KEY NOTE ADDRESS

# Importance of palaeobotany in the study of botany, zoology, geology and archaeology

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WITH the presently mounting emphasis on interdisciplinary studies of Science, Palaeobotany should rank very high among such areas of Botany. Indeed, it should become far more important than what it has been in the past since it stands not only between the various branches of Botany but also between other subjects like: Zoology, Geology, Archaeology and Ancient History. A palaeobotanist has to be a generalist in Botany before he can claim to be a specialist. Instead of claiming a mastery of any particular branch of botany or a particular group of plants he must have a deep understanding of plants of diverse groups ranging from bacteria to angiosperms, because all of them may occur mixed up in a fossiliferous bed. At the same time he has to be a specialist on diverse plants of such a high order than he can identify them in their fragmented and distorted condition in which not only the plants but even their organs are broken down and preserved with or without structure, in a state where they lie helter skelter and mixed up with those of similar or very diverse other organisms and organs. Sometimes the fossils may be isolated single cells or groups of cells, at other times the broken remains may be more or less distorted fragments of particular stages in the life cycles of past plants, their ecotypes, mutants or polyploids and at other times the fossils may not be morphological but degraded chemical remains or chemical fossils of past forms of life. From such fragmentary and mutilated remains of plants, a palaeobotanist may have to reconstruct not only the entire plants but the entire floras or the ecological conditions in which they lived, their relationships with past and present day forms of life and on that basis reconstruct even the geography of the time which they lived. Although Palaeobotany has links with the diverse aspects of Botany, Geology, Zoology, Palaeontology and Archaeology. A knowledge of Palaeobotany is therefore important, nay, essential for a study of these subjects.

Therefore, I wish to discuss this importance and the recent achievements in the ever widening vistas of Palaeobotany in the present lecture.

## FUNDAMENTAL IMPORTANCE OF PALAEOBOTANY

In dealing with the importance of Palaeobotany, in the study of Botany, one has to remember that the basic theme of all biological studies is evolution and the only direct proof of evolution is supplied by palaeontological studies, all other evidences being indirectly inferred conclusions. The branches of biology called palaeobotany and palaeozoology are therefore of fundamental importance for all biological studies.

In this connection it is also important to mention that many aspects of living plants particularly morphology and anatomy, received a phillip from palaeobotanical studies because a palaeobotanist needs intricate knowledge of living plants for interpreting his fragmentary and often mutilated material of fossil plants. In fact, Williamson, Lang, Bower, Arber, Scott, Oliver, Seward, Sahni, Florin, Chaney, Solms-Laubach, Walton, Thomas, Harris and so many others have contributed as much to the knowledge of living plants as they did to that of Palaeobotany. In particular anatomical studies, especially cuticular, epidermal and xylem studies of living plants and palynology attained their present status more from the work of palaeobotanists than from that of workers on living plants. Indeed, wherever one needs intricate knowledge of parts or fragments for identification, as in forensic science it needs the methodology of Palaeobotany.

## MISCONCEPTIONS BASED ON PREJUDICES

A misconception about the subject claims that Palaeobotany is a very old subject where, using the familiar Bonner metaphor, "all the oil in the old oil well has exhausted" and there is very little scope for further research. In this connection one has to point out that palaeobotany is actually younger than many of the fashionable areas of Botany like Plant Physiology, Cytogenetics or Plant Pathology and Molecular Biology, etc. which are believed to be new and full of scope for further research (see Table below).

## EARLY HISTORY OF DIFFERENT BRANCHES OF BOTANY

| | | |
|---|---|---|
| *Palaeobotany* | —1820 | Sternberg, *Flora der Vorwelt* |
| | —1828 | Brongniart, *Histoire des Vegetaux* |
| | —1831 | Lyell, *Principles of geology* |
| | —1833, 1868 | Witham, Binney-*Fossil plant anatomy* |
| *Taxonomy* | BC 287 | Theophrastus |
| | —AD 77 | Dioscorides, *Materia Medica*, described 600 plants |
| | —1300 | Albertus Magnus, *On plants* |
| | —1753 | Linnaeus *Species Plantarum* (1st May) |
| *Plant Anatomy* | —1672 | Grew *Anatomy of vegetables begun* |
| | —1672 | Malpighi *Anatomy Plantarum* |
| *Embryology* | —1694 | Camerarius, *Letter on sex in plants* |
| | —1823 | Amici sees pollen tube approach ovary |
| *Pathology* | —1546 | Fracastoro, *De contagione* first scientific statement about transmission of infections |
| | —1658 | Kircher sees "Innumerable worms" under microscope |
| *Plant Physiology* | —1648 | Van Helmont experiments on plant nutrition |
| | —1727 | Hales measures root pressure |
| | —1772 | Priestley concludes that plants give out oxygen |
| | —1779 | Ingenhousz concludes that plants utilize $CO_2$ and produce $O_2$ in light |
| *Cytogenetics and Molecular Biology* | —1665 | Hooke gives first drawing of plant cell |
| | —1750 | Mapertis foresees chromosomal basis of heredity |
| | —1765 | Trembley makes first drawing of cell division |
| | —1866-69 | Mendel's paper on heredity |
| | —1869 | Meischer discovers nucleic acid |
| | —1875 | Strasburger describes chromosomes and reduction division. |

As for the oil in the oil well becoming exhausted let me ask people who know even a little of palaeobotany to name a single fossil plant which is completely known. Even one of the most studied fossils like *Lyginopteris* or *Calymmatotheca* is incompletely known. Its earliest remains were discovered before 1828, named by Brongniart in 1828 but still after the lapse of more than 160 years its parts are imperfectly known and its microsporophylls, male gametophytes, embryology and seed germination are entirely unknown. Let me therefore assert that the oil in other wells may dry up but it is not likely to dry up easily in the well of Palaeobotany. In fact, as we dig deeper the oil seems to be welling up with ever increasing force.

## PLATE 1

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1. *Lepidocarpon lomaxi*: Longitudinal section showing vascularized embryo embedded in tissue of megagametophyte Phillips.
2. L. S. of *Callospermarion* ovule with pollination droplet, Rothwell.
3. Embryo of *Bothrodendrostrobus mundus* Stubblefield & Rothwell.
4, 5. Germinating *Samaropsis* seeds, Krassilov.
6. Seedling of *Samaropsis* Krassilov.
7. Median longitudinal section of apical meristem of *Sphenophyllum* Good & Taylor.
8. Saccate pollen grain of a Cordaite with large central body, Taylor & Millay.
9. Structure of phloem cells showing sieve plates (from Smoot).


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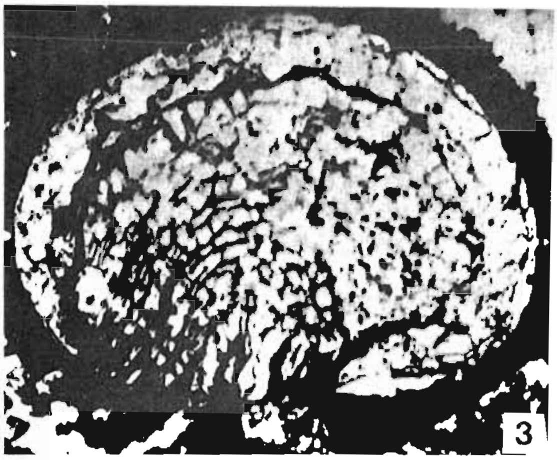
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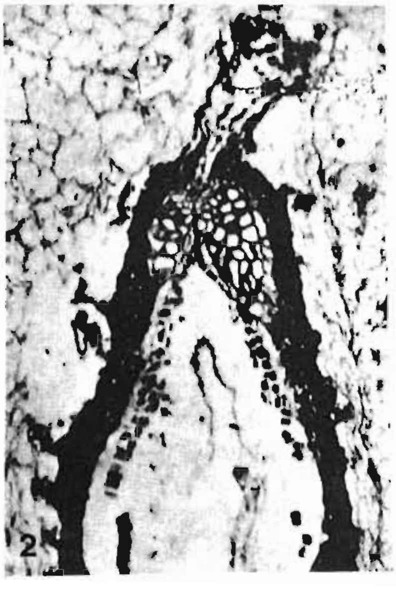
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**PLATE 1**

## EVER INCREASING SCOPE OF PALAEOBOTANY

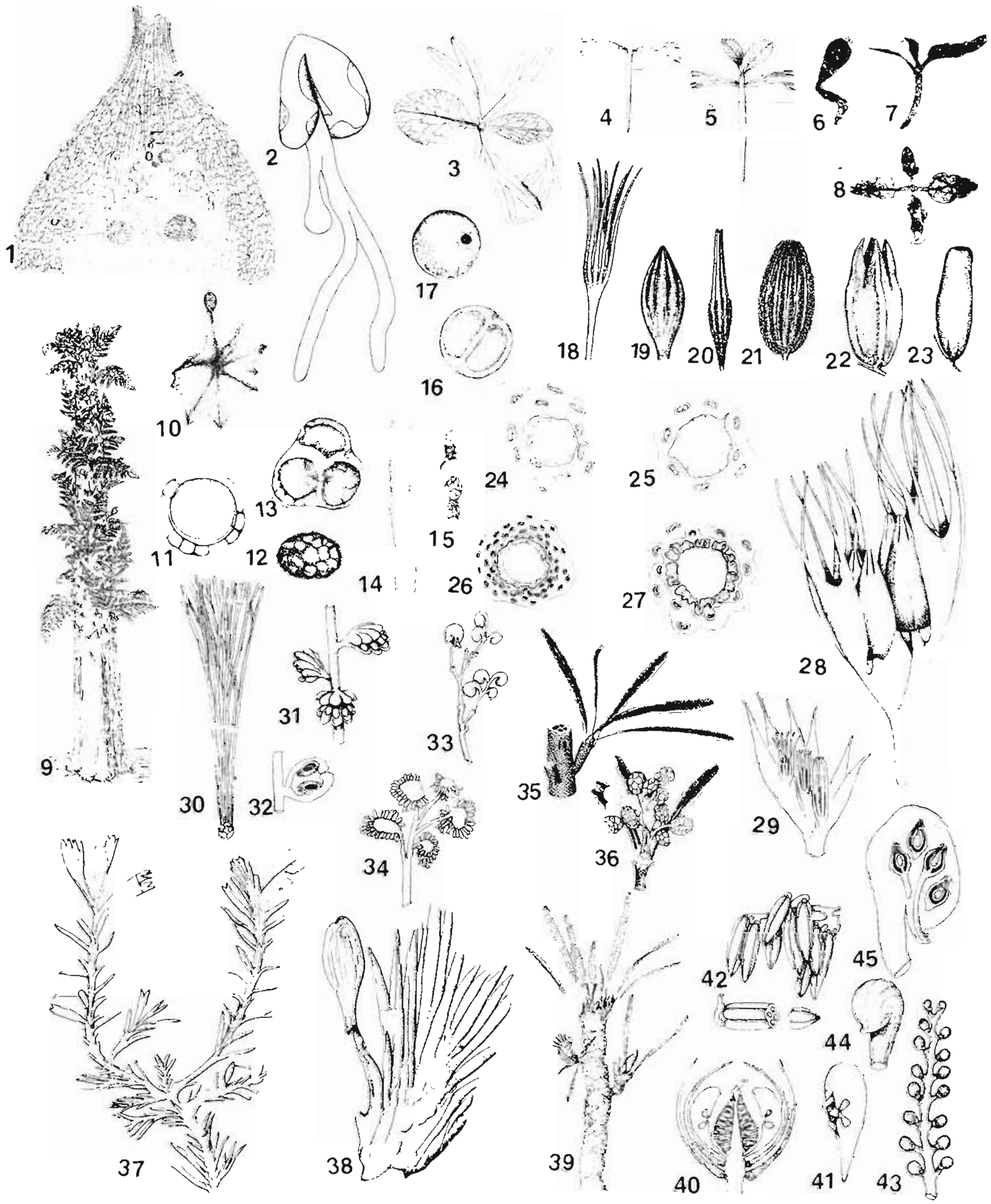
As for the scope of research in palaeobotany it is my assertion that it is becoming greater and brighter every day than that of many other fields of botany and science in general. The importance of the discoveries in palaeobotany is so great that they have changed some of our fundamental concepts about life on earth and brought forth indubitable evidence in support or against ideas that had been prevailing about plant life on earth.

### Impact of new techniques and discovery of better preserved material

Before I cite examples in support of the above contentions made by me I must mention something about the new techniques which have become available to the palaeobotanist to enlarge his scope for research. Besides the techniques which were developed by Walton (1928, 1930) like the peel-section method and its later improvements which can enable us to cut serial sections or even circumferential sections of petrified fossils quite expeditiously, the transfer (Walton 1923), celloidin pulls (Lang, 1926) and mass maceration techniques (Harris, 1926), excavation and plastic embedding (Leclercq & Noel, 1953) preparation of latex and rubber casts (Chaloner & Gay, 1972; Watson & Alvin, 1976) and the use of scanning electron microscope and improved techniques of light microscopy like fluorescent, phase contrast, Nomarsky interference microscopy infrared and X-ray photography (Walton, 1936; Schaarschmidt, 1985) and chipping technique (Croft & George, 1958) have given us far greater insights in the structure of fossils. Collection of more specimens increased the chances of finding better preserved remains and this has been another source of greater information about fossils. The new techniques and better material have provided unexpected details of fossils like nuclei and chromosomes—*see* Pl. 3, figs 1, 2, 6, 7 (Darrah, 1938; Vishnu-Mittre, 1969; Brack Hanes & Vaughn, 1978) and stroma/grana in chloroplasts—*see* Pl. 3, fig. 2; possible nuclei and mitochondria in Miocene angiosperm leaves (Niklas & Brown, 1981)—*see* Pl. 2, fig. 4 petrified starch grains (Baxter, 1964) or palisade, spongy mesophyll, and vascular tissues in compressed leaves of *Glossopteris* (Pant, 1958) and other plants, starch grains and archegonia in compressed seeds (Pant & Srivastava, 1964), and vascular cambium in Carboniferous plants (Cichan, 1986). Sieve cells in a Devonian progymnosperm and even sieve areas have been identified in the Carboniferous phloem of cordaitean axes—*see* Pl. 1, fig. 9; Pl. 2, fig. 1 (Taylor, 1988), fungi—*see* Pl. 3, figs 8, 9; mycorrhiza (Stubblefield *et al.*, 1987); pollination drops—*see* Pl. 1, fig. 2 (Rothwell, Miller & Brown, 1973), formation of pollen, spores and their intrasporic germination as well as gametophytes or embryos in Carboniferous pteridophytes and pteridosperms—*see* Pl. 1, figs 1, 3; Pl. 3, fig. 6 (Rothwell, 1981), archegonia, pollen tubes and megaspores and embryos inside prothalli of seeds and germinated seedlings—*see* Text-fig. 1, figs 1-8 (Krassilov, 1987). Some of them show cotyledons which may have been photosynthetic (Pant & Nautiyal, 1987). Bundle sheaths like those of grass leaves seen around bundles of *Glossopteris talbragarense* (Pant & Nautiyal, 1984) have led these authors to suspect that it could have $C_4$ plant. We have greater insights now on the pollination and ecology of fossil plants.

### Surprises in the diversity and unexpected strangeness of fossil plants

Palaeobotanists have repeatedly come across rather strange fossils in the geological record whose form and nature are so unexpected and so odd that they are unable to fit them in any known group of plants or in any accepted scheme of classification of the plant kingdom. At first, they call them *genera incertae sedis* which can be regarded as riddles of classification till they discover clues about their evolution and affinities. Some of these fossils emphasize the greater diversity of past plants many of which have become extinct. It seems as if Nature was experimenting in different directions and many of its experiments failed to make the forms extinct. Examples of this kind are the Bennettitales, Caytoniales, Glossopteridales (Text-fig. 5: figs 1-19), Czeckanowskiales, Pentoxylales, Corystospermaceae, *Buriadia, Rhexoxylon,* Cheirolepidaceae, *Tempskya* and a host of other forms and groups (Text-fig. 1: figs 9, 30-45). Sometimes these fossils temporarily misled us into imagining that we had discovered in them the ancestors of some of our living plants. At other times they seem to complete the picture of plant evolution by fitting in as missing links in the evolution of known groups, e.g., Progymnosperms, *Buriadia, Lebachia,* Palaeozoic seeds like *Genomosperma, Physostoma, Stamnostoma,* and others (Text-fig. 1: figs 18-23, 28-29). Some of them like the seeds of *Lagenostoma* even emphasize the wrong functional notions which we once had about their nine chambered canopy of vascular bundles which was claimed as forming a copious vascular supply at the micropylar end to supply water to



**Text-figure 1**—figs. 1-45. **1.** Seed of *Callospermum ovalis* Pant, Nautiyal & Tiwari showing archegonia, × 22.5; **2.** *Vesicaspora* type of pollen grain with branched pollen tube from Rothwell, × 650; **3,4,5.** Seedlings of *Glossopteris* ( *Diphyllopteris verticillata* Srivastava), 3 × 2; 4,5 × 1; **6,7,8.** Seedlings of *Joffrea speirsii* Crane & Stockey, 6 × 3.5: 7, 8 × ca 2; **9.** *Tempskya* reconstruction of plant after Andrews & Kern. **10.** *Kakabekia* Barghoorn & Tyler **11.** *Eosphaera* Barghoorn & Tyler **12.** *Huronispora* Barghoorn & Tyler **13.** *Eotetrahedrion* Schopf & Barghoorn. **14.** *Animikiea* Barghoorn & Tyler. **15.** *Archaeonema* Schopf & Barghoorn. **16.** *Eozygion,* Schopf & Blacic. **17.** *Glenobotrydion* Schopf & Blacic. **18.** *Genomosperma kidstonii* Long. **19.** *G. latens* Long. **20.** *Salpingostoma dasu.* **21.** *Physostoma elegans.* **22.** *Eurystoma angulare.* **23.** *Stamnostoma huttonense* Long. **24.** *Grammatopteris rigollotii.* **25.** *Thamnopteris gwynne-vaughanii.* **26.** *Zalesskia gracilis.* **27.** *Plaeosmunda playfordii;* **28.** Cupule of *Archaeosperma arnoldii* Pettitt & Beck; **29.** Cupule of *Moresnetia zalesskyi* Rothwell & Scheckler; **30.** *Czechanowskia* short shoot; **31, 32.** *Leptostrobus longus* Harris; **33.** *Umkomasia macleani* Thomas; **34.** *Pteruchus africanus* Thomas; **35.** Shoot of Pentoxylon Srivastava; **36.** *Carnoconites* Srivastava; **37, 38.** *Buriadia heterophylla* Seward & Sahni; **39.** *Williamsonia sewardiana* Sahni; **40,41.** *Williamsoniella coronata* Thomas; **42.** *Caytonanthus* Harris; **43,44,45.** *Caytonia* Thomas.

ciliated motile sperms. As it appears now the nine chambers of hard tissue enclosing soft tissue and vascular bundles represent vestiges of nine telomes which fused to form the integument.

## Precambrian life

Before 1965, we had no authentic records of morphological fossils to support the existence of plant life during the Precambrian times although we had come to know that the earth was about 4.5 to 5 billion years old. Definite morphological plant fossils extended backwards in time only up to 0.6 b.y. or 600 million years. No doubt Oparin (1924—*see* Oparin, 1953) and Haldane (1929) had speculated on the origin of life on the basis of biochemical pathways and experimental support for their ideas was supplied by Miller (1953) but we had no direct proof on palaeontological or palaeobotanical grounds in favour or against the theory. Likewise some people thought that procaryotes were more primitive than the eucaryotes but direct evidence from fossils in favour of such notions was completely lacking. However, Barghoorn and Tyler (1965), Schopf (1968) and subsequent workers on Early Precambrian Fig Tree Formation and Swaziland System of Africa (ca 3-3.5 b.y.), Middle Precambrian Gunflint Chert of Canada (ca 2 b.y.) and Bitter Springs Formation of Australia (0.9-0.8 b.y.) brought forth direct evidence to show that the first forms of life found in Early Precambrian were simple bacteria-like procaryotes called *Eobacterium*, some present day mycoplasma-like bodies called *Eoastrion* and a number of types of cyanobacteria. Some biota like *Kakabekia umbellata* which have since been found in the living state in ammonia rich environments of today could even confirm the ideas of Oparin and Haldane about the primeval atmosphere of the Precambrian times being rich in ammonia (Text-fig. 1: figs 10-17). Later work on Precambrian fossils from various areas has tried to reassess the evidence of Precambrian biota. Doubts were cast by some workers on the presence of eucaryotes in the Bitter Springs Formation of Australia but these have been dispelled by more critical assessments. The overall impact of this later work has been to carry the earliest fossil record still further back to 3.5 billion years.

## Bacteria, Algae, Lichens, Fungi and Bryophytes of later periods

Palaeobotanical knowledge of the above groups of plants is rather scanty and accordingly the evolutionary history of these groups is poorly known and there are doubts about the origin and evolution of their diverse forms. The classification of the living bacteria, algae and lichens is mainly based on their reproductive organs, chemistry or staining reactions or pigments which are difficult to find among their fossils. The classification of fossil algae in particular is chiefly based on their siliceous or calcareous skeletons and it is therefore useful for combining botanical and geological approaches. There is need for intensive search of the fossils of these diverse groups to arrive at definite conclusions about their evolution. The relationships between the various groups of bryophytes like Marchantiales, Jungermanniales, Anthocerotales, Sphaerocarpales, Bryales and Sphagnales are obscure and it is difficult to decide whether they represent a reduced or progressively advanced group of plants. Recent reports of Ordovician spores which have been attributed to the Bryophytes may give us some clues

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### PLATE 2

1 Sieve cell in phloem of *Medullosa noei*—showing elongated sieve areas on radial wall. × 850, from Smoot.
2. TEM photograph of chloroplast showing details of grana, from Niklas & Brown.
3. TEM photograph showing double membranes in cells of Miocene leaf, from Niklas & Brown.
4. Starch filled cells in the female gametophyte of *Cardiocarpus spinatus*, from Baxter.
5. Insect, *Ceroxyela* with pollen grains in the gut, from Krassilov
6. *Vitimipollis* pollen grain from the gut of insect in fig. 5, from Krassilov.
7 *Kallospora extrudeus* spore with gelatinous contents (cytoplasm?) extruding from proximal surface, from Hall.
8. Cytoplasm belonging to egg or zygote in the archegonium of a pteridospermous ovule, from Stewart.
9. Longitudinal section of seed showing megagametophyte (G) with two archegonia (arrows), embryos are present within archegonial chambers, from Smoot & Taylor.
10. Longitudinal section of *Lagenostoma ovoides* ovule with well-developed cellular female gametophyte and archegonial cavity, from Taylor & Millay.
11 Longitudinal section of apical half of *Taxospermum undulatum*, ovule showing female gametophyte with 'tentpole' and archegonium, from Taylor & Millay.
12. Sperm like contents of a monolete pollen grain, from Stewart.
13. Transverse section of an archegonium showing neck canal (c) and neck cells (n), from Brack-Hanes.

