and Anand-Prakash (1972) also observed the presence of similar shales at the top of the Talchir Formation. These records suggest a marine transgression during the deposition of the younger sediments of the Talchir Formation in Godavari Graben. The basal tillite in the older part has not yielded palynofossils.

Barakar Formation

The Lower Member of the Barakar Formation in Godavari Graben, characterised in general by coarse-grained gritty sandstone, shale and coal, is comparable to the Karharbari sediments of the type area, the Giridih Coalfield. In Godavari Graben the Karharbari sediments have not been marked as a mappable unit, though the microflora occurs persistently in the Lower Member of the Barakar Formation overlying the Talchir (Ramakrishnapuram area, GRK-1 : 798.90-795.60 m; GRK-24 : 775.55-645.20 m; GRK-25 : 676.50 m; Ramagundam area, GGK-20 : 854.00-827.25 m; Ainapallam area GAG-1 : 436.00-202.60 m; Manuguru area—Thick Seam; Kothagudem and Yellandu areas—King Seam). Since sediments pertaining to this horizon are exposed to a limited extent, the recognition of Karharbari as a formation in Godavari Graben has not been given much attention. However, based on palynological studies, a Karharbari palynozone is identifiable.

In recent years leiosphaerids have been recorded in the Karharbari sediments from Umaria Coalfield (Venkatachala & Tiwari, 1988). Banerjee (1988) also reported brackish water acritarchs including *Leiosphaeridia* from Rajmahal Basin. Chaudhuri (1988) suggested a marine influence in Hutar Coalfield on the basis of foraminifera and evaporites. In Godavari Graben also *Leiosphaeridia* alongwith monosaccate pollen grains in Upper Karharbari palynozone have been observed in Ainapallam area (Bore-hole GAG-1). All these records represent marine influence during the Upper Karharbari palynozone.

The Upper Member of the Barakar Formation lithologically exhibit a repeated cyclothem and contains the important coal seams from Belampalli-Kothagudem areas. The palynoflora contained in these sediments compare the Lower Barakar palynoflora (Srivastava, 1987; Srivastava & Jha, 1989). The Upper Barakar palynoflora has not been encountered in any bore-hole studied from the Godavari Graben.

Barren Measures (Kulti) Formation

The palynoassemblage of the Kulti Formation has been observed in Ramakrishnapuram area (boreholes GRK-1 : 493.57-109.45 m; GRK-24 : 515.75-363.70 m; GRK-25 : 582.70 m) and Ramagundam-Mantheni area (bore-hole GGK-20 : 628.44-215.00). In all these boreholes a complete epibolic development of *Densipollenites* is present between the underlying Barakar and overlying Kamthi sediments. This palynozone is comparable to the known Kulti palynozone of the Jharia Coalfield (Bharadwaj *et al.*, 1965).

Kamthi Formation

The Lower Member containing palynozone 6 has been recorded in a number of bore-holes (Srivastava & Jha, 1988) and is comparable to the Raniganj palynoflora of the Damodar Valley. In Ramagundam area, a thick coal seam known as Sondila Seam has been suggested to belong to this palynozone (Bharadwaj *et al.*, 1987). In the Chintalpudi sub-basin thick coal seams encountered in the younger part of the bore hole GAG-1 also contain similar palynoflora.

Palynozones 7-10, as shown in Table 1, occur within the younger part of the Lower Member and older part of the Middle Member of the Kamthi Formation and in general compare to the younger Raniganj palyozones of the Damodar Valley except some significant variations (Bharadwaj, Tiwari & Anand-Prakash, 1979). However, palynozones 8-9 are more comparable to the palynoflora of the Bijori

Formation in Satpura Basin (Bharadwaj *et al.*, 1978) and Chidru Formation, Salt Range (Balme, 1970) in view of the higher incidence of *Corisaccites* and *Guttulapollenites*. *Striasulcites* palynozone (Palynozone 7) is not reported so far from any other basin. Reoccurrence of *Parasaccites* (Palynozone 8) alongwith striate-disaccate pollen is also known from the Godavari Graben only. In addition to these, *Iraquispora, Triquitrites, Taeniaepollenites, Phidiaesporites, Concavissimisporites* and *Columinisporites* found in the Godavari Graben have not been observed in other peninsular basins of India.

DISCUSSION

The sedimentation of the Permian sequence in Godavari Graben appears to have been initiated by the deposition of tillite beds at the base of the Talchir Formation. Some of the clasts embedded in it show polished surfaces and striations indicating glaciation (Ramanamurty, 1985). Palynological records are not available at this level of sedimentation but following glaciation fluvio-glacial and lacustrine environment developed permitting a thick pile of lacustrine deposits. Palynological assemblages indicate periodic marine incursions as is evidenced by the occurrence of *Leiosphaeridia*, foraminifers, etc. The possible gate-way for these marine incursions could have been from the eastern sea bay along the Krishna-Godavari lineament. The radial monosaccate dominant assemblage pertaining to gymnosperms also suggests a cool humid environment.

The Talchir Formation is overlain by the Barakar Formation during which the sedimentation pattern was dominantly fluvial and a luxurient flora appears to have existed which led to the development of rich coal-forming swamps. In the Lower Member of the Barakar Formation the lithologic association is distinctly different from that of the Upper Member and is comparable to the Karharbari sediments; it has remained a debatable unit so far on the Godavari Graben. Basu (1964) has suggested the occurrence of Karharbari coal seams in Godavari Graben but since then it has not been identified as a separate unit. The palynological records also suggest the existence of Karharbari sediments among the coal seams which are being worked out in various mines (Srivastava, 1987) and also subsurface sediments of Ramakrishnapuram, Budharam, Manuguru, Mailaram and Kothagudem areas. The palynological assemblages thus provide enough evidence to identify Karharbari's in Godavari Graben.

The Upper Member of the Barakar Formation is the principal coal-bearing horizon in Godavari Graben. The palynoflora recorded in these sediments compare with the Lower Barakar palynoflora of other basins (Tiwari, 1974). In boreholes GRK-1, GRK-24 and 25 and GGK-20 the Lower Barakar palynozones are immediately succeeded by the Barren Measures (Kulti) palynozone, thus indicating the possible absence of the Upper Barakar palynozones in Godavari Graben.

The sediments overlying the Barakar and underlying the Maleri formations have been classified into Barren Measures and Kamthi Formation by Raja Rao (1982). Kutty *et al.* (1988) included the former as a basal unit (Lithozone 1) of the Infra-Kamthi Formation and considered the Upper Member of the Kamthi Formation of Raja Rao (1982) as Kamthi Formation in view of its distinct lithology. Sengupta (1970) recognised Barren Measures as a distinct unit which was later accepted by Raja Rao (1982). Ramanamurty (1985) also preferred to maintain it as a separate unit on the basis of lithology and heavy minerals and suggested that the deposition during Barren Measures was largely under braided system with rapid sedimentation. These sediments have yielded a striate disaccate rich assemblage having epibole zone of *Densipollenites* which is characteristic of Barren Measures palynoflora of Damodar Valley. The thickness of Barren Measures appears to be maximum (450 ± 50 m) around Ramagundam-Mantheni area while in the rest it is highly variable. The sediments being essentially arenaceous do not yield palynofossils, in general. In the same way recognition of this formation as a separate unit in other areas has remained elusive. Nonetheless the lithological suit attributed to Barren Measures Formation is distinct from the underlying Barakar and overlying Kamthi Formation both of which are coal-bearing horizons.

The Kamthi Formation (*sensu* Raja Rao, 1982) attains its maximum thickness (± 1600 m) around Ramagundam-Mantheni area (Ramanamurty, 1985). The Lower Member has been proved to be coal-bearing while the Middle and Upper Members are devoid of coal. Palynozone 6 is restricted to the coal-bearing Lower Member, palynozones 7 and 8 transgress the Lower and Middle Members and palynozones 9 and 10 occur only in the older part of the Middle Member. The Permian-Triassic transition occurs within the Middle Member of the Kamthi Formation. Lithozone-2 of the Infra-Kamthi Formation (Kutty *et al.*, 1988) appears comparable to the Lower Member of the Kamthi Formation (*sensu* Raja Rao, 1982) while Lithozones-3 and 4 of the Infra-Kamthi Formation may be considered equivalent to the Middle Member of the Kamthi Formation. Kutty *et al.* (1988) have described vertebrate fossils, viz., *Endothiodon* and *Cistecephallus* from the Lithozone-3 and have correlated it with the *Cistecephallus* Zone (Beaufort Formation) of South Africa. Lithologically, Lithozone-3 of the Infra-Kamthi Formation compares with the older part of the Middle Member of the Kamthi Formation. Palynozones-9 and 10 described here occurs in this unit and represent almost the youngest Upper Permian palynozone. Ramanamurty (1985) considered the lithological set up of the Lower Member of the Kamthi Formation equivalent to the Raniganj Formation while Upper and Middle Members being equivalent to the Panchet and Mahadeva formations of the Damodar Valley. However, occurrence of *Cistecephallus* fauna and also *Densipollenites* rich palynoassemblage extends the Upper Permian sequence further up in the older part of the Middle Member. Srivastava and Jha (1988, 1989) recorded Lower Triassic palynoflora from the upper part of the Middle Member of Kamthi Formation. Thus it was observed that the Permian-Triassic transition occurs right in the Middle Member.

The Upper Member of the Kamthi Formation is distinguishable by its characteristic lithology. Raja Rao (1982, p. 15) mentioned the presence of fragmentary remains of *Ptilophyllum* (earlier observed by C. Nageswar Rao) in Jaipuram Ridge. In recent years a vertebrate skull (Daptocephalid dicynodont?) was discovered among the sandstones of this member near Jaipur Village (GSI News, Coal Wing, January, 1986) which indicates the occurrence of Late Permian sediments. Well-preserved, though scanty, leaf-impressions of *Glossopteris* have also been observed in ferruginous shales in sandstone quarries near Jaipur Village. The size of the leaf is small as compared to those occurring in the Upper Permian sequence. With these varied evidences it appears difficult to correlate the Upper Member but considering the palynological evidences it appears probable that this member may be equivalent of the Supra-Panchet/Mahadeva formations of the Damodar Valley.

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Triassic flora of India—a transition

Shyam C. Srivastava & S. R. Manik

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Extensive floral modifications occurred from Late Palaeozoic to Triassic (Early Mesozoic) Period. Differentiation of Permian and Triassic strata in the Indian subcontinent has been done mostly on lithological, palaeontological and palaeobotanical grounds, but recent investigations on Triassic succession in the Damodar Basin (Panchet Formation), South Rewa Basin (Tiki and Parsora formations), Satpura Basin (Mahadeva Formation) and Pranhita-Godavari Basin (Maleri Formation) have demonstrated gradual changes in palaeofloristics from Early Triassic to Late Triassic. The concept that there was a sudden change in the composition of megaflora from the Late Palaeozoic to Early Triassic reflecting a floral break is modified in the light of palaeofloral data accumulated from various Triassic formations.

In Peninsular India, the megaflora of Late Permian Period is usually dominated by glossopterids and their representative taxon *Glossopteris* continued further in Permo-Triassic contact associated with some newly emerged forms like the genus *Dicroidium*, which dominated the vegetation and thrived for nearly 30 million years. In the early part of Triassic, *Dicroidium* appeared in a very low frequency in association of *Lepidopteris* but towards the mid-part of Triassic it exhibited overwhelming dominance and superseded the Glossopteris flora. As a result the seed-bearing plants possessing pinnate leaves appeared on the floristic scene and lasted throughout the Triassic time. They started declining in the Late Triassic giving way to the cycadean and coniferous forms which later constituted a considerable part of plant community during Jurassic-Cretaceous period. *Dicroidium*, its associates, and the seed taxon *Savitrispermum*, which were prolifically represented in the Gondwana continents during Triassic, vanished out. *Pterophyllum, Pagiophyllum* and *Elatocladus* were represented in abundance during Late Triassic, whereas the pteridospermous forms registered a decline. The presence of zamoid seed cones and archegoniate seeds became most distinguishing feature for the Late Triassic floral deposits. Gymnosperms were the main components of the flora associated with some lower plant groups. Seed plant groups attained potential value in defining the floral regions of this period. Thus, the Early Mesozoic flora contained new taxa, as well as those continuing from the Palaeozoic times. Systematic analysis has now shown that the transition from Permian-Early Triassic-Late Triassic was a gradual one.

Key-words—Evolution, Triassic flora, Palaeoecology.

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साराँश

भारत का त्रिसंघी वनस्पतिजात—एक परिवर्तन

श्याम चन्द्र श्रीवास्तव एवं सुरेन्द्र राघोबा माणिक

अनंतिम पुराजीवी से त्रिसंघी कल्प तक अत्याधिक वनस्पतिजातीय परिवर्तन हुए हैं। भारतीय उपमहाद्वीप में परमी एवं त्रिसंघी स्तरों में विभिन्नता शैलिकीय, पुरातात्विक एवं पुरावनस्पतिक आँकड़ों के आधार पर प्रदर्शित की गई है। प्रायद्वीपीय भारत में अनंतिम परमी कल्प का गुरुवनस्पतिजात **ग्लॉसॉप्टेरिस** से प्रभावी है तथा परमी-त्रिसंघी कल्प में **डाइक्रोइडियम** प्रजाति से सहयुक्त है। **डाइक्रोइडियम्** प्रजाति की लगभग 300 करोड़ वर्ष तक अपने समय के वनस्पतिजात में बाहुल्यता रही।

अनंतिम त्रिसंघी कल्प में **टेरोफ़िल्लम्, पेजियोफ़िल्लम** एवं **इलेटोक्लेडस** नामक वर्गक प्रभावी थे जबकि टेरिडोस्पर्मी प्ररूपों का निरंतर ह्रास होता चला गया। इस कल्प में अन्य अवयवों के साथ-साथ अनावृतबीजी पौधे वनस्पतिजात के मुख्य अवयव थे। अध्ययन से पता चला है कि उक्त परिवर्तन परमी-प्रारम्भिक त्रिसंघी से अनंतिम त्रिसंघी तक शनैः शनैः होता रहा है।

Four Decades of Indian Palaeobotany
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Life and time of Indian *Williamsonia*

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The *Williamsonia* plant, belonging to the order Bennettitales, consists of stem—*Bucklandia* Presl, leaf—*Ptilophyllum* Morris, male flower—*Weltrichia* Braun and female flower—*Williamsonia* Carruthers. This plant was perhaps a small, much branched woody tree of xerophytic environment. It co-existed alongwith extremely variable and rich flora including highly diversified plant groups from algae to gymnosperms. In India, it appeared during the marine Jurassic, proliferated and widely distributed in the Lower Cretaceous and disappeared from the vegetational scenario of Upper Cretaceous Period with the advent of angiosperms.

Key-words—Bennettitales, *Williamsonia*, Jurassic-Cretaceous (India).

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सारॉंश

भारतीय विलियमसोनिया का जीवनकाल

जयश्री बैनर्जी

बैन्नेटाइटेलिस क्रम से सम्बद्ध **विलियमसोनिया** पौधे के विभिन्न अवयव अलग-अलग नामों से जाने जाते हैं इसका तना—**बुक्लैंडिया** प्रेस्ल, पत्ती—**टाइलोफ़िल्लम्** मोरिस, नर पुष्प—**वेल्ट्राइकिया** ब्रॉन एवं मादा पुष्प—**विलियमसोनिया** कैरुथर्स से नामॉंकित किया जाता है। यह पौधा शुष्क वातावरण में उगने वाला एक छोटा, अधिक शाखाओं से युक्त वृक्ष था। यह विभिन्नता से युक्त वनस्पतिजात, जिसमें शैवालों से लेकर अनावृतबीजी समूह के पौधे विद्यमान थे, का ही एक अवयव है। इसका समुद्री जूराई कल्प में उदय हुआ, अधरि क्रीटेशी कल्प में विकसित एवं दूर-दूर तक फैला तथा उपरि क्रीटेशी कल्प में आवृतबीजी पौधों के उदय होने के साथ-साथ विलुप्त हो गया।

LIFE OF *WILLIAMSONIA* PLANT

In the Upper Mesozoic Era, a new group of plants—the Bennettitales, developed that colonised various habitats of terrestrial areas. This group continued till Early Cretaceous. In India, it is represented by the members of the family Williamsoniaceae and occurs pre-dominantly during Lower Cretaceous Period (Text-figure 1). The *Williamsonia* plant is known through its stem—*Bucklandia* Presl, leaf—*Ptilophyllum* Morris, male flower—*Weltrichia* Braun, and *Williamsonia* Carruthers female flower.

Stem—*Bucklandia* Presl

The *Bucklandia* stem was erect and cylindrical, protected by armour of rhomboidal leaf-bases. Four species of *Bucklandia* described from India are: *B. indica* Seward, *B. sahnii* Bose, *B. guptai* Sharma and *B. dichotoma* Sharma. In *B. indica* Seward, the secondary wood is more compact than recent cycads and cycadeoids. The medullary rays are uniseriate and tracheids have multiseriate bordered pits on their radial walls instead of scalariform pitting in the majority of cycadeoid stems. Secretory canals are abundant in the parenchymatous ground tissue, the cambium and phloem are not preserved. The cross section (Text-figure 2) of *B. sahnii* Bose 1953a shows well-defined growth rings in the secondary wood, 4-9 cell thick cork cambium present outside the cortex. Cortex is fairly wide, parenchymatous with thick-walled cells, singly or in group and leaf traces with a single bundle which finally breaks up into 5-7 strands. Pericycle is with few layers of polygonal cells. The phloem ring is marked by alternate bands of poorly developed rays leaving big

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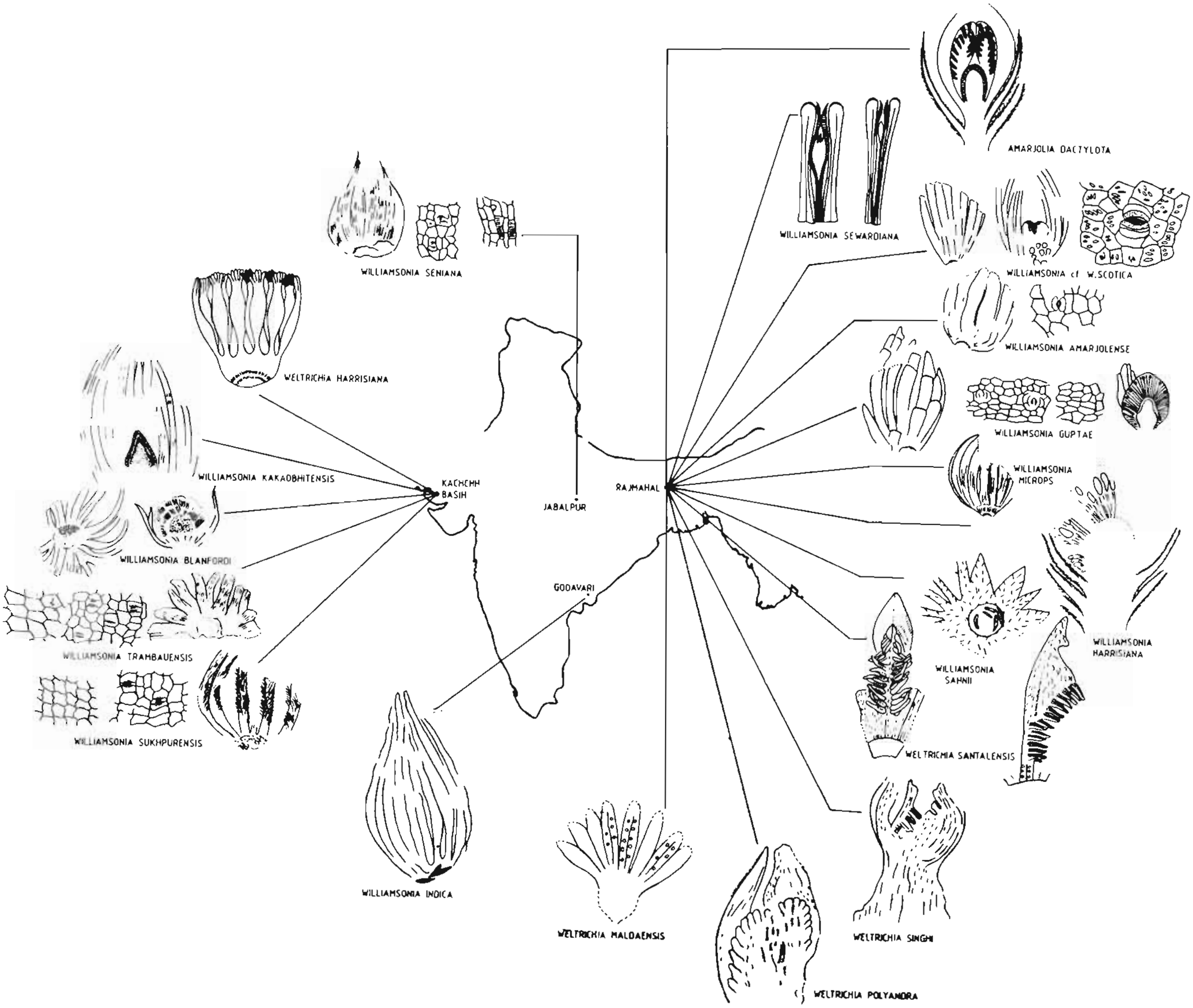
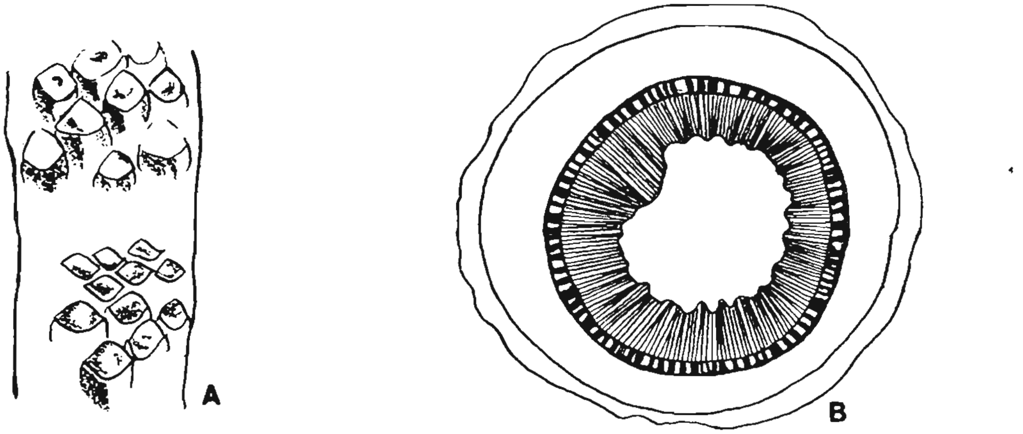


Text-figure 1—Distribution of Indian Williamsonian flowers.

cavities. Phloem consists of alternate thick- and thin-walled elements. Traces of cambium are seen below the phloem. The tracheids of early wood have a large diameter with a thinner wall than those of the late wood. The late wood is remarkably developed and occupies about two-third of the whole growth rings. Radial surface of the late wood tracheids have not so variable pitting but the early wood shows different type of pitting from scalariform to multiseriate. Ray cells in radial view are rectangular and much wider than high. The pits in the field are bordered, usually one to six or more, oval or circular in shape. Longitudinal section shows that the inner-most part of xylem ring consists of 4 to 8 layers of slender tracheids with spiral thickening in their walls. Pith is very wide and consists of parenchymatous cells with numerous scattered thick-walled cells similar to the cortex. In *B. sahnii* the stem had forked branches and the flowers were borne at the point of bifurcation as in *Wielandiella angustifolia* Nathorst. *Bucklandia guptai* Sharma 1967 has sparsely arranged symmetrical leaf basis and anatomically it shows the presence of numerous growth rings and mostly uniseriate medullary rays which are rarely biseriate. *B. dichotoma* Sharma 1969b is characterised by having longer rays, biseriate in nature and bordered pits with narrow elliptical pit pores. According to Bose (1974, p. 196), this species is based on variable characters and these should not be used for specific differentiation. Besides, he considers it perhaps as a young stem.

Mode of branching—Seward (1912), while describing petrified *Williamsonia* from Scotland, suggested the existence of a sympodial branching,



Text-figure 2—A, *Bucklandia*—stem; **B,** T.S. of *Bucklandia*—stem.

while Sahni (1932) suggested monopodial branching in *W. sewardiana.*

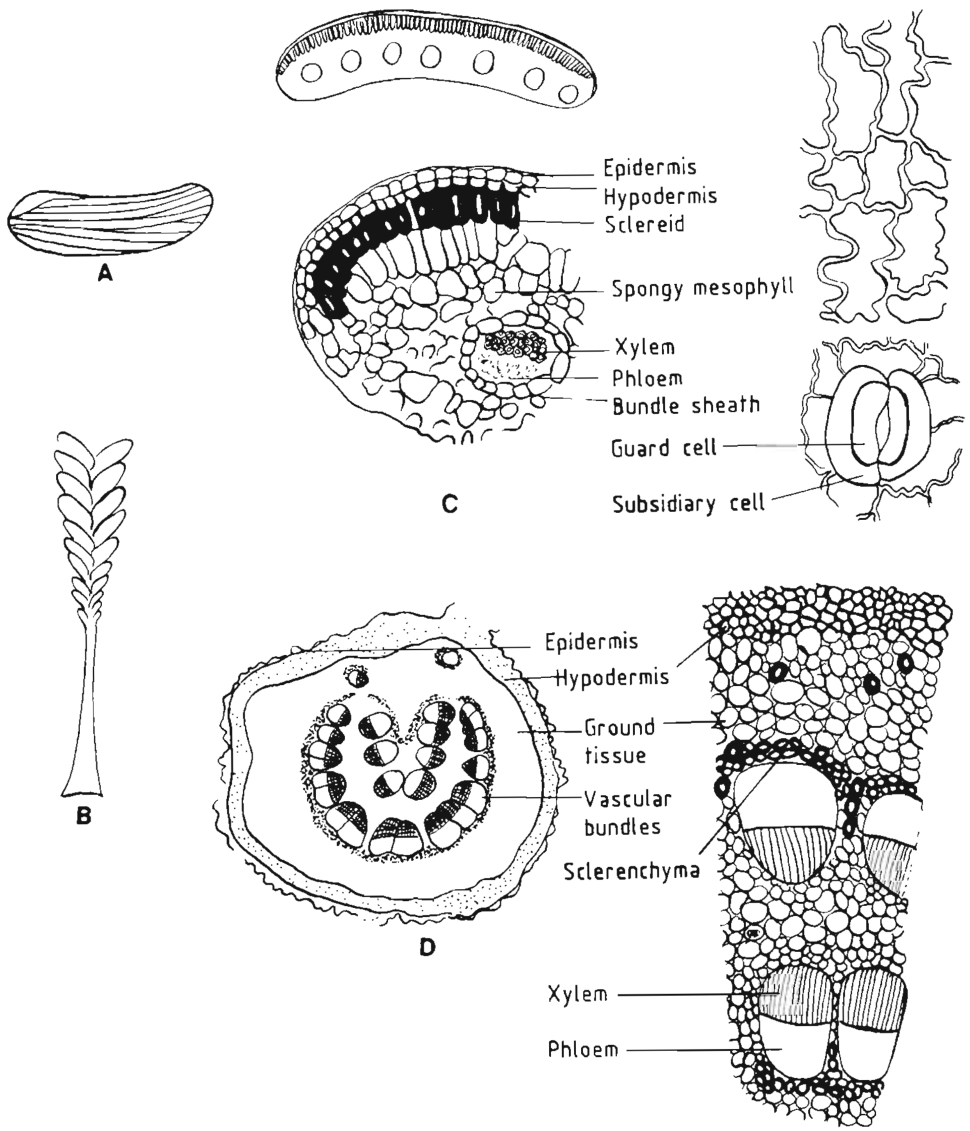
Leaf—*Ptilophyllum* Morris

The genus *Ptilophyllum* Morris in Grant (1840) originally comprised pinnate fronds, pinnae with acute or obtuse apices. The circumscription of the genus was later enlarged to include pinnate frond, pinnae linear-falcate in shape with acute, sub-acute to obtuse apices, basal acroscopic margin round, basal basiscopic margin decurrent and veins sub-parallel to slightly diverging towards the apical margin. The rachis contains a double arc of collateral vascular bundles comparable to the pteridosperms (Text-figure 3). Sclerenchymatous patches and sclereids are found in the cortex. Single bundle arises from the upper corner of the double arc of vascular bundle of rachis which divides into two at the base of the pinna. It is repeatedly forked at different levels to form a more or less parallel venations.

The anatomy of pinna shows collateral, exarch xylem with a parenchymatous bundle sheath. Sclereids occur isolated or in groups in the palisade and spongy mesophyll. The salient features of the cuticle of *Ptilophyllum* leaves are hypostomatic condition with syndetocheilic stomata, but vary in the pattern of distribution of stomata, papillae and its morphological differences, being the main criteria for speciation. *P. acutifolium* Morris has pinnae with acute apices, whereas *P. cutchense* Morris possesses sub-acute to obtuse apices. *P. rarinervis* (Feistmantel) Bose has pinnae with 2-3 veins only. *P. tenerrimum* Feistmantel has narrow, long pinnae. In *P. indicum* Jacob & Jacob 1954, stomata are distributed in stomatal bands. *P. oldhami* Jacob & Jacob 1954 shows irregular distribution of stomata except on the marginal region. In *P. distans* Jacob & Jacob 1954 pinnae have acute apices and the lower cuticle is differentiated into broad stomatiferous and narrow non-stomatiferous bands, cells are devoid of papillae and the outer wall of the subsidiary cells is looped. *P. jabalpurensis* Jacob & Jacob 1954 is characterised in having 1-3 papillate marginal cells and papillae are solid circular or semi-circular, hollow-circular or crescent-shaped. In *P. nipanica* Vishnu-Mittre 1956 lower epidermis has non-papillate cells and stomata are arranged in bands. *P. gladiatum* Bose & Sukh-Dev 1958 is distinct in having gladius-like pinnae and non-papillate epidermal cells of veins and subsidiary cells. *P. institacallum* Bose 1959 is significant in possessing papillae of various shapes. The epidermal cells of lower cuticle and stomata are irregularly scattered in the inner zone. *P. sakrigaliensis* Sah 1958 has elongated pinnae with acute apices. Lower cuticle is studded with stomata arranged in bands. One or two papillae are present on each epidermal cell of the vein band. *P. horridum* Roy 1967 shows lower cuticle with stomata in bands and two or more papillae on each epidermal cell of the vein band but they do not form a frill-like structure over the vein band as in *P. institacallum*. *P. sahnii* Gupta & Sharma 1968 has small pinnae, oblong or oval in shape with obtuse apices, lower cuticle is differentiated into broader stomatal, narrow non-stomatal band and marginal non-stomatal region, epidermal and subsidiary cells are devoid of papillae. *P. amarjolense* Bose 1953b is distinguished by its broader leaves and stomatal bands are 4-5 stomata broad.

Male flower—*Weltrichia* Braun

The male flower is characterised by having microsporophylls forming a cup-shaped structure at



Text-figure 3—A, *Ptilophyllum*—pinna showing venation; **B,** *Ptilophyllum* leaf; **C,** T.S. of pinna; **D,** T.S. of rachis.

the base. They bear polleniferous appendages adaxially or distally. Each appendage has two rows of pollen chambers. The pollen grains are oval and monocolpate.

From India, male flower was first described as *Williamsonia santalensis* Sitholey & Bose 1953. Later, Bose (1967) suggested that the specimen of *Williamsonia santalensis* be included under the genus *Weltrichia* Braun as it has priority. The male flower consists of a whorl of 20 (?)microsporophylls coalescent towards the base to form a shallow cup. Each microsporophyll bears on its upper surface two rows of finger-like appendages which are presumed to have been the spore-bearing organs. The rows of small chambers are present inside each appendage. The distal sterile portion of the microsporophyll shows an asymmetrical and obliquely twisted expansion of the lamina. Sharma (1969a) suggested that there are two whorls, the outer whorl consists of 20 sterile bracts and the inner whorl has 20 twisted microsporophylls. He also opines that the appendages are in two rows on the adaxial side of the proximal part of the microsporophyll and there is only one row on the distal part of the microsporophyll (Text-figure 4C). Later, Sitholey and Bose (1971) commented that the bracts are spirally arranged and are not in whorls. The receptacle of *Weltrichia* is, in fact, cup-shaped flower formed by the fusion of microsporophylls. The fertile organ consists solely of a tubular thick-walled structure, tapering distally which completely encloses the polleniferous chambers. Revised restoration of microsporophyll given by Sitholey and Bose (1971) shows that the microsporophylls were bilaterally symmetrical structures without any twisting of distal portion. The abaxial surface of the expanded distal portion is raised into a prominent hump-like structure (Text-figure 4A, B).

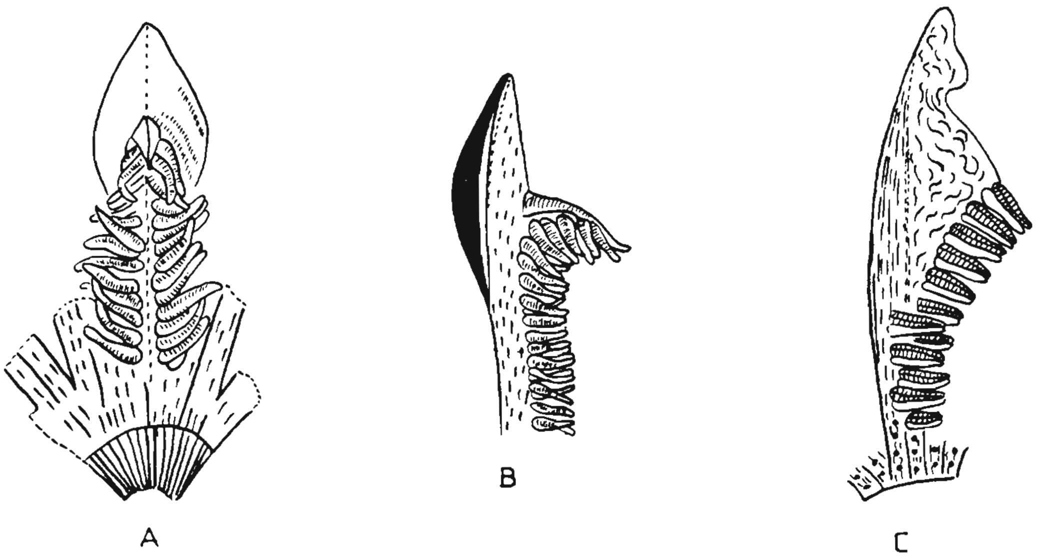
Ontheanthus polyandra Ganju 1947, a unique bennettitalean fructification, was transferred by Sharma (1969a) to *Williamsonia santalensis* Sitholey & Bose 1971 recognised it as a separate taxon under *Weltrichia.* It needs further examination whether it is a part of an unopened flower of *Weltrichia santalensis* or an incomplete preserved part of a bisexual flower—*Amarjolia dactylota. Weltrichia singhii* Bose 1967 is supposed to represent bud conditions of *W. santalensis* (Sharma, 1969a). *Williamsonia companulatiformis,* known by an incomplete specimen, is built more or less on the same plan of construction as *Weltrichia santalensis* (Sharma 1969a, p. 102; Sitholey & Bose 1971). *Weltrichia harrisiana* (Bose & Banerji, 1984) is about 12-15 cm in diameter. Microsporophylls 12-14 in number, coalesce towards the base and form a circular depression, about 2 cm in diameter. The microsporophylls are distally expanded, coriaceous and their adaxial surface exhibits prominent ridges. Each microsporophyll terminates into five uniformly broad fertile appendages, each appendage having a double row of polleniferous chambers. *Weltrichia maldaensis* Pal & Ghosh 1985 shows microsporophylls with some small circular lateral projections.

Female flower—*Williamsonia* Carruthers

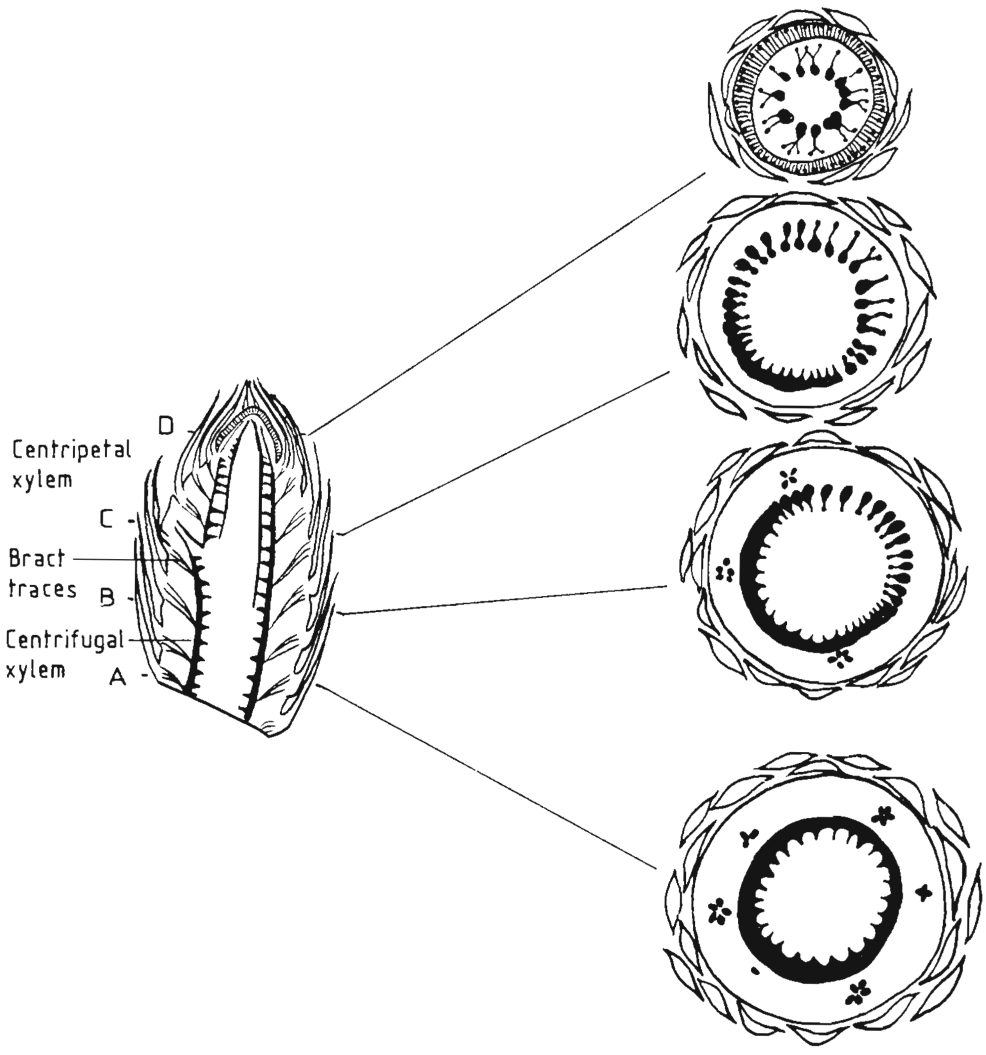
Williamsonia Carruthers, the female flower, has receptacles of various shapes, e.g., rhomboidal, hemispherical-conical with numerous interseminal and seminal scales. The receptacle is surrounded by numerous spirally arranged bracts.

The anatomy of peduncle (Text-figure 5) shows the changes in the vascular organisation at different levels (Sharma, 1973b). The centrifugal xylem is gradually reduced in thickness and broken into segments. Centripetal xylem originates from the endarch protoxylem points of centrifugal xylem and gradually increases in amount towards the upper side of peduncle. In the receptacle centripetal xylem forms the main vascular cylinder and the remnants of the centrifugal xylem are connected with each other by their tangentially elongated protoxylem points.

Anatomy of receptacle shows the main stele consisting of a number of isolated, collateral inverted, exarch vascular bundles which maintain their shape and size from base to apex (Text-figure 6). In the basal position bundles gives off paired traces to the bracts, while in the middle part of the receptacle they are connected with isolated, collateral or concentric, endarch or mesarch vascular bundles present in the peripheral region of cortex. These peripheral bundles are the source of vascular traces to the scales. The tracheids of bract traces have spiral thickening on their lateral walls. Transverse section through the concavity of receptacle shows inverted bundles in the main stele indicating a change from endarch condition of vascular bundle in the peduncle to exarch condition in the receptacle. The main stele gives off traces only at two places in the whole receptale. The first point lies in the pedicel while the second is present in the middle part of receptacle. These two points in the



Text-figure 4—Restoration of microsporophyll—**A, B,** after Sitholey and Bose (1971); **C,** after Sharma (1969a).



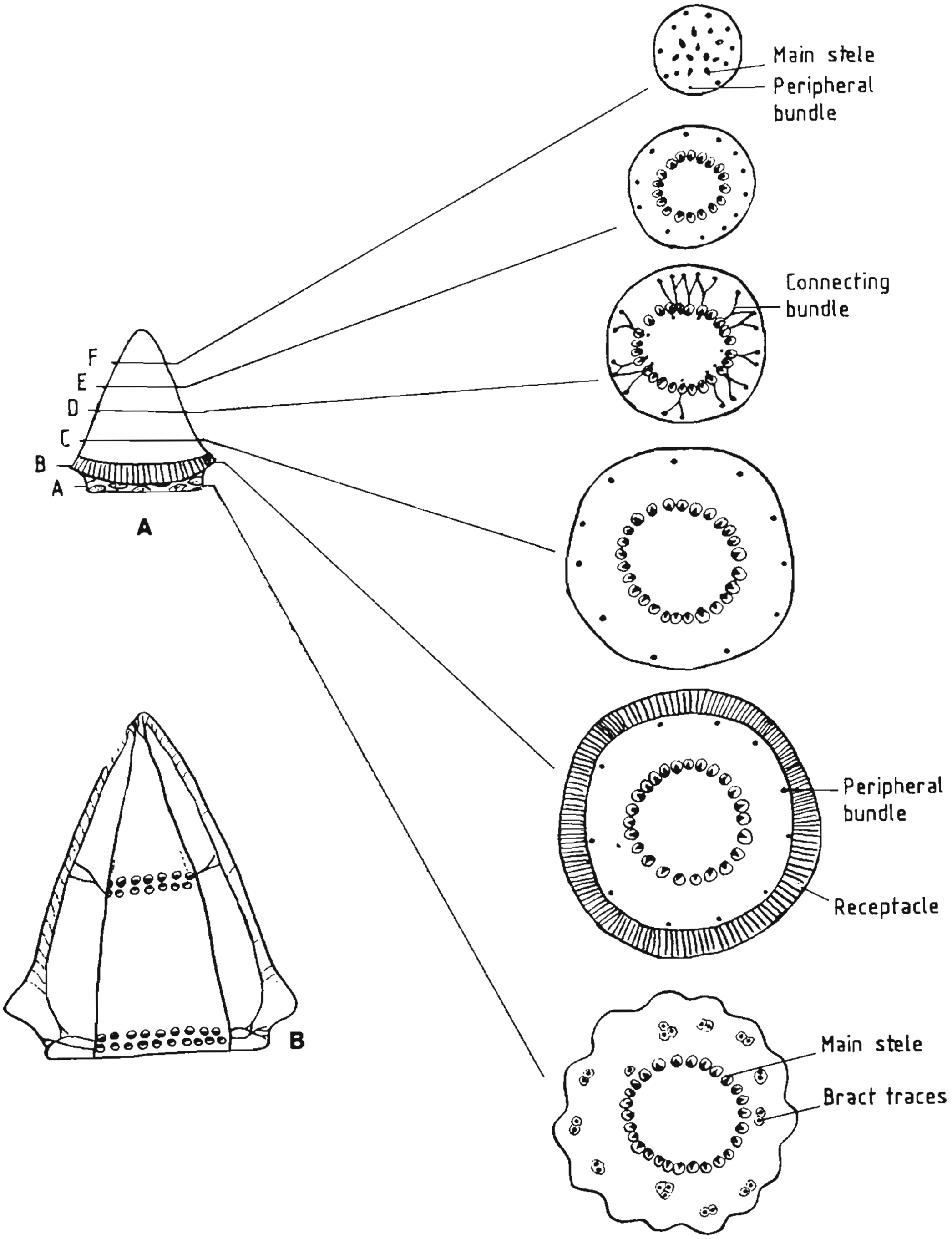
Text-figure 5—Reconstruction of the vascular organisation in transverse and longitudinal section of peduncle.

receptacle may be compared with the two modes of a branch or stem. According to Sharma (1973b) the receptacle of a seed-bearing *Williamsonia* is comparable with a two noded inflorescence axis.

Bract anatomy shows a thick sclerenchymatous hypodermal zone which consists of relatively larger cells on the abaxial side. There are usually 7 collateral, endarch vascular bundles, two above near the middle line and five forming an arc parallel to the lower surface. The xylem of the bundles facing each other in the radial portion of the bract and in the distal flattened part, the number of bundles reaches up to 11 or more. The ground tissue is parenchymatous but without mucilage canals (Sahni, 1932; Sharma, 1975).

The upper surface of the bracts has rectangular or squarish epidermal cells which are arranged in rows, parallel to the long axis of the bracts. The lateral walls of the cells are thin and sinuous. Outer wall of the epidermal cells is provided with circular, scattered simple pits. Stomata are syndetocheilic, non-sunken and transversely oriented.

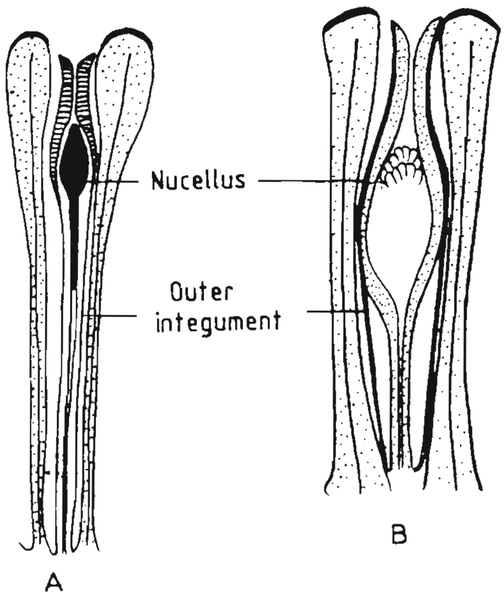
The fertile portion consists of a small, conical receptacle which is produced terminally on a thick peduncle. The receptacle is covered with a thick layer of sterile and fertile scales. The sterile scales consist of hexagonal-rectangular parenchymatous cells with a central vascular strand up to the highly cutinized distal regions. Five or six sterile scales surround a fertile seminiferous scale represented by an orthotropous ovule which consists of a small, thick stalk or funiculus and a long, oblong body. The stalk has a definite concavity at its basal end, representing the abscission point of the scale. From the upper part of funiculus arise a central long, slender nucellar stalk and a thin outer integument. The former consists of two types of cells, central thin-walled parenchymatous and the surrounding



Text-figure 6—A, Transverse section of the receptacle showing vascular organisation; **B,** Longitudinal section of the receptacle showing vascular organisation.

thick-walled, darkish, elongated cells. The nucellar stalk terminates into an oval-shaped nucellus, the apical end of which is made up of a rosette of elongated cells. The nucellus is fused with integument which is made up of rectangular, parenchymatous cells. It is three or four cells thick in the region of micropyle but reduces downward, so that near the basal part of nucellus it is only one cell thick and then merges into the surrounding layer of nucellar stalk.

The distal end of micropyle is more or less a funnel-shaped structure and reaches the level of the terminal end of the surrounding interseminal scales. The outer integument arises from the funiculus remains which are thin, delicate and mostly one cell thick throughout its length. It remains free from the



Text-figure 7—Vertical section of ovule—**A**, after Sahni (1932), and **B**, after Sharma (1975).

nucellar stalk, but fuses with the inner integument near the basal part of the nucellus and then continues upwards as an outermost layer of integument up to the distal end of micropyle (Text-figure 7A, B.

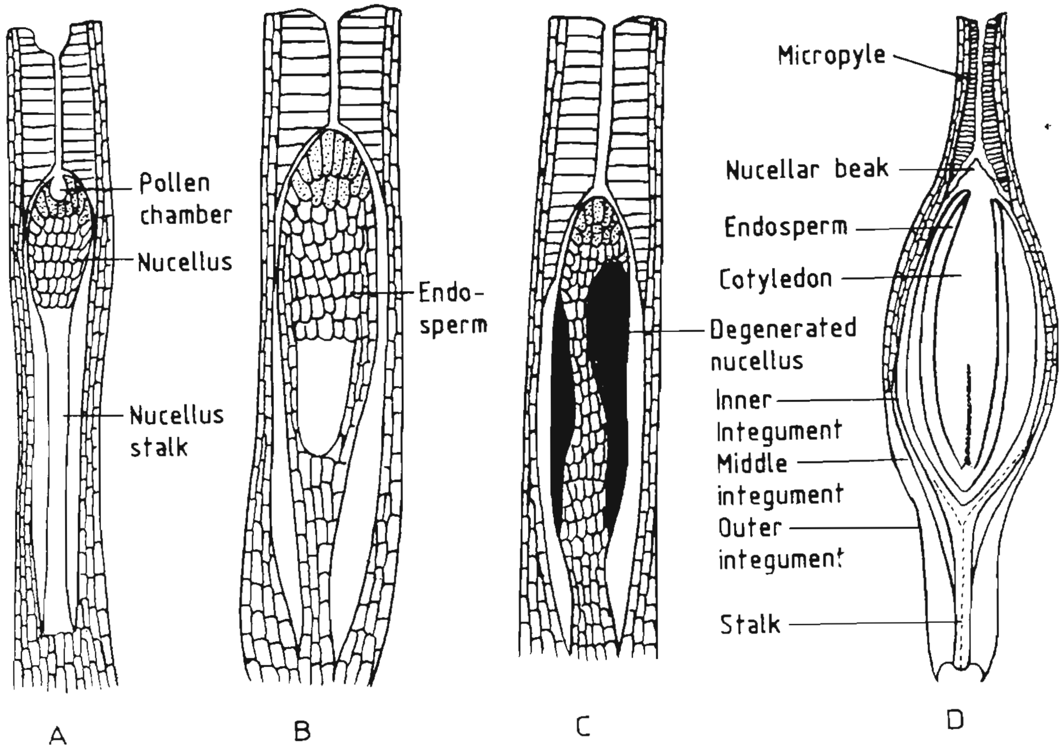
The different developmental stages of an ovule show that the development of fertile layer is basipetal (Sharma, 1974b). In the basal part of receptacle the fertile layer consists of thin-walled polygonal cells without any distinction of scales. The scales are produced as a result of ingrooving of epidermis. Differentiation of fertile scale starts from the micropylar end. The development of integument takes place at an early stage of ovule ontogeny. In a young ovule there is a long cylindrical nucellar stalk which terminates into a conical nucellus; pollen chamber is differentiated in the upper part of nucellus (Text-figure 8A). A megaspore mother cell is produced in the nucellus which divides by free nuclear divisions for the formation of an endosperm. The endosperm wall formation starts from the micropylar side and continues on the descending side (Text-figure 8B). On maturity of endosperm the surrounding cells of nucellus degenerate, except the micropylar side (Text-figure 8C). Pollen chamber formed by the degeneration of nucellar cells shows affinity of *Williamsonia* with the cycads on one hand and *Ephedra* on the other (Sharma, 1974b). Sharma (1979) further observed that the megaspore mother cell is situated not very deep in the nucellus. The female gametophyte covers almost whole nucellus and is made up of thin-walled cells. In the apical part of endosperm two or more archegonia are seen arranged in a ring and distinct from the cells of endosperm. The micropylar canal in young ovule is long, narrow and lined with large cells, while in mature ovules or seeds the canal becomes small, wide and filled by a nucellar plug. The thickness of micropyle reduces from 3-4 cells to one showing relationship with *Cycadeoides* and *Gnetum*. Mature seeds are found in ripe, nacked, bractless fruits. Seeds are oblong or ovate, stalked, dicotyledonous, partially endospermic and have a long micropyle (Sharma, 1970c). Seed coat includes outer tubular cells, middle parenchymatous true integument and inner vascularized tissue formed after fertilization by modification of the peripheral portion of nucellus. The seed of *Williamsonia* differs from cycadeoideas in being partially endospermic and shows more affinities with the seeds of pteridosperms and Gnetales than with the angiosperms.

On maturity, the flower produces abscission layer in between the receptacle and the compact layer of sterile and fertile scales. The sterile scales and ovules are ontogenetically identical. It is related to the extant genus *Ginkgo* in the manner of detachment of flower from the parent plant before fertilization. The inter-locking cells of the micropyle was either absent or the flower was detached before pollination.

ATTACHMENT OF FLOWER

On the basis of their plan of construction the flowers can be divided into two main types, viz., "exposed type" as in *W. guptae* and *W. amarjolense* Sharma and partially "hidden type" as in *W. sewardiana* Sahni. In exposed type, the flower were borne either terminally on the branches or directly on the sides of the stem. They had a definite point of abscission and covered with bracts produced from the base of the receptacle. Moreover, on the basis of number, shape and size of bracts they can be further divided into three main types (Sharma, 1971). In the first type, the bracts are large, incurved and mostly arranged in one row as in *W. amarjolense* (Text-figure 9A). The second type has long, linear bracts arranged in two rows as in *W. guptae* (Text-figure 9B). The third type includes the flower with linear, thin, straight and arranged in several rows of bracts as in *W.* cf. *W. scotica* (Text-figure 9C). The second type of partially embedded flower probably detached itself from the parent plant on maturation leaving a depression on the side of the stem (Text-figure 9D). The variation on the basis of number, shape and size of bracts might be due to seasonal fluctuation.

Feistmantel (1876) described *Williamsonia*



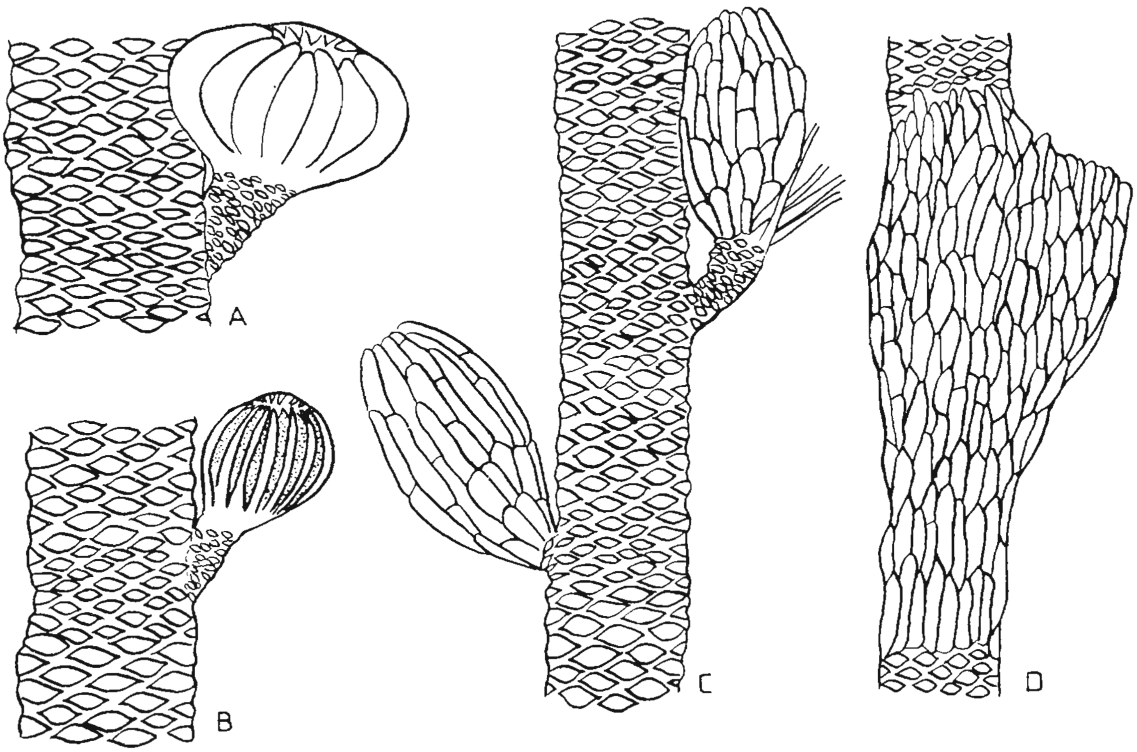
Text-figure 8—A-C, Vertical section of ovules showing different stages of development; **D,** Seed restoration.

blanfordi from Kachchh. *W. gigas* Carruthers recorded by Feistmantel (1877a) has been ultimately placed under *Weltrichia santalensis. W. microps* Feistmantel 1877a is visualized as a small pedicellate bud-like specimen of *W. gigas* or *W. blanfordi* by Seward (1917, p. 445) and Seward and Sahni (1920). *Williamsonia* comb. *W. gigas* Feistmantel 1877b has been placed under a new species—*W. indica*, by Seward (1917) in being larger in size. In *W. sewardiana* (Sahni, 1932) the flower has hemispherical receptacle, seminal and interseminal scales 3 mm in length which gradually reduce up to 1.5 mm. Soft investment around the nucellus continued downwards forming the outer layer of nucellar stalk. Sharma (1975) observed adherence of nucellus and integument throughout its length (Text-figure 7B). *W. sahnii* Gupta 1943 is supposed to be a bisexual flower but as there is no positive evidence of the presence of androecium, the author himself doubts about its bisexuality. *W. harrisiana* Bose 1968 is characterised by dome-shaped receptacle, seminal and interseminal scales up to 1 cm in length and the presence of a sterile disc. Sharma (1977) observed sterile disc in almost all the species.

W. guptae Sharma 1968 has conical receptacle with seminal and interseminal scales up to 1 cm in length, epidermal cells of the bract rectangular and stomata sunken. *W. amarjolense* Sharma 1968 is distinct in having hemispherical receptacle, epidermal cells of bracts are polygonal and stomata non-sunken. Perhaps *W. guptae* is similar to *W. harrisiana* in shape of receptacle, size of seminal and inter-seminal scales and epidermal features of the bracts. *W. seniana* Bose & Kasat 1969 can be distinguished by its epidermal features. In *W.* cf. *W. scotica*, the bracts are considered as reduced pinnate leaves having pinnae in the form of reduced vascularised appendages (Sharma, 1970a). *W. kakadbhitensis* Bose & Banerji 1984 is distinct in having rhomboidal receptacle and hairy bracts. *W. trambauensis* (Bose & Banerji, 1984) is characterized in having ramentum scars and trichome bases. *W. sukhpurensis* (Bose & Banerji, 1984) has jagged-thickening on the lateral walls of epidermal cells.

HABIT OF *WILLIAMSONIA* PLANT

On the basis of morphological and anatomical characters, it is suggested that the plants of *Williamsonia* were perhaps small, much branched woody trees of xerophytic environment. They had adopted various ecological strategies to meet the water stress conditions as shown by different parts of the plants. The columnar stem was branched monopodially or sympodially, bearing large and small slender branches with spirally arranged



Text-figure 9—A, B, Showing attachment of flower on lateral branch; **C,** Reconstruction showing terminal or lateral attachment as shown by *Williamsonia* cf. *W. scotica*; **D,** Partially hidden type of *Williamsonia* flower.

pinnate foliage leaves. The pedunculate flowers were borne terminally/laterally at the point of dichotomy or the sessile flowers were partially embedded into the stem. These woody trees perhaps formed a part of mixed subtropical community of the forest. The palaeolatitudinal position of the Indian subcontinent during the period was between 20°-45° south latitude (Smith & Briden, 1979) and this supports the existence of tropical to subtropical climate. The stem of ***Williamsonia*** possesses persistent armours of leaf-bases which perhaps acted as a protective covering either from predators or to withstand unfavourable conditions. The armours might have provided mechanical strength to the stem also. The variation in size and shape of the leaf scars depends upon the position of abscission layer and is probably environmentally induced variation. The presence of periderm and the stem anatomy show arborescent nature of the plant. The periderm protects the inner tissue from weathering. The presence of sclereids in the peduncle and rachis, sclerenchyma cells outside and in between the vascular bundle of the rachis provides hardness to these parts. Stem has a large pith and less secondary tissue suggesting that the plant could grow in moisture deficit soil. The secondary wood shows large lumened variously pitted tracheids in the growing season (Early wood) indicating that water availability was high. Thick-walled tracheids with less variable pitting (Late wood) show water stress condition. The leaf anatomy shows sheathed vascular bundles. Sclerenchymatous hypodermis acts as a supporting tissue and provides rigidity to the leaves to withstand wilting. The occurrence of sunken stomata on the lower surface (hypostomatic condition) in most of the species and sclerenchymatous hypodermis show xeromorphic characters. Sclerenchyma and sclereids give mechanical strength and protection. Papillae in the epidermal cells as well as subsidiary cells act in two ways, i.e., they reduce the intensity of the incoming radiation and also check the wind action. High stomatal frequency of occurrence in a few species perhaps is due to high rate of transpiration. Growth rings in the secondary wood and abscission of leaf show seasonal fluctuation in light, temperature and water availability. The mechanism of abscission gives protection against desiccation in adverse conditions. Abscission of bracts shows maturity of the flowers. The abscission of the reproductive parts, i.e., seminal, interseminal scales and microsporophylls from the receptacle base helps in dissemination for fertilization and manner of dispersal. Hairs on the bracts perhaps protect the reproductive parts from insect predators and also reduce the transpiration rate. The ovules are further protected by interseminal scales which possibly acted as protective covering but, later attracted the insects for pollination. In *Williamsonia*, flowers were unisexual suggesting out-breeding by anemophilly, whereas *Amarjolia*-flower (another bennettitalean flower) was hermaphrodite. The curved nature of microsporophyll and protandrous nature of *Amarjolia* also indicate out-breeding by entomophily. Whether these major selective characters provide protection from phytophagus insects or from self-incompatibility are questions to be considered squarely.