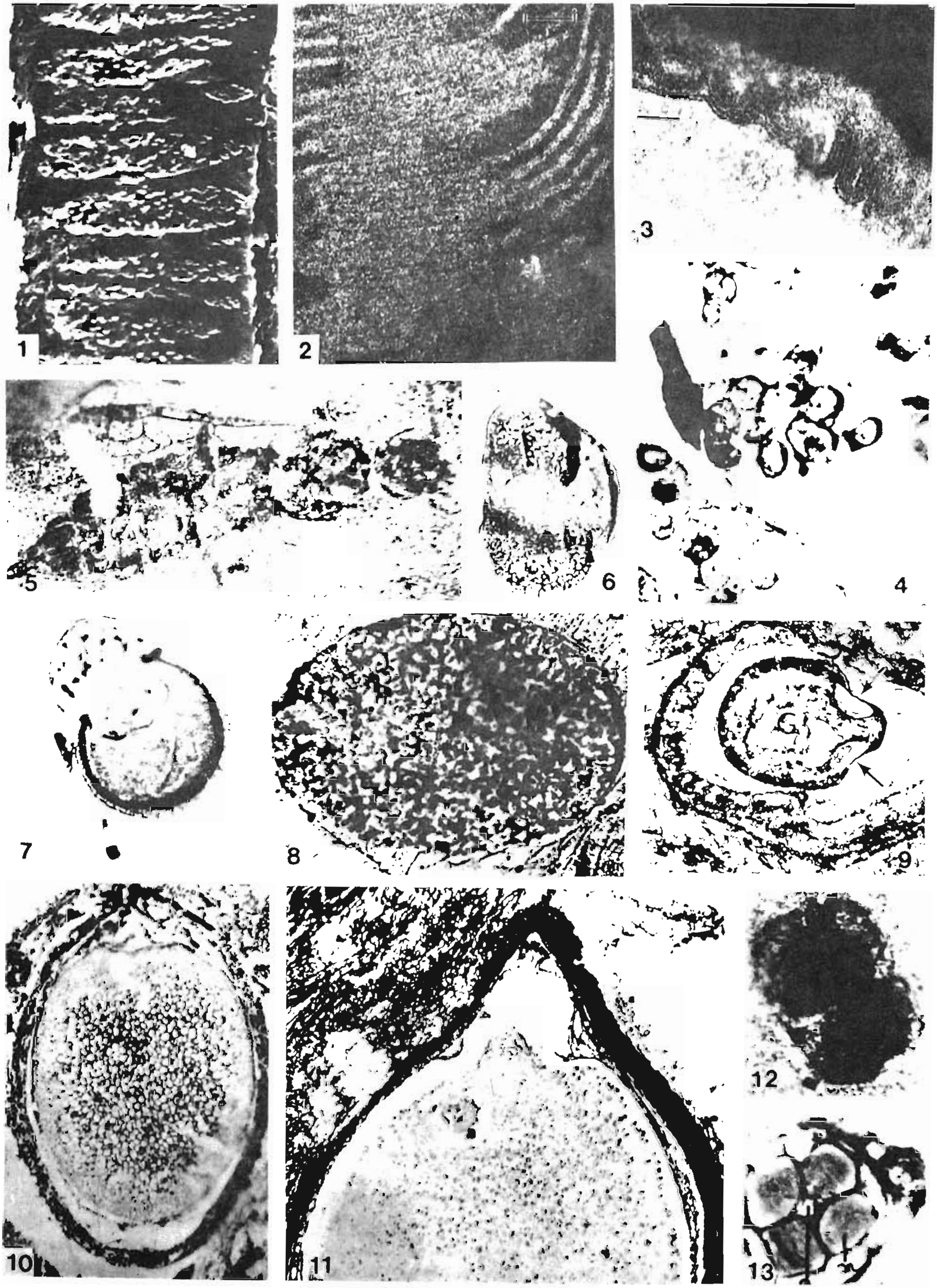
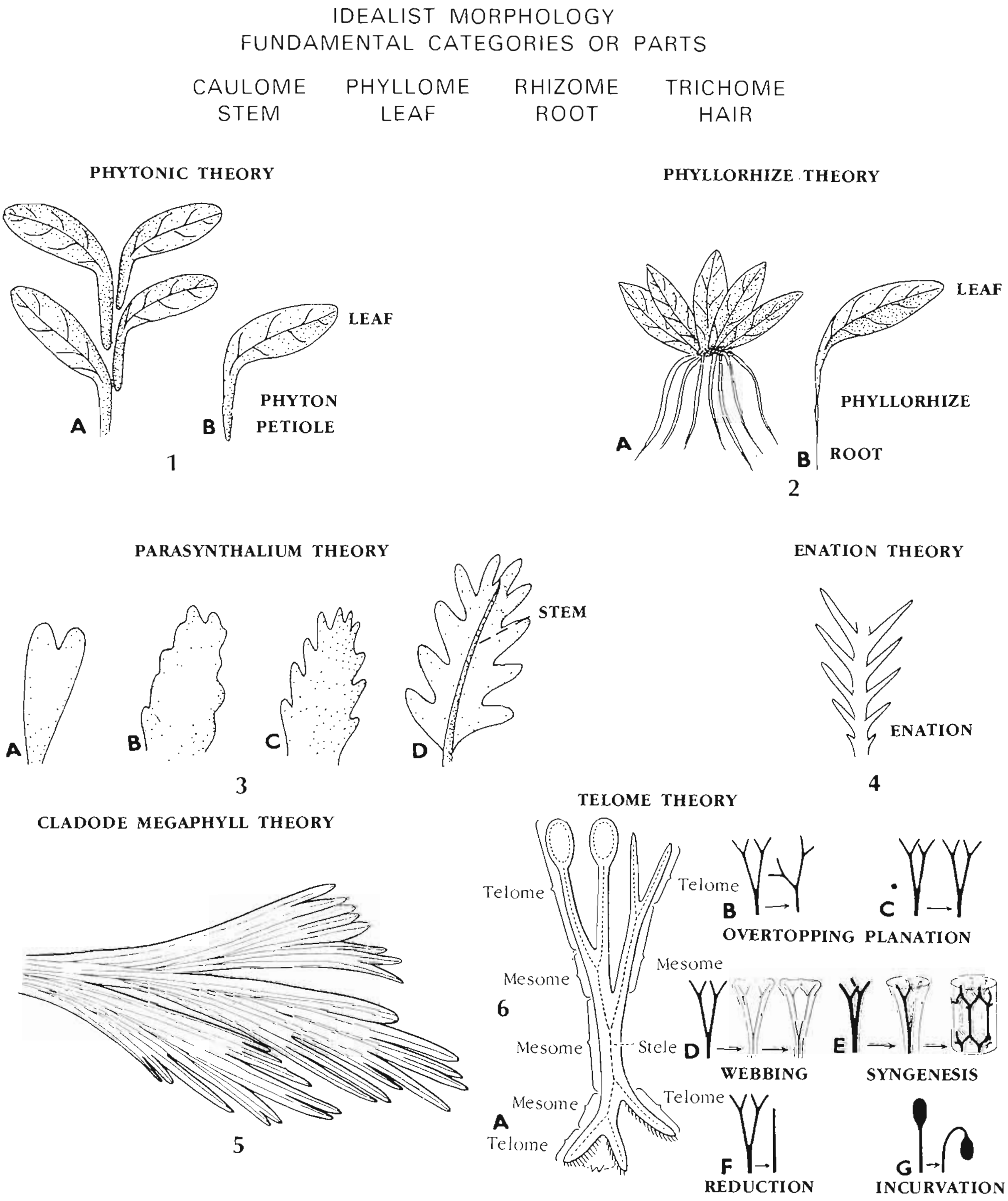


PLATE 2



**Text-figure 2**—figs. **1-6.** Diagrams to illustrate various idealistic theories of plant construction and the Telome Theory.

about the evolution of this group but we need more information.

## Origin of land plants

Till 1919, we had only vague ideas about the "Thallisiophyta and Subaerial Transmigration" on land as suggested by Church and others but these were only ideas or theories lacking any direct proof.

Beginning with Dawson's (1859) early work and the later publications of Kidston and Lang (1917-1921) on structurally preserved Psilophytales which was continued subsequently by Hφeg (1942), Banks and a host of other botanists we arrived at indubitable evidence about the origin of land plants from algae so much so that Arber (1921) characterised the first land plants by the title "Vascular Thallophytes".

### Characters of first land plants

Palaeobotanical discoveries of Late Silurian and Early Devonian plants have shown that early land plants evolved by donning waxy or fatty waterproof coats (cuticles) over their exposed parts to protect them from drying in dry subaerial environments. Their cells could now remain in an active state of growth (algae too can remain alive under dry conditions but their cells hibernate and become inactive). Accompanying their water proof impervious coat land plants also developed pores or stomata for gaseous exchange and inside their axes they developed a core of conducting cells with water proof lignified walls to conduct water from the prostrate axes which grew over wet soil or under it. They absorbed water through their rhizoids and conducted it right up to their actively growing tips. The spores of these plants started being formed in sporangia held high at the ends of fertile axes so that their dissemination by wind had better chance and the spores too became coated with a cuticle for their protection in dry air.

### Theories of plant construction

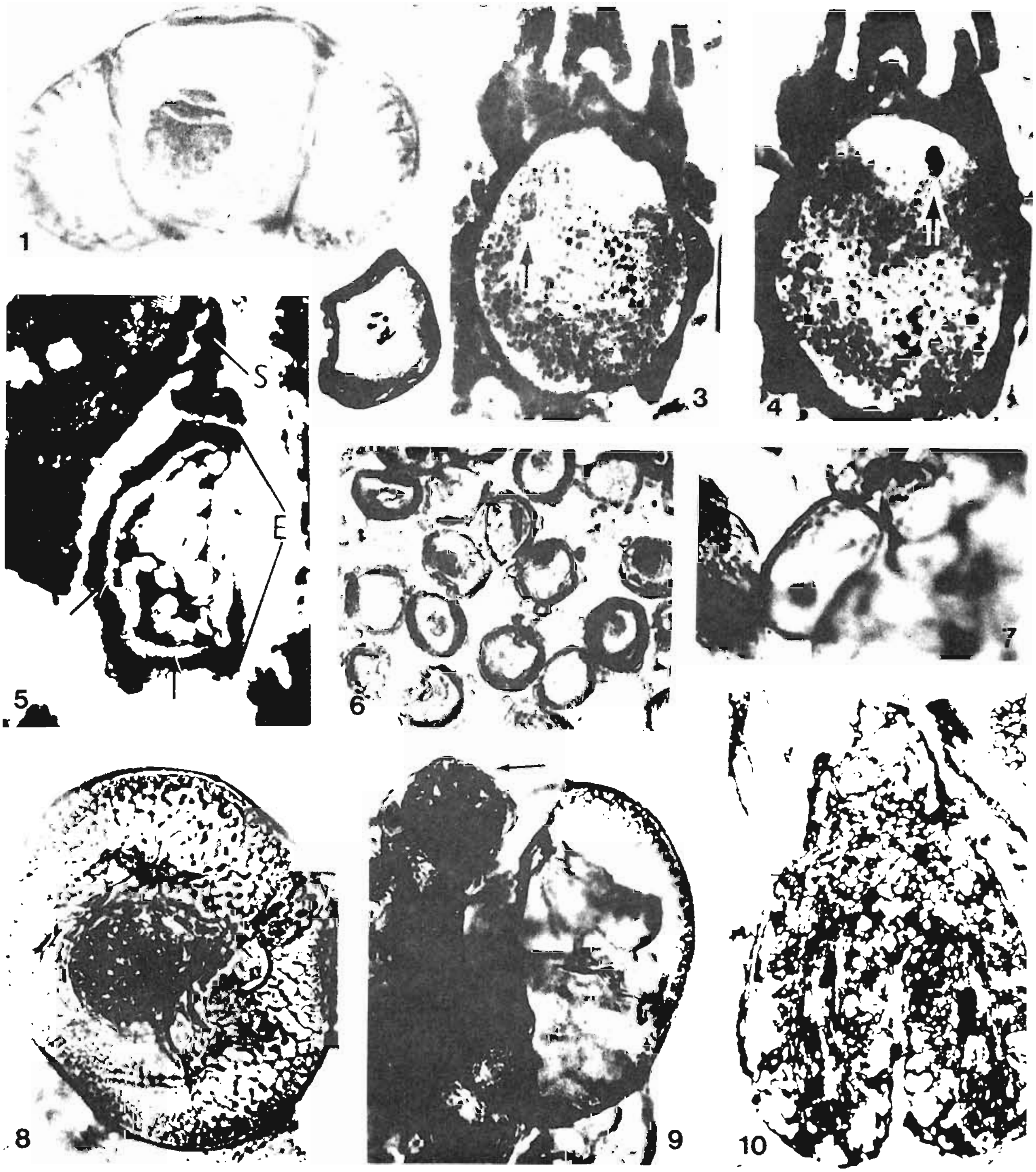
There was a time when morphologists were theorizing and debating the evolution of various plant organs of ideal plants. The idealistic concepts indulged in arguments like hen first or egg first about the organs of the plant body which came first and which came later. Some idealistic morphologists thought that the first plants were made of phyllorhizes or leaf-roots (Phyllorhize theory), others thought that they were wholly fertile (Strobilus theory) or made up of phytons or leaf-petioles (Phytonic theory), still others thought that the first plants were protocorms or undifferentiated corm-like structures or thallus-like bodies whose lobing gave rise to leaves (Parasynthalium theory—see Eames, 1936). The discoveries of *Rhynia* and *Cooksonia* and other early vascular plants showed that those who believed in idealistic morphology were viewing things upside down. They were usually trying to interpret the structure of simple plants on the basis of more complex plants which had a differentiation of organs like a stem or caulome, a leaf or phyllome and a root or rhizome, a hair or trichome besides other accessory organs for reproduction which were believed to be modifications of one or the other of the aforementioned organs. The discovery of early vascular plants gave us the clue that the bodies of earliest land plants were not differentiated into organs like leaves and roots but they consisted merely of an axis system. Ultimately a new theory based on such plants called the 'Telome theory' was proposed by Zimmermann (1930) and now instead of looking downwards from complex to simple plants we started looking upwards from simple to complex plants (Text-fig. 2 : figs 1-6).

### Evolution of Stelar System and ontogenetic studies

The evolution of the stelar system cannot be understood without the help of the stelar systems of fossil plants (Text-fig. 1  figs 24-27). We know now that those who interpreted the pith as an "invasion" or invagination of the cortex into the centre of stele were proved to be incorrect by fossil forms like *Thamnopteris* and *Zalesskia*. A host of other forms showed that a parenchymatous pith was gradually evolved in-situ from a solid protostele. It was a developmental diversion of central cells (Kidston & Gwynne-Vaughan, 1907, 1909). Ontogenetic studies of fossil plants started by Walton (1934) and continued by Morgan (1959), Eggert (1961, 1962), Good (1971a, 1971b), Good and Taylor (1972) and others have also helped in understanding stelar evolution and apical structure.

### Spore evolution

The stages in the evolution of spore sculpturing and heterospory have also been elucidated by recent palaeobotanical discoveries. It appears that spores of diverse early vascular plants were all equal in size or homosporous and their surface was to begin with smooth but thereafter plants started producing unequal spores and their coats started becoming variously ornamented. An intermediate stage in the evolution of heterospory was incipient heterospory when the spores started becoming unequal inside one and the same sporangium and the sporangia of such plants could not be called mega—or micro-sporangia. Some of the present day mosses have stopped at such a stage which bryologists call anisospory but later diverse vascular plants became heterosporous by producing two kinds of sporangia, the mega-sporangia and micro-sporangia which produced unmixed megaspores and microspores. Recent work has suggested that megaspores of some *Lepidocarpon*-like plants called *Achlamydocarpon* had both functional and aborted megaspores and they developed a spongy mass of sporopollenin like that of modern *Azolla* or *Salvinia* and they were floating in water and were fertilized by spermatozoids from microspores which too were swimming in water. Well-developed archegonia with eggs or embryos have been recognised by Galtier (1964, 1970) in *Lepidocarpon* and the entire life cycles of these plants are now known.



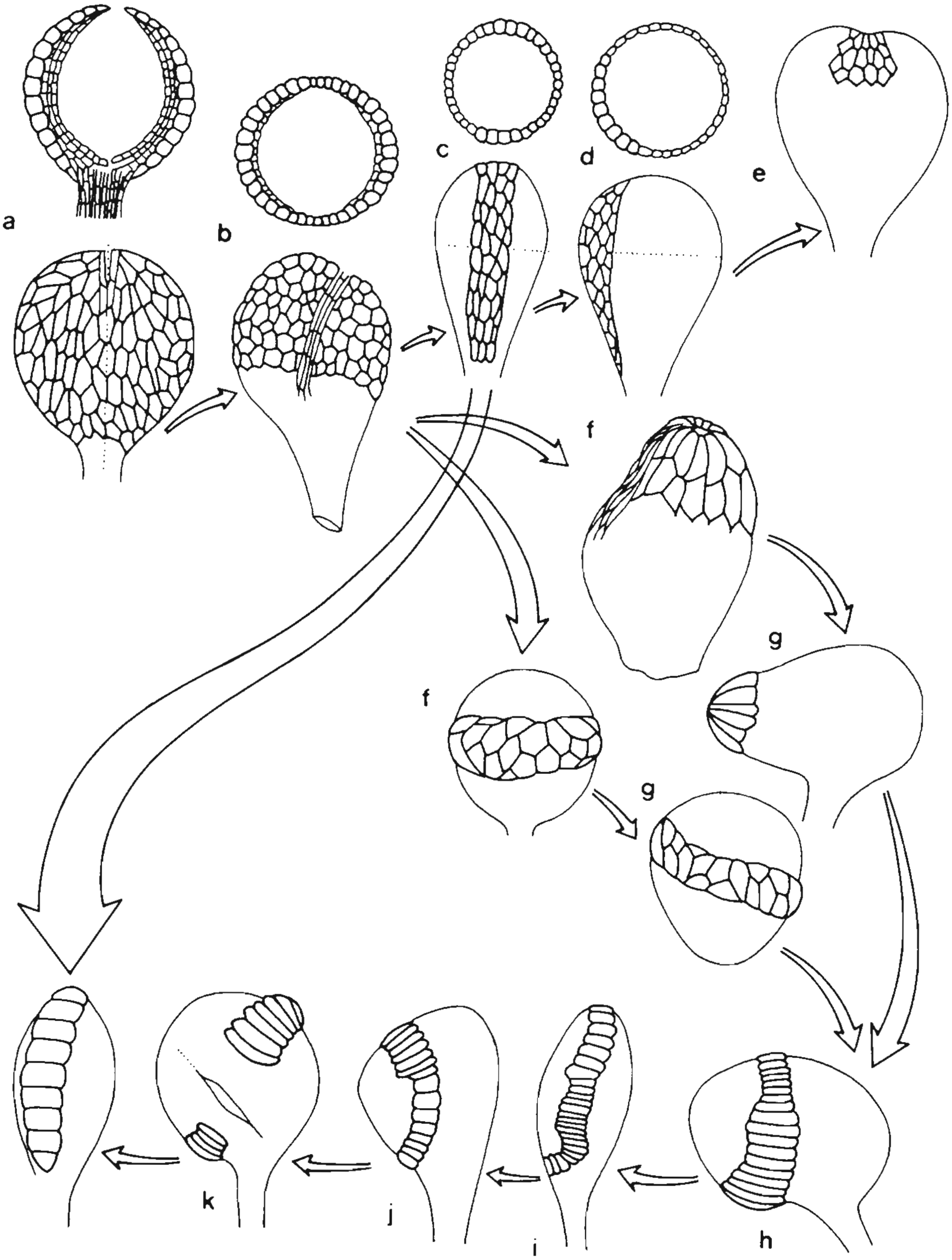
## PLATE 3

1. *Vesicaspora* pollen grain showing three celled stage of microgametophyte, from Millay & Eggert.
2. Microspore showing prophase, from Brack-Hanes.
3, 4. Ovules of *Hydrasperma tenuis* showing archegonia (arrow), from Matten *et al.*
5. Archegonium with multicellular embryo (E) and suspensor (s), from Smoot & Taylor.
6. *Lasiostrobus polysacci*, pollen grains showing microgametophyte development, from Taylor.
7. Nuclei in the monolete spores of *Peltastrobus reedae*, from Baxter
8. *Sullisaccites* pollen grain with zoosporic fungi within the central body, from Taylor
9. Pollen grain with epibiotic sporangium extruding from saccus wall-cap, from Taylor
10. Possible Lower Carboniferous embryo with two cotyledons, from Taylor & Millay

## Evolution of sporangium, annulus and sorus

The evolution of a leptosporangium from a eusporangium, the phyletic slide of annulus (Text-fig. 3 : figs a-l), the evolution of a sorus from a monangial condition and the phyletic slide of sorus in ferns too had to be understood in the light of fossil plants (Bower, 1935).

We were again having vague conjectures about the origin of gymnosperms from some heterosporous ferns through pteridosperms. These ideas were disputed by Thompson (1927) and Doyle (1953) who pointed out that the seed plants were not heterosporous but only heterothallic. In support of this contention Thompson pointed out that the seed spores of some gymnosperms are smaller than their pollen spores and Doyle emphasized that the oldest seed plants antedated the earliest heterosporous ferns or pteridophytes. They thought that the seed plants seemed to have descended from



**Text-figure 3**—Possible alternative modes of phyletic slide of annulus (after Pant & Khare): **a,** *Stauropteris oldhamia*; **b,** *Botryopteris globosa*; **c,** *Etapteris laccatei*; **d,** *Botryopteris forensis*; **e,** *Osmunda*; **f,** *Senftenbergia*; **g,** *Lygodium*; **f,** *Damudopteris*; **g,** *Sermaya*, **h,** *Gleichenia*; **i,** *Plagiogyria*; **j,** *Loxosoma*, **k,** *Hymenophyllum*; **l,** *Leptochilus*.

homosporous but heterothallic ancestors among the ferns or pteridophytes. Subsequent palaeobotanical work has shown that heterospory came into existence in the Lower Devonian while the first seeds (or seed plants) appeared in the Upper Devonian. The origin of gymnosperms can now be traced to the heterosporous Progymnosperms like *Archaeopteris* whose compound fern-like leaves have now been shown to be of the nature of short shoots bearing simple leaves. Its long shoots or trunks could become 5 feet or more in thickness, and with abundant secondary xylem of gymnosperm type. Some species of *Archaeopteris* were heterosporous but at least one of them seems to be closely associated with seeds called *Archaeosperma arnoldii*. Such a unique plant was earlier unimaginable since some of its species are like pteridophytes in reproduction while other species could have been gymnosperms if their association with seeds has any meaning. Beck (1960a, 1960b, 1961, 1970, 1976) has termed such plants as Progymnosperms and they possibly are at the beginning of gymnosperms. Palaeobotany has thus supplied a very much wanted clue about the origin of seed plants.

## Origin and evolution of seeds and cupules

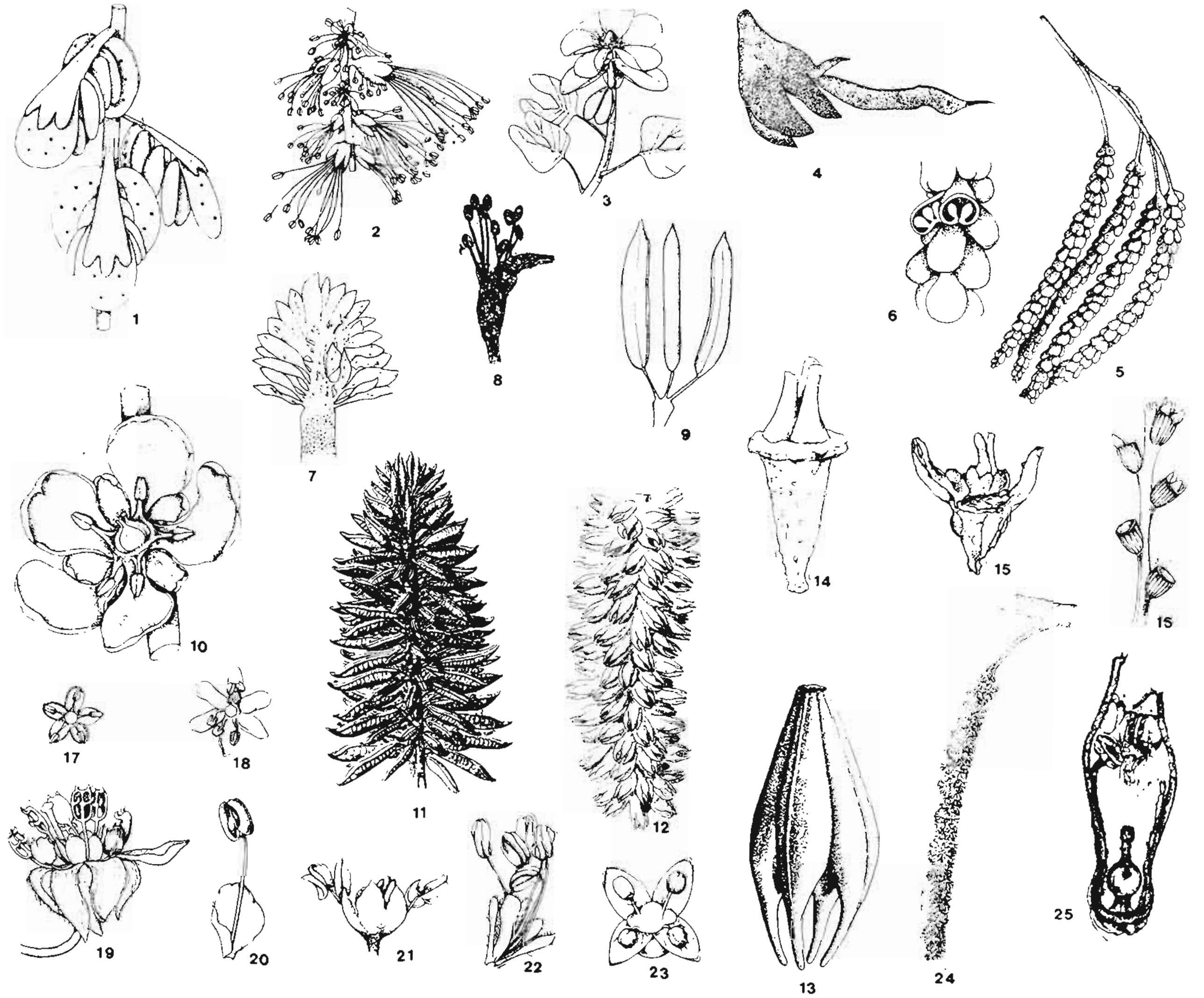
The organs called seeds had themselves formed a morphological riddle after the work of Wilhelm Hofmeister (1851) indicated that they could be regarded as integumented megasporangia. The manner of the evolution of the integument was, however, problematic but the work of Long (1960a, 1960b, 1966) and others has shown that the integument has been formed by the fusion of 2 or more sterile telomes in the gymnosperms whereas the seed-like structures of *Lepidocarpon* and *Miadesmia* have integument-like envelopes formed by the megasporophylls. The seeds described lately by Long and others have thus vividly shown the steps in the evolution of the integument from sterile lobes of megasporophylls around the megasporangia (Text-fig. 1 : figs 28, 29) and they also show that seed-like structures or seeds evolved along several parallel lines. May be we discover more lines of evolution, e.g., the evolution of the vasculatureless double integumented seeds of modern angiosperms.

## Nature of the female cone of conifers

Likewise an age old riddle about the morphological nature of the female cone of conifers could be solved by the epoch making work of Florin (1939-1945, 1951) and others on fossil conifers which conclusively showed that the so-called ovuliferous scale was an axillary shoot and the female cone of Coniferales was a compound strobilus.

## Origin of Angiosperms

Darwin termed the origin and evolution of Angiosperms to be an "abominable mystery". We were all the time depending on ideas based on comparative morphology and the result has been a multiplicity of classifications of the flowering plants. Some authors like Engler (see Engler *et al.*, 1954) believed that naked unisexual anemophilous flowers like those of the Casuarinales were the most primitive, others like (Arber & Parkin, 1907) and Hutchinson (1959) suggested that bisexual complete flowers having indefinite number of parts like those of the Magnoliales-Ranales complex were most primitive. Some authors derived the angiosperms from the Caytoniales or the Bennettitales, others from the conifers or Gnetales. Unlike the blind man who meant to see the elephant and could not see it whole but only felt its parts, the botanists who were searching for clues about the origin and evolution of angiosperms were sure that they had functional eyes but they were not aware that they needed the light of fossils to solve the problem. Faint glimmers of this light have started coming from the discoveries of a few fossil reproductive parts of angiosperms in the Uppermost Lower Cretaceous, Upper Cretaceous and Eocene beds. So far we were under the impression that we could only see pollen grains and leaves of angiosperms which are preserved as fossils and we thought that floral parts were too delicate to be found in the fossil state but thanks to the work of Dilcher and Crane (1984), Doyle (1978), Hickey and Doyle (1977), Crepet (1979) and their co-workers in U.S.A., Friis (1983, 1984, 1985), Skarby and Friis (1982) in Sweden, Vakhrameev and Kotova (1977), Vakhrameev and Krassilov (1979) and others in U.S.S.R., a number of well-preserved fossil angiospermous gynaecia, androecia, flowers and inflorescences have been discovered in the Middle Albian (105 m.y.) beds (Text-fig. 4 : figs 1-25). These include *Caspiocarpus* and *Hyrcantha* which are gynaecia attributed to the Magnoliidae (Chloranthaceae), gynaecia attributed to Hammamelidae, Platanaceae, *Archaeanthus* are just the beginnings of a new field of work (see also Friis *et al.*, 1987). So far we have only found Archichlamydeous flowers in the Cretaceous to be able to say only tentatively that even during the Eocene most of the angiospermous genera were

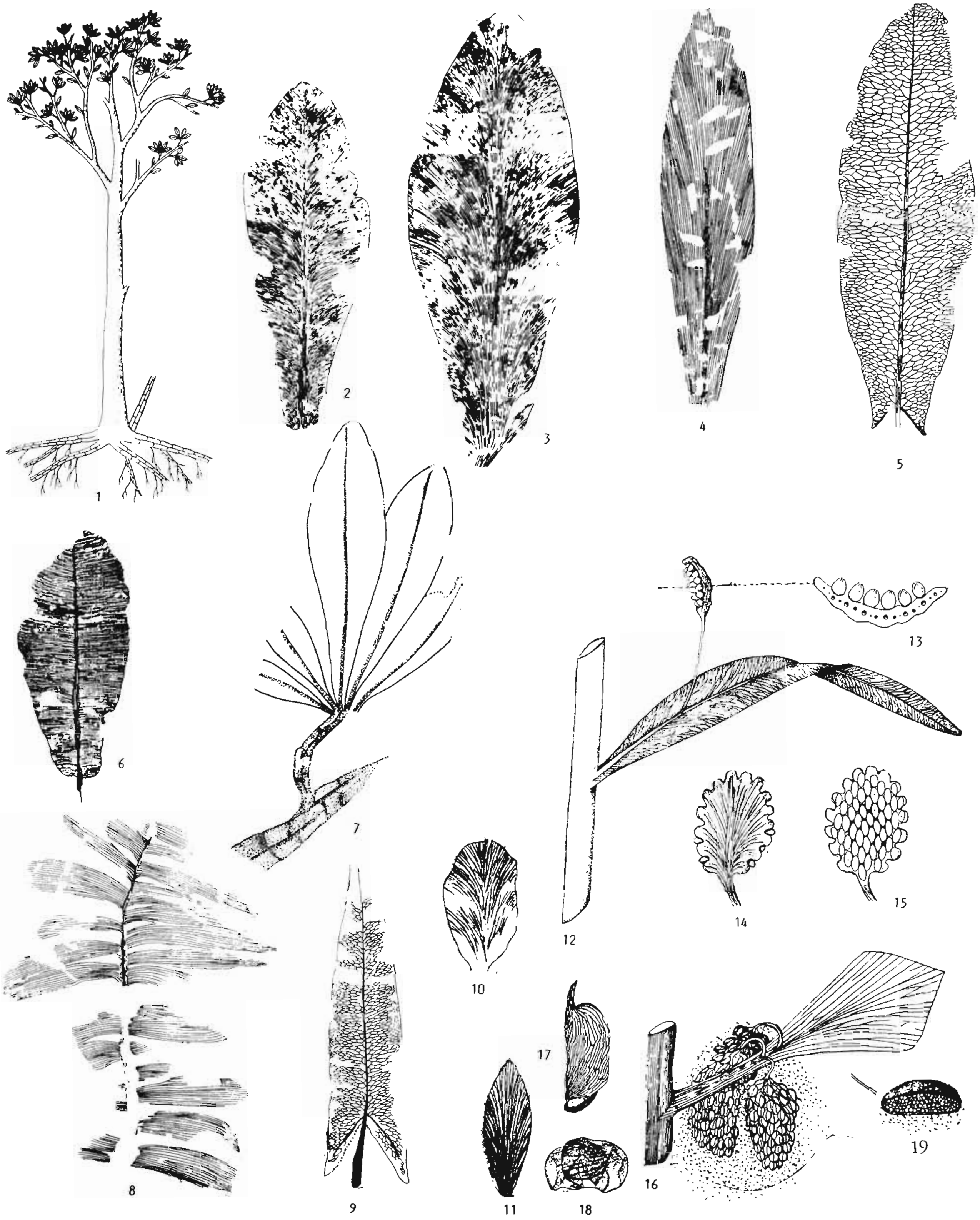


**Text-figure 4**—figs. 1-25. **1.** *Eokachyra aeolia* Crepet, Dilcher & Cotter; **2.** *Eomimosoidea* Crepet & Dilcher; **3.** *Archaeanthus linnenbergeri* Dilcher & Crane; **4.** A papilionoid legume flower with pod Crepet & Taylor; **5,6.** *Prisca reynoldsii* Retallack & Dilcher; **7.** Magnolialean multicarpellate fruit Crane & Dilcher; **8.** *Protomimosoidea buchananensis* Crepet & Taylor; **9.** *Triplicarpus purkynei* Velenovsky & Viniklar; **10.** Unnamed flower from Dakota Formation, Cretaceous, Basinger & Dilcher; **11.** *Archaeanthus linneanbergeri*, fertile axis bearing spirally arranged conduplicate carpels, Dilcher & Crane; **12,13.** Catkin-like inflorescence with spirally arranged four parted florets; **14.** Epigynous saxifragalean flower with three stout styles, Friis & Skarby; **15.** *Scandianthus costatus* Friis & Skarby; **16.** *Leptospermum macrocarpum* Velenovsky; **17.** *Berendtia primuloides* Conwentz; **18.** *Sambucus succinea* Conwentz; **19.** *Cinnamomum prototypum* Conwentz; **20.** *Forskobleanthium nudum* Conwentz; **21.** *Quercus taeniatopilosa* Conwentz; **22.** *Quercus meyeriene* Conwentz; **23.** *Myrsinopsis succinea* Conwentz; **24.** *Caloda delevoryani* Dilcher & Kovach; **25.** *Sahnianthus parijai* Shukla.

different although some of them would be assigned to modern families or to families which combined characters of more than one modern family. Indeed, flowers and fruits of angiosperms started being described in India by Sahni, Shukla (1944) and others in the forties.

### Origin and evolution of plant-animal relationships in pollination and insectivory

Connected with the new field of research on fossil flowers is another novel area of research on pollination studies in living and fossil plants and on animal-plant relationships. This carries us further into the field of palaeoecology since we know that megafossils of plants occur in terrestrial deposits which have been largely neglected by palaeontologists and geologists since they are mostly interested in marine sediments and marine animals. We are aware, however, that right from the Devonian or Silurian, animals were existing in association with plants and Carboniferous onwards a fauna of phytophagous insects existed in the forests



**Text-figure 5**—figs. 1-19. **1.** Reconstructed plant of *Glossopteris*, from Pant, 1971; **2.** *Glossopteris major;* **3.** *Gangamopteris cyclopteroides;* **4.** *Palaeovittaria raniganjensis;* **5.** *Sagittophyllum verticillatum* Pant, Nautiyal & Chauhan; **6.** *Rhabdotaenia danaeoides;* **7.** Bunch of *Glossopteris* leaves attached to a branched *Vertebraria* axis from Pant; **8.** *Pteronilssonia gopalii;* **9.** *Belemnopteris sagittifolia,* **10.** *Rubidgea obovatum;* **11.** *Euryphyllum;* **12,15.** *Ottokaria zeilleri,* from Pant & Nautiyal; **12.** Reconstruction of a stem bearing a fertilizer; **13.** T.S. of head; **14,15.** Sterile and fertile sides of head, respectively; **16.** Reconstructed axis with attached fertilizer of *Eretmonia* raining pollen; **17.** A single sporangium, *Arberiella* of *Eretmonia;* **18.** Bisaccate pollen grain of *Arberiella;* **19.** Disc of *Nesowalesia* bearing *Arberiella* with its presumed stalk.

throughout geological time. We know of coprolites containing cuticles and pollen of *Caytonia*-like those described by Harris (1946, 1964). We also have reports of some fossil insects with pollen grains in their alimentary canals and pollen grains sticking to fossil insect legs—*see* Pl. 2, figs 5, 6 (Krassilov, 1987) but what we need to do is to concentrate our efforts on extending such work. Who can say that it will be stereotyped.

### Palaeophytogeography, palaeoecology and taphonomy

Work on the study of palaeofloras from the point of view of demarcating the boundaries of palaeofloristic provinces or phytochoria of the Indian region, their palaeoecology and taphonomy require a great deal of our attention.

### History of present day floras

An almost untouched field of research in this country is the study of the history of our present day floras. We do not even know the kinds of forests which existed in various parts of India before the advent of man and how our shoreline has receded or extended and how man has changed the vegetation by extending cultivation. Work of this kind has been done in England by Godwin and his coworkers and it is epitomised in the *History of British flora* (Godwin, 1956). Some workers have taken up such studies in India also (Banerjee & Sen, 1984, 1985, 1986) but who cares for such work in a country mimicking advanced countries and wasting vast sums of money on its space programme that brings repeated failures and at the same time leaves no funds for basic science which can achieve wonders with relatively modest amounts of expenditure.

History of present floras has another aspect which can give us clues about the origin of our cultivated plants or medicinal plants and about the centres of diversity of such plants. Archaeological sites would be particularly useful for such research. Dendrochronology of our archaeological woods too needs our attention.

### Continental drift

One of the great achievements of Palaeobotany has been the impetus it gave to the ideas of 'Continental Drift' (Wegener, 1924). At one time people, mainly physicists, were ridiculing the idea for lack of motive force but today it has culminated in plate tectonics, oceanographic research, mineral and biological wealth under the sea, demarcation of volcanic and earthquake prone areas, and the motive force has been supplied by the physicists themselves.

### Palaeobiochemistry and ultrastructure

Palaeobiochemistry and ultrastructure are yet other fields which are grossly neglected aspects of fossil study requiring the attention of Indian palaeontologists and palaeobotanists (Niklas, 1981, 1982; Niklas & Brown, 1981).

### Experimental palaeobotany

A relatively new field of palaeobotany may be called experimental palaeobotany A paper published by Walton (1936) could be regarded as one of the earliest studies of this kind. In this work Walton made observations and experiments on the formation of compression fossils. Subsequently, Oehler and Schopf (1971) and others have performed experiments on the formation of petrifactions but this important field needs to be worked out more thoroughly by experiments and observations on the formation of diverse fossils and their beds by experiments under a variety of conditions.

### Mineral prospecting

A field of palaeoecological research which is still largely untouched is mineral prospecting with the help of fossils. Coal and oil are no doubt correlated and even prospected with the help of pollen analysis but we know now that microorganisms and even plants of different groups are associated with rocks or minerals of different kinds. There are, for example, sulphur and iron bacteria, copper mosses, calcicoles and calciphobes. There are also associations of algae with minerals of various kinds like calcareous or silicious algae and if we can determine the preferences of fossil plants for particular soils or substrates for rock building, we can use them as palaeoindicators for mineral prospecting.

### Sedimentology and stratigraphy

Sedimentology and stratigraphy derived immense help from palaeobotanical studies. A vivid manner in which deposition of sediments can record past events is furnished by the Sunday Stone, a piece of chalky mud kept in the British Museum (Pl. 4, fig. 1). Since it is evidently recorded that the Sunday Stone was formed in a small pool or "horse trough" in a British coalmine in South Shields, County of Tyne and Wear about 1880. Into the pool was flowing a little stream after passing through a chalky

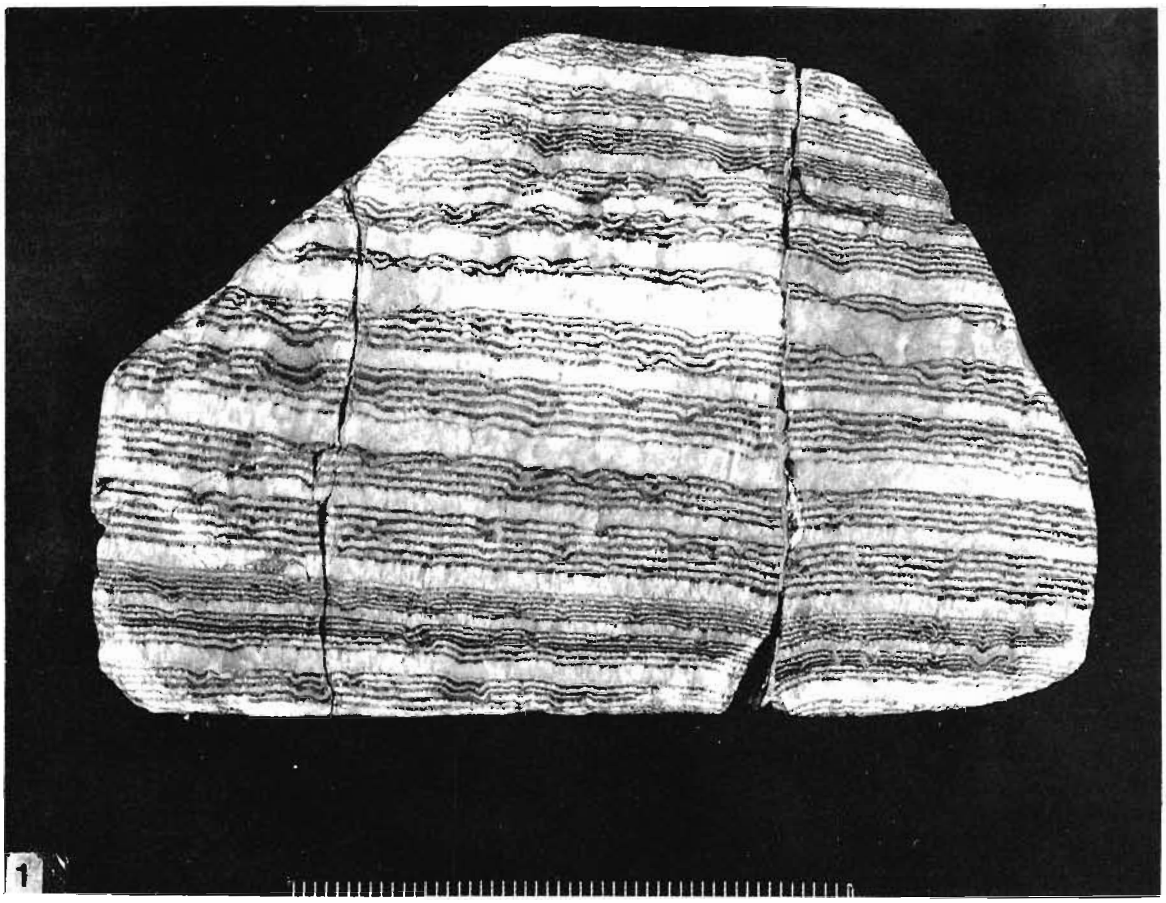


**PLATE 4**

"Sunday Stone", Specimen no. BM 1988 Pl, formed in a "horse trough" in a British coalmine in South Shields, County of Tyne and Wear about 1880 (Photograph through kind courtesy of Dr C. Hill of British Museum).

bed and depositing chalky sediment at its bottom or it could have been barium sulphate which was used to reduce the risk of fires spreading in the mine During the days, when the coalime was working the air was full of coal dust which settled over the water and got mixed up with the chalk or $BaSO_4$ to settle at the bottom of the trough and the deposit of chalk or $BaSO_4$ became dark. During the nights the air was relatively free from coal dust and the nocturnal deposit was whiter. The six week days are thus marked by darker layers in the Sunday Stone which alternate with lighter layers formed in the nights following week days up to Friday but after the deposit formed on Saturday there is a thicker white band beginning with Saturday night, Sunday and Sunday night. Thus the thicker white bands in the layered stone represent Sundays and also holidays. Hereafter, it is easy to understand the importance of fossils in recording the past history of life. Since spores and pollen grains can float in the air like coal dust and settle down on land or water, they furnish a vivid record of past life. Fortunately, they have a resistant, sporopollenin coat which furnishes clues about the plants which produced them. They are frequently used in correlation in sedimentology but can be readily preserved even when other parts of plants are not preserved. Another fortunate feature of spores and pollen is the characteristic sculpturing of their other coats which often helps us in identifying the plants which produced them. Now since different periods in earth's history were having their characteristic forms of life, palynology is of immense help in dating and correlating rocks. Indeed the same is true of megafossils. Palynology has been extensively used by geologists but they also need to study megafossils and thus palaeobotany too can help us in determining the vertical and horizontal geographic location of various strata in different parts of the world. Radioactive dating, may be useful in absolute age determinations, lithology and petrology too may be useful in dating rocks but palaeobotany and palaeozoology form the most convenient and cheapest method of dating and locating rocks.