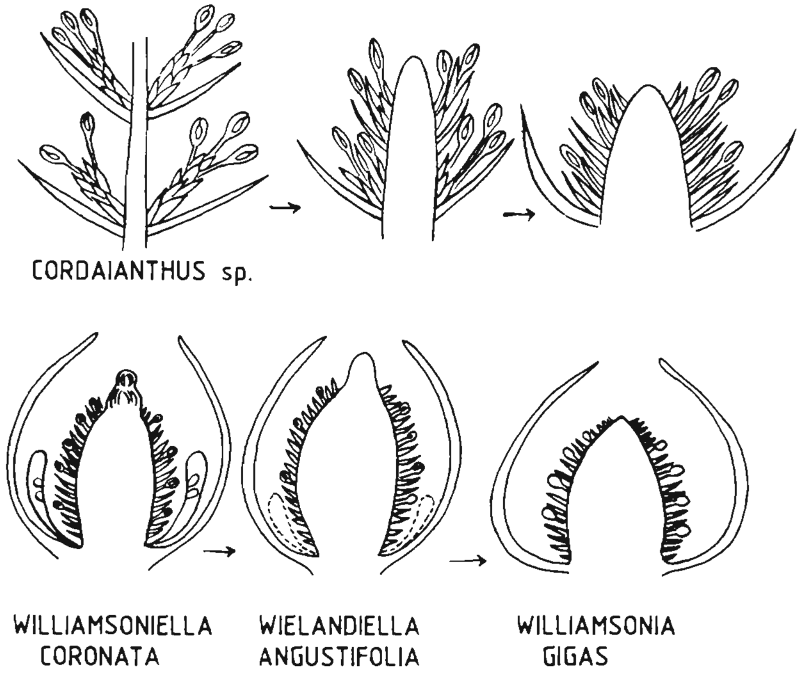
A cycas-like habit for *Williamsonia sewardiana* was proposed by Sahni (1932), plant with columnar stem—*Bucklandia indica* Seward, crown of pinnate foliage leaves—*Ptilophyllum* cf. *cutchense* Morris and female flower borne terminally on short branched laterals—*Williamsonia sewardiana*. Later, the recovery of more species of female flower: *W. guptae* Sharma, *W. amarjolense* Sharma, Stem—*Bucklandia sahnii* Bose, and leaves—*Ptilophyllum amarjolense* Bose and *P. sahnii* Gupta & Sharma from the same locality raised doubts about Sahni's reconstruction of *W. sewardiana, Bucklandia indica* and *Ptilophyllum* cf. *cutchense*. Anatomically the peduncle of *W. sewardiana* is more similar to *Bucklandia sahnii* Bose than with *B. indica* Seward (Bose, 1953a; Sharma 1975). Besides, the discovery of branched stem of *B. sahnii* and *B. dichotoma* suggested that these plants had equal or unequal branched stems and perhaps due to the deciduous nature of small laterals and leaves they were found in large number. Recently, a specimen has been recovered from Rajmahal Hills in which the *Williamsonia*-flower seems to be laterally attached to a narrow branch perhaps by a small peduncle. On the basis of these evidence, the branching in *Williamsonia* was probably more akin to the reconstruction of Harris (1969, fig. 59c) for *Bucklandia pustulosa, Ptilophyllum pecten* and *Williamsonia leckenbyi*. This view has also been supported by Bose (1974, p. 197), but it needs better specimens with branching habit.

RELATIONSHIPS OF *WILLIAMSONIA*

Williamsonia, belonging to Bennettitales, shows primitive as well as advance gymnospermous characters. It shows affinities with the plants of Pteridospermales, Cordaitales, Cycadales, Gnetales, etc.

Affinities with Pteridospermales

Presence of secretory canals in pith and cortex of stem shows affinity with the Pteridospermales. In the petiole the bundles are united at places exhibiting a continuous C-shaped strand as in some pteridosperms, viz., *Rhetinangium arberi* Gorden. The endospermic seed of *Williamsonia* also shows



Text-figure 10—Stages showing derivation of an ovulate cone of *Williamsonia* from a female inflorescence of *Cordaianthus* sp. as a result of condensation and swelling of the axis.

affinity with the seed of pteridosperms. The microsporangiate flower having pinnate microsporophylls shows some similarities with pteridosperms. But, in *Weltrichia*, a cup-shaped receptacle with microsporophylls and microsporangia which are either directly attached or arranged on finger-like appendages are those notable characters not exhibited by an extinct or extant group of plants.

Affinities with Cordaitales

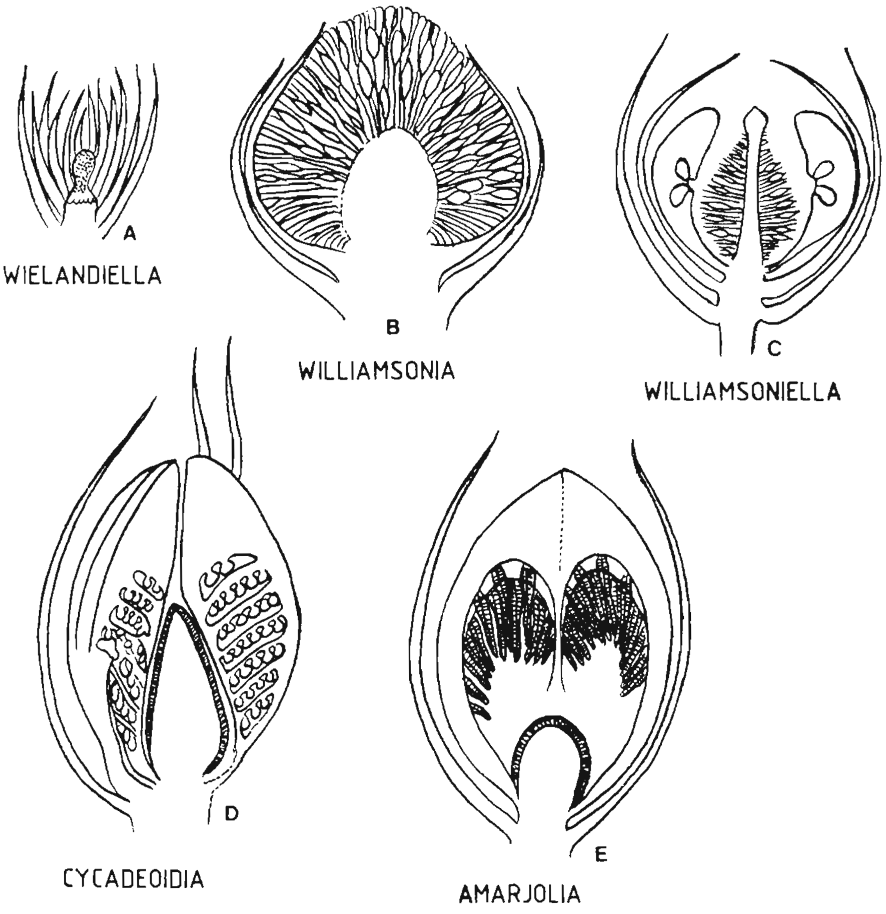
Sharma (1982) derived bennettitalean seed bearing fructification from *Cordaianthus* as a result of reduction and swelling of inflorescence axis producing receptacle and modification of the axillary bud bearing megasporophylls and scales to seminiferous and interseminal scales (Text-figure 10). However, in ovule ontogeny *Cordainthus* and *Williamsonia* are different from each other.

Affinities with Cycadales

Presence of armours of leaf bases on the stem, crown of pinnate leaves and secretory canals in pith and cortex shows similarity with that of *Cycas*. Girdle leaf traces are absent unlike *Cycas*. Cuticle and anatomy of leaf also differ from *Cycas*. In *Williamsonia*, stomata are syndetocheilic and transversely oriented, whereas in Cycadales stomata are haplocheilic. Diploxylic condition in the anatomy of *Cycas* leaf is also unlike Williamsonias. In *Cycas*, petiole shows omega-shaped, collateral endarch bundles, whereas in *Williamsonia* they are arranged in double row. Non-vascularised integument of ovule differs from cycads but the megagametophyte with 3-4 archegonia and pollen chamber formed by the degeneration of nucellar cells are the common features.

Other affinities

Mehra (1988) derived Bennettitales independently from Protoseminales, a plexus which gave rise to Cordaitales and Pteridospermales. Presence of definite abscission point at the base of fructification suggests similarity with the *Ginkgo*. In *Williamsonia*, the integument surrounding each

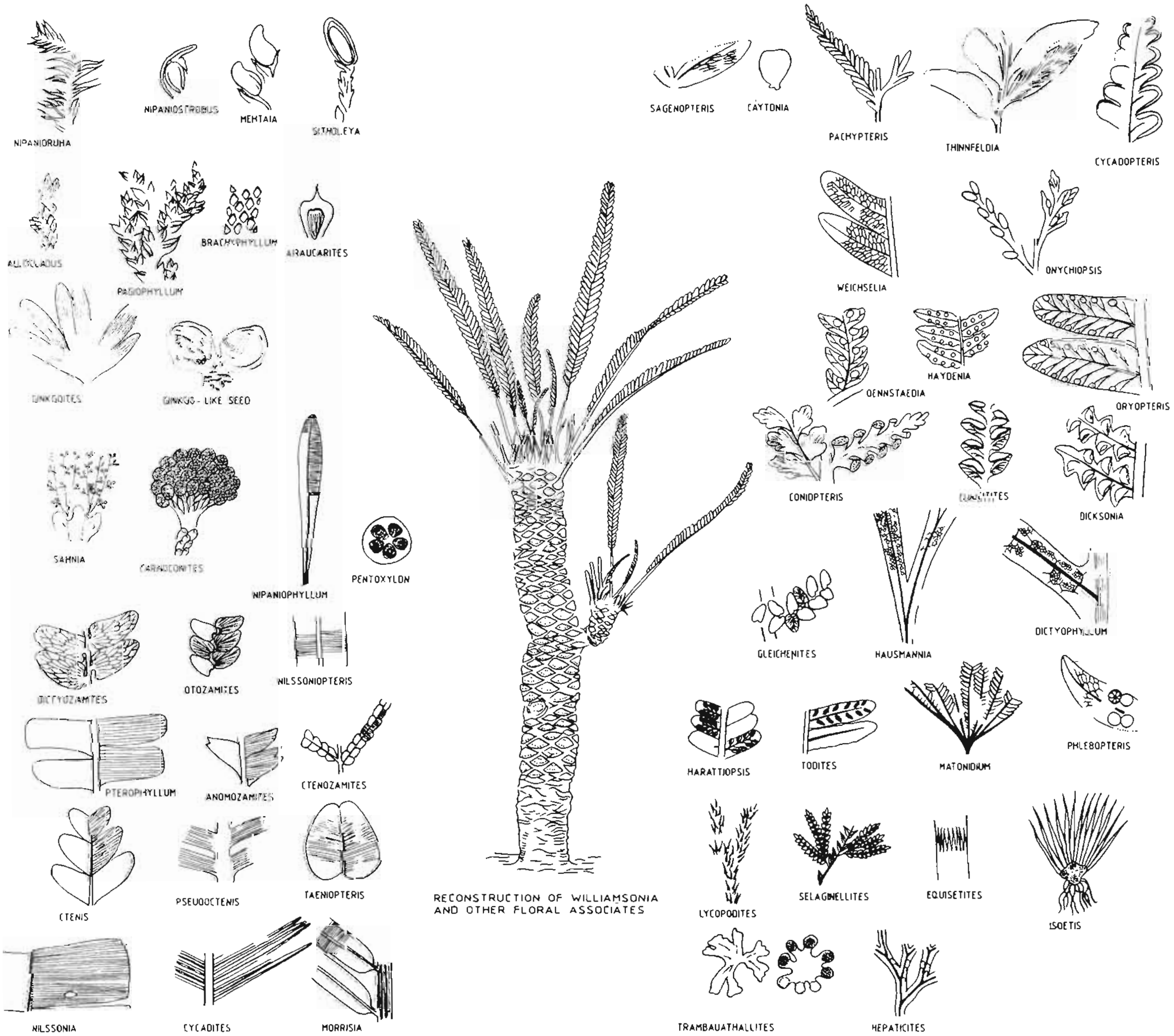


Text-figure 11—Showing gradual sequence of flower from monosporangiate to bisporangiate condition or vice versa; **A,** *Weilandiella*; **B,** *Williamsonia*; **C,** *Williamsoniella*; **D,** *Cycadeoidea*; and **E,** *Amarjolia*.

ovule and extending up to a long micropyle exhibits an advanced feature shown by *Gnetum* and *Welwitschia*. The formation of pollen chamber by the degeneration of nucellar cells shows its relationship with *Ephedra*. Flower-like organisation of *Williamsonia* fructifications led Wieland (1906) and Arber and Parkin (1907) to suggest that Mesozoic Bennettitales are the ancestral group of angiosperms. A gradual sequence can be drawn from monosporangiate to bisporangiate flower, i.e., *Wiellandiella, Williamsonia, Williamsoniella, Amarjolia* to *Cycadeoidea* or vice versa (Text-figure 11), but which one is primitive is difficult to say.

TIME OF WILLIAMSONIAS

The Williamsonias appeared in India during Upper Jurassic Period and flourished well in tropical to subtropical climate of Lower Cretaceous Period. The other floral associates of Williamsonias are represented by extremely variable taxa of highly diversified plant groups (Text-figure 12). They are: *Hepaticites* Walton, *Trambauathallites*' Banerji, *Equisetites* Sternberg, *Lycopodites* Lindley & Hutton, *Isoetes* Linnaeus, *Selaginellites* Zeiller, *Marattiopsis* (Oldham & Morris) Seward & Sahni, *Todites* Seward, *Klukia* Raciborski, *Gleichenites* Goeppert, *Matonidium* Schenk, *Phlebopteris* Brongniart, *Hausmannia* Dunker, *Dictyophyllum* Lindley & Hutton, *Haydenia* Seward, *Dicksonia* L'Heritier, *Culcitites* Appert, *Onychiopsis* Yokoyama, *Coniopteris* Brongniart, *Dennstaedtia* Bernhardi, *Weichselia* Stiehler, *Pachypteris* Brongniart, *Cycadopteris* Zigno, *Thinnfeldia* Ettingshausen, *Sagenopteris* Presl, *Caytonia* Thomas, *Pterophyllum* Brongniart,



Text-figure 12—Reconstruction of *Williamsonia* (after Sahni, 1932) and other floral associates.

Otozamites Braun, *Dictyozamites* Oldham, *Anomozamites* Schimper, *Nilssoniopteris* Nathorst, *Pentoxylon* Srivastava, *Nipaniophyllum* Sahni, *Carnoconites* Srivastava, *Sahnia* Vishnu-Mittre, *Nilssonia* Brongniart, *Morrisia* Bose, *Pseudoctenis* Lindley & Hutton, *Ctenozamites* Nathorst, *Cycadites* Sternberg, *Taeniopteris* Brongniart, *Ginkgoites* Seward, *Araucarites* Presl, *Brachyphyllum* Lindley & Hutton, *Pagiophyllum* Heer, *Nipanioruha* Rao, *Elatocladus* Halle, *Nipaniostrobus* Rao, *Mehtaia* Vishnu-Mittre, *Sitholeya* Vishnu-Mittre, *Podostrobus* Rao & Bose and *Stachyotaxus* Nathorst.

The Williamsonias were one of the dominant plant groups growing in dry open lands alongwith pteridophytes and conifers and perhaps formed a part of tropical semi-evergreen and subtropical broad-leaved type of forest. In India, they appeared and established themselves during the Upper Jurassic (marine), proliferated in the Lower Cretaceous and disappeared in the Upper Cretaceous with the advent of the highest evolved plant group the angiosperms perhaps due to inherent genetic factors. The rapid radiation of angiosperms caused the sudden extinction of Williamsonias due to strong selective pressure. Perhaps they could not compete with the early angiosperms and ultimately perished from the Upper Cretaceous floristic scenario.

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Indian Williamsoniaceae—an overview

B. D. Sharma

Sharma BD 1992. Indian Williamsoniaceae—an overview. *Palaeobotanist* **40** : 260-265.

The morphology, anatomy and phylogeny of the known extinct representatives of the family Williamsoniaceae from India have been overviewed. The family occurs in the Upper Mesozoic rocks and is represented by fronds, stems, male, female and bisexual fructifications. Though the fronds vary in shape, size and venation, all possess identical syndetocheilic stomata. The stems *Bucklandia* and *Sahnioxylon* show minor variations in structure of tracheary elements and are related with cycadeoideas and homoxylous angiosperms. The male fructification *Weltrichia* is built on very distinct and different plan than the seed-bearing fructification—*Williamsonia*, which has been derived from *Cordaianthus*. The bisexual fructification—*Amarjolia* is terminal and exposed like *Williamsonia*, while in structure and arrangement of microsporophyll resembles *Cycadeoidea*. Relationship among different organs is suggested and phylogeny of Williamsoniaceae is discussed.

Key-words—Williamsoniaceae, Morphology, Phylogeny, India.

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सारांश

भारतीय विलियमसोनिएसी–एक समालोचना

बी० डी० शर्मा

भारत से विलियमसोनिएसी कुल के विदित विलुप्त सदस्यों की आकारिकी, शारीर एवं जातिवृत्त की विवेचना की गई है। यह कुल उपरि मध्यजीवी चट्टानों में मिलता है तथा इसके सदस्यों के अश्मित प्रपर्ण, तना तथा नर, मादा एवं उभयलिंगी फलन मिलते हैं। प्रपर्ण हालाँकि आकार तथा शिरान्यास में विभिन्नता प्रदर्शित करते हैं तथापि इनके वातरन्ध्रों में समानता है। **बुक्लैंडिया** एवं **साहनिऑक्सीलॉन** नामक तने में वाहिनिकाओं में थोड़ी सी विभिन्नता है तथा ये साइकेडिऑयडीयों समदारु आवृतबीजीयों से सजातीयता व्यक्त करते हैं। बीज-धारक फलन–**विलियमसोनिया** की अपेक्षा नर फलन–**वेल्ट्राइकिया** बनावट में बिल्कुल भिन्न है। बीज-धारक फलन की उत्पत्ति कोर्डेन्थस से हुई है। उभयलिंगी फलन–**अमरजोलिया** ऊपर स्थित होता है तथा **विलियमसोनिया** की भाँति प्रतीत होता है। विन्यास एवं संरचना में लघुबीजाणुपर्ण **साइकेडिऑइडिया** से सजातीयता व्यक्त करते हैं। विभिन्न अवयवों में पारस्परिक सम्बन्ध प्रदर्शित किये गये हैं तथा **विलियमसोनिया** के जातिवृत्त की विवेचना की गई है।

FAMILY Williamsoniaceae, belonging to the class Bennettitopsida, flourished and dominated the vegetation during the Mesozoic Era (Harris, 1969). Members of this family originated sometimes during Middle Triassic and disappeared by the end of Lower Cretaceous. The family includes extinct plants in which the stem surface has spirally arranged rhomboid leaf bases, parenchymatous pith and cortex well developed with mucilage ducts; vascular zone narrow made up of collateral, conjoint and endarch bundles; secondary wood mano-or picnoxylic; leaf trace is unilacunate. Leaves are pinnate or partly pinnate, with parallel or reticulate venation; stomata transverse to veins and syndetocheilic. Fructifications are terminal, exposed, seed-bearing and bisexual. Microsporophylls are spread with two rows of appendages on which microsynangia are produced. Ovules/seeds are produced intermingled with sterile scales in a compact layer covering the receptacle. In bisexual fructification baloon-shaped microsporophylls encircle the central receptacle with a covering of ovules and sterile scales.

In India, members of this family occur at several Mesozoic localities, e.g., Rajmahal Hills, Bihar; Golapilli near Elore; Madras outliers, Jabalpur, Jaisalmer, Kachchh, etc. (Oldham & Morris, 1963; Feistmantel, 1876, 1877, 1879; Seward & Sahni 1920; Sitholey, 1954; Gupta, 1966; Sharma, 1967a, 1977,

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1990; Bose, 1953a, 1953b, 1968; Bose & Kasat, 1972a; Bose & Banerji, 1981, 1984). The Williamsonian fossil plants described from the Indian rocks are:

Fronds—Ptilophyllum (18 sp.), *Pterophyllum* (10 sp.), *Otozamites* (7 sp.), *Anomozamites* (3 sp.) and *Dictyozamites* (7 sp.).

Stems—Bucklandia (4 sp.) and *Sahnioxylon* (2 sp.)

Male fructification— Weltrichia (3 sp.)

Seed-bearing fructification— Williamsonia (12 sp.)

Bisexual fructification—Amarjolia (1 sp.)

Plant remains of Williamsoniaceae occur as impressions, incrustations and petrifactions. The impressions show external morphology. In incrustations the epidermal characters are studied through maceration and peel techniques using nitric acid as etching acid (Jacob & Jacob, 1954; Bose & Kasat, 1972a; Bose & Banerji, 1981, 1984; Sukh-Dev & Rajnikanth, 1988a, 1988b). The petrifactions have been studied by the usual method of cutting, grinding and polishing techniques. At Amarjola, the material being soft and fragile needs cooking in Canada balsam prior to sectioning. Canada balsam is used as mounting medium. Sometimes, the polished surface is examined with a water film under reflected light.

DESCRIPTION

A systematic account of the extinct plants of Williamsoniaceae known from India is given as under:

Fronds

Ptilophyllum Morris

Frond pinnate, pinnae linear to round, base asymetrical, upper basal angle round, lower decurrent; apex acute, obtuse, truncate or round; veins parallel with forkings. Epidermal cells mostly sinuous, stomata hypostomatic, transversely oriented and syndetocheilic. Rachis with a number of bundles arranged in double U-manner.

Sharma (1967a), Bose and Kasat (1972a) and Bose and Banerji (1981, 1984) published reviews on the Indian species of the genus *Ptilophyllum* and identified 18 species. Some of these fronds are morphologically alike but separated on epidermal characters, e.g., *P. nipanica* Mittre 1956, *P. indicum* Jacob & Jacob 1954, *P. sahnii* Gupta & Sharma 1968. Minor variations in morphological and epidermal characters may be due to environmental differences and age of the frond. A re-investigation is likely to reduce the number of species of *Ptilophyllum* in India. Search should also be made to find out their associated stems and fructifications.

***Pterophyllum* Brongniart**

Frond pinnate, pinnae linear, base symmetrical attached on lateral side of rachis, apex acute, obtuse or truncate, veins parallel with few forkings. Epidermal and anatomical characters of Indian species are not known. Oldham and Morris (1863) and Feistmantel (1877) identified a number of species of this genus from India, but Seward and Sahni (1920) merged many of these species into the genus *Nilssonia* Brong. Sharma (1969b) also transferred two species of *Pterophyllum* into *Nilssonia*. On the other hand Bose and Benerji (1981, 1984) retransferred all known *Nilssonia* species from India into *Pterophyllum* species without studying the epidermal and anatomical characters.

***Otozamites* Braun**

Frond pinnate, pinnae small to linear to triangular or round; base asymetrical and auriculate, apex acute, obtuse or round; veins diverging and dichotomised. Epidermal cells sinuous, stomata hypostomatic, syndetocheilic and restricted to stomatal bands.

Oldham and Morris (1963) and Feistmantel (1876, 1877, 1879) described a number of species of this frond genus from India. Seward and Sahni (1920) merged many of the species into the genus *Ptilophyllum*. Roy (1963) described *Otozamites bellus* from Kachchh. Bose and Banerji (1981, 1984) described the morphology and epidermal characters of *O. imbricatus* Feistmantel 1876, *O. Walkamotaensis* Bose & Zeba-Bano 1981, *O. kachchhensis* Bose & Banerji 1984. *Otozamites* occurs more frequently in the Mesozoic rocks of Kachchh than any other exposure in India.

***Dictyozamites* Oldham**

Frond pinnate, pinnae linear, falcate or round, base asymetrical and auriculate, apex acute, obtuse or round, venation reticulate, stomata hypostomatic, syndetocheilic and restricted to stomatal bands. Rachis has vascular bundles arranged in double U-manner similar to that of *Ptilophyllum* (Bose & Kasat, 1972a). In *Dictyozamites*, the number of areoles present in the middle of pinna is used in the identification of species. Seven species, viz., *D. falcatus* Oldham 1963, *D. indicus* Feistmantel 1877, *D. hallei* Sahni & Rao 1933, *D. sahnii* Gupta & Sharma 1964, *D. feistmantelii* Bose & Zaba-Bano 1978 and *D. gondwanensis* Sukh-Dev & Rajnikanth

1988a are known from India. Associated stems and fructifications are yet to be discovered.

Anomozamites Schimper

Frond lobed or pinnate, pinnae unequal, base symmetrical, attached on lateral side of rachis, apex obtuse to truncate, veins parallel with forkings. Epidermal cells sinuous. Stomata hypostomatic, transversely oriented and syndetocheilic. Important species of the genus known from India are: *A. fissa* (Feist.) Sharma 1969b, *A. amarjolense* Sharma *et al.* 1971, and *A. haburensis* Bose & Banerji 1981. Associated stems and fructifications remain unknown.

Stems—Bennettitalean stems are simple or branched and possess spirally arranged rhomboid leaf bases on the surface. Two stem genera, viz., *Bucklandia* Presl. 1825 and *Sahnioxylon* Bose & Sah 1954 are known from the Indian rocks.

Bucklandia Presl.

Stem simple (*B. indica*), branched (*B. sahnii*) or dichotomised (*B. dichotoma*). Stem surface has close or sparse leaf bases. Pith and cortex are parenchymatous with mucilage ducts. Vascular zone is made up of a large number of collateral, conjoint, open and endarch bundles. Secondary wood is compact and differentiated into growth rings. The tracheids have spiral, scalariform or bordered pits on radial walls. Rays 1 to many cells high, uni-to-multiseriate, homogeneous. Pits in crossfield 1-4 or more, circular with narrow border. Leaf trace is unilacunate and divides into a number of bundles (5-11) in cortex.

Four species of *Bucklandia*, Viz., *B. indica* Seward 1917, *B. sahnii* Bose 1953, *B. guptai* Sharma 1967b and *B. dichotoma* Sharma 1970d are known from India. Anatomically, *B. dichotoma* resembles cycadeoideas and homoxylous angiosperms in having cross-shaped pit pores and scalariform pittings (Gupta, 1934).

Sahnioxylon Bose & Sah

Originally the wood was described as *Homoxylon rajmahalense* by Sahni (1932a) who believed that it was an angiospermous wood. But Gupta (1934) related it with cycadeoidea. Hsü and Bose (1952) made further observations on this wood. Bose and Sah (1954) transferred the *Homoxylon* to *Sahnioxylon* as the earlier name had already been used for a fossil conifer wood, so they called it *Sahnioxylon rajmahalense* (Sahni) Bose & Sah and also described a new species—*S. andrewsii* Bose & Sah 1954. In the former only wood is known, while in the latter partly preserved ground tissues are also seen. Whether *Sahnioxylon* had leaf bases on surface and what kind of leaf traces were present, is yet to be discovered.

Fructifications

Weltrichia Braun

This male fructification was described earlier under the generic name *Williamsonia.* Sitholey and Bose (1953) instituted *Williamsonia santalensis* which was later on transferred to *Weltrichia santalensis* by Sitholey and Bose (1971). Sitholey and Bose (1953) described a single whorl of microsporophylls surrounding a cup-shaped receptacle, while Sharma (1969a) on the basis of study of more than 50 specimens, some of which are nicely preserved counter parts, suggested two whorls, i.e., the abaxial of sterile bracts and adaxial of microsporophylls. Sitholey and Bose (1971) did not agree to it. Each microsporophyll has two rows of appendages on which parallel rows of microsynangia occur. Sharma (1969a) suggested restorations of *W. santalensis* and also described a new species *W. campanulatiformis* preserved as cast and mold. Bose and Banerji (1984) described another species of *Weltrichia, W. harrisiana* from Kachchh. In this fructification the fertile appendages are terminal on 12-14 microsporophylls which are coalescent towards base forming a circular depression. Further investigations are required on *W. campanulatiformis* and *W. harrisiana* as these are established on insufficient and poorly preserved materials.

Williamsonia Carruthers

Feistmantel (1876) described *W. blanfordii* from Kachchh and *W. microps* from the Rajmahal Hills (Feistmantel, 1877). Sahni (1932b) described *W. sewardiana* from the Rajmahal Hills and suggested its restoration and showed its association with the stem *Bucklandia indica* and fronds of *Ptilophyllum* cf. *cutchense.* Gupta (1943) described a probable bisexual fructification—*W. sahnii* in which the bracts are spread and in the basal portion of receptacle 20 markings are seen, which may be of fallen microsporophylls. Gupta (1958) divided williamsonian fructification into open type and close type. In the former, bracts spread out as in *W. sahnii,* while in the latter the bracts did not open out as in *W. guptai.* This hypothesis is applicable to all the known species of *Williamsonia* throughout the world. Bose (1966a) called *W. sahnii* only a seed-bearing fructification. Bose (1968) described *W. harrisiana* from Amarjola in the Rajmahal Hills which is identical to *W. guptai* Sharma 1968 collected from the same locality. Sharma (1968) also established *W. amarjolense* and separated it from *W. guptai* on the basis of different epidermal characters of bracts. Bose and Kasat (1969) instituted *W. seniana* in honour of Dr J. Sen (Calcutta) from Jabalpur. It is an incrustation and preserves the epidermal structures.

Sharma (1970a, 1970b, 1970c, 1974, 1975, 1976, 1980) studied petrified specimens of *Williamsonia* collected from Amarjola and described the anatomy of peduncle and receptacle, structure of seed, ovule ontogeny and development of fruit. Sharma (1977) published an illustrated review as Indian Williamsonias. Sharma (1982a) interprets the morphology of interseminal scales and derives *Williamsonia* from *Cordaianthus* as a result of modification and condensation of cone axis. Bose and Banerji (1984) described three new species of *Williamsonia*, viz., *W. kakadbhitensis, W. trambuensis* and *W. sukhpurensis* from Kachchh. All these are incrustations and fertile structures remain unknown. Identification is based mainly on epidermal characters of bracts. In *W. kakadbhitensis* and *W. sukhpurensis* the bracts are densely hairy while trichomes/ramenta bases are rare in *W. trambuensis.*

Amarjolia Bose et al.

This bisexual fructification was originally described as *Cycadeoidea dactylota* by Bose (1966b). Sitholey and Bose (1971) amplified the description. The fructification is terminal and exposed, and the microsporophylls differ in structure from *Cycadeoidea* so the new genus *Amarjolia* was proposed by Bose, Banerji and Pal (1984) and called it *A. dactylota.* The bracts are hairy like in *W. sewardiana* Sahni 1932b. There are nearly 20 baloon-shaped microsporophylls, surrounding the central conical receptacle which bears a compact layer of seminiferous and interseminal scales. Each microsporophyll bears appendages on which rows of microsynangia are produced. Our present knowledge on *Amarjolia* is based only on two specimens and more collection is required for further investigations.

In addition to the above described fructifications, a number of incomplete (Sharma, 1982b) or poorly preserved (Sharma, 1990) bennettitalean organs and scales (*Cycadolepis*) are also known from the Mesozoic rocks of India (Bose & Banerji, 1984).

DISCUSSION

The extinct representatives of the family Williamsoniaceae dominated the vegetation during the Mesozoic Era in India, especially the frond genus *Ptilophyllum* which occurs in all the Upper Mesozoic exposures and is represented by nearly half the total number of species known throughout the world. This frond is associated with the stem *Bucklandia* and the seed-bearing fructification *Williamsonia* (Feistmantel, 1877; Sahni, 1932b). The male fructification *Weltrichia* is also found in close association with the fronds of *Ptilophyllum* (Sharma, 1969a) both at Sakrigalighat and Dhokuti in the Rajmahal Hills. The association of other fronds—*Otozamites, Pterophyllum, Anomozamites* and *Dictyozamites* with allied stems and fructifications are yet to be discovered. Similarly, the phylogeny of reticulate venation of *Dictyozamites* needs investigation.

Sahnioxylon though resembles in the structure of tracheary elements with the stem *Bucklandia*, specially *B. dichotoma*, its affinities remain doubtful for want of complete and better preserved material to study the origin and nature of leaf traces and structure of pith and cortex. Associated leaves and fertile parts of *Sahnioxylon* are yet to be discovered. The stem genus *Bucklandia* also needs further investigations as wide variations occur in the morphology and distribution of leaf bases on stem surfaces.

In all the species of *Weltrichia* known from India the microsporophylls originate from the brim of a cup-like receptacle. The abaxial whorl of sterile bracts is present in *W. santalensis*, while in others it is yet to be seen. *W. companulatiformis* and *W. harrisiana* are based on the study of 1-3 incomplete specimens.

Though the seed-bearing *Williamsonia* is represented by several species (12 sp.), the basic structure, i.e., presence of a compact layer of sterile and fertile scales surrounding a receptacle, and the linear, simple, curved bracts which protect the fertile parts are identical. Despite the study of all internal details including anatomy, ontogeny and structure of seeds/ovules, and fruit development, the phylogeny of the fructification remains doubtful. Though Sharma (1982a) derives *Williamsonia* from *Cordaianthus*, the intermediate presumptions are hypothetical and need proof. Further investigations of the petrified fructifications are likely to provide solution to the problem.

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Evolutionary reproductive biologies in the Mesozoic plants of India

Sukh-Dev

Sukh-Dev 1992. Evolutionary reproductive biologies in the Mesozoic plants of India. *Palaeobotanist* **40** : 266-274.

The reproductive biologies in the Mesozoic plants are dealt with taking into consideration form and function of the reproductive organs. The Mesozoic flora inherited homospory, heterospory, pollen and seed formation from their Palaeozoic ancestors. Most of the Palaeozoic forms vanished by the close of Permian due to change of environment. The Triassic Period nursed the leftovers from the Permian as well as putforth new elements like *Lepidopteris, Dicroidium* and allied genera of Peltaspermaceae, Corystospermaceae and members of Caytoniaceae in which the seeds were protected in cupules. Thus the development of cupule in these genera changed the course of plant evolution. Later, with the amelioration of climate the cycads grew to prominence with exposed seeds, and subsequently they were overtaken by the rise of more advanced conifers. Meanwhile this flora also produced 'flower-like' structures in the cycadeoides and 'fruit-like' structures in Caytoniales and Pentoxyleae by providing fleshy growth around the seeds. The hot, arid conditions again reoccurred towards the close of Early Cretaceous. At this time the angiosperms appeared with enclosed seeds, heralding another change in the course of plant evolution.

Key-words—Reproductive biologies, Evolution, Mesozoic plants.

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सारांश

भारत के मध्यजीवी पौधों में जननांगीय विकास

सुख-देव

जननांगों के आकार एवं कार्य को ध्यान में रखते हुए मध्यजीवी पौधों के जननांगों का वैकासीय अध्ययन किया गया है। मध्यजीवी वनस्पतिजात को, समबीजाणु, विषमबीजाणु, परागकण एवं बीज बनने की प्रक्रिया अपने पूर्वज पुराजीवी वनस्पतिजात से उपलब्ध हुए हैं। वातावरण में परिवर्तन के कारण अधिकतर पुराजीवी प्ररूप परमी कल्प के समाप्त होने तक विलुप्त हो गये। शेष बचे प्ररूप त्रिसंघी कल्प में विकसित हुए तथा पेल्टास्पर्मेसी, कोराइस्टोस्पर्मेसी तथा केटोनिएसी से सम्बद्ध प्रजातियाँ तथा **लेपिडॉप्टेरिस** एवं **डाइक्रोइडियम** नामक नये वर्गकों की उत्पत्ति हुई। इन सभी प्रजातियों में प्यालिका के विकास से पादप-विकास में एक महत्वपूर्ण परिवर्तन हुआ। बाद में जलवायु में सुधार होने के कारण साइकेड पादप-समूह की बाहुल्यता हो गई जिनमें कि बीज नग्न थे। इनके बाद अधिक विकसित कोनिफ़रों की उत्पत्ति हुई। इसी बीच इस वनस्पतिजात से साइकेडों में 'पुष्प-सदृश' संरचनाओं तथा केटोनिएल्स एवं पेंटॉक्सीली में 'फल-सदृश' संरचनाओं का विकास हुआ। प्रारम्भिक क्रीटेशी के समाप्त होते-होते गर्म तथा शुष्क परिस्थितियाँ पुनः लौट आईं। इसी समय आवृतबीजीयों की उत्पत्ति हुई जिनमें कि बीज एक आवरण से ढ़के हुए रहते हैं।

THE Mesozoic Era in the beginning not only nursed the scanty vanishing leftovers from the Permian, but also successfully gave rise to various plant groups, such as new pteridosperms, cycads, cycadeoides, ginkgos and conifers which reigned supreme on land alongwith Caytoniales and Pentoxyleae. The origin, development and radiation of angiosperms also took place in the upper part of this Era. The evolutionary aspects in the reproductive biologies of Mesozoic plants exhibit prominent successful selective characters inherited from the Palaeozoic flora. Reference to Palaeozoic forms is made in order to understand the Mesozoic reproductive biologies. Some important ones are discussed below.

The pioneer land plants, e.g., *Rhynia, Horneophyton, Cooksonia, Baragwanathia* and many others invaded the land from the sea and surmounted several hurdles to make land their

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permanent abode. The early plants being delicate were easily perishable and hence were rarely preserved. Whereas the spores being made of resistant sporopollenin had better chances of preservation, therefore, they are commonly encountered in the dispersed condition in rocks. Moreover, the spores are unique structures for the preservation of the progeny of plant communities. These early spores had marine ancestory, therefore they preferred moist conditions for their terrestrial life.

The second most significant adventive and selective development was heterospory in the land flora in the later Devonian time in certain plants. *Lepidodendron, Sigillaria, Bothrodendron* and species of *Selaginellites* are the best examples in the development of heterospory, though homospory is still continuing in Psilotaceae, Lycopodiaceae, Equisetaceae and all ferns excepting Hydropterideae. Heterospory laid foundation for cross-fertilization and it was a step towards the seed formation.

Heterospory was established firmly in the Carboniferous. It was followed by reduction in the number of megaspores and increase in their size in a megasporangium, thus supplying nourishment for the surviving megaspores—two megaspores in *Stauropteris burntislandica*, a pteropsid, and a single megaspore in *Lepidocarpon*. The megasporangium was protected by overgrowths of bracts as found in *Miadesmia membranacea*—a Carboniferous lycopod. Thus a 'seed-like' habit was initiated, paving a way for the 'true seed' development.

In the dispersed megaspores the wall was quite thick. But as the megaspore was protected by nucellus and integument during the course of time the purpose of thick wall became unnecessary. A pteridosperm seed *Stephanospermum elongatum* is the thickest known, 18-35 μm (Hall, 1954). In the present plants the seed coat thickness is 10 μm in *Dioon edule*, 4.6 μm in *Abies balsamea*, 3 μm in *Pinus sylvestris*, 2.7 μm in *Sequoia sempervirens*, 1.3 μm in *Welwitschia*, and in angiosperms wall thickening is not very significant (Mehra, 1974).

In spore evolution from spore to pollen, the germination in the spores was through a trilete/monolete suture on the proximal surface in the pteridophytes. Several prepollen in many of the early gymnosperms retained this mode. Later, the dehiscence mark shifted to the soft distal surface of pollen in most of the gymnosperms. A pollen tube developed from this sulcus. Primarily it was haustorial in function and also carried male gametes. Whereas the angiosperms developed colpi and pores for the germination of pollen tubes on the stigma of carpel.

THE MESOZOIC ERA

Phase I : Protecting seeds in the cupule

Towards the close of the Palaeozoic Era due to changes in climate and environment towards hot and arid conditions most of the forms of this Era died out, leaving behind some ramnants. In response to the prevailing conditions the Triassic Period putforth new elements, namely *Lepidopteris, Dicroidium* and allied genera belonging to Peltaspermaceae and Corystospermaceae in the Gondwanaland and *Thinnfeldia* in the northern countries . Along with these genera ferns, glossopterids and horse-tails in lesser number and smaller size, cycads, ginkgos and conifers also constituted part of the flora.

Peltaspermaceae and Corystospermaceae

Text-figure 1A-H

Leaves *Lepidopteris* and *Dicroidium* belonging to Peltaspermaceae and Corystospermaceae are found in the Triassic sediments of India, but only few species of pollen-bearing organs *Pteruchus* of *Dicroidium* of the latter family have been discovered so far (Srivastava, 1987).

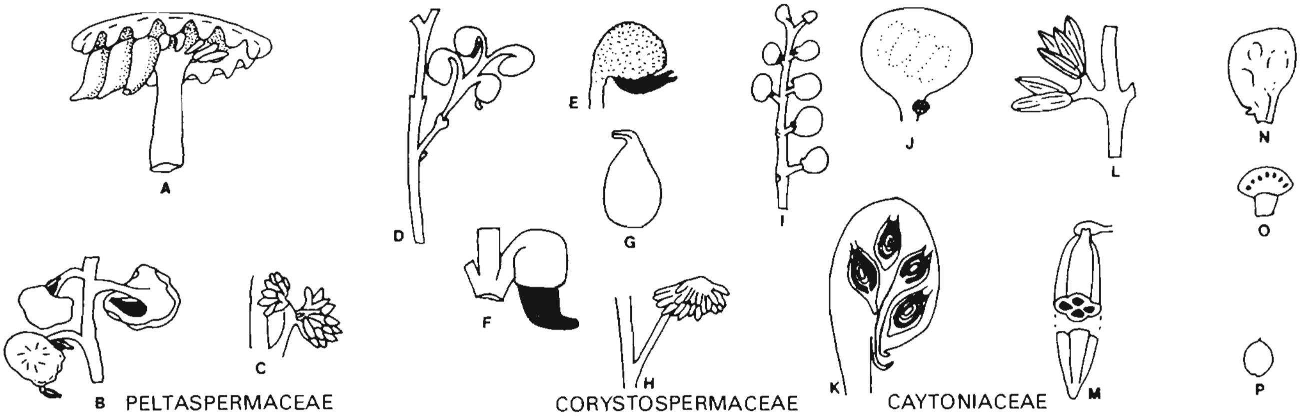
The seeds in *Lepidopteris* were small, borne singly in cupule with a characteristic curved micropylar beak and pinnately arranged on the stalk (fertile frond). Seeds in *Dicroidium* (genus *Umkomasia*) also had long curved bifid micropylar beak of the cupule which had stomata on both the surfaces. Seeds were also borne singly in the cupule.

The pollen-bearing organ *Antevsia* of Peltaspermaceae had 4-12 pollen sacs on the ultimate branches of bipinnate sporophyll. Pollen sacs were photosynthetic on the dorsal surface and had a longitudinal dehiscence line on ventral surface. Pollen grains were circular with a single longitudinal furrow. Pollen-bearing organ *Pteruchus* of *Dicroidium* had a central axis, bearing short lateral branches in one plane. Each branch terminated in a peltate head having more than 30 sporangia on the underside. Dehiscence was by a longitudinal slit. Pollen grains had two large lateral bladders.

Remarks—Pinnate nature of fertile leaves (stalk) and their photosynthetic character signify their primitive frond character.

Caytoniaceae

Text-figure 1I-M



Text-figure 1—Peltaspermaceae : **A.** Reconstruction of seed-bearing organ *Peltaspermum rotula*, disc with three cupulate-seeds, × 1.5; **B,** Part of *P. thomasii*, × 1.5; **C,** Part of pollen-bearing organ *Antevsia zeilleri*, × 1. Corystospermaceae : **D,** Part of *Unkomasia macleanii* seed-bearing organ, × 1; **E,** *Pilophorospermum granulatum* cupulate-seed, × 3; **F,** *Pilophorospermum* sp. cupulate-seed, × 3; **G,** Seed, × 4; **H,** Part of *Pteruchus stormbergensis* pollen-bearing organ, × 1.5. Caytoniaceae : **I,** *Caytonia nathorstii* fruit-bearing rachis, × 1.5; **J,** *C. sewardii* fruit, × 3; **K,** L.S. of *Caytonia* fruit; **L,** Part of *Caytonanthus arberi* pollen-bearing organ, × 2; **M,** Reconstruction of *C. arberi* before dehiscence, × 10. (A, C, based on Harris; B, D-H, Thomas).

Seeds were borne in fruit-like structures or cupules which enclose variable number of seeds covered by juicy pulp. Fruits were borne on a dorsiventral rachis (megasporophyll, primitive character). A flange was present towards one side of fruit close to rachis which had about the same number of ridges as the seeds inside. Only *Caytonia* seeds are discovered in the Chawad River sediments in Kutch (Bose & Banerji, 1984).

Pollen-bearing organ *Caytonanthus* is a 4-lobed synangium, borne terminally on branches of a dorsiventral rachis. Pollen grains had two lateral bladders.

Affinity—Caytoniaceae once created a great stir regarding the origin of angiosperms.

1. Flange of the fruit was earlier considered a kind of stigma where pollen grains germinated—an angiosperm character. But later it was discovered that actually the pollen reached each seed through a separate passage in a drop mechanism as in many living gymnosperms.
2. *Caytonanthus* was considered an angiosperm stamen, but it was radial in symmetry lacking filament and connectives in contrast to angiosperms.

Remarks—The aforementioned three families, viz., Peltaspermaceae, Corystospermaceae and Caytoniaceae did not have favourable mechanism of pollination. The first two families had curved micropyles while in Caytoniaceae the pollen were sucked in through different passages. These mechanisms were devised to protect seeds from hot air reaching directly inside the cupules. As the environmental conditions worsened, *Lepidopteris, Dicroidium* and allied genera of Peltaspermaceae and Corystospermaceae vanished by the end of Triassic. In Caytoniaceae juicy pulp around the seeds was provided, which was possibly meant for protecting them from arid environment. Caytoniaceae had rather tough leaves and also poor pollination mechanism, so members of this family did not flourish well and died out by Early Cretaceous.

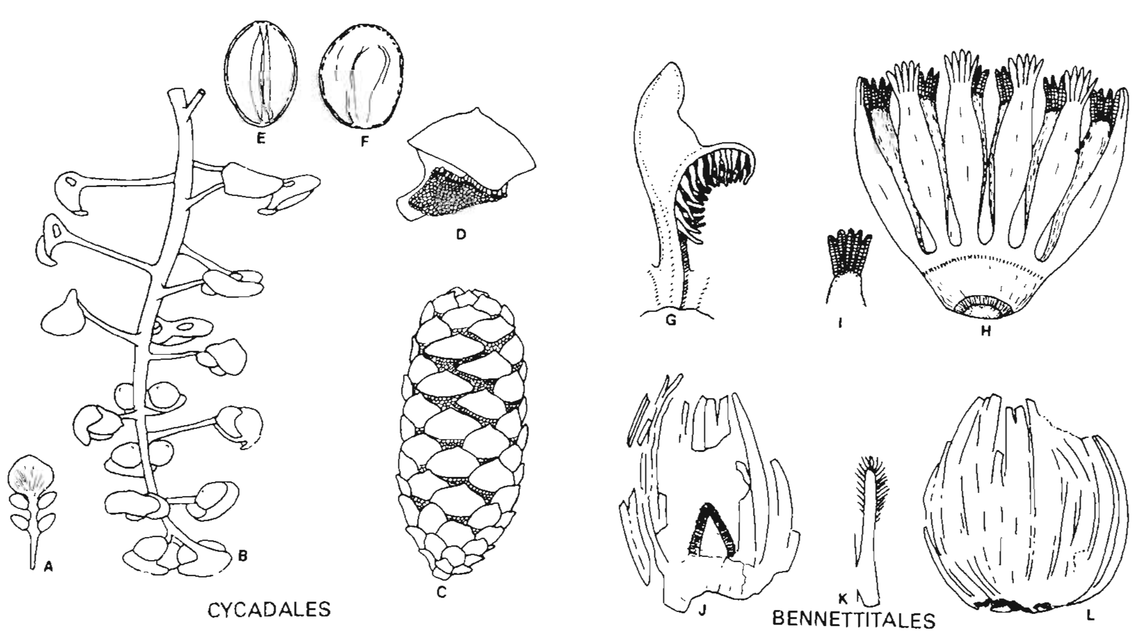
Phase II : Exposing the seeds

Cycadales

Text-figure 2A-F

As the environment became favourable for plant growth, the cycads having large trunks and cones with naked seeds gained prominence. They were abundant in the Jurassic with world-wide distribution; presently they are restricted to Central America, South Africa, Eastern Asia and Australia. They are represented by 10 genera having about 65 species. In gymnosperms, cycads were the first to have cones. Cycad leaves like *Morrisia, Cycadites* and *Taeniopteris* are commonly found in the Mesozoic rocks of India, but their reproductive organs are yet not recovered.

One of the most informative and well known association is of *Nilssonia* leaves, *Beania* seeds and *Androstrobus* pollen organs occurring together in the Middle Jurassic sediments of the Yorkshire coast in England. *Beania gracilis* is a loose cone up to 10 cm long. It bears spirally borne appendages having two seeds on inner side. The largest seed is 16 × 13 mm. Another plant *Beania mamayi* occurring in the Yorkshire Coast sediments had bifid



Text-figure 2—Cycadales : **A,** *Palaeocycas integer* sporangiophore with seeds, × 1/12; **B,** lose 'seed-cone' *Beania gracilis,* × approx. 1/2; **C,** Microsporangiate cone—*Androstrobus manis,* × approx. 1; **D,** Microsporophyll of *A. manis;* **E, F,** pollen grains of *A. manis,* × 400. Bennettitales : **G,** Microsporophyll of *Weltrichia santalensis;* **H,** Reconstruction of *Weltrichia harrisiana* 'male flower'; **I,** Apical part of microsporophyll; **J,** 'Female flower' *Williamsonia kakadbhitensis,* receptacle part slightly modified, × 1/2; **K,** Bract hairy towards apical portion × 1/2; **L,** *W. kakadbhitensis,* × 1/2. (A, based on Florin; B-F, Harris; G, Sitholey & Bose; H-L, Bose & Benerji).

sporangiophores. *Androstrobus manis,* a male cone is about 5 × 2 cm. It bears numerous spirally borne sporophylls, each of which had several cylindrical sporangia containing monosulcate oval pollen grains, typically 36 × 26 μm.

Florin reconstructed a plant *Palaeocycas integer* from the Upper Triassic rocks of Sweden, which bears simple leaves—*Bjuvia simplex* and female sporangiophores—*Palaeocycas integer* terminally on the stem. The sporophylls had probably seeds on the sides of lower portion as in modern *Cycas,* a primitive character still continues today.

Remarks—Though the cycads were abundant in Jurassic-Early Cretaceous in xerophytic habitat, their slow growth, manoxylic stems, large terminal cones and lax female cones later proved as to be drawbacks in comparison to the more advanced conifers. Therefore, the cycads declined, their reproductive biology failed to compete with the vigorously advancing conifers.

Bennettitales (Cycadeoidales)

Text-figure 2G-L

The order is characterized by 'flower-like' structures which appeared for the first time in gymnosperms. The flowers were hermaphrodite or unisexual, protected by numerous bracts. Ovules were stalked, scattered over a receptacle amongst interseminal scales. Micropyles were projected through the loose shield formed by interseminal scales. Pollen-bearing organs were arranged in a whorl. They were free or united, entire or pinnate, having numerous microsporangia borne usually in capsules. Presence of syndetocheilic stomata is also a significant character. Stems, leaves and 'flowers' are commonly found in the Jurassic-Cretaceous rocks of India.

Williamsonia sewardiana is reconstruction of the plant from the Lower Cretaceous of Rajmahal Hills. A lateral branch of 2 m tall slender stem terminates in a female flower having interseminal scales and few seeds. Leaves belong to *Ptilophyllum cutchense.* Male, female and bisexual flowers have also been found (Bose, 1966, 1974; Bose & Banerji, 1984).

Affinity—The flower of Bennettitales shows some similarity in its general organization with the *Magnolia* flower (angiosperm) as its microsporophylls surround the receptacle at its base. The group has been considered as an ancestor of angiosperms. But the bennettitalean flower is quite different in having stalked seeds and interseminal scales from that of *Magnolia* flower.

However, it is quite noteworthy that the bennettitalean flower deviated from the general plan of similarity from the fossil and living cycads. Probably these flowers amused the dinosaurs. However, the flowers were insect pollinated (Crepet, 1974; Taylor, 1982).

Ginkgoales

Text-figure 4A

The ginkgolean remains in the Mesozoic rocks in India are meagerly represented. However, the group had a glorious past with many genera and species spread world over during Jurassic-Early Cretaceous. The group dwindled sharply and is survived by *Ginkgo biloba* only. The terminal seeds and motile sperms of *G. biloba* are features of great antiquity.

Seeds of *Ginkgo* have been described by Zeba-Bano *et al.* (1979) from Pathargama from Lower Cretaceous of Rajmahal Hills. The seeds had an outer fleshy and inner stony layer. The fossil female strobilus differs from *G. biloba* in the absence of seed 'collar' and smaller size of the seeds.

Pentoxyleae

Text-figure 3A-E

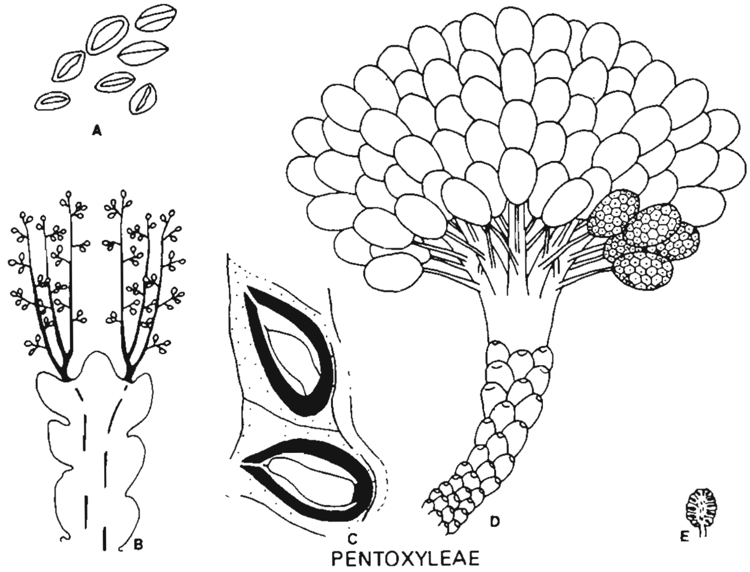
In Pentoxyleae the female cones *Carnoconites* consisted of sessile seeds with inner stony layer of integument and outer fleshy layer by which they were closely united together looking like stalked mulberries. Male flower—*Sahnia* had sporangiophores borne on raised collar-like margin of receptacle with simple pollen sacs. Pollen grains were boat-shaped, monocolpate, 25-26 × 10-25 μm with smooth exine.

Affinity—Sporangiophores of male flower in Pentoxyleae apparently look like the bennettitalean ones, but their detail structure is altogether different from the latter female flower in lacking interseminal scales and stalked seeds. Stomatal structure and leaf-trace anatomy of the Pentoxyleae resemble cycads but the former lacks cycadean encircling girdles. Pentoxylon has pycnoxylic wood like conifers. Polystelic stem of Pentoxyleae resembles Medullosacean woods of *Medullosa* and *Rhexoxylon*, but differs in having stachysporous reproductive organs. Meeuse (1961) considers Pentoxyleae as the possible ancestor of angiosperms.

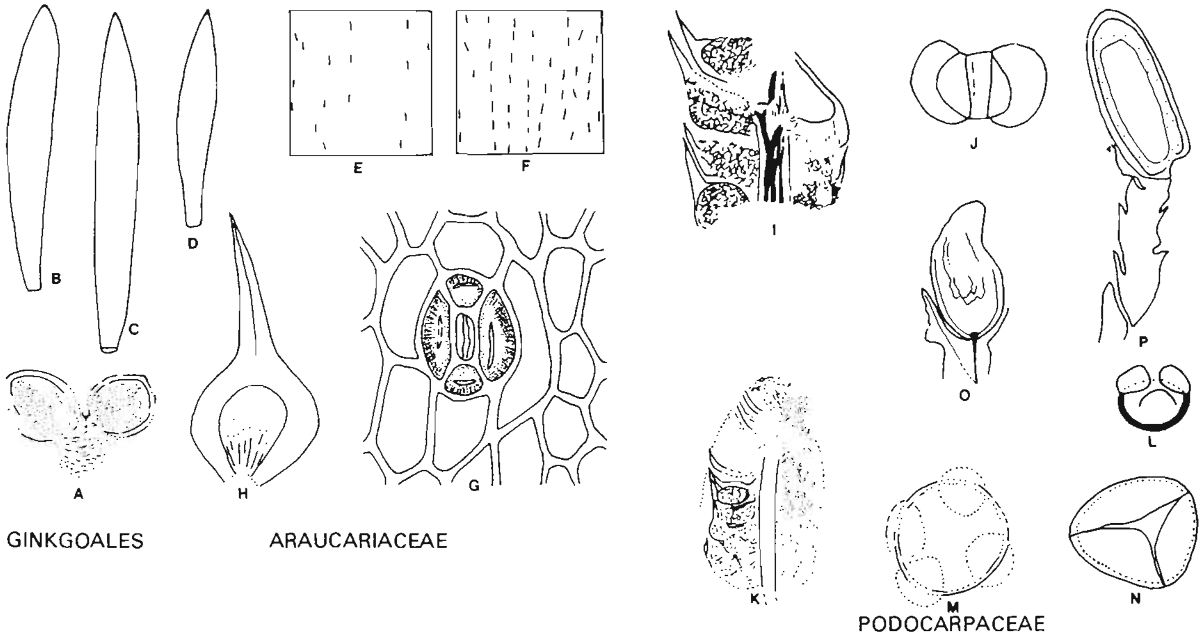
Remarks—In the adventive and selective character experimentation, Pentoxyleae offers the best example of synthesis of characters from various plant groups. It combines characters of Medullosaceae, Bennettitales, Cycadales and Coniferales as mentioned above, but unfortunately this combination of characters did not prove stable and hence Pentoxyleae did not flourish for long. Pentoxyleae probably remained a small localized group in the Early Cretaceous. This group is known only from a few countries—India, New Zealand and Australia.

Coniferales

Text-figure 4B-F



Text-figure 3—Pentoxyleae : **A,** Pollen grains of *Sahnia nipaniensis,* × 150; **B,** Reconstruction of *Sahnia nipaniensis* flower; **C,** *Carnoconites compactus* showing two seeds with inner stony (black) and outer flesly (dotted) layers of integument, × 5; **D,** Reconstruction of *C. compactus* borne on short shoot; **E,** L.S. of *C. compactus,* × 1/2. (A, based on Vishnu-Mittre; B-D, Bose, Pal & Harris; E, Sahni).



Text-figure 4—Ginkgoales : **A**, Strobilus with two seeds, × 2. Araucariaceae : **B-D**, Leaves of *Araucaria indica*, × 1; **E,F**, Distribution and orientation of stomata in 1 sq mm of ?upper and ?lower surfaces of leaves; **G**, Stoma and epidermal cells of leaf, × 250; **H**, Seed-scale, × 1. Podocarpaceae : **I**, Part of microstrobilus *Podostrobus rajmahalensis*, × 13.5; **J**, *in situ* pollen grain, × 265; **K**, *P. sahnii*, × 7.5; **L-N**, *in situ* pollen grains, × 250(L), × 425(M, N); **O**, *Mehtaia rajmahalensis*, seed with bract-scale and vascular supply, × 14; **P**, *Sitholeya rajmahalense*, apical inverted ovule with fertile bract, × 6.5. (A, based on Zeba-Bano *et al.*; B-H, Sukh-Dev & Zeba-Bano; I-N, Rao & Bose; O, P, Vishnu-Mittre).

During Mesozoic time, members of Araucariaceae and Podocarpaceae were abundant in India. The conifers exhibit comparatively a greater economy in the production of cones than the less advanced fossil and living cycads. Further, the cones in conifers are spread over large areas on the tree-branches rather than being borne terminally on the stems in cycads. These features possibly improved the pollination process, favouring the dominance of conifers over the cyads.