I could have proceeded further in stressing the importance of palaeobotany but limitation of time prevents me from doing so. Therefore, I must end by saying that the importance of palaeobotany which I have mentioned should be enough to open the eyes of those who prevent palaeobotany in getting its due share in funds and posts in the University Departments since they are actually harming the progress of Science. We must remember that scientists at our Institutes also receive their initial training in the Universities.

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# Metaphyte and metazoan remains from the Indian Proterozoic successions

P. K. Maithy

Maithy, P. K. 1990. Metaphyte and metazoan remains from the Indian Proterozoic successions. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 20-28.

Evidences for the metaphyte and metazoan remains from the Indian Proterozoic are discussed. Two distinct macroscopic biota assemblages are described. The older macroscopic biota is from Middle Proterozoic and consists of planktonic and benthic metaphytes belonging to Chuarid, Tawuid, Krishnanid, Vendotaenid, and Frondoid forms. Uptil now distinct metazoan evidence from Middle Proterozoic (800-1,000 Ma) was doubtful. The previous records of jelly fishes are debated and considered here to be the encystment structures. The younger macrobiota, the Ediacaran fauna, are being reported for the first time from the youngest bed of the Vindhyan sequence. The remains of coelenterates and annelids are morphologically alike to the Lower Palaeozoic forms. The records of macroscopic biota indicate that the morphological diversification had started right from the Middle Proterozoic time.

**Key-words**—Morphology, Macrobiota, Metaphyte-metazoan remains, Proterozoic (India).

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## साराँश

### भारतीय प्राग्जीवी अनुक्रमों से मेटाफ़ाइटी एवं मेटाजीवी अवशेष

प्रभात कुमार माइती

भारतीय प्राग्जीवी कल्प से मेटाफ़ाइटी एवं मेटाजीवी अवशेषों के प्रमाणों की विवेचना की गई है। दो विभिन्न गुरुजीविता समुच्चयों का वर्णन किया गया है। प्राचीनतर गुरुजीविता मध्य प्राग्जीवी कल्प से है तथा इसमें **चुआरिड, तवुइड, कृष्णानिड, वेन्डोटीनिड** एवं **फ्रोन्डॉयडी** प्ररूपों से सम्बन्धित प्लवकीय एवं बेन्थीय मेटाफ़ाइटी अवशेष विद्यमान हैं। अभी तक मध्य प्राग्जीवी कल्प (800-1,000 ऍम-ए०) से मेटीजीवीयों का प्रमाण सन्देहास्पद था। इस शोध-पत्र में जेली-फिशों के पहले अभिलेखों पर भी प्रकाश डाला गया है तथा इन्हें पुटीयन संरचनायें प्रस्तावित किया गया है। विन्ध्य अनुक्रम की संस्तर से पहली बार अल्पतर आयु का सूक्ष्मजीविता, ऐडियाकरन जन्तुजात वर्णित किया जा रहा है। सीलॅनट्रेटा एवं ऍनॅलिडा समूह के अवशेष आकारिकीय दृष्टि से एक जैसे हैं। गुरुजीविता के अभिलेखों से व्यक्त होता है कि आकारिकीय विभिन्नता मध्य प्राग्जीवी से ही प्रारम्भ हुई हैं।

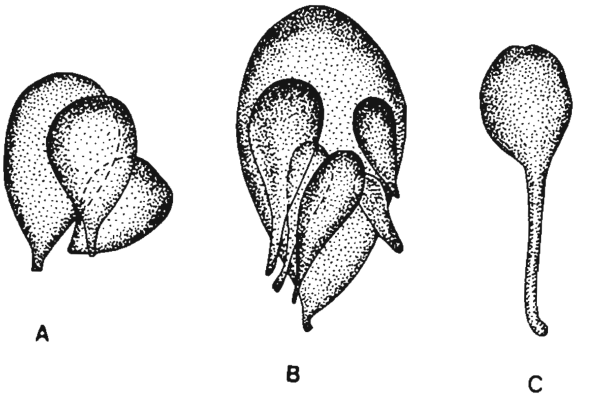
METAPHYTE and metazoan remains are well known world wide towards the close of Late Precambrian. The soft-bodied marine metazoan fauna—the Ediacarans, existed in many parts of the world during Eocambrian time (Glaessner, 1984; Hofmann, 1987). This fauna is older and different from the fauna traditionally called as Tommotian of Cambrian, yet its elements have attained a grade of morphologic organisation and size comparable to that exhibited in Palaeozoic fossils. This fauna is devoid of shelly fossils of Tommotian of the Lower Cambrian. It is presumed that the widespread Late Precambrian glaciation has helped in the rapid organic evolution (Schopf *et al.*, 1973). The occurrence of tillites at approximately the same stratigraphic level in different parts of the world appears to provide operational limit for correlation, though this evidence is still lacking in the Indian Precambrian sediments.

Below this stratigraphical limit, i.e., between 800-1,000 Ma diversified assemblages of carbonaceous films, including metaphytes and microbial colonies are well known. They are associated with *Chuaria* Walcott 1902. They include remains with regular rounded outlines, ribbon-like films, rounded structures with protrusion and frond-like forms. All are usually preserved on bedding planes and mostly showing wrinkling due to compaction. This assemblage had several forms of enigmatic nature which may find their placement both in the metaphytes and metazoans. Hofmann (1972, p. 22) has categorically emphasized—"At the present time no unquestionable metazoans are known from levels below the widespread terminal Precambrian glaciation". This view has also been supported by Cloud (1968). Therefore, this fact calls for a critical assessment of the known Precambrian Indian forms, claimed especially to be the remanents of metazoans from 800-1,000 Ma. Several such records have earlier been reported from the close of Middle Proterozoic succession of Vindhyan. The present paper deals with a re-assessment of these Middle Proterozoic remains based on new material and also records a new find of Ediacaran remains from the Late Proterozoic.

## PREVIOUS RECORDS OF MACROBIOTA FROM INDIA

The macroscopic biological remains were first recorded as discinoid discs by Jones (1909, in: Holland, 1909) from Suket Shales, Lower Vindhyan of Rampura. These remains attracted the attention of palaeontologists and geologists who considered them to be either the remains of brachiopods (Chapman, 1935) or algae (Sahni & Shrivastava, 1954). Contrary to this, Misra and Dubey (1952) considered them to be abiogenic structures. Maithy and Shukla (1984a) opined that these are the encystment structures of plankton resembling *Chuaria*.

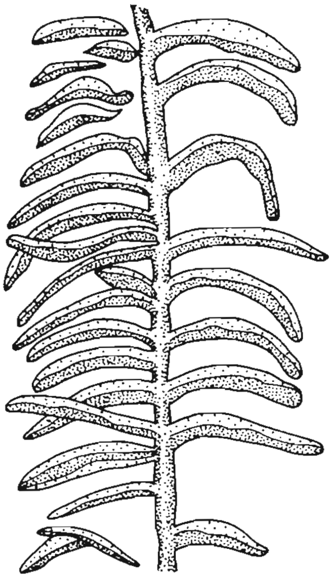
Beer (1919) recorded 'spiral impression' from Rohtas Limestone Formation. Mathur (1983) transfered this form to a new genus *Spiroichnus*. However, Hofmann (1985a) considered it to be a carbonaceous megafossil—*Grypania spiralis*. Rode (1946) recorded the presence of shell-like structures from the topmost bed of the Rohtas Limestone of Ramdehra Village, Bihar; these are of different sizes, ranging from half an inch to nearly two inches in length, conical in shape, broad at one end and gradually tapering at the other. The body of the specimen is transversely striate. These forms, according to Rode (1946), are referable to Pteropod genus *Hyolithes* Eichwald 1840. Besides, from the same bed Rode (1946, p. 248) recorded a number of discoidal remains which he opined to have resemblance with *Orthis*-type brachiopods.



**Text-figure 1—A,** *Krishnania acuminata* Sahni & Shrivastava; **B,** *Vindhyavasnia* Tandon & Kumar; **C,** *Vindhyania* Mathur (redrawn from published figures of specimens to show details).

From Suket Shale Formation (Neemuch District, central India) Sahni and Shrivastava (1954) reported *Fermoria* Chapman 1935 attached to apparently convergent filaments showing funnel-shaped ends. These are possibly the algal remains. They also reported a new genus *Krishnania* from the same formation. This fossil is acuminately ovate in shape narrowing abruptly at one end but evenly rounded at the other; the specimen shows superficial resemblance with *Lingula* Bruguiére 1797.

Misra (1949) claimed the finding of a dasycladous alga from carbonaceous limestone of Rohtas Formation at Banjari. The specimen has a verticillate, slender stalk terminated by globular head. Volgdin (1957, see also Balkrishnan, 1974, p. 9) commented that this form was not an alga but an early primitive form of Archaeocyatha; thus transfered it to a new form *Misracyathus vindhyanus*. Misra and Bhatnagar (1950) reported 'carbonaceous disc-like bodies' from Rohtas Limestone Formation of Banjari quarries. Prakash (1966) claimed the finding of broken cast of branchiopod remain from the Kajrahat Limestone Formation in Chopan area. Tandon and Kumar (1977) have recorded the impression of an annelid—*Katania singhii*, and an arthropod—*Vindhyavasnia misrae* from the Rohtas Limestone Formation of Katni. Maithy and Gupta (1981) reported archaeocyathid from the Vindhyan Supergroup. However, its identification has been questioned by Zhuravlev (1986). Presence of jelly fish-like remains from the Rohtas or its equivalent formations have earlier been reported by Sisodiya (1982) and Maithy (1984). Maithy and Shukla (1984a) recorded a new form *Ramapuraea*. Maithy, Narain and Sarkar (1986) reported a probable coelenterate *Sekwia* Hofmann 1981 from the Rohtas Limestone Formation of Amjhore. Maithy and Babu (1986) reported *Misraea*, a body fossil of uncertain affinity, from the Chopan Porcellanite Formation of Vindhyan in Mirzapur District. Recently, Maithy and Babu (1988) found algal encystment structure, viz., *Tawuia, Chuaria*, cf. *Sekwia, Longfengsahnia* and ichnofossils from the Semri and Kaimur groups of Vindhyan in Chopan area.



**Text-figure 2**—Frondoid form. × 1

## DESCRIPTION

### Carbonaceous megafossils

Several schemes for the suprageneric classification of carbonaceous megafossils recorded from Precambrian sequence (800-1,000 Ma) have been proposed. For example, *Chuaria* and its synonyms have been considered belonging to diverse groups, such as brachiopods, gastropods, foraminifera, plants, parasinophytes, acritarchs, or even inorganic structures (Maithy & Shukla, 1984a). A number of family-level taxa have been errected; *Fermoriidae* (Sahni, 1936), Chuariidae (Wenz, 1938), Megasphaeromorphida (Timofeev, 1970), Chuariamorphida (Soklov, 1965) and Chuariaceae (Wenz *nom. trans.* emend. Duan, 1982). The affinities of these forms are uncertain. Therefore, these carbonaceous compressions and moulds are considered as the orphans of palaeontology. Many are described as "unrecognised and unrecognisable genera" in the Treatise (Hantzschel, 1975). On the basis of external morphology, it is difficult to assign most of the taxa to major groups, but for the sake of convenience broad morphological groups have been proposed as under :

*Chuarid remains*—The forms are sphaeroids or compressed sphaeroids (discs); surface with concentric wrinkles, or with a distinct circular area indicating inner body or central opening. *Chuaria* is the best known form of this group (Pl. 1, figs 1, 2). They are simple in organisation, platyspermic carbonaceous discs, commonly circular, solitary, measuring 2.5 mm, surface smooth or with concentric wrinkles. In some specimens, Maithy and Babu (1988) found a small central area indicating a possible opening point. Isolated specimens found on the sediments support their being the encystment structures (Maithy & Shukla, 1984a).

Misra and Bhatnagar (1950) reported large, 26 mm diameter, carbonaceous spheroids from Rohtas Formation. Externally the forms are similar to *Chuaria*, except for their large size. In a recently recorded specimen (Pl. 1, fig. 3) one finds several, fine surface-thickenings and raised portion in the centre. Sokolov (1965) introduced the name *Beltanelloides* for such forms. However, Ford and Breed (1973) questioned the separation of *Beltanelloides* from *Chuaria* which is based only on the larger size of the former; however, Hofmann (1985) favoured its distinct identity on the same basis. The morphology supports for the encystment structures, like *Chuaria*.

Spheroids (discs) with distinct central area have been reported under *Sekwia* Hofmann 1981 by Maithy *et al.* (1987), *Ramapuraea* Maithy & Shukla 1984 and *Rohtasea* Singh & Chandra 1987. These forms were considered to be the relics of jelly fishes. A critical re-assessment raises doubt regarding their medusoid affinity, particularly because of their small size (3-8 mm) and the presence of recognisable organisation of coelenterate. Probably all of them are allied forms of *Chuaria*, with a distinct circular inner body.

The genus *Ramapuraea* is a small circular form, measuring 3-6 mm in diameter with a distinct central

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**PLATE 1**

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1. *Chuaria* Walcott & *Tawuia* Hofmann. × 1; Specimen no. BSIP 36105.
2. *Chuaria* and *Tawuia*. a portion of fig. 1 enlarged showing a circular area in the centre of *Chuaria*.
3. *Beltanelloides* Sokolov showing fine thickenings on surface. × 3; Specimen no. BSIP 35956.
4. *Sekwia excentrica* Hofmann. specimen showing presence of globular structures in central area. × 4; Specimen no. BSIP 35857
5. *Sekwia excentrica* Hofmann under SEM showing compactly arranged globular structures in central area.
6. *Ramapuraea* Maithy & Shukla showing globular structure in central area and fine radial thickenings. × 8; Specimen no. BSIP 27341
7. *Rohtasia tandonii* Singh & Chandra. × 8; Specimen no. BSIP 35960.
8. Vendotaenid remain.

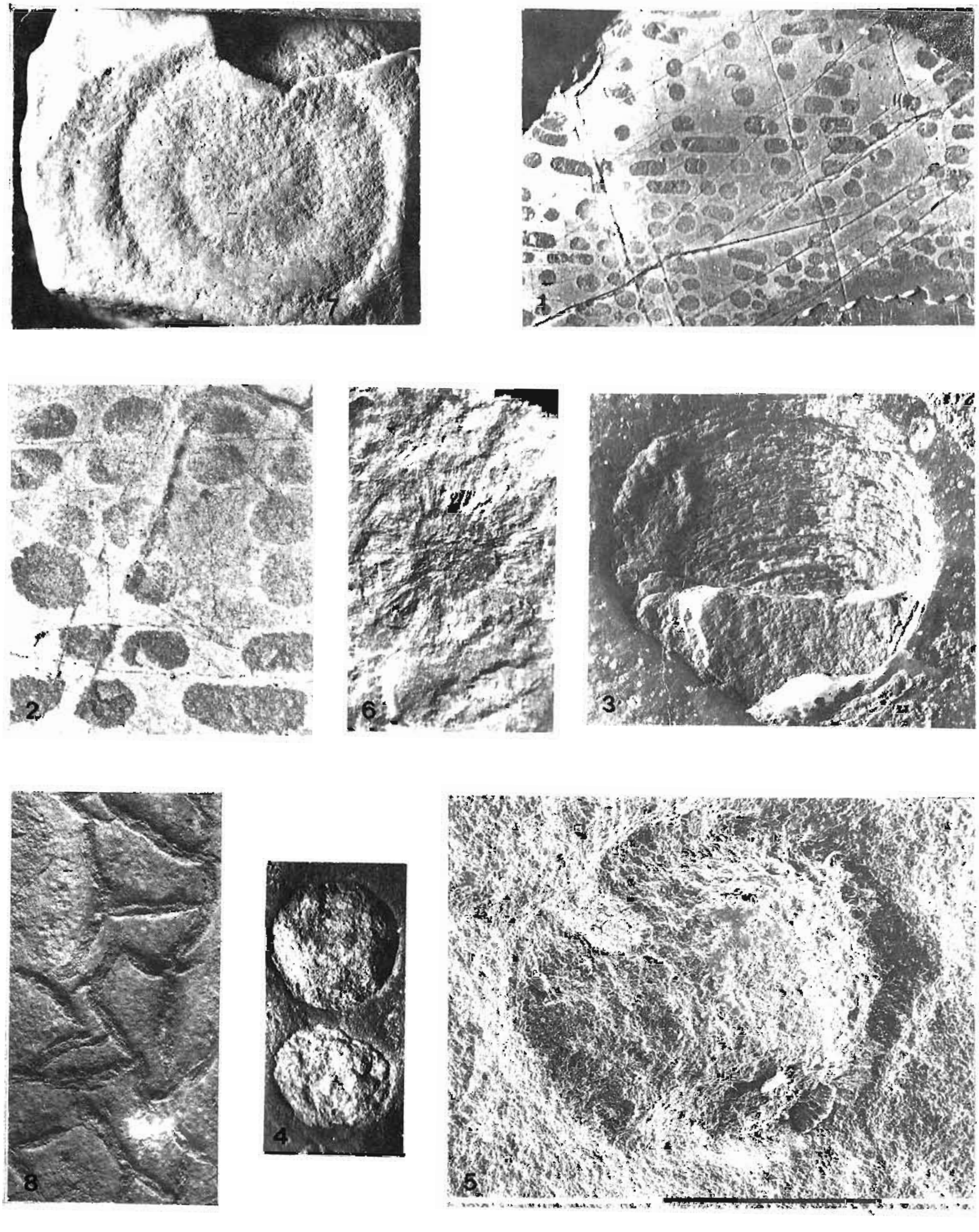

PLATE 1

area from where the thickenings radiate out up to the margin, thus resulting into a fimbriated margin. A re-examination of the specimen figured by Maithy and Shukla (1984a, pl. 1, fig.1) shows that the central area has several small globular structures, which are compactly packed together (Pl 1, fig. 4). This character raises doubts about its metazoan affinity. In all probabilities, they are vesicles with inner body similar to the encystment structures recorded by Butterfield, Knoll and Swett (1988) from the Upper Proterozoic shales of Svanbergfjellet. Similarly, the specimens of *Sekwia* described by Maithy, Narain and Sarkar (1986, fig. 1) from the Rohtas Formation of Amjhore and later by Maithy and Babu (1988, pl. 1, figs 7, 8; pl. 2, fig. 1) from Chopan, are sphaeroidal in outline, measuring 7-35 mm in diameter In all the specimens, a distinct thick central area is marked which has a number of small, closely adpressed globular structures representing the remanents of algal cells, or a large inner body (Pl 1, figs 4, 5). If it is so, then the forms in their gross organisation compare well with the large encystment structures of *Nucellosphaeridium* Timofeev 1965 obtained after digesting the rocks in acid. Another form—*Rohtasea* Singh & Chandra 1987, recently reported from the Rohtas Formation of Katni was claimed to be the remain of jelly fish. Similar looking forms have recently been collected from the Rohtas Formation of Baulia, Bihar (Pl. 1, fig. 7). The specimens show prominent concentric thickenings alongwith fine radial thickenings but no oral opening. Hence, their assignment to jelly fish is questionable; rather it converges to support for large encystment structures.

*Tawuid remains*—The forms are sausage-shaped, straight or bent with rounded extremities, surface with or without wrinkles (Pl. 1, figs 1, 2). This form in India is represented by *Tawuia dalaensis* Hofmann 1979 (Maithy & Shukla, 1984b; Maithy & Babu, 1988). The specimens of *T. dalaensis* did not show any structural details. Therefore, its biological affinity is enigmatic, though the consensus of opinion is that they might represent eucaryotic algae.

Sahni and Shrivastava (1954) and Sahni (1975) reported 'filament-like structure' associated with *Chuaria* from the Middle Proterozoic, belonging to Suket Shale Formation of Ramapura, Madhya Pradesh. These structures are sausage-shaped with rounded ends, smooth surface, measuring 5-14 mm in length and 2-5 mm in breadth. On re-examination of photographs it could be ascertained that the specimens are in no way different from that of *Tawuia dalaensis*. Similarly, Maithy (1984, pl. 1, fig. 5) reported a form from the Suket Shale Formation, Ramapura which is also identical to *Tawuia dalaensis*.

The association of *Chuaria* and *Tawuia* on the same rock has earlier been noted by Hofmann (1985a) from the Mid-Proterozoic of Little Dal, Canada, and were also recorded by Maithy and Babu (1988) from the Middle-Proterozoic of Rohtas Formation, Vindhyan Supergroup exposed at Chopan. On the basis of such *Chuaria-Tawuia* association, Hofmann (1985) speculated genetic relationship between *Chuaria* and *Tawuia* but till date it is not established.

*Vendotaenid remains*—Slender filamentous structures, generally unbranched, twisted or untwisted, smooth with striate or speckled pattern are assigned to this group. Beer (1919) reported linear, spiral impression with fine transverse partitions and rounded ends, from Rohtas Formation of Saridaner Village, Bihar. Mathur (1983) proposed a new generic name—*Spiroichnus* for the above mentioned forms and considered it to be a ichnofossil. Contrary to this, Hofmann (1985, p. 349) considered it to be slender algal filament and transferred it to *Grypania spiralis* Walter *et al.* 1976. Similar looking linear, elongate forms with fine transverse partitions were also described by Tandon and Kumar (1977, fig. 1) from the Rohtas Formation of Katni under a new name *Katnia* and considered it to be an annelid remain. Glaessner (1987) expressed doubts about the affinity of *Katnia*. He opined that they might be very large oscillatorean cyanobacteria. However, the other possibility is that they may be episodic remains of plankton-blooms or mass encystment structures or algal in nature. This view is supported by the findings of recent specimens from the Ghurma Shale, Kaimur, Upper Vindhyan of Chopan and Rohtas Limestone Formation of Murlipahar. The forms of Ghurma shales are either clustered or solitary, linear, measuring up to 50 mm in length and 2-4 mm in width with distinct transverse thickenings (Pl. 1, fig. 8). The other form from the Rohtas Formation of Murlipahar (Pl. 2, figs 1, 2) includes narrow, linear structures preserved compactly parallel to one another, measuring 30 mm in length and 3 mm in width, with rounded ends and fine transverse thickenings.

*Krishnanid remains*—The forms are oval to oblong in shape with single stipe or appendage. The genus *Krishnania* Sahni & Shrivastava 1954 was first reported from Suket Shale, Ramapura. In a recent collection, several specimens of *Krishnania* have been collected from the Rohtas Formation (Middle


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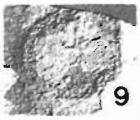
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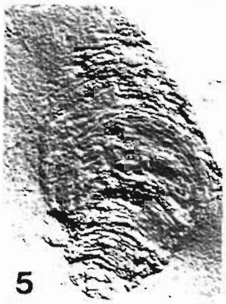
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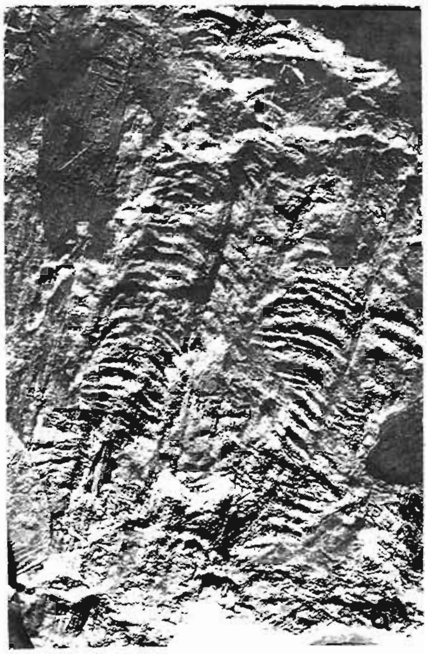
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**PLATE 2**

1, 2 Vendotaenid forms (fig 1 × 1, Specimen no BSIP 35959, fig. 2 × 4, Specimen no BSIP 35961)

3-5 Krishnanid forms (fig. 3 × 1, Specimen no. BSIP 36109, fig. 4 × 1, Specimen no BSIP 35919 fig 5 × 1, Specimen no. BSIP 36576)

6, 7 Frondoid forms (fig 6. × 1 Specimen no BSIP 36226, fig 7 × 4)

8 *Cyclomedusa* Sprigg × 1 Specimen no. BSIP 10256

9 *Medusinites* Glaessner & Wade × 1 Specimen no BSIP 10258

Proterozoic) which add new information. The body is distinctly divisible into two parts (Pl 2, figs 4, 5). The distal structure is foliate, circular-oval or elongate-oval, occasionally with a distinct border on the margin. Surface of the specimens may be smooth (Pl 2, fig. 4) or with thickenings (Pl 2, figs 4, 5). Narrow stalk-like structures emerge out from the contracted point of the 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. The length of the stalk is variable, either shorter or longer than the body size. Sometimes, they are even ten times longer than the foliate part. Small rounded structures with raised borders are preserved alongwith body fossils on the rock denoting a holding-point of the stalk with the rock.

Du (1982) proposed a new generic name *Longfengsahnia* for the forms which appear to be similar to *Krishnania* from the Proterozoic of China; probably he overlooked the earlier record of similar form. The diagnosis of *Krishnania* given by Sahni and Shrivastava (1954, p. 40) agrees in all respects with that of *Longfengsahnia*. According to Sahni and Shrivastava (1954) the fossil is accuminately ovate in shape. Its longest axis measures 7.5 mm and has maximum width of 4 mm. It narrows somewhat abruptly at one end but evenly rounded at the other. A characteristic feature of the genus is a deep marginal furrow more prominent on one side and apparently continuous all around. The figured specimens of *Krishnania* have been redrawn here in proper orientation from the photograph given by Sahni and Shrivastava (Text-fig. 1A). It is established now that three specimens are preserved overlapping each other, the middle one has a short stalk-like structure. *Krishnania* resembles *Longfengsahnia ovalis* Du & Duan 1985 in all aspects.

A 'filament showing funnel-shaped end' described by Sahni and Shrivastava (1954, p. 39, fig. 2) is 1.85 cm long and 3 mm wide which widens appreciably (6 mm across) towards one end becoming nearly funnel-shaped. The specimen shows morphological characters similar to *Longfengsahnia longipetiolata* from the Proterozoic of China. From the above discussion, it is clear that the genus *Krishnania* and *Longfengsahnia* are identical; the former name has a priority over the latter.

Rode (1946) reported *Hyolithes rohitaswei* from the Rohtas Formation of Vindhyan near Banjari. This species is identical to *Krishnania acuminata* Sahni & Shrivastava 1954. Similarly, the genera *Vindhyavasinia* Tandon & Kumar 1977 and *Vindhyania* Mathur 1982, both from the Rohtas Formation of Vindhyan, are morphologically similar to *Krishnania*. *Vindhyavasinia* was assigned to class 'Insecta' by Tandon and Kumar (1977). From a critical examination of the photograph of *Vindhyavasinia* (Tandon & Kumar, 1977; figs 2, 3) it can be concluded that it is in no way different from *Krishnania*. The figured specimen has five overlapping forms as redrawn here in Text-figure IB.

While proposing *Vindhyania*, Mathur (1982) did not provide any description except for a photograph; therefore, the proposition is invalid. However, from the photograph it can be marked that in its morphology the specimen is similar to *Krishnania (Longfengsahnia) longipetiolata* Du & Tian 1985 emended herein. Thus, *Vindhyavasinia* Tandon & Kumar, *Longfengsahnia* Du and *Vindhyania* Mathur are the junior synonyms of *Krishnania* Sahni & Shrivastava 1954.

Sahni and Shrivastava (1954) opined that *Krishnania* in its general outline resembles *Lingula*. But they considered this similarity to be a superficial one. Further, they opined that the 'Filaments showing funnel-shaped end' found associated with *Krishnania* were the remanant of plants, possibly algae. This has been supported by the recent collection in which all specimens are preserved in unidirectional position alongwith the attachment point of stalk. *Krishnania* also resembles Devonian algae *Drydenia* reported from the marine sediment of New York by Fry and Banks (1955). *Drydenia* has elliptical laminae (8.5 cm long) attached to a narrow stipe and terminating to a branching holdfast. *Krishnania* differs only in being smaller in size. *Drydenia* has been described by Taylor (1981) under Rhodophyta whereas Stewart (1981) considered it to be a member of Phaeophyta. *Krishnania* has been considered by Du and Tian (1985) to be algal in nature, either belonging to Phaeophyta or Chlorophyta. According to them, the apical foliate-part was used for photosynthesis and the basal part, the parastem, for the support attached to rhizome. Because of its clustered appearance Hofmann (1985) opined that it could be a colony of complex organisms, possibly algae of phaeophytic or rhodophytic affinity. Recent collections from Vindhyan support the view putforth by Hofmann (1985) that they were photosynthetic carbonaceous organisms possibly belonging to Phaeophyta or Rhodophyta. They were probably growing in a shallow, shelf-like marine setting and were attached to the soil by narrow stalk-like endings. Concomitant with the attainment of this level of organisation, i.e., the development of holdfasts, the anchoring devices that enabled the organisms to resist the wave action made them suitable to remain in favourable habitat. Further, the bilateral symmetry for standing upright from the ground was advantageous for absorbing the sunlight and gaseous exchange in open atmosphere. This organisation is more advance than the free-floating ones where the absorption of sunlight is only on one exposed surface. The organisms have also developed well-oriented anterior and posterior sides.

*Frondoid remains*—From the beds of Rohtas

Formation (Middle Proterozoic) several specimens have been recorded with a median stalk and alternately attached, finely segmented lateral structures (Pl. 2, figs 6, 7; Text-fig. 2) These structures, however, in their overall morphology are similar to the Petalonamid form—*Pteridinium* Gürich 1930 recorded from Vendian. However, in these forms the presence of characteristic structure of Petalonameae, i.e., autozoids and scyphozoids are not marked. Therefore, their coelenterate nature remains doubtful. The possibility of their being algae seems to be more justifiable. The forms show resemblance to the members of Rhodophyceae, viz., Rhodomelaceae, Ceramiaceae and Chlorophyceae—(*Caulerpa*).

## EDIACARAN MEGAFOSSILS (± 600 Ma)

A distinct, soft-bodied, marine metazoan fauna—the Ediacaran fauna, exists below the Tommotian Stage and above the Infra-Cambrian glaciation in many parts of the world, viz., Australia, South Africa, Brazil, China, Russia, Sweden, United Kingdom and Canada. This fauna is characterised by the absence of shelly fossils of the Cambrian, and is represented by coelenterates, annelids and arthropods. Uptill now, the Ediacaran fauna was not known from India. During a recent field work, Ediacaran remains have been found for the first time in India from the Dholpur Shales, Bhander Group representing the youngest bed of the Vindhyan. The recorded forms are *Ediacaria flindersi* Sprigg 1947, *Cyclomedusa davidi* Sprigg 1947 (Pl. 2, fig. 8), *Medusinites* Glaessner & Wade 1966 (Pl 2, fig. 9) and *Dickinsonia elongata* Glaessner & Wade 1966. The assemblage has forms belonging to medusoids and bottom-dweller annelids.

## MICROBIOTA

Maithy *et al.* (1983, pl. 1, fig. 18; pl. 2, fig. 25) reported '?fungal body' as large bulbous structures attenuated to a particular point which is further drawn to a aseptate filamentous structure. These organic-walled structures because of their marked asymmetry and pliant walls resemble germinating zoospores of filamentous protists. Modern analogous to this are known among Xanthophycean algae *Protosiphon* Klebs 1896 or *Vaucheria* Heidiniger 1908.

The thick-walled vasiform microfossils (Melanocyrillids) ranging in size from 30-200 $\mu$m are known from Vindhyan Supergroup (Salujha *et al.*, 1971a, 1971b; Maithy & Babu, 1989), Kurnools (Salujha *et al.*, 1972) and Satpuli (Nautiyal, 1982). Although, vase-shaped microfossils are considered as encystment stages of algae (Bloesser, 1985), they resemble Tintinnids and Chitinozoans, therefore, possibly they are protozoans and early protistan heterotrophs.

## CONCLUSION

From the analysis of the known biological records from Proterozoic successions of India, it is evident that well-known metazoan forms are recorded towards the close of Late Proterozoic. The claim for the finds of metazoan during 800-1,000 Ma is doubtful. In all probability, the ?Coelenterates (jelly fishes) are large carbonaceous discs with an inner body. However, the fossil record indicates that the biological remains had attained different morphological configuration as well as habitat. Both planktonic and benthic forms are known In benthic forms, epibiont habitat has been exhibited in 'Krishnanid forms' and flat floating habitat prevailed in 'Frondoid forms'. The planktonic remains are radial in symmetry while the benthic ones show bilateral symmetry. The benthic metaphytes would have occurred in shallow shelf-like, presumably marine, setting. The development of hold-fast, an anchoring device, enabled metaphytes to resist dislodgement by wave action, and the group remained in favourable habitat. It can be concluded from the known data that the seas before the Precambrian glaciation were well-populated by diverse assemblages of relatively advanced metaphytes which were well-adapted to the agitated shallow-water environment. This environment was favourable and thus helped the evolution of metazoan during Late Proterozoic times.

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# Upper Proterozoic microfossils from the Infra Krol sediments, Nainital Synform, Kumaon Himalaya, India

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Venkatachala, B. S., Shukla, Manoj, Bansal, Rajendra & Acharyya, S. K. 1990. Upper Proterozoic microfossils from the Infra Krol sediments, Nainital Synform, Kumaon Himalaya, India. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 29-38.

Thin sections of cherty nodules, occurring within the dark grey to black carbonaceous slates of Infra Krol sediments from Nainital Synform of Kumaon Himalaya, India show abundant microfossils. These are attributed to *Gunflintia minuta, Eomycetopsis robusta, Palaeolyngbya barghoorniana, Siphonophycus kestron. Animikiea septata, Myxococcoides minor, Palaeoanacystis vulgaris, Huroniospora psilata, Eosphaera* sp., *Sphaeranasillos irregularis, Melanocyrillium* sp. (vase-shaped microfossils) and associated unnamed Form "A" They are distributed randomly in the matrix containing a large amount of dispersed organic matter which imparts brown to dark brown colour to the chert matrix. The fossiliferous nodules may have been transported and redeposited along with the Infra Krol slates. The vase-shaped microfossils indicate possibility of Upper Riphean-Lower Vendian age for this assemblage. The age of Infra Krol sediments may be younger.

**Key-words**—Microfossils, Infra Krol, Lesser Himalaya, Upper Proterozoic (India).

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## साराँश

### कुमायुं हिमालय (भारत) में नैनीताल अभिनत रूप के निम्न क्रोल अवसादों से उपरि प्राग्जीवी सूक्ष्म-जीवाश्म

बेंगलूर श्रीनिवासा वेंकटाचाला, मनोज शुक्ला, राजेन्द्र बन्सल एवं ऍस० के० आचार्य

भारत में कुमायुं हिमालय के नैनीताल अभिनत रूप से निम्न क्रोल अवसादों के गहरे भूरे अथवा काले कार्बनी स्लेटों में मिलने वाले रामसैकाश्मों की पतली काटों में सूक्ष्मजीवाश्म प्रचुर मात्रा में मिले हैं। इन्हें **गनफ्लिंशिआ माइन्यूटा, ईओमाइसिटॉप्सिस रोबस्टा, पेलियोलिंगबिआ बार्घूनियाना, साइफ़ोनोफ़ाइकस केस्ट्रॉन, एनिमिकिया सैप्टेटा, मिक्सोकोकॉयडिस माइनर, पेलियोऍनासिस्टिस वुल्गेरिस, ह्यूरोनिओस्पोरा साइलेटा, ईओस्फ़ेयरा** जाति, **स्फ़ेयरानासिलॉस इर्रेगुलेरिस, मिलेनोसाइरिल्लियम** जाति एवं सहयुक्त प्ररूप ए० नाम दिये गये हैं। ये विकीरित कार्बनिक पदार्थ में अविन्यस्त बिखरे हुए मिलते हैं, जिसके कारण रामसैकाश्मों का रंग भूरे से गहरे भूरे रंग का हो गया है। उक्त जीवाश्ममय ग्रंथिकायें अन्य स्थान से आकर निम्न क्रोल स्लेटों के साथ पुनःनिक्षेपित हो गई हैं। ये जीवाश्म इस समुच्चय की सम्भवतया उपरि रिफियन-अधरि वेन्डियन आयु इंगित करते हैं। निम्न क्रोल की आयु और कम हो सकती है।

KROL BELT is a 3,000 meter thick sedimentary sequence of limestones, dolomites, shales, slates and nodular cherts on the southern margin of Lesser Himalaya. The age of this sequence has been controversial. A Palaeozoic-Mesozoic age for the Blaini-Infra Krol-Krol-Tal sequence was initially assigned on the basis of correlation of Blaini conglomerate with the Late Palaeozoic basal Gondwana conglomerate (=Talchir Boulder Bed) (Oldham, 1888). The occurrence of Late Mesozoic fossiliferous bed at the top of Tal Formation (Shrivastava, 1972; Bhatia, 1980), the records of Late Palaeozoic microflora (Sitholey *et al.*, 1954; Lakhanpal *et al.*, 1958; Sah *et al.*, 1968; Tewari & Singh, 1979) and a solitary Permian brachiopod, *Linoproductus* (Valdiya, 1980) from the Krol Formation lent further support to this view. However, recent palaeobiological evidences, viz., well-preserved microfossils from Blaini (Tewari, 1988a) indicate an Upper Riphean age

**Table 1—Fossil log of Krol Belt**

| FORMATION | MEMBER | MICRO - AND MACROBIOTA | | LEBENSPURREN | AGE | REFERENCE |
|---|---|---|---|---|---|---|
| | | PLANTAE | ANIMALIA | | | |
| TAL | PHULCHATTI QUARTZITE MEMBER | | BRACHIOPOD | | LENIAN | Tripathi et al. 1984 |
| | CALCAREOUS MEMBER | | BRACHIOPOD<br>GASTROPOD<br>HYOLITHS<br>CHANCELLORIIDS | TAPHRHELMINTHOPSIS | ATDABANIAN | Kumar et al., 1983 1987 |
| | ARENACEOUS MEMBER | | CHANCELLORIIDS<br>POLYMERID TRILOBITE | SKOLITHOS<br>PLAGIOGMUS<br>PHYCODES | | Singh & Rai 1983<br>Rai & Singh, 1983<br>Singh et al. 1984<br>Kumar et al., 1987 |
| | ARGILLACEOUS MEMBER | | | SMALL VERTICAL BURROWS | | |
| | CHERT - PHOSPHORITE MEMBER | | CONODONTS & SMALL SHELLY FOSSILS | | TOMMOTIAN | Azmi et al. 1981<br>Azmi et al., 1983<br>Bhatt et al., 1983, 1985 |
| KROL | E | EPIPHYTON<br>RENALCIS | ? ARCHAEOCYATHA<br>KORGAICYATHA | | UPPER VENDIAN | Singh & Rai, 1983<br>Singh & Rai, 1984<br>Tewari & Ghosh, 1986 |
| | D | | | PHOSPHATIC TUBES & ROUND FORMS | | Singh & Rai, 1983 |
| | C | | | SMALL VERTICAL BURROWS<br>WORM TUBES | | Singh & Rai, 1983 |
| | B | CALCAREOUS ALGAE | | | MIDDLE VENDIAN | Gansser, 1974 |
| | A | VENDOTAENIDES (BROWN ALGAE) | | | | Tewari, 1988b |
| INFRAKROL | | GUNFLINTIA<br>EOMYCETOPSIS<br>PALAEOLYNGBYA<br>SIPHONOPHYCUS<br>ANIMIKIEA<br>MYXOCOCCOIDES<br>PALAEOANACYSTIS<br>EOSPHAERA<br>VSMs | PROBLEMATICA | | LOWER VENDIAN | Acharyya et al., 1989<br>Venkatachala et al., 1988 (This ms) |
| BLAINI | | TRACHYSPHAERIDIUM<br>ALGAL MAT<br>PROTOSPHAERIDIUM<br>SYMPLASSOSPHAERIDUM | | | UPPERMOST RIPHEAN TO LOWER VENDIAN | Tewari, 1988 a |
| NAGTHAT FORMATION | | | | | | |

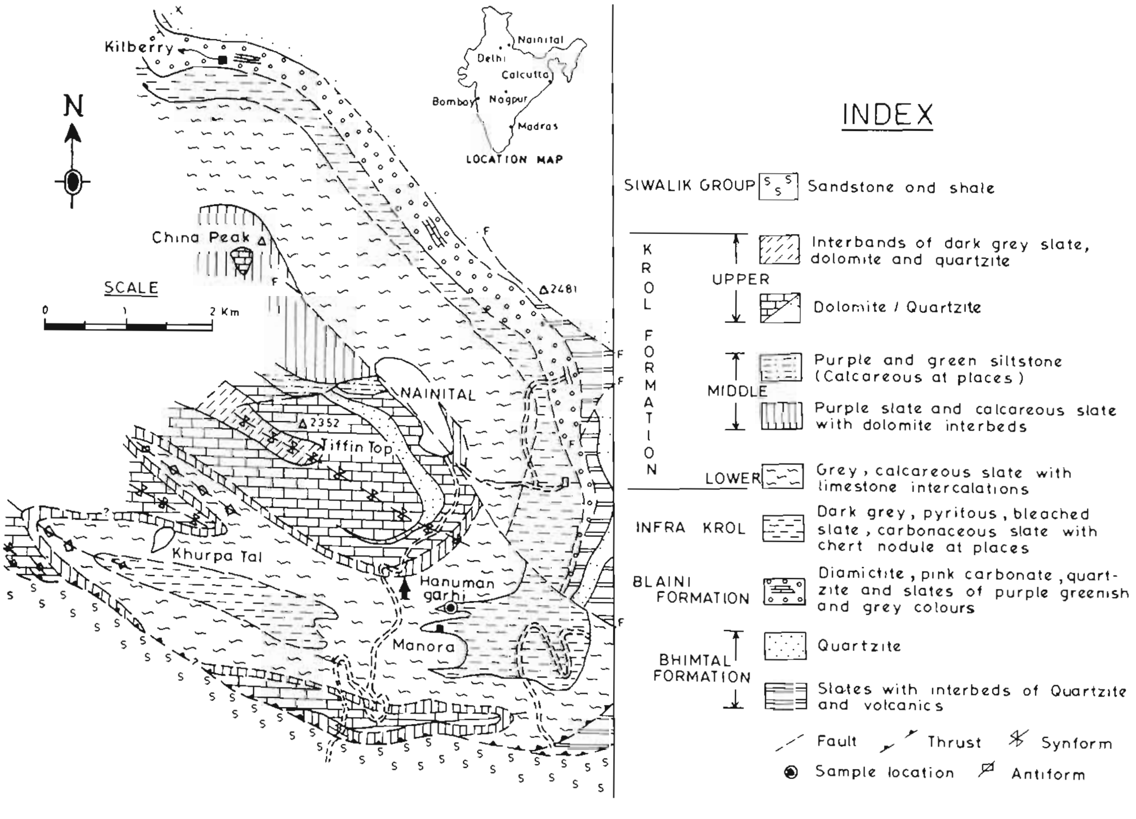
Vendotaenides (Tewari, 1988b) from the Lower Krol Formation, Archaeocyatha (Singh & Rai, 1984) and ediacaran fossils (Mathur & Shankar, 1989) from the Upper Krol Formation show Vendian age for the Krol Formation. The presence of shelly Tommotian fauna (Azmi, 1983; Azmi *et al.*, 1981; Bhatt *et al.*, 1983, 1985) and stromatolites (Tewari, 1984) from the Chert-Phosphorite Member, Trilobites (Rai & Singh, 1983; Joshi *et al.*, 1989) and brachiopods (Mathur & Joshi, 1989) from the Arenaceous Member, stromatolites (Tewari *et al.*, 1988) and brachiopods (Tripathi *et al.*, 1984) in the Phulchatti Quartzite Member indicates a Lower Cambrian age for the Tal Formation (Table 1). The palaeobiological evidences from the Infra Krol sequence are important to afford logical support to date the lower limit of the Krol Formation.