ARAUCARIACEAE

Text-figure 4B-H

In the Mesozoic rocks of India Araucariaceae is represented by detached leaves, leafy-twigs, female cones, detached seed-scales and petrified woods.

Bose and Jain (1964) referred to an incomplete megastrobilus of Araucariaceae on the basis of its compact nature, spirally borne non-ligulate megasporophylls having a single seed embeded medianly.

Sukh-Dev and Zeba-Bano (1978) instituted *Araucaria indica* plant, based on cuticular similarity of seed-scales *Araucaria indica* Bose & Maheshwari with the leaves of *Desmiophyllum indicum* Sahni in the distribution and structure of stomatal apparatus. Further, both these organs are found in close association in Bansa, Chandia, Jabalpur, Sehora, etc. in the Jabalpur Formation, Madhya Pradesh. Florin (1937) had already stated that in structure and distribution of stomata the *Desmiophyllum* leaves indeed belong to the living genus *Araucaria*.

PODOCARPACEAE

Text-figure 4I-P

Male and female cones of Podocarpaceae are reported from Rajmahal Hills, Bihar.

Podostrobus sahnii (Vishnu-Mittre) Rao & Bose 1971 is a cone, 7 × 3.5 mm in size, bears closely and spirally arranged sporophylls on a slender axis which in turn produce a broadly ovoid sporangium on their lower surface. Distal part of sporophyll is turned upwards, attenuated and overlap the upper sporophylls. Sporangium contains numerous, 2-4 saccate (mostly 2-3 saccate) pollen grains.

Podostrobus rajmahalensis (Rao) Rao & Bose 1971 is about of the same size as *P. sahnii* except the sporangium containing bisaccate pollen grains.

Female cones, compact or lax, are also reported from Rajmahal Hills (Vishnu-Mittre, 1959) in which the single seeded scales are much reduced or absent and bear terminally erect or inverted ovules. They are known as *Nipaniostrobus, Nipanioruha, Mehtaia* and *Sitholeya*.

Phase III : Enclosing seeds in the carpel

Angiosperms

Text-figure 5A-F

The angiosperms are a dominant and most widely distributed plant group in the modern flora which is more advanced in having enclosed ovules or seeds in an ovary in contrast to the naked seeded gymnosperms. More than 200,000 to 300,000 species are described according to the type of classification one follows. At times ferns, pteridosperms, cycadeoides, Caytoniales, conifers, Gnetales, glossopterids and Pentoxyleae have been considered as the possible ancestors of angiosperms keeping in view character similarities of various plant parts, viz., stem, leaf, perianth, cupule, carpel, anther, flower, etc.

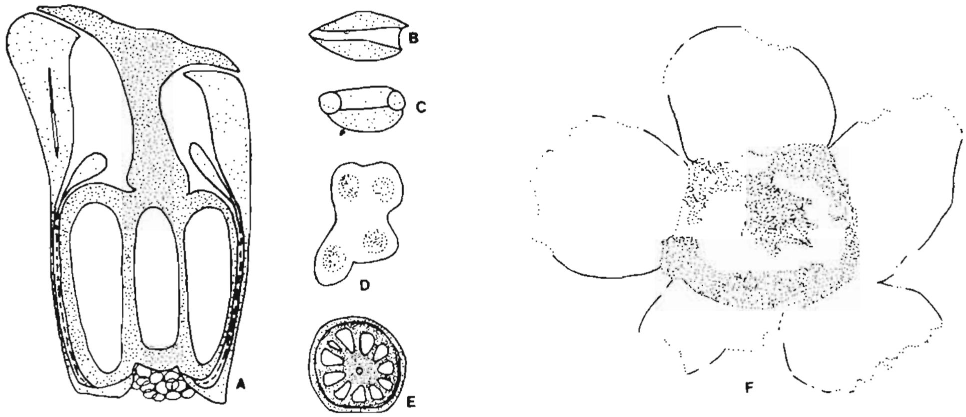
The gymnosperms of the Mesozoic Era were wind pollinated excepting Bennettitales which were partially pollinated by beetles (Crepet, 1972; Taylor, 1982). Before the close of Mesozoic, flower loving insects (anthophilous)—Coleoptera, Diptera, Hymenoptera and Lepidoptera had appeared. Therefore, a shift of wind pollination mechanism of gymnosperms over to insect pollination in angiosperms accelerated the pace of diversity of angiospermous flower in order to attract more insects.

Clavatipollenites is considered to be a primitive angiospermous pollen (Hughes, 1976; Doyle, 1978). It has a monosulcate aperture comparable to those of Cycadales, Ginkgoales, Bennettitales and Pentoxyleae. Therefore, the study of Early Cretaceous monosulcate type of pollen may reveal characters of the early angiosperm pollen.

ORIGIN OF ANGIOSPERMS

The Early Cretaceous (Aptian-Albian) *Weichselia-Onychiopsis-Gleichenia* Assemblage Zone 10 (Sukh-Dev, 1987) exhibited dry conditions by the presence of red beds at the top sediments in the Jabalpur Formation at Bansa, Jabalpur, Jatamao, Morand River in Madhya Pradesh, Rajmahal Hills in Bihar, and Himmatnagar in Gujarat. *Matonidium, Phlebopteris, Gleichenia* and *Weichselia* ferns with small thick, leathery leaves, recurved margins and sunken stomata occurred alongwith the decline of cycadophytes and conifers, coinciding with the successive erruptions of lava flows in the Rajmahal Hills area in Bihar. The hot and adverse environmental conditions once again subjected the existing plants to stress conditions and in response they quickly developed defensive mechanisms to protect their reproductive organs with the result several new forms appeared (as had earlier happened in the Early Triassic time). So a synthesis of already tested successful characters alongwith the development of new characters the coming up angiospermous group evolved rapidly. The following angiospermous characters are worthy to be considered for the evolution of angiosperms.

1. Carpel of angiosperms is a modified *Caytonia* cupule which had stigma-like structure and variable number of seeds.
2. Whorled arrangement of androecium in angiosperms is a derivation of similar arrangement occurring in Bennettitales and Pentoxyleae.
3. Fruit formation in angiosperms is a character of Caytoniaceae and Pentoxyleae where juicy growth or pulp was present around the seeds.



Text-figure 5—Angiosperms : **A,** L.S.—*Sahnipushpam shuklai* flower (semi-diagramatic), × 10; **B, C,** Pollen grains, dorsal and lateral views, × 500; **D,** T. S. anther having pollen grains, × 50; **E,** T. S. -ovary showing 11 loculii, × 5; **F,** Perianth of Siwalik angiosperm flower. (A-E, based on Prakash & Jain; F, Awasthi, Prasad & Antal).

4. Stamens possibly evolved from *Caytonanthus* (Caytoniales) which had bilateral symmetry of synangia in their early stages of development (Krassilov, 1977) like the bilateral angiosperm anthers and from *Williamsoniella* microsporophylls (Bennettitales) which are near to foliar angiosperm stamens.
5. Perianth in angiosperms probably developed from the bracts of the bennettitalean flowers which were protective in function. Later, the perianth differentiated into Calyx (protective) and Corolla (decorative and facilitating pollination).
6. Reticulate venation pattern of angiosperm leaves is borrowed from *Sagenopteris* leaves of Caytoniaceae.
7. Introduction of new character like double fertilization in angiosperms for the formation of endosperm is a new innovation of their own.

Consolidation of the earlier characters and innovation of new ones in due course of time proved very useful in the world-wide radiation of angiosperms from Early Cretaceous onwards to the present time. Thus the angiosperms have a polyphyletic origin. The arid environment in the Indo-European Palaeofloristic Province extending from Europe to India and South China to Japan supported xerophytic floras (Sukh-Dev 1987, Assemblage Zone 10) during Aptian-Albian. The structurally preserved angiosperm flowers with inferior ovary reported by Friis and Skarby (1981) from the Upper Cretaceous sediments of southern Sweden exhibiting rugged appearance possibly testify the prevalence of arid environment. The Indian angiospermous flower *Sahnipushpam* from the Deccan Intertrappean (Late Cretaceous of Eocene) from Madhya Pradesh and Maharashtra had a large, umbrella-shaped over-shadowing stigma and apically enlarged lysigenous perianth to provide shade and cut heat for the developing ovules or seeds and pollen grains in the ovary and stamen respectively (Text-figure 5A). These characters seem to have appeared in response to hot, dry atmosphere prevailing there due to intermittent lava flows. The structure of the *Sahnipushpam* flower from the Deccan Intertrappean and the asymmetrical perianth leaves of the flower from Siwalik sediments, Nepal (Awasthi *et al.*, 1990) also denote primitive angiospermous characters.

Recently, Tiwari and Tripathi (1990) reported angiospermous pollen from the Lower Cretaceous subsurface samples from the Rajmahal Hills. Further palynological investigations of the Lower Cretaceous sediments are the pressing need of the time to decipher early angiospermous characters.

CONCLUSIONS

In the course of evolutionary development in the reproductive biologies of Mesozoic plants in India, only significant characters from pteridosperms to cycads, cycadeoides, ginkgos, Pentoxyleae, conifers, ultimately leading to the origin of angiosperms are mentioned below:

The Mesozoic Era inherited an impoverished Palaeozoic flora characterized by homospory, heterospory, pollen and seed formations.

In response to the prevailing hot, arid environmental conditions in Early Triassic new forms—*Lepidopteris, Dicroidium* and allied genera of Peltaspermaceae, Corystospermaceae and members of Caytoniaceae appeared with their seeds covered in cupules. The seeds in Caytoniaceae were further provided with fleshy growth forming 'fruit-like' structures. *Lepidopteris, Dicroidium* and allied genera vanished by the end of Triassic Period. Members of Caytoniaceae continued to thrive up to Early Cretaceous.

As the climatic conditions improved for plant growth, the cycads gained prominence. They developed cones for the first time in the history of gymnosperms. The cones in cycads were terminal and large.

With the advent of Jurassic Period cycadeoides originated which resembled cycads in general habit but developed 'flower-like' reproductive organs.

Soon the conifers radiated to dominate the less advanced cycads and cycadeoides. They had small, compact cones spread over larger areas on the stem-branches.

In Early Cretaceous, a new small group Pentoxyleae combined the characters from Medullosaceae, cycads, cycadeoides, conifers and formed mulbery-like globose to elongate fleshy female cones and 'flower-like' male structures.

Towards the late Early Cretaceous (Aptian-Albian) a new group of angiospermous plants appeared with a unique carpel which covered and saved the ovules and seeds from drying up and produced true flowers and fruits. The angiosperms developed double fertilization for the formation of endosperm. The angiospermous pollen grains developed colpi or pores for their germination on the stigma of carpel. Several angiosperm characters have lineage with Caytoniaceae, Bennettitales and Pentoxyleae.

The Mesozoic Era seems to have influenced the course of plant evolution twice in response to the hot, arid environment prevailing during the Early Triassic, and Early Cretaceous times; the latter led to the rise of angiosperms.

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The Palaeogene vegetation of peninsular India (Megafossil evidences)

M. B. Bande

Bande MB 1992. The Palaeogene vegetation of peninsular India (Megafossil evidences). *Palaeobotanist* **40** : 275-284.

The Palaeogene represents the age of spread and diversification of angiosperms in the Indian sub-continent. A comprehensive knowledge of the Palaeogene flora of peninsular India is, therefore, necessary to decipher the history of the modern flora of India. The Palaeogene plant megafossils of this region can broadly be considered under (i) Deccan Intertrappean flora, (ii) Eocene flora of Kutch, (iii) Eocene plant fossils described from the Fuller's earth deposits near Barmer in Rajasthan, and (iv) Eocene plant records from Meghalaya.

The flora as a whole is characteristically tropical in character. It consists of taxa belonging to marine, estuarine, freshwater, and terrestrial habitat with both evergreen and deciduous forms. It is suggestive of an equable warm and moist tropical climate over the whole of peninsular India during the Palaeogene. The existence of this type of climate was the result of (i) a more or less equatorial position of peninsular India during the Palaeocene-Eocene period, and (ii) a warm sea which not only surrounded the peninsula from all the sides but also intruded into the landmass.

Most of the plants recovered from the Palaeogene localities of peninsular India still continue to grow in various forests of this region. Part of this flora, thus, can be considered to be the ancestral stock for the present day flora of India. Occurrence of some African, Madagascarian, Australian and South American elements in this flora suggests India's past connections with these Gondwanaland countries.

Key-words—Plant megafossils, Palaeoecology, Phytogeography, Palaeogene, Peninsular India.

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साराँश

प्रायद्वीपीय भारत की पूर्व-तृतीयक वनस्पति (गुरुपादपाश्म प्रमाण)

मोहन बलवंत बाँडे

भारतीय उपमहाद्वीप में पूर्व-तृतीयक कल्प आवृतबीजीयों के विस्तार एवं विभिन्नता को प्रदर्शित करता है। अतएव भारत के वर्तमान वनस्पतिजात का इतिहास सुनिश्चित करने हेतु प्रायद्वीपीय भारत के पूर्व-तृतीयक वनस्पतिजात की यथार्थता जानना आवश्यक है। इस क्षेत्र के पूर्व-तृतीयक गुरुपादपाश्म मोटे तौर पर चार समूहों में विभाजित किये जा सकते हैं: (i) दक्खिन अन्तर्ट्रैपी वनस्पतिजात, (ii) कच्छ का आदिनूतन वनस्पतिजात, (iii) राजस्थान में बाड़मेर के पास फुलर अर्थ निक्षेपों से वर्णित आदिनूतन अश्मित पौधे, तथा (iv) मेघालय से आदिनूतन पौधों के अभिलेख। यह वनस्पतिजात कुल मिलाकर उष्णकटिबन्धीय है। इसमें समुद्री, सरोवरी, स्वच्छजलीय तथा स्थली स्वभाव वाले सदाहरित एवं पर्णपाती प्रकार के अवयव विद्यमान हैं। पूर्व-तृतीयक कल्प में समूचे प्रायद्वीपीय भारत में ये अवयव सामान्य गर्म एवं नम उष्णकटिबन्धीय जलवायु का होना इंगित करते हैं। पुरानूतन-आदिनूतन काल में इस प्रकार की जलवायु का होना प्रायद्वीपीय भारत की प्राय: भूमध्यरेखीय स्थिति का द्योतक है तथा इस समय गर्म सागर ने प्रायद्वीप को चारों ओर से घेर ही नहीं रखा था अपितु भू-भाग में अन्दर तक प्रवेश किये हुए था।

प्रायद्वीपीय भारत की पूर्व-तृतीयक संस्थितियों से उपलब्ध पौधों में से अधिकतर अभी भी इस क्षेत्र के विभिन्न वनों में उगते हैं। अत: इस वनस्पतिजात का कुछ भाग भारत के वर्तमान वनस्पतिजात का पूर्वज कहा जा सकता है। इस वनस्पतिजात में कुछ अफ्रीकी, मेडागास्करी, आस्ट्रेलियाई तथा दक्षिण अमेरिकी अवयवों की उपस्थिति अतीत में इन गोंडवाना देशों से इसके सम्बन्ध व्यक्त करती है।

THE Palaeogene has been considered as the age of spread and diversification of angiosperms in the Indian sub-continent. During this period the Indian Plate broke away from the main land-mass of the Gondwanaland but it had not yet joined with the

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Asian Plate. A critical analysis of the Palaeogene flora of the peninsular India is, therefore, necessary to decipher the history of the modern flora of the Indian sub-continent. The evidence of fossil plants can also be made use of to reconstruct the palaeoclimate and palaeogeography of peninsular India during the Palaeogene.

Geographically, peninsular India consists of the triangular peninsula including the Shillong Plateau in the north-east and the Kutch-Kathiawar region in the west. The Palaeogene flora of this region as a whole can be treated under the following four assemblages:

1. Deccan Intertrappean flora,
2. Eocene flora of Kutch,
3. Eocene plant fossils described from the Fuller's earth deposits near Barmer in Rajasthan, and
4. Eocene plant records from Meghalaya.

The age of the Deccan Intertrappean flora has been a matter of discussion since several decades. The main controversy being whether the flora is Upper Cretaceous or Early Tertiary in age. This problem is linked with the problem of the age and span of the Deccan volcanism. On the basis of radiometric dating the span of Deccan volcanism has been suggested to be as long as 70 Ma, i.e., between 100 to 30 Ma (Alexander, 1981) to as short as 1 Ma at the Cretaceous-Tertiary boundary (Courtillot *et al.*, 1986, 1988; Duncan & Pyle, 1988a, 1988b). On the basis of palaeontological evidence, especially on the evidence of dinosaur fossils recovered from the Intertrappean beds of Takli and Naksal, Sahni *et al.* (1988) have supported the later view. However, ^{39}Ar-^{40}Ar dates obtained for the basalt flow underlying the fossiliferous intertrappean bed at Takli has given an age of 63.6 ± 0.2 Ma, i.e., Palaeocene (Shukla *et al.*, 1988). Thus, the possibility cannot be ruled out that the dinosaurs in India might have survived even up to Palaeocene. Similar view has also been expressed by Mathur (1987). Survival of the Dinosaurs in the Palaeocene has also been envisaged in North and South America as well as in China (Gauthier *et al.*, 1990). The evidence of the Intertrappean plant fossils described from around Nagpur-Chhindwara and Mandla is in favour of an Early Tertiary age for the flora rather than the Upper Cretaceous (Bande *et al.*, 1988). Under the circumstances, the Deccan Intertrappean flora has been treated to be of Palaeogene age for the present discussion.

The Neyveli lignite deposits have been traditionally considered to be of Neogene age (Ramanujam, 1966, 1966-67). On the basis of palynofossils a Palaeocene-Eocene age has been advocated for these deposits (Deb, Bakshi & Ghosh, 1973; Venkatachala, 1973; Siddhanta, 1986; Saxena, 1992). A Neogene age has been suggested on the basis of megafossil evidences (Guleria, 1992). Singh *et al.* (1992) have also supported the later view. The flora of these deposits therefore, has not been included in the present discussion.

FLORAL RECORD

Deccan Intertrappean Flora

The Deccan Intertrappean flora can be considered to be the most important and thoroughly studied flora of the Indian Palaeogene. Constituted by the plant fossils preserved in the sediments deposited between successive lava flows, the flora consists of woods, leaves, flowers, fruits and other organs representing all the major groups of Plant Kingdom. Besides, the stray reports of fossil plants described from various localities distributed all over the vast area of the Deccan Trap country, and the charophytes described from Gurmatkal, the flora can be studied under four different assemblages:

i. Rajahmundry assemblage,
ii. Nagpur-Chhindwara assemblage,
iii. Bombay-Malabar-Worli Hills assemblage, and
iv. Mandla assemblage.

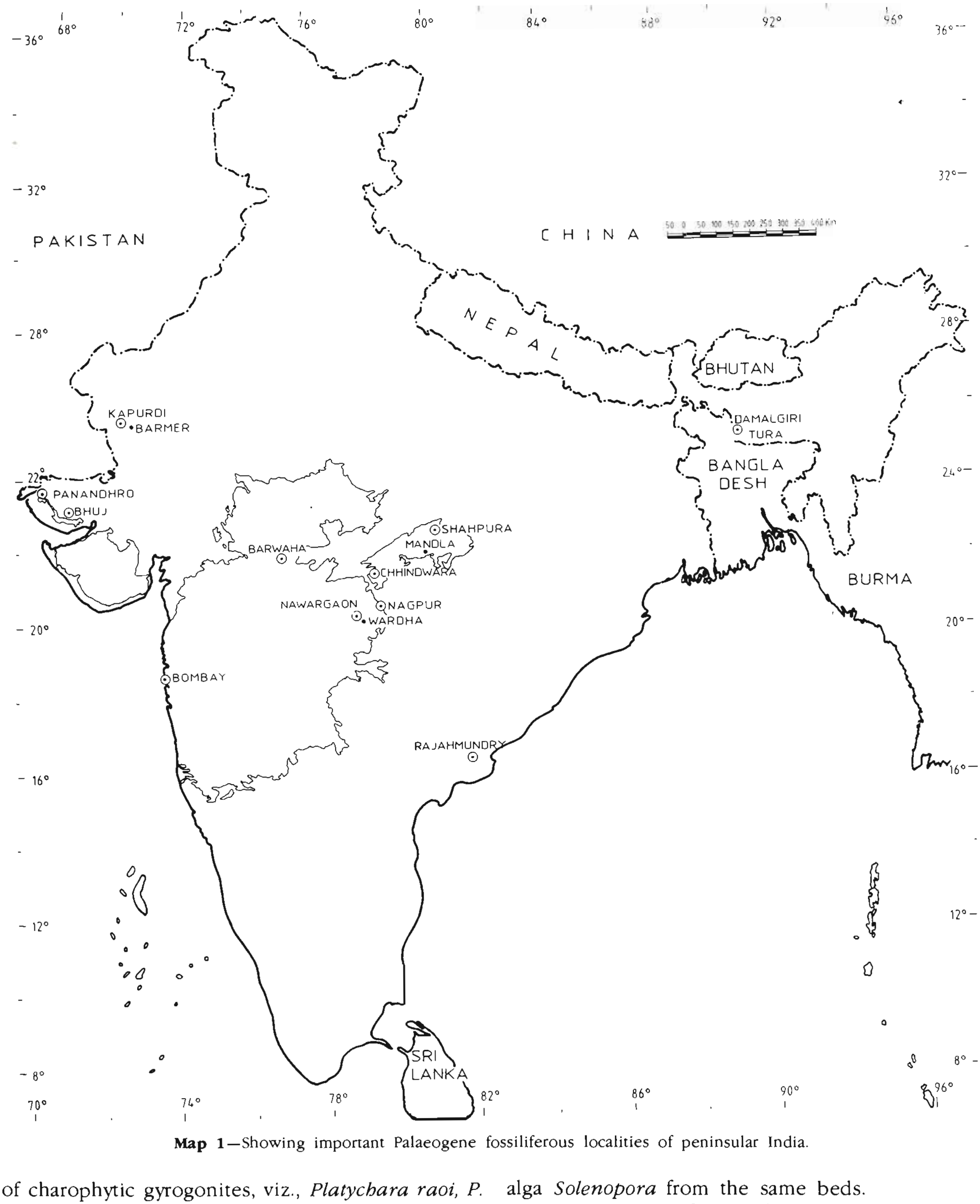
A comprehensive review of the plant taxa described from all these assemblages has recently been made by Bande *et al.* (1988). A summary of the available information is given below.

Rajahmundry Assemblage—This assemblage is mainly dominated by a number of algal taxa of estuarine habitat and thirteen species of charophytic gyrogonites. Important algal genera are *Helimeda, Dissocladella, Terquemella, Acetabularia, Neomeris, Holosporella* and *Acicularia.*

Three gymnospermous woods, viz., *Taxaceoxylon kateruense, Mesembrioxylon fusiforme* and *M. dudukurense* representing Taxaceae and Podocarpaceae have been described. *Rhizopalmoxylon sundaram* and *Palmoxylon sundaram* (showing affinities with the extant genus *Cocos*) and *Sonneratioxylon dudukurense* are indicative of a mangrove habitat.

Nagpur-Chhindwara Assemblage—The important fossiliferous localities are Mohgaonkalan and Keria near Chhindwara and Sausar, Mahurzari and Takli near Nagpur. Many fossil taxa are common to these different localities. The important floral elements of the assemblage are:

Algae—Fresh water elements are represented by *Spirogyrites, Oedogonites* and *Westielopsis* from Mohgaonkalan and *Ulothrix*-like filaments from Sausar. *Chara sausari*, the only fossil record of a gyrogonite of *Chara* with attached vegetative filament, is known from Sausar. Three more species



Map 1—Showing important Palaeogene fossiliferous localities of peninsular India.

of charophytic gyrogonites, viz., *Platychara raoi, P. sahnii* and *Microchara* sp. have also been described from the Gitti Khadan area near Nagpur. Two marine algae *Peyssonnelia antiqua* and *Distichoplax raoi* have been described from Mohgaonkalan. Recently, Mehrotra (1989) has described yet another marine alga *Solenopora* from the same beds.

Fungi—Some fungal forms, viz., *Shuklania, Diplodia rodei* and *Tetracosporium* are from Mohgaonkalan, while *Palaeosordaria* and *Perisporacites varians* have been described from Sausar.

Bryophytes—The record of bryophytes is very poor. An anthocerotaceous capsule—*Shuklanites deccani* has been described from Mohgaonkalan. *Riccia chitaleyii*, a thallus similar to *Riccia*, is also known from the same beds.

Pteridophytes—The pteridophytic elements in this assemblage are mainly composed of fresh water ferns. The important genera described are *Azolla, Rodeites, Marsilea* and *Salvinia*. *Rodeites* probably has affinities with the southern American fern *Regnelidium*. A strobilus resembling that of *Selaginella* has been reported from Mohgaonkalan.

Gymnosperms—The gymnosperms are mostly represented by cones, e.g., *Takliostrobus alatus, Indostrobus bifidolepis* and *Pityostrobus crassitesta*, all described from Takli. *Pityostrobus crassitesta* shows affinities with the family Abietineae. The other two cones possess characters of Abietineae as well as Podocarpaceae. *Mohgaonstrobus sahnii*, described from Mohgaonkalan, shows affinities with the modern Araucariaceae. Presence of both Araucariaceae and Podocarpaceae in these sediments is also confirmed by fossil woods of these families described from the same locality. Another gymnospermous cone, *Harrisostrobus intertrappea* with uncertain affinities, is known from Mohgaonkalan. A cycadean ovule is also recorded from the same locality.

Angiosperms—Both monocotyledons and dicotyledons are recorded. Besides palms, the other important monocot family is Musaceae. While the fossil fruit and the pseudostem (*Musocaulon*) have been assigned to the genus *Musa*, the leaf *Musophyllum* has been assigned to the family Musaceae. Yet another noteworthy genus is *Cyclanthodendron sahnii* which is said to possess affinities with the South American family Cyclanthaceae. Woods, fruits, petioles and roots of palms are of frequent occurrence. *Palmoxylon sundaram* is of special interest as it is comparable to *Cocos* and indicative of a coastal habitat. *Nipa*, a characteristic floral element of estuarine habitat, is also recorded from Mohgaonkalan.

Tricoccites, Viracarpon and *Monocotylostrobus* are well-preserved fruit genera with uncertain affinities in the assemblage. The structure and affinities of *Viracarpon hexaspermum* have been recently restudied and new interpretations given (Bande & Awasthi, 1986). Earlier the affinities of this fruiting axis were suggested to be with the Pandanaceae. However, Bande and Awasthi (1986) have questioned its affinities with Pandanaceae with the remarks that they still remain to be ascertained.

Dicotyledons are well-represented by a number of flowers, fruits and woods. Amongst these, the flower *Sahnianthus parijai* and the fruit *Enigmocarpon parijai* have affinities with *Sonneratia apetala* and *S. acida*. Other noteworthy flowers and fruits are *Sahnipushpam, Chitaleypushpam, Harrisocarpon* and *Sahniocarpon*. The affinities of these taxa are not known.

Fossil woods are mostly known from Keria and Mahurzari, the most common species being *Ailanthoxylon indicum*. The other known genera are *Simarouboxylon, Boswellioxylon, Bridelioxylon, Mallotoxylon, Tetrameleoxylon*, etc. from Keria and *Grewioxylon, Elaeocarpoxylon, Leeoxylon, Barringtonioxylon*, etc. from Mahurzari. *Aeschynomenoxylon* is comparable to the extant genus *Aeschynomene* indicative of a marshy habitat. A peduncle showing affinities to the aquatic family Nymphaeaceae is also described.

Further south of Nagpur, the intertrappeans near Nawargaon in Wardha, Maharashtra contain a rich floral assemblage. It is difficult to assess its relationship with the Nagpur-Chhindwara assemblage at present. The fossils so far described include five species of *Palmoxylon*, important amongst which is *Palmoxylon livistonoides* showing affinities with the extant genus *Livistona*. A palm petiole *Palmocaulon hyphaeneoides* showing similarities with the living genus *Hyphaene* has also been described. The dicotyledonous woods show affinities with the extant genera *Evodia* (Rutaceae), *Amoora* (Meliaceae), *Sonneratia* (Sonneratiaceae), *Ardisia* (Myrsinaceae), *Heterophragma* (Bignoniaceae), *Gmelina* (Verbenaceae), *Phyllanthus* (Euphorbiaceae) and *Aristolochia*.

Bombay-Malabar-Worli Hills Assemblage—The plant fossils described from the Intertrappeans of this area are limited and consist of a fossil wood of bamboo, leaflets similar to those of *Acacia* and seeds similar to *Artabotrys*. A fossil wood of Podocarpaceae has also been recorded.

Mandla Assemblage—Extensive palaeobotanical studies on the Deccan Intertrappean localities in the Mandla District have substantially added to our knowledge of the Deccan Intertrappean flora. The monocotyledons are exclusively represented by woods of palm and a fruit attributed to the modern branched palm *Hyphaene indica*. Recognizable modern genera in the assemblage are *Arenga, Licuala, Chrysalidocarpus, Hyphaene, Polyalthia, Homalium, Hydnocarpus, Garcinia, Sterculia, Grewia, Elaeocarpus-Echinocarpus, Atalantia-Limonia, Bursera, Canarium, Gomphandra (Stemonurus), Heynea, Aglaia, Walsura, Dracontomelum, Ailanthus, Lophopetalum, Artocarpus, Syzygium, Eucalyptus, Melaleuca-Tristania, Barringtonia, Sonneratia, Bischofia* and *Drypetes*.

Recently, some doubts have been raised against the presence of mangrove, coastal and marine taxa like *Nipa, Sonneratia, Cocos, Distichoplax* and *Peyssonellia* in the Deccan Intertrappean flora around Nagpur-Chhindwara and Mandla (Borkar, 1987). As the occurrence of these taxa in the Deccan Intertrappean assemblage is very significant in reconstructing the palaeoenvironment of this area, the objections raised by Borkar (1987) are briefly discussed below:

Presence of *Nipa* in the Deccan Intertrappean sediments is based on a well-preserved fruit described by Sahni (*in* Sahni & Rode, 1937) from Mohgaonkalan. In fact, the similarity of this specimen, both morphological and anatomical, with the modern *Nipa* fruit is so close and convincing that Sahni (1937, p. 167) had no hesitation in referring the fossil to *Nipa*. Borkar (1987) makes no observation on the structure and affinities of this particular fossil. The minor differences referred to by Borkar (1987, pp. 38, 39) in no way alter the generic affinities of this fossil with *Nipa*. Recent discovery of *Nipa* pollen from the Deccan Intertrappean sediments of Padwar on Jabalpur-Mandla road (Tanu Prakash *et al.*, 1990), further confirms the presence of this genus in the Deccan Intertrappean flora. Occurrence of *Sonneratia* in the Deccan Intertrappean flora is envisaged not only on the evidence of *Sahnianthus parijai* and *Enigmocarpon parijai* which bear affinities with Sonneratiaceae but also on the evidence of well-identified fossil woods exhibiting very close affinities with *Sonneratia* described from Mohgaonkalan, Nawargaon and recently from near Shahpura in Mandla District (Mehrotra, 1988). Borkar has mentioned not a single character on the basis of which the identification of these woods can be doubted.

It should be noted here that *Barringtonia*, a genus often found in association with *Nipa'* and *Sonneratia*, has been well documented from the Deccan Intertrappean beds of Nagpur-Chhindwara as well as of Mandla District.

Regarding *Cocos*, although Borkar suggests the occurrence of this genus in the Deccan Intertrappean flora as doubtful, he does not give a single reason against accepting its presence in this assemblage.

The identification of the marine algal genera *Distichoplax* and *Peyssonnelia* (Bande *et al.*, 1981) from Mohgaonkalan has also been questioned by Borkar (1987, p. 41). In doubting the identification of *Distichoplax* the above author refers to the observations of Kundal (1987) but makes no mention of the work of Varma (1962) in which the structure of *Distichoplax* has been discussed in detail. The identification of *Distichoplax* described by Bande *et al.* (1981) is based on the work of Varma (1962). Incidentally, under the references provided by Borkar, Kindal's work finds no place!

Lastly, although Borkar (1987, p. 41) himself admits that the anatomical structures of *Peyssonnelia antiqua* described by Bande *et al.* (1981) are closely comparable to those of the modern genus *Peyssonnelia*, he questions on its identification merely on the basis of a comment made by a third person and that too in personal communication. Recent finding of yet another marine alga of Solenoporaceae (Mehrotra, 1989) from Mohgaonkalan Intertrappeans is another evidence in favour of the presence of marine algae in this assemblage.

It should thus be clear that the objections raised by Borkar against the presence of *Nipa, Sonneratia, Cocos, Distichoplax* and *Peyssonnelia* in the Deccan Intertrappeans are not tenable. Occurrence of coastal and marine environment around Nagpur during Deccan Intertrappean sedimentation is also supported by palaeontological evidence (Sahni, 1983, 1984; Bhattacharya *et al.*, 1990).

Eocene flora of Kutch

The available information on the Eocene flora of Kutch has been reviewed at length by Lakhanpal *et al.* (1984). The flora consists of three species of calcareous red algae and a variety of angiospermous leaf-impressions. The algae, described from the locality of Babbia Hills (23°42'30" N : 68°47' E) situated at a distance of 122 km north-west of Bhuj and 5 km north-west of Panandhro, are representatives of the subfamily Melobesoideae of the family Corallinaceae (Kar, 1979). The species described are *Lithothamnium* sp. cf. *L. validum* Foslie, *Lithothamnium* sp. cf. *L. bofilli* Lemoine and *Lithophyllum* sp.

All the leaf-impressions described so far under this assemblage are from the lignite deposits near the village Panandhro (23°41'45" N : 68°47'22" E) situated at a distance of 126 km north-west of Bhuj on Bhuj-Narayan Sarovar Road. Palaeocene-Eocene leaf-impressions have also been reported from the localities of Matanomadh, Baranda and Sherdi (Lakhanpal *et al.*, 1984). However, no genera and species have been identified from these localities.

The Panandhro assemblage consists of leaves assigned to *Terminalia panandhroensis, Syzygium kachchhense, Lagerstroemia patelii, Cinnamomum eokachchhensis, Ficus kachchhensis* and *Pandanus eocenicus* belonging to the families Combretaceae, Myrtaceae, Lythraceae, Lauraceae, Moraceae and Pandanaceae respectively. Three species of

Dicotylophyllum, viz., *Dicotylophyllum cordatum, D. panandhroensis* and *D. quadrinervatum* have also been described from these deposits (Lakhanpal *et al.*, 1984).

Recently, the carbonised woods resembling *Terminalia calamansanai* and *Sonneralia apetala* have been described from the Rajpardi lignite mine, district Bharuch, Gujarat of Eocene age (Guleria, 1991).

Eocene plant fossils from the Fuller's earth deposits

A small fossil assemblage has also been described from the Fuller's earth bed at Kapurdi (25°54′30″ N : 70°21′30″ E), a village about 18 km from Barmer in Rajasthan. The assemblage, considered to be Middle Eocene in age, consists of leaf and fruit-impressions belonging to *Mesua* (cf. *M. ferrea*), *Garcinia* and *Calophyllum* of Guttiferae (Lakhanpal & Bose, 1951) and a fruit of *Cocos* (Kaul, 1951). The leaves of *Mesua* and *Garcinia* were later assigned to the species *Mesua tertiara* and *Garcinia barooahii* (Lakhanpal, 1964).

Eocene plant records from Meghalaya

From the Lower to Middle Eocene beds near Cherrapunji (25°17′ N : 91°44′ E) and Laitryngew (25°21′ N : 91°44′ E) in Meghalaya fossils of the mangrove palm *Nipa* and *Calophyllum* (Guttiferae) have been described (Bhattacharya, 1967). A few leaf-impressions have also been described from the Middle Eocene beds near Damalgiri in the Garo Hills, Assam (Lakhanpal, 1954, 1955). The locality (25°32′ N : 90°7′ E) lies about 18 km west of Tura. The leaves described from these beds are *Nelumbium* sp. (Nymphaeaceae), *Trema garoensis* (Ulmaceae), *Neolitsea sahnii* (Lauraceae), *Grewia foxii* (Tiliaceae) and *Bombacites orientalis* (Bombacaceae). The modern taxa comparable to these forms are *Nelumbium, Trema orientalis, Neolitsea zeylanica, Grewia tilifolia* and *Eriodendron anfructuosum/Bombax* sp.

A palm leaf referred to the genus *Sabalites* has also been reported from near Laitryngew near Shillong (Bose & Sah, 1964). However, as it is a feather palm, it should be referred to the genus *Phoenicites* Brongniart and not to *Sabalites.* From some other Lower to Middle Eocene localities of Garo Hills Bhattacharya (1979, 1983, 1985) has described a number of angiospermous leaf, flower and fruit-impressions. Locality-wise, the forms described are:

(i) West Daranggiri (25°28′ N : 90°42′ E)—*Nelumbo* Adans. affinity *Nelumbo nucifera.*

(ii) Rongrenggiri (25°34′ N : 90°33′ E), Nangalbibra (25°28′ N : 90°42′ E)—*Nipa sahnii, Poacites* sp., *Nelumbo nangalensis, Litsea* sp., *Phoebe sublanceolata, Artocarpus garoensis, Triumfetta rhomboideocarpa, Heteropanax* sp., *Osmanthus eocenicus, Ligustrum turaensis, Antholithes oleaceaeformis* and *A. campanulatus.* The modern genera identified in this assemblage are *Nipa* (Palmae), *Nelumbo* (Nymphaeaceae), *Litsea* (Lauraceae), *Phoebe* (Lauraceae), *Artocarpus* (Moraceae), *Osmanthus* (Oleaceae) and *Ligustrum* (Oleaceae).

(iii) Garo Hills, Meghalaya (25°31′ N : 90°15′ E)—Five species of leguminoceous fruits—*Leguminocarpon*, viz., *L. desmodioides, L. derrisoides, L. millettioides, L. pongamioides* and *L. albizioides* have been described. The comparable modern taxa are *Desmodium triquetrum, Derris cuneifolia, Millettia rubiginosa, Pongamia pinnata* and *Albizia lucida.*

PALAEOENVIRONMENTAL ANALYSIS

Because any plant community is the result of interaction between the plant and surrounding environment, the evidence of fossil plants has been made use of to reconstruct the palaeoclimate and palaeogeography of different areas of peninsular India during the Palaeogene (Lakhanpal, 1970; Lakhanpal *et al.*, 1984; Prakash, 1973; Bande & Prakash, 1982; Bande *et al.*, 1988). The data have also been used to reconstruct the vegetation around Nagpur-Chhindwara and Mandla during the Deccan Intertrappean sedimentation (Bande & Chandra, 1990).

As mentioned earlier, most of our information regarding the Deccan Intertrappean flora, the oldest of the Indian Palaeogene is from the Rajahmundry assemblage, the Nagpur-Chhindwara assemblage and the Mandla assemblage. Occurrence of estuarine algae and *Cocos* in the Intertrappean beds of Rajahmundry indicates the existence of sea shore which was a little more inland than the present shore line.

The Nagpur-Chhindwara assemblage is typically tropical in character in which a number of ecological facies can be recognized. These are:

(i) marine—indicated by *Distichoplax, Peyssonnelia* and Solenoporaceae

(ii) mangrove—indicated by *Sonneratia* and *Nipa*

(iii) coastal—indicated by *Cocos*

(iv) fresh water lakes, ponds, streams marshes—indicated by fresh water algae, water ferns, aquatic angiosperms—*Barringtonia, Syzygium, Aeschynomene*

(v) terrestrial and upland—indicated by Araucariaceae, Podocarpaceae and other arborescent angiosperms.

Although occurrence of conifers is usually taken to be indicative of a high altitude, both Araucariaceae and Podocarpaceae show a wide range of altitudinal distribution and can as well grow at the sea level (Florin, 1963). Most of the modern comparable taxa of this assemblage are presently found in the evergreen to semi-evergreen forests of Western Ghats and north-east India with some forms occurring in the dry deciduous forest. Thus, the assemblage indicates a depositional site at the mouth of a river in the near vicinity of sea.

Compared to the Nagpur-Chhindwara assemblage, the Mandla assemblage is exclusively angiospermous dominated by arborescent species. Similar to the Nagpur-Chhindwara assemblage this assemblage is also characteristically tropical in character with most of its modern equivalent taxa growing in the evergreen to semi-evergreen forests of Western Ghats and north-east India. The genera constituting the assemblage are *Hyphaene, Chrysalidocarpus, Licuala, Arenga, Polyalthia, Homalium, Hydnocarpus, Garcinia, Sterculia, Grewia, Echinocarpus, Atalantia-Limonia, Bursera, Canarium, Gomphandra* syn. *Stemonurus, Heynea, Walsura, Dracontomelum, Lophopetalum, Syzygium, Eucalyptus, Tristania, Sonneratia, Bischofia, Drypetes* syn. *Putranjiva* and *Artocarpus*.

Taking into consideration the habit and habitat of the modern equivalents it has been deduced (Bande & Chandra, 1990) that the forest was constituted by water loving forms, like *Syzygium, Drypetes* and *Barringtonia*, low trees or shrubs like *Garcinia, Gomphandra, Grewia, Heynea, Atalantia-Limonia, Tristania, Polyalthia*, etc., moderate to large-sized trees like *Bischofia, Bursera, Dracontomelum, Hydnocarpus* and *Walsura*, and some very large trees like *Artocarpus, Canarium, Lophopetalum* and *Sterculia* with their crowns projecting up in the sky through the main forest canopy. The palm genera like *Chrysalidocarpus, Licuala* and *Arenga* must have constituted the understorey but *Hyphaene* must have occupied some open area. Presence of *Sonneratia* indicates brackish water conditions, most probably at some distance from the main forest.

Analysing the Nagpur-Chhindwara and the Mandla assemblages together, Bande and Prakash (1982) have envisaged in central India a climate similar to the present day climate of the Western Ghats. It has been postulated that the area enjoyed a humid tropical climate with an annual rainfall over 2000 mm, an uniform temperature throughout the year and a long duration of rainy season. The factors responsible for the occurrence of such a type of climate were : (i) almost equatorial position of the area during that period, (ii) presence of sea in near vicinity, and (iii) probable absence of Western Ghats as main barriers in the path of the southwest monsoon currents. The northward drift of the Indian Plate, the withdrawl of the sea and uplifting of the Western Ghats in the post-trappean times resulted in the establishment of the present day climate and tropical dry deciduous to moist deciduous vegetation in central India against a tropical wet evergreen to semi-evergreen forest of the past (Bande & Prakash, 1982).

Similar to the Deccan Intertrappean flora, the Panandhro assemblage has also been analysed to decipher the palaeoenvironment around the basin during the Lower Eocene (Lakhanpal *et al.*, 1984). The occurrence of marine algae indicates that there was transgression of sea in the Kutch area during the deposition of these sediments. The modern comparable forms for the angiospermous species described from Panandhro are: *Terminalia crenulata, Syzygium* sp., *Lagerstroemia speciosa, Cinnamomum zeylanicum, Ficus tomentosa, Pandanus diversus, P. furcatus* and *P tectorius*. The occurrence of these taxa is suggestive of a moist evergreen to deciduous vegetation around Panandhro. Further, the littoral and swampy elements like *Lagerstroemia speciosa, Syzygium* sp. and *Pandanus tectorius* are indicative of marshes around this locality in which the vegetation got buried and resulted in the formation of lignite in due course of time (Lakhanpal *et al.*, 1984).

In continuation of the Lower Eocene, the poorly known Middle Eocene flora of Kapurdi, Rajasthan is also typically tropical in character. Presence of *Mesua* cf. *M. ferrea, Garcinia* and *Calophyllum* clearly indicates that a moist tropical climate with evergreen forest flourished around Kapurdi at the time of deposition of the Fuller's earth bed. Presence of *Cocos* in addition, further suggests that the shoreline was not far away from Kapurdi during the Middle Eocene.

The small assemblage of fossil plants described from near Damalgiri in the north-east suggests presence of evergreen to semi-evergreen vegetation and a tropical to sub-tropical climate around Damalgiri during the Middle Eocene. Of the various plant taxa identified from these deposits, *Trema orientalis* and *Neolitsea zeylanica* are small to middle-sized evergreen trees, *Grewia tilifolia* is distributed in east tropical Africa and peninsular and northeastern parts of India and *Nelumbium* is a well known aquatic plant of the tropics. *Eriodendron* mostly occurs in America but *E. anfructuosum* is a moderate-sized deciduous tree occurring in Burma, Andamans, Malaya Peninsula and the Archipelago, western parts of Indian Peninsula and tropical America. *Bombax malabaricum*, another comparable form, is well distributed in tropical Himalayas and throughout the warmer forests of India to Burma and Ceylon, also in Java and Sumatra. *Bombax insigne*, yet another species of the genus, is a common tree of mixed deciduous forests extending into evergreen to semi-evergreen forests. It is essentially a tropical tree occurring in Burma, Andamans, Chittagong, Malay Peninsula and the Western Ghats of India (Lakhanpal, 1954).

Presence of *Nipa* in the Lower to Middle Eocene beds around Cherrapunji and Garo Hills indicates an estuarine condition in both these areas. Similarly, occurrence of *Nelumbo* suggests the presence of fresh water lakes and ponds. In addition, occurrence of terrestrial trees, shrubs, and herbs like *Calophyllum, Artocarpus, Litsea, Phoebe, Ligustrum* and *Osmanthus*, all of which are tropical to sub-tropical in habitat, suggests a depositional site, especially around Rongrengiri and Nangalbibra in Garo Hills, very similar to that around Mohgaonkalan during the Deccan Intertrappean sedimentation. It should be noted that at least four families, viz., Palmae, Guttiferae, Nymphaeaceae and Moraceae and two genera *Nipa* and *Artocarpus* are common in the Deccan Intertrappean flora of central India and the Lower to Middle Eocene assemblage of Meghalaya. Lastly, the evidence of the fossil fruits comparable with different genera of Leguminosae also suggests that the assemblage was composed of trees, shrubs, herbs and woody climbers growing in and around the banks of streams in tropical to sub-tropical moist deciduous forest (Bhattacharya, 1985

An overview of the Palaeogene flora of India broadly suggests that the wet evergreen to semi evergreen forest and humid tropical climate in central India, prevalent during Early Palaeogene—i.e. during the Deccan Intertrappean sedimentation, continued to prevail in the west as well as north-east India at least till the Middle Eocene. It was only in the post-Palaeogene period, after the joining of the Indian Plate with the Asian Plate, that the Indian sub-continent started acquiring its present day topography resulting in the onsetting of the current vegetational and climatic pattern of this sub-continent.

PHYTOGEOGRAPHICAL CONSIDERATIONS AND PLANT MIGRATIONS

As mentioned earlier, in the history of the Indian sub continent the Palaeogene represents a period when the Indian Plate had already broken away from the rest of the continents of the Gondwanaland but had not yet joined with the Asian Plate. It is, therefore, but natural to expect, in the Palaeogene flora of peninsular India, at least a few taxa showing affinities with those presently confined to the other countries belonging to Gondwanaland of the past. An analysis of the Indian Palaeogene flora, especially the Deccan Intertrappean flora, brings out some interesting evidences in support of this assumption. Affinities of *Rodeites*, described from Mohgaonkalan intertrappeans, have been traced to *Regnellidium* a water fern of Brazil. Similarly, *Cyclanthodendron* and *Simarouboxylon* bear resemblance with the tropical American genera *Cyclanthus* and *Simarouba*, respectively. Although the affinities of all these fossils are not beyond doubt, their presence does indicate the possibility of the presence of some tropical American genera in the Indian Palaeogene. From the Intertrappean beds of Mandla District, a fossil fruit exhibiting close affinity with the fruit of the branched palm *Hyphaene* has been described (Bande *et al.*, 1982). A palm petiole belonging to this genus has also been described from the Intertrappean beds of Nawargaon, district Wardha (Shete & Kulkarni, 1980). Only a single species of *Hyphaene—H. indica* is found in India which is distributed all along the western coast up to Goa. The other 41 species are distributed in tropical and sub-tropical areas of Africa and Arabia. From the same assemblage, yet another palm—*Chrysalidocarpus*, a genus native of Madagascar, has been described.

Occurrence of some Australian taxa like *Eucalyptus, Tristania-Melaleuca* (Bande *et al.*, 1986) is also interesting. It is essential to rethink regarding the position of India in relation to Australia in the past. Further, if the view proposed by some that before the Gondwana break-up Australia and India were in juxtaposition to each other is accepted (Bande *et al.*, 1988, p. 100), then what was the time of separation of India and Australia? Even after the separation took place, were these two landmasses inter-connected through some land bridges till as late as the Palaeogene ? Can it be presumed that during the Palaeogene the present day tropical America, Africa, Madagascar, India and Australia enjoyed a similar type of climate permitting the existence of at least some common plant taxa on them? It should be interesting to note that atleast a few Indian Palaeogene families like Myrtaceae, Lauraceae, ?Sterculiaceae, etc. have been recorded from the Palaeogene deposits of Antarctica also (Birkenmajer & Zastawniak, 1986).

The extant flora of India is usually termed as Indo-Malayan. However, it should be born in mind that the flora of this region acquired its present composition only after the Indian Plate joined with the Asian Plate and establishment of land connections between India and South-east Asia (Bande & Prakash, 1986). A detailed comparison of the Palaeogene flora of India vis-a-vis Palaeogene as well as Neogene floras of South-east Asia has already been made to understand the migration of various plant taxa between these two land masses (Bande & Prakash, 1986). Some of the genera which appear to have migrated from India to South-east Asia during the Neogene are: *Sterculia, Grewia, Polyalthia, Gomphandra, Lophopetalum, Syzygium* and *Sonneratia*. Similarly, the most important taxa which were added to the Indian flora from South-east Asia during the post-Palaeogene are, Dipterocarpaceae and many genera of Leguminosae.

The Palaeogene flora of peninsular India, thus, can be considered as the parental stock for the present day flora of India. To this stock the elements of South-east Asia, Africa and also Europe were added during the post-Palaeogene period ultimately resulting in the evolution of the modern Indian subcontinent flora.

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Neogene vegetation of peninsular India

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The Neogene vegetation of peninsular India has been analysed on the basis of which some broad conclusions have been derived. During the Neogene Period the whole of peninsular India was covered by luxuriant tropical evergreen to deciduous forests. Occurrence of Dipterocarpaceae from East to West and North to South alongwith other common elements suggests a more or less uniform warm tropical climate throughout the peninsula. A gradual decrease in rainfall during Neogene due to northward shift of the Indian peninsula from equator and growing continentality caused by the rise of Himalayan mountains is decipherable. Further decrease in rainfall towards the end of Neogene is evidenced by the complete eradication of dipterocarps and the appearance of dry or desertic conditions towards the end of Pliocene in the western (Gujarat and Rajasthan) and south-eastern (Cuddalore) part of the peninsula is noticeable. Large scale migration and admixture of floras took place between the Indian peninsula, south-east Asia and Africa due to establishment of land connections by the Neogene. Wide spread occurrence of Dipterocarpaceae and dominance of legumes together with Sapotaceae, Ebenaceae and Rosaceae, etc. distinguishes the Neogene flora of peninsular India from the Palaeogene.

Key-words—Neogene, Megafossils, Palaeoecology, Peninsular India.

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साराँश

प्रायद्वीपीय भारत की पश्च-तृतीयक युगीन वनस्पति

जसवन्तसिंह गुलेरिया

प्रायद्वीपीय भारत की पश्च-तृतीयक वनस्पति का विश्लेषण किया गया है जिसके आधार पर कुछ महत्वपूर्ण निष्कर्ष निकाले गये हैं। इस कल्प में सम्पूर्ण प्रायद्वीपीय भारत उष्णकटिबन्धीय सदाहरित से पर्णपाती वनों से युक्त था। पूर्व से पश्चिम तक तथा उत्तर से दक्षिण तक डिप्टेरोकार्पेसी कुल की उपस्थिति तथा अन्य सहयुक्त अवयवों से यह प्रस्तावित होता है कि प्रायः एक जैसी जलवायु पूरे प्रायद्वीप में विद्यमान थी। इस काल में भूमध्यरेखा से भारतीय प्रायद्वीप के उत्तर की ओर खिसकने से शनैः शनैः कम वर्षा तथा हिमालय के उत्थान से महत्वपूर्ण परिवर्तन हुए। पश्चनूतन कल्प की समाप्ति पर डिप्टेरोकार्पेसी कुल का विलुप्तीकरण तथा प्रायद्वीप के पश्चिमी (गुजरात व राजस्थान) तथा दक्षिण-पूर्वी भाग में शुष्क अथवा मरुस्थली स्थिति का प्रादुर्भाव अत्यन्त महत्वपूर्ण है। इसी कल्प में भारतीय प्रायद्वीप, दक्षिण-पूर्व एशिया तथा अफ्रीका के बीच वनस्पतिजातों का बड़े पैमाने पर पारस्परिक प्रवासन हुआ। डिप्टेरोकार्पेसी कुल का दूर-दूर तक विस्तार तथा सैपोटेसी, एबीनेसी एवं रोजेसी आदि कुलों के साथ-साथ लैग्यूमों की बाहुल्यता से प्रायद्वीपीय भारत के पश्च-तृतीयक वनस्पतिजात की तृतीयक-पूर्व वनस्पतिजात से पृथकता इंगित होती है।

THERE has been a considerable work on the Neogene fossil floras during the last four decades. Investigations have been intense during the past three decades resulting into a better understanding of the flora of this period on account of newly discovered fossiliferous localities, increased availability of fossil material and knowledge of anatomy. Perhaps, the history of Neogene fossil studies in the country is about two hundred years old when a French naturalist (Sonnerat, 1782) reported the occurrence of petrified woods near Pondicherry. However, no attention was paid to these fossils for a very long time until and after the return of Prof. Birbal Sahni from Cambridge. Prof. Sahni initiated work on Tertiary plants of India in thirties (1922, 1924, 1928, 1931a, b, c) and thus provided necessary impetus to Indian Tertiary Palaeobotany.

Peninsular India lies south of Indo-Gangetic Plains and includes Rajasthan, Kutch, Saurashtra in the West to Assam Shelf in the north-east. The Assam Shelf includes the Shillong Plateau, the Garo, Khasi, Jaintia, Mikir hills and Upper Assam Valley.

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Geologically this is north eastern prolongation of the Indian Peninsular Shield. Compared to extensive Deccan Trap deposits of Upper Cretaceous to Palaeogene age in the peninsular India the Neogene sediments appear sporadically along the West (Kutch, Saurashtra, Cambay, Konkan and Kerala Coast) and East Coast (Cauvery, Krishna, Godavari, Mahanadi and Bengal basins). In the northeast region they are fairly well-developed. Recently fossils belonging to Neogene have been reported from Rajasthan, Madhya Pradesh and south Bihar, thereby indicating the occurrence of Upper Tertiary sediments in these areas.

For quick perusal the floras of different basins have been listed along with their affinities with the extant genera and remarks on identification of some of the taxa have been made.

COMPOSITION OF NEOGENE FLORA OF PENINSULAR INDIA

The commonest plant fossils found in the Neogene deposits are petrified woods. Most of the woods belong to dicotyledons and monocotyledons. Palms are few and gymnosperms rare. In addition, some impressions or compressions of leaves, fruits and seeds have also been reported.

The Neogene flora of peninsular India has been divided into five groups for consideration and discussion.

1. *Western India Floras*
   - (i) Gujarat flora (Kutch and Saurashtra basins)
   - (ii) Rajasthan flora (Jaisalmer and Bikaner basins)
   - (iii) Konkan flora
   - (iv) Kerala Coast flora (Kerala-Lakshadweep Basin)
2. *East Coast Floras*
   - (i) Rajahmundry flora (Krishna-Godavari Basin)
   - (ii) Neyveli lignite flora
   - (iii) Cuddalore Series flora
3. *North East Flora (Assam-Arakan Basin)*
4. *Bengal and Bihar flora*
5. *Central India flora*
6. *Andaman and Nicobar Islands flora*

DISCUSSION

1. Western Indian Neogene floras

(i) Gujarat *(Kutch and Saurashtra basins)*—A fairly large amount of data is now available on the Neogene flora of Kutch (Lakhanpal & Guleria, 1983; Lakhanpal *et al.*, 1984). The flora is represented by four genera of calcareous red algae, a gymnosperm (*Podocarpoxylon*), three monocot and over 25 dicot genera (see Table 1). The number of known algal taxa is very small, consisting of five species belonging to four genera, viz., *Aethesolithon, Archaeoporolithon, Lithophyllum* and *Mesophyllum.* Occurrence of the algae indicates definite marine habitat, transgression and regression of the sea in Kutch during Miocene. The fossil localities lie adjacent to the Tropic of Cancer and hence fall in the tropical region, indicating tropical conditions which is corroborated by *Aethesolithon, Archaeoporolithon* and *Lithophyllum* together with fossil remains of higher plants. *Mesophyllum* is the only exception which is primarily a cold water genus (Wray, 1977, p. 67). Structurally *Mesophyllum, Lithophyllum* and *Neogoniolithon* are very similar except in a few characters, but whereas *Mesophyllum* is a cold water genus the last two are warm water genera. It is thus suggested that the affinities of *Mesophyllum* need reinvestigation based on more and better preserved material because it is highly improbable that cold water genus would survive in tropical sea around Kutch.

The higher plants primarily consists of petrified woods, impression of leaves and a few fruits and seeds. A general survey of the Neogene flora shows that out of the known modern comparable genera, viz., *Afzelia-Intsia, Albizia, Bauhinia, Barringtonia, Cassia, Ceriops, Chlorophora, Cinnamomum, Cynometra, Dialium, Dipterocarpus, Euphoria, Ficus, Gluta, Isoberlinia, Lagerstroemia, Millettia, Millettia-Pongamia, Murraya, Podocarpus, Pterospermum, Schleichera, Sonneratia, Sterculia* and *Terminalia,* only *Bauhinia, Cassia, Ceriops, Ficus* and *Sterculia* are represented in the present day flora of Kutch. These five genera are found in protected and limited places in Kutch. It is clear from the above data that majority of the genera had a wider distribution and extended up to Kutch in the western part of the country during Neogene. Analysis of the flora has brought to light that Kutch had been the meeting ground of eastern (*Cinnamomum, Dipterocarpus, Euphoria, Gluta, Murraya, Pterospermum, Schleichera*) and western floral elements, particularly African (*Isoberlinia, Chlorophora*). This could be possible due to establishment of land connections between Malaysia, India, Arabia and East Africa during Neogene. The occurrence of *Ceriops, Sonneratia, Barringtonia* and *Lagerstroemia* indicates the existence of littoral and riverine or swampy conditions. Likewise the occurrence of *Afzelia-Intsia, Cinnamomum, Cynometra, Dipterocarpus,*

Table 1—Neogene megafossils of Gujarat (Kutch and Saurashtra basins)

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/SERIES
ALGAE			
Corallinaceae	*Lithophyllum* aff. *L. kladosum* Johnson; Pal & Ghosh 1974	*Lithophyllum* Philippi	Khari Series (Lower Miocene)
	Mesophyllum commune Lemoine; Pal & Ghosh 1974	*Mesophyllum* Lemoine	Khari Series (Lower Miocene)
	Aethesolithon problematicum Johnson; Pal & Ghosh 1974	*Aethesolithon* Johnson	Khari Series (Lower Miocene)
	Aethesolithon cutchensis Pal & Ghosh 1974	*Aethesolithon* Johnson	Khari Series (Lower Miocene)
	Archaeoporolithon miocenicum Pal & Ghosh 1974	*Archaeoporolithon* Pal & Ghosh	Khari Series (Lower Miocene)
GYMNOSPERMS			
Podocarpaceae	*Podocarpoxylon kutchensis* Lakhanpal *et al.* 1975	*Podocarpus wallichianus* C. Presl.	Kankawati Series (Pliocene)
ANGIOSPERMS			
Poaceae	*Culmites cutchensis* Sahni 1964		?
Arecaceae	*Palmoxylon mathuri* Sahni 1964	Palm	?
	Palmoxylon seriatum Sahni 1964	Palm	?
	Palmacites khariensis Lakhanpal & Guleria 1982	Palm	Khari Series (Lower Miocene)
	Palmoxylon kachchhensis Guleria 1983	Palm	Kankawati Series (Pliocene)
Dipterocarpaceae	*Dipterocarpoxylon malavii* Ghosh & Ghosh 1959; Guleria, 1983	*Dipterocarpus dyeri* Pierre ex De Laness	Kankawati Series (Pliocene)
	D. pondicherriense Awasthi; Guleria 1983	*D. indicus* Bedd.	Kankawati Series (Pliocene)
	Hopea (MS)	*Hopea*	Miocene-Pliocene
Sterculiaceae	*Sterculinium kalagarhense* (Trivedi & Ahuja) Guleria 1983	*Sterculia coccinea* *S. oblonga* Mast. *S. rhinopetala* K. Schum.	Kankawati Series (Pliocene)
	Pterospermoxylon kutchensis Awasthi *et al.* 1980	*Pterospermum glabrescens* W & A *P. reticulatum* W & A *P. rubiginosum* Heyne	Kankawati Series (Pliocene)
Rutaceae	*Murraya khariensis* Lakhanpal & Guleria 1982	*Murraya paniculata* (Linn.) Jack	Khari Series (Lower Miocene)
Sapindaceae	*Euphorioxylon indicum* Awasthi *et al.* 1982	*Euphoria longana* Lamk.	Kankawati Series (Lower Miocene)
	Schleicheroxylon kachchhensis Awasthi *et al.* 1982	*Schleichera oleosa* (Lour) Oken	Kankawati Series (Lower Miocene)
Anacardiaceae	*Glutoxylon burmense* (Holden) Chowdhury 1952; Guleria, 1984b Syn. *G. kalagarhense* Trivedi & Ahuja 1978	*Gluta travancorica* Bedd.	Khari Series (Lower Miocene)
Fabaceae	*Millettia asymmetrica* Lakhanpal & Guleria 1982	*Millettia ovalifolia* Kurz	Kankawati Series (Lower Miocene)
	M. miocenica Lakhanpal & Guleria 1982	*M. auriculata* Baker	Kankawati Series (Lower Miocene)
	Bauhinia kachchhensis Lakhanpal & Guleria 1982	*B. phoenicea* Heyne *B. purpurea* Linn.	Kankawati Series (Lower Miocene)
	Cassia miokachchhensis Lakhanpal & Guleria 1982	*Cassia* sp.	Khari Series (Lower Miocene)
	Leguminocarpon khariensis Lakhanpal & Guleria 1982	Fruit cf. Fabaceae	Khari Series (Lower Miocene)
	Leguminophyllum khariensis Lakhanpal & Guleria 1982	Leaf cf. Fabaceae	Khari Series (Lower Miocene)
	Leguminosites khariensis Lakhanpal & Guleria 1982	Seed cf. Fabaceae	Khari Series (Lower Miocene)

Contd.

Table 1—Contd.

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/SERIES
	Millettioxylon indicum Awasthi; Guleria 1984a	*Millettia pendula* Benth. *M. prainii* Dunn. *Pongamia pinnata* (Linn.) Pierre	Kankawati Series (Pliocene)
	Pahudioxylon sahnii Ghosh & Kazmi; Guleria 1984a	*Afzelia-Intsia*	Kankawati Series (Pliocene)
	P. assamicum Prakash & Tripathi; Guleria 1984a	*Afzelia-Intsia*	Kankawati Series (Pliocene)
	Cynometroxylon holdenii (Gupta) Prakash & Bande; Guleria 1984a	*Cynometra polyandra* Roxb. *C. ramiflora* Linn.	Kankawati Series (Pliocene)
	Isoberlinioxylon congoense Lakhanpal & Prakash; Guleria 1984a	*Isoberlinia angolensis* (Welw.) Hoyle & Brenan *I. niembaensis* Duvigan	Kankawati Series (Pliocene)
	Dialiumoxylon indicum Guleria 1984a	*Dialium* sp.	Kankawati Series (Pliocene)
	Albizinium eolebbekianum Prakash; Guleria 1984a	*Albizia lebbek* Benth.	Kankawati Series (Pliocene)
	A. pondicherriensis Awasthi; Guleria 1984a	*Albizia amara* Boivin *A. odoratissima* Benth.	Kankawati Series (Pliocene)
Rhizophoraceae	*Ceriops kachchhensis* Lakhanpal *et al.* 1984	*Ceriops decandra* (Griff.) Ding Hou *C. tagal* (Perr.) C. B. Rob.	Khari Series (Lower Miocene)
Combretaceae	*Terminalia kachchhensis* Lakhanpal *et al.* 1984	*Terminalia chebula* Retz.	Khari Series (Lower Miocene)
	Terminalioxylon burmense Mädel-Angeliewa & Müller-Stoll; Guleria 1983	*Terminalia tomentosa* W & A	Kankawati Series (Pliocene)
	T. felixii Ramanujam; Guleria 1983	*Terminalia arjuna* Bedd. *T tomentosa* W & A	Kankawati Series (Pliocene)
Barringtoniaceae (Lecythidaceae)	*Barringtonia* (Ms)	*Barringtonia* J. R. & G. Forst.	Khari Series (Lower Miocene)
Lythraceae	*Lagerstroemioxylon eoflosreginum* Prakash & Tripathi; Lakhanpal *et al.* 1984	*Lagerstroemia speciosa* L. Pers.	Khari Series (Lower Miocene)
Sonneratiaceae	*Sonneratioxylon preapetalum* Awasthi; Lakhanpal *et al.* 1984	*Sonneratia apetala* Buck-Ham. *S. caseolaris* (Linn.) Engler	Khari Series (Lower Miocene)
Lauraceae	*Cinnamomum miokachchhensis* Lakhanpal & Guleria 1982	*Cinnamomum zeylanicum* Breyn.	Khari Series (Lower Miocene)
Moraceae	*Ficus khariensis* Lakhanpal & Guleria 1982	*Ficus infectoria* Roxb.	Khari Series (Lower Miocene)
	Chlorophora (Ms)	*Chlorophora* Gaudich.	Kankawati Series (Pliocene)

Gluta, Podocarpus, Pterospermum, Sonneratia along with other deciduous elements (see Table 1) indicates luxuriant vegetation and warm conditions with plenty of rainfall during Neogene in contrast to dominant scrubby vegetation and xeric conditions of present day Kutch. The prevailing xeric conditions in Kutch can be attributed to change in the climatic conditions during post-Pliocene time.

Plant fossils have lately been collected from Miocene and Pliocene sediments of Saurashtra and are under investigation. A fossil wood of *Hopea* belonging to Dipterocarpaceae has been identified by the author from the Miocene sediments of Bhavnagar coast. It is an important component of evergreen to semi-evergreen forests. The occurrence of *Hopea* indicates that there was luxuriant forest around Bhavnagar supported by plenty of rainfall during Miocene. This kind of forest no longer exists in the area thereby indicating considerable change in the climatic conditions since Miocene. Detailed investigations of the assemblage may further substantiate the above conclusions.

(ii) *Rajasthan (Jaisalmer and Bikaner basins)*—The Late Tertiary flora of Rajasthan has a great bearing on the advent of desertic conditions. The author has under taken extensive study of Late Tertiary fossils from western part of Rajasthan. He has reported the occurrence of a number of plant fossils in a series of communications (Guleria, 1984b, 1986, 1990a, b, 1991, 1992). The flora as known today exclusively consists of petrified woods and is represented by about 25 genera (see Table 2). Except for two gymnosperms, *Araucaria-Agathis* and *Podocarpus* all other fossils are dicot genera. A fossil wood (*Araucarioxylon bikanerense*) said to be belonging to the Eocene has been described by Harsh and Sharma (1988) from Bikaner. It has already been pointed out (Guleria, 1990a) that this wood belongs to Pliocene rather than Eocene. The dicot recorded are: *Afzelia-Intsia, Anisoptera,*

Table 2—Neogene megafossils of Rajasthan (Jaisalmer and Bikaner basins)

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/SERIES
Araucariaceae	*Araucaria-Agathis* Guleria 1986	*Araucaria-Agathis*	Shumar Formation (probably Pliocene)
	Araucarioxylon bikanerense Harsh & Sharma 1988	*Araucaria-Agathis*	Mar Formation (probably Pliocene)
Podocarpaceae	*Podocarpus* Guleria 1986	*Podocarpus* L'.Herit ex. Pers.	Shumar Formation (probably Pliocene)
Dipterocarpaceae	*Dipterocarpus* Guleria 1986	*Dipterocarpus* Gaertn. f.	Shumar Formation (probably Pliocene)
	Anisoptera (Ms)	*Anisoptera* Korth.	Shumar Formation (probably Pliocene)
Sterculiaceae	*Sterculia* Guleria 1986	*Sterculia* Linn.	Shumar Formation (probably Pliocene)
Meliaceae	*Entandrophragma* Guleria 1990b	*Entandrophragma* C.DC	Shumar Formation (probably Pliocene)
	Khaya Guleria 1990b	*Khaya* A. Juss	Shumar Formation (probably Pliocene)
Rhamnaceae	*Ziziphus oxyphylla* Guleria 1992	*Ziziphus oxyphylla* Edgw.	Mar Formation (probably Pliocene)
Anacardiaceae	*Mangiferoxylon assamicum* Prakash & Tripathi; Guleria 1984b	*Mangifera sylvatica* Roxb. *M. indica* Linn.	Shumar Formation (probably Pliocene)
Fabaceae	*Afzelia-Intsia* Guleria 1986	*Afzelia-Intsia*	Shumar Formation (probably Pliocene)
	Baphia Guleria 1990b	*Baphia* Afzel.	Shumar Formation (probably Pliocene)
	Bauhinia Guleria 1986	*Bauhinia* Linn.	Shumar Formation (probably Pliocene)
	Copaifera-Detarium-Sindora Guleria 1986	*Copaifera-Detarium-Sindora*	Shumar Formation (probably Pliocene)
	Cynometra Guleria 1986	*Cynometra* Linn.	Shumar Formation (probably Pliocene)
	Erythrophleum Guleria 1990b	*Erythrophleum* Afzel-ex G. Don	Shumar Formation (probably Pliocene)
	Millettia-Pongamia Guleria 1986	*Millettia-Pongamia*	Shumar Formation (probably Pliocene)
	Ormosia Guleria 1986	*Ormosia* G. Jacks	Shumar Formation (probably Pliocene)
	Pterocarpus Guleria 1986	*Pterocarpus* Jacq.	Shumar Formation (probably Pliocene)
	Tetrapleura Guleria 1990b	*Tetrapleura* Benth.	Shumar Formation (probably Pliocene)
	Dialiumoxylon indicum Guleria 1990a	*Dialium travancoricum* Bourd.	Mar Formation (probably Pliocene)
	Ougeinioxylon tertiarum Guleria 1990a	*Ougeinia oojeinensis* (Roxb.) Hocht.	Mar Formation (probably Pliocene)
Combretaceae	*Terminalia* Guleria 1986	*Terminalia* Linn.	Shumar Formation (probably Pliocene)
Lythraceae	*Lagerstroemia* Guleria 1986	*Lagerstroemia* Linn.	Mar Formation (probably Pliocene)
	Lagerstroemioxylon eoflosreginum Prakash & Tripathi; Guleria 1990a	*Lagerstroemia speciosa* Pers.	Mar Formation (probably Pliocene)
	L. parenchymatosum Prakash; Guleria 1990a	*L. parviflora* Roxb.	Mar Formation (probably Pliocene)
Boraginaceae (Ehretiaceae)	*Cordia* Guleria 1986	*Cordia* Linn.	Shumar Formation (probably Pliocene)

Baphia, Bauhinia, Dialium, Dipterocarpus, Copaifera-Detarium-Sindora, Cordia, Cynometra, Entandrophragma, Erythrophleum, Khaya, Lagerstroemia, Mangifera, Millettia-Pongamia, Ormosia, Ougeinia, Pterocarpus, Sterculia, Terminalia, Tetrapleura and *Ziziphus.* The occurrence of member of evergreen forests such as *Araucaria-Agathis, Podocarpus, Anisoptera* and *Dipterocarpus* indicates luxuriant vegetation and tropical humid climate. However, the numerical abundance of these genera in the assemblage is meagre. The majority of the genera being deciduous, they indicate a trend towards shift in the rainfall. This is further suported by the occurrence of African elements in Rajasthan. Nevertheless, the rainfall seems adequate for fairly thick forest cover during Pliocene in contrast to the desertic conditions encountered in the area today. The occurrence of typical African genera such as *Baphia, Entandrophragma, Erythrophleum, Khaya* and *Tetrapleura* are phytogeographically significant. They are primarily confined to tropical Africa and Madagascar. They indicate migration of plants from East Africa to western part of India. These elements, however, failed to move further into eastern or southern India as none of them have so far been recorded from other Neogene deposits of India. On the whole the above mentioned flora perished subsequently from the Jaisalmer and Bikaner region due to progressive increase in aridity. Obviously, the present desertic conditions in Rajasthan are the result of post-Pliocene climatic changes as also has been inferred in Kutch. The probable means of migration of African taxa are high velocity winds, birds and animals. The possible routes could be (i) Egypt to northern Arabia to Persia to Baluchistan and Sind to western India, (ii) Ethiopia to southern Arabia to Persia to Baluchistan and Sind to western India. The flora has a great bearing in dating the Shumar and Mar formations of Jaisalmer and Bikaner area as equivalent to Kankawati Series (Pliocene) of Kutch on account of very close floral similarity exhibited by them including the presence of tropical African elements (Guleria 1986, 1990a).

In addition to the fossils listed in Table 2, Trivedi (1959) reported six dicot leaf-impressions from the tufaceous limestone beds of Miocene age near Udaipur. She subsequently (1980) identified them as the leaves of *Ficus religiosa, F. carica* and *Psidium guava.* The presence of *Ficus* trees in the area are the result of protection provided to the trees owing to religious feelings of the natives. *Psidium guava* is an exotic plant belonging to Central America, cultivated and naturalised throughout India. Guava plant may have been planted around the limestone quarry office. Obviously, the reported leaves are infact, the imprints of recent leaves on tufaceous sediments, hence cannot be recorded as fossils of Miocene age. Thus these record should be totally discarded.

(iii) *Konkan flora*—The flora of this region is meagrely known (see Table 3) at present and comes from the lignitic beds of Ratnagiri District (Kulkarni & Phadtare, 1980; Dalvi & Kulkarni, 1982; Phadtare & Kulkarni, 1984; Shinde & Kulkarni, 1989). The fossils are in the form of compressions or mummified leaf remains and carbonised fruits. In terms of extant comparable genera the assemblage consists of *Alangium, Diospyros, Dracontomelum, Eugeissona, Garcinia, Nothopegia, Nypa* and *Nyssa* and ranges from deciduous to evergreen trees. The occurrence of *Nypa* indicates estuarine conditions which even now exist at Ratnagiri allowing the growth of mangroves. However, *Nypa* no longer occurs in the present day flora of Ratnagiri. *Garcinia, Diospyros, Nothopegia* are presently found in Western Ghats whereas *Nyssa* is confined to Sikkim, North Bengal and Assam extending further to Malayan region. *Eugeissona* and *Dracontomelum* are typical tropical Malaysian genera. Of the two, *Dracontomelum* is found in the Andaman and Nicobar Islands in damp places along streams and rivers. The overall assemblage indicates a warm humid palaeoclimate.

(iv) *Kerala Coast flora (Kerala-Lakshadweep Basin)*—The sedimentary rocks along the Kerala Coast, classified as Warkalli beds or Varkala beds overlying the Quilon beds contain rich deposits of carbonised woods. According to Poulose and Narayanaswamy (1968) the age of Warkalli beds is Late Miocene or Miocene-Pliocene and the beds are considered equivalent to the Cuddalore Sandstones. The flora of Neogene deposits of Kerala Coast is better known than the Konkan flora and is entirely based on carbonised woods. So far twenty genera belonging to 15 families have been reported (Table 4) by Awasthi and Ahuja (1982), Awasthi and Panjwani (1984), Awasthi and Srivastava (1989, 1990, 1992) from the Warkalli beds of Varkala, Payangadi and Padappakara. The extant comparable taxa reported are: *Anisophyllea, Anisoptera, Calophyllum, Canarium, Careya, Cassia, Cynometra, Diospyros-Maba, Dryobalanops, Fagara-Acronychia, Gluta, Gonystylus, Hopea, Hydnocarpus, Leea, Litsea-Cinnamomum, Payena-Palaquium, Shorea, Swintonia* and *Terminalia.* Most of the genera are important elements of tropical evergreen forests and are found in the present day flora of Western Ghats thus indicating the existence of nearly similar climatic conditions. The occurrence of *Anisoptera,*

Table 3—Neogene megafossils of Konkan area

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/SERIES
Arecaceae	*Eugeissonocarpon indicum* Shinde & Kulkarni 1989	*Eugeissona* Griff.	Lignite beds of Ratnagiri District (age—Miocene)
Nypaceae	*Nypa fruticans* Kulkarni & Phadtare 1980	*Nypa fruticans* Wurmb	Lignite beds of Ratnagiri District (age—Miocene)
Clusiaceae	*Garcinia indica* Dalvi & Kulkarni 1982	*Garcinia indica* Choiss	Lignite beds of Ratnagiri District (age—Miocene)
Anacardiaceae	*Nothopegia* Dalvi & Kulkarni 1982	*Nothopegia colebrookiana* Blume	Lignite beds of Ratnagiri District (age—Miocene)
	Dracontomelumoxylon mangiferumoides Ghosh & Roy; Phadtare & Kulkarni 1984	*Dracontomelum mangiferum*	Lignite beds of Ratnagiri District (age—Miocene)
	Anacardioxylon ratnagiriense Phadtare & Kulkarni 1984	? *Gluta* Linn.	Lignite beds of Ratnagiri District (age—Miocene)
Alangiaceae	*Alangium* Dalvi & Kulkarni 1982	*Alangium salvifolium* Wang	Lignite beds of Ratnagiri District (age—Miocene)
Ebenaceae	*Diospyros microphylla* Dalvi & Kulkarni 1982	*Diospyros microphylla* Bedd.	Lignite beds of Ratnagiri District (age—Miocene)
Nyssaceae	*Nyssa brandoniana* Shinde & Kulkarni 1989	*Nyssa* Gronov. ex. L.	Lignite beds of Ratnagiri District (age—Miocene)

Dryobalanops, Gonystylus and *Swintonia* which are rain forest trees further suggests that high rainfall and excessive humid conditions at the time of deposition. However, their total absence in the present day flora of Western Ghats or Kerala Coast probably indicates a shift in the amount of precipitation in the Western Ghats since Neogene.

2. East Coast Neogene floras

(i) *Rajahmundry flora (Krishna-Godavari Basin)*—A few plant fossils have been reported from the Rajahmundry Sandstones of Godavari Basin in Andhra Pradesh. The Rajahmundry Sandstones overlie unconformably, the Deccan Trap sediments and have been considered to be equivalent to the Cuddalore Sandstones of South Arcot District, Tamil Nadu (King, 1880; Pascoe, 1963; Krishnan, 1960). On the basis of their deposition over the Deccan Traps, the age of Rajahmundry Sandstones has been given as Middle Eocene by King (1880), Miocene-Pliocene by Krishnan (1960) and Miocene? by Rao & Raju (1968). Most of the fossils said to be belonging to the Rajahmundry Sandstones have been reported by Mahabale and his associates (see Table 5) who consider the age of the sandstones as Oligo-Miocene. In addition, dicotyledonous leaves have been reported by Ramanujam and Rao (1967b), and Verma and Mathur (1968). However, the occurrence of typical Gondwanic taxa like *Dadoxylon* cf. *barakarense, Dadoxylon* cf. *jamudhiense, Mesembrioxylon rajmahalense, Polyloboxylon raniganjense, Ginkgo* and intertrappean species like *Mesembrioxylon* sp. cf. *M. dudukurense, Cocos nucifera* (leaf) together with dicotyledonous leaf impressions gives a very confusing picture. The composition of the flora seems to be most unlikely of Oligo-Miocene age. The possibility of reworking of fossils from the older horizons and their mixing with the Intertrappean fossils cannot be ruled out since the Gondwana and Intertrappean sediments are closely associated with the Rajahmundry Sandstones in the area. The occurrence of *Terminalia* which ranges from Eocene onwards in India (Lakhanpal & Guleria, 1981; Guleria, 1991) does not help much in fixing the age of Rajahmundry Sandstones. The generic affinity of dicotyledonous leaf-impressions recovered from the Rajahmundry Sandstones (Ramanujam & Rao, 1967b; Verma & Mathur, 1968; Mahabale & Rao, 1973) has not been ascertained. Thus in view of the available fossil records known so far and in the absence of any index fossil of Neogene the Rajahmundry flora cannot be regarded as belonging to Miocene or Neogene. A detailed exploration and critical investigation of the fossils of Rajahmundry sandstones may provide us evidence in deciphering its age. Till such time the question of exact age of the Rajahmundry sandstones may be kept open.

(ii) *Cuddalore Series flora (Cauvery Basin)*—The Cuddalore flora of South Arcot District, Tamil Nadu is one of the best investigated Neogene floras of India and consists almost exclusively of petrified woods. Occurrence of these woods are known since long (Sonnerat, 1782). The flora has been extensively reviewed by Ramanujam (1968), Lakhanpal (1970, 1973) and Awasthi (1974b). The

Table 4—Neogene megafossils of Kerala Coast (Kerala-Lakshadweep Basin)

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/BEDS
Clusiaceae	*Calophylloxylon* sp. Awasthi & Ahuja 1982	*Calophyllum* L.	Warkalli beds
Dipterocarpaceae	*Dryobalanoxylon keralaensis* Awasthi & Ahuja 1982	*Dryobalanops* Gaertn. f.	Warkalli beds
	Anisopteroxylon varkalaensis Awasthi & Srivastava 1990	*Anisoptera polyandra* Bl.	Warkalli beds
	Hopenium payangadiensis Awasthi & Srivastava 1990	*Hopea parviflora* Bedd.	Warkalli beds
	Shoreoxylon arcotense Awasthi; Awasthi & Srivastava 1992	*Shorea acuminata* Dyer	Warkalli beds
Ampelidaceae	*Leeoxylon cannanorense* Awasthi & Panjwani 1984	*Leea angulata* Korth. *L. philippinensis* Merill	Warkalli beds
Anacardiaceae	*Swintonioxylon tertiarum* Awasthi & Ahuja 1982	*Swintonia foxworthyi* Elmer	Warkalli beds
	Glutoxylon burmense (Hold) Chowdhury; Awasthi & Panjwani 1984	*Gluta* Linn.	Warkalli beds
Fabaceae	*Cynometroxylon holdenii* (Gupta) Prakash & Bande; Awasthi & Ahuja 1982	*Cynometra* Linn.	Warkalli beds
	Cassinium prefistulai Prakash; Awasthi & Srivastava 1992	*Cassia fistula* Linn.	Warkalli beds
Combretaceae	*Terminalioxylon varkalaensis* Awasthi & Ahuja 1982	*Terminalia chebula* Retz. *T. travancorensis* W & A	Warkalli beds
Ebenaceae	*Ebenoxylon obliquiporosum* Awasthi & Ahuja 1982	*Diospyros-Maba*	Warkalli beds
Lauraceae	*Laurinoxylon varkalaensis* Awasthi & Ahuja 1982	*Litsea-Cinnamomum*	Warkalli beds
Tymelaceae	*Gonystyloxylon indicum* Awasthi & Panjwani 1984	*Gonystylus* spp.	Warkalli beds
	G. tertiarum Awasthi & Panjwani 1984	*Gonystylus macrophyllus* (Miq.) Airy Shaw *Gonystylus* sp.	Warkalli beds
Burseraceae	*Canarium palaeoluzonicum* Awasthi & Srivastava 1989	*Canarium luzonicum* (Bl.) A Gray	Warkalli beds
Flacourtiaceae	*Hydnocarpoxylon keralaensis* Awasthi & Srivastava 1990	*Hydnocarpus sumatrana* Koorders	Warkalli beds
Sapotaceae	*Sapotoxylon prepayena* Awasthi & Srivastava 1990	*Payena-Palaquium*	Warkalli beds
Rutaceae	*Fagaroxylon acronychioides* Awasthi & Srivastava 1992	*Fagara-Acronychia*	Warkalli beds
Rhizophoraceae	*Carallioxylon indicum* Awasthi; Awasthi & Srivastava 1992	*Anisophyllea* R. Br.	Warkalli beds
	C. miocenicum Awasthi & Srivastava 1992	*Anisophyllea* R. Br.	Warkalli beds
Lecythidaceae	*Careyoxylon pondicherriense* Awasthi; Awasthi & Srivastava 1992	*Careya arborea* Roxb.	Warkalli beds

flora consists of about 78 species belonging to 48 genera (see Table 7). The flora is predominently angiospermous and dominated by dicots. Monocots are represented by only 3 species of palms. Although gymnosperms are particularly abundant at a few localities yet they are only represented by 6 species, five of them belong to a single genus of Podocarpaceae and one to Taxodiaceae. However, the affinities of *Taxodioxylon cuddalorense* with Taxodiaceae have been doubted by Ramanujam (1976, p. 105). .The occurrence of evergreen moisture loving elements such as *Anisoptera, Dipterocarpus, Dryobalanops, Hopea, Calophyllum, Mesua, Gluta, Cynometra, Afzelia-Intsia, Alangium, Duabanga, Sonneratia*, and *Podocarpus* along with other deciduous trees suggest the existence of

Table 5—?Oligo-Miocene megaflora of Rajahmundry area (Krishna-Godavari Basin)

	FOSSIL TAXA	LOCALITY
Gymnosperms	*Dadoxylon* sp. cf. *D. barakarense* Surange & Saxena; Mahabale & Satyanaryana 1978a	Pangidi, West Godavari District
	Dadoxylon sp. cf. *D. jamudhiense* Maheshwari; Mahabale & Satyanaryana 1978a	Rajahmundry, East Godavari District
	Mesembrioxylon rajmahalense Jain; Mahabale & Satyanaryana 1978a	Pangidi, West Godavari District
	Mesembrioxylon sp. cf. *M. dudukurense* Mahabale & Rao; Mahabale & Satyanaryana 1978a	Rajahmundry, East Godavari District
	Ginkgo dixitii Mahabale & Satyanaryana 1978b	Pangidi, West Godavari District
	Polyloboxylon raniganjense Kräusel *et al.*; Mahabale & Rao 1973	Rajahmundry, East Godavari District
Angiosperms	*Phyllites* spp. 1-4; a seed-like organ Ramanujam & Rao 1967b	1.5 miles east of Tyajampudi, West Godavari District
	Dicotylophyllum sp. 1-4 Verma & Mathur 1968	About 1.5 km south of Pangidi, West Godavari District
	Dicot and monocot leaf-impressions Mahabale & Rao 1973	Bommuru, East Godavari District
	Terminalioxylon ghoshii Satyanaryana & Mahabale 1984	Pangidi, West Godavari District
	Palm leaves Leaf-impression cf. *Cocos nucifera*	Pangidi, West Godavari District
	Palm fruit cf. *Cocos plumosa* *C. coronata* Mahabale & Rao 1968	Pangidi, West Godavari District

Table 6—Neogene megafossils of Neyveli lignite (Cauvery Basin)

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/SERIES
Arecaceae	Wood Navale, 1973, 1974a Compressed bark/leaf sheath	Palm	Neyveli lignite (Miocene)
	Shoot with crown of leafy bracts/leaves Chatterjee & Bhattacharya 1965	Palm	Neyveli lignite (Miocene)
	Phoenix Upadhyay & Verma 1986	*Phoenix* L.	Neyveli lignite (Miocene)
Agavaceae	*Dracaena* Ambwani 1982	*Dracaena* Wand. ex. L.	Neyveli lignite (Miocene)
Poaceae	Cuticle Navale 1973, 1974a	—	Neyveli lignite (Miocene)
Clusiaceae	*Calophyllum/Mesua* Navale 1973, 1974a	*Calophyllum/Mesua*	Neyveli lignite (Miocene)
Dipterocarpaceae	*Dipterocarpus* Navale 1973, 1974a	*Dipterocarpus* Gaertn. f.	Neyveli lignite (Miocene)
	Hopenium neyveliensis Awasthi 1984	*Hopea plagata* Vidal	Neyveli lignite (Miocene)
	Shorea Verma *et al.* 1989	*Shorea robusta* Gaertn. f.	Neyveli lignite (Miocene)
Sterculiaceae	**Sterculioxylon* sp. Reddy 1989	*Sterculia* Linn.	Neyveli lignite (Miocene)
Tiliaceae	*Grewioxylon microcoides* Agarwal 1991a	*Grewia microcos* Linn.	Neyveli lignite (Miocene)
Anacardiaceae	*Glutoxylon burmense* (Holden) Chowdhury; Awasthi 1984	*Gluta* Linn.	Neyveli lignite (Miocene)
	Bouea neyveliensis Agarwal 1989	*Bouea burmanica* Griff.	Neyveli lignite (Miocene)
Fabaceae	*Cassia/Acacia* Navale 1973, 1974a	*Cassia/Acacia*	Neyveli lignite (Miocene)
	Bauhinia deomalica Awasthi & Prakash; Agarwal 1991b	*Bauhinia foveolata* Dalz. *B. malabarica* Roxb. *B. racemosa* Lam. *B. retusa* Ham.	Neyveli lignite (Miocene)
Rosaceae	*Parinarioxylon neyveliensis* Awasthi & Agarwal 1986	*Parinari indicum* Bedd. *P. travancoricum* Bedd.	Neyveli lignite (Miocene)
Hamamelidaceae	+*Altingia rhodoleioides* Kramer; Agarwal 1991b	*Altingia excelsa* Noronha	Neyveli lignite (Miocene)
Rhizophoraceae	*Carallioxylon indicum* Awasthi 1984	*Carallia lucida (= C. brachiata)*	Neyveli lignite (Miocene)

Contd.

Table 6—Contd.

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/SERIES
Combretaceae	*Terminalia* Navale 1973, 1974a	*Terminalia* Linn.	Neyveli lignite (Miocene)
Lythraceae	*Lagerstroemia* Verma *et al.* 1989	*Lagerstroemia indicum* Linn.	Neyveli lignite (Miocene)
Lecythidaceae (Barringtoniaceae)	*Careyoxylon pondicherriense* Awasthi; Agarwal 1990	*Careya* Roxb.	Neyveli lignite (Miocene)
Rubiaceae	*Randia neyveliensis* Agarwal 1990	*Randia uliginosa* Retz.	Neyveli lignite (Miocene)
Sapotaceae	Wood cf. Sapotaceae Lakshmanan & Levy 1956	Probably Sapotaceae	Neyveli lignite (Miocene)
	Bassia/Mimusops Navale 1973	*Bassia-Mimusops*	Neyveli lignite (Miocene)
Ebenaceae	*Diospyros-Maba* Navale 1968a	*Diospyros-Maba*	Neyveli lignite (Miocene)
	Ebenoxylon arcotense Awasthi 1984	*Diospyros-Maba* *D. assimilis* Bedd.	Neyveli lignite (Miocene)
Apocynaceae	+*Malodinus japonicus* Tanai; Agarwal 1990	*Melodinus monogynus* Roxb.	Neyveli lignite (Miocene)
Asclepiadaceae	*Cryptostegia* Verma *et al.* 1989	*Cryptostegia grandiflora* R. Br.	Neyveli lignite (Miocene)
Boraginaceae	*Cordioxylon multiseriatum* Awasthi 1984	*Cordia myxa* Linn.	Neyveli lignite (Miocene)
Lauraceae	*Litsea* Srivastava 1984	*Litsea* Lam.	Neyveli lignite (Miocene)
Euphorbiaceae	Wood cf. Phyllanthoidae group Navale 1973, 1974a	—	Neyveli lignite (Miocene)
	Excoecaria preagallocha Agarwal 1990	*Excoecaria agallocha* Linn.	

+Need confirmation.

*It should be treated as *Sterculinium* sp. (see Guleria, 1983).

Table 7—Neogene megafossils of Cuddalore Series near Pondicherry (Cauvery Basin)

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA
Gymnosperms		
Podocarpaceae	*Podocarpoxylon schmidianum* (Sahni) Krausel 1949 Syn. *Mesembrioxylon schmidianum* Sahni 1931	*Podocarpus* L'Herit ex. Pers.
	P. tiruvakkarainum (Ramanujam) Trivedi & Srivastava 1990	*Podocarpus* L'Herit ex. Pers.
	Syn. *Mesembrioxylon tiruvakkarainum* Ramanujam 1953b	*Podocarpus* L'Herit ex. Pers.
	P. sahnii (Ramanujam) Trivedi & Srivastava 1990 Syn. *Mesembrioxylon sahnii* Ramanujam 1953b	*Podocarpus* L'Herit ex. Pers.
	P. speciosum (Ramanujam) Trivedi & Srivastava 1990 Syn. *Mesembrioxylon speciosum* Ramanujam 1954	*Podocarpus* L'Herit ex. Pers.
	P. mahabalei (Agashe) Trivedi & Srivastava 1990 Syn. *Mesembrioxylon mahabalaei* Agashe 1969	*Podocarpus* L'Herit ex. Pers.
?Taxodiaceae	*Taxodioxylon cuddalorense* Ramanujam 1960	?
Angiosperms		
Arecaceae/Palmae	*Palmoxylon pondicherriense* Sahni 1931, 1964	Palms
	P. arcotense Ramanujam 1953a	*Livistona* R. Br.
	P. puratanum Ramanujam 1958	Palms
Polygalaceae	*Xanthophyllum cuddalorense* Awasthi 1986	*Xanthophyllum flavescens* Roxb.
Guttiferae/Clusiaceae	*Calophylloxylon indicum* Lakhanpal & Awasthi 1965	*Calophyllum wightianum* Wall.
	C. cuddalorense Lakhanpal & Awasthi 1965	*C. inophyllum* L. *C. tomentosa* Wight
	Mesuoxylon arcotense Lakhanpal & Awasthi 1964	*Mesua ferrea* L.
Dipterocarpaceae	*Dipterocarpoxylon pondicherriense* Awasthi 1974a	*Dipterocarpus indicus* Bedd.
	Dipterocarpoxylon arcotense Awasthi 1980	*Dipterocarpus tuberculatus* Roxb.
	Dryobalanoxylon indicum (Ramanujam) Awasthi 1971 Syn. *Dipterocarpoxylon indicum* Ramanujam 1956a	*Dryobalanops oblongifolia* Dyer
	Dryobalanoxylon holdeni (Ramanujam) Awasthi 1971 Syn. *Shoreoxylon holdeni* Ramanujam 1956a	*Dryobalanops* Gaertn. f.
	S. mortandranse Ramanujam 1956a	
	S. megaporosum Ramanujam 1960	

Contd.

Table 7—Contd.

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA
	Anisopteroxylon cuddalorense Ramanujam 1960	
	**Anisopteroxylon coromandalense* Navale 1963b	*Anisoptera* ?
	Shoreoxylon kraeuseli Ramanujam & Rao 1967a, 1969	*Shorea* Roxb. ex Gaertn.
	**S. speciosum* Navale 1963b	*Shorea* ?
	S. indicum Awasthi 1974a	*Shorea, Parashorea* and *Pentacme*
	S. arcotense Awasthi 1974a	*Shorea* spp.
	**Hopeoxylon indicum* Navale 1963b	*Hopea* ?
	Hopenium pondicherriense Awasthi 1980	*Hopea* spp.
Sterculiaceae	*Sterculinium pondicherriense* (Awasthi) Guleria 1983	
	Syn.	
	Sterculioxylon pondicherriense Awasthi 1981	*Sterculia-Firmiana*
Simaroubaceae	*Ailanthoxylon indicum* Prakash; Awasthi 1975b	*Ailanthus* Desf.
	Syn.	
	+*A. scantiporosum* Ramanujam 1960	
	+*A. pondicherriense* Navale 1964c	
	+*Guttiferoxylon indicum* Ramanujam 1960	
	+*Celastrinoxylon dakshinense* Ramanujam 1960	
Sapindaceae	**Sapindoxylon indicum* Navale 1957	Sapindaceae ?
	Euphorioxylon indicum Awasthi *et al.* 1982	*Euphoria longana* Lamk.
Anacardiaceae	*Mangiferoxylon scleroticum* Awasthi 1966	*Mangifera altissima* Blanco
	Glutoxylon cuddalorense Awasthi 1966	*Gluta* Linn.
	G. burmense (Hold) Chowdhury; Awasthi 1966	*Gluta* Linn.
	**Anacardioxylon mangiferoides* Ramanujam, 1960	Anacardiaceae ?
Leguminosae	*Millettioxylon indicum* Awasthi 1967, 1975a	*Millettia pendula-Pongamia glabra*
	Erythrophloeoxylon feistmanteli (Ramanujam) Muller-Stoll & Mädel, 1967	?*Erythrophloem* and allied genera
	syn.	
	Caesalpinioxylon feistmanteli Ramanujam 1960	
	**Pterogynoxylon felexii* (Navale) Müller-Stoll Madel 1967	?*Pterogyne* and allied genera
	Syn.	
	Caesalpinioxylon felexii Navale 1963a	
	**Pterocarpoxylon arcotense* Ramanujam 1960; Awasthi 1992	*Pterocarpus*
	Peltophoroxylon indicum (Ramanujam) Müller-Stoll & Mädel 1967	*Peltophorum* and allied genera
	Syn.	
	Acacioxylon indicum Ramanujam 1954	
	P. variegatum (Ramanujam) Müller-Stoll & Mädel 1967	?*Peltophorum* and allied genera
	Syn.	
	Cassioxylon variegatum Ramanujam 1960	
	Cynometroxylon dakshinense Navale 1959	?*Cynometra* Linn.
	C. indicum Chowdhury & Ghosh; Ramanujam & Rao 1966a	*Cynometra* Linn.
	Tamarindoxylon antiquum Ramanujam 1961	?*Tamarindus* Linn.
	**Pahudioxylon arcotense* Navale 1963a	*Afzelia* and *Intsia*?
	P. sahnii Ghosh & Kazmi; Awasthi 1975b	*Afzelia-Intsia*
	Syn.	
	Albizzioxylon sahnii Ramanujam 1960	
	Ingoxylon sahnii (Ramanujam) Müller-Stoll & Mädel 1967	
	Cf. *Bauhinia* Ramanujam & Rao 1966b	*Bauhinia* Linn.
	Euacacioxylon bharadwajii (Navale) Müller Stoll & Mädel 1967; Awasthi 1975b	*Acacia* Mill.
	Syn.	
	Acacioxylon bharadwajii Navale 1963a	
	Dalbergioxylon antiquum Ramanujam 1960	

Contd.

Table 7—Contd.

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA
	Hopeoxylon indicum (Navale) Awasthi 1977b	*Sindora* Miq.
		Sindora supa Merr.
		S. siamensis Teysm. ex Miq.
		S. velutina Baker
	H. speciosum (Navale) Awasthi 1977b; Prakash, Mishra & Srivastava 1988	*S. siamensis* Teysm ex Miq.
	Syn.	
	Hopeoxylon arcotense Awasthi 1977b	
	Shoreoxylon speciosum Navale 1963b	
	Albizinium pondicherriensis Awasthi 1979	*Albizia amara* Boivin
	Cassinium arcotense Awasthi 1979	*Cassia javanica* Linn.
	Pericopsoxylon indicum Awasthi 1979	*Pericopsis mooniana* Thw.
Rosaceae	*Parinarioxylon cuddalorense* Awasthi 1969b	*Parinarium corymbosum* (Blume) Mignel
Combretaceae	*Terminalioxylon speciosum* Ramanujam 1956b	*Terminalia* Linn.
	T. felixii Ramanujam 1956b	*Terminalia* Linn.
	T. mortanderense Navale 1956	*Terminalia* Linn.
	T. sahnii Navale 1956	*Terminalia* Linn.
	T. grandiporosum Ramanujam 1966; Awasthi 1975b	*Terminalia* Linn.
	Syn.	
	Dipterocarpoxylon cuddalorense Navale 1963b	*Terminalia* Linn.
	T. coromandelinum Ramanujam 1966	*Terminalia* Linn.
	T. traumaticum Ramanujam 1966	*Terminalia* Linn.
	Anogeissusoxylon indicum Navale 1964b	*Anogeissus* Wall ex Guillem & Perr.
Barringtoniaceae (Lecythidaceae)	*Barringtonioxylon arcotense* Awasthi 1970a	*Barringtonia angusta* Kurz.
	Careyoxylon pondicherriense Awasthi 1970a	*Careya arborea* Roxb.
Lythraceae	*Lagerstroemioxylon arcotense* Awasthi 1981b	*Lagerstroemia flos-reginae* Retz.
		L. lanceolata Wall.
Sonneratiaceae	**Sonneratioxylon dakshinense* Ramanujam 1957	*Sonneratia* ?
	Sonneratioxylon preapetala Awasthi 1969a	*Sonneratia apetala* Ham.
	Duabangoxylon indicum (Navale) Awasthi 1981a	*Duabanga grandiflora* (Roxb. ex DC) Walp.
	Syn.	
	Sapindoxylon indicum Navale 1957	*D. moluccana* Bl.
Sapotaceae	*Chrysophylloxylon pondicherriense* Awasthi 1977a	*Chrysophyllum roxburghii* Linn.
Ebenaceae	*Ebenoxylon arcotense* Awasthi 1970b	*Diospyros—Maba*
		Diospyros assimilis Bedd.
Alangiaceae	*Alangioxylon sclariforme* Awasthi 1969c	*Alangium javanicum*
		A. meyeri
Euphorbiaceae	*Putranjivoxylon puratanum* Ramanujam 1956c	*Putranjiva* wall.
	†**Bridelioxylon cuddalorense* Ramanujam 1956c	*Bridelia* ?
	†**B. miocenicum* (Ramanujam) Madel 1962	*Bridelia* ?
	Syn.	
	Bischofioxylon miocenicum Ramanujam 1960	
	Paraphyllanthoxylon tertiarum (Ramanujam) Mädel 1962	Phyllanthoideae
	Syn.	
	Glochidioxylon tertiarum Ramanujam 1956c	
	P. bangalamodense (Navale) Lakhanpal & Dayal 1964	Phyllanthoideae
	Syn.	
	Phyllanthinium bangalamodense Navale 1962	
Ulmaceae	*Holopteleoxylon indicum* Awasthi 1977a	*Holoptelea integrifolia* Planch.
	Erythrophloexoxylon sitholeyi (Ramanujam) Müller-Stoll & Mädel 1967; Awasthi 1992	*Holoptelea*
	Syn.	
	Caesalpinioxylon sitholeyi Ramanujam 1954	
Fagaceae	**Castanoxylon indicum* Navale 1964a	*Castanopsis* ?
	**C. tertiarum* Navale 1964a	*Castanopsis* ?

*Species marked (*) need re-investigation (see Awasthi, 1974b, 1992).

+Occurrence doubtful in the Cuddalore Series (see Awasthi, 1974b, 1975b).

Table 8—Neogene megafossils of peninsular North-east (Assam-Arakan Basin)

FAMILY	FOSSIL TAXA	MODERN TAXA	COMPARABLE LOCALITY	HORIZON-FORMATION/ SERIES/BED
Flacourtiaceae	*Homalioxylon assamicum* Prakash & Tripathi 1974	*Homalium tomentosum* Benth.	Kuchila near Hailakandi, Cachar District, Assam	Tipam Sandstone (Miocene)
Clusiaceae	*Kayeoxylon assamicum* Chowdhury & Tandon 1949	*Kayea assamica* Prain	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
	Calophylloxylon eoinophyllum Prakash 1966a; Prakash & Awasthi 1970; Prakash & Awasthi 1971	*Calophyllum inophyllum* Linn.	Namsang River Bed Deomali, Arunachal Pradesh, Buri-Dehing River Bed near Jaipur, Assam	Probably Tipam Sandstone Dupitila Series (Miocene-Pliocene)
Dipterocarpaceae	*Dipterocarpoxylon chowdhurii* Ghosh 1956	*Dipterocarpus* Gaertn. f.	Buri-Dehing River between Nahorkatiya and Margherita.	Probably Tipam Series
	D. kalaicharparense Eyde 1963	*Dipterocarpus* Gaertn. f.	Kalaicharpara Hills in Garo Hills, Assam	Mid-Tertiary
	Anisopteroxylon garoense (Chowdhury) Prakash & Tripathi 1970b	*Anisoptera scaphula* Pierre *A. oblonga* Dyer	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
	Shoreoxylon tipamense Prakash & Awasthi 1970	*Shorea assamica* Dyer	Buri-Dehing River Bed, Jaipur, Assam	Tipam Series
	S. deomaliense Prakash & Awasthi 1971	*Shorea* Roxb. ex. Gaertn.	Namsang River Bed near Deomali, NEFA	Namsang beds Dupitila Series
	S. evidens Eyde 1963	*Shorea* Roxb. ex. Gaertn.	Sonamati near Garo badha, Garo Hills, Assam	Mid-Tertiary
Celastraceae	*Gymnosporioxylon palaeomarginatum* Lalitha & Prakash, 1984	*Gymnosporia emarginata*	Sultanicherra, cachar District, Assam	Tipam Sandstone (Upper Miocene)
Sterculiaceae	*Sterculinium dattai* (Prakash & Tripathi) Guleria 1983 Syn. *Sterculioxylon dattai* Prakash & Tripathi 1974	*Sterculia villosa* Roxb.	Sultanicherra, Hailakandi, Cachar District, Assam	Tipam Sandstone
	S. varmahii (Lakhanpal, Prakash & Awasthi) Gurleria 1983 Syn. *Sterculioxylon varmahii* Lakhanpal *et al.* 1981	*S. alata* Roxb.	Namsang River Bed near Deomali, Arunachal Pradesh	Namsang beds, Dupitila Series
	Heritieroxylon arunachalensis Lakhanpal *et al.* 1981	*Heritiera fomes* Buch	Namsang River Bed near Deomali Arunachal Pradesh	Namsang beds, Duptilia Series
Elaeocarpaceae	*Elaeocarpoxylon hailakandiense* Prakash & Tripathi 1975	*Elaeocarpus-Echinocarpus*	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
Burseraceae	*Burseroxylon preserratum* Prakash & Tripathi 1975	*Bursera serrata* Wall. ex. Coleb.	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
	B. garugoides Lakhanpal *et al.* 1981	*Garuga pinnata* Roxb.	Namsang River Bed near Deomali Arunachal Pradesh	Namsang beds, Dupitila Series
Sapindaceae	*Pometioxylon tomentosum* Prakash & Tripathi 1970a	*Pometia tomentosa* Teysm et Binn.	Kartikcherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
Anacardiaceae	*Mangiferoxylon assamicum* Prakash & Tripathi 1970a; Lakhanpal *et al.*, 1981	*Mangifera indica* Linn.	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone

Contd.

Table 8—Contd.

FAMILY	FOSSIL TAXA	MODERN TAXA	COMPARABLE LOCALITY	HORIZON-FORMATION/ SERIES/BED
			Namsang River beds near Deomali, Arunachal Pradesh	Namsang beds, Dupitila Series
	Glutoxylon burmense (Holden) Chowdhury 1952; Ghosh & Taneja 1961; Prakash & Tripathi 1969b; Prakash & Awasthi 1971	*Gluta-Melanorrhoea*	Near Nailabung Rly. St., Cachar Hills; Rath Tila about 25 km from Hailakandi, Assam Buri Dehing River Bed near Jaipur, Assam	Tipam Series Tipam Sandstone
	Swintonia hailakandiense Prakash & Tripathi 1968, 1969a	*Swintonia floribunda* Griff.	Hailakandi, Cachar District, Assam	Tipam Series
	Lanneoxylon grandiosum Prakash & Tripathi 1967, 1969a	*Lannea grandis* Engler Syn. *Odina wodier* Roxb.	Road cutting at mile stone 9 on Dimapura-Diphu road in Mikir Hills, Assam	Tipam Series
	Holigarnoxylon assamicum Prakash & Awasthi 1970	*Holigarna beddomei* Hook. f.	Buri-Dehing River Bed Jaipur, Assam	Tipam Series
	Glutoxylon cacharense (Prakash & Tripathi) Guleria 1984b Syn. *Melanorrhoeoxylon cacharense* Prakash & Tripathi 1976	*Gluta*	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Series
	Anacardioxylon shardai Prakash & Tripathi 1976	—	Karitkcherra near Hailakandi, Cachar District, Assam	Tipam Series
Fabaceae (Leguminosae)	*Adenantheroxylon pavoninium* Prakash & Tripathi 1968, 1969a	*Adenanthera pavonina* Linn.	Hailakandi Cachar District, Assam	Tipam Series
	Cassinium prefistulai Prakash, Awasthi 1992 Syn. *C. cassioides* Prakash 1975 *Peltophoroxylon cassioides* Prakash & Awasthi 1970	*Cassia fistula* Linn.	Buri-Dehing River Bed near Jaipur, Assam	Tipam Series
	C. borooahi (Prakash 1966c; Prakash 1975		Mikir Hills, Assam	Tipam Sandstone
	C. tripuranum Acharya & Roy 1986	*Cassia* Linn.	Near Khowi bridge Teliamura, Tripura	Probably Tipam Sandstone
	Cynometroxylon holdeni (Gupta) Prakash & Bande 1980; Chowdhury & Ghosh 1946; Prakash 1966a; Prakash & Awasthi 1971; Prakash & Tripathi 1976	*Cynometra polyandra* Roxb. *C. ramiflora* Linn.	Sultanicherra near Hailakandi, Cachar District, Assam; Nailalung Rly. St. Assam	Tipam Sandstone
			Namsang River Bed near Deomali, NEFA	Namsang beds, Dupitila Series.
	Pahudioxylon assamicum Prakash & Tripathi 1975	*Afzelia-Intsia*	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
	P. sahnii Ghosh & Kazmi 1961; Prakash 1966a; Prakash & Awasthi 1971	*Afzelia-Intsia*	Khowai bridge at Teliamura, Tripura; Namsang River Bed Deomali, Arunachal Pradesh	Tipam Sandstone Dupitila Series

Contd.

Table 8—Contd.

FAMILY	FOSSIL TAXA	MODERN TAXA	COMPARABLE LOCALITY	HORIZON-FORMATION/ SERIES/BED
	P. deomaliense Prakash 1965	*Afzelia-Intsia*	Namsang River Bed Deomali, Arunachal Pradesh.	Dupitila Series
	Ougeinioxylon tertiarum Prakash & Tripathi 1977	*Ougeinia dalbergioides* Benth.	Sultanicherra near Hailakandi Cachar District, Assam	Tipam Sandstone
	Hopeoxylon assamicum Lalitha & Prakash 1980	*Sindora-Copaifera-Detarium*	Sultanicherra near Hailakandi Cachar District, Assam	Tipam Sandstone
	Albizinium eolebbekianum Prakash; Lakhanpal *et al.* 1981	*Albizia lebbek* Benth.	Namsang River Bed Near Deomali, Arunachal Pradesh	Namsang beds, Dupitila Series
	Millettioxylon palaeopulchera Lakhanpal *et al.* 1981	*Millettia pulchra* Kurz.	Namsang River Bed near Deomali, Arunachal Pradesh	Namsang beds, Dupitila Series
	M. bengalensis Ghosh & Roy; Acharya & Roy 1986	*M. pulchra* Kurz.	Near Khowai bridge Teliamura, Tripura	Probably Tipam Sandstone
	Kingiodendron prepinnatum Awasthi & Prakash 1987	*Kingiodendron pinnatum* Harms	Namsang beds along Namsang River at Deomali	Namsang beds (Mio-Pliocene)
	Bauhinia deomalica Awasthi & Prakash 1987	*Bauhinia foveolata* Dalz *B. racemosa* Lam.	Namsang beds along Namsang River at Deomali	Namsang beds (Mio-Pliocene)
	Bauhinia tertiara Awasthi & Mehrotra 1990	*B. racemosa* Lam.	Nagnimara Village Mon District, Nagaland	Tipam Series
	Koompassioxylon elegans Kramer; Awasthi & Mehrotra 1990	*Koompassia malaccensis* Benth.	Bimlapur, Dibrugarh District, Assam	Tipam Series
Combretaceae	*Terminalioxylon tertiarum* Prakash 1966a; Prakash & Awasthi 1970	*Terminalia tomentosa* Wight & Arn.	Namsang beds along Namsang River at Deomali, near Jaipur, Assam	Namsang beds (Mio-Pliocene) Tipam Series
	T. burmense (Prakash) Mädel-Angeliewa & Müller-Stoll, 1973 Syn. *Terminalia tomentosa* Prakash 1966b		Nagaland	
	T. coriaceum Prakash & Awasthi 1971	*T. coriacea* (Roxb.) W & A	Kartikcherra near Hailakandi; Namsang River Bed near Deomali, Assam	Dupitila Series Namsang beds
	Terminalioxylon chowdhurii Prakash & Navale 1963; Eyde 1963	*Terminalia* Linn.	Barail reserve, Cachar; Sanamati near Garobadha, Garo Hills, Assam	Mid-Tertiary
Barringtoniaceae (Lecythidaceae)	*Barringtonioxylon assamiam* Prakash & Tripathi 1972	*Barringtonia acutangula* (Linn.) Gaertn.	Kartikcherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
	Careyoxylon pondicherriense Awasthi & Srivastava 1992 Syn. *C. kuchilense* Prakash & Tripathi 1972	*Careya arborea* Roxb.	Kuchila near Hailakandi, Cachar District, Assam	Tipam Sandstone
Lythraceae	*Lagerstroemioxylon eoflosreginium* Prakash & Tripathi 1970a	*Lagerstroemia flos-reginae*	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone

Contd.

Table 8—Contd.

FAMILY	FOSSIL TAXA	MODERN TAXA	COMPARABLE LOCALITY	HORIZON-FORMATION/ SERIES/BED
	L. deomaliense Lakhanpal _et al._ 1981	_L. villosa_ Wall.	Namsang River Bed near Deomali, Arunachal Pradesh	Namsang beds, Dupitila Series
Sonneratiaceae	_Duabangoxylon tertiarum_ Prakash & Awasthi 1970	_Duabanga grandiflora_ Walp.	Buri-Dehing River Bed near Jaipur, Assam	Tipam Series
Sapotaceae	*_Madhucoxylon cacharense_ Prakash & Tripathi 1977	_Madhuca butyracea_ Roxb.	Sultanicherra near Hailakandi, Cachar District, Assam	Tipam Sandstone
	Siderinium deomaliense Prakash & Awasthi 1970	_?Sideroxylon grandifolium_ Wall.	Namsang River Bed near Deomali, NEFA	Namsang beds, Duplitila Series
Ebenaceae	_Ebenoxylon kartikcherraense_ Prakash & Tripathi 1970b	_Diospyros-Maba_ _Diospyros ebritioides_ Wall.	Kartikcherra near Hailakandi, Cachar District, Assam.	Tipam Sandstone
	*_E. indicum_ Ghosh & Kazmi 1958	_Diospyros-Maba_	Namsang River Bed, NEFA	Probably Dupitila Series
Verbenaceae	_Vitexoxylon miocenicum_ Prakash & Tripathi 1974	_Vitex canescens_ Kurz	Kartikcherra near Hailakandi, Cachar District, Assam.	Tipam Series
Lauraceae	_Laurinoxylon tertiarum_ Prakash & Tripathi 1974	_Dehassia-Cinnamomum_	Sultanicherra near Hailakandi, Cachar District, Assam.	Tipam Series
	L. namsangensis Lakhanpal _et al._ 1981	_Phoebe_ Nees.	Namsang River Bed near Deomali, Arunachal Pradesh	Namsang beds, Duplitila Series
	L. deomaliensis Lakhanpal _et al._ 1981	_Alseodaphne-Actinodaphne_	Namsang River Bed near Deomali, Arunachal Pradesh	Namsang beds, Dupitila Series
	L. naginimariense Awasthi & Mehrotra 1990	—	Nagnimara Village Mon District, Nagaland	Tipam Sandstone
Euphorbiaceae	_Mallotoxylon assamicum_ Prakash & Tripathi 1975	_Mallotus philippinensis_ Muell-Arg.	Sultanicherra near Hailakandi, Cachar District, Assam.	Tipam Sandstone
	Paraphyllanthoxylon palaeoemblica Prakash _et al._ 1986	_Phyllanthus emblica_ Linn.	Near Nailalung Railway Station, about 33 km from Lumding, Assam	Tipam Sandstone
Bischofiaceae	_Bischofia palaeojavanica_ Awasthi 1989; Awasthi & Mehrotra, 1990	_Bischofia javanica_ Bl.	Namsang River Bed Arunachal Pradesh; Nagnimara Village Mon District, Nagaland	Namsang beds; Tipam Series
Moraceae	_Artocarpoxylon kartikcherraensis_ Prakash & Lalitha 1978	_Artocarpus chaplasha_ Roxb. _A. incisa_ Linn.	Kartikcherra near Hailakandi, Cachar District, Assam	Tipam Series
	Antiaris deomaliensis Awasthi 1989	_Antiaris toxicaria_ Lesch.	Namsang River Bed, Deomali, Arunachal Pradesh	Namsang beds
	Dryoxylon sp. Chowdhury 1938	—	Garobadha, West of Tura, Garo Hills	Tipam Series
	Nipa salinii Lakhanpal 1952	_Nipa fruiticans_	Western extremity of Garo Hills	Upper Tertiary (Miocene)

*Species marked (*) need re-investigation.

luxuriant forest supported by high amount of precipitation during Mio-Pliocene. Most of these elements are presently confined to Western Ghats and Assam region. The absence of these elements in the present day flora of Cuddalore indicates distinct and drastic change in climate. Obviously the area has become drier since the Mio-Pliocene time. The flora is also phytogeographically significant as indicated by the occurrence of a number of Indo-Malayan taxa. The comparison of the flora with other known Neogene flora of India tends to suggest the age of Cuddalore Sandstone as Upper Miocene to Pliocene.

Table 9—Neogene megafossils of West Bengal (Bengal Basin) and Bihar

	FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/ SERIES AND LOCALITY
A) West Bengal				
GYMNOSPERMS	Araucariaceae	*Araucarioxylon* sp. Srivastava & Prakash 1984	*Araucaria-Agathis*	Tipam Series (=Miocene) Bolpur, Birbhum District
ANGIOSPERMS	Clusiaceae	*Calophylloxylon bengalense* Ghosh & Roy 1979e	*Calophyllum tomentosa* Wight *C. inophyllum* Linn.	Santiniketan near Bolpur, Birbhum District
		Kayea assamica Bande & Srivastava 1989	*Kayea assamica* King & Prain	Muhammad Bazar, Birbhum District
	Dipterocarpaceae	*Dipterocarpoxylon bolpurense* Ghosh & Roy 1979c	*Dipterocarpus* Gaertn. f.	Santiniketan, Birbhum District
		Shoreoxylon tipamense Prakash & Awasthi; Bande & Prakash 1980	*Shorea assamica* Dyer	Santiniketan, near Bolpur
		S. robustoides Roy & Ghosh 1981a	*S. robusta* Roxb.	Near Santiniketan, Birbhum District
		Anisopteroxylon santiniketanense Ghosh & Roy 1980b	*Anisoptera* Korth.	Santiniketan, near Birbhum District
		A. aduriensis Acharya & Roy 1989	*Anisoptera* Korth.	Aduria forest, Burdwan District
	Burseraceae	*Canarioxylon indicum* Ghosh & Roy 1978	*Canarium* Linn.	Santiniketan near Bolpur, Birbhum District
	Meliaceae	*Chisochetonoxylon bengalensis* Ghosh & Roy 1979d	*Chisocheton paniculatus* Hiern	Labpur, Birbhum District
	Anacardiaceae	*Dracontomelumoxylon mangiferumoides* Ghosh & Roy, 1979b; Roy & Ghosh 1981b	*Dracontomelum mangiferum* Blume	Labpur, Birbhum District
		Glutoxylon burmense (Holden) Chowdhury; Chowdhury & Tandon, 1952; Roy & Ghosh, 1979b	*Gluta-Melanorrhoea*	Garbeta, Midnapur District; Santiniketan, Birbhum District
		Glutoxylon garbetaense (Ghosh & Roy) Guleria 1984b	*Gluta-Melanorrhoea*	
		Syn. *Melanorrhoeoxylon garbetaense* Ghosh & Roy 1980c; Roy & Ghosh, 1981b		Garbeta, Midnapur
		Mangiferoxylon assamicum Prakash & Tripathi; Ghosh & Roy 1980e; Roy & Ghosh 1981b.	*Mangifera indica* Linn.	Santiniketan—Labpur, Birbhum District
		Lanneoxylon grandiosum Prakash & Tripathi; Roy & Ghosh 1981b.	*Lannea coromandelica* (Houtt.) Merr.	Labpur, Birbhum District
		Buchananioxylon indicum Ghosh & Roy, 1980d; Roy & Ghosh 1981b	*Buchnania latifolia* Roxb.	Labpur, Birbhum District
	Fabaceae (Leguminosae)	*Pahudioxylon bankurensis* Chowdhury *et al.* 1960; Awasthi 1992	*Pahudia* Miq.	Bankura District
		Syn. *P. bengalensis* Ghosh & Roy 1982		Labpur, Birbhum District

Contd.

Table 9—Contd.

	FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/ SERIES AND LOCALITY
		Millettioxylon bengalensis Ghosh & Roy 1979a	*Millettia pulchra* Kurz.	Garbeta, Midnapur District
		M. indicum Awasthi 1967; Awasthi 1992 Syn. *M. pongamiensis* Prakash; Bande & Prakash 1980; Ghosh & Roy 1981a	*Millettia prainii* Dunn	Bolpur, Birbhum District; Labpur, Birbhum District
		Cassinium barooahii Prakash, Bande & Prakash 1980; Ghosh & Roy 1982	*Cassia siamea* Lam.	Santiniketan near Bolpur; Labpur, Birbhum District
		C. prefistulai Prakash; Awasthi 1992 Syn. *C. ballavapurense* Ghosh & Roy 1981b	*Cassia fistula* Linn. *C. nodosa* Linn.	Bolpur, Birbhum District
		Cynometroxylon holdenii (Gupta) Prakash & Bande; Prakash & Bande 1980	*Cynometra ramiflora* Linn. *C. polyandra* Roxb.	Bolpur, Birbhum District
		C. indicum Chowdhury & Ghosh; Ghosh & Roy 1982	*Cynometra ramiflora* Linn *C. polyandra* Roxb.	Labpur, Birbhum District
		Koompassioxylon elegans Kramer; Bande & Prakash 1980	*Koompassia malaccensis* Benth.	Santiniketan near Bolpur
		Ormosioxylon bengalensis Bande & Prakash 1980	*Ormosia robusta* Wight *O. watsonii* Fischer	Shantiniketan near Bolpur
		Albizinum eolebbekianum Prakash; Ghosh & Roy 1981a	*Albizia lebbek* Benth.	Labpur, Birbhum District
		Peltophoroxylon ferruginoides Bande & Prakash 1980	*Peltophorum ferrugineum* Benth.	Bolpur, Birbhum District
	Combretaceae	*Anogeissusoxylon bengalensis* Roy & Ghosh 1979b	*Anogeissus acuminata* Wall.	Santiniketan, Birbhum District
		Terminalioxylon Deb & Ghosh 1974	*Terminalia* Linn.	Santiniketan near Bolpur, Birbhum District
		Terminalioxylon tertiarum Prakash; Ghosh & Roy 1980a	*Terminalia* Linn	Garbeta, Midnapur District
	Datiscaceae	*Tetrameleoxylon prenudiflora* Lakahanpal & Verma; Acharya & Roy 1989	*Tetrameles nudiflora* R. Br.	Aduria forest, Burdwan District
	Lauraceae	*Laurinoxylon* sp. cf. *namsangensis* Lakhanpal *et al.*, Bande & Srivastava 1989	*Phoebe attenuata* Nees. *P. goalparense*	Muhammad Bazar, Birbhum District
	Euphorbiaceae	*Mallotoxylon cleidionoides* Roy & Ghosh 1982	*Mallotus-Blumeodendron* *Trewia-Cleidion*	Bolpur, Birbhum District
	Arecaceae	*Palmoxylon coronatum* Sahni; Roy & Ghosh 1980	*Borassus* Linn.	Labpur, Birbhum District and Bishnupur, Bankura District
B) Bihar	Dipterocarpaceae	*Shorea robusta* Gaertn. f.		Leaves
	Sterculiaceae	*Sterculia villosa* Roxb.		Leaf

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Table 9—Contd.

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/ SERIES AND LOCALITY
	Pterygota alata (Roxb.) R. Br.		Leaf
	Syn.		
	Sterculia alata Roxb.		
Tiliaceae	*Grewia tiliaefolia* Vahl.		Leaf
	Srivastava *et al.* (in press)		
Rutaceae	*Evodia meliaefolia* Benth.		Leaf
	Murraya paniculata (Linn.) Jack.		
	Srivastava *et al.* (in press)		
Burseraceae	*Garuga pinnata* Roxb.		Leaf
Anacardiaceae	*Spondias pinnata* (Lf.) Kurz.		Leaf
	Syn.		
	S. mangifera Willd.		
	Mangifera indica Linn.		Leaf
	Srivastava *et al.* (in press)		
Fabaceae	*Erythrina suberosa* Roxb.		Leaf
	Millettia auriculata Baker ex. Brandis		Leaf
	Ougenia oojeinensis (Roxb.) Hochr.		Leaf
	Syn.		
	O. dalbergioides Roxb.		
	Bauhinia sp. cf. *B. purpurea* Linn.		Leaf
	Hopeoxylon speciosum (Navale) Awasthi 1977		cf. *Sindora siamensis* Tesym ex Miq. Wood, Age—Mio-Pliocene
	Syn.		
	H. arcotense Awasthi 1977b		
	Prakash, Mishra & Srivastava 1988		
Combretaceae	*Combretum decandrum* Roxb.		Leaf
	Terminalia tomentosa Wight & Arn.		Leaf
	Terminalia tomentosa Wight & Arn.		Wood, Age—Mio-Pliocene
	Srivastava & Bande 1992		
Rubiaceae	*Mitragyna parviflora* (Roxb.) Korth.		Leaf
Sapindaceae	*Schleichera oleosa* (Lour.) Oken		Leaf
	Srivastava *et al.* (in Press)		
Sapotaceae	*Madhuca indica* J. F. Gmel		Leaf
Lythraceae	*Lagerstroemia* sp. cf. *L. parviflora* Roxb.		Wood, Age—Mio-Pliocene
	Srivastava & Bande 1992		
Ebenaceae	*Diospyros montana* Roxb.		Leaf
Verbenaceae	*Vitex negundo* Var. *incisa* Clarke		Leaf
	Srivastava *et al.* (in Press)		
Apocynaceae	*Alstonia scholaris* Brown		Leaf
Asclepidaceae	*Cryptolepis buchanani* Roem & Schult.		Leaf
Euphorbiaceae	*Mallotus philippensis* Muell-Arg.		Leaves
Utricaceae	*Ficus foveolata* Wall. ex. Miq.		Leaf
(Moraceae)	*F. glaberrima* Bl.		Leaf
	Syn.		
	F. infectoria Roxb.		
	F. tomentosa Roxb.		Leaf
	A dicot flower		Flower
	Dicot flowers Type I-IV		Flowers
	Srivastava *et al.* (in Press)		
	Dicot fruit Type-1 cf.		Fruit
	Dillenia sp.		
	Dicot fruit Type-2 cf. *Ziziphus xylopyrus* Willd.		Fruit
	Dicot fruit Type-3 cf. *Z. mauritiana* Lamk.		Fruit
	Dicot fruit Type-4 cf. *Dalbergia sissoo* Roxb.		Fruit

All the taxa against which no reference has been given, have been described by Bande and Srivastava, 1990. The age of the fossils other than the woods have been assigned as Upper Tertiary or Quaternary. All the above fossils have been reported from near Mahuadanr in Palamu District, Bihar.

Table 10—Neogene megaflora of central India

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/ SERIES
Fabaceae	*Millettia* sp. *miocenica* Lakhanpal & Guleria; Yadekar & Pitchai Muthu 1988	*Millettia* spp.	Katni Formation (Mio-Pliocene)
Lythraceae	*Lagerstroemia* sp. ? Yadekar & Pitchai Muthu 1988	*Lagerstroemia indica* Linn.	Katni Formation (Mio-Pliocene)
Moraceae	*Ficus* sp. *khariensis* Lakhanpal & Guleria; Yadekar & Pitchai Muthu 1988	*Ficus infectoria* Roxb.	Katni Formation (Mio-Pliocene)
Polygonaceae	*Rumex* sp. *acetosella* Yadekar & Pitchai Muthu 1988	*Rumex Acetosella* Linn.	Katni Formation (Mio-Pliocene)

Table 11—Neogene megaflora of Andaman and Nicobar Islands

FAMILY	FOSSIL TAXA	MODERN COMPARABLE TAXA	HORIZON/FORMATION/ SERIES/AGE
Corallinaceae	*Lithothamnion nummuliticum* Gee 1926 = (*Archaeolithothamnium nummuliticum*)	—	? Middle or Late Tertiary
	Lithothamnion suganum Gee 1926	—	? Middle or Late Tertiary
	Lithothamnium wilsonensis Chatterji & Gururaja 1972	—	Lower Limestone of the Archipelago Series of Lower Miocene (Aquitanian)
	Lithophyllum cf. *fosliei* (Hydr.) Hydr.; Chatterji & Gururaja 1972	—	Lower Limestone of the Archipelago Series of Lower Miocene (Aquitanian)
	Lithophyllum aff. *prelichenoides* Lemoine; Chatterji & Gururaja 1972	—	Lower Limestone of the Archipelago Series of Lower Miocene (Aquitanian)
	Lithophyllum sp. Chatterji & Gururaja 1972	—	Lower Limestone of the Archipelago Series of Lower Miocene (Aquitanian)
	Amphiroa oceanica Narayana Rao 1941-42	—	Oligo-Early Miocene
	Amphiroa cf. *prefragilissima* Lemoine; Chatterji & Gururaja 1972	—	Upper Limestone of the Archipelago Series of Lower Miocene
	Amphiroa sp. Chatterji & Gururaja 1972	—	Upper Limestone of the Archipelago Series of Lower Miocene
	Corallina andamanensis Narayana Rao 1941-1942	—	Oligo-Early Miocene
	Corallina roai Chatterji & Gururaja 1972	*Corallina*	Lower Limestone of Archipelago Series (Lower Miocene)
	Jania sp. Chatterji & Gururaja 1972	—	Lower Limestone of Archipelago Series (Lower Miocene)
Solenoporaceae	*Neosolenopora ramaraoi* Gururaja 1977	—	Limestone Hut Bay Formation (Middle Miocene).
	Aethesolithon sp. 1 Venkatachalapathy & Gururaja 1984	—	Miocene
	Aethesolithon sp. 2 Venkatachalapathy & Gururaja 1984	—	Miocene

(iii) *Neyveli lignite flora*—The Neyveli lignite deposits are situated in South Arcot district of Tamil Nadu and considered to be one of the biggest brown coal deposits of India. The lignite is associated with Cuddalore Sandstone and clays. The known megafossils of the lignite are based on carbonised woods and dispersed xylinoid and nonxylinoid tissues. However, woody tissues are not as common as nonoxylinoid tissues (Navale, 1974b). It was Jacob and Jacob (1950) who first reported the occurrence of leaf cuticles belonging to Oleaceae from the Neyveli lignite. The flora at present is represented by 22 families (see Table.6) and the important genera are: *Bouea, Cassia* or *Mimusops, Calophyllum* or *Mesua. Cassia* or *Acacia, Carallia, Careya, Cordia, Cryptostegia, Diospyros-Maba, Dipterocarpus, Dracaena, Excoecaria, Gluta, Grewia, Hopea, Lagerstroemia, Litsea, Parinari,* *Randia, Shorea, Sterculia* and *Terminalia*. In addition, leaf cuticles belonging to Arecaceae, Poaceae and wood fragments of Euphorbiaceae have also been reported. The evidence provided by the fossils and by the petrologic nature (Navale, 1968b; Misra, 1992) of the lignite suggests the existence of humid tropical conditions during the formation of the lignite. The occurrence of Dipterocarpaceae, Ebenaceae, Sapotaceae, *Gluta* and the general similarity exhibited by the Neyveli flora with other Neogene floras of India suggests an Upper Tertiary age of the lignite. On the contrary, microfossil workers have inferred various ages for the Neyveli lignite ranging from Palaeocene-Eocene (Saxena, 1992), Eocene (Deb *et al.*, 1973; Venkatachala, 1973) and Miocene (Ramanujam, 1982; Singh *et al.*, 1992; Misra, 1992).

3. North-east Flora (Assam-Arakan Basin)

The flora comprises mostly of dicotyledonous woods. In addition, a fruit of *Nypa* and a few dicot leaves have also been reported (Lakhanpal, 1952; Seward, 1912). The earliest record of the fossil woods from this region goes back to 1882 when Schenk reported the occurrence of *Cedroxylon hermanii* from Dischaipur (Jaipur), Assam. This wood was subsequently discarded by Sahni (1931b) on account of incomplete preservation and lack of diagnostic features of the family Abietineae. At present about 45 genera belonging 20 families have been described by various workers (see Table 8). The important components of the flora are· *Adenanthera, Afzelia-Intsia, Albizia, Anisoptera, Antiaris, Artocarpus, Bauhinia, Barringtonia, Bursera-Garuga, Calophyllum, Careya, Cassia, Cinnamomum-Dehasia, Cynometra, Diospyros, Dipterocarpus, Duabanga, Elaeocarpus-Echinocarpus, Gluta, Heritiera, Holigarnia, Homalium, Kayea, Kingiodendron, Koompassia, Lagerstroemia, Lannea* or *Odina, Madhuca, Mangifera, Mallotus, Millettia, Ougeinia, Phyllanthus, Pometia, Sindora-Capaifera-Detarium, Shorea, Sterculia, Swintonia, Terminalia* and *Vitex*. All these elements indicate the existence of warm tropical rain forest conditions in the area during Neogene. Most of these components are still growing in the area. From this evidence it can be inferred that the vegetation and climate had not changed much since the Neogene. The occurrence of *Nypa* in Garo Hills, *Afzelia-Intsia* and *Cynometra ramiflora* near Hailakandi in Mezoram indicates the existence of coastal conditions in the area during the Neogene. Obviously, sea had receeded to its present position since Neogene. The occurrence of certain genera like *Anisoptera, Dipterocarpus, Koompassia, Pometia* indicates the migration of Indo-Malayan elements in the flora.

4. Bengal and Bihar Neogene Flora

(A) *West Bengal (Bengal Basin)*—A rich flora, comprising mainly the fossil woods has been worked out from the Neogene exposures of Midnapur, Bankura, Birbhum and Bardhaman District of peninsular part of West Bengal. The flora consists of 26 genera belonging to 10 dicotyledonous families (see Table 9A). In addition, a palm and an araucarian wood have also been reported. The important components of the flora are: *Afzelia-Intsia, Anisoptera, Agathis-Araucaria, Calophyllum, Canarium, Cassia, Cynometra, Dipterocarpus, Mangifera, Dracontomelum, Gluta, Kayea, Koompassia, Laurinoxylon, Shorea*. The vegetation indicates the occurrence of warm tropical climate. The flora shows general similarity with other Neogene floras of India particularly with that of the North-east and the Cuddalore. The flora of West Bengal, like Cuddalore flora, indicates change in climatic conditions although the change has not been as drastic as in the case of flora of Cuddalore.

(B) *Bihar*—A Late Tertiary flora consisting of a large number of taxa mostly based on impression of leaves, fruits, flowers and a few petrified woods has recently been reported from the Palamu District in South Bihar (see Table 9B). The assemblage comes from two different horizons considered to be of Upper Tertiary age (Puri & Misra, 1982) exposed around village Mahudanr. The woods have been derived from the sandstone bed whereas a large number of impressions come from the overlying shaly bed. *Sindora, Terminalia* and *Lagerstroemia* which are represented by fossil woods in the Palamu flora have been reported from the Pliocene deposits of Kutch and Rajasthan. On this basis it is surmised that the woods may belong to Pliocene. Gymnosperms are totally lacking and the assemblage is represented by a large number of taxa belonging to Fabaceae. Thus the available evidence suggests that drier conditions had set in by the time the shaly material was preserved. *Dipterocarpus* and *Anisoptera* which were wide spread up to Pliocene in India as seen in Kutch and Rajasthan are lacking and the family Dipterocarpaceae is represented in Palamu flora only by *Shorea robusta*, which relatively grows in dry habitats. This probably indicates that the assemblage of shaly bed represented by impressions may belong to post-Pliocene time which continued till today. This is also supported by the very close similarity of the present day flora with that of the fossil one. However, more work in this area will help in deciphering the precise age of the flora.

5. Central Indian Neogene Flora

Yadekar and Pitchai Muthu (1988) reported the occurrence of angiospermic plant remains belonging to both dicots and monocots from the sediments of Katni Formation in Madhya Pradesh (see Table 10). The formation has been assigned Mio-Pliocene age. The assemblage consists of impressions of leaves representing Leguminosae (*Millettia*), Lythraceae (*Lagerstroemia*), Moraceae (*Ficus*) and a seed cast of (*Rumex*) Polygonaceae. This is probably the first record of Neogene plant fossils from the central India. More work is required in this area to have a better picture of the flora of this region.

6. Andaman and Nicobar Islands Neogene Flora

The area has practically remained uninvestigated as far as the megafossils are concerned except for a few records of Red algae (Table 11). Gee (1926) was the first to report the occurrence of *Lithothamnion* which is now recognised as *Archaeolithothamnium*. The other known members of the assemblage are *Aethesolithon, Amphira, Corallina, Jania, Lithophyllum, Lithothamnium* and *Neosolenopora*. Obviously the area needs detailed exploration for the study of megafossils of higher plants in order to know the past flora of the islands.

SIGNIFICANT CONCLUSIONS

The Neogene vegetation of peninsular India is mainly represented by dicotyledonous woods which are widely distributed throughout the peninsula. Palms are infrequent and gymnosperms rare.

During Neogene entire peninsula was covered by rich vegetation since the climate must have been more or less uniform on account of situation of the Indian peninsula in the tropical zone.

All the floras from different basins show very close similarity in their composition as most of the genera are common. The wide distribution of tropical rain forest family Dipterocarpaceae from East to West and North to South along with other genera clearly indicates a more or less uniform tropical moist climate throughout the peninsular India during the Neogene.

Aridity could have gradually increased towards the close of Neogene due to the growing continentality caused by the rise of the Himalayan mountains and disappearance of the Tethys Sea in the North. This resulted in complete eradication of dipterocarps from Kutch, Rajasthan, Cuddalore and their recession from the western Himalayan foothills to north eastern India.

There were large scale migrations and admixture of floras over Malaysia, India, Arabia and Africa during Neogene due to establishment of land connections by Early Miocene. This was most probably the time when dipterocarps migrated into India, colonised the peninsula and spread westward to Africa via Rajasthan, Kutch and Arabia. Likewise some genera did migrate into India from Africa as seen particularly in the flora of Kutch and Rajasthan.

The presence of some families and genera such as Dipterocarpaceae, Ebenaceae, Rhamnaceae, Sapotaceae, *Afzelia-Intsia, Gluta, Swintonia* along with the dominance of legumes distinguishes the Neogene flora from the Palaeogene flora of India.

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Changing patterns of vegetation through Siwalik succession

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The palaeobotanical record from the Neogene of Himalaya has been examined and an attempt has been made to reconstruct the vegetation patterns and throw light on palaeoclimate of the region during Siwalik time. Though the flora of the Pre-Siwalik Neogene from which the Siwalik flora evolved is poorly documented, a few palynofossils from the Kasauli and Dagshai formations indicate the existence of subtropical to temperate vegetation in the Upper reaches of the newly built Himalaya. On the contrary, a fairly rich assemblage of megafossils from the Siwalik indicates widespread tropical evergreen to moist deciduous mixed forest in the lowland sub-Himalayan zone during Middle Miocene-Pliocene. The assemblage is dominated by wet-evergreen dipterocarps and associated taxa, most of which are known to have entered the Indian subcontinent from southeast Asia during Miocene and subsequently spread all over and finally reached the lower slopes of sub-Himalaya. This has resulted increase in the diversity of tropical vegetation.

The post-Pliocene orogeny of Himalaya brought great changes in the topography and climate which adversely affected the vegetation patterns of the region. The Early and Middle Siwalik tropical evergreen forest whose chief component are *Anisoptera, Dipterocarpus, Hopea, Shorea* (other than *Shorea robusta*), *Polyalthia, Calophyllum, Aphanamixis, Dysoxylum, Gluta, Dracontomelum, Mangifera, Swintonia, Cynometra, Koompassia, Ormosia, Pongamia, Sindora, Duabanga, Diospyros* spp., *Myristica*, etc. started dwindling towards the end of Middle Siwalik and subsequently disappeared from western and central sectors, though a few taxa like *Mangifera, Litsea, Cinnamomum, Bauhinia, Dalbergia, Ficus*, etc. continued to adjust to the new climatic conditions. Extinction of tropical evergreen taxa and further rise of Himalaya gave way to proliferation and diversification of tropical and subtropical moist deciduous to dry deciduous temperate vegetation in the lower and higher slopes respectively, as is also evidenced from palynological record.

Key-words—Palaeobotany, Vegetation, Evolution, Climate, Siwalik, Neogene, India.

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साराँश

शिवालिक अनुक्रम में वनस्पति का बदलता स्वरूप

नीलाम्बर अवस्थी

हिमालय के पश्चनूतन कल्प से पुरावनस्पतिक अभिलेखों का अध्ययन किया गया तथा वनस्पतिक स्वरूपो की पुर्नरचना का प्रयास किया गया है। इसी के आधार पर शिवालिक क्षेत्र की पुराजलवायु अन्वेषित करनें का प्रयास किया गया है। हालाँकि शिवालिक से पहले के वनस्पतिजात, जिससे शिवालिक वनस्पतिजात का विकास हुआ है, के विषय में कम जानकारी है तथापि कसौली एवं दागशाई शैल-समूहों से प्राप्त कुछ अश्मित परागाणु नवनिर्मित हिमालय के ऊपरी भाग में उपोष्णकटिबन्धीय से शीतोष्ण वनस्पति की उपस्थिति इंगित करते हैं। इसके विपरीत शिवालिक से उपलब्ध गुरुपादपाश्म समुच्चय में मध्य-मध्यनूतन से अतिनूतन कल्प में उष्णकटिबन्धीय सदाहरित से नमपर्णपाती मिश्रित वनों की उपस्थिति इंगित होती है। ये समुच्चय नम सदाहरित डिप्टेरोकार्प्स तथा सहयुक्त वर्गकों से प्रभावी हैं। इन वर्गकों में से अधिकतर ने मध्यनूतन कल्प में दक्षिण-पूर्व एशिया से भारतीय उपमहाद्वीप में प्रवेश कर हिमालय के गिरिपादों में सर्वत्र फैल गये हैं। इसी के कारण उष्णकटिबन्धीय जलवायु में विभिन्नता देखने को मिलती है।

अतिनूतन कल्प के पश्चात् हिमालय के विकास से यहां की भौगोलिकी तथा जलवायु में काफी बदलाव आया है तथा जिसका प्रभाव वनस्पति पर असाधारण रूप से हुआ है। **ऐनाइसॉप्टेरा**, **डिप्टेरोकार्पस**, **होपिया**, **शौरिआ**, **पोलिएल्थिया**, **केलोफ़िल्लम्**, **एफ़ेनामिक्सिस**, **डाइसोजाइलम**, **ग्लूटा**, **ड्रेकोन्टोमिलम**, **मेंजिफ़ेरा**, **स्विंटोनिआ**, **साइनोमेट्रा**, **कूम्पासिआ**, **ओर्मोसिआ** इत्यादि प्रारम्भिक एवं मध्यशिवालिक के उष्णकटिबन्धीय अवयव मध्य शिवालिक के बाद कम होते चले गये तथा तत्पश्चात् पश्चिमी एवं केन्द्रीय भागों से विलुप्त हो गये। हालाँकि, कुछ थोड़े से वर्गक—**मेंजिफ़ेरा**, **लिट्सिआ**, **सिनामोमम्**, **बॉहीनिआ**, **डेल्बर्जिया**, **फ़ाइकस** आदि नई जलवायवी परिस्थितियों में समायोजन करने के कारण अभी भी पाये जाते हैं। सदाहरित

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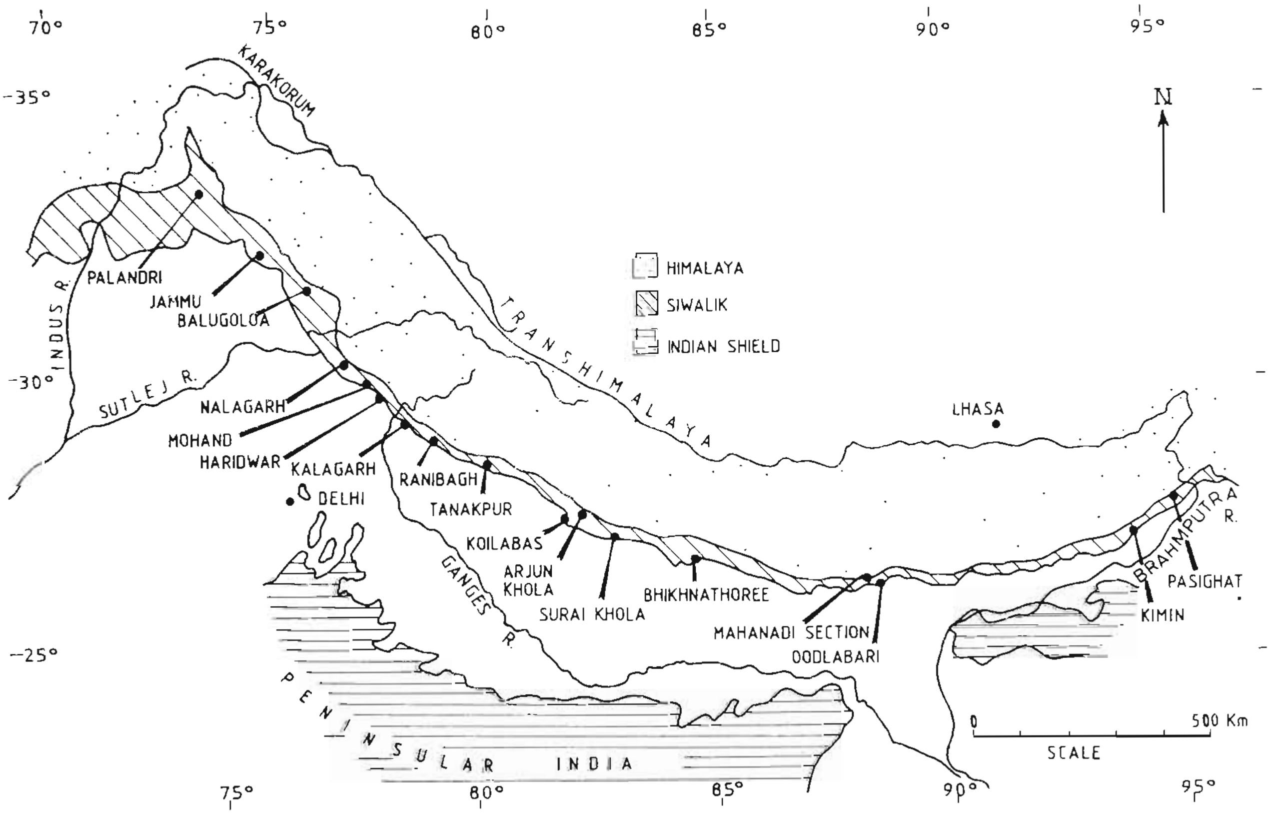
उष्णकटिबन्धीय वर्गकों तथा हिमालय के पुनः उत्थान से उष्णकटिबन्धीय एव उपोष्णकटिबन्धीय नम पर्णपाती से शुष्क पर्णपाती शीतोष्ण वनस्पति हिमालय के क्रमशः निम्न एव उच्चतर ढलानों पर विकसित हो गई है। इसकी पुष्टी परागाणविक अभिलेखों से भी होती है।

THE three major sedimentary zones identified in the Himalayan orogenic belt are: (i) the sub-Himalayan Zone, (ii) the lesser Himalayan Zone, and (iii) the Tethys Himalayan Zone. The sub-Himalayan Zone is also known as the Himalayan foot-hill zone which represents the Siwalik rocks of Neogene age. They extend from Potwar Plateau in the west to Arunachal Pradesh in the east covering a distance of about 2,400 km in length and generally 20-25 km in width. They are essentially formed by accumulation of alluvial detritus into a long narrow foredeep derived from the rising Himalaya during Middle Miocene to Lower Pleistocene. Along with erosional debris, the plants and animals which inhabited the then relatively low hills were deposited. The foredeep was formed as a sequel to the collision of Indian Plate with Laurasia and complete evacuation of Tethys Sea during Oligocene. During the final phase of the rise of Himalaya in Pleistocene-Recent, the Siwalik sediments were also upheaved, folded and faulted forming a continuous mountain range of relatively low height ranging from 1,000-1,200 m above mean sea level. The Siwalik sequence is about 6,000 km thick and consists of coarsely bedded sandstone, sandrock, clays and conglomerates. It is believed that they have been deposited in different environments, namely, lacustrine, channel and flood-plains, outwash and piedmont (Sahni & Mathur, 1964).

On the basis of lithology and mammalian fauna Pilgrim (1913) finally proposed a three-fold stratigraphic division of the Siwalik Group, i.e., Lower Siwalik, Middle Siwalik and Upper Siwalik. During the last two decades several workers have unearthed enormous amount of plant megafossils from the Lower and Middle siwalik sediments represented both in India and Nepal. In contrast to Lower and Middle Siwalik, the Upper Siwalik sediments lack well-preserved plant fossils, though fragments of leaves have been occasionally found in friable sandy clays. Their absence in the Upper Siwalik sediments has been attributed to their destruction due to oxidation at the place of origin, during transportation and also the place of burial (Ranga rao *et al.*, 1981).

The systematic study of plant fossils has



Map 1—Extent of the rocks of Siwalik Group.

Table 1—Balugoloa Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
SMILACEAE			
Smilax sp. Lakhanpal & Dayal 1966	*Smilax roxburghiana*, *S. macrophylla*, *S. prolifera*	—	—
ANNONACEAE			
Fissistigma senii Lakhanpal 1969	*Fissistigma bicolor*	Northeast India	Evergreen
F. siwalika Lakhanpal & Awasthi 1992	*F. rubiginosum*	Assam, Bangladesh, Burma, Thailand, Borneo	Evergreen
DIPTEROCARPACEAE			
Dipterocarpus siwalicus Lakhanpal & Guleria 1987	*Dipterocarpus tuberculatus*	Northeast India, Andaman Islands, Mynmar, Malaya	Evergreen
RHAMNACEAE			
Berchemia balugoloensis Lakhanpal 1967	*Berchemia floribunda*	Sub-Himalayan region, Northeast India	Evergreen
Ziziphus siwalicus Lakhanpal 1965, 1967	*Ziziphus incurva*, *Z. xylopyrus*	India, Mynmar	Moist deciduous to dry deciduous
FABACEAE			
Dalbergia (fruit) Lakhanpal & Dayal 1966	*Dalbergia sissoo*	Greater part of India	Deciduous
COMBRETACEAE			
Terminalia balugoloensis Lakhanpal & Awasthi 1992	*Terminalia alata* var. *nepalensis*	Sub-Himalayan tracts, Punjab eastwards to Mynmar	Deciduous
LYTHRACEAE			
Lagerstroemia sp. Lakhanpal & Dayal 1966	?*Lagerstroemia indica*	—	—
MORACEAE			
Ficus precunea Lakhanpal 1968	*Ficus cunea*	Himalayan foot-hills, Assam region, Bangladesh	Evergreen

generated a rich database for the reconstruction of Siwalik floristics. Realizing the extent and thickness of Siwalik sediments present in India and Nepal, the plant megafossils data available so far is still far from satisfactory. Nevertheless, several important and significant plant taxa have been studied and documented from several localities in the foot-hills (Map 1; Tables 1-7). The data have been used in deciphering palaeoecology and palaeophytogeography of the region. Evolutionary trends of the Siwalik flora have also been traced through time and space. The influence of periodical northward drift of the Indian Plate and rise of Himalaya on the flora has also been one of the objectives of the study.

PRE-SIWALIK NEOGENE FLORISTICS AND CLIMATE

Before an attempt is made to reconstruct the changing patterns of the Siwalik vegetational scenarios, it is necessary to furnish background information about the pre-existing vegetation and environment of the Himalayan region particularly of pre-Siwalik time. The pre-Siwalik sediments developed in the Lesser Himalayan zone are designated as Murree, Dharamsala, Dagshai and Kasauli formations.

In comparison to Siwalik sediments these formations are poor in plant megafossils. Sahni (1953, 1964) described for the first time a few plant remains, viz., *Sabalites microphylla* and *Sabalites* sp. resembling leaves of *Sabal*-like palms, leaf fragments cf. palm, other monocotyledonous fragmentary leaves of uncertain affinities and ill-preserved dicotyledonous leaves as *Dicotylophyllum* spp. from the Kasauli Formation of Shimla Hills. Similar ill-preserved indeterminate dicotyledonous leaves have been reported by Chaudhury (1969) from the Koshaliya River bank near Kalka, Himachal Pradesh. However, the only satisfactorily preserved leaf-

Table 2—Nalagarh Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
DIPTEROCARPACEAE			
Dipterocarpoxylon siwalicus Prakash 1975	*D. indicum* *D. turbinatus* *D. gracilis*	Western Ghats northeast India, Andaman Islands, Malaya Peninsula	Evergreen Evergreen
D. nalagarhense Prakash 1975	*D. dyeri*	Malay Peninsula	Evergreen
D. premacrocarpum Prakash 1975	*D. macrocarpus*	Northeast India, Mynmar	Evergreen
MELIACEAE			
Aglaia nahanensis Yadav 1989	*Aglaia edulis*	Northeastern India, Bangladesh, Mynmar, Malay Peninsula	Evergreen
ANACARDIACEAE			
Dracotomelumoxylon mangiferumoides Prakash 1979a	*Dracontomelum mangiferum*	Andaman and Nicobar islands, Malaya Peninsula	Evergreen
FABACEAE			
Acrocarpus siwalicus Yadav 1989	*Acrocarpus fraxinifolius*	India, Mynmar	Moist deciduous
Adenantheroxylon Yadav 1989	*Adenanthera pavonina*	Indo-Malayan region	Moist deciduous
Albizinium eolebbekianum Prakash 1975	*Albizia lebbek*	Himalayan foot-hills	Deciduous
Cassinium prefistulai Prakash 1975	*Cassia fistula*	India, Mynmar	Deciduous
Cynometroxylon holdenii (Gupta) Bande & Prakash. (= *Cynometroxylon indicum*) Chowdhury & Ghosh. Prakash 1975	*Cynometra polyandra*	Northeast India, Mynmar, Malaya	Evergreen
Koompassioxylon elegans Yadav 1989	*Koompassia malaccensis*	Malayan region	Evergreen
Millettioxylon pongamiensis Prakash 1975	*Pongamia pinnata*	India, Mynmar, South-east Asia, North Australia, China	Evergreen
Ormosioxylon bengalensis Bande & Prakash. Yadav 1989	*Ormosia robusta*	India, Bangladesh, Mynmar	Evergreen
LECYTHIDACEAE			
Careyoxylon pondicherriense Prakash	*Careya arborea*	India, Mynmar	Moist deciduous

impression comparable to the leaves of *Artocarpus* is described by Sharma and Gupta (1972) from the Murree sediments in Rajori District, Jammu and Kashmir. Recently, Mehra *et al.* (1990a) have reported a few monocotyledonous and dicotyledonous leaves from typical Dagshai Formation, exposed near Kumarhatti on Kalka-Shimla Highway. They also reported impressions of leaves and flowers from Kasauli Formation exposed along the same highway and provisionally referred them to Fabaceae and Moraceae (Mehra *et al.*, 1990b).

The leaves documented so far are invariably smaller in size which obviously belong to grasses, bushes and small trees. It is astonishing that in a long stretch of well developed Lower Miocene sedimentary sequence not a single bigger dicotyledonous leaf suggesting broad-leaved mesophytic vegetation has been found so far. Leaves and other plant megafossils, reported from Dharamsala, Dagshai, Kasauli and Murree sediments, belong to such plants which were most probably the first ones to invade the newly emerged low hills of the Himalaya from the nearby area.

The available meagre plant megafossils data alone is not enough for precise reconstruction of the

Table 3—Kalagarh Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
ARECACEAE			
Palmoxylon wadiai Sahni. Prasad 1987	*Palm* in general	—	—
ANNONACEAE			
Polyalthioxylon indicum Prakash 1978	*Polyalthia* spp.	Indo-Malayan	Evergreen
DIPTEROCARPACEAE			
Anisopteroxylon kalagarhense Prakash 1978	*Anisoptera scaphula*	Mynmar, Thailand, Malaya Peninsula	Evergreen
A. oblongoides Yadav 1989	*A. oblonga*	Mynmar, Malay Peninsula	Semi-evergreen to deciduous
Dipterocarpoxylon kalagarhense Yadav 1989	*Dipterocarpus obtusifolius*	Mynmar, Thailand, Malay Peninsula	Evergreen
D. parabaudii Prakash 1978	*D. baudii*	Mynmar, Cambodia Thailand, Malay Peninsula	Evergreen
D. surangeii Prakash 1981	*D. tuberculatus*	Bangladesh, Mynmar, Thailand	Evergreen
D. nungarhense Trivedi & Ahuja 1980	*D. tuberculatus*		
Shoreoxylon ornatum Trivedi & Ahuja) Bande & Prakash 1980 Syn. *Pentacmeoxylon ornatum* Trivedi & Ahuja *Vaterioxylon kalagarhense* Trivedi & Misra *V. miocenicum* Trivedi & Misra	*Shorea* spp.	Indo-Malayan region	Evergreen
Shoreoxylon siwalicus Prasad & Prakash 1988	*Shorea minor*	Malaysia	Evergreen
Hopenium prenutanoides Prasad & Prakash 1988	*Hopea nutan*	Malaya Peninsula	Evergreen
H. kalagarhensis Prasad & Prakash 1988	*H. sulcata*	Mynmar, Malaya	Evergreen
STERCULIACEAE			
Sterculioxylon kalagarhensis Trivedi & Ahuja 1978a	*Sterculia coccinia* *S. oblonga* *S. rhinopetala*	Northeast India to Malayan region	Evergreen
ANACARDIACEAE			
Dracontomelumoxylon mangiferumoides Ghosh & Roy. Prakash 1981	*Dracontomelum mangiferum*	Andaman Islands	Evergreen
Glutoxylon kalagarhensis	*Gluta* spp.	Mynmar, Malaya	Evergreen
FABACEAE			
Bauhinium palaeomalabaricum Prakash & Prasad 1984	*Bauhinia malabarica*	India, Mynmar	Moist deciduous
B. miocenicum Trivedi & Panjwani 1986	*Bauhinia retusa*	Chota Nagpur, Eastern and Western Ghats	Moist deciduous
Cynometroxylon holdenii (Gupta) Prakash & Bande. Syn.	*Cynometra polyandra*	Northeast India	Evergreen
C. siwalicus Trivedi & Ahuja 1978c	*Millettia pulchra*	Mynmar	Evergreen
Millettioxylon kalagarhensis			

Contd.

Table 3—Contd.

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
(Trivedi & Misra) Guleria 1984 Syn. *Dialiumoxylon kalagarhensis* Trivedi & Misra			
Hopeoxylon eosiamensis Prakash 1981	*Sindora siamea*	Malay Peninsula	Evergreen
Ormosioxylon bengalensis Bande & Prakash. Prasad 1989	*Ormosia robusta*	Northeast India, Bangladesh, Mynmar	Evergreen
ROSACEAE			
Parinarioxylon splendinum Trivedi & Ahuja 1979a	Affinities doubtful	—	—
COMBRETACEAE			
Terminalioxylon palaeomanii Prakash 1981	*Terminalia manii*	Andaman and Nicobar Islands	Dry to moist deciduous
T. siwalicus Prasad 1989	*T. paniculata*	Western Ghats	Deciduous
SONNERATIACEAE			
Duabangoxylon indicum Awasthi. Awasthi & Prasad 1988	*Duabanga* spp.	Northeast Indian region	Evergreen
EBENACEAE			
Ebenoxylon siwalicus Prakash 1981	*Diospyros brandisiana*	Mynmar	Evergreen
E. kalagarhensis Prasad 1989	*D. malabarica*	Indo-Malayan region	Evergeen
LAURACEAE			
Lourinoxylon siwalicus Prasad 1990c	Lauraceous genera	—	—

Table 4—Poornagiri (Tanakpur) Assemblage (Awasthi, MS)

FOSSIL LEAVES: FAMILY/GENUS	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
STERCULIACEAE			
Sterculia	*Sterculia urens*	India, Mynmar	Dry deciduous
FABACEAE			
Ormosia	*Ormosia robusta*	Nepal, Northeast India, Bangladesh, Mynmar	Evergreen
COMBRETACEAE			
Terminalia	*Terminalia chebula*	India	Deciduous
MYRTACEAE			
Syzygium	*Syzygium cumini*	India, Mynmar	Evergreen to deciduous
BORAGINACEAE			
Cordia	*Cordia myxa*	India, Mynmar, Southeast Asia	Deciduous
EBENACEAE			
Diospyros	*Diospyros ebenum* *D. sylvatica*	India, Sri Lanka	Moist deciduous
LAURACEAE			
Persea	*Persea* spp.	Indo-Malayan	Evergreen
Cryptocarya	*C. griffithiana*	Indo-Malayan	Deciduous
MORACEAE			
Artocarpus	*Artocarpus integrifolius*	India, Mynmar	Evergreen

Table 5—Bhikhnathoree Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
MALVACEAE			
Urena palaeolobata Awasthi & Lakhanpal 1990	*Urena lobata*	Tropical to subtropical region	Deciduous
MELIACEAE			
Aphanamixis bhikhnathoriensis Awasthi & Lakhanpal, 1990	*Aphanamixis polystachya*	Indo-Malayan	Evergreen
Toona siwalika Awasthi & Lakhanpal 1990	*Toona ciliata* Roxb.	Indo-Malayan, Australia	Evergreen to deciduous
RHAMNACEAE			
Ziziphus champarensis Lakhanpal & Awasthi 1984	*Ziziphus mauritiana*	Tropical to subtropical region of the world	Moist to dry
ANACARDIACEAE			
Mangifera someshwarica Lakhanpal & Awasthi 1984	*Mangifera indica*	Indo-Malayan	Evergreen to deciduous
FABACEAE			
Indigofera prepulchella Lakhanpal & Awasthi 1984	*Indigofera pulchella*	India	Semi-evergreen to dry deciduous
Dalbergia sp. Lakhanpal & Awasthi 1984	*Dalbergia sissoo* *Dalbergia latifolia*	India	Dry deciduous
Derris champarensis Awasthi & Lakhanpal 1990	*Derris scandens*	Indo-Malayan	Semi-evergreen to dry deciduous
Pongamia siwalika Awasthi & Lakhanpal 1990	*Pongamia pinnata*	India, Southeast Asia, North Australia	Semi-evergreen to dry deciduous
Cassia antiqua Lakhanpal & Awasthi 1990	*Cassia glauca*	Indo-Malayan	Evergreen
Bauhinia siwalika Lakhanpal & Awasthi 1984	*Bauhinia* spp. *(B. diptera, B. tomentosa, B. corymbosa)*	Indo-Malayan	Deciduous
MYRTACEAE			
Syzygium palaeobracteatum Awasthi & Lakhanpal 1990	*Syzygium bracteatum*	Northeast India, Orissa	Evergreen
RUBIACEAE			
Gardenia palaeoturgida Lakhanpal & Awasthi 1984	*Gardenia turgida*	Northern India	Moist deciduous
MYRSINACEAE			
Ardisia antiqua Awasthi & Lakhanpal 1990	*Ardisia solanacea*	India, Mynmar, Sri Lanka	Moist deciduous
CONVOLVULACEAE			
Ipomoea eriocarpoides Awasthi & Lakhanpal 1990	*Ipomoea eriocarpa*	India, Mynmar, Sri Lanka	Moist deciduous
LAURACEAE			
Phoebe champarensis Awasthi & Lakhanpal 1990	*Phoebe lanceolata*	India, Mynmar, Sri Lanka	Evergreen
Cinnamomum palaeotamala Lakhanpal & Awasthi 1984	*Cinnamomum tamala*	India, Mynmar	Evergreen to moist deciduous
Litsea prenitida Lakhanpal & Awasthi 1984	*Litsea nitida*	Eastern Himalaya, Assam, Bangladesh	Semi-evergreen
MORACEAE			
Ficus champarense Lakhanpal & Awasthi 1984	*Ficus* spp.	—	—

floral pattern and interpreting the palaeoclimate of the lesser Himalayan zone during Early Miocene. However, on the basis of palynological assemblage from the Kasauli Formation which includes

Table 6—Koilabas Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
DILLENIACEAE			
Dillenia palaeoindica Prasad & Prakash 1984	*Dillenia indica*	India, Mynmar	Moist evergreen
FLACOURTIACEAE			
Ryparosa prekunstleri Prasad 1990b	*Ryparosa kunstleri*	Malaya	Evergreen
CLUSIACEAE			
Mesua tertiara Prasad 1990b	Affinities doubtful	—	—
DIPTEROCARPACEAE			
Dipterocarpus siwalicus Lakhanpal & Guleria. Prasad 1990a	*Dipterocarpus tuberculatus*	Northeast India, Mynamar, Southeast Asia	Evergreen to moist deciduous
MELIACEAE			
Chloroxylon palaeoswietenia Prasad 1990b	*Chloroxylon swietenia*	India, Sri Lanka	Deciduous
FABACEAE			
Albizia siwalika Prasad 1990a	*Albizia gambelei*	Northeast India	Moist deciduous
Cassia nepalensis Prasad 1990b	*Cassia hirsuta*	Central India	—
Dalbergia miosericea Prasad 1990b	*Dalbergia sericea*	Sub-Himalayan region, Madagascar	Deciduous
Millettia siwalica Prasad 1990b	*Millettia ovalifolia*	Jammu to Sikkim, Upper Mynmar	Moist deciduous
Millettia koilabasensis Prasad 1990b	*Millettia macrostachya*	Upper Mynmar	—
Ormosia robustoides Prasad 1990a	*Ormosia robusta*	Northeast India, Mynmar	Evergreen
COMBRETACEAE			
Anogeissus eosericea Prasad & Prakash 1984	*Anogeisus sericea*	Central India	Deciduous
Calycopteris floribundoides Prasad 1990b	*Calycopteris floribunda*	Western Peninsula, Northeast India, Mynmar	Deciduous
Terminalia koilabasensis Prasad 1990b	*Terminalia angustifolia*	Malaya	Evergreen
Terminalia siwalica Prasad 1990b	*T. pyrifolia*	Mynmar	—
Terminalia sp. Tripathi & Tiwari 1983	*Terminalia arjuna*	Throughout India, Mynmar	Deciduous
RUBIACEAE			
Randia miowallichii Prasad 1990b	*Randia wallichii*	Northeast India to Mynmar, Andaman Islands	Evergreen
APOCYNACEAE			
Tabernaemontana precoronaria Prasad 1990b	*Tabernaemontana coronaria*	Sub-Himalayan region, Sri Lanka, Mynmar	Evergreen
SOLANACEAE			
Datura miocenica Prasad 1990b	*Datura fastuosa*	Tropical region	—
VERBENACEAE			
Vitex prenegundo Prasad 1990b	*Vitex negundo*	India, Sri Lanka, China	Deciduous
Vitex siwalicus Prasad 1990b	*Vitex pubescens*	India, Mynmar	Evergreen

Contd.

Table 6—Contd.

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
LAURACEAE			
Cinnamomum mioinunctum Prasad 1990b	*Cinnamomum inunctum*	Mynmar, Malaya	Evergreen to moist deciduous
MORACEAE			
Ficus precunea Lakhanpal & Prasad 1990b	*ficus cunea*	Sub-Himalaya region, Assam, Mynmar	Deciduous
Ficus retusoides Prasad 1990b	*Ficus retusa*	Indo-Malayan	Evergreen
Ficus nepalensis Prasad 1990b	*Ficus glaberrima*	Indo-Malayn	Evergreen

Table 7—Surai Khola Assemblage in stratigraphical sequence

STRATIGRAPHIC SEQUENCE	FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
Surai Khola beds	MARANTACEAE			
	Clinogyne ovatus Awasthi & Prasad 1990	*Clinogyne grandis*	Indo-Malayan region	Moist deciduous
	FLACOURTIACEAE			
	Flacourtia nepalensis Awasthi & Prasad 1990	*Flacourtia ramnotchii*	India, Mynmar, Sri Lanka	Deciduous
	FABACEAE			
	Millettia miocubithii Awasthi & Prasad 1990	*Millettia cubithii*	Malayan region	Moist deciduous
	Bauhinia nepalensis Awasthi & Prasad 1990	*Bauhinia malabarica* *B. variegata*	India, Mynmar	Evergreen to deciduous
	EBENACEAE			
	Diospyros miokaki Hu & Chaney. Awasthi & Prasad 1990	*Diospyros kaki*	India, Mynmar, China, Japan	Moist deciduous
	EUPHORBIACEAE			
	Breynia prerhamnoides Awasthi & Prasad 1990	*Breynia rhamnoides*	Indo-Malayan region	Moist deciduous
Kaila Khola	ARECACEAE			
	Caryota siwalika Awasthi & Prasad 1990	*Caryota urens*	Indo-Malayan region	Evergreen to moist deciduous
	ANACARDIACEAE			
	Mangifera someshwarica Lakhanpal & Awasthi. Awasthi & Prasad 1990	*Mangifera indica*	India, Southeast Asia	Evergreen
	Gluta siwalika Awasthi & Prasad 1990	*Gluta renghas*	Mynmar, Malaysia	Evergreen
	Swintonia miocenica Awasthi & Prasad 1990	*Swintonia floribunda*	Bangladesh, Mynmar	Evergreen
	FABACEAE			
	Entada palaeoscandens (seed) Awasthi & Prasad 1990	*Entada scandens*	Indo-Malayan region	Moist deciduous to evergreen
	COMBRETACEAE			
	Terminalia palaeochebula Awasthi & Prasad 1990	*Terminalia chebula*	India, Mynmar, Sri Lanka	Moist deciduous

Contd.

Table 7—Contd.

STRATIGRAPHIC SEQUENCE	FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
	Terminalia panandbroensis Lakhanpal & Guleria. Awasthi & Prasad 1990	*Terminalia coriacea*	India, Mynmar	Deciduous
Chor Khola beds	MYRISTICACEAE			
	Myristica palaeoglomerata Awasthi & Prasad 1990	*Myristica glomerata*	Malay peninsula	Evergreen
	POACEAE			
	Bambusa siwalika Awasthi & Prasad 1990	*Bambusa tulda*	India, Mynmar	Moist deciduous
	FABACEAE			
	Millettia palaeoracemosa Awasthi & Prasad 1990	*Millettia racemosa*	India, Mynmar	Deciduous
	Entada palaeoscandens (Leaf). Awasthi & & Prasad 1990	*Entada scandens*	India, Mynmar	Moist deciduous to to semi-evergreen
	EUPHORBIACEAE			
	Excoecaria palaeocrenulata Awasthi & Prasad 1990	*Excoecaria crenulata*	Southern India	Evergreen
	CLUSIACEAE			
	Calophyllum suraikholaensis Awasthi & Prasad 1990	*Calophyllum polyanthum*	Sikkim and Khasi Hills	Evergreen
	DIPTEROCARPACEAE			
	Dipterocarpus siwalicus Lakhanpal. Guleria, Awasthi & Prasad 1990	*Dipterocarpus tuberculatus* *D. turbinatus*	Northeast India to Southeast Asia	Evergreen
Paira Khola beds and Bankas beds	DIPTEROCARPACEAE			
	Dipterocarpus siwalicus	*Dipterocarpus tuberculatus* *D. turbinatus*	Northeast India to Southeast Asia	Evergreen
	ANNONACEAE			
	Polyalthia simiarum Awasthi & Prasad 1990	*Polyalthia simiarum*	Northeast India, Mynmar	Evergreen
	FABACEAE			
	Cynometra siwalika Awasthi & Prasad 1990	*Cynometra polyandra*	Khasi and Cachar Hills, Malay Peninsula	Evergreen

representatives of modern families of upland and lowland vegetations, viz., Cyatheaceae, Schizaeaceae, Lindasaeaceae, Polypodiaceae, Pinaceae, Liliaceae, Arecaceae, Bombacaceae, Oleaceae, etc. Singh and Sarkar (1990) have broadly inferred that the vegetation in the western Himalaya during Lower Miocene was subtropical and humid. A similar assemblage of palynofossils representing the families Hymenophyllaceae, Schizaeaceae, Polypodiaceae, Lycopodiaceae, Pinaceae, Arecaceae, Aquilifoliaceae, Rutaceae, Tiliaceae, Chenopodiaceae and Pandanaceae is reported from Dharamsala sediments (equivalent to Dagshai and Kasauli formations) of Himachal Pradesh by Mathur and Venkatachala (1979) and Mathur (1984). Saxena and Bhttacharyya (1990) added a few new families, viz., Parkeriaceae, Adiantaceae, Araucariaceae, Potamogetonaceae, Lentibulariaceae, Malvaceae and

Mimosaceae to the Dharamsala palynoflora assemblage, suggesting prevalence of tropical to subtropical humid conditions. Occurrence of *Pinus* pollen in the Kasauli and Dharamsala sediments suggests that during Early Miocene the Himalaya seem to have attained sufficient elevation enabling Pinaceae and other subtropical and temperate elements from the North and West Asian mainland to immigrate and subsequently proliferate all over in the higher reaches.

SIWALIK FLORISTICS

The Siwalik flora includes the following assemblages from a number of exposures located in the foot-hills, covering an area between Jammu in the west and Arunachal Pradesh in east (Map 1).

Jammu—The study of Siwalik plant fossils was infact initiated by Professor Sahni (1931) who for the first time reported two petrified woods as *Palmoxylon jammuense* and *P. wadiai* from the alluvial boulder deposits from the banks of Tawi and Tarangiri rivers near Jammu, but the exact stratigraphical position of the rocks from which these woods were derived is not known. However, detailed account of these woods by Sahni was posthumously published (Sahni, 1964). The only other known plant fossil from Jammu area is *Poacite-siwalicus*, a grass-like monocot leaf from the Palandri Formation = Chinji Formation near Palandri, Rajouri District (Sahni, 1964).

Himachal Pradesh—Balugoloa near Jawalamukhi in Kangra District and Nalagarh in Solan District are two important localities of the Lower Siwalik which have been subjected to palaeobotanical study. The former is famous for excellently preserved leaf-impressions borne on fine to coarse-grained hard sandstone. They have been studied by Lakhanpal (1965, 1967, 1968, 1969), Lakhanpal and Dayal (1966), Lakhanpal and Guleria (1987) and Lakhanpal and Awasthi (1992). The latter contains exlusively petrified woods which have been worked out intensively by Prakash (1975, 1979a, 1979b) and Yadav (1989). They have been listed in the Tables.

Besides, Lakhanpal, Tiwari and Awasthi (1987) reported leaf and culm of bamboo from the Lower Siwalik' of Ranital, Kangara-Jawalamukhi Road, Kangara District. From Khundian, a locality of Middle Siwalik in Jawalamukhi area, a solitary wood — *Anisopteroxylon jawalamukhi* comparable to *Anisoptera* of Dipterocarpaceae is described by Ghosh and Ghosh (1958). From the same area Mathur (1974, 1978) reported a seed (*Boraginocarpon lakhanpalii*) and a leaf of Lauraceae—*Litsea bhatiai*, from the Upper Siwalik beds, and a papilionaceous leaf, *Papilionid, Mallotus* sp. and grass-like leaves from Lower Siwalik. Dayal and Chaudhri (1967) also reported some ill preserved dicotyledonous leaves, from Lower Siwalik beds of Koshalya River near Kalka.

Uttar Pradesh—In the foot hills of Uttar Pradesh, from Mohand in Saharanpur District to Tanakpur in Nainital District, there are a number of exposures of Lower and Middle Siwalik which contain a great variety of woods and leaves. However, concerted efforts have so far been made by several workers to study the petrified woods from Kalagarh area, Pauri Garhwal District (Prakash, 1978, 1981; Prakash & Prasad, 1984; Awasthi & Prasad, 1988; Prasad, 1987, Prasad & Prakash, 1988; Prasad, 1989, 1990b, 1990c; Trivedi & Ahuja, 1978a, b, c, 1979a, b, 1980; Trivedi & Misra, 1978, 1979, 1980; Trivedi & Panjwani, 1986) and leaf-impressions from Poornagiri Hill (also spelt as Punyagiri Hill) near Tanakpur, Nainital District (Lakhanpal & Guleria, 1978; Awasthi, unpublished data).

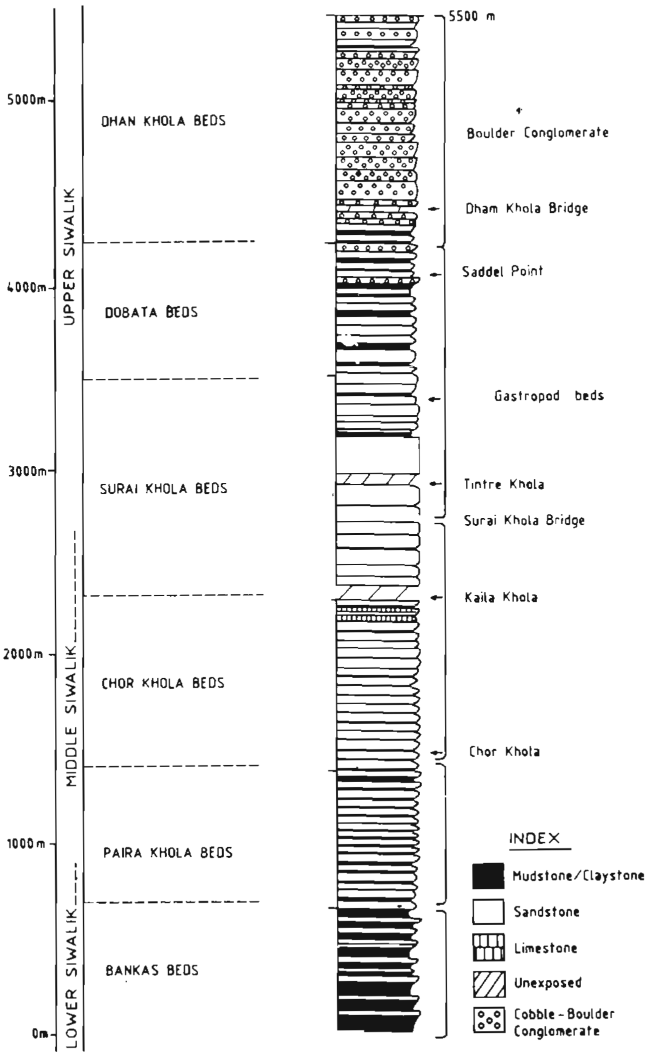
In Mohand area, district Saharanpur, the Middle Siwalik sediments contain semi-carbonised and petrified woods which have been meagrely studied. Rawat (1964, 1964-1965), in his preliminary reports briefly described two fossil woods as *Dipterocarpus* and *Bauhinia*. The Siwalik beds near Hardwar, locally known as "Hardwar beds" .contain leaf-impressions. Varma (1968) described a few leaves from Bagh Rao near Hardwar as *Meliaceaephyllum mahagonites, Eucalyptophyllum raoi, Diospyros embryopterisites* and a leaf cf. ? *Croton tegelis*. Except for *Diospyros embryopterisites* the identification of these leaves is doubtful. *Meliaceaephyllum mahagonites* cannot be a leaf of *Sweitenia mahagoni* since it is an exotic plant which is known to have been introduced in India from central America about 200 years ago. The leaf assigned to *Eucalyptophyllum raoi* does not exhibit the characters of *Eucalyptus*; *Eucalyptus* too is an introduced Australian tree.

Bihar-Nepal Border—From a small patch of fossiliferous beds of the Siwalik exposed near India-Nepal boundary Post no. 35 Bhikhnathoree, West Champaran District, Bihar, Lakhanpal and Awasthi (1984) and Awasthi and Lakhanpal (1990) have reported 20 species of dicotyledonous leaves.

Nepal—The Siwalik Hills of India extended into Nepal are designated as Churia Hills and the sedimentary sequence is known by Churia Group. Our recent study of plant megafossils from the Siwalik of the western sector of India and the Churia Group of Nepal indicates better representation of plants both qualitatively and quantitatively. The plant remains from the Churia Group have been studied in detail.

(i) *Koilabas*—Koilabas is a small village situated at the base of foot-hills, 1 km inside Nepal territory, near Jarwa, Gonda District, Uttar Pradesh. The sediments are exposed along the upstream of Koilabas Nala. Unfortunately, detailed stratigraphical information of the sequence is lacking. However, the sediments show gradual coarsening from fine-grained hard calcareous sandstone and shales to sandstone and shales obviously representing the Lower and Middle Siwalik. The fossil plants comprising leaf-impressions have been studied by Prasad and Prakash (1984), Prasad (1990a, 1990b) and Tripathi and Tiwari (1983).

(ii) *Surai Khola*—Geologically, Surai Khola is one of the important areas in the Churia Hills where a complete and uninterrupted sequence of the Siwalik Group is exposed along Mahendra Highway, covering a distance of about 16 km from Surai Naka to Rangsing Khola in Kapilvastu District, Nepal. This sequence measures about 5,650 m in thickness, representing the Lower, Middle and Upper Siwalik (Corvinus, 1988, 1990). On the basis of lithology Corvinus (1990, text-fig. 2) divides the whole sequence into the Bankas beds, Paira Khola beds (Upper part of Lower Siwalik), Chor Khola beds (Lower part of Middle Siwalik), Surai Khola beds (Upper part of Middle Siwalik), Dobata beds and Dhan Khola beds (Upper Siwalik). The first four beds contain large number of excellently preserved leaf-impressions and rarely fruits/seeds in the fine grained calcareous sandstone, mudstone and shales while the last three beds show rare occurrence of unidentifiable fragmentary grass-like leaves in clays and friable sands. Out of a big collection of leaves, Awasthi and Prasad (1990) have so far identified the following taxa which are listed in the stratigraphical sequence (see Text-figure 1).



Text-figure 1—Surai Khola profile (after Corvinus 1990).