The present paper concerns with thin-section studies detailing the morphology, taxonomy and affinities of the biota. An attempt has also been made to compare Infra Krol assemblage with well documented assemblages of the world and to infer the age of the Infra Krol sequence.

## GEOLOGY OF THE AREA

The Blaini-Infra Krol-Krol-Tal sequence forms a persistent litho-stratigraphic unit in the Krol Belt of Himalaya. In the Nainital area (29°25′ : 75°28′), an undisturbed stratigraphic succession from Infra Krol to Upper Krol succession is present from Manora to Tiffin Top section. According to Acharyya *et al.* (1989), the stratigraphic contact between the Blaini and Infra Krol sequence is not clear owing to structural complications. The Infra Krol sequence is constituted of bleached pyritiferous slates. It conformably grades upwards into Lower Krol succession constituted by marl, calcareous slates and limestones. The contact between the Lower Krol and overlying Middle Krol sequence is gradational; middle Krol consists of purple-green and grey slates and calcareous siltstones with dolomite beds and conformably grades upwards into the Upper Krol carbonate near Hanumangarhi. In Kailakhan area and on the Manora-Hanumangarhi mule-track, bleached pyritiferous slates of the Infra Krol thicken in outcrop. On this mule-track a thin bed of black slate with black chert nodules is exposed which form material for the present study. They have been collected by one of us (SKA) from about 250 m north of Manora Village towards Hanumangarhi. The black slates are exposed in a narrow wedge of about 3 m width at this point (Text-fig. 1).

The fossiliferous chert nodules form a minor constituent of the bulk lithology which is made up of black slates. The nodules measure about 2-3 cm in thickness and are slightly compressed along the plane of bed, though they themselves do not form any bedding. Their surface is polished and shows concoidal fractures. It is apparent that these nodules may have been transported and redeposited with black slates of Infra Krol sediments which have been attributed to shallow lagoonal environment (Bhargava & Singh, 1981; Singh, 1981). Microbiota and few broken parts of algal mats are seen randomly distributed in the cryptocrystalline to amorphous matrix. The dispersed organic matter imparts a brown to dark brown colour to the chert



**Text-figure 1**—Geological map of the area around Nainital, Uttar Pradesh.

matrix. However, Acharyya *et al.* (1989) have observed well-preserved mat structures with preferred orientation in thin sections of these chert nodules. This has led them to conclude that the area mainly represents progressive trapping of superficial microorganisms in abiogenic shales and these microfossils must have been later replaced by silica.

## TAXONOMIC AFFINITIES

The microfossils are organically preserved They have been studied in petrographic thin-sections. The highly diagenised nature imposes some limitations on assigning taxonomic affinities. The assemblage is dominated by hollow sheaths and cell envelopes.

The slides have been deposited in the Museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

### Genus—*Gunflintia* Barghoorn & Tyler 1965

*Gunflintia minuta* Barghoorn & Tyler 1965
Pl. 1, fig. 6

*Description*—Filaments multicellular, unbranched, uniseriate, straight or slightly curved, septa indistinct and occasionally variably spaced. Surface texture granular. Filament width 3 to 5 μm, $\tilde{g} = 3.8$ μm (n = 12, see Text-fig. 2). Maximum filament length observed 120 μm (incomplete filament).

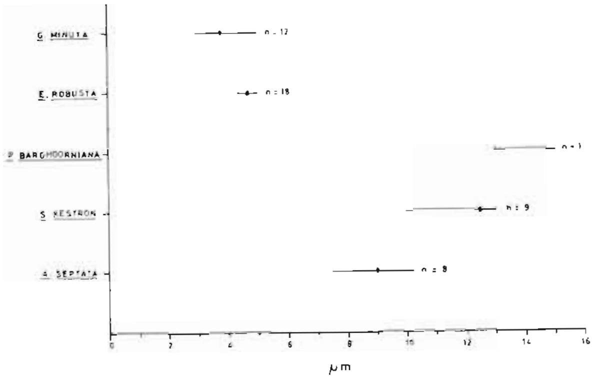
*Remarks*—Few forms with ill-defined septa and variable cell lengths have also been included here. They may be diagenetically altered forms.

### Genus—*Eomycetopsis* Schopf 1968

*Eomycetopsis robusta* Schopf 1968
Pl. 1, figs 1, 2

*Description*—Filaments unbranched, tubular, non-septate, occasionally in entangled mesh (Pl. 1, fig. 1), surface texture granular. Filament width 4.4 to 5.0 μm, $\tilde{g} = 4.7$ (n = 18, see Text-fig. 2). Maximum filament length observed 80 μm (incomplete filament).

*Remarks*—The Infra Krol microfossils have larger width.



**Text-figure 2**—Comparative graph of size variation of filamentous cyanobacteria.

### Genus—*Palaeolyngbya* Schopf 1968

*Palaeolyngbya barghoorniana* Schopf 1968
Pl. 1, fig. 4

*Description*—Filament solitary, multicellular, unbranched, uniseriate, constricted at septa, apex rounded, cross walls distinct, evenly spaced, surface texture granular. Cells discoid, 4.5 to 5.0 μm long and 13.00 to 15.00 μm wide (only one specimen observed).

*Remarks*—The solitary filament described here is comparable to *P. barghoorniana* Schopf 1968 in overall morphology. However, the specimen is larger in size and the sheath is not preserved.

### Genus—*Siphonophycus* Schopf 1968

*Siphonophycus kestron* Schopf 1968
Pl. 1, fig. 3

*Description*—Solitary, unbranched, tubular, non-septate, tapers towards rounded apex. Surface texture granular. Filament width 10-13 μm, $\tilde{g} = 12.5$

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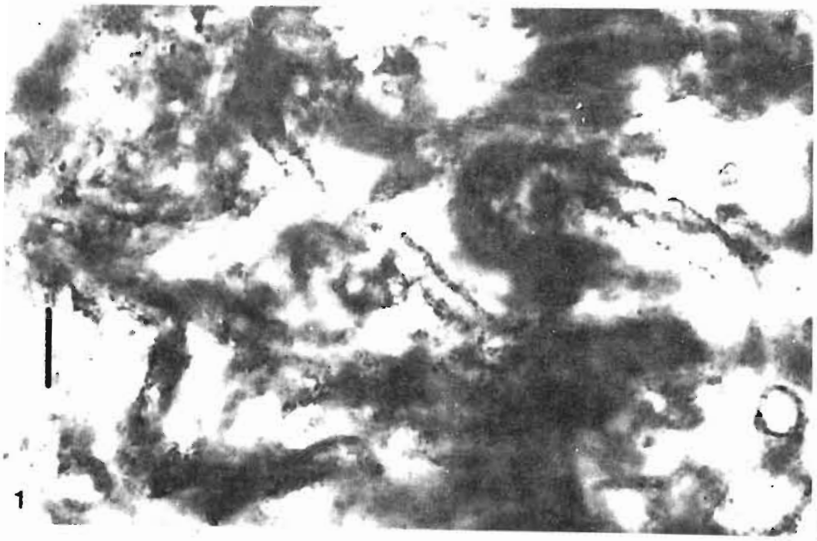
→

## PLATE 1

Bar = 10 μm

1, 2. *Eomycetopsis robusta*, Slide no. BSIP 10260.
3. *Siphonophycus kestron*, Slide no. BSIP 10258.
4. *Palaeolyngbya barghoorniana*, Slide no. BSIP 10261.
5, 12, 14. *Incertae sedis*, Unnamed Form 'A', Slide no. BSIP 10258.
6. *Gunflintia minuta*, Slide no. BSIP 10260.
7 *Melanocyrillium* sp., Slide no. BSIP 10261.
8. *Animikiea septata*, Slide no. BSIP 10258.
9. *Huroniospora psilata*, Slide no. BSIP 10258.
10. *Eosphaera* sp., Slide no. BSIP 10258.
11 *Myxococcoides minor*, Slide no. BSIP 10261.
13. *Palaeoanacystis vulgaris*, Slide no. BSIP 10258.
15, 16. *Sphaeranasillos irregularis*, Slide nos. BSIP 10259, 10261.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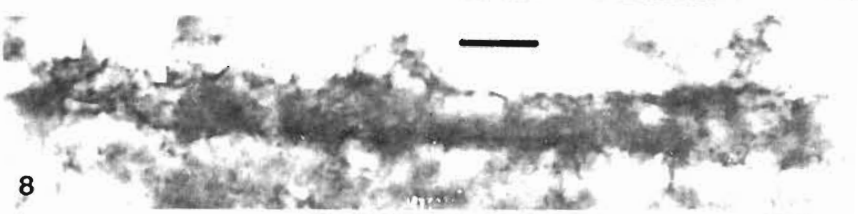
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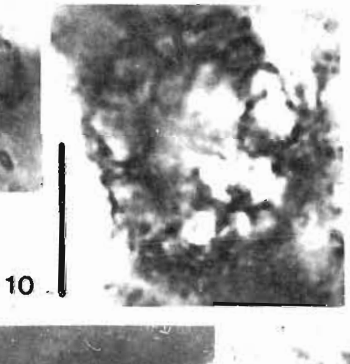
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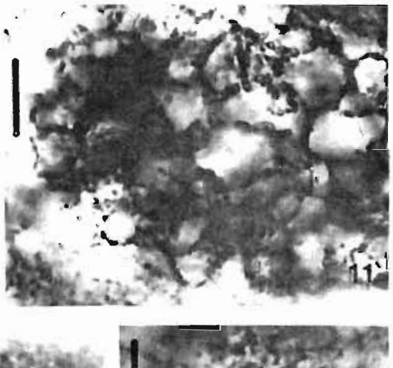
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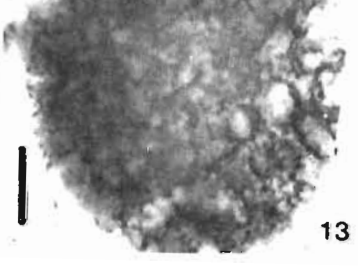
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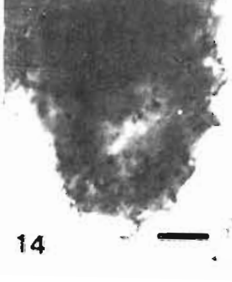
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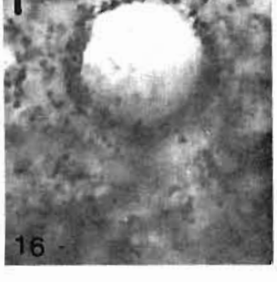
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PLATE 1

μm (n = 9, see Text-fig. 2). Maximum length observed 90 μm (incomplete specimen).

*Remarks*—The microfossils described here have smaller average width and granular surface texture. The granular texture may be due to diagenetic alteration.

### Genus—*Animikiea* Barghoorn & Tyler 1965

*Animikiea septata* Barghoorn & Tyler 1965
Pl. 1, fig. 8

*Description*—Filaments unbranched, straight or slightly curved, multicellular with indistinct septa. Filament diameter 7.5 to 10.2 μm wide, g̃ = 9.0 μm (n = 8, see Text-fig. 2).

*Remarks*—These microfossils do not show distinct septa due to diagenesis.

### Genus—*Myxococcoides* Schopf 1968

*Myxococcoides minor* Schopf 1968
Pl. 1, fig. 11

*Description*—Cells spherical or ellipsoidal, clumped in globular colonies composed of few to many cells, occasionally distorted due to mutual compression. Surface texture psilate to finely granular. Sheaths around individual cells absent. Individual cell diameter 9.0 to 12.0 μm, g̃ = 11.0 μm (n = 178, see Text-fig. 3).

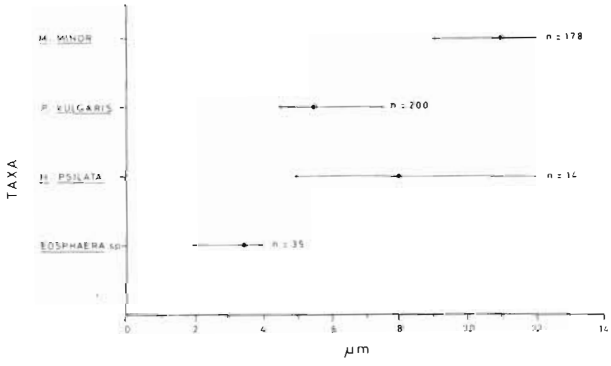
*Remarks*—The microfossils here have larger individual cells. They are distorted perhaps due to diagenetic alteration.

### Genus—*Palaeoanacystis* Schopf 1968

*Palaeoanacystis vulgaris* Schopf 1968
Pl. 1, fig. 13

*Description*—Cells spheroidal, clumped in spherical to oval colonies, composed of 100 to 125 cells. Surface texture psilate, cells distorted due to mutual compression. Cell diameter 4.5 to 7.5 μm, g̃ = 5.5 μm (n = 200, see Text-fig. 3).

*Remarks*—The colonies have smaller number of cells which are larger in size as compared to similar forms from Bitter Springs Formation (Schopf, 1968).



**Text-figure 3**—Comparative graph of size variation of coccoidal cyanobacteria.

### Genus—*Huroniospora* Barghoorn & Tyler 1965

*Huroniospora psilata* Barghoorn & Tyler 1965
Pl. 1, fig. 9

*Description*—Cells solitary, spherical to oval, psilate, cell size 5 to 12 μm, g̃ = 8 μm (n = 14 see Text-fig. 3).

### Genus—*Eosphaera* Barghoorn & Tyler 1965

*Eosphaera tyleri* Barghoorn & Tyler 1965
*Eosphaera* sp. Barghoorn & Tyler 1965
Pl. 1, fig. 10

*Description*—Hollow sphaeroidal colony with outer ring formed by granular cells. Diameter of inner sphere 8-10 μm and outer 15 to 18 μm. Individual cells 2 to 4 μm, g̃ = 3.5 μm (n = 35, see Text-fig. 3).

*Remarks*—These microfossils are distorted due to diagenetic alterations, but morphologically resemble hollow globular colonies of the chroococcacean cyanophytes.

### Genus—*Sphaeranasillos* Allison & Awramik 1989

*Sphaeranasillos irregularis* Allison & Awramik 1989
Pl. 1, figs 15, 16

*Description*—Round, solitary, cell-like body, surface double-walled, walls distinct with spinose or pyramidal projections. Surface projections irregularly distributed. Texture granular. Size 28-30 μm in diameter. Projections 4-8 μm in height.

*Remarks*—The forms described here morphologically compare with the form from the earliest Cambrian or latest Proterozoic Tindir Group, Yukon Territory, Canada (Allison & Awramik, 1989). However, the forms described are larger in size.

### Genus—*Melanocyrillium* Bloeser 1985

*Melanocyrillium* sp. Bloeser 1985
Pl. 1, fig. 7

*Description*—Greyish black to black, flask or vase-shaped vesicles, base rounded, body tapers towards apex, wall apparently rigid permitting undistorted preservation of shape. Size 45 to 80 μm long. Maximum cross sectional diameter 20 to 35 μm.

*Remarks*—These forms morphologically compare with the vase-shaped microfossils from Kwagunt Formation, Chuar Group, Arizona (Bloeser, 1985). However, they do not show the characteristic excystment pore (pylome) mostly seen in SEM studies.

## INCERTAE SEDIS

### Unnamed Form 'A'

Pl. 1, figs 5, 12, 14

*Description*—Solitary, unbranched, hollow cylindrical, straight or slightly curved, tubular, tapering towards apices. With single or multichambered (?cellular) margin, texture microgranular. Microfossils 120 to 180 μm long and 20 to 40 μm broad, marginal cells 3 to 5 μm in size.

*Remarks*—On the basis of morphology the form depicted in Pl. 1, fig. 14 resembles *Eosphaera* sp., a hollow globular colonial form. However, on change of focus, the circular arrangement of cells project unidirectionally in a linear manner. It perhaps represents cross section of the horizontally inclined tubular sheath (Pl. 1, figs 5, 12) with thick margins.

## DISCUSSION

Forms attributed to *Gunflintia* and *Eomycetopsis* have more or less overlapping size ranges and hence it is probable that the *Eomycetopsis* sheaths are envelopes left by *Gunflintia* like trichome (see Comparative graph for size-variation of filaments: Text-fig. 2). *Gunflintia* like trichomes and *Eomycetopsis* type of sheaths are morphologically comparable to extant cyanobacteria belonging to the Family Oscillatoriaceae (Hofmann, 1976; Knoll & Golubic, 1979). *Animikiea* is morphologically comparable to *Oscillatoria* and *Lyngbya* (Barghoorn & Tyler, 1965). A solitary specimen of *Palaeolyngbya* recorded here and sheaths attributed to *Siphonophycus* apparently represent fossilised trichomes and sheath of *Oscillatoria* and *Lyngbya* respectively (Schopf, 1968). They also show overlapping size ranges in the Infra Krol assemblage. The coccoid unicells referred here as *Huroniospora* has cell sizes comparable to both *Palaeoanacystis* and *Myxococcoides* (see Comparative graph for size variation of coccoids: Text-fig. 3), and may represent detached cells from crushed colonies. Hollow spherical colonies of *Eosphaera* have been compared with extant genera *Gomphosphaeria* and *Coelosphaerium* (Golubic & Barghoorn, 1977). *Myxococcoides* and *Palaeoanacystis* are the two colonial forms which occur as solid globular colonies and have been compared with extant chroococcacean genus *Anacystis* (Golubic & Barghoorn, 1977).

The round cell-like forms with spinose projections have been assigned to *Sphaeranasillos irregularis* of unknown affinity. The vase-shaped organic structures here refered to *Melanocyrillium* have been compared with Palaeozoic chitinozoans (Bloeser *et al.*, 1977) and chitinozoan-like microfossils (Vidal, 1979; Binda & Bokhari, 1980). Another more plausible comparison has been given by Fairchild *et al.* (1978), who considers these as unequivocal evidence of heterotrophic protists, a group about which very little is known.

The Unnamed Form 'A', with single to multichambered (?cellular) margin resembles the diploblastic stage in the ontogenic phase of the cnidarians. The Cnidarians are the most primitive and presumably the oldest of all the metazoan phyla. They are generally triploblastic but they pass through a diploblastic stage in their ontogenic development. It is quite possible that this diploblastic stage, sometimes in the evolutionary history of that phylum, could have been a free living form. Diploblastic forms refered to as Unnamed Form 'A' could represent precursors of Cnidarians.

The Infra Krol assemblage is predominantly constituted by filamentous and coccoid cyanophytes which are not helpful as specific age indicators. However, the presence of vase-shaped microfossils help tentatively to deduce the age of the Infra Krol microbiota. These vase-shaped organic structures are recorded to appear at the end of Riphean and extend into Vendian.

The present microfossil assemblage from the Infra Krol also compares well with the records from Suket Shale Formation (Maithy & Shukla, 1977), Gangolihat Dolomite (Nautiyal, 1980), Ujhani Deep Well, Ganga Basin (Maithy *et al.*, 1983), Kheinjua Formation (McMenamin *et al.*, 1983), Deoban Formation (Shukla *et al.*, 1987), Rohtas Formation (Venkatachala *et al.*, in press) of India; Doushantuo Formation, China (Zhang, 1985), Yudoma Suite, USSR (Lo, 1980), Bitter Springs Formation (Schopf, 1968), Amelia Dolomite (Muir, 1976), H.Y.C. Pyritic Shale (Oehler, 1977), Balbirini Dolomite (Oehler, 1978) of Australia, Hecla Hoek Sequence, Svalbard (Knoll, 1982a), Draken Conglomerate (Knoll, 1982b) of Europe and Tindir Group (Allison & Awramik, 1989) of Canada. But many other genera of both coccoid and filamentous cyanobacteria as well as Acritarchs recorded in these assemblages are not found in the Infra Krol assemblage (see Table 2). The assemblage recorded from Dismal Lakes Group, Canada (Horodyski & Donaldson, 1980), Hailuoto

**Table 2—Comparison of Infra Krol microfossils with other assemblages of the world**

| Infra Krol genera / Other Areas | *Gunflintia* | *Eomycetopsis* | *Palaeolyngbya* | *Siphonophycus* | *Animikiea* | *Myxococcoides* | *Palaeoanacystis* | *Huroniospora* | *Eosphaera* | *Sphaeranasillos* | V.S.M.'s |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Deoban Formation, India | + | + |  | + | + | + |  |  |  |  | + |
| Rohtas Formation, India |  | + |  | + |  | + | + | + |  |  |  |
| Kheinjua Formation, India | + | + |  |  |  | + |  |  |  |  |  |
| Gangolihat Dolomite, India |  | + |  | + |  | + |  |  |  |  |  |
| Suket Shale, India |  | + |  |  |  | + | + |  |  |  |  |
| Ujhani deep well, Ganga Basin, India | + |  |  |  |  | + | + |  |  |  |  |
| Hecla Hoek sequence, Svalbard |  | + |  | + |  | + |  |  |  |  | + |
| Visingso$^{3}$ beds, Sweden |  |  |  |  |  |  |  |  |  |  | + |
| Draken conglomerate, Svalbard |  | + |  | + |  | + |  |  |  |  |  |
| Hailuoto Area, Finland |  |  | + |  |  |  |  |  |  |  |  |
| Amelia Dolomite, Australia | + |  |  |  |  | + | + | + |  |  |  |
| Bitter Springs Formation, Australia |  | + | + | + |  | + | + |  |  |  |  |
| Dismal lakes group, Canada |  |  |  |  |  | + |  |  |  |  |  |
| Balbirini Dolomite, Australia |  | + | + | + |  | + | + |  |  |  |  |
| HYC pyritic shale, Australia | + |  |  |  |  | + |  | + |  |  |  |
| Yudoma suite, USSR |  | + |  |  |  | + |  |  | + |  |  |
| Doushantuo Formation, China | + | + | + | + |  | + |  | + |  |  |  |
| Tindir Group, Canada |  | + | + | + |  | + | + |  |  | + |  |

area, Finland (Tynni & Donner, 1980) and Visingsö beds, Sweden (Knoll & Vidal, 1980) differs from the Infra Krol assemblage in the absence of all Infra Krol genera except for *Myxococcoides* in Dismal Lakes Group, *Palaeolyngbya* in Hailuoto area and the vase-shaped microfossils in Visingso beds (see Table 2). The available palaeobiological evidences from the Krol Formation (see Table 1) suggest a Vendian age for the Lower Krol sediments, thus implying a pre-Vendian or Upper Riphean-Lower Vendian age to the Infra Krol sequence. This conclusion is further substantiated by the occurrence of vase-shaped microfossils, viz., *Melanocyrillium*. Thus even if the nodules were deposited in some other environment and transported later, there must not have been a considerable time lag between their deposition, erosion and redeposition in the lagoonal site of the Infra Krol sediments.

## ACKNOWLEDGEMENTS

The authors are thankful to Mr Mukund Sharma for useful discussion. They are also thankful to Mr P. C. Roy for assistance in photography and Mr Madhukar Arvind for secretarial assistance.

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# Epidermal morphology of Permian Gondwana gymnosperms

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Tewari, Rajni 1990. Epidermal morphology of Permian Gondwana gymnosperms. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 39-42.

A review of cuticular features of species of the glossopterids reveals that most of the species from Karharbari and Barakar formations are hypostomatic while a few species in the Raniganj Formation are amphistomatic. Lateral walls of cells in species from older horizons are mostly straight, whereas, in Raniganj species they are often sinuous. Similarly, surface walls of cells of species of Karharbari Formation are mostly unspecialised, while those of Barakar and Raniganj formations may be papillate or non-papillate, striated or mottled and sometimes with epidermal hairs. In most species the stomata are anomocytic, irregularly oriented and distributed. Rarely, a regular distribution and a definite orientation is seen. In the older horizons the stomata may be dicyclic or partly amphicyclic besides monocyclic, whereas in Raniganj species they are usually monocyclic. Guard cells are mostly sunken in Karharbari species, normal and usually hyaline in Barakar species and sunken and thickened in the species of Raniganj Formation. Subsidiary cells are usually unspecialised in the species of older horizons, whereas in the Raniganj Formation they are usually papillate, invariably overhanging guard cells. No significant trend is observed in other gymnosperms.

**Key-words**—Epidermal morphology, Gymnosperms, Gondwana, Permian (India).

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## साराँश

### परमी गोंडवाना अनावृतबीजीयों की अधिचर्मीय आकारिकी

रजनी तिवारी

**ग्लॉसॉप्टेरिस** की जातियों की उपत्वचा के लक्षणों के पुनरीक्षण से व्यक्त होता है कि करहरबारी एवं बराकार शैल-समूहों की अधिकतर जातियाँ अधोरन्ध्री हैं, जबकि रानीगंज शैल-समूह में कुछ जातियों में द्विपार्श्वी रन्ध्र विद्यमान हैं। अधिक आयु के संस्तरों से उपलब्ध जातियों में कोशाओं की पार्श्व भित्तियाँ प्रायः सीधी हैं जबकि रानीगंज से प्राप्त जातियों में सामान्यतः लहरदार हैं। इसी प्रकार करहरबारी शैल-समूह की जातियों की कोशाओं की सतही भित्तियाँ किसी विशेष प्रकार की नहीं हैं, जबकि रानीगंज एवं बराकार शैल-समूहों की पैपिलामय या अपैपिलामय, धारीदार अथवा चित्तीदार और कभी-कभी अधिचर्मी रोमों से युक्त होती हैं। अधिकतर जातियों में रन्ध्र एनोमोसाइटी तथा अनियमित रूप से वितरित हैं। अधिक आयु के संस्तरों से उपलब्ध जातियों में रन्ध्र एकचक्री के अलावा द्विचक्री भी हो सकते हैं, जबकि रानीगंज की जातियों में ये प्रायः एकचक्री होते हैं। करहरबारी से उपलब्ध जातियों में द्वार-कोशायें प्रायः दबी हुई, बराकार जातियों में सामान्य एवं काचाभ तथा रानीगंज शैल-समूह की जातियों में दबी हुई एवं मोटी होती हैं। सहायक कोशायें अधिक आयु के संस्तरों में प्रायः किसी विशेष आकार की नहीं होती जबकि रानीगंज शैल-समूह में ये प्रायः पैपिलामय तथा लटकी हुई द्वार कोशाओं से युक्त होती हैं। अन्य अनावृतबीजीयों में कोई विशेष लक्षण प्रेक्षित नहीं किया गया।

THOUGH during the last three decades a vast amount of data has accrued on the epidermal morphology of gymnospermous leaves recorded from the Permian of India, yet there has been hardly an attempt to trace evolutionary aspects of this feature. Therefore, the available data needs to be collated and organised for proper understanding of the evolutionary significance, if any.

Characters which are considered important for epidermal morphology are: cuticle hypo-, epi- or amphi-stomatic; cells differentiated into vein and mesh areas or undifferentiated; anticlinal walls straight, curved, arched, undulate, sinuous, toothed or pitted; surface walls unspecialised, papillate, mottled, striated or with trichomes; orientation and distribution of stomata; guard cells sunken or normal, thickened or hyaline; subsidiary cells unspecialised or papillate.

The three major groups of Permian gymnosperms from India are: glossopterids, cordaites and conifers.

## GLOSSOPTERIDS

Cuticular features are known for the genera *Gangamopteris, Glossopteris, Palaeovittaria, Rhabdotaenia* and *Belemnopteris.* Most of the leaves from the Karharbari Formation are hypostomatic but amphistomatic leaves are also reported, e.g., *Gangamopteris cyclopteroides, G. papillosa* and *G. obtusifolia* (Pant & Singh, 1968). Most leaves of Barakar Formation too are hypostomatic except for a few species of *Glossopteris* which are amphistomatic. In the Raniganj Formation, though the hypostomatic cuticle is more common, yet amphistomatic elements are not uncommon, e.g., *Gangamopteris indica, Palaeovittaria raniganjensis, Glossopteris brongniartii, G. formosa, G. tortuosa, G. varia, G. vulgaris* (Srivastava, 1956; Pant & Verma, 1964; Pant & Gupta, 1968). Cells are usually differentiated into midrib, vein and mesh areas with a few exceptions, e.g., *Gangamopteris hispida, G. gondwanensis* and *Glossopteris pandurata* (Karharbari); *Glossopteris damudica, G. obscura, G. intermittens, G. rhabdotaenioides*—to name a few (Barakar Formation) and *Gangamopteris flexuosa, G. indica, Glossopteris arberi, G. stenoneura, G. conspicua, G. contracta, G. elongata, G. ghusikensis, G. gondwanensis, G. lanceolatus, G. oldhamii, G. radiata, G. sahnii, G. taeniopteroides, G. major, Belemnopteris sagittifolia, B. pellucida* (Raniganj—Srivastava, 1956; Pant & Gupta, 1971; Pant & Singh, 1971; Pant & Choudhury, 1977).

Although the lateral walls of cells are straight in most of the leaves, departures frequently occur, e.g., undulate to sinuous walls in *Glossopteris zeilleri* and *G. giridihensis*, pitted in *Gangamopteris cyclopteroides* and *G. hispidia* (Karharbari); straight to undulate walls in *Glossopteris pseudocommunis, G.* cf. *leptoneura* and other *Glossopteris* species (Barakar); sinuous walls in *Gangamopteris flexuosa, G.* cf. *hughesi, Glossopteris elongata, G. gondwanensis, G. harrisii, G. tenuifolia, G. waltonii, G. longifolia, G. maculata, G. oldhamii, G. sastrii, G. singularis, G. subtilis, G. transversalis, G. nautiyalii* (Pant & Gupta, 1968, 1971; Pant & Singh, 1974), *Rhabdotaenia fibrosa, R. daenioides* (Pant & Verma, 1963), *Belemnopteris sagittifolia* and *B. pellucida*; straight to arched walls in *Glossopteris brongniartii, G. stenoneura, G. petiolata, G. searsolensis, G. varia, G. vulgaris,* and pitted walls in *G. maculata* and laminated in *G. contracta* (Raniganj). Surface walls are usually unspecialised; sometimes papillae are present which may be numerous, small as in *Glossopteris angusta* or single median as in *G. giridihensis* (Pant & Gupta, 1968) or single, conical or dome-shaped as in *Gangamopteris cyclopteroides, G. papillosa, G. hispida* and *G. media* (Pant & Singh, 1968—Karharbari Formation). Single hollow, dome-shaped papillae are also present in *Glossopteris ornatus, G. intermittens* (Barakar) and in *Gangamopteris flexuosa, Glossopteris gondwanensis, G. major, G. oldhamii, G. tortuosa, G. vulgaris, G. varia, Rhabdotaenia fibrosa, R. daenioides* and *Palaeovittaria raniganjensis* (Raniganj). In the Raniganj Formation, apart from the single papilla, numerous small papillae are seen in *Glossopteris tenuifolia* and *G. waltonii.* The surface walls are mottled in *Glossopteris harrisii, Rhabdotaenia fibrosa, Belemnopteris sagittifolia* and *B. pellucida,* striated in *Glossopteris contracta* and *G. rhabdotaenioides* and with circular hair bases in *Glossopteris tenuifolia.*

The stomata are anomocytic throughout and monocyclic in majority of the leaves. Stomata are sometimes amphicyclic in the Karharbari Formation as in *Gangamopteris cyclopteroides, G. hispida, Glossopteris giridihensis,* or dicyclic—as in *G. karharbariensis.* In the Barakar Formation no exceptions are found. In the Raniganj Formation amphicyclic (*Glossopteris browniana, G. harrisii, G. major, G. petiolata*) and dicyclic (*Gangamopteris* cf. *hughesii, G. indica, Glossopteris formosa, G. tortuosa, G.* cf. *divergens*) stomata occur in few cases. Stomata are usually irregularly distributed in the Karharbari species. However, sometimes they are distributed in groups in *G. obscura* (Barakar) or in linear rows in *Gangamopteris* cf. *hughesii, Glossopteris conspicua, G. taeniopteroides* and *G. vulgaris* (Raniganj). Orientation of stomata is mostly irregular. However, in some of the members of Karharbari and Raniganj formations the stomata show a definite orientation, e.g., they are oriented longitudinally in *Gangamopteris cyclopteroides* and obliquely in *Gangamopteris papillosa* (Karharbari) and show a longitudinal orientation in *Glossopteris conspicua* and *Palaeovittaria raniganjensis* (Raniganj). Guard cells are sunken and usually thickened in the leaves of Karharbari and Raniganj formations and normal and hyaline in the species of Barakar Formation. However, they are sometimes hyaline in *Gangamopteris hispida* (Karharbari), thickened in *Glossopteris pseudocommunis* (Barakar) and normal in *Glossopteris formosa* (Raniganj).

Subsidiary cells in the leaves of Karharbari and Barakar formations are usually unspecialised, whereas those of the Raniganj Formation are usually papillate with papillae invariably overhanging the guard cells. However, papillate subsidiary cells are known to occur in *Gangamopteris cyclopteroides* of Karharbari Formation and a few Barakar species of *Glossopteris*. Unspecialised subsidiary cells are present in *Gangamopteris indica*, *G.* cf. *cyclopteroides*, *G.* cf. *hughesii*, *Glossopteris brongniartii*, *G. browniana*, *G. maculata*, *G. bengalensis*, *G. conspicua* and *G. elongata* of Raniganj Formation.

Cells of the cuticle of midrib are usually undifferentiated in most of the members throughout the Lower Gondwana. However, a few species of *Glossopteris* and *Rhabdotaenia fibrosa* show differentiation of cells into striated and non-striated areas corresponding to vein and mesh areas. Anticlinal walls of cells are usually thick and straight. However, straight to sinuous walls have been reported in *G. angusta* (Karharbari); undulate walls are present in *G. rhabdotaenioides*, *G. obscura*, *G. pseudocommunis* (Barakar) and sinuous walls have been reported in *Glossopteris arberi*, *G. contracta*, *G. tenuifolia*, *G. gondwanensis*, *G. ghusikensis*, *G. harrisii* and *Rhabdotaenia daenioides* (Raniganj). Surface walls of cells over the midrib are usually unspecialised though a single hollow, dome-shaped papilla is present in *Glossopteris angusta* (Karharbari), *G. ornatus* (Barakar) and *G. spathulata*, *G. vulgaris*, *G. contracta*, *G. major* (Raniganj). Sometimes, single-celled hair-bases are also present, as in *Glossopteris intermittens* (Barakar) and *G. subtilis* (Raniganj). In the Raniganj Formation other types of variations on cell surfaces also occur, e.g., the walls are mottled in *Glossopteris spathulata* and *Belemnopteris sagittifolia* and striated in *Glossopteris contracta*, *Rhabdotaenia daenioides* and *R. fibrosa*. Stomata, as a rule, are absent from midrib but they have been reported in some species of *Glossopteris* of Raniganj Formation, e.g., *G. varia*, *G. nautiyalii*, *G. subtilis*, *G. tenuifolia*, *G. formosa*, *G. gigas*, *G. petiolata*, *G. spathulata* and *G. waltonii* (Pant & Gupta, 1968, 1971; Pant & Singh, 1971).

## CORDAITES

Epidermal morphology is known only for the Karharbari species of the genus *Noeggerathiopsis* (Lele & Maithy, 1964; Pant & Verma, 1964). The cuticle, though usually hypostomatic, is amphistomatic in *N. bunburyana* and *N. indica*. The cells of lower surface of all the species are differentiated into vein and mesh areas whereas, those of upper surface are undifferentiated. The cell walls are straight except in *N. zeilleri* where they are flexuous and toothed. Whereas the upper surface has unspecialised cells the lower surface often has dome-shaped papillae (Pant & Verma, 1964). The stomata are anomocytic, usually monocyclic, rarely amphicyclic as in *N. fibrosa*, oriented longitudinally and distributed in longitudinal rows except in *N. gondwanensis* and *N. zeilleri* (Lele & Maithy, 1964) where they are irregularly arranged. The guard cells are sunken, usually thickened, sometimes hyaline, e.g., *N. indica*, *N. gondwanensis* and *N. zeilleri*. The subsidiary cells may be papillate (*N. papillosa*, *N. indica*, *N. gondwanensis*) or non-papillate (*N. bunburyana*, *N. fibrosa*, *N. zeilleri*) and are usually heavily cutinised.

## CONIFERS

Of the four conifer genera known, *Paranocladus* (Talchir) is amphistomatic, *Buriadia* (Karharbari) and *Walkomiella* (Barakar) are epistomatic and *Searsolia* (Raniganj; Pant & Bhatnagar, 1975) is ?hypostomatic. Anticlinal walls of cells are straight and pitted in *Buriadia* (Pant & Nautiyal, 1967) and sinuous and toothed in *Walkomiella* (Surange & Singh, 1957). In rest of the genera, they are straight. Surface walls of either one surface (*Paranocladus*, *Buriadia*, *Searsolia*) or both the surfaces (*Walkomiella*) show papillae. Sometimes epidermal hairs are present as in *Buriadia* and *Walkomiella*. Stomata in all the genera are monocyclic, sometimes incompletely amphicyclic in *Paranocladus*, usually longitudinally oriented except in *Walkomiella* where they are irregularly oriented. The stomata are distributed in wide bands in *Buriadia* and *Searsolia*. Guard cells are sunken and thickened and subsidiary cells are papillate in all the genera with papillae overhanging guard cells.

## CONCLUSIONS

The data available is insufficient to critically evaluate the evolutionary pattern in epidermal morphology of Gondwana gymnosperms. The hypostomatic cuticle, differentiated cells of laminar region, straight anticlinal walls, unspecialised surface walls, monocyclic stomata, their irregular distribution and orientation, sunken and thickened guard cells, unspecialised subsidiary cells are dominant characters and are present throughout, however, exceptions are not uncommon. Amongst the exceptions, normal and hyaline guard cells dominate over the sunken and thickened ones in the

Barakar Formation and papillate subsidiary cells are more frequent than the unspecialised ones in Raniganj Formation. Among the exceptional characters it is observed that their occurrence in older horizons, viz., Karharbari and Barakar formations, is lesser as compared to in the Raniganj Formation. This may be due to the fact that cuticular features of a larger number of genera and species are known in the Raniganj Formation. However, as an overview, it can be said that cuticle tends to be hypostomatic although a few amphistomatic species occur in Karharbari and Barakar formations, their number being larger in the Raniganj Formation. Lateral walls of cells in species from older horizons are mostly straight whereas in Raniganj they are often sinuous and pitted. Similarly, surface walls of cells of species of Karharbari Formation are mostly unspecialised (with the exception of *Noeggerathiopsis* and *Buriadia*), while those of Barakar and Raniganj formations show variations and may be papillate or non-papillate, laminated, striated, mottled and sometimes with epidermal hairs. In most species, except for those of *Noeggerathiopsis* the stomata are irregularly distributed and oriented. The leaves of Karharbari and Raniganj formations apart from monocyclic may also have dicyclic and amphicyclic stomata. The species of Barakar Formation are always monocyclic with one exception, viz., *Walkomiella* where they are partly amphicyclic. Guard cells are mostly sunken in Karharbari species, normal and hyaline in Barakar species and again sunken and thickened in the species of Raniganj Formation. The above overview clearly shows that more data is needed on epidermal morphology of Gondwana gymnosperms for tracing evolutionary tendencies.

## ACKNOWLEDGEMENTS

I am thankful to Dr Hari K. Maheshwari for critically going through the manuscript and helpful suggestions.

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# Plant fossils from upper beds of Raniganj Formation in Jharia Coalfield

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Bajpai, Usha & Tewari, Rajni 1990. Plant fossils from upper beds of Raniganj Formation in Jharia Coalfield. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 43-48.

There are three major coal seams in the Raniganj Formation of Jharia Coalfield, viz., Mahuda, Bhurungia and Lohpiti, in ascending order The main constituents of the plant fossil assemblage from the roof shale of Lohpiti Seam, that underlies the Lohpiti Sandstone Member, are the leaf *Glossopteris shailae*, the stem *Araucarioxylon kumarpurensis* and the megaspore *Noniasporites harrisii*. A similar fossil assemblage has earlier been reported from the roof shales of Kajora Seam that underlies the Kumarpur Sandstone Member of Raniganj Formation in Raniganj Coalfield. The correlatability of Lohpiti Sandstone Member with Kumarpur Sandstone Member is established.

**Key-words**—Megafossils, Raniganj Formation, Permian (India).

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## साराँश

### झरिया कोयला-क्षेत्र में रानीगंज शैल-समूह के उपरि संस्तरों से अश्मित पादप

ऊषा बाजपेयी एवं रजनी तिवारी

झरिया कोयला-क्षेत्र के रानीगंज शैल-समूह में आरोही क्रम में महुदा, भुरुगिंया एवं लोहपिती नामक तीन प्रधान कोयला-सीम विद्यमान हैं। लोहपिती सीम के ऊपर स्थित शैल, जो लोहपिती बालुपत्थर सदस्य के नीचे स्थित है, से उपलब्ध पादपाश्म समुच्चय में **ग्लॉसॉप्टेरिस शैली** पत्ती, **ॲराकेरिऑक्सीलॉन कुमारपुरेन्सिस** तना एवं **नोनियास्पोराइटिस हेरिसाई** गुरुबीजाणु विद्यमान हैं। इसी प्रकार की पादपाश्मी समुच्चय कजोरा सीम के उपरिशायी शैलों से पहले अभिलिखित की गई है यह सीम रानीगंज कोयला-क्षेत्र में रानीगंज शैल-समूह के कुमारपुर बालुपत्थर सदस्य के नीचे स्थित है। लोहपिती बालुपत्थर सदस्य से कुमारपुर बालुपत्थर सदस्य का सहसम्बन्धन स्थापित किया गया है।

IN Jharia Coalfield, the Raniganj Formation is developed in south-western part in Mahuda sub-basin. Fox (1930) recognized four units in the Raniganj Formation of Jharia Coalfield, viz.,

Lohpiti Sandstone
Telmucha Coal Measures
Jamdiha Sandstone
Murulidih Coal Measures

Gee (1932) correlated the above units with those of the Raniganj Formation of Raniganj Coalfield.

| *Jharia Coalfield* | *Raniganj Coalfield* |
|---|---|
| Lohpiti Sandstone . | Kumarpur Sandstone |
| Telmucha Coal Measures | Nituria Coal Measures |
| Jamdiha Sandstone | Hijuli Sandstone |
| Murulidih Coal Measures | Sitarampur Coal Measures |
| Mahuda Sandstone | Ethora Sandstone |

On the basis of contained mega-and microflora the age of the Raniganj Formation is considered to be Late Permian. Three coal seams are recognised in the Raniganj Formation of Jharia Coalfield, viz., Mahuda, Bhurungia and Lohpiti seams, in order of superposition. The first and the third seam locally split into bottom, middle and top. Thus the total number of seams is up to seven.