BENGAL AND ARUNACHAL PRADESH

In the eastern sector of India Siwalik has received very little attention for palaeobotanical study. There are some stray published report on megafossils from the foot-hills of Bengal and Arunachal Pradesh. Pathak (1969) documented a few fragmentary leaves as *Castanopsis tribuloides, Cinnamomum tamala, Machilus villosa, Litsea polyantha, Bridelia stipularis, B. verrucosa, Mallotus philippinense* and *Rhododendnon lepidotum* from the Middle Siwalik sediments of Mahanadi section in the foot-hills of Darjeeling District. Since the fossil leaves are fragmentary, Awasthi (1982) opines that their generic and specific determinations are doubtful.

From Arunachal Pradesh leaves of *Ziziphus* and *Dioscoria* have been reported by Singh and Prakash (1980) from a small exposure, about 5 km north of Pasighat, district Siang. A small collection of semisilicified and semi-carbonised woods from the Upper Subansiri of Ghoghra River section in Siang and near Kimin in Subansiri District show the presence of mostly evergreen taxa, viz., *Shorea, Euphoria, Gluta, Albizia, Afzelia-Intsia, Cynometra, Cassia* and *Sindora* (Awasthi, unpublished data). From the same area dicotyledonous leaves of uncertain generic affinities have been reported by Chowdhury *et al.* (1970).

PALAEOCLIMATE AND FLORAL EVOLUTION

From a perusal of the above assemblages of

Siwalik flora (Table 1-7), provided with comparable extant taxa, their distribution and type of forest indicated, it is evident that in the Himalayan foot-hills tropical forest with overwhelming majority of evergreen elements existed during Middle Miocene-Pliocene times when the Siwalik sediments were laid down. Among them the most common and widely distributed genera are: *Polyalthia, Calophyllum, Dipterocarpus, Anisoptera, Hopea, Shorea* (other than *Shorea robusta*), *Aglaia, Dracontomelum, Mangifera, Gluta, Swintonia, Sterculia, Dysoxylum, Koompassia, Cynometra, Pongamia, Ormosia, Sindora, Dialium, Bauhinia, Albizia, Cassia, Duabanga, Syzygium, Diospyros, Mallotus, Litsea, Cinnamomum, Phoebe*, etc. The flora includes a sizeable number of evergreen taxa of southeast Asian distribution, e.g., *Anisoptera, Gluta, Koompassia, Sindora, Swintonia* and some species of *Dipterocarpus* and *Hopea*. Besides, a number of other taxa which occurred during Siwalik and continued to exist even today were not found in the pre-Siwalik sediments of peninsular and extra-peninsular regions. Obviously, such taxa must have come from the neighbouring countries.

With the rise of Himalaya a large area previously occupied by Tethys was converted into land with numerous water basins. Thus the major changes in the physiography brought about progressive changes in the climate all along the foot-hills which became more warm and humid with high precipitation. During that time the Indian Plate had already joined with Eurasia resulting in the formation of land connection between India and neighbouring continents. It is widely accepted that through land connections several tropical moist evergreen to semi-evergreen elements from Southeast Asia led by dipterocarps entered the Indian subcontinent possibly via Mynmar where they spread all over and ultimately reached the Himalayan foot-hills region and got mixed up with the then existing local vegetation. Thus in the Tertiary floral history of Indian Peninsula and extra-peninsula Middle Miocene was the time of maximum proliferation, diversification of tropical vegetation, particularly of the evergreen forest.

The megafloral assemblage of Siwalik has no representation of gymnosperms. However, the palynological studies of Siwalik sediments by Banerjee (1968), Lukose (1968), Nandi (1972, 1975), Mathur (1974), Saxena and Bhattacharyya (1987), Singh and Saxena (1980, 1981), Saxena and Singh (1980, 1982a, b), Singh and Sarkar (1984) and Saxena *et al.* (1984) have revealed a wide representation of gymnospermous pollen comparable to *Pinus, Podocarpus, Abies, Cedrus, Picea, Tsuga* and pollen of temperate angiospermous genera, like *Alnus, Betula, Carya, Juglans*, etc. The pollen evidence suggests that these had already occupied the higher reaches of the newly emerged Himalaya from northern side before Miocene orogeny. The occurrence of tropical and subtropical to temperate pollen taxa together in the Siwalik sediments, therefore, leads to infer that the vegetation during Miocene was disposed altitudinally, tropical forest on the lower slopes up to 1,000 m elevation and temperate forest on the higher slopes and with perhaps a subtropical belt in between.

As a result of the rising Himalaya small fresh water basins also formed on the Tibetan side in which the Kargil molasse and other Miocene sediments of Ladakh-Karakoram area were laid down. Occurrence of temperate elements of Sino-Japanese origin, such as *Trachycarpus, Prunus* and *Populus* in the Liyan/Kargil Formation (Guleria *et al.*, 1983; Lakhanpal *et al.*, 1984a) further supports a different floral pattern on the higher slopes where tropical plants like *Livistona* had grown earlier in the lower slopes (Lakhanpal, 1982; Lakhanpal *et al.*, 1984b).

The tropical forest mostly comprised overwhelmingly the taxa of Malayan and southeast Asian distribution while the subtropical and temperate forests had a considerable Sino-Japanese and Russian elements. In the lower slopes, as is evident from megafossil record, the flora remained nearly unchanged in its overall composition and distribution pattern until the close of Pliocene.

The Surai Khola megafossil assemblage of Nepal is the only floral assemblage known from a continuous and uninterrupted sequence of Lower, Middle and perhaps the basal part of Upper Siwalik. It depicts a gradual change in the floral composition (Awasthi & Prasad, 1990). The basal sediments assigned to the Lower Siwalik contain more of lowland evergreen elements. The most important amongst them are *Polyalthia, Dipterocarpus, Calophyllum, Gluta, Cynometra*, etc. Along with the leaves of these taxa, algal forms, viz., *Pediastrum, Botryococcus, Zygnema, Mougeotia* and pteridophytes such as *Azolla* and *Ceratopteris* have also been recovered (Sarkar, 1990) suggesting the existence of fresh water bodies like swamps and flood plains in the area which created excessive humid conditions for the luxuriant growth of evergreen forest. More or less similar conditions seem to have prevailed during the Middle Siwalik as evidenced from the Chor Khola assemblage. But the total absence of evergreen taxa in the Surai Khola beds which are assigned to the upper part of Middle

Siwalik, provides evidence that the luxuriant evergreen forest started dwindling towards the end of Middle Siwalik or the beginning of Upper Siwalik and ultimately were replaced by deciduous elements such as *Clinogyne, Flacourtia, Millettia, Bauhinia, Breynia*, etc. This is corroborated by high incidence of pollen of the members of Malvaceae and Mimosaceae (Sarkar, 1990).

The last phase of the Himalayan uplift which occurred during Early Pleistocene brought further change in the physiography. The climatic conditions progressively changed from warm humid to drier and cooler adversely affecting the vegetation patterns of the entire region. The dipterocarps community growing luxuriantly suffered a big setback when all its members totally disappeared from the western and central sectors of the Himalayan foot-hills. *Dipterocarpus* and *Shorea assamica* are the sole survivors which have restricted distribution in the evergreen forest of Assam and Arunachal Pradesh. As replacement of dipterocarps and their associates some new taxa had evolved while others adapted the changing conditions, e.g., *Ziziphus*. This genus, occurred in association of *Dipterocarpus* and other evergreen taxa, is now growing luxuriantly in moist to dry deciduous and grassland forest (Savannah). Amongst dipterocarps, *Shorea robusta* is the only taxon which today occurs as a dominant tree in the Himalayan foot-hills of central and western sector. Surprisingly not a single piece of wood or a leaf of this species has been found in the Neogene sediments of India, although a leaf of *Shorea robusta* has been reported from the Pleistocene (most probably Holocene) deposits of Mahuadanr, Palamu District, Bihar, along with a number of other taxa which grow in nearby deciduous forest (Bande & Srivastava, 1990). Thus the diversity of environment especially cooler climate and mountainous physiography during Pleistocene have affected the plant life of the entire region and must have given impetus to hybridization, an important mechanism in providing generic diversity and preserving the adaptability in plants (Vishnu-Mittre, 1969). *Shorea robusta* may be considered as an example of this phenomenon. This taxon seems to have evolved sometimes during Pleistocene. It is now widely accepted that changes in physiography and climate of the Himalayan region during different phases of its upheaval have largely been responsible for the changes of vegetational scenario and evolution its flora.

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Cenozoic plant fossils and the Himalayan orogeny

H. P. Singh

Singh HP 1992. Cenozoic plant fossils and the Himalayan orogeny. *Palaeobotanist* **40** : 328-335.

Selected palyno- and megafloras from the Cenozoic Era of extrapeninsular India have been examined in the orogenic context of the Himalaya. Distribution of vegetations and variation in climates are in conformity with the periodic phases of the Himalayan uplift. Continued rise of the Himalaya acted as a barrier for the flow of moisture resulting in lesser precipitation, higher snow cover and increased aridity. In response to the topographical and climatic variations a progressive change occurred in the composition of vegetations during the past 60 Ma. The ancestral tropical floras inhabited the lower slopes, whereas the temperate floras colonized the higher slopes. Altitudinal segregation of floras is clearly evident from the Mid-Miocene orogeny. Palaeocene to Mid-Pleistocene plant diversity generally varies from evergreen, semi-evergreen, dry/moist deciduous, warm temperate to temperate forest types. Migrations/immigrations and extinctions of plant taxa were largely influenced by physiographical and climatic changes. Enrichment and diversification of the Neogene Himalayan floras have also been brought in through the process of evolution. Cult-historical evidences point out that the Himalayan range continued to rise even after the advent of man.

Key-words—Palynology, Palaeobotany, Cenozoic, Himalayan orogeny, India.

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साराँश

नूतनजीवी अश्मित पौधे एवं हिमालय की उत्पत्ति

हरिपाल सिंह

हिमालय की उत्पत्ति के सन्दर्भ में प्रायद्वीपीय भारत के नूतनजीवी कल्प से उपलब्ध परागाणविक एवं गुरुवनस्पतिजातों का अध्ययन किया गया। विभिन्न चरणों में हिमालय के उत्थान के समय वनस्पति के वितरण एवं जलवायु में विभिन्नता में पारस्परिक सम्बन्ध है। हिमालय के लगातार उत्थान से पानी की कमी, उच्चतर बर्फ के शिखर तथा मरुस्थली परिस्थितियाँ उत्पन्न हो गईं। भौगोलिक एवं जलवायवी विविधताओं के कारण पिछले 60 एम-ए० काल में वनस्पति की संरचना में लगातार परिवर्तन होते रहे हैं। पूर्वजी उष्णकटिबन्धीय वनस्पतिजात निचली ढलानों पर विकसित हो गये जबकि शीतोष्ण वनस्पतिजात और ऊँचाई पर स्थापित हो गये। हिमालय के मध्य-मध्यनूतन उद्भव से वनस्पतिजातों में अन्तर स्पष्ट हो जाता है। पुरानूतन कल्प से मध्य-अत्यन्तनूतन कल्प तक के पौधे सामान्यतः सदाहरित से अर्धसदाहरित, शुष्क/नम पर्णपाती, गर्म उष्णकटिबन्ध से उष्णकटिबन्ध प्रकार के वनों को इंगित करते हैं। भौगोलिक एवं जलवायवी परिवर्तनों के कारण पौधों का प्रवासन और विलुप्तीकरण हुआ। पश्चतृतीयक युगीन हिमालय का सघन एवं विविधता युक्त वनस्पतिजात विकास प्रक्रिया का ही एक उदाहरण हैं। अतीतकालीन प्रमाणों से व्यक्त होता है कि हिमालय का उत्थान मानव के पृथ्वी पर पदार्पण करने के पश्चात भी होता रहा है।

THE Himalayan range is the youngest mountain range in the world and is believed to have started uplifting about 60-70 million years ago. Delineating the northern boundary of the Indian subcontinent, it runs about 2,400 km from the west to the east. Several views on its origin, orogeny, extent and limits have been expressed from time to time. Generalized accounts of the Himalayan Tertiary mega-and palynofloras with reference to their emergence, radiation and extinction patterns are available in scattered form. The object of the present paper is to tag the palynological and palaeobotanical data with major geological events so that problems associated with endemism, regionalism and floral evolution as influenced by orogenic movements of Himalaya in time and space are understood through the Cenozoic Era.

It was to the credit of Professor Birbal Sahni (1936a) who made the first attempt to adduce palaeobotanical evidence to explain the Mid-Pleistocene uplift of Himalayas in the Karewas of

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Kashmir. In fact, the discovery of an Early Pleistocene subtropical fossil flora from the lacustrine deposits of Pir Panjal Range at an elevation of about 3,666 m, which at present enjoys a temperate climate, triggered a sense of query in Sahni (1936a) who observed that, "How can we explain the presence of their fossil remains at altitudes where we know that they can not exist today". The extant forms of most of the Pir Panjal fossil flora (Early Pleistocene), viz., *Vallisneria, Trapa, Mallotus, Pittospermum, Myrsine, Cedrus, Pinus,* oaks, laurels, figs, alders, charophytes, etc. are known to inhabit today altitudes lower than 2,000 m. Based on this analysis Sahni (1936a) remarked that, "Since the time when the plants and animals, of which the fossils remains are now found at 11,000 ft. or even higher, flourished in and around this lake, the sediments have been lifted out of their original horizontal position and have been upheaved through at least five thousand feet with (geologically speaking) recent upheaval of the Pir Panjal Range". Even the extant acquatic plants, viz., *Trapa, Vallisneria,* charophytes, etc. still continue to grow in the lakes of Kashmir which are situated at several thousand feet lower than the present elevation of Pir Panjal Range. This led Sahni (1936a) to sum up that "Their study leads to irrestible, though at first incredible, conclusion that the Himalayas have been thrown up by several thousand feet since the advent of man". A decade later Puri (1947) published a comprehensive account of fossil flora from the Pir Panjal Range. This study supported the conclusions of Sahni (1936a). During subsequent years, a considerable palaeobotanical and palynological data have been generated from the Palaeocene to Pleistocene sediments of the Himalaya, yet no effort has been made to examine them in the orogenic perspective of Himalaya.

OROGENIC HISTORY

The rise of the Himalaya is ascribed to several periodic orogenic movements. Five major phases of orogenic episodes have been recognized by Sharma (1984): (i) Karakoram orogeny (Upper Cretaceous); (ii) Post-Kirthar orogeny (end of Eocene-Oligocene); (iii) Sirmurian orogeny (Middle Miocene); (iv) Siwalik orogeny (close of Pliocene-Pleistocene); (v) Post-Pleistocene orogeny. Raina *et al.* (1982) have recognized 3 principal phases of orogenic episodes— (i) the Ladakh phase (Late Cretaceous-Early Eocene); (ii) Dharamsala phase (Miocene); and (iii) the Siwalik phase (Late Pliocene-Middle Pleistocene). Though orogenic movements slowed down considerably after Middle Pleistocene yet their pulsations seemed to have affected the rise of the Himalaya even after the advent of man for which cult-historical evidences are available. The three major Himalayan orogenic belts constitute: (i) the southern most sub-Himalayan Zone, (ii) the lesser Himalayan Zone, and (iii) the Tethyan Himalayan Zone.

During the Late Cretaceous the Tethys sea underwent shallowing and narrowing with the result two or more longitudinal basins appeared in Eocene. The Oligocene Epoch witnessed wide spread regression. The Middle Miocene orogeny of Himalaya created a foredeep along its southern side in which were laid the Siwalik molasse sediments. The Tibetan side received the Kargil molasse and other Miocene sediments of Ladakh Karakoram area. Therefore, the first phase of Himalayan orogeny (Cretaceous-Early Eocene) is observed at Indus-Suture Zone of Ladakh. The second phase of episode is recorded in the Eocene-Pliocene epochs. Rapid sedimentation of Murrees and Siwaliks is due to Middle Miocene orogenic movements of Himalaya which later continued up to Pleistocene Epoch. The present physiognomy of Himalaya was attained as the molassic sediments of Late Pliocene-Pleistocene were uplifted.

DATA ANALYSIS

Palaeobotanical and palynological data sifted from the Tertiary sediments of Ladakh, Jammu, Himachal Pradesh, Uttar Pradesh, Nepal and Arunachal Pradesh have been analysed with the object to select such taxa or groups of taxa which may provide information on their past and present distributional requirements particularly in regard to their possible botanical relationship, climatic tolerance, ecological association, latitudinal and altitudinal adaptation. Although such refined data are not sufficient for precise determination of exact time and corresponding vegetational changes in response to orogenic movements, climatic variations, differential topographic elevations and sustained migration and immigration of several plant species from adjoining areas yet a generalized picture of vegetational changes within the well recognized orogenic pulsations has been deciphered. In order to have a better understanding of vegetation patterns, palyno- and mega-floral evidences from the Cenozoic sediments of Himalaya have been considered together.

Palaeofloras of Ladakh/Post Kirthar orogeny

During the Ladakh/Post Kirthar phase of

orogeny (Palaeocene to Oligocene) the physiography of the Himalaya, both in western and eastern parts, is assumed to support low relief landscapes. It further leads to assume that due to lack of elevated topography the climate was equitable and tropical, supporting evergreen to semi-evergreen type of vegetations covering a wider stretch of areas from north-west to north-east on the southern face of Himalaya. In the absence of altitudinal variation, the latitudinal influence on the composition of flora seems to be less pronounced. The Palaeocene-Eocene vegetations from the Dras Volcanics of Ladakh, Kalakot area of Jammu, Kalka-Simla Hills of Himachal Pradesh, Nepal and Arunachal Pradesh contain largely tropical components of semi-evergreen to coastal swamp-type vegetation. Dinoflagellate cysts constitute a larger part of some assemblages alongwith *Pediastrum* and *Botryococcus* (Sarkar & Singh, 1988; Singh, 1981, 1989). The main palaeofloral components of western Himalaya were palms and several members of tropical families represented by Lycopodiaceae, Schizaeaceae, Matoniaceae, Polypodiaceae, Parkeriaceae, Podocarpaceae, Liliaceae, Nymphaeaceae, Poaceae, Oleaceae, Fagaceae, Anacardiaceae, Alangiaceae, Fabaceae, Clusiaceae, Lecythidaceae, Sapotaceae, Myristicaceae, Bombacaceae, etc. Members of Parkeriaceae, Alangiaceae, Juglandaceae and Fagaceae, which were hitherto known only from the Neogene sediments, have been recorded from the Palaeogene sediments as well (Singh, 1991; Singh & Sarkar, 1990). Based on palaeobotanical and palynological evidence it is surmised that the Palaeocene-Eocene landscape of eastern Himalaya was studded with mixed type of coastal swamp vegetation with a tropical climate. The Eocene assemblage from the Siang District (Arunachal Pradesh) contains palynotaxa, viz., *Ctenolophonidites, Lakiapollis, Pellicieroipollis, Incrotonipollis*, etc. (Tripathi & Singh, 1992). Some important pollen, frequently recovered from areas (Assam-Arakan Basin) adjacent to Himalaya, are of Podocarpaceae, Arecaceae, Liliaceae, Brassicaceae, Meliaceae, Clusiaceae, Rhizophoraceae, Anacardiaceae, Euphorbiaceae, Nymphaeaceae, Nelumboniaceae, etc. Most of the palynofloras studied contain dinoflagellate cysts indicating a near coastal environment of deposition. The Eocene marker taxa, viz., *Ctenolophonidites (Ctenolophon)* and *Lakiapollis (Durio)* from Arunachal Pradesh denote the post-Eocene terminal event. Their absence in the younger successions depict that they migrated to Malaya and adjoining areas of far east in order to escape the adverse onslaught of the changing climate. The aforesaid data denotes that the Palaeocene-Eocene palynological assemblages from western as well as eastern Himalaya broadly contained components of tropical vegetation conforming to semi-evergreen and mixed coastal type though they were represented in different latitudinal areas of Himalaya. It has been estimated that the Indian Plate collided with the Asian Plate during the Eocene which resulted in the rise of Himalaya. Prior to this collision it is apparent that during the later phase of the Ladakh orogeny or earlier part of the post-Kirthar phase of orogeny the floral components of low land coastal vegetation covered the southern face of Himalaya. Based on the present day ecological requirement of the then existing flora, it may be imagined that overall altitudes near to the present Gangetic plains along with tropical climate might have supported these floras. Later this Himalayan landscape appears to have been grossly disturbed by tectonic upheavals. At present the Palaeocene-Eocene strata are located on elevations varying from 800 to 2500 m or higher. Vegetations varying from tropical, subtropical to temperate type inhabit these rocks depending upon the extent of altitude they inhabit and the amount of precipitation they receive. Therefore, their present day altitudinal disposition on these sediments is a secondary phenomenon subsequent to the rise of the Himalaya. Composition of the *in situ* Palaeocene-Eocene floras is altogether different as compared to the present day vegetation growing on these rocks.

The Oligocene Epoch witnessed a large scale sinking evidenced by the thick deposits of sediments, as well as raised elevations after the Eocene collision of the Indian Plate. The raised topography resulted in the development of several land connections between India, Burma and Malaya. These pathways facilitated migration/immigration of several plant taxa. To exemplify members of Fabaceae and Sapotaceae seem to have migrated from Malaya to India. Recovery of pine pollen from the Oligocene strata of eastern Himalaya leads to believe that the pines made a pioneering venture to move from the north to invade the Indian subcontinent. Thereafter, they continued to migrate towards the north-west. The earliest record of pine pollen from the western Himalaya is from the Kasauli Formation (Early Miocene), Himachal Pradesh (Singh & Sarkar, 1984a). Palaeobotanical data sets are meagrely known from the Oligocene Epoch of Ladakh and Himachal Pradesh though they are reasonably well documented from the Assam-Arakan Basin in the north-east which is believed to constitute the same botanical province as that of the

Himalaya. The Oligocene pollen assemblages of Ladakh Himalaya (Bhandari *et al.*, 1977) contain components mostly conforming to moist deciduous type of forest. Some of them are *Carya, Betula, Alnus, Juglans,* Chenopods, grasses, etc. The present day elevation of Ladakh Himalaya supports temperate vegetation. The rise of the Himalaya in this part has been substantial after the Oligocene Epoch through a series of orogenic pulsations. The Oligocene palynoflora of Himachal Pradesh (Singh & Khanna, 1980; Mathur & Venkatachala, 1979; Mathur, 1984) is closely comparable to coastal transitional type of vegetation. It is conspicuous by the absence of dinoflagellate cysts and has high incidence of palm pollen. Pollen grains of *Inaperturopollenites*-complex (including *Araucariacites*) and *Podocarpidites* also abound in abundance. Besides the presence of herbaceous elements and tree forms, pollen comparable to *Castanea, Galium, Amaranthus, Chenopodium,* Arecaceae, Fabaceae, Sapotaceae, Buxaceae, Acquifoliaceae, etc. have been observed (Mathur, 1984). The present day elevation of these strata varies from 800 to about 1,700 m, supporting tropical to subtropical vegetation. Spores comparable to those of Parkeriaceae (*Polypodium*) constitute a major proportion of the Oligocene assemblages in north-eastern part of the Indian subcontinent. Though the representation of angiospermous pollen is poor yet some pollen taxa comparable to those as found in Arecaceae, Fabaceae, Oleaceae, Bombacaceae, Lamiaceae, Potamogetonaceae, etc. are frequently noticeable. Early Miocene palynoflora from the Kasauli Formation (western Himalaya) contains the presence of *Pinus* pollen along with pollen grains of Bombacaceae, Arecaceae, Oleaceae and several other angiosperm families indicative of a subtropical climate. This evidence provides a clue that the Kasauli Formation during the Early Miocene time would have attained sufficient height with a cooling of climate which supported the growth of *Pinus.* The Lower Miocene assemblages, in general, depict a gradual shift towards colder climate which heralded the appearance of moist deciduous components. The Dharamsala palynological assemblages (Oligocene-Lower Miocene) are more varied in the composition of taxa and have pollen comparable to Acquifoliaceae, Rutaceae, Tiliaceae, Chenopodiaceae, Caprifoliaceae, Oleaceae, Pandanaceae, etc. The land topography from the Palaeocene-Lower Miocene time of Himalaya seems to have witnessed several changes particularly in regard to the rise in elevation, change in climate, development of physical barriers and wide spread regression of the sea beginning from the Upper Eocene to Late Oligocene. The continued inflow of subtropical elements into the tropical vegetation by the Early Miocene time is progressively discernible. The gymnospermous pollen particularly of *Pinus* lends substantial support towards this inference. Subsequent changes in the composition and distribution of Neogene floras of Himalaya are well documented.

PALAEOFLORAS OF DHARAMSALA/SIRMURIAN OROGENY

The Dharamsala/Sirmurian phase of orogeny (Miocene) changed the floristic scenario of Himalaya drastically. The most distinctive features of the distributional pattern of floras seem to be their adaptation to different altitudinal belts. The tropical elements continued to inhabit lower slopes of Western Himalaya (< 1000 m) and perhaps transgressed marginally into the subtropical zone of climate, as is the case at present although to draw a precise boundary between the two zones is difficult.

The occurrence of *Prunus* (Kargil Formation) and *Livistona* (Hemis Conglomerate) has been reported by Guleria *et al.* (1983) and Lakhanpal *et al.* (1983) from the Middle Miocene strata of Ladakh Himalaya. The latter authors have also inferred that *Trachycarpus, Prunus* and possibly *Populus* immigrated from the mainland of Asia and became a part of the temperate Himalayan flora. By this time gymnospermous elements of Abietineae and subtropical angiospermous families (Moraceae, Myrtaceae, Euphorbiaceae, Fabaceae, etc.) seem to have adapted themselves to grow on different altitudinal belts (500-2,000 m).

Some important constituents of the Middle-Late Miocene megaflora from Uttar Pradesh and Himachal Pradesh (Prakash, 1972, 1979; Awasthi, 1982) are *Afzelia, Albizia, Anisoptera, Cassia, Cynometra, Dalbergia, Diospyros, Dipterocarpus, Ficus, Fissistigma, Milletia, Polyalthia, Acacia* and *Ziziphus* alongwith other members of Moraceae, Euphorbiaceae, Myrtaceae, Fabaceae, etc. So far no megafossils of gymnospermous plants have been recorded from these areas. Palynological studies of several sections of Middle Siwalik sediments (Upper Miocene) from these areas have brought to light pollen taxa comparable to those of extant equivalents, viz., *Pinus, Abies, Cedrus, Picea, Podocarpus, Tsuga* and members of Arecaceae, Liliaceae, Myricaceae, Juglandaceae, Magnoliaceae, Fabaceae and Moraceae (Banerjee, 1968; Lukose, 1969; Nandi, 1975, 1980; Singh & Saxena, 1981; Saxena & Singh, 1982a, b; Singh & Sarkar, 1984b; Saxena *et al.*, 1984). Because of the absence of gymnospermous megafossils and temperate plants in the Siwalik sediments, authenticity of the identification of gymnospermous pollen in these assemblages was questioned by Lakhanpal (1988). He opined that their occurrence in these sediments was due to their being blown in from the surrounding higher hills. However, palynological information provides compelling evidence to believe that the pines had established themselves reasonably well even during the Early Miocene on wider stretches of Himalaya. Later, they attained a position of near dominance after the Mid-Miocene orogeny. The other members of gymnosperms also seem to have attained a pronounced diversity. Here it may be recalled that near temperate conditions had set in during the Middle Miocene (Ladakh Himalaya) as is evidenced by the occurrence of *Prunus, Trachycarpus*, etc. It is a known fact that by then the Pir Panjal Range had not been upheaved in the Kashmir Valley. This situation might have allowed the cold winds to sweep over several areas in northern India. The earlier inference that these areas were warmer and wetter needs rethinking. It also does not seem logical to imagine that the Siwalik vegetation would have flourished with the exclusive absence of gymnosperms. Palynological evidences strongly suggest that this problem needs reconsideration. Based on palynological information a mangrove swamp vegetation in Jawalamukhi area and a near-shore vegetation in Nahan area as indicated by Mathur (1984) has not been confirmed by our extensive palynological work in the latter area. It is believed that the Eocene epicontinental sea had completely regressed by the close of Early Oligocene. However, in Arunachal Pradesh the end of Middle Eocene witnessed marine transgression which recommenced in the Middle Miocene in a foredeep in front of the mountain range where the Siwalik sediments were laid. These sediments mainly represent fluviatile deposition though palynological evidences indicate the existence of brackish water environment. As the Himalyan orogeny uplifted the Siwalik foredeep, it resulted in quick erosion and deposition simultaneously. Thus a thick mass of strata was accumulated in a short span of geological time.

The Miocene assemblages from the eastern Himalaya are few. They are restricted to areas in Kameng, Subansiri and Siang districts (Dutta, 1980; Dutta & Singh, 1980; Singh & Tripathi, 1990). Pollen grains comparable to the members of Lycopodiaceae, Polypodiaceae, Matoniaceae, Schizaeaceae, Osmundaceae, Parkeriaceae, Pteridaceae, Podocarpaceae, Pinaceae, Arecaceae, Araceae, Ctenolophonaceae, Bombacaceae, Meliaceae, Liliaceae, Loranthaceae, Malvaceae are present. One of the assemblages (Dutta & Singh, 1980) also contains reworked Permian and Eocene palynofossils in addition to Miocene palynofossils like those of Parkeriaceae, Arecaceae, Meliaceae, Malvaceae, Bombacaceae, Labiatae, Pinaceae, Araucariaceae, Potamogetonaceae, *Nyssa* and several others. Palynofossils of Parkeriaceae and Arecaceae point out that the site of deposition was not far away from the coastal environment. Similar observation has been made by Singh and Tripathi (1990).

PALAEOFLORAS OF NEPAL HIMALAYA

Palaeobotanical and palynological investigations of the Siwalik sediments of Nepal Himalaya, though at a preliminary stage, bring to light the fact that the fossil leaf assemblage consists of Marantaceae, Poaceae (Gramineae), Arecaceae (Palmae), Anonaceae, Flacourtiaceae, Clusiaceae (Guttiferae), Dipterocarpaceae, Anacardiaceae, Fabaceae (Leguminosae), Combretaceae, Ebenaceae, Myristicaceae and Euphorbiaceae (Awasthi & Prasad, 1990). These authors inferred that the vegetation varied from tropical evergreen to semi-evergreen elements. The climatic shift from the tropical humid to tropical dry has been reflected by the vegetation from the older to younger horizons in Siwalik sediments. It is interesting to record that modern equivalents of these fossil taxa are represented in the tropical evergreen and moist deciduous forests of Assam, Bangla Desh, Burma and the Malayan region. The Early Siwalik flora from Surai Khola contains evergreen elements like *Polyalthia, Dipterocarpus, Calophyllum* and *Cynometra*. The lower part of the Late Siwalik flora consists of moist deciduous to dry deciduous elements, viz., *Clinogyne, Flacourtia, Milletia, Bauhinia, Diospyros, Breynia*, etc. The change in vegetation pattern seems to have been caused by the northward movement of the Indian Plate and subsequent rise of Himalaya.

Palynological assemblages from the Early, Middle and Late Siwalik Group of sediments from Surai Khola area of Nepal (Sarkar, 1990) show that the palynological spectra changed from fresh water swampy environment to a bottom land habit having largely semi-evergreen palaeoassociations of vegetation. Specimens comparable to *Botryococcus, Pediastrum, Zygnema* and *Mougeotia* have been recorded. Palynofossils comparable to *Lygodium, Ceratopetris, Schizaea*, Polypodiaceae, Matoniaceae, *Azolla*, Cycadaceae, *Pinus, Hibiscus*, Gramineae, Nymphaea, Liliaceae, Palms, *Acacia*, Typhaceae, Compositae, etc. constitute a large part of the assemblages. The changes in vegetational pattern from swampy evergreen, moist deciduous to dry deciduous vegetation are seen in the Early, Middle and Late Siwalik palynological successions respectively, the later part being rich in graminaceous pollen alongwith bisaccate pollen indicating the onset of drier conditions. The pinaceous pollen are detected in the Middle Siwalik which is coincident with the Mid-Miocene orogeny of Himalaya. By the middle of Miocene, floral evidences indicate that the Himalayan range had risen sufficiently high which provided favourable environment to the immigration of several cold loving plants from the Mediterranean and Sino-Japanese regions.

PALAEOFLORAS OF SIWALIK OROGENY

The Siwalik phase of orogenic movements (Late Pliocene-Middle Pleistocene) led to climatic changes, increased continentality, semi-arid conditions and further rise of Himalaya forcing the moisture loving plants like *Dipterocarpus* and others to migrate or perish. Cold loving plants like *Cedrus, Picea, Abies, Pinus, Magnolia, Alnus, Betula, Clematis, Juglans, Quercus, Rhododendron, Tsuga,* etc. established themselves well on the elevated landscapes of western Himalaya. The Pliocene assemblages though scantily known from Punjab, Himachal Pradesh, Haryana and Jammu and Kashmir bring out the fact that cool dry climate had set in, which supported growth of *Pinus, Larix* and magnoliaceous plants. Ranga Rao *et al.* (1981) ascribed the poor and bad preservation of organic matter in the Pliocene assemblages due to the prevalence of largely oxidising environment. Palynofossils comparable to some extant families, viz., Poaceae, Arecaceae, Pinaceae, Fabaceae, Betulaceae, Chenopodiaceae, Amaranthaceae, Euphorbiaceae, Linaceae, etc., distributed in the Mio-Pliocene assemblages from these regions have been studied (Saxena & Singh, 1982a, b; Singh, 1982; Singh & Saxena, 1981; Singh & Sarkar, 1984b). Abundance of palm pollen alongwith grass pollen representing the palm savana in the Boulder Conglomerate Bed has also been observed (Vishnu-Mittre, 1984).

Palaeobotanical evidence for the uplift of the Himalaya during the post Pliocene to Middle Pleistocene was provided by Sahni (1936b) and Puri (1947) in the Kashmir Valley. Plant megafossils of subtropical climate, viz., *Trapa, Typha, Vallisneria,* oaks, laurels, figs, alders, *Malotus, Pittospermum, Myrsine, Rhamnus, Cedrus, Pinus* which cannot grow beyond 1,730 m have been recovered from the Pir Panjal Range at a height of 3,660 m or more which at present has a temperate climate. Extant plants of these fossil taxa continue to thrive in the subtropical zone of climate at about 1,600 m or so. This evidence conclusively proves that the Pir Panjal Range was upheaved at least by 2,000 m during the mid-Pleistocene time. As a consequence of this uplift the subtropical climate changed to a temperate one on the high hills of Pir Panjal Range.

GENERAL DISCUSSION

Imprints of Cenozoic floras leave evidences of their altitudinal disposition. The temperate floras (Sino-Japanese) inhabited the higher slopes whereas the tropical forests (Malayan and South-east Asian taxa) continued to grow on the lower slopes. To decipher the limits and extinction of subtropical plants between the two belts remains to be understood squarely as floral elements of this type marginally grow in either of the two environments.

A cursory glance of floras through the Cenozoic Era of Himalaya brings out the fact that the Palaeocene-Oligocene time generally supported tropical to mixed coastal type vegetations which grew between 100-500 m. The Miocene floras varied from tropical wet semi-evergreen, wet subtropical to humid temperate types having altitudinal disposition between 500-2,000 m. The Pliocene floras conformed to dry or moist forest types as the wet subtropical and temperate forest dwindled (1,000-3,000 m). The Pliocene-Pleistocene floras of Himalaya exhibited the presence of several Sino-Japanese floral elements. The Pleistocene vegetation above the tree line limit (3,000 m) in Ladakh is distinct in having *Artemisia*/Chenopod grass steppe typical of glacial environment. The Pleistocene rise of Himalaya brought in the arctic-alpine elements from Chinese and Euro-Siberian regions.

Enrichment and diversification of the Neogene Himalayan flora took place due to several factors some of which are: the development of physical barriers brought in by orogenic movements, change in climatic patterns as controlled by the rise of Himalaya and sustained migration/immigration of several plant species from the adjoining areas. The modern flora of Himalaya contains the Euro-Mediterranean, Malayan-Burmese, African and Sino-Japanese elements. Spatial invasions and subsequent proliferation of immigrant plant taxa through the Tertiary Period of Himalaya is an inviting enquiry which needs indepth study in the chronological and orogenic context.

Cult-historical data (Sahni, 1936b) provide evidence that cultural contacts between China and India existed via Himalaya during Palaeolithic and

Neolithic times as the Pir Panjal Range was not high enough to act as an effective barrier for the migration of Palaeolithic or even Neolithic man. This evidence clearly brings out the fact that the Himalayan range continued to rise even after the advent of man.

The position of the Indian Plate during the Early Tertiary was at 45° to 50° south of its present position. It was more or less like a large island. Therefore, the possibility of the existence of land connections in Palaeocene with the northern continents seems to be remote. It also seems likely that no land connections existed between India, Africa and central Asia during the Eocene as well. The endemic character of plant communities provides evidence of restricted communication between India and the rest of Asia. Early Oligocene witnessed a wide spread regression of the sea and also uplift of the Himalaya leading to raised land topography which resulted in inflow and outflow of plant species in the eastern part of India. The endemic features of vegetation started vanishing in Early to Middle Miocene assemblages though several endemic forms continued to flourish. The Late Miocene and Pliocene floral evidences (9.5 Ma-2.5 Ma) exhibit restricted provincialism due to the development of lofty mountain ranges separating the Indian subcontinent from the rest of Eurasia. Migration and immigration of plant taxa seems to have continued up to 2.5 Ma. The final phase of Himalayan orogeny (mid-Pleistocene) raised the range so high that it restricted migration and immigration of plant taxa. Plant communities at present display a more or less regional character due to selective adaptation.

The exact mechanism of horizontal and vertical movements of land resulting in uplift of the Himalaya is widely debated. It has been observed that larger areas of land were elevated to approximately half of the value between 10-5 Ma. Areas of low land topography, viz., southern China and South-east Asia have continued to support tropical vegetation for the last 40 Ma. History of the vegetation and variations in climate by and large match with the periodic phases of the Himalayan uplift. The continued rise of the Himalaya, in general acted as a barrier for the flow of moisture from the Indian Ocean resulting in lesser precipitation, higher snow cover and increased aridity. The progressive change in vegetation during the last 60 Ma particularly corresponding to the altitudes and latitudes of the Himalaya, is clearly reflected by rapid diversity in the composition of taxa evolving from evergreen, semi-evergreen, moist deciduous, dry deciduous, warm temperate, temperate to alpine types (Singh & Sarkar, 1990). However, low lands and plains of South-east Asia and India have continued to remain warm and wet/dry even after the uplift of the Himalaya. Immigration and extinction of plant taxa have played a major role from the Miocene time onwards when land connections among circum-Mediterranean areas had mostly been established. Beside climatic consideration, it seems possible that the immigrating plant taxa might have caused extinction of several endemic forms through tough competition and vigorous colonization of the newly acquired lands. All these factors are likely to have contributed in developing the modern flora of extra-peninsular India.

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Stratigraphical implications of Tertiary palynological succession in north-eastern and western India

R. K. Kar

Kar RK 1992. Stratigraphical implications of Tertiary palynological succession in north-eastern and western India. *Palaeobotanist* **40** : 336-344.

Cretaceous and Tertiary sedimentary rocks are found overlying a Precambrian granite basement or occasionally the Sylhet Trap (Late Jurassic) in north-east India whereas in Kutch, western India, the Tertiary rocks rest on the Deccan Trap and its derivatives. In north-east the Tertiary succession is almost complete whereas in Kutch the Early and Middle Palaeocene and Late Eocene sediments are missing. More than 150 spores and pollen genera are described from the Tertiary sediments but except about 20 all are long ranging. The Early Tertiary palynological succession in north-east and Kutch is more or less similar and all the marker taxa are found simultaneously in the equivalent formations in both the regions. In north-east India, throughout the Tertiary succession, the pteridophytic spores are found in abundance whereas in Kutch they are found in meagre percentage. The distribution of marker taxa throughout the Tertiary has been shown with the help of a chart. It is assumed that during Palaeocene to Eocene the plants grew in tropical, coastal swamps whereas from Oligocene onwards the deposition was mostly riverine in the eastern region.

Key-words—Palynology, Palaeoecology, Tertiary, North-eastern India, Western India.

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साराँश

उत्तर-पूर्वी एवं पश्चिमी भारत में तृतीयक युगीन परागाणविक अनुक्रम का स्तरिकीय महत्व

रंजीत कुमार कर

क्रीटेशी एवं तृतीयक युगीन चट्टानें कम्बिय-पूर्व ग्रेनाइट अथवा कभी-कभी उत्तर-पूर्व भारत में सिल्हट ट्रैप (अनंतिम जूराई) के ऊपर स्थित पाई जाती हैं जबकि पश्चिमी भारत में कच्छ में तृतीयक चट्टानें दक्खिन ट्रैपों एवं इनसे सहयुक्त चट्टानों पर स्थित हैं। उत्तर-पूर्व में तृतीयक अनुक्रम लगभग पूर्ण है जबकि कच्छ में प्रारम्भिक एवं मध्य पुरानूतन तथा अनंतिम आदिनूतन अवसाद अनुपस्थित हैं। तृतीयक अवसादों से 150 से भी अधिक बीजाणु एवं परागकण प्रजाति वर्णित की गई हैं लेकिन इनमें से लगभग 20 को छोड़कर सभी लम्बी अवधि तक मिलती हैं। उत्तर-पूर्व एवं कच्छ में प्रारम्भिक तृतीयक परागाणविक अनुक्रम प्रायः एक जैसे ही हैं तथा दोनों क्षेत्रों में सूचक प्रजातियाँ समतुल्य शैल-समूहों में साथ-साथ मिलती हैं। उत्तर-पूर्व भारत में तृतीयक अनुक्रम में टेरीडोफ़ाइटी बीजाणुओं की बाहुल्यता है जबकि कच्छ में इनकी काफी कम संख्या है। इस कल्प में विभिन्न वर्गकों का वितरण एक चार्ट के द्वारा प्रदर्शित किया गया है। ऐसा अनुमान है कि पुरानूतन से आदिनूतन कल्प तक पौधे उष्णकटिबन्धीय, तटीय दलदल में विद्यमान थे जबकि ओलिगोसीन और उसके बाद उत्तरी क्षेत्र में निक्षेपण का वातावरण नदीय था।

TERTIARY rocks are very well developed in north-eastern and western India. In north-east, Palaeocene to Pliocene rocks are found almost in continuous sequence except the post-Barail (Oligocene) unconformity. In western India, well exposed Tertiary sediments are mostly confined in Kutch, Gujarat, but the Early-Middle Palaeocene and Late Eocene rocks are missing.

North-east India

The north-east India comprises Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur, Mizoram and Tripura. Of these states, palynological work has mostly been carried out in Assam, Meghalaya and Tripura. The paper is based mostly on the information of these three states.

The alluvium covered foreland shelf zone of Upper Assam Valley, which is a part of the major Assam-Arakan Basin, forms the north-eastern corner

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of the Indian sub-continent. Outcrops of rocks all along the Naga-Patkai Hills separated from the Upper Assam alluvial plain by the major Naga and Margherita thrusts provide a geological succession of the Late Tertiary sediments in the region.

The Cretaceous and Early Tertiary sediments, on the other hand, are found in Meghalaya unconformably overlying on the Precambrian granitic basement. A general lithological succession is given in Text-figure 1 following the Oil India Limited, Duliajan. The geology of this region has mainly been worked out by Oldham (1858), Medlicott (1869), Palmer (1923), Ghosh (1940), Baksi (1962), Biswas (1962), Evans (1964), Bagchi (1964), Dutta and Sah (1970), Handique and Dutta (1981), Samanta and Raychaudhuri (1983), Handique and Mallick (1989) and others.

Langpar Formation

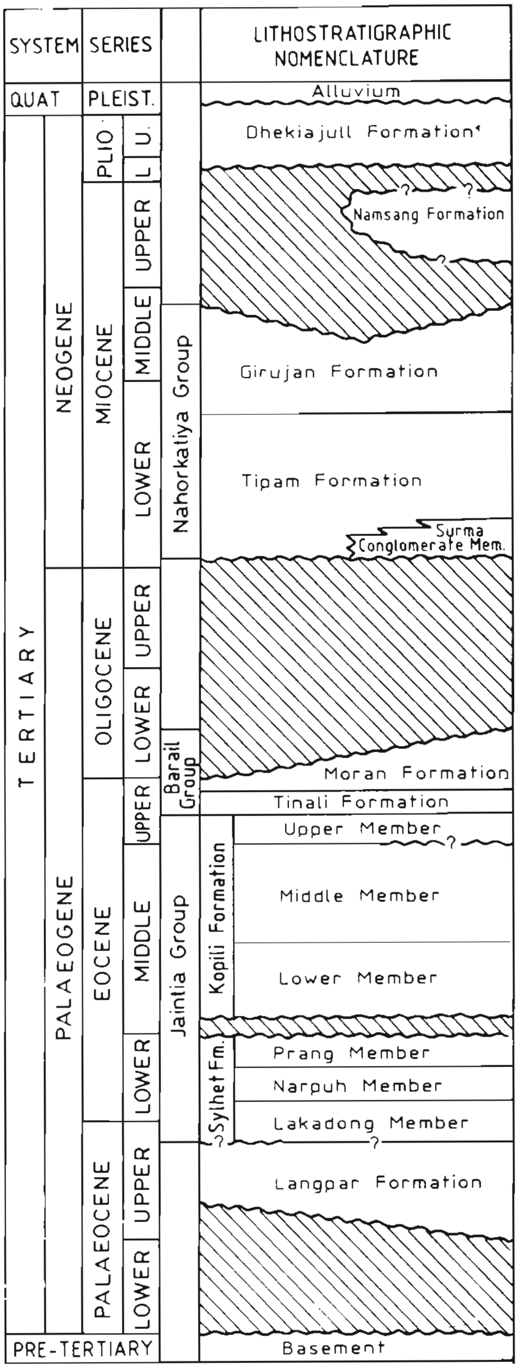
This formation exposed at Therriaghat on the Umshoringkew River, Meghalaya is not rich in spores and pollen and instead the phytoplanktons are quite common. The spores and pollen genera recovered are: *Cyathidites, Lygodiumsporites,* spores of *Acrostichum, Contignisporites, Schizaeoisporites, Matanomadhiasulcites, Dracaenoipollis, Proxapertites, Saturna, Tercissus, Araucariacites, Schizosporis* and *Phragmothyrites.* Besides, some reworked Permian genera, e.g., *Striatriletes, Rhizomaspora* and *Densipollenites* are also recorded.

Presence of *Saturna* and *Tercissus* in this formation claims special attention. The genus *Saturna* (Salard-Cheboldaeff, 1978) is so far known from Africa, while *Tercissus* is recorded from U.S.A., western Venezuela (Tschudy, 1970) and Africa (Kieser & Jan du Chêne, 1979; Boudouresque, 1980; Caratini *et. al.,* 1991).

The assemblage is dominated by pteridophytic spores, mostly represented by *Lygodiumsporites lakiensis, Cyathidites minor* and spores of *Acrostichum.* Among angiosperm pollen *Saturna enigmatus, Proxapertites cursus* and *Matanomadhiasulcites maximus* are occasionally met with. *Araucariacites* represents the gymnosperms.

Presence of the spores of *Acrostichum* in appreciable percentage at Therriaghat indicates that the deposition took place in a back mangrove swamp. Occurrence of Permian striate and monosaccate genera in the sediments provides testimony to the erosion of Permian rocks in the sediments.

Therria Formation



Text-figure 1

Therria Formation witnessed the emergence of some important marker spore-pollen genera for Palaeocene and Lower Eocene. Notable amongst them are: *Lycopodiumsporites, Dandotiaspora, Palmaepollenites, Neocouperipollis, Diporoconia, Spinizonocolpites* and *Tripilaorites. Lycopodiumsporites, Diporoconia* and *Tripilaorites* occur from the lower part of the formation, whereas *Dandotiaspora dilata* appears from the middle. *Spinizonocolpites* and other palm pollen are found almost in all the samples.

The pteridophytic spores out number the

angiospermous pollen. Amongst the pteridophytes, *Dictyophyllidites* spp., *Lycopodiumsporites speciosus, Lygodiumsporites lakiensis* and *Cyathidites minor* are quite common. Among the angiosperms, *Verrucolporites verrucus, Matanomadhiasulcites maximus, Diporoconia* sp., *Spinizonocolpites echinatus* and *Palmaepollenites ovatus* are frequently found. *Spiniferites* and other phytoplanktons are also encountered often.

Lakadong Formation

Sah and Dutta (1966), Dutta and Sah (1970) and Kar and Kumar (1986) studied the sediments of Lakadong Sandstone Member exposed at Laitryngew and Mawlong coalfields, Sohrarim, Mawmluh and Shillong-Cherrapunji road section, Khasi Hills, Meghalaya. The assemblage consists of 45 genera and 86 species, of them 15 genera and 31 species belong to pteridophytes and 30 genera and 55 species to angiosperms.

Kar and Kumar (1986) divided the assemblage into *Lycopodiumsporites speciosus* Cenozone and *Kielmeyerapollenites syncolporatus* Cenozone. *Lycopodiumsporites speciosus* Cenozone is recognized by the common occurrence of *Lycopodiumsporites speciosus, Dandotiaspora dilata, Dandotiaspora telonata, Lycopodiumsporites parvireticulatus, Pteridacidites meghalayensis, Pteridacidites robustus, Proxapertites crassimurus, Neocouperipollis wodehousei, Neocouperipollis kutchensis* and *Retitribrevicolporites matanomadhensis.*

Kielmeyerapollenites syncolporatus Cenozone is characterised by the good representation of *Kielmeyerapollenites syncolporatus, Dandotiaspora dilata, D. telonata, Polypodiisporites umstewensis, Lygodiumsporites lakiensis, Palmidites plicatus, P. excellensus, Psilastephanocolporites psilatus, P. subcircularis, Retistephanocolporites multirimatus* and *Polymargocolporites mawlensis.*

Prang Formation

Spores and pollen grains are not known from the Prang Formation so far. Kar (Ms) recovered an assemblage from near 132 km post on Jowai-Badarpur Road, Meghalaya, which consists of 28 genera and 34 species. Pteridophytes are represented by 17 genera and 24 species, gymnosperms by 2 genera and 3 species, angiosperms by 9 genera and 7 species. The pteridophytic spores are mainly represented by *Todisporites kutchensis, Lygodiumsporites lakiensis, Osmundacidites kutchensis, Cyathidites minor, Striatriletes susannae, Podocarpidites khasiensis, Polypodiaceaesporites chatterjii* and *Polypodiisporites repandus.* The angiospermic pollen are occasionally found and generally represented by *Lakiapollis ovatus* and *Pellicieroipollis langenheimii.*

Kopili Formation

Trivedi (1985) investigated Kopili Formation exposed at 136 km post on Jowai-Badarpur Road, Meghalaya. The assemblage is dominated by pteridophytic spores comprising only *Striatriletes susannae* Cenozone. It includes *Striatriletes susannae, Striatriletes paucicostatus, Striatriletes microverrucosus, Polypodiaceaesporites tertiarus, Laevigatosporites lakiensis, Dermatobrevicolporites verrucosus* and *Cleistosphaeridium heteracanthum.*

Barails

The Barails in the geosynclinal facies of north east India are subdivided into Laisong, Jenam and Renji formations. Sein and Sah (1974), Salujha, Kindra and Rehman (1972, 1974), Saxena and Rao (1984), Rao and Singh (1986) and others worked on the palynology of the geosynclinal sediments. Kar (1990) studied in detail the palynofossils of these formation exposed on Silchar-Half Long Road.

Palynotaxa of Laisong Formation consist of 30 genera and 28 identifiable species. Kar (1990) proposed *Osmundacidites wellmanii* Cenozone for this formation, which has a good representation of *Osmundacidites wellmanii, Cyathidites minor, Striatriletes microverrucosus, Polypodiaceaesporites tertiarus, Pinuspollenites crestus* and *Inapertusporites kedvesii.*

Jenam Formation is populated by 49 genera and 42 identifiable species. Kar (1990) divided the whole assemblage into three palynological cenozones, viz., *Malayaeaspora costata* Cenozone, *Polypodiaceaesporites tertiarus* Cenozone and *Striatriletes susannae* Cenozone. *Malayaeaspora costata* Cenozone has the dominance of *Malayaeaspora costata, Striatriletes microverrucosus, Osmundacidites wellmanii* and *Polypodiaceaesporites tertiarus. Polypodiaceaesporites tertiarus* Cenozone shows the abundance of *Polypodiaceaesporites tertiarus, Striatriletes microverrucosus, Phragmothyrites eocaenica, Notothyrites setiferus* and *Polyadopollenites* spp. The characteristic species of *Striatriletes susannae* Cenozone are: *Striatriletes susannae, Striatriletes multicostatus, Striatriletes microverrucosus, Lygodiumsporites lakiensis* and *Polypodiaceaesporites tertiarus.*

Cyathidites minor Cenozone stands for Renji Formation and has good percentage of *Cyathidites minor, Striatriletes microverrucosus, Striatriletes paucicostatus, Pinuspollenites crestus* and

Podocarpidites khasiensis.

In Upper Assam, Barails are divided into Naogaon, Baragolai and Tikak Parbat formations. Palynological knowledge on Naogaon and Baragolai formations is scanty. The palynological assemblage of Tikak Parbat Formation due to its richness in coal is well known. Mandaokar (Ms.) has divided the assemblage into *Schizaeoisporites crassimurus* Cenozone, *Meyeripollis naharkotensis* Cenozone and *Osmundacidites wellmanii* Cenozone. *Schizaeoisporites crassimurus* Cenozone has the dominance of *Schizaeoisporites crassimurus, Surmaspora sinuosa, Crassoretitriletes vanraadshoovenii, Polypodiaceaesporites major, Polypodiisporites speciosus, Striatriletes susannae* and *Cucurbitariaceites bellus. Meyeripollis naharkotensis* Cenozone is associated with *Meyeripollis naharkotensis, Polypodiisporites miocenicus, Polypodiisporites oligocenicus, Retitricolpites robustus, Pteridacidites vermiverrucatus* and *Osmundacidites wellmanii. Osmundacidites wellmanii* Cenozone is characterised by *Osmundacidities wellmanii, Striatriletes susannae, Polypodiaceaesporites levis, Lygodiumsporites lakiensis, Polypodiisporites turbinatus* and *Crassoretitriletes vanraadshoovenii.*

Tipam-Surma units

Kar (1990) studied the samples of Tipam-Surma units from Rokhia bore-hole no. 1, Gajalia bore-hole no. 1 and Baramura bore-hole no. 2 drilled in Tripura by the Oil and Natural Gas Commission, Dehradun.

The assemblage comprises 114 genera and 164 species and is divisible into three cenozones, viz., *Aplanosporites robustus* Cenozone, *Striatriletes susannae* Cenozone and *Pinuspollenites crestus* Cenozone. Significant species of *Aplanosporites robustus* Cenozone are: *Operculodinium centrocarpum, Cleistosphaeridium cephalum, Spiniferites mirabilis, Oligosphaeridium complex, Tuberculodinium vancampoae, Striatriletes multicostatus, Polypodiisporites ornatus, Lycopodiumsporites lakiensis* and *Pinuspollenites crestus. Striatriletes susannae* Cenozone constitutes *Striatriletes susannae, Striatriletes multicostatus, Striatriletes aidaensis, Osmundacidites cephalus, Azolla aglochidia, Lycopodiumsporites globatus, Pilamonoletes excellensus, Conitricolporites triangulus, Pinuspollenites crestus* and *Operculosculptites globatus.* The important species of *Pinuspollenites crestus* Cenozone are: *Pinuspollenites crestus, Operculosculptites globatus, Palaeomalvaceaepollis mammilatus, Pteridacidites tripuraensis, Polypodiisporites ornatus, Lycopodiumsporites globatus* and *Lygodiumsporites lakiensis.*

Pinuspollenites crestus Cenozone also holds good for the Bhuban Formation (Surma) exposed near Bandarkhal on Silchar-Half Long Road, Assam. *Operculosculptites globatus,* which is one of the dominant forms in subsurface of Tripura, is almost absent in Bhuban. Besides, presence of reworked Permian and Cretaceous forms in appreciable percentage in this formation also helps to identify this cenozone in Meghalaya.

In Duarmara bore-hole no. 2 and Nahorkatiya bore-hole nos. 263 and 268 (Assam) the reworked Permian and Cretaceous palynomorphs are very negligible in Tipam-Surma. Besides, gymnospermous bisaccate pollen are found in low percentage.

In Arunachal Pradesh, as evidenced by Kharsang bore-hole nos. 2 and 3, the gymnospermous pollen are found in abundance in Tipam-Surma.

Girujan Clay Formation

The palynological assemblage of this formation is known from the bore-hole nos. Lakwa 27, Duarmara 2 and Kharsang 2 and 3. The assemblage consists of 25 genera and 37 species. In Lakwa 27 and Kharsang 2, Girujan is dominated by gymnospermous pollen whereas in Duarmara bore-hole no. 2 the pteridophytes are abundant and many species of angiosperms are also met with (Kar *et al.*, MS).

In Lakwa bore-hole 27, Girujan is overwhelmingly dominated by *Pinuspollenites crestus.* The other associated significant species are: *Lycopodiumsporites globatus, Psiloschizosporis psilata* and some spores with elaters.

Namsang Sandstone/Clay Formation

In Lakwa bore-hole no. 27, the gymnosperms are poorly represented while the pteridophytes are found in good numbers. They are mostly represented by *Osmundacidites wellmanii, Striatriletes susannae, Striatriletes paucicostatus* and *Polypodiaceaesporites tertiarus.*

In Kharsang 2, Namsang exhibits the abundance of *Crassoretitriletes vanraadshoovenii* and *striatriletes susannae.* Besides, frequent presence of *Palaeomalvaceaepollis mammilatus, Palaeomalvaceaepollis rudis, Acanthotricolpites* sp., *Compositoipollenites conicus, Compositoipollenites tricolporatus, Palaeosantalaceaespites primitiva* and *Monoporopollenites* sp. marks Namsang in the bore-hole.

WESTERN INDIA

The Tertiary sediments in western India

exposed in the district of Kutch represents exposures from Palaeocene to Pliocene. The outcrops are mostly confined in the south-western coastal plain of Kutch between Guvar and Khari rivers. The geology of this area has been worked out by Grant (1840), Wynne (1872), Vredenburg (1925), Nuttal (1926), Tewari (1952, 1957), Poddar (1959, 1963), Sen Gupta (1959, 1964), Tandon (1962), Bhatt (1968), Biswas (1971), Biswas and Deshpande (1970), Biswas and Raju (1971, 1973), Hardas and Biswas (1973), Sahni and Misra (1975), Mishra (1980) and others. However, the rock-stratigraphic classification of Biswas and Raju (1971, 1973) for the Tertiary sediments of Kutch has been followed as under:

FORMATION	MEMBER		AGE
Sandhan		Pliocene	
Vinjhan Shale	Siltstone	Miocene	Langhian
	Chhasra		Burdigalian
Khari Nadi			Aquitanian
Maniyara	Ber Moti		Chattian
	Coral	Oligocene	Rupelian
	Limestone		Lattorfian
	Lumpy clay		
	Basal Member		
Fulra Limestone			Luttetian
Harudi		Eocene	
Naredi			Ypresian
Matanomadh		Palaeocene	
Deccan Trap		Upper Cretaceous to Palaeocene	

Matanomadh Formation

This formation is best exposed around the village Matanomadh. The lithology is extremely variable and comprises trap wash, ash, agglomerate, variegated white and tuffaceous shales, red tuffaceous sandstones with occasional layers of lignite.

Kar (1985) divided this formation into five palynological cenozones. These in the ascending order are: (i) Barren zone, (ii) *Dandotiaspora dilata* Cenozone, (iii) *Tricolpites minutus* Cenozone, (iv) *Neocouperipollis kutchensis* Cenozone, and (v) Sponge spicules Zone.

Dandotiaspora dilata Cenozone has the following significant species: *Dandotiaspora dilata, Dandotiaspora plicata, Lygodiumsporites lakiensis, Lygodiumsporites pachyexinous, Todisporites major, Intrapunctisporis apunctis, Proxapertites microreticulatus, Psilastephanocolpites guaduensis, Tricolpites retibaculatus, Tricolpites crassireticulatus, Proteacidites protrudus, Cyathidites australis* and *Liliacidites matanomadhensis. Tricolpites minutus* Cenozone is characterised by *Tricolpites minutus, Tricolpites brevis, Phragmothyrites eocaenica, Osmundacidites microgranifer, Cyathidites australis, Dandotiaspora plicata, Palmaepollenites nadhamunii, Palmaepollenites ovatus, Sonneratioipollis bellus* and *Inapertusporites kedvesii. Neocouperipollis kutchensis* Cenozone has *Neocouperipollis kutchensis, Tricolpites minutus, Phragmothyrites eocaenica, Lakiapollis matanomadhensis, Meliapollis ramanujamii, Palmaepollenites kutchensis, Neocouperipollis robustus, Kielmeyerapollenites eocaenicus, Neocouperipollis achinatus, Polycolpites flavatus, Polypodiaceaesporites levis* and *Lakiapollis ovatus.*

Naredi Formation

This is made up of three members—the lower Gypseous Shale Member, the middle Assilina Limestone Member and the upper Ferruginous Claystone Member. This formation rests on the Deccan Trap in the type locality but at other places it rests unconformably on the Matanomadh Formation.

The palynological assemblage has been divided by Kar (1985) into two cenozones—the lower *Lakiapollis ovatus* Cenozone and the upper *Lygodiumsporites lakiensis* Cenozone. *Lakiapollis ovatus* Cenozone has the association of *Lakiapollis ovatus, Neocouperipollis kutchensis, Proxapertites microreticulatus, Meliapollis ramanujamii, Palmaepollenites kutchensis, Umbelliferoipollenites ovatus, Inapertusporites kedvesii, Botryococcus palanaensis, Pellicieroipollis langenheimii* and *Lygodiumsporites lakiensis. Lygodiumsporites lakiensis* Cenozone has *Lygodiumsporites lakiensis, Dandotiaspora plicata, Intrapunctisporis apunctis, Palmaepollenites kutchensis, Proxapertites microreticulatus, Neocouperipollis kutchensis, Lakiapollis ovatus* and *Inapertusporites kedvesii.*

Harudi Formation

This consists of green-greenish grey, splintery shale with limnotic partings in the lower part and calcareous claystone, siltstone with layers of gypsum and carbonaceous shale in the upper part.

Proxapertites microreticulatus Cenozone and *Cheilanthoidspora enigmata* Cenozone are the two cenozones proposed by Kar (1985) for this formation. *Proxapertites microreticulatus* Cenozone has common occurrence of *Proxapertites microreticulatus, Palmaepollenites kutchensis, Cyathidites minor, Neocouperipollis kutchensis, Scantigranulites sparsus, Palmaepollenites ovatus, Seniasporites verrucosus* and *Laevigatosporites cognatus*. The significant species in *Cheilanthoidspora enigmata* Cenozone are: *Cheilanthoidspora enigmata, Striatriletes susannae,* *Neocouperipollis kutchensis, Oligosphaeridium complex, Striatriletes multicostatus, Polypodiaceaesporites strictus, Palmaepollenites kutchensis, Proxapertites microreticulatus* and *Lakiapollis ovatus.*

Fulra Limestone

It comprises massive to thickly bedded, cream to dirty white foraminiferal limestone with numerous animal fossils comprising mostly *Discocyclina* and *Nummulites.* No palynological assemblage is known from this formation.

Maniyara Fort Formation

This is divisible into (i) Basal Member characterised by alternating beds of foraminiferal, glauconitic-siltstone and calcareous to gypseous claystone, (ii) Lumpy Clay Member has cement coloured to brownish calcareous lumpy claystone with intercalation of thin bands of limestone and marlite, (iii) Coral Limestone Member consists of dirty white nodular limestone alternating with calcareous claystone, and (iv) Ber Moti Member comprises mostly brown argillaceous sandstone and thin bedded hard, foraminiferal limestone.

The three cenozones recognised by Kar (1985) are: *Operculodinium centrocarpum* Cenozone, *Trisyncolpites ramanujamii* Cenozone and *Aplanosporites robustus* Cenozone. *Operculodinium centrocarpum* Cenozone is dominated by microplankton, e.g., *Operculodinium centrocarpum, Cleistosphaeridium heterocanthum, Tuberculodinium vancampoae, Inapertusporites kedvesii* and *Phragmothyrites eocaenica.*

Trisyncolpites ramanujamii Cenozone has a high percentage of *Trisyncolpites ramanujamii, Leptolepidites chandrae, Striatriletes susannae, Laevigatosporites lakiensis, Polypodiaceaesporites chatterjii, Polypodiisporites constrictus, Podocarpidites cognatus* and *Palaeosantalaceaepites ellipticus.* The species associated with *Aplanosporites robustus* Cenozone are: *Aplanosporites robustus, Operculodinium centrocarpum, Cleistosphaeridium heterocanthum, Inapertusporites kedvesii* and *Phragmothyrites eocaenica.*

Khari Nadi Formation

This formation is composed of laminated, mottled to variegated siltstone with occasional bands of grey-brown, gypseous claystone.

This formation is represented by *Cordosphaeridium cantharellum* Cenozone, *Striatriletes susanne* Cenozone and *Operculodinium israelianum* Cenozone. The important taxa belonging to *Cordosphaeridium cantharellum* Cenozone are: *Cordosphaeridium cantharellum, Operculodinium centrocarpum, Striatriletes susannae, Operculodinium israelianum, Aplanosporites robustus, Cordosphaeridium exilimurum, Podocarpidites densicorpus* and *Piceapollenites excellensus. Striatriletes susannae* Cenozone comprises *Striatriletes susannae, Azolla aglochidia, Podocarpidites densicorpus, Striatriletes aidaensis, Striatriletes paucicostatus, Khariasporites densus, Abiespollenites cognatus, Piceapollenites excellensus* and *Tsugaepollenites velatus. Operculodinium israelianum* Cenozone includes *Operculodinium israelianum, Cordosphaeridium cantharellum, Operculodinium centrocarpum, Tuberculodinium vancampoae, Spiniferites bulloideus, Millioudinium unicarpum, Cordosphaeridium exilimurum* and *Abiespollenites cognatus.*

Vinjhan Shale

The grey and khaki coloured, laminated, gypseous shales and claystones with alternation of argillaceous limestones are the characteristic lithology of this formation. No spores and pollen could be recovered from this formation.

Sandhan Formation

The basal part of this formation consists of coarse grained massive sandstone and laminated sandstone while the upper part has generally hard calcareous grit. Palynological fossils are absent in this formation.

DISCUSSION

The Tertiary palynological assemblages of north-east and western India show broad similarity. The appearance and disappearance of some of the marker forms also indicate striking similarity. *Dandotiaspora dilata, D. telonata, D. auriculata* and *D. densicorpa* in both the regions are restricted to Palaeocene. Likewise, *Matanomadhiasulcites maximus, Kielmeyerapollenites syncolporatus, Tripilaorites triangulus, Triangulorites bellus, Spinizonocolpites echinatus* and *Neocouperipollis kutchensis* are confined to Palaeocene-Lower Eocene. *Striatriletes* makes its first appearance in Middle Eocene both in north-east as well as western India and maintains its prominence in Oligocene and Miocene. Gymnospermous pollen mostly represented by *Pinuspollenites crestus, Piceapollenites excellensus, Abiespollenites cognatus* and *Podocarpidites densicorpus* are commonly found in Miocene in the two areas. In the terminal Eocene all the marker palynofossils disappear except for *Spinizonocolpites echinatus* which is rare in the

Oligocene. In Kutch, Late Eocene Period is absent while in north-east India *Dermatobrevicolporites dermatus*, *Spinizonocolpites echinatus*, *Triangulorites bellus*, *Lakiapollis ovatus* and *Retitribrevicolporites matanomadhensis* do not continue in Oligocene. *Umbelliferoipollenites ovatus*, *Tricolporopilites robustus* and *Tricolporocolumellites pilatus* are the index species

Table 1—Distribution of some Index species in Tertiary Period in India

EARLY PALAEOCENE	MIDDLE PALAEOCENE	LATE PALAEOCENE	EARLY EOCENE	MIDDLE EOCENE	LATE EOCENE	OLIGOCENE	MIOCENE	
************								*Saturna enigmatus*
************								*Tercissus* sp.
************								*Acrostichum* spore
	************							*Diporoconia* sp.
	************	************						*Lycopodiumsporites speciosus*
	************	>>>>>>> ************						*Dandotiaspora dilata*
	************	>>>>>>> ************	>>>>>>> ************	>>>>>>> ************				*Neocouperipollis kutchensis*
************	************	>>>>>>> ************	>>>>>>> ************					*Matanomadhiasulcites maximus*
	************	>>>>>>> ************	>>>>>>> ************					*Tripilaorites triangulus*
	************	>>>>>>> ************	>>>>>>> ************	>>>>>>> ************				*Palmaepollenites ovatus*
		>>>>>>> ************	>>>>>>> ************	>>>>>>> ************	************			*Dermatobrevicolporites dermatus*
************	************	************	>>>>>>> ************	>>>>>>> ************				*Proxapertites microreticulatus*
		>>>>>>> ************	>>>>>>> ************	>>>>>>> ************				*Cheilanthoidspora enigmata*
	************	>>>>>>> ************	>>>>>>> ************	>>>>>>> ************	************	??????????????		*Spinizonocolpites echinatus*
		>>>>>>> ************	>>>>>>> ************	>>>>>>> ************	************			*Triangulorites bellus*
		>>>>>>> ************	>>>>>>> ************	>>>>>>> ************	************			*Lakiapollis ovatus*
		>>>>>>> ************	>>>>>>> ************	>>>>>>> ************	************			*Retitribrevicolporites matanomadhensis*
		>>>>>>> ************	>>>>>>> ************					*Kielmeyerapollenites eocenicus*
				>>>>>>> ************				*Tricolporopilites robustus*
				>>>>>>> ************				*Tricolporocolumellites pilatus*
			>>>>>>>					*Umbelliferoipollenites ovatus*
						>>>>>>>		*Trisyncolpites ramanujamii*
						>>>>>>> ************	>>>>>>> ************	*Bombacacidites triangulus*
						>>>>>>> ************	>>>>>>> ************	*Crassoretitriletes vanraadshoovenii*
						>>>>>>> ************	>>>>>>> ************	*Pinuspollenites crestus*
						>>>>>>> ************	>>>>>>> ************	*Abiespollenites cognatus*
						>>>>>>> ************	>>>>>>> ************	*Piceapollenites excellensus*
							>>>>>>> ************	*Azolla aglochidia*
							>>>>>>> ************	*Hibisceaepollenites splendus*
							>>>>>>>	*Khariasporites densus*

>>>>>>> KUTCH ************ NORTH-EAST INDIA

for Eocene. *Umbelliferoipollenites ovatus* is confined to Lower Eocene in Kutch while the other two species are found only in the Middle Eocene in both the regions. *Trisyncolpites ramanujamii* is an index fossil for Oligocene and found so far only in western India. *Bombacacidites triangulus, Crassoretitriletes vanraadshoovenii, Pinuspollenites crestus, Abiespollenites cognatus* and *Piceapollenites excellenus* are found in both the regions in Oligocene and Miocene. *Azolla aglochidia, Hibisceaepollenites splendus* and *Khariasporites densus* are the marker species for Miocene (Table 1)

There are, however, some differences in the palynological consituents of the two regions. In north-east India, pteridophytic spores are found in abundance in all the formations. The various species of *Lycopodiumsporites* and *Dandotiaspora* are the marker fossils for the Upper Palaeocene. *Lycopodiumsporites* is hardly found in the Upper Palaeocene rocks in Kutch. Similarly, *Osmundacidites, Polypodiaceaesporites, Polypodiisporites* and *Malayaeaspora* which play decisive role in demarcating different formations in north-east India are either insignificant or absent in western India.

This disparity in palynofossils may perhaps be explained due to different physiographic features of the two regions. It may be recalled that due to continental drift, north-east India came into direct contact with the Asian Plate and a substantial part of it was subducted under it. Further, due to upliftment of the Himalaya many hills came into existence in this area with an access to the open sea on the south and south-eastern side. Shillong Plateau should also not to be forgotten in this context. It was a high land surrounded by sea in the Early Tertiary time and must have harboured many pteridophytes. The spores got deposited in nearby swamps and shores resulting high frequency in the assemblage.

Kutch and adjacent area on the other hand was far away from the Asian Plate and the rising of the Himalaya did not imprint any direct signature on it. Moreover, during pre-Tertiary time it witnessed intense volcanic eruption and the existing flora must have been perished. Non depositional period continued for a long time which caused erosion and weathering of the traps.

The transgression and regression pattern of sea in these areas are also different. In north-east India deposition in shelf areas continued from Palaeocene-Upper Eocene resulting huge accumulation of limestone. The sea regressed mostly from north-east India thereafter. In Kutch, major transgression took place in Middle Eocene but the sea was in proximity even in Oligocene and Miocene. Climax of vegetation pattern is also different in both the parts. In north-east India, coal is found in abundance in Upper Palaeocene and Oligocene. Tectonic disturbance due to Himalayan uplift, Naga and Margerita thrusts transformed the vegetative matter into good quality of coal and also gave rise to oil. In Kutch, lignite occurs in Lower Eocene but this was not transformed into coal due to lack of sufficient overburden and tectonic activity.

In Meghalaya, Permian reworked fossils are known from Palaeocene. During Upper Oligocene and Miocene they are very common in Arunachal Pradesh also. They are, however, hardly found in north-east Assam indicating perhaps thereby different source materials. In Kutch, reworked palynofossils are hardly encountered.

The deposition in north-east India started with Langpar Formation in back mangrove swamp, from Therria to Kopili formations the deposition was mostly coastal swamps and shelf. But from Barails onwards it seems to be riverine. In Kutch throughout the Tertiary, the sedimentation took place in coastal and coastal swamps.

In north-east India, the flora is rich in diversity throughout the Tertiary culminating in two highs in Palaeocene and Oligocene. In Kutch, the flora is well represented in Palaeocene and Eocene, starts dwindling in Oligocene and becomes scanty in Miocene. It seems that Kutch enjoyed favourable climate up to Eocene which gradually altered into an inhospitable climate allowing no room for luxuriant vegetation.

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Neyveli lignites and associated sediments—their palynology, palaeoecology, correlation and age

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The Neyveli Formation is a subsurface stratigraphic unit, containing thick workable lignite deposits at its top, and is unconformably overlain by the Cuddalore Formation. The age of the lignite has remained a subject of controversy and therefore effort has been made here to date it by means of palynological evidence. Rich palynofloras have been recorded from the Neyveli Formation encountered in the Neyveli Mines-I and II in South Arcot District and Jayamkondacholapuram well-12 in Tiruchirapalli District, Tamil Nadu. These assemblages contain pteridophytic spores, angiospermous pollen and algal and fungal remains with angiospermous pollen being predominant. Based on the present day distribution and habitat of the families represented, a tropical climate with plenty of rainfall has been inferred during the sedimentation of the Neyveli Formation. The environment of deposition for these sediments has been deduced as coastal, ranging from back mangrove to mangrove, with a short transgressive phase before the deposition of lignite. The Neyveli Formation is divisible into three biozones, viz., *Neocouperipollis* spp. Cenozone, *Triangulorites bellus* Cenozone, and *Trilatiporites sellingii* Cenozone. These are identifiable by their characteristic significant and restricted palynotaxa and correlatable with the Late Palaeocene to Middle Eocene biozones of Kutch, Rajasthan, Bengal Basin, Garo, Khasi and Jaintia Hills of Meghalaya and Cauvery Basin. A Late Palaeocene to Middle Eocene age has therefore been assigned to the Neyveli Formation.

Key-words—Palynology, Palaeoecology, Correlation, Neyveli lignites, India.

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साराँश

निवेली लगुड़ंगार तथा सहयुक्त अवसादः परागाणविक अध्ययन, पुरापारिस्थितिकी, सहसम्बन्धन एवं आयु

रमेश कुमार सक्सेना

निवेली शैल-समूह एक उपसतही स्तरिक इकाई है जिसके ऊपर मोटे लगुड़ांगार निक्षेप विद्यमान हैं। ये शैल-समूह कुडलोर शैल-समूह के ऊपर असम्बद्ध रूप से विद्यमान हैं। इन लगुड़ांगारों की आयु विवादास्पद रही है अतःएव इस शोध-पत्र में परागाणविक प्रमाणों के आधार पर इन्हें कालनिर्धारित करने का प्रयास किया गया है। तमिलनाडु में तिरुचिरापल्ली जनपद में जयमकोंडाचोलापुरम कुआँ-12 तथा दक्षिण आरकोट जनपद में निवेली खान-प्रथम एवं द्वितीय में विद्यमान निवेली शैल-समूह से सघन परागाणुवनस्पतिजात उपलब्ध हुआ है। इन समुच्चयों में टेरीडोफ़ाइटी बीजाणु, आवृतबीजी परागकण तथा शैवालीय एवं कवकीय अवशेष विद्यमान हैं। विभिन्न कुलों के वर्तमान वितरण के आधार पर अवसादन के समय अधिक वर्षा के साथ-साथ उष्णकटिबन्धीय जलवायु का होना सुनिश्चित किया गया है। ये अवसाद तटीय तथा मैंग्रोवी वातावरण में निक्षेपित हुए हैं तथा निक्षेपण से पहले कुछ धंसाव जैसी अवस्था विकसित हो गई थी। निवेली शैल-समूह तीन जैवमंडलों–(अ) निओकाउपरिपॉलिस जाति नवमंडल, (आ) ट्राइएंगुलोराइटिस बेल्लस नवमंडल, तथा (ई) ट्राइलेटिपोराइटिस सेलिंगाई नवमंडल में विभक्त किया गया है। ये सभी अपने लाक्षणिक वर्गकों के आधार पर पहचाने जा सकते हैं तथा कच्छ, राजस्थान, बंगाल द्रोणी एवं मेघालय की गारो, खासी और जयन्तिया पहाड़ियों तथा कावेरी द्रोणी के अर्नतिम पुरानूतन से मध्य आदिनूतन जैवमंडलों से तुलनीय हैं अतः निवेली शैल-समूह की अर्नतिम पुरानूतन से मध्य आदिनूतन आयु प्रस्तावित की गई है।

THE lignite deposits of Tamil Nadu, mined around Neyveli, are popularly known as Neyveli lignites. These deposits constitute the largest lignite reserve of India and have been able to attract attention of geologists, mining engineers, palaeobotanists and palynologists since last over fifty years. Till recently, the lignite was considered to be a part of the Cuddalore Formation. However, Siddhanta (1986) divided the Cuddalore Formation into two parts and named the lower part, which includes lignite, as the Neyveli Formation and retained the term Cuddalore

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Formation for the upper part.

The Neyveli Formation (over 300 m thick) is a subsurface lithostratigraphic unit and consists of semiconsolidated sandstone and clay beds with occasional limestone intercalations followed by carbonaceous clay (about 1 m thick) and brownish black lignite (up to 23 m thick). It is overlain by the Cuddalore Formation (60 to 120 m thick) which is made up of ferruginous, arkosic, semiconsolidated sandstone exhibiting some herringbone type cross laminations. The contact between the two formations is marked by an erosional unconformity (Siddhanta, 1986, p. 63).

The geology and ground water aspects of the Neyveli Formation have been studied by Krishnan (1949), Balasunder (1968), Subramanyam (1969), Gowrisankaran *et al.* (1987), etc. The lignite and underlying clay bands are rich in palynofossils and a number of papers have been published on their study (Navale, 1962; Thiergart & Frantz, 1963; Ramanujam, 1963, 1966a, b, 1967, 1982; Ramanujam & Ramachar, 1963, 1980; Deb, 1972; Deb *et al.*, 1973; Venkatachala, 1973; Navale & Misra, 1979; Ambwani *et al.*, 1981; Bande & Ambwani, 1982; Reddy *et al.*, 1982, 1984; Ambwani, 1983; Ramanujam & Reddy, 1984; Sarma *et al.*, 1984; Saxena, 1984; Ramanujam *et al.*, 1984, 1985, 1988; Siddhanta, 1986; Sarma & Ramanujam, 1988; Sarma & Reddy, 1988; Singh & Misra, 1991a, b, c). However, most of the above studies are largely confined to the description of palynofloras and their interpretation for inferring palaeoclimate and environment of deposition with no or little stratigraphic consideration, particularly regarding age and correlation of the lignite deposits.

The age of the Neyveli lignites (belonging to the Neyveli Formation) has remained a subject of dispute. Till 1973, these deposits were believed to be of Miocene age. However, Venkatachala (1973), Deb *et al.* (1973) and Siddhanta (1986) on the basis of palynological and geological evidences inferred a Palaeocene-Eocene age. The possibility of these deposits being time-transgressive, ranging in age from Eocene to Miocene, has also been suggested. The controversy regarding the age of lignite appears mainly due to lack of studies from measured stratigraphic sections. Siddhanta (1986) recognized four palynoassemblages from: (i) carbonaceous clay (just underlying the lignite), (ii) basal lignite (0-1.5 m), (iii) middle lignite (1.5-15 m), and (iv) top lignite (15-23 m). The main objectives of the present paper are, therefore, to attempt dating of the lignite deposits on the basis of palynofossils and their correlation with the contemporary stratigraphic units and also to infer palaeoclimate and environment of deposition.

The palynological study on the Neyveli lignites has so far been done only on the material collected from the Neyveli Mines-I and II in South Arcot District, Tamil Nadu. This paper is based on the published palynological information from these mines as well as author's own palynological study on the Neyveli Formation of Neyveli Mines-I and II and also of Jayamkondacholapuram well-12 in Tiruchirapalli District, Tamil Nadu (Text-figure 1).

PALYNOLOGY

Rich palynofloral assemblages have been recovered from the Neyveli Formation of Neyveli Mines-I and II and Jayamkondacholapuram well-12. The assemblages consist of algal and fungal remains, pteridophytic spores and angiospermous pollen. Detailed description of these assemblages would be beyond the scope of the present paper. However, a list of palynotaxa recovered is given below.

Pteridophytic spores—Cyathidites australis Couper, *Garotriletes assamicus* Singh & Singh, *Gemmatriletes* sp., *Gleicheniidites* sp., *Intrapunctisporis gigantica* Kar & Kumar, *Intrapunctisporis* sp., *Laevigatosporites lakiensis* Sah & Kar, *L. tertiarus* (Dutta & Sah) Saxena & Khare, *L. variabilis* Saxena & Khare, *Lygodiumsporites eocenicus* Dutta & Sah, *L. lakiensis* Sah & Kar, *Neyvelisporites bolkhovitinae* (Ramanujam) Ramanujam, *N. cooksoniae* (Ramanujam) Ramanujam, *Osmundacidites* sp., *Polypodiisporonites mawkmaensis* (Dutta & Sah) Mathur & Chopra, *P. repandus* (Takahashi) Saxena & Khare, *Polypodiisporonites* sp., *Schizaeoisporites crassimurus* Dutta & Sah, *S. digitatoides* (Cookson) Potonié, *S. ghoshii* Ramanujam, *S. minimus* Ramanujam, *S. multistriatus* Rao & Ramanujam, *S. ramanujamii* Saxena & Khare, *S. sinuta* Ramanujam, *Seniasporites verrucosus* Sah & Kar, *Todisporites kutchensis* Sah & Kar and *T. major* Couper.

Angiospermous pollen—Acanthotricolpites brevispinosus Saxena & Khare, *A. microreticulatus* Saxena & Khare, *A. neyveliensis* Saxena & Khare, *A. robustus* Saxena & Khare, *A. tiruchirapalliensis* Saxena & Khare, cf. *Acanthotricolpites* sp., *Alangiopollis* sp., *Araliaceoipollenites matanomadhensis* Venkatachala & Kar, *Arecipites bellus* Sah & Kar, *A. punctatus* Wodehouse, *Arengapollenites achinatus* Kar, *Assamiapollenites* sp., *Bacutricolporites neyveliensis* Saxena & Khare, *B. triangulus* Saxena & Khare, *Clavaperiporites jacobii* Ramanujam, *Clavatricolporites leticiae* Leidelmeyer, *Cryptopolyporites* spp. 1 and 2, *Ctenolophonidites costatus* (von Hoeken Klinkenberg) von Hoeken Klinkenberg, *C. erdtmanii* Ramanujam & Rao, *C.*

ramanujamii Saxena & Khare, *C. saadii* Ramanujam & Rao, *C. stellatus* Navale & Misra, *Ctenolophonidites* sp., *Dracaenoipollis* sp., *Droseridites parvus* Dutta & Sah, *Echimonoporopollis grandiporus* Saxena *et al.*, *E. neyveliensis* Saxena *et al.*, *Echitricolporites* sp., *Ericipites sahnii* Ramanujam, *Foveotricolpites* sp., *Gemmamonocolpites* sp., *Gemmatriporopollis triangulus* Saxena & Khare, *Granustephanocolpites* sp., *Hippocrateaceaedites vancampoae* Ramanujam, *Incrotonipollis neyveliensis* (Baksi *et al.*) Jansonius & Hills, *Jacobipollenites magnificus* Ramanujam, *Lakiapollis ovatus* Venkatachala & Kar, *Longapertites cuddalorense* Ramanujam, *Margocolporites complexum* Ramanujam, *M. ghoshii* (Ramanujam) Saxena & Khare, *M. oligobrochatus* Ramanujam, *M. perforatus* Saxena & Khare, *M. siddhantae* Saxena & Khare, *M. sitholeyi* Ramanujam, *M. tsukadae* Ramanujam, *Margocolporites* spp. 1 and 2, cf. *Margocolporites* sp., *Matanomadhiasulcites kutchensis* (Saxena) Kar, *M. major* (Singh) Saxena & Khare, *M. ramanujamii* Saxena & Khare, *Meliapollis gratus* Saxena & Khare, *M. iratus* (Sah & Kar) Navale & Misra, *M. melioides* (Ramanujam) Sah & Kar, *M. navalei* Sah & Kar, *M. quadrangularis* (Ramanujam) Sah & Kar, *M. ramanujamii* Sah & Kar, *M. raoi* Sah & Kar, *M. venkatachalae* Saxena & Khare, *Meliapollis* sp., *Myricipites singhii* Saxena & Khare, *Myricipites* sp., *Neocouperipollis achinatus* (Sah & Kar) Kar & Kumar, *N. brevispinosus* (Biswas) Sarkar & Singh, *N. cymbatus* (Venkatachala & Rawat) Saxena & Khare, *N. donaensis* (Rao *et al.*) Saxena & Khare, *N. kutchensis* (Venkatachala & Kar) Kar & Kumar, *N. rarispinosus* (Sah & Dutta) Singh, *N. robustus* (Saxena) Saxena & Khare, *N. wodehousei* (Biswas) Saxena & Khare, *Neyveliapites indicus* Saxena & Khare, *Paleosantalaceaepites minutus* Sah & Kar, *Palmaepollenites plicatus* Sah & Kar, *Palmidites maximus* Couper, *P. naviculus* Kar & Saxena, *P. plicatus* Singh, *Pellicieroipollis langenheimii* Sah & Kar, *Periretitricolpites* sp., *Polybrevicolpites neyvelii* Saxena & Khare, *Polybrevicolporites punctatus* Saxena & Khare, *Polybrevicolporites* sp., *Proxapertites assamicus* (Sah & Dutta) Singh, *P. microreticulatus* Jain *et al.*, *Proxapertites* sp., *Pseudonothofagidites cerebrus* Venkatachala & Kar, *P. septaporatus* Saxena & Khare, *Psilastephanocolpites quadrangularis* Saxena & Khare, *Psilatricolporites* sp., *Retimonosulcites ovatus* (Sah & Kar) Kar, *Retipilonapites arcotense* Ramanujam, *R. delicatissimus* Ramanujam, *Retipollenites laevigatus* Saxena & Khare, *R. neyveliensis* Saxena & Khare, *Retistephanocolpites angeli* Leidelmeyer, *Retitrescolpites decipiens* Sah, *R. neyveliensis* Saxena & Khare, *R. oblongus* Sah, *Retitricolpites* spp. 1 and 2, *Retitricolporites minor* Saxena & Khare, *R. perforatus* Saxena & Khare, *Retitricolporites* spp. 1 and 2, *Spinainaperturites conatus* Venkatachala & Rawat, *S. densispinus* Venkatachala & Rawat, *Spinainaperturites* sp., *Spinizonocolpites echinatus* Muller, *S. neyveliensis* Saxena & Khare, *Stephanoporopollenites duttae* Saxena & Khare, *Tetrapollis* sp., *Thomsonipollis sahii* Saxena & Khare, *Thomsonipollis* sp., *Triangulorites bellus* Kar, *Triangulorites* sp., *Tricolpites crassireticulatus* Dutta & Sah, *T. matanomadhensis* Saxena, *T. minutus* Sah & Kar, *T. retibaculatus* Saxena, *T. reticulatus* Cookson, *Tricolpites* sp. cf. *T. crassireticulatus* Dutta & Sah, *Tricolpites* sp. cf. *T. margocolpites* Venkatachala & Rawat, *Tricolporopollis matanomadhensis* (Venkatachala & Kar) Tripathi & Singh, *T. rubra* Dutta & Sah, *Tricolporopollis* sp., *Trilatiporites erdtmanii* Ramanujam, *T. noremii* Ramanujam, *T. sellingii* Ramanujam, *Triporopollenites parvus* Sah, *T. tamilensis* Saxena & Khare, *Triporotetradites singhii* Saxena & Khare, cf. *Verrucolporites* sp., *Verrutricolpites* sp., and *Warkallipollenites reticulatus* Saxena & Khare.

Besides the above spore/pollen taxa, the assemblage also contains algal spores (2 genera & 2 species) and fungal remains (13 genera & 26 species). Because of their limited stratigraphical and palaeoecological significance, they are not listed here.

PALAEOCLIMATE AND ENVIRONMENT OF DEPOSITION

Analysis of the Neyveli palynoflora provides some information regarding palaeoclimate and depositional environment which prevailed during the sedimentation of the Neyveli Formation. It is generally an accepted fact that the environmental requirements of the past plants had been the same as of their present day equivalents. The present day distribution of the extant plants therefore plays a key role in inferring palaeoclimate and depositional environment. A list of palynotaxa and their probable affinities and present day distribution is given in Table 1 which shows that majority of the families represented in the Neyveli palynoflora have their present day distribution in tropical (subtropical) regions. These families are: Schizaeaceae, Cyatheaceae, Gleicheniaceae, Arecaceae, Meliaceae, Rhizophoraceae, Bombacaceae, Araliaceae, Ctenolophonaceae, Alangiaceae, Rubiaceae, Caesalpiniaceae, Sapotaceae and Hippocrateaceae. Other families represented in the palynoflora are cosmopolitan in distribution and none of them is restricted to temperate (or even subtemperate) regions. Typical rain-forest elements, viz.,

Table 1—Botanical affinities of the palynofossils from the Neyveli Formation and present day distribution of their extant counterparts

FAMILIES	PALYNOTAXA	PRESENT DAY DISTRIBUTION
Cyatheaceae	*Cyathidites australis*	Tropical-subtropical
Osmundaceae	*Osmundacidites* sp., *Todisporites kutchensis, T major, Intrapunctisporis gigantica, Intrapunctisporis* sp.	Cosmopolitan (shady places or swamps)
Polypodiaceae	*Polypodiisporonites repandus, P. mawkmaensis, Polypodiisporonites* sp., *Laevigatosporites lakiensis, L. tertiarus, L. variabilis, Seniasporites verrucosus*	Cosmopolitan
Gleicheniaceae	*Gleicheniidites* sp.	Tropical-subtropical
Schizaeaceae	*Schizaeoisporites digitatoides, S. ramanujamii, S. ghoshii, S. multistriatus, S. minimus, S. sinuta, Lygodiumsporites lakiensis, L. eocenicus, Neyvelisporites bolkhovitinae, N. cooksoniae*	Tropical-subtropical
Arecaceae	*Neocouperipollis wodehousei, N. brevispinosus, N. achinatus, N. cymbatus, N. rarispinosus, N. kutchensis, N. robustus, N. donaensis, Arecipites punctatus, A. bellus, Arengapollenites achinatus, Spinainaperturites conatus, S. densispinus, Spinainaperturites* sp., *Proxapertites assamicus, P. microreticulatus, Proxapertites* sp., *Trilatiporites sellingii, T erdtmanii, T noremii, Spinizonocolpites echinatus, S. neyveliensis, Echimonoporopollis grandiporus, E. neyveliensis, Acanthotricolpites brevispinosus, A. microreticulatus, A. neyveliensis, A. tiruchirapalliensis, A. robustus,* cf. *Acanthotricolpites* sp., *Palmidites maximus, P. naviculus, P. plicatus, Palmaepollenites plicatus*	Tropical-subtropical
Potamogetonaceae	*Retipilonapites arcotense, Assamiapollenites* sp.	Cosmopolitan (aquatic)
Liliaceae	*Matanomadhiasulcites kutchensis, M. major, Dracaenoipollis* sp.	Cosmopolitan
Meliaceae	*Meliapollis ramanujamii, M. navalei, M. iratus, M. raoi, M. quadrangularis, M. gratus, M. melioides, M. venkatachalae, Meliapollis* sp.	Tropical-subtropical
Brassicaceae	*Tricolpites minutus*	Cosmopolitan (grows in diverse situations)
Gunneraceae	*Tricolpites reticulatus*	Cosmopolitan
Araliaceae	*Araliaceoipollenites matanomadhensis*	Tropical-subtropical
Oleaceae	*Retitrescolpites decipiens, Tricolpites crassireticulatus, T. retibaculatus*	Cosmopolitan (chiefly tropical)
Rubiaceae	*Retitricolporites minor, Retitricolporites* sp.	Tropical-subtropical
Caesalpiniaceae	*Margocolporites tsukadae, M. sitholeyi, M. oligobrochatus, M. ghoshii, Margocolporites* sp.	Tropical-subtropical
Bombacaceae	*Lakiapollis ovatus, Tricolporopollis rubra, T. matanomadhensis*	Tropical-subtropical
Rhizophoraceae	*Paleosantalaceaepites minutus*	Tropical-subtropical
Sapotaceae	*Thomsonipollis* sp.	Tropical-subtropical
Myricaceae	*Myricipites* sp.	Cosmopolitan
Alangiaceae	*Pellicieroipollis langenheimii, Alangiopollis* sp.	Tropical-subtropical
Ericaceae	*Ericipites sahnii*	Cosmopolitan
Hippocrateaceae	*Hippocrateaceaedites vancampoae*	Tropical-subtropical
Betulaceae	*Triporopollenites parvus, T. tamilensis*	Cosmopolitan
Ctenolophonaceae	*Ctenolophonidites saadii, C. costatus, C. erdtmanii, C. ramanujamii, C. stellatus, Ctenolophonidites* sp.	Tropical-subtropical
Onagraceae	*Triangulorites bellus, Triangulorites* sp.	Cosmopolitan
Plumbaginaceae	*Warkallipollenites reticulatus*	Tropical-subtropical
Thymeliaceae	*Clavaperiporites jacobii*	Cosmopolitan (absent in extremely cold region)

Alangiaceae and Ctenolophonaceae and a good number of pteridophytic spores clearly point out towards a tropical climate with plenty of rainfall. This contention is further supported by profuse occurrence of a variety of epiphyllous microthyriaceous fungi and fungal spores.

The palynotaxa recorded from the Neyveli Formation are referable to the floral elements of diverse ecology, viz., (i) upland, (ii) fresh water swamps and water edge, (iii) back mangrove, (iv) mangrove, and (v) sand dune and beach (Table 2).

Table 2—Ecological expression of the palynofossils from the Neyveli Formation

ECOLOGICAL GROUPS	PALYNOTAXA
Upland elements	*Hippocrateaceaedites, Retitricolporites, Ericipites*
Fresh water swamps and water edge elements	*Schizaeoisporites, Polypodiisporonites, Laevigatosporites, Meliapollis, Ctenolophonidites, Margocolporites, Retipilonapites, Matanomadhiasulcites*
Back mangrove elements	*Meliapollis, Alangiopollis, Araliaceoipollenites*
Mangrove elements	*Paleosantalaceaepites, Warkallipollenites*
Sand dune and beach elements	*Palmaepollenites, Arecipites, Longapertites, Spinizonocolpites*

The lower part of the Neyveli Formation, represented by *Neocouperipollis* spp. Cenozone, is very rich in arecaceous pollen belonging to sand dune and beach floral elements which suggest a coastal environment slightly away from the storm-tide zone. The overlying part of the sequence, represented by *Triangulorites bellus* Cenozone, contains a mixture of upland, fresh water swamps and water edge, mangrove, back mangrove and only a few sand dune and beach elements. Such composition indicates deposition in mangrove swamps with local pockets of marine influence and sufficient fresh water supply. The overlying *Trilatiporites sellingii* Cenozone, comprising lignite part of the sequence, contains upland, fresh water swamps and water edge, back mangrove and sand dune and beach elements. This indicates deposition of lignite in back mangrove conditions. It may therefore be concluded that the Neyveli Formation was deposited in coastal environment, ranging from back mangrove to mangrove, with a short transgressive phase just before the deposition of lignite.

BIOSTRATIGRAPHIC ZONATION

Based on first and last appearance of palynotaxa and their maximum development, decline, restricted occurrence and absence, the Neyveli Formation has been divided into three biozones. In ascending order, these are: (i) *Neocouperipollis* spp. Cenozone, (ii) *Triangulorites bellus* Cenozone, and (iii) *Trilatiporites sellingii* Cenozone. A brief account of these biozones is given below.

Neocouperipollis spp. Cenozone

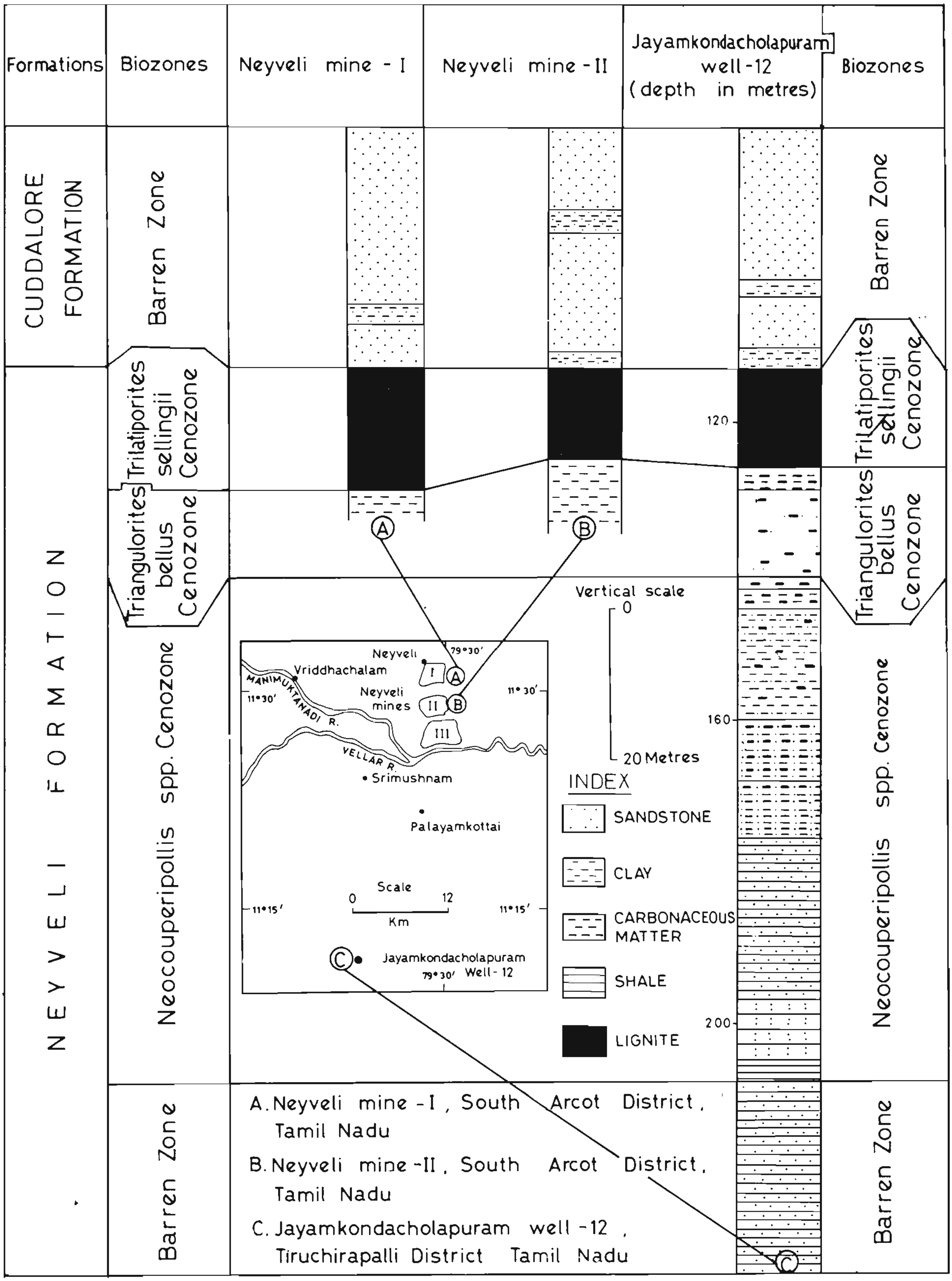
This biozone is designated in the Jayamkondacholapuram well-12 in Tiruchirapalli District, Tamil Nadu between 206 and 142 metres below ground level. The characteristic feature of this biozone is the overwhelming occurrence (85%) of a variety of spinose pollen grains, viz., *Spinainaperturites, Neocouperipollis, Arengapollenites, Spinizonocolpites, Echimonoporopollis* and *Acanthotricolpites*. Besides, other important palynotaxa of this biozone are *Lygodiumsporites eocenicus, Todisporites kutchensis, Meliapollis iratus* and *Triporopollenites parvus*.

Triangulorites bellus Cenozone

This biozone is designated in the Jayamkondacholapuram well-12 in Tiruchirapalli District, Tamil Nadu between 142 and 127 metres below ground level. It can be differentiated from the underlying *Neocouperipollis* spp. Cenozone by the absence or rarity of spinose pollen and first appearance and dominant representation of *Tricolporopollis, Trilatiporites, Retipilonapites, Palmidites, Retipollenites, Cryptopolyporites, Tricolpites, Meliapollis, Lakiapollis, Ctenolophonidites, Psilastephanocolpites, Matanomadhiasulcites, Schizaeoisporites, Seniasporites, Gleicheniidites* and *Polypodiisporonites* and restricted occurrence of *Retipollenites laevigatus, R. neyveliensis, Margocolporites oligobrochatus, Triangulorites bellus, Tricolporopollis matanomadhensis, Tricolpites retibaculatus* and *Psilastephanocolpites quadrangularis*.

Trilatiporites sellingii Cenozone

This biozone is designated in the Jayamkondacholapuram well-12 of Tiruchirapalli District and Neyveli Mines-I and II in South Arcot District, Tamil Nadu. In Jayamkondacholapuram well-12, this biozone was marked between 127 and 114 metres below ground level whereas in Neyveli Mines-I and II, it includes lignite bed about 16 and 12 metres thick respectively. The characteristic feature of this biozone is the abundant occurrence of *Trilatiporites* and *Proxapertites* (in the upper part of the biozone) and absence of spinose pollen complex and *Triangulorites*. The significant genera



Text-figure 1—Palynostratigraphic correlation of the Neyveli Formation of Neyveli Mines-I and II (South Arcot District) and Jayamkondacholapuram Well-12, Tiruchirapalli District, Tamil Nadu.

of this biozone are *Trilatiporites, Proxapertites, Neyvelisporites, Meliapollis, Pseudonothofagidites, Schizaeoisporites, Tricolpites, Margocolporites, Cryptopolyporites, Palmidites, Retitrescolpites, Pellicieroipollis, Ctenolophonidites, Lygodiumsporites* and *Laevigatosporites*, whereas species restricted to this biozone are *Proxapertites assamicus, P. microreticulatus, Meliapollis raoi, Pseudonothofagidites cerebrus, P. septaporatus* and *Pellicieroipollis langenheimii* (Text-figure 1).

CORRELATION AND AGE

The palynofloral compositions of three biozones of the Neyveli Formation are distinctly different from each other. An attempt has been made here to correlate these biozones with the contemporary stratigraphic units and to deduce the age of the Neyveli Formation.

The bulk of the *Neocouperipollis* spp. Cenozone assemblage is constituted by spinose pollen grains, viz., *Neocouperipollis* (30 per cent), *Acanthotricolpites* (23 per cent), *Spinizonocolpites* (14 per cent), *Echimonoporopollis* (9 per cent) and *Spinainaperturites* (8 per cent) along with *Lygodiumsporites. Margocolporites, Meliapollis* and *Palmidites* also commonly occur in the upper part of this cenozone. It is a known fact that spinose pollen constitute a dominant and essential part of the well dated Late Palaeocene assemblages of India. Besides, other palynofossils of this biozone also commonly occur in them. The Late Palaeocene biozones, thus correlatable with the *Neocouperipollis* spp. Cenozone, are: (i) *Neocouperipollis brevispinosus* Cenozone (Saxena, 1981) of the Matanomadh Formation of Kutch, Gujarat; (ii) *Proxapertites cursus* Zone (Baksi & Deb, 1980, in part) and *Monocolpopollenites eocenicus* Zone (Baksi & Deb, 1980, in part) of Bengal Basin; (iii) *Palmidites plicatus* Cenozone (Sah & Singh, 1974) of the Tura Formation of Garo Hills, Meghalaya; (iv) *Lycopodiumsporites speciosus* Cenozone (Kar & Kumar, 1986) of the Lakadong Sandstone of Khasi Hills, Meghalaya; (v) *Palmidites ovatus* Cenozone (Tripathi & Singh, 1984) and *Apectodinium homomorphum* Cenozone (Tripathi & Singh, 1984, in part) of the Therria Formation of Jaintia Hills, Meghalaya; and (vi) *Proxapertites hammenii* Cenozone (Venkatachala & Rawat, 1972) of Cauvery Basin, Tamil Nadu. The *Neocouperipollis* spp. Cenozone is homotaxial to the SP. 4 Zone (Late Palaeocene) of Singh and Dogra (1988).

The *Neocouperipollis* spp. Cenozone is overlain by *Triangulorites bellus* Cenozone which is further

Table 3—Correlation of the Neyveli Formation with Palaeocene—Eocene biozones/palynofloras from various parts of India

					MEGHALAYA		
PRESENT STUDY	CAUVERY BASIN	KUTCH	RAJASTHAN	BENGAL	GARO HILLS	KHASI HILLS	JAINTIA HILLS
Trilatiporites sellingii Cenozone *Triangulorites bellus* Cenozone	—	*Triangulorites triangulus* Cenozone—Kar, 1978; *Tricolpites reticulatus* Subzone—Kar, 1985; *Meliapollis ramanujamii* Subzone—Kar, 1985	Palana lignite assemblage—Sah & Kar, 1974; SP. 5 Zone—Singh & Dogra, 1988	*Trilatiporites biswasii* Zone—Baksi & Deb, 1980 (in part); *Monocolpopollenites eocenicus* Zone—Baksi & Deb, 1980 (in part)	*Proxapertites assamicus* Cenozone—Sah & Singh, 1974; & Simsang Palynological Zone 1—Baksi, 1962		—
Neocouperipollis spp. Cenozone	*Proxapertites hammenii* Cenozone—Venkatachala & Rawat, 1972	*Neocouperipollis brevispinosus* Cenozone—Saxena, 1981	SP.-4 Zone—Singh & Dogra, 1988	*Monocolpopollenites eocenicus* Zone—Baksi & Deb, 1980 (in part) *Proxapertites cursus* Zone—Baksi and Deb, 1980 (in part)	*Palmidites plicatus* Cenozone—Sah & Singh, 1974	*Lygodiumsporites speciosus* Cenozone—Kar & Kumar, 1985	*Apectodinium homomorphum* Cenozone—Tripathi & Singh, 1984 (in part). *Palmidites obtusus* Cenozone—Tripathi & Singh, 1984

succeeded by *Trilatiporites sellingii* Cenozone. The latter one has been encountered in both the Neyveli mines and also in Jayamkondacholapuram. The collective palynofloral composition of the *Triangulorites bellus* and *Trilatiporites sellingii* Cenozones is very closely identical, and hence homotaxial, to those of the Early-Middle Eocene palynofloras of India known from: (i) *Triangulorites triangulus* Cenozone (Kar, 1978) of the Naredi Formation of Kutch, Gujarat; (ii) *Meliapollis ramanujamii* Subzone (Kar, 1985) and *Tricolpites reticulatus* Subzone (Kar, 1985) of the Naredi Formation of Panandhro area of Kutch, Gujarat; (iii) palynoflora from the Palana lignite of Rajasthan (Sah & Kar, 1974); (iv) *Monocolpopollenites eocenicus* Zone (Baksi & Deb, 1980, in part) and *Trilatiporites biswasii* Zone (Baksi & Deb, 1980) of Bengal Basin; (v) *Proxapertites assamicus* Cenozone (Sah & Singh, 1974) of the Tura Formation of Garo Hills, Meghalaya; and (vi) Simsang Palynological zone of the Sylhet Limestone Formation of Meghalaya (Baksi, 1962). SP.—5 Zone (Early Eocene) proposed by Singh and Dogra (1988) is synchronous to a part of the above sequence (Table 3).

The above account and the fact that the Neyveli palynoflora is not comparable to any post-Eocene palynoflora known till date, strongly suggest a Late Palaeocene to Middle Eocene age for the Neyveli Formation.

CONCLUSIONS

From the palynofloral study of the Neyveli Formation, following conclusions have been derived.

1. The palynoassemblage from the Neyveli Formation consists of algal and fungal remains, pteridophytic spores and angiospermous pollen. However, bryophytic and gymnospermous elements appear to be unrepresented.
2. The pteridophytic spores are represented by Cyatheaceae, Osmundaceae, Polypodiaceae, Gleicheniaceae and Schizaeaceae, whereas angiospermous pollen are referable to Arecaceae, Potamogetonaceae, Liliaceae, Meliaceae, Brassicaceae, Gunneraceae, Araliaceae, Oleaceae, Rubiaceae, Caesalpiniaceae, Bombacaceae, Rhizophoraceae, Sapotaceae, Myricaceae, Alangiaceae, Ericaceae, Hippocrateaceae, Betulaceae, Ctenolophonaceae and Onagraceae.
3. The palynoflora suggests a tropical (warm-humid) climate with plenty of rainfall during the sedimentation of the Neyveli Formation.
4. The environment of deposition has been deduced as coastal, ranging from back mangrove to mangrove, with short transgressive phase just before the deposition of lignite.
5. The Neyveli Formation is divisible into three biozones, viz. *Neocouperipollis* spp. Cenozone, *Triangulorites bellus* Cenozone, and *Trilatiporites sellingii* Cenozone. These biozones can be identified by their characteristic and restricted palynofossils. In Jayamkondacholapuram Well-12, all the above zones were encountered whereas in Neyveli Mines-I and II only upper zone could be located.
6. The Neyveli Formation is correlatable with Late Palaeocene-Middle Eocene biozones of Kutch, Rajasthan, Bengal Basin, Cauvery Basin and Garo, Khasi and Jaintia Hills of Meghalaya and hence has been considered synchronous to them.

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Changing pattern of vegetation in the intermontane basin of Kashmir since 4 Ma : a palynological approach

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Gupta HP 1992. Changing pattern of vegetation in the intermontane basin of Kashmir since 4 Ma : a palynological approach. *Palaeobotanist* **40** : 354-373.

The Upper Karewas are devoid of biomass potential and hence no palynostratigraphy could be established. In contrast, Lower Karewas are both quantitatively and qualitatively rich in biota. The major areas of study include Dubjan, Hirpur, Krachipathra, Ningle Nullah, Laredura, Liddarmarg, Butapathri, Wapjan, etc. Dubjan, supposedly the basal part of the Karewa sequence, overlies unconformably the Panjal volcanics and Hirpur overlies the Dubjan. Recent palaeomagnetic studies suggest that these sediments span late Gilbert to middle Matuyama magnetic polarity ranging in age between 3.5 to 2.0 Ma. Wapjan is the uppermost part of the Lower Karewa and falls between late Matuyama to early Bruhnes ranging in age between 0.75 to 0.70 Ma.

Palynological and palaeobotanical investigations carried over a large number of exposures have revealed that there is no unanimity in vegetation all through the Karewa deposits, instead a variety of vegetation type has been recorded in time and space indicating their development under different circumstances. The vegetation met here varies from typical subtropical to desertic alpine type. The climate has not been static for a long period rather reciprocity in the climate has been recorded which has been deciphered from vegetal signatures left by the nature. Post-glacial sediments from the lake basin in the valley have also been investigated, which reveal three-fold vegetational development reflecting on three-fold climatic evolution.

Key-words—Palynology, Palaeoclimate, Vegetation, Intermontane Basin, Karewa, Kashmir.

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सारॉंश

पिछले 40 लाख वर्ष में कश्मीर की अन्तरपर्वतीय द्रोणी में बदलती वनस्पति : परागाणविक दृष्टिकोण

हरीपाल गुप्ता

उपरि करेवा में जैवद्रव्य न मिलने के कारण यहाँ की परागाणुस्तरिकी अन्वेषित नहीं की जा सकी और इसके विपरीत अधरि करेवा परिमाणात्मक एवं गुणात्मक दृष्टि से जीविता से भरपूर है। दुबजन, हीरपुर, कराचीपथरा, निंगल नाला, लरेड्डुरा, लिडरमार्ग, बूटापथरी, वापजन इत्यादि नामक मुख्य अध्ययन किये गये क्षेत्र हैं। ये सम्भवतः करेवा अनुक्रम के आधारी भाग हैं तथा पंजाल ज्वालामुखी ऊपर परन्तु असम्बद्ध स्थित है, हीरपुर दुबजन के ऊपर स्थित है। अभी हाल में पुराचुम्बकीय अध्ययन से प्रस्तावित होता है कि ये अवसाद अंतिम गिल्बर्ट से मध्य मातुयामा चुम्बकीय ध्रुवता तक विस्तृत हैं तथा 30 से 20 लाख वर्ष आयु के हैं। अधरि करेवा का ऊपरी भाग वापजन कहलाता है तथा अंतिम मातुयामा से प्रारम्भिक ब्रुहनेस तक विस्तृत हैं और 75,000 से 70,000 वर्ष आयु के हैं।

अनेक अनावरणों के परागाणविक एवं पुरावनस्पतिक अध्ययन से व्यक्त होता है कि यहां की वनस्पति में समांगता नहीं है जिससे यह व्यक्त होता है कि इनका विकास विभिन्न परिस्थितियों में हुआ है। यहाँ मिलने वाली वनस्पति सामान्य उपोष्ण कटिबन्धीय से शुष्क अॅल्पीय प्रकार की है उपलब्ध आँकड़ों से यह व्यक्त होता है कि यहाँ की वनस्पति में जल्दी-जल्दी परिवर्तन हुए हैं। झील के पश्चहिमानी अवसादों के अध्ययन से वनस्पति की तीन पुनरावृत्तियाँ इंगित होती हैं और इसी प्रकार जलवायु की भी।

PAST forty years, especially the preceding two decades, have witnessed a phenomenal progress in the development of science of palaeobotany and palynology in India. Palynologists have played an important role in resolving many a vexed problems related to various aspects of botany and geology.

An article published in May, 1936 on the occurrence of prehistoric lake with abundance of fossil plants at a height of 3,400 m just above Gulmarg (Stewart, 1936), had drawn the attention of Sahni (1936) to explain the significance of these

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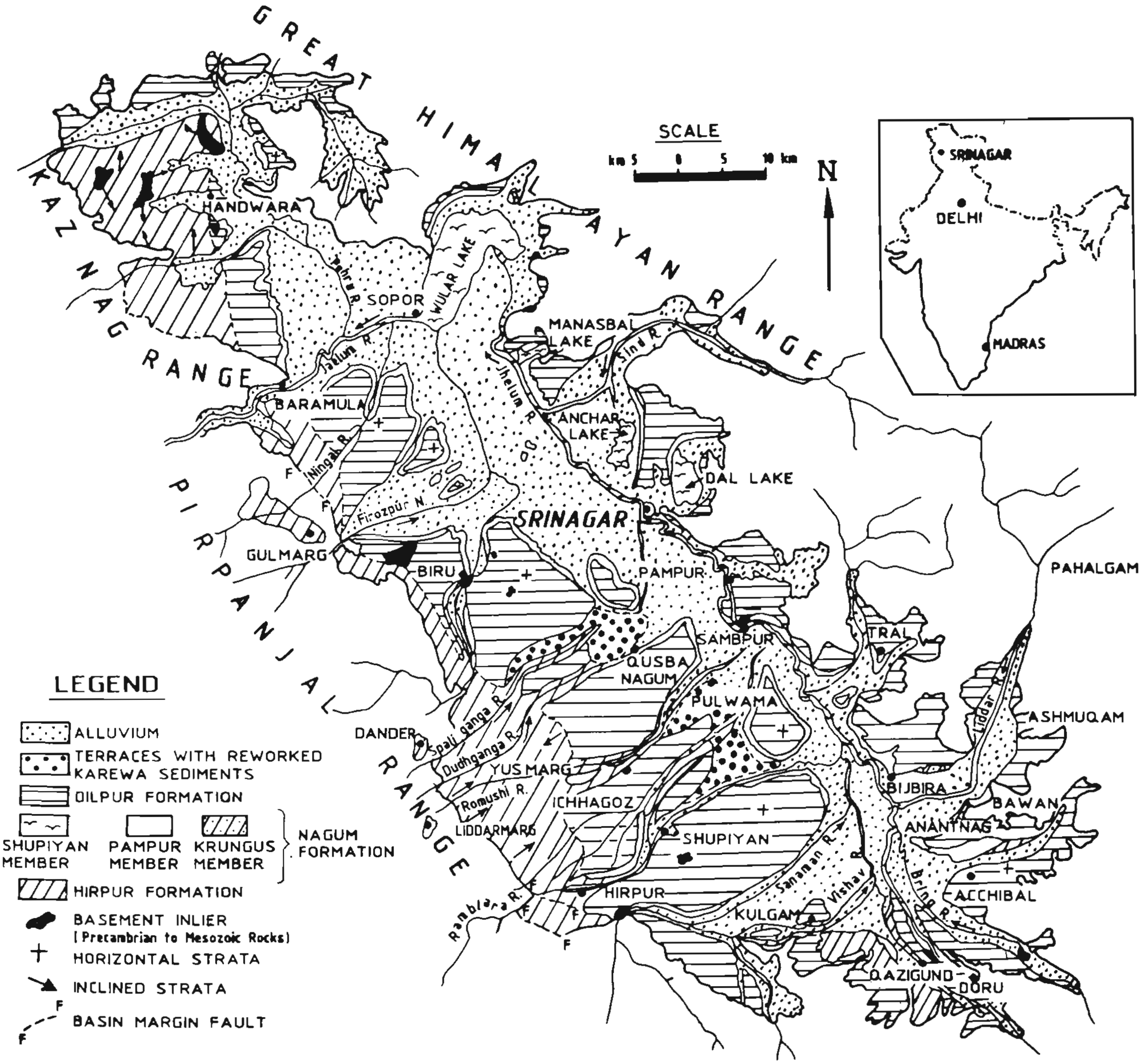
deposits at high level known as the Karewa Series.

Recently these Karewa deposits have been traced and mapped as far as the crest of Pir Panjal range which bounds the Kashmir Valley on the south-west (Bhatt, 1989).

Kashmir Valley is an intermontane fault basin and lies between Pir Panjal and the Great Himalayan ranges (Text-figure 1). The Pir Panjal range attains an elevation of about 4,000 m and the Great Himalayan range about 6,000 m. The minimum and maximum elevations in the valley are 1,500 m and 2,200 m respectively. This difference of elevation is evenly distributed through numerous Karewa terraces. Lakes and swamps occupy much of the north-western part of the valley. The lakes, Wular, Manasbal, Anchar, Dal, etc. lie in the flood plain of Jhelum River whose broad meanders have cut swampy lowlands out of the Karewa terraces (de Terra & Paterson, 1939). Some of the above mentioned lakes have been radiocarbon dated and mostly represent deglacial, Holocene or parts thereof. The occurrence of subrecent/recent alluvium is generally restricted to the central portions of the valley. Along the major drainage lines, the alluvial tract extends deep into the Pir Panjal and the Great Himalayan range (Bhatt, 1975).

The fossil bearing sediments near Gulmarg, like many other deposits of clay, sand and gravel on north-east slopes of Pir Panjal were laid down in the lake bed (Stewart, 1936). But, Sahni (1936) did not



Text-figure 1—Lithostratigraphic map of Karewa Group, Kashmir Valley, Jammu and Kashmir (after Bhatt, 1989).

reconcile with Stewart's view point rather opined that the lake never existed at such a high altitude where its bed can be seen today. Strange though it may appear, this lake must have been situated several hundred meters lower than the present main valley level. The sediments have been lifted out of their horizontal position atleast by about 1,500 to 2,000 meters. de Terra (1934) has suggested three orogenies in the region such as Karakoram phase, Sirmurian phase and Siwalikian phase which took place during Middle Cretaceous, Oligocene-Miocene and Late Pliocene-Middle Pleistocene, respectively. He further added that the fourth orogeny took place during middle-Late Pleistocene, which elevated the Pir Panjal. The same orogenic movement lifted the Lower Karewa deposits to the present height of 1,850 m a.s.l.