Not much is known about the fossil flora of the Raniganj Formation in Jharia Coalfield. Feistmantel (1881, pp. 134, 135) listed :

> "*Schizoneura gondwanensis* Fstm., *Dicksonia hughesi* Fstm., *Asplenium whitbyense Heer, Macrotaeniopteris danaeoides* Royle, *Glossopteris communis* Fstm."

Maheshwari (1964, 1967) reported fossil wood and *Phyllotheca australis* from the area, to which Banerjee and Banerjee (1984) added *Trizygia speciosa, Phyllotheca griesbachii, Dichotomopteris major, D. lindleyii, Dizeugotheca phegopteroides, Neomariopteris polymorpha* and *N. lobifolia*.

## MATERIAL

Plant fossils were collected by one of us (U.B.) from. (i) Shale above Lohpiti Top Seam, Lohpiti Colliery, pit no. 2. (*Glossopteris shailae, Vertebraria indica*, equisetaceous stems, *Neomariopteris hughesii* and fossil wood), (ii) Coal seam in Lohpiti Colliery, New Incline (fossil wood); (iii) Shale partition in Mahuda Seam, Bhatdih and Murulidih collieries (*Glossopteris* spp., *Vertebraria indica*); (iv) Roof shale, Mahuda Top Seam, Bhurungia Colliery (*Glossopteris* sp., *Vertebraria indica*).

### *Glossopteris shailae* Bajpai 1986
Pl 1, figs 1-5

*Description*—The collection consists of more than twenty specimens, majority of which are incomplete The leaf compressions mostly have a carbonified crust. The overall shape of the leaves probably was lanceolate (Pl. 1, figs 1, 2) with rounded apex (Pl 1, fig. 4), narrow base (Pl. 1, fig. 5) and entire margin The leaf was widest in the middle part. The midrib is flat, striate and distinct in the basal region. Prominent pits are present between the striations (Pl 1, fig 1). Midrib is evanescent in the apical region (Pl. 1, fig. 5). The lateral veins emerge from midrib at very acute angles (1°-6°), take an outward curve and after successive dichotomies and anastomoses approach the margin at an angle between 60° to 69° in the apical region, 39° to 50° in the middle region and 28° to 35° in the basal region. The vein dichotomies usually are of gamma and lambda types, rarely of psi type and the cross-connections between the veins which form the meshes are usually of zeta type, rarely forming zeta series, and occasionally of psi-lambda types. The size of the meshes varies in different parts of the leaves. The shape of the meshes is usually arcuate near the midrib, rarely angled or deltoid and mostly trapezoidal elsewhere.

The leaf appears to be hypostomatic since cuticle of only one surface (probably lower) shows stomata. Stomata are rare. The upper cuticle of lamina is differentiable into vein and mesh areas through shape and arrangement of cells. Veins show anastomoses. The cells over the veins are elongate, rectangular to elongate-polygonoid and are arranged end-to-end in almost linear rows The cells over the mesh areas are irregular to polygonal in shape and are arranged irregularly The lateral walls of the cells are straight to slightly undulate. The surface walls are papillate, each cell showing a single, dome-shaped papilla.

The lower cuticle of lamina is also differentiable into vein and mesh areas in the same way as the upper cuticle. The cells over the veins are elongate rectangular or polygonoid, sometimes squarish and are arranged end-to-end in linear rows. The cells over the mesh areas are polygonal to irregular in shape (Pl 1, fig. 3) and are arranged irregularly. The lateral walls of the cells are straight to undulate. The surface wälls of cells both over the veins and the meshes are non-papillate. The stomata are anomocytic (haplocheilic) and are irregularly distributed and oriented. The stomatal apparatus is monocyclic and has 5-6 subsidiary cells which are like other epidermal cells. The guard cells are sunken.

**Dimensions**

| | |
|---|---|
| *Overall size* | . 5.1-13.0 × 1.6-2.8 cm |
| *Width of midrib* | |
| in basal region | : 3 mm |
| in middle region | : 1 mm |
| *Number of veins in apical region* | |
| near midrib | : 10 (10.7) 12/cm |
| near margin | : 24 (22) 26/cm |
| *Number of veins in middle region* | |
| near midrib | : 11 (12.5) 15/cm |
| near margin | : 21 (24) 27/cm |

→

## PLATE 1

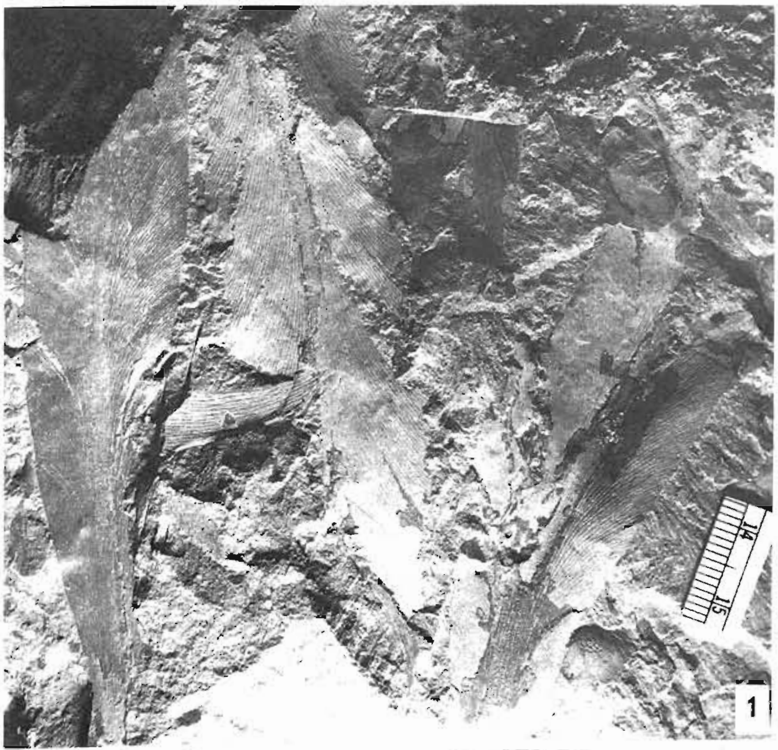
1,2. *Glossopteris shailae* Bajpai, leaves. × 1. Specimen nos. BSIP 36268, 36270

3. Lower cuticle of *G shailae* showing stomata. × 150, Slide no. BSIP 36268.

4,5 Apex and basal portions respectively of the leaf of *G. shailae* × 1 Specimen nos. BSIP 36269, 36271

6. Proximal view of a differentially macerated megaspore of *Noniasporites harrisii*, rill-like structures are also seen. × 100; Slide no. BSIP. 10097

7 A macerated megaspore of *Noniasporites harrisii* showing a dark circular mesosporium. × 100; Slide no. BSIP 10098.



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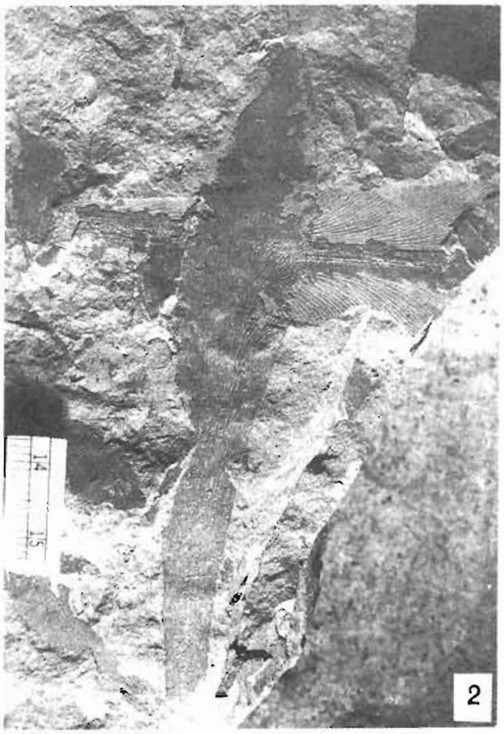

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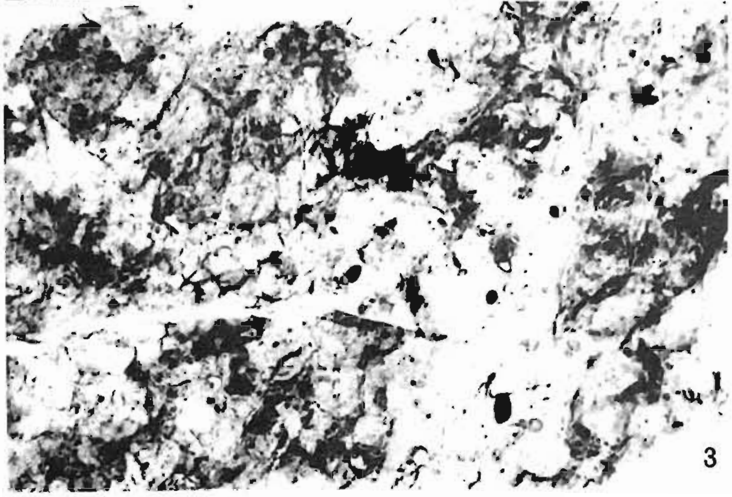
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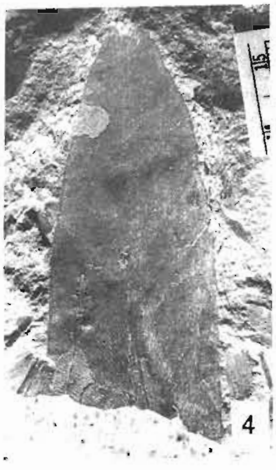

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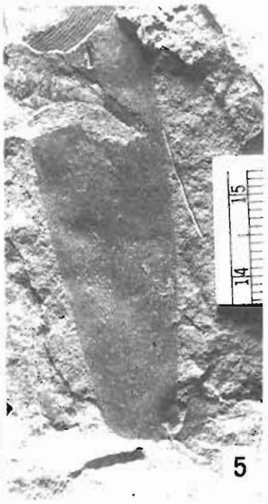

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6


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**PLATE 1**

*Number of veins in basal region*

| | |
|---|---|
| near midrib | 8 (10.7) 13/cm |
| near margin | 15 (18) 23/cm |

*Size of meshes in apical region*

| | |
|---|---|
| in general | 1.7 (2.9) 5.8 × 0.4 (0.6) 0.7 mm |
| near midrib | 3.7 (4.2) 4.7 × 0.5 (0.6) 0.7 mm |
| in between | 4.6 (5.1) 5.8 × 0.4 (0.5) 0.8 mm |
| near margin | 1.7 (2.2) 2.5 × 0.4 (0.5) 0.6 mm |

*Size of meshes in middle region*

| | |
|---|---|
| in general | 2.4 (3.5) 5.3 × 0.4 (0.6) 0.6 mm |
| near midrib | 2.8 (3.3) 4.3 × 0.4 (0.6) 0.6 mm |
| in between | 3.8 (4.6) 5.3 × 0.5 (0.6) 0.6 mm |
| near margin | 2.4 (2.7) 3.0 × 0.4 (0.6) 0.6 mm |

*Size of meshes in basal region*

| | |
|---|---|
| in general | 1.2 (3.3) 5.1 × 0.4 (0.5) 0.6 mm |
| near midrib | 2.9 (4.0) 5.1 × 0.4 (0.5) 0.6 mm |
| in between | 2.7 (3.8) 4.8 × 0.4 (0.6) 0.6 mm |
| near margin | 1.8 (2.2) 2.5 × 4 mm |

*Upper cuticle of lamina*

| | |
|---|---|
| Size of cells over veins | 40-116 × 24-40 μm |
| Thickness of cell walls over veins | 4-8 μm |
| Size of cells over meshes | 28-80 × 28-44 μm |
| Thickness of cell walls over meshes | 2-4 μm |
| Height of papillae | 12-20 μm |
| Diameter of papillae | 12-16 μm |
| Thickness of papillae wall | 1-2 μm |

*Lower cuticle of lamina*

| | |
|---|---|
| Size of cells over veins | 28-60 × 24-40 μm |
| Thickness of cell walls over veins | 2-4 μm |
| Size of cells over meshes | 24-56 × 18-40 μm |
| Thickness of cell walls over meshes | 1-2 μm |
| Size of stomata | 32-40 × 12-36 μm |
| Size of guard cells | 32-40 × 4-12 μm |
| Thickness of guard cell wall | 1-4 μm |
| Size of stomatal pore | 32-40 × 4-8 μm |
| Size of subsidiary cells | 32-100 × 36-68 μm |
| Thickness of subsidiary cell wall | 4 μm |
| Stomatal index | 1.78-2.54 |

Under Scanning Electron Microscope the leaf cuticle shows rod-shaped, 2-3 μm long bacteria (Pl. 2, fig. 5) that had completely degraded the cell margins, probably during biodiagenesis.

### *Araucarioxylon kumarpurensis* Bajpai & Singh 1986

Pith and primary xylem are not preserved in any of the woods. The secondary xylem is preserved only in patches (Pl. 2, figs 4, 6). Its organisation is similar to that of *Araucarioxylon kumarpurensis.*

On most of the area, the lignin material is completely lost and therefore the details of the tissue are not seen. The bordered pits are often filled with crystalline structures (Pl. 2, fig. 2) which are restricted to pit pores. Due to complete absence of any biogenic remains it is difficult to comment on the mode of degradation of the woods.

### *Noniasporites harrisii* Maheshwari & Bajpai 1984

*Description*—Megaspores are azonate, golden brown, circular to subcircular in outline in proximo-distal view. Tri-radiate rays are almost indistinguishable in incident and transmitted light but clearly seen under SEM. Contact ridges are not marked. Contact area is not well marked but is

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**PLATE 2**

1. Proximo-lateral view of *Noniasporites harrisii.* × 100.
2. Numerous crystalline bodies present in the pit pore of *Araucarioxylon kumarpurensis* Singh & Bajpai. × 4500.
3. Proximal view of *Noniasporites harrisii* showing the tri radiate ridges and rill-like structures. × 100.
4. Uniseriate bordered pits of *Araucarioxylon kumarpurensis.* × 90.
5. Bio-degradation of cuticle of *Glossopteris shailae* by colonies of rod-shaped bacteria. × 2200.
6. *Araucarioxylon kumarpurensis*; biseriate bordered pits on the radial walls of tracheids. × 100.


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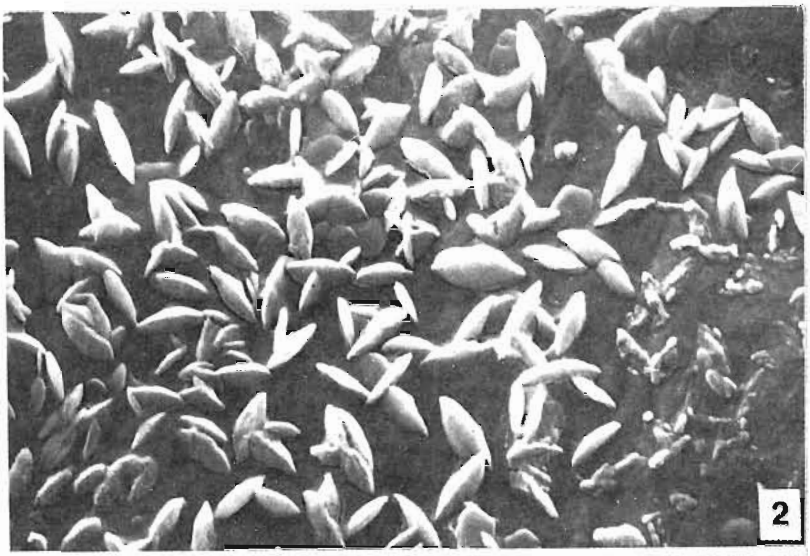
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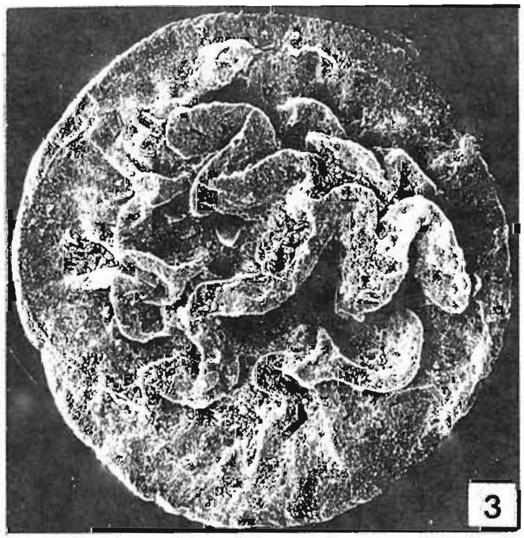
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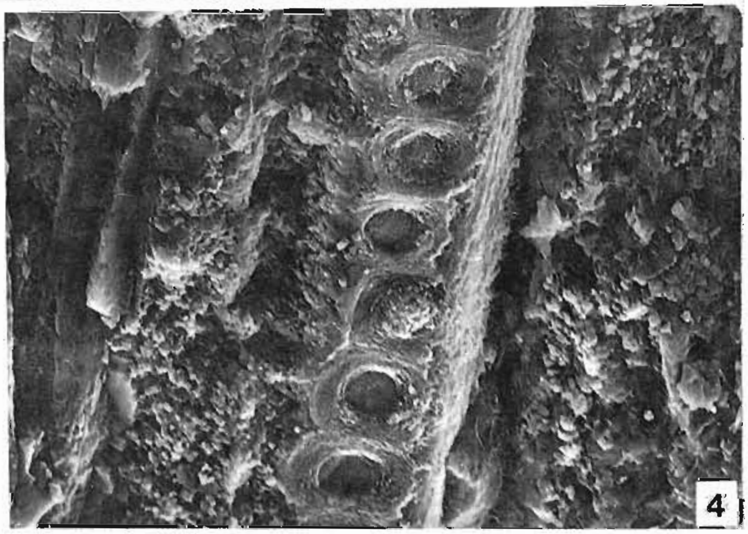
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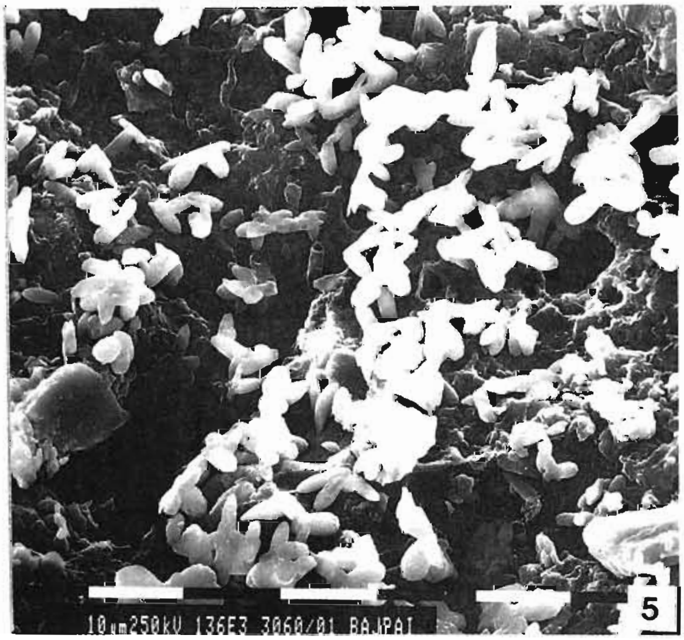

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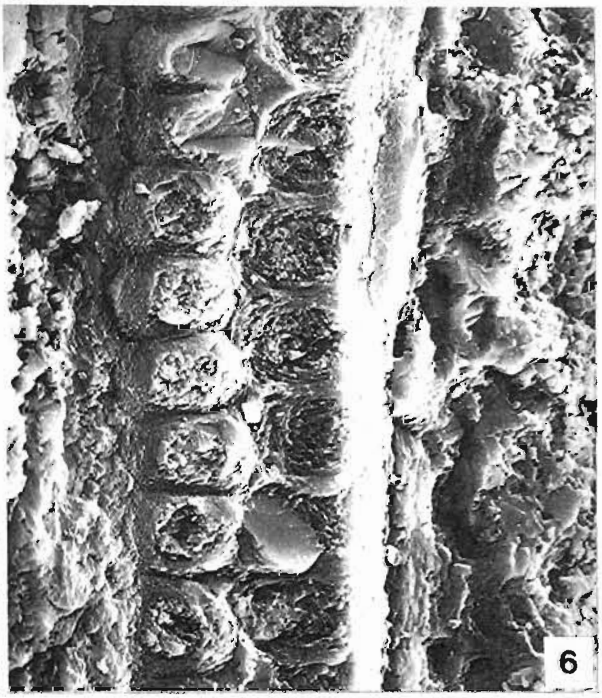
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**PLATE 2**

defined by the presence of a number of fine rills (Pl 2, figs 1, 3). Exosporium is laevigate (Pl 1, fig. 6). Differential maceration in $HNO_3$ and KOH reveals thin, spherical, light-brown mesosporium