The study of the fossil plants from the Pir Panjal dates back to 1864 when Godwin-Austen reported the occurrence of fossil leaves belonging to the modern species of plants in clay deposits at Gojipathri near Nilnag and at Liddarmarg, southwest of Gulmarg. Since then fossil plants have been discovered in similar deposits at numerous localities in the Pir Panjal by Middlemiss (1911), Wodehouse (1935) and Puri (1948a, b). The hunt for plant remains is still continuing and a lot of information about the occurrences of fossil plants is pouring in.

The concept that Pir Panjal range is relatively of recent origin was floated by Godwin-Austen (1864) in unmistakable terms. Middlemiss (1911) further supported this idea. de Terra (1933) provided convincing evidence for the same. Sahni (1936) demonstrated that the fossil plants collected from lacustrine beds in the Gulmarg-Baramula region were undoubtedly deposited in the low level lake basin, where the climate was milder.

Similar strata, now tilted at angles as high as 30° to 40° are known to occur in the Pir Panjal range, sometimes at altitudes as high as 4,000 m a.s.l. It is significant that except for some local variations, their dip tends towards the valley and they could be traced downward with gradually decreasing dip into the valley, where they are seen mostly in their undisturbed and almost horizontal position. With this analysis it could be conjectured that at one time Kashmir must have been covered from end to end by the Karewa deposits representing the sediments either of a single vast lake or perhaps a series of water bodies. Thus, the existence of Karewa deposits, as far as the Pir Panjal range, shows beyond doubt that the ancient Karewa lake(s) must have greatly exceeded the present width of the Kashmir Valley.

The nature of stratum, whether clay, sand, lignite, lignitic mud or gravel, its relationship to the underlying/overlying strata, and its fossil contents, if any, indicates as to whether it was deposited in deep water, near shore, stagnant water or stream that fed the lake. Its careful study has led to tangible conclusions regarding the depositional environment and character of the flora and fauna that existed at the time of deposition. Efforts are made to decipher the signatures of vegetal remains from the Kashmir Basin in order to synthesize the data and to reconstruct the vegetation of the past.

GEOLOGY OF KAREWAS

Geology of Karewa deposits in the Kashmir Valley has been a subject of study for more than a century but different views advanced periodically in regards to the origin, nature, stratigraphical status, thickness and the age of these deposits. In the beginning attempts were made to define these deposits in order to establish a stratigraphic base (Godwin-Austen, 1864, 1880; Lyddeker, 1878; Middlemiss, 1911, 1924; Wadia, 1961; Farooqi, 1973; Farooqi & Desai, 1974; Bhatt, 1975, 1976, 1978; Bhatt & Chatterji, 1976). The concept of two-fold classification of Karewa deposits into lower and upper has been in practice since the inception of Karewa. Considering two well-marked regional unconformities, Pal and Srivastava (1982) have suggested three-fold classification into lower, middle and upper Karewas, yet it has not received much attention.

De Terra and Paterson (1939) and Wadia (1938, 1941) opined that the Karewa deposits are of glacial origin. They pleaded that moranic deposits of Glacial Stage I and II resulted into thick conglomerate sequences in the Karewa succession such as Rembiara Member (Hirpur Formation) as I glacial deposit and Suphiyan Member (Nagum Formation) as the II glacial deposit. This view was followed by Bhatt (1975, 1978). Thereafter, the glacial status of Karewa sequence was either prefixed or suffixed with fluvial event. Recent geological and chronological analyses of Karewa sediments have revealed that the conglomerate zones, which were till now considered as marker of I and II glaciers are tectonically generated fluvial sequences (Burbank & Johnson, 1982; Bhatt, 1982a, b). Palaeobotanical and palynological studies conducted over the Karewa sediments have not provided clues for glacial signatures (Puri, 1947; Dodia *et al.*, 1982; Gupta *et al.*, 1984a,b; Gupta & Khandelwal 1987; Gupta & Sharma, 1989; Sharma & Gupta, 1984; Sharma *et al.*, 1984).

Sedimentological data, although meagre, have revealed that the conglomerate beds in the Karewa sequence are perhaps the deposits of pro-glacial braided channels (Tandon, 1981). Tandon *et al.* (1982) have further advocated that the Karewa sediments are largely of fluvio-lacustrine origin. Singh (1982) has provided a conceptual analysis of sedimentation pattern in the Kashmir Basin and has remarked that the deposition took place in a lacustrine basin encompassing the whole Kashmir Valley. In the initial stages the lake was shallow ranging in depth from 5-10 m and later it deepened at several places. He has further emphasized that lithological and sedimentological records do not support the glacial environment for the Karewa deposits. Therefore, Rembiara and Suphiyan members do not show any positive evidence of glaciation and cannot be correlated to either I or II glacial phase respectively.

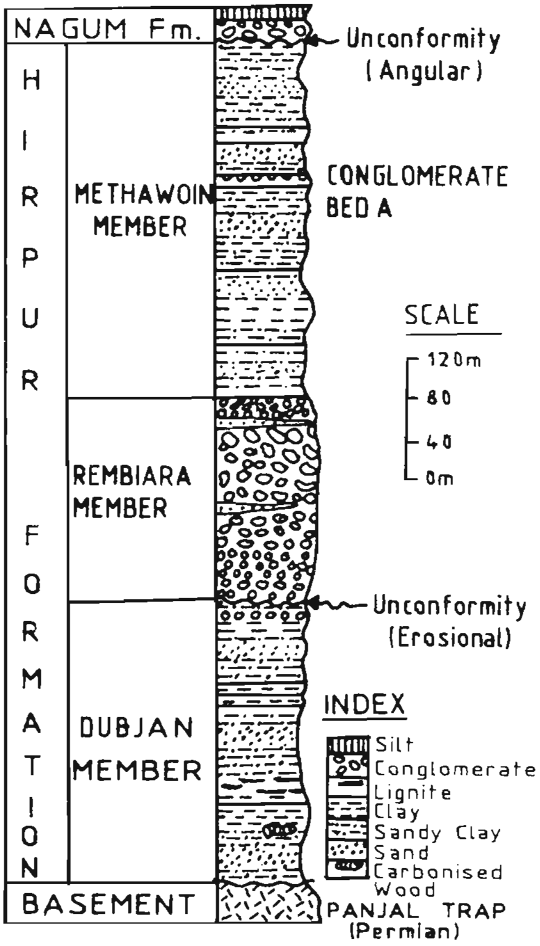
Stratigraphic succession and thickness measurements of the Karewa sequence estimated by various workers are given as follows:

Godwin-Austen (1859, 1864)	130 m
Middlemiss (1924)	1,360 m
de Terra and Paterson (1939)	900 m
Wadia (1961)	1,850-2,175 m
Farooqi and Desai (1974)	1,610 m
Bhatt and Chatterji (1976)	2,755 m
Singh (1982)	1,300 m
Burbank and Johnson (1983)	1,350 m
Pal and Srivastava (1982)	450-500 m
Kaila *et al.* (1984)	1,100 m
Bhatt D.K. (1989)	1,200 m

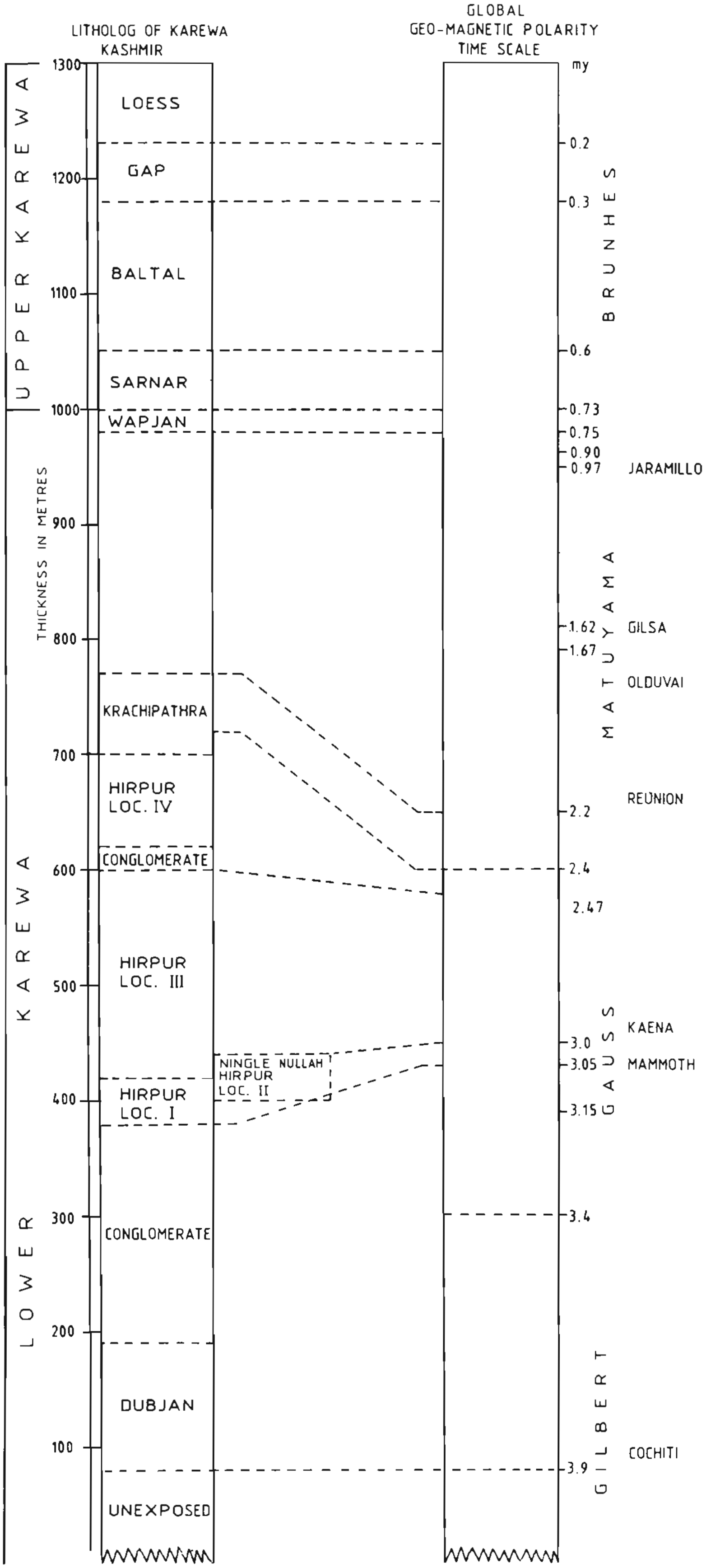
CHRONOLOGY AND AGE OF KAREWAS

Divergent chronologies have been given for the sedimentation in the ancient Karewa Lake/lakes in the Kashmir Valley. Godwin-Austen (1864) referred Karewa deposits to Pleistocene. Lydekker (1883) divided them into lower and upper parts and assigned Pliocene age to the Lower Karewa. Middlemiss (1911, 1924) assigned Plio-Pleistocene age to the Karewas. de Terra and Paterson (1939), on the evidence of *Elephas hysudricus* in the Lower Karewa, assigned a definitive Pleistocene age and correlated them with the Pinjor Stage of the Upper Siwaliks. They worked with the concept of four-fold glaciations and considered Karewa sequence to represent complete cycles of Pleistocene Ice age and correlated Rembiara Member with I glaciation (Lower Pleistocene) and Suphiyan Member with II glaciation (Middle Pleistocene). Wadia (1941, 1951) assigned pre-glacial (Pliocene) age to the basal part of the Lower Karewa and equated them with the Dhok Pathan of Siwaliks. Roy (1974, 1980), on the basis of diatom zonation, opined that the base of the Lower Karewa is as old as Miocene. Singh (1977) employing ostracode analysis, supported Roy's view. Bhatt (1982), while evaluating the existing data, proposed that the base of Hirpur Formation is Pontian (Pliocene) and the top goes up to the beginning of Holocene. Gupta *et al.* (1984a,b), on the basis of palynostratigraphy have suggested pre-Quaternary age to the basal part of Zone III which was later referred to as lower part aof Methawoin Member (Bhatt, 1979, 1982). The pollen yield of zone III or Methawoin Member characterizes the pre-glacial milieu. Likewise, the composition of mammalian assemblage also suggests Lower Pleistocene age for the Methawoin Member (Bhatt, 1982).

Palaeomagnetic and fission-track analyses dates the volcanic ash layer in Romushi Valley as 2.40 ± 0.3 Ma (Burbank & Johnson, 1982, 1983). These findings were later endorsed by Kusumgar *et al.* (1985). This ash layer occurs beneath the conglomerate bed of Rembiara Member at Abhom in Romushi Valley (Text-figure 2). The Olduvai event is



Text-figure 2—Lithocolumn of Hirpur Formation at Hirpur Village Upper Rembiara Valley (after Bhatt, 1989).



Text-figure 3—Karewa lithostratigraphy, correlation and geomagnetic polarity (after Agarwal *et al.*, 1989).

recorded in 50 m sequence which underlies the conglomerate bed of Methawoin Member in the Romushi Valley section (Burbank & Johnson, 1982). The top of the Olduvai normal palaeomagnetic event in the Matuyama reversed epoch is considered to mark the base of the Pleistocene and therefore, Plio/Pleistocene boundary could be drawn in the middle of Methawoin Member sequence in the Romushi Valley. Palynology too, supports the demarcation of Plio/Pleistocene boundary at the said level of Methawoin Member. The Matuyama/Brunhes contact is considered to mark lower/middle Pleistocene boundary (Text-figure 3).

PALAEOBOTANY OF KAREWAS

The occurrence of mega-plant remains was first observed by Godwin-Austen (1864) from Hirpur Formation. Thereafter, Middlemiss (1911) collected a number of fossil leaves, fruits, etc. from Liddarmarg which were later identified as *Quercus glauca, Buxus sempervirens, Alnus* sp., *Cinnamomum* sp. and *Jasminum* sp. The assemblage typifies the subtropical forest which presently grows at the height of 1,165-1,670 m a.s.l.

It would not be worthwhile to enumerate here all those references that are available on the subject but the mention of G.S. Puri's work is quite important since he has made a systematic attempt to highlight the palaeobotanical evidences burried in the Karewas and also reviewed the mega-plant remains discovered by earlier explorers. Puri (1948) re-examined several hundred plant species collected and identified by earlier workers from Karewa beds and summarized his decade's palaeobotanical observations. Almost all the plant-bearing material was procured from the strata of Hirpur Formation. The fossiliferous beds at various localities have been categorised under two main groups. The first group includes beds exposed at Laredura, Dangarpur. Butapathri, Nagbal, Gojipathri and Liddarmarg. Sediments at these places are largely composed of grey clays with blackish tinge and are compactly set into thick layers. The second group is composed of slightly coarse-grained clays often in pale yellow and occasionally bluish grey colour. These clays are thinly layered alternating with coarse and fine sediments and are known as "varves". Such beds are exposed at several places in the upper Ningle Valley and Hajabal. They are highly friable and do not prove useful for collection of fossils.

The Lower Karewa deposits towards Pir Panjal have yielded rich plant megafossils both quantity and quality-wise (Table 1). Three distinct floristic assemblages have been identified, which are termed as Laredura, Ningle Nullah and Liddarmarg floras (Puri, 1948).

Laredura flora—Laredura (lat. 34°7′, long. 74°21′) lies at an elevation of 2,000 m a.s.l. about 12 km south-west of Baramula town. Other equivalent fossiliferous sites clubbed in this category are Nichahom and Nagbal. Laredura flora comprises a rich plant assemblage comprising both warm-temperate and subtropical forms. It is chiefly dominated by a large number of leaves belonging to *Quercus dilatata, Q. incana, Ulmus, Alnus, Cedrus, Pinus roxburghii, Aesculus indica, Acer caesium*, etc. At present their modern representatives do not exist in the valley, rather they are confined to the lower elevations between 1,165-2,000 m a.s.l.

Ningle Nullah flora—Ningle Nullah (lat. 34°4′; long. 74°19′) lies at an elevation of 3,200 m a.s.l. and could be easily approached from Gulmarg. Other equivalent sites grouped in this category are Butapathri and Gojipathri and both lie almost at the same elevation. Ningle Nullah flora is composed of exclusively temperate forms like willows, poplars, cherries, walnuts, maples, elms, alders, spruce, silver fir, blue pine, deodar, etc. Besides, well-preserved leaf fragments of *Nelumbo nucifera* have been recovered. The modern representatives of the past analogues still exist on the northern slope of Pir Panjal in Kashmir Valley occupying an elevation between 2,300-3,300 m a.s.l.

Liddarmarg flora—Liddarmarg (lat. 33°48′; long. 74°39′) lies at an elevation of 3,500 m a.s.l. The clay here is blackish grey and well bedded; the nature and texture of sediments are the same as found in Laredura and Ningle Nullah localities but the flora greatly differs.

It is composed of mostly subtropical taxa but a few belong to the tropical zone as well. The important taxa encountered are *Quercus incana, Machilus* sp., *Acer oblongum, Pittosporum eriocarpum, Berchemia* sp., *Mallotus* sp., *Leea* sp., *Myrsine* sp. and *Ficus cunia*. This kind of flora does not grow in the valley rather it is confined to sub-Himalayan rain forest.

PALYNOLOGY OF KAREWAS

Kashmir Valley exhibits a complete sequence of Pleistocene and Holocene deposits in Karewas and lakes/swamps respectively which provide an opportunity to reconstruct palaeofloristics through palynology. During early days emphasis was given mainly to enumerate the taxa from sediments. Wodehouse (1935) pollen analysed samples from lower as well as Upper Karewas and quantified arboreal and nonarboreal taxa separately. Based on

Table 1—Plant fossils from Karewa, Kashmir

TAXA	PLANT REMAIN	CLIMATIC SIGNAL
LAREDURA FLORA		
Euphorbiaceae		
Mallotus philippensis	Leaf	Subtropical
Hippocastanaceae		
Aesculus indica	Leaf	Temperate
Myrsinaceae		
Myrsine sp.	—	Subtropical
Oleaceae		
Olea grandulifera	Leaf	Subtropical
Fraxinus sp.	Fruit	Warm temperate
Ulmaceae		
Ulmus wallichiana	Leaf	Warm temperate
U. laevigata	Leaf	Cool temperate
U. campestris	Leaf	
Juglandaceae		
Engelhardtia colebrookiana	Leaf	Subtropical
Lythraceae		
Woodfordia fruticosa	Leaf	Subtropical
Salicaceae		
Salix elegans	Leaf	Temperate
Fagaceae		
Quercus semecarpifolia	Leaf	Cool temperate
Q. dilatata	Leaf	Subtropical
Q. ilex	Leaf	Subtropical
Betulaceae		
Betula utilis	Leaf	Cold temperate
B. alnoides	Leaf	Cool temperate
Alnus nitida	leaf	Subtropical
Corylaceae		
Corylus ferox	—	Warm temperate
Aceraceae		
Acer villosum	Leaf and fruit	Temperate
A. caesium	Leaf and fruit	Temperate
Berberidaceae		
Berberis lycium	Leaf	Subtropical
Aralliaceae		
Hedera nepalensis	Leaf	Temperate
Papilionaceae		
Desmodium natans	Leaf	Subtropical
D. latifolium	Leaf	Subtropical
D. tiliaefolium	Leaf	Subtropical
Indigofera hepeptelea	Leaf	Subtropical
Anacardiaceae		
Rhus punjabensis		
R. succedenea	Leaf	Subtropical
Lannea coromandelica *(Odina woodier)*	Leaf	temperate
Rosaceae		
Prunus cerasiodes	Leaf	
Pyrus pashia	Leaf	

Contd.

Table 1—Contd.

TAXA	PLANT REMAIN	CLIMATIC SIGNAL
Rosa webbiana	Leaf	Subtropical-temperate
R. macrophylla	Leaf	Subtropical-Temperate
	Leaf	Temperate
Spiraea sp.	Leaf	Temperate
Cotoneaster bacillaris	Leaf	Temperate
Rubus fruticorus		
Ranunculaceae		
Ranunculus sp.	Fruit	Temperate
Clematis sp.	Fruit	Temperate
NINGLE NULLAH FLORA		
Hippocastanaceae		
Aesculus indica	Leaf	Cool temperate
Ulmaceae		
Ulmus laevigata	leaf	Warm temperate-cool temperate
Salicaceae		
Salix wallichiana	Leaf	Warm temperate-cold temperate
S. elegans	leaf	Warm Temperate
Populus ciliata	Leaf	Warm temperate
P. balsamifera	Leaf	Warm temperate
Betulaceae		
Betula utilis	Leaf	Cold temperate-subalpine
Alnus nepalensis	Leaf	Warm temperate-cold temperate
Aceraceae		
Acer pictum	Leaf	Cold temperate
A. pentapomicum	Leaf	Cool temperate
A. villosum	Leaf	Cool temperate
Cornaceae		
Cornus macrophylla	Leaf	Warm temperate
Marlea begoniaefolia	Leaf	Cold temperate
Oleaceae		
Fraxinus excelsior	Leaf	Warm temperate-cool temperate
Rosaceae		
Prunus cornuta	Leaf	Warm temperate
Pyrus malus	Leaf	Cool temperate
Cotoneaster nummularia	Leaf	Warm temperate
C. microphylla	Leaf	Cold temperate
LIDDARMARG FLORA		
Fagaceae		
Quercus incana	Leaf	Subtropical
Q. glauca	Leaf	Warm temperate
Urticaceae		
Ficus cunia	Leaf	Tropical
Euphorbiaceae		
Mallotus philippensis	Leaf	Tropical
Lauraceae		
Litsea lanuginosa	Leaf	Subtropical
Cinnamomum tamala	Leaf	Subtropical
Machilus odoratissima	Leaf	Subtropical
M. duthie	Leaf	Subtropical
Phoebe lanceolata	Leaf	Subtropical

Contd

Table 1—Contd.

TAXA	PLANT REMAIN	CLIMATIC SIGNAL
Buxaceae		
Buxus wallichiana	Leaf	Subtropical-warm temperate
B. papillosa	Leaf	Subtropical-warm temperate
Rutaceae		
Skimmia laureola	—	Tropical-subtropical
Toddalia sp.	—	Tropical-subtropical
Rhamnaceae		
Rhamnus virgatus	—	Tropical
R. triquetra	—	Tropical
Berchemia floribunda	—	Tropical
Myrsinaceae		
Myrsine africana	—	Tropical-subtropical
M. semiserrata	—	Tropical-subtropical
Rubiaceae		
Wendlandia exserta	Leaf	Tropical
Rosaceae		
Pyrus communis	Leaf	Subtropical-temperate
Cotoneaster bacillaris	Leaf	Subtropical-temperate
Spiraea sp.	Leaf	Subtropical-temperate
Berberidaceae		
Berberis lycium	Leaf	Subtropical
Cornaceae		
Dendrobenthamia capitata	—	Subtropical
Papilionaceae		
Desmodium podocarpum	Leaf	Subtropical
D. laxiflorum	Leaf	Subtropical
Asteraceae		
Inula cappa	—	Tropical
Araceae		
Acorus sp.	—	Tropical
Cyperaceae		
Scripus sp.	—	Tropical
Cyperus sp.	—	Tropical

frequency comparison of pollen in lower and upper Karewas he concluded that pollen content was essentially the same in both except for more grass pollen in the former which were almost absent in the latter. Cogner (*in* de Terra & Paterson, 1939), Iyenger and Subramanyam (1943), and Rao and Awasthi (1962) have enumerated diatom taxa from the Lower Karewa sediments, which mostly belong to Pennales. Goswami (1955-56) analysed Nichahom lignite samples and reported the occurrence of gymnospermous cuticles, a few disaccate pollen and one fern sporangium. Purekar (1962) made a report of some fungal conidia-like structures from Ningle Nullah sediments.

Nair (1960) pollen analysed some grab samples from both lower and upper Karewas. Besides, enumerating a number of arboreal and nonarboreal pollen taxa, he reflected on palaeobiogeography and migration of plants. He also observed that certain taxa like *Alnus, Carpinus, Pinus roxburghii* and *Quercus*, though present in the sediments, are absent today in the Kashmir Valley proper. Nevertheless, their counterparts do grow at present on southern slope of Pir Panjal mountains. Nair (1968) re-evaluated his previous work and provided a short pollen diagram to highlight the evolution of flora in the Lower Karewa. The approach was undoubtedly good but was sketchy and did not apply to Karewas in a larger perspective. Vishnu-Mittre *et al.* (1962), in their brief study of grab samples from the Lower Karewa dealt with floral assemblages but the data was too little to reconstruct palaeofloristics.

Vishnu-Mittre (1964) tried to apply palynology to define Plio/Pleistocene boundary but mostly without the support of palynodata. He had also not considered the demarcation of lower/middle/upper Pleistocene boundaries, rather endorsed de Terra and Paterson's (1939) view based on lithostratigraphy, that P/P boundary be drawn at the base of lithozone-I. In 1973, Vishnu-Mittre studied palynology from the four out of five lithozones, formulated by de Terra and Paterson (1939) in Lower Karewa. Vishnu-Mittre and Robert (1973) pollen analysed Lower Karewa samples and made comparative study of both micro- and megafossils from the same locality, but the results were not complementary. Later, based on diatom analysis the base of Lower Karewa was assigned Miocene age, being preponderant in centrale diatoms (Roy, 1974). However, the diatom analysis of Hirpur Loc. III sediments has revealed the preponderance of pennate diatom (Gupta & Khandelwal, 1987).

Keeping in view the high potential of palynostratigraphy and pollen yield of Karewa deposits, it was deemed necessary to investigate samples from measured sections. Several hundred samples from Dubjan, Rembiara and Methawoin members within Hirpur Formation were collected and pollen analysed. The samples were collected from all lithofacies but all of them did not yield. Lignitic muds and lignites yielded invariably a high biomass. Laminated muds at Dubjan and sands at Hirpur also yielded biota, though not qualitatively rich.

Palynological results obtained from different chronological sequence are primarily presented here separately and independently which would be later synthesized and put in unilinear manner so as to focus all vegetational shifts and their impacts on the palaeoenvironment. All possible efforts have been made to synchronize palynological findings with the up-to-date Karewa lithostratigraphy (Bhatt, 1989) and Karewa chronostratigraphy (Agarwal *et al.*, 1989).

Dubjan Member—It consitutes the oldest sequence in the Hirpur Formation and overlies the Panjal Trap basement. It consists of sand, sandy clay, clay, laminated mud, lignitic mud, etc. with sporadic pebble layers of restricted lateral extent. It has about 250 m thick section exposed and a major part is concealed below the rock debris (Bhatt, 1989). This zone was earlier referred to as zone I (Bhatt 1979, 1982). Its age has been extrapolated between 4 to 3.8 Ma and considered as Remzone I (Agarwal *et al.*, 1989). In view of the fact that only one datable volcanic ash deposit in the Karewas has been found and palaeomagnetic dating alone is not enough to provide high resolution, Agarwal *et al.* (1989) have advocated that the age estimation and extrapolation of various undated sequences in the valley could be done on the basis of sedimentation rate. As boulder conglomerates/sandstones are the result of rapid deposition and clays alone represent slow slack water deposition, they have used the thickness of mudstones to calibrate the sedimentation rate.

The total estimated thickness of the sampled Dubjan sediments for palynological investigation is around 20-23 meter. The stratigraphy is marked by lower and upper thick deposits of loose, coarse sand sandwitching several bands of lignitic mud and laminated mud alternating with each other. Pollen analytical investigations were performed on all types of lithofacies. It was found that laminated and lignitic mud are productive while sand, being coarse and porous, is almost always devoid of any biomass. The investigations have further revealed that the coherence exists in the palynological set-up throughout the pollen diagram but for the different values of different taxa. In order to elaborate significant epoch and events in time and space, the whole Dubjan diagram has been phased into three zones namely DB-1, DB-2 and DB-3 in ascending chronological order (Sharma *et al.*, 1984).

DB-1 symbolises the oak-chirpine composition but owing to constant competition amongst the forest constituents, chirpine improved and spread but oaks reduced and disappeared. Spruce was present in low values. The occurrence of deodar and birch was sporadic whereas alder was found to be fluctuatingly low. *Acacia* and *Berberis* made their way in lower and upper parts of the zone respectively. Nonarboreals are high in frequency as compared to arboreals. Poaceae made a humble beginning but improved its position in the younger strata while Cyperaceae showed contrary results. Chenopods and *Polygonum* remained sporadic throughout. Aquatic taxa, although feeble, were represented by *Potamogeton, Typha* and *Myriophyllum.*

DB-2 is featured by an erratic trend in the vegetation development and therefore to obtain precision, the zone is further divided into DB-2a and DB-2b subzones respectively.

DB-2a witnessed constant competition between chirpine and oak-woods owing to fluctuations in precipitation. Chirpine, after experiencing a serious set-back in the middle, rose to attain 60 per cent at the close of this subzone and oaks attained fairly high values in the middle but otherwise remained insignificant at the lower and upper limits of the subzone. *Alnus* continues to be abundant even at the chirpine fall but *Juglans* did not react sharply to the erratic climate, rather it maintained constant values throughout not exceeding 10 per cent. Another

Table 2—Indicates vegetational and climatic development in Kashmir Valley

STRATIGRAPHY 1	PERIOD 2	LITHOZONE 3	LOCALITY 4	POLLEN ZONE 5	CLIMATE 6	AGE 7
(Bhatt, 1989)		(Agarwal *et al.*, 1989)		(Dodia, 1988; Dodia *et al.*, 1982, 1984; Gupta & Khandelwal, 1987; Gupta & Sharma, 1989, 1992; Gupta *et al.*, 1984a, b, 1990; Sharma & Gupta, 1984; Sharma & Vishnu-Mittre, 1969; Sharma *et al.*, 1984 Singh, 1964; Vishnu-Mittre & Sharma, 1966)		(Burbank & Johnson, 1982; Kusumgar *et al.*, 1985)
	Postglacial to Deglacial		Toshmaidan, Higam, Hokarsar	Pine-Quercetum mixtum	Period of decreasing warmth.	500 years B.P.
			Butapathri Anchar	Quercetum mixtum-Pine	Period of warmth maximum	10,000 years N.P.
				Pine-Quercetum mixtum	Period of increasing warmth	14,000 years B.P.
Nagum Formation	Upper Pleistocene	Remzone, 9 Remzone, 7-8	Loess capping Karewas all over	Barren	Gap	0.2 Ma 20,000 years B.P.
				Barren	Gap	0.3-0.2 Ma
HIRPUR FORMATION Methawoin Member (400 m)			Baltal	B-2-Blue pine-Spruce-Silver-fir	Subalpine & moist	
				B-1-Spruce-Silver fir-Blue pine	Subalpine & dry	
			Sarnar	Blue pine-Quercetum mixtum	Cool temperate & moist	0.6-0.3 Ma
	Upper-Middle Pleistocene		Wapjan	Poaceae-Chenopodiaceae-Rosaceae (*Dryas*)—*Artemisia*—Asteraceae-Apiaceae (Scrub-heathland vegetation).	Alpine desert/ Glacial milieu	0.72-0.6 Ma 2.2-0.72 Ma
			GAP			
	Middle-Pleistocene	Remzone, 6	Krachipathra	BZ-Barren zone KP-4-Spruce-Blue pine-Larch-Birch-Oak	Cool temperate with moderate humidity	
				KP-3-Silver fir-Spruce-Cypresses-Deodar-Blue pine	Cold temperate with moderate humidity	
				BZ-Barren zone KP-2-Spruce-Cypresses-Silver fir-Blue pine-Birch-Oak	Cool temperate & humid	
				BZ-Barren zone KP-1-Oak-Blue pine-Spruce-Birch-Silver fir-Cypresses	Temperate & humid	2.4-2.2 Ma
	Lower-Pleistocene					
	Upper Pliocene	Remzones-4, 5	Hirpur Loc-IV	Barren zone		2.6-2.4 Ma
		Remzone, 3	Hirpur Loc. III	H-III 15-Blue pine-Silver fir-Spruce-Birch-Hazel-Alder-Walnut	Cool temperate & dry	
				BZ-Barren zone		
				H-III 14-Oak-Poaceae	Cool temperate & moderately dry	

Contd.

Table 2—Contd.

STRATIGRAPHY 1	PERIOD 2	LITHOZONE 3	LOCALITY 4	POLLEN ZONE 5	CLIMATE 6	AGE 7
HIRPUR FORMATION (contd.) Methawoin Member (contd.)	Pontian (Pliocene)			BZ-Barren zone		
				H-III-13-Alder-Oak-Ash-Poplar-Silver fir	Cool temperate & humid	
				BZ-Barren zone		
				H-III-12-Poaceae-Liliaceae *Potamogeton*-Cyperaceae-Ferns	Temperate & wet	
				BZ-Barren zone		
				H-III-11-Poaceae-Oak-Alder-Cyperaceae-Chenopodiaceae-*Typha*	Warm temperate & humid.	
				BZ-Barren zone		
				BZ-Barren zone		3.7-2.6 Ma
				H-III-10-Pure Chir pine forest with an admixture of Poaceae and Oleaceae	Subtropical warm	
				BZ-Barren zone		
				H-III-9-c-Pure Chir pine forest	Subtropical warm and dry	
				H-III-9-b-Blue pine-Silver fir-Spruce-Deodar-Birch	Temperate & dry.	
				H-III-9-a-Pure Chir pine forest	Subtropical warm & dry	
				BZ-Barren zone		
				H-III-8-Oak-Cypresses-Juniper-Poplar-Ash-Poaceae-*Potamogeton*-Typha	Warm temperate & wet	
				BZ-Barren zone		
				BZ-Barren zone		
				H-III-7-Pure-Chirpine forest	Subtropical warm & dry	
				H-III-6-Deodar-Silver fir-Alder	Temperate & warm	
				H-III-5-Pure Chir pine forest	Subtropical warm & dry	
				BZ-Barren zone		
				H-III-4-Larch-Oak-Poaceae-*Potamogeton*-Ferns	Warm temperate & wet	
				BZ-Barren zone		
				H-III-3-Pure Chir pine forest	Subtropical warm & dry	
				BZ-Barren zone		
				H-III-2-Larch-Oak-Carya-Walnut-*Engelhardtia*-Ash-Poaceae	Warm temperate & wet	
				H-III-1-Pure Chir pine forest	Subtropical warm & dry	
			Ningle Nullah	NN-Spruce-Juniper forest with sprinkling of *Cupressus*, Larch, Hazel and Oak	Cold temperate & & very humid	
			Hirpur Loc. I	H-I-4-Spruce forest	Cool temperate & dry	
				H-I-3-Larch-Oak-Silver fir Birch-Hazel-Alder	Cold temperate & wet	
				H-I-2-Spruce-Oak-Birch	Cool temperate & humid	
				H-I-1-Oak-Spruce-Alder-*Salix*-Ericaceae-Rosaceae	Warm temperate & humid	

Contd.

Table 2—Contd.

STRATIGRAPHY 1	PERIOD 2	LITHOZONE 3	LOCALITY 4	POLLEN ZONE 5	CLIMATE 6	AGE 7
Rembiara Member (200 m)		Remzone, 2		BARREN		3.8-3.7 Ma
Dubjan Member (300 m)		Remzone, 1	Dubjan	DB-3-Spruce-Cypresses-yew-Larch-Silver fir-*Nymphaea* *Potamogeton*-Fern	Cool temperate & wet	
				DB-2-b-Alder-Birch-Oak-Walnut-Spruce	Warm temperate & moderately humid	
				DB-2-a-Chir pine-Alder Oak-Walnut-Spruce	Subtropical/ temperate transition & moderately humid	
				DB-1-Oak-Alder-Spruce-Poaceae-Cyperaceae	Warm temperate & moderately humid	4.0-3.8 Ma

feature recorded here is the occurrence of *Picea* and *Quercus* in reasonably high values in the lower and middle of this subzone respectively. *Betula* and *Corylus* present in low values, are the two main components of *Picea*. The strength of nonarboreals as such remained poor since Poaceae reduced drastically. Marshy and aquatic taxa are scantily present.

DB-2b is characterized by low but static values of chirpine. *Betula* recorded sudden spurt in its values. Oaks, though in low values, remain constant throughout. *Corylus* and *Juglans* gained values in the beginning but declined upward. *Viburnum* is locally high. Ground cover continued to be depressed with further supression in Poaceae but *Polygonum* thrived well in the heathland. *Potamogeton* remained low but ferns were sporadically high.

DB-3 witnessed a shift in vegetation from chirpine to spruce forest. The associates of spruce like *Cupressus, Taxus, Larix* and *Abies* appeared in this zone which were otherwise absent till zone DB-2. *Quercus, Ulmus, Corylus, Alnus* and *Juglans* continued sporadically. Shrubby vegetation, in general, improved and is marked by high values of *Fraxinus* and low values of *Viburnum* and Poaceae. Shrubby taxa go very well with the spruce forest as the exterior components of the forest denote cold climate. Sudden spurt in Poaceae and its consistency throughout is another notable feature of this zone. Other herbs such as Chenopodiaceae, Urticaceae, Liliaceae, Asteraceae, Cyperaceae and *Polygonum* improved. *Nymphaea* and *Potamogeton* improved but *Typha* remained in low profile. Ferns improved to the maximum indicating congenial conditions for their revival and survival.

Rembiara Member—de Terra and Paterson (1939) described it as 'basal gravel fan' and considered it to be the base of Lower Karewa. Farooqi and Desai (1974) termed it as 'Hirpur conglomerate' and inferred that it was not developed elsewhere in the basin except for the upper Rembiara Valley section. Bhatt (1989) thoroughly studied the basin development and found 'conglomerate horizon' or 'Rembiara Member' is a regular lithological unit of Hirpur Formation and is developed in all the sections. It has earlier been referred to as Zone-II. The thickness of the Rembiara Member in the type section is from 200-225 m (Bhatt & Chatterji, 1976; Farooqi & Desai, 1974). It consists mainly of conglomerate deposits with occasionally and irregularly developed sand and clay lenses. It is considered to be a rapid deposition zone as a result of a major uplift of the Pir Panjal.

A large number of samples from both sand and clay lenses were tried for palynological investigations but they were almost always found palynologically barren and hence no sustainable vegetational and/or climatic picture could be established.

Methawoin Member—It is named after a small *marg* up the cliff opposite to Hirpur Village, making the youngest lithological unit of the Hirpur Formation (Bhatt, 1989). It was earlier referred to as Zone-III (Bhatt, 1979, 1982). It consists of a succession of sand, sandy clay, clay, lignitic mud, laminated mud and lignitic bands. However, its lignitic bands are thinner as compared to Dubjan. The total thickness of the Methawoin Member in the type section is between 350-400 m. Chronologically, it has been put under Remzone III and covers a time span between 2.92 to 2.6 Ma.

About 200 m thick sediments covering all lithofacies were sampled for palynological investigation. The most important aspect in this sequence is that besides lignitic mud, laminated mud, and lignite, some sand samples have also yielded enormous quantity of pollen. The palynological investigations of Methawoin Member have been carried out in the name and style of Hirpur Locality-I, III and IV (Gupta & Sharma, 1989; Gupta *et al.*, 1984a, b). Hirpur Locality I and III have yielded rich pollen assemblages both quantitatively and qualitatively but Hirpur Locality IV did not yield sufficient pollen for percentage calculation. The variation in the output of pollen is largely due to the porosity of Hirpur Locality IV sediments which might have led to oxidation and destruction of pollen and spores.

Hirpur Locality I—Sediments of Hirpur Locality I constitute the basal part of the Methawoin Member and consist of laminated and lignitic mud with distinct overlying and underlying beds of sand making a total thickness of 40 m. A large number of samples were pollen analysed. Only lignitic mud yielded pollen in appreciable frequency, whereas other lithofacies proved to be palynologically barren.

The overall vegetational picture indicates the predominance of *Picea* and *Quercus* together with other broad-leaved arboreals. On the basis of subtle vegetational shifts, it has been possible to phase the whole pollen diagram into four assemblage zones, viz., HLI-1 to HLI-IV in ascending chronological order.

HLI-1—The early phase of this zone is recognized by exceedingly high values of *Quercus* followed by *Picea, Alnus, Salix, Acacia*, Ericaceae and low values of *Abies*. Nonarboreals are scantily present. AP/NAP ratio has demonstrated the predominance of arborescent vegetation. The later phase of this zone is marked by a steep fall in the values of *Quercus* and *Picea*. *Carpinus* and *Berberis* appeared, whereas *Salix* and Ericaceae disappeared in this phase. *Alnus* remained static. *Arcicolpites hirpurensis* (Gupta *et al.*, 1990) and Rosaceae appeared in this phase and maintained 17 per cent each. Poaceae improved and attained maximum values of 20 per cent, whereas other herbs remained low. AP/NAP ratio shows considerable decline in the arboreal vegetation as compared to early phase of this zone.

HLI-II—This zone is identified by the preponderance of *Picea* pollen throughout indicating a shift of vegetation from preceding zone and establishment of spruce forest. *Quercus* declined to moderate values and remained confined to the middle of the zone. Spruce associates namely *Juniperus, Larix, Betula, Carpinus, Ulmus*, etc. are sporadic. *Alnus* continued in moderately high values till the beginning, declined in the middle and disappeared in the upper half of this zone. *Carya* appeared in moderately high values right in the beginning and continued throughout with enhanced values upward. *Juglans* appeared in the lower half and continued throughout in fairly high frequencies. Shrubby taxa like Berberidaceae and Rosaceae are present in low and high values respectively almost throughout but both vanished at the close of this zone. *Arcicolpites hirpurensis* is present throughout in quite high frequencies but relatively lesser than the preceding zone.

Nonarboreals have distinctly low values in this zone. Poaceae, having exceedingly high values in the later phase of preceding zone, was reduced to a fraction in the beginning of this zone. However, Poaceae gradually improved and continued to gain high values till the end of the zone. *Typha* and *Potamogeton* are present in relatively improved values than before. AP/NAP ratio portrays the overall dominance of arborescent vegetation.

Zone HLI-III—It is markedly a short phase which experienced an abrupt fall in spruce forest to the tune that it shrunk to a fraction. The downfall of spruce is witnessed by corresponding rise of *Larix* and *Quercus* in almost equally high values and this followed by *Abies, Betula, Carpinus, Alnus* and *Juglans*. *Carya* disappeared but *Engelhardtia* emerged in this zone. *Arcicolpites hirpurensis* is surprisingly absent in this zone. Ground cover seems to have further reduced. Aquatic taxa and fern spores are absent. AP/NAP ratio continues to maintain predominance of arborescent vegetation.

Zone HLI-IV—This zone is represented by the re-emergence of spruce forest in exceptionally high values (80%). *Juglans* improved but *Betula, Alnus* and *Salix* reduced. No shrubby element is recorded in spruce wood zone. Ground vegetation is represented by scanty values of Poaceae and Primulaceae only. Aquatic taxa are almost absent except for low values of *Typha*. AP/NAP ratio depicts the sketchy presence of nonarboreals in contrast to the arboreals.

Hirpur Locality III—It constitutes the major lower-middle part of the Methawoin Member comprising almost the same lithofacies as found in Hirpur Locality-I. The only difference between the two is that even sand samples have yielded pollen which were otherwise absent in Hirpur Locality I.

Pollen investigation of about 200 m thick (vertical cliff) strata has been carried out.

Palynological investigations of Hirpur Locality-III sediments (Gupta *et al.*, 1984a, b) have suggested unstability, cyclicity and reversibility in vegetation owing to changing climatic conditions. On the basis of these observations the pollen diagram drawn from Hirpur Locality-III has been classified into fifteen pollen zones and thirteen barren zones reflecting on periodical shifts in the vegetation and covering a time span of around half a million years. These zones are initiated from HL-III-1 to HL-III-15 in ascending chronological sequence. Henceforth, for all practical purposes, I prefer to use zones 1-15.

Zone-1 is populated by 79 per cent of chirpine of the total population. A subtropical and dry climate is inferred. It characterizes the pure chirpine forest with a little underground herbaceous vegetation composed of Poaceae, Chenopodiaceae, etc. Zone 2 represents notable change-over from pure chirpine woods to mixed conifer quercetum-mixtum forest, indicating a broad climatic catastrophe. *Carya, Fraxinus, Larix*, etc. are other important taxa of this mixed community. *Arcicolpites hirpurensis* appears in low values after its disappearance from the upper phase of Hirpur Locality I. Amongst nonarboreals, Poaceae dominated and other herbs trailed. High values of aquatic taxa like *Nymphaea, Myriophyllum* and *Potamogeton* were recorded.

Zone-3 is marked by reversibility of the type of vegetation of Zone-1 wherein chirpine formed the pure forest with little understorey of a few tree stands and little ground cover of grasses and other herbs.

In Zone-4 no chirpine pollen has been noticed. They have been replaced by the high values of *Larix* (23%), *Quercus* (10%), *Engelhardtia* (6%) and *Alnus* (2%). Non-arboreals are largely dominated by grasses alongwith some chenopods. *Potamogeton* and ferns became abundant while *Typha* reduced to low values.

Zone-5 again records the pure chirpine forest touching the peak of 81 per cent of the total vegetation, wherein *Alnus* and *Salix* have 4 per cent representation. The rest is represented by grasses. Climate remained subtropical and very dry.

Zone-6 has witnessed a slight deviation from the routine picture of vegetational development. It records deodar forest wherein silver fir and alders also make their way in low proportion with sprinkling of poplar, walnut, Fabaceae and Oleaceae. Poaceae, *Artemisia* and ferns compose the ground vegetation in low profile. Aquatic taxa record high values for *Pediastrum* and low values for *Potamogeton* and *Nymphaea*.

Zone 7 is another phase wherein the reversibility and cyclicity of vegetation could be observed. It is marked by excessively high values of chirpine, attaining a new height of 94 per cent of the total population. In this pure chirpine woods, the stray occurrence of *Juglans, Salix, Artemisia*, Chenopodiaceae and Poaceae is noticeable. Water plants completely absent. Such a vegetation seems to have developed under subtropical and dry climate.

Zone-8 depicts entirely different type of vegetation composition wherein the open conditions spread far and wide ceding pace for better development of nonarboreals. Arboreal taxa encountered, varying from moderately high to low, are *Quercus, Fraxinus, Populus, Cupressus, Larix*, etc. and *Carpinus, Alnus, Salix, Engelhardtia*, etc. respectively. Water plants improved satisfactorily. Ferns and bryophytes also found conducive conditions to colonize.

Zone-9, although spanned for a short period, has recorded rapid changes in the vegetational shifts. For instance, chirpine/bluepine/chirpine phases are the major events during this period and have been marked by three subphases in the pollen diagram, viz., subzones a, b and c. Fluctuations in the climate from warm-cold-warm have led these shifts in vegetation.

Zone-10 is a transitional zone wherein the pure chirpine forest of preceding subzone-9c is on decline and ultimately replaced by vast stretches of grassland with little proportion of oaks and oleaceous shrubs invading the grassland towards the close of this zone. Water plants improved very satisfactorily and recorded *Potamogeton* (25%), *Typha* (5%) and *Polygonum* (7%). These shifts in the vegetation are indicative of dramatic change in climate from very arid to very humid recording high degree of precipitation.

Zone-11 is almost the continuance of preceding zone denoting the open grasslands wherein oaks have improved and were also joined by *Abies, Juniperus, Larix, Betula, Carpinus, Carya*, etc. indicating a slow and gradual invasion of woods into the grassland. Water plants also reduced to a fraction. There was practically no noticeable change in the climate than the preceding zone except for slight depression in precipitation.

Zone-12 is almost a tree less zone except for sporadicity of silver fir and oleaceous shrubs. There is a total coverage by the non-arboreals. However, Poaceae does not make any break-through in building the grassland instead Liliaceae, Cyperaceae and ferns made their headway in formulating the non-arboreals to dominate. *Potamogeton* and other water plants inhabit the lakes and lake margins.

Thus, the zone has witnessed torrential rains and cloud bursts inundating the land mass within temperate climatic regime.

Zone-13 is marked by entirely a different set up of vegetation composition and typifies the cool temperate climatic regime with moderate precipitation. Under this set up *Alnus, Quercus, Fraxinus, Populus* and *Abies* are dominant; *Carpinus Salix*, Rosaceae, etc. are co-dominant and Tubiliflorae, Brassicaceae, Cyperaceae, etc. are low. *Typha* is high but *Potamogeton* is moderate.

Zone-14 depicts more or less the continuance of cool temperate climatic regime although further reduction in precipitation is recorded. With this fluctuating trend in precipitation the vegetation mosaic also changed as the values of nonarboreals bye-passed arboreals. Amongst tree taxa *Quercus* is high; *Juglans, Alnus, Carpinus, Larix, Engelhardtia*, etc. are moderate and *Cedrus, Juniperus*, Rosaceae, etc. are sporadic. Aquatic and fern taxa are moderate.

Zone-15 is composed of mixed conifer-broad-leaved forest. Arboreals' spread was so high that it dominated the nonarboreals. The ratio of conifer and broad-leaved elements is almost equal in this zone except for their positions within the same altitudinal range. With this set up of vegetation, cool temperate and dry conditions are construed.

Hirpur Locality-IV—It constitutes the middle-upper part of Methawoin Member and is denoted by conglomerate bed (Bhatt, 1989). It can also be correlated with Remzone-4 (Agarwal *et al.*, 1989). This conglomerate bed is around 20 m thick. A few samples from the mud lenses proved palynologically unproductive.

Ningle Nullah—It consists of bluish-grey and violet clay, coarse to medium green sand, light-grey sandy clay and lignite. It represents the lower-middle part of the Methawoin Member but earlier it was informally thought that Ningle Nullah sediments directly overlie the Panjal Trap basement forming the base of Hirpur Formation and equated with Dubjan Member. The palynological study suggests the superimposition of Ningle Nullah sequence at the base of Hirpur Locality-III or on the top of Hirpur Locality-I.

Nine samples from different lithofacies at Ningle Nullah section, covering a vertical thickness of about 20 m, have been pollen analysed. But only four samples, two each from lignite and blackish clay yielded pollen and spores while rest of the samples from sand and mud facies turned unproductive (Gupta & Sharma, 1992). The pollen diagram has revealed uniformity in palaeovegetation and an overall dominance of arboreals over nonarboreals is recorded.

The study has brought to light the existence of *Picea-Juniperus* forest with the sporadic presence of *Cupressus, Larix, Betula, Carpinus* and *Quercus*. This type of vegetation develops under cold temperate and subalpine transition climatic regime. Further, the evidence of high precipitation and expansion of lake margins are exemplified by the abundance of marshy and water plants.

The occurrence of *Arcicolpites hirpurensis* in the lower samples has enabled the author to correlate with the basal part of Hirpur Locality-III.

Krachipathra—It constitutes the lower-upper part of the Mathawoin Member and partly covers Remzone-6. It covers a time span between 2.4 to 2.2 Ma. Out of three lithofacies recognized in 50 m Krachipathra sequence, only two—lignitic mud and laminated mud, turned to be productive both quantitatively and qualitatively. The sand samples except for the lower most of the litholog proved barren.

Palynological results from Krachipathra, though coherent in general vegetational set up, differ in the values for different taxa and therefore, the whole pollen diagram (Sharma & Gupta, 1984) has been classified into four pollen assemblage zones, viz., KP-1 to KP-4 in ascending chronological order. Likewise three barren zones have been recognized intervening pollen zones, which have not been used for any practical purpose except to show that the conditions were not conducive for the preservation of biota.

Zone KP-1 is largely composed of muddy sand and characterised by the occurrence of high values of *Quercus semecarpifolia, Pinus wallichiana, Betula, Juglans, Cupressus, Picea* and *Alnus* are present in relatively low values. The former taxa declined and vanished but latter taxa improved upward. In addition, *Abies, Cedrus* and Rosaceae made their way in good values at the close of this zone. Nonarboreals are represented mostly by grasses. Water plants and ferns on the whole, have high values. This type of vegetation thrives well under temperate and wet climatic regime.

Zone KP-2 is marked by a decline in oak-pine woods. Spruce rose tremendously at the beginning but declined upward. The decline of spruce woods corresponds to the spurt of *Abies* and *Cupressus*. *Cedrus* reappeared at the top and *Betula* remained consistently high throughout the zone. *Alnus* and *Juglans*, high in the beginning, declined upward. Herbage remained predominated by grasses. Water plants and ferns continued to be high as in the preceding zone. This shows that the climatic conditions further deteriorated.

Zone KP-3 is dotted by sudden and abrupt spurt in *Abies* in particular and conifers in general. Angiosperms, both arboreals and nonarboreals including water plants have reduced considerably as compared to the preceding zone. The climatic conditions continued to be the same except for some reduction in precipitation.

In Zone KP-4 both *Abies* and *Cupressus* suddenly declined and succeeded by *Picea, Betula, Quercus, Corylus* and *Ulmus* indicating a little amelioration in temperature.

Wapzan—It constitutes the upper most part of Methawoin Member and its age has been extrapolated between 0.7-0.6 Ma. Close to Anantipur Canal headworks, linear lenses of Lower Karewa beds are exposed, probably due to neotectonics. They are unconformably superimposed by the Upper Karewa sediments of Saki Paparian facies. The sample was collected from the lignitic lense of the Lower Karewa exposure and investigated palynologically.

Arboreal vegetation is almost negligible and is represented by bluepine-oak woods not exceeding more than 5 per cent of the total vegetation composition. Amongst nonarboreals, Poaceae and Chenopodiaceae predominate attaining 35.5 per cent and 36 per cent values respectively. Rosaceae (*Dryas*) and *Artemisia* are the codominant taxa in the assemblage. Caryophyllaceae, Asteraceae and Apiaceae are low to very low in values. Marshy and swampy taxa belonging to Ranunculaceae, Cyperaceae and *Typha* are scantily present, whereas *Potamogeton* is sporadic.

Wapzan's palaeofloristic assemblage categorically reveals the presence of meadows and/or scrubs-heathlands comparable to the modern alpine desertic vegetation of Ladakh (Dodia *et al.*, 1982). Arboreal taxa in this composition are absent. Nevertheless, certain tree taxa like *Betula, Juniperus*, etc. do extend their limit up to tree-line albeit dwarf and are stunted to the maximum of a few feet in height. However, pollen record of bluepine and oak do not go well with the composition known from Wapzan. Instead, pollen of these two tree taxa might have been blown up and mixed in the pollen rain there. Thus, the set up of vegetation composition at Wapzan enunciates the existence of glacial milieu around 0.7-0.6 Ma.

Baltal—It is exposed along the Romushi River about 60 km south-west of Srinagar. It covers 55 m thick deposits consisting mainly of bluish, compact, fractured mud and yellowish, laminated clays intercalated with fine to medium grained, greenish sand. Extrapolated date for Baltal section could be to a time bracket of 0.6 and 0.2 Ma.

The face value evaluation of the pollen diagram has revealed the overall dominance of conifer woods including bluepine, spruce and silver fir. Other arboreal taxa are either low or sporadically present in the conifer forest. Nonarboreals too, except for locally high values for Cheno/Ams, are meagerly present.

On the pattern of vegetation composition, two phases have been demarcated. Phase B-1 (between 10 to 30 m) is characterized by spruce-silver fir-bluepine forest, denoting subalpine and moderately moist climatic regime. Phase B-2 (between 31 to 47 m) has witnessed rise in the values of pine and corresponding fall in spruce and silver fir. Cheno/Ams. have suddenly spurted indicating increase in aridity under the subalpine climatic regime (Dodia, 1988).

Diatom analysis from Baltal samples has revealed the occurrence of both centric and pennate diatoms. Further, the existence of *Pinnularia, Stauroneis* and *Cymbella* have suggested subalpine climate (Gandhi & Mohan, 1983).

PALYNOLOGY OF LAKES AND SWAMPS IN KASHMIR

Palynological investigations have been carried out on several lakes and swamps representing postglacial and Holocene time span, whereas others represent a part of Holocene Period. Toshmaidan (Singh, 1964; Singh & Agrawal, 1976) and Butapathri (Dodia *et al.*, 1984) have been dated around 15,000 and 17,000 yrs B.P. respectively. Anchar and Hokarsar Lake sediments (Dodia *et al.*, 1984) have been dated *ca.* 4,000 and 1,150 yrs B.P., respectively. Haigam (Vishnu-Mittre & Sharma, 1966), Baba Rishi and Yus Maidan (Sharma & Vishnu-Mittre, 1969), Burman and Walanwar (Singh, 1964) profiles are not yet dated radiometrically. However, evidence from vegetational development indicates that the Haigam lake represents complete Holocene sequence, whereas other lakes are shallow and represent either middle or upper part of the Holocene Period.

Pollen analytical evidence from postglacial deposits suggest three-fold vegetation development, viz., pine—quercetum mixtum-pine. This pattern of vegetation development reflects on three-fold climatic oscillations, viz., cool-warm-cool coinciding with the worldwide scheme of postglacial climatic changes put forward by von Post (1946).

CONCLUSION

Kashmir Valley, as a result of combined study of litho-stratigraphy, palynostratigraphy, fission-track, palaeomagnetic and 14C dating, provides a long sequence of changing pattern of vegetation and climatic oscillations.

Vegetation composition characterizing chirpine-oak-alder-spruce-walnut-Poaceae remained almost uniform between 4.0 to 3.8 Ma except for some minor variations at the top where spruce replaced chirpine. The frequency of water plants also improved slightly. Thus, the climate seems to be warm-temperate, becoming cooler towards the top of this phase. Between 3.8 to 3.7 Ma, there is no pollen record available and hence nothing could be construed about the climate.

Cyclicity in the vegetation development had been quite evident from 3.7 to 2.6 Ma. Between 3.7 to 3.5 Ma, the vegetation was mostly dominated by spruce forest denoting cool/cold temperate type of climate. Thereafter, a catastrophy in the vegetation composition took place resulting into the establishment of subtropical and dry climate. This encouraged the colonization of pure chirpine forest. However, this type of vegetation did not last longer and the change in vegetation mosaic became inevitable owing to changing pattern in palaeoclimate. This shift in vegetation is marked by the onset of warm temperate type of climate. Thus, the climatic cycles of subtropical and warm-temperate alternating with each other could be worked out till about 2.8 Ma. Thereafter, temperate climatic regime was set-in. Slow and gradual deterioration in temperature continued till 2.6 Ma where cool temperate and dry climate developed encouraging the establishment of bluepine-silver fir-spruce forest.

Hirpur Locality-IV, covering a time span between 2.6 to 2.4 Ma proved to be palynologically barren and hence climatic inferences could not be made.

From 2.4 to 2.2 Ma, there existed typical temperate climate in the beginning which successively became cooler and ultimately cold temperate climate was established towards the top. Krachipathra sequence encompasses this time span and is marked by the establishment of silver fir-spruce-cypresses forest.

Between 0.72 to 0.6 Ma, the vegetation encountered here belongs to alpine scrubs with the preponderance of Rosaceae (*Dryas*), Chenopodiaceae, Asteraceae, Apiaceae, Poaceae, etc. This grade of vegetation forming meadows is generally found in the alpine desert areas above the tree-line zone and could be equated with the present day vegetation of Ladak where usually no arborescent plant is found. Nevertheless, certain tree taxa are found albeit in dwarf posture. Considering the type of vegetation met in Wapzan sediments, it is envisaged that glacial conditions must have prevailed during the period between 0.72 to 0.6 Ma.

Between 0.6 to 0.3 Ma, the glacial influence began to sink and late glacial conditions switched on ceding pace to establish spruce-silver fir-bluepine forest typifying the existence of subalpine climate.

Loess, capping the Karewa scarpment all through the valley, was deposited between 0.3 to 0.2 Ma. It has yielded no pollen and spore, rather it is devoid of biomass. Therefore, nothing could be committed about the prevailing climatic conditions except to say that loess is mainly of aeolian nature and indicative of enhanced aridity.

Thereafter, postglacial period began which could vary at places from 20,000 to 15,000 yrs B.P. We have plentiful records of postglacial events from lakes and swamps in the valley. With the help of 14C dating the age has roughly been estimated about 17,000 yrs B.P. at Butapathri and 15,000 yrs B.P. at Toshmaidan. The postglacial vegetation all through the valley is marked by a three-fold development, viz., pine-quercetum mixtum—pine in chronological order. This line of vegetation set up is greatly influenced by the period of increasing warmth, period of maximum warmth and period of decreasing warmth respectively or in nutshell it could be spelled out as cool-warm-cool.

To summarize, the climate does not seem to be static for a long period rather it remained changing all through the basinal development in the valley since four million years. The concept that Kashmir Valley witnessed four-fold glaciations is untenable in the light of recent multidisciplinary data. Nevertheless, palynological findings have highlighted the monoglacial concept, contrary to lithological and sedimentological evidences (Singh, 1982; Tandon *et al.*, 1982) which does not record any glaciation in Kashmir Valley.

The discovery of *Arcicolpites hirpurensis* (Gupta *et al.*, 1990) from the Hirpur Formation has greatly helped to superimpose Ningle Nullah sequence over Hirpur Locality-I and under Hirpur Locality-III. P/P boundary is also suggested to be drawn at the top of zone-10 of Hirpur Locality-III where *Arcicolpites hirpurensis* pollen disappears and this boundary falls almost in the middle of Methawoin Member.

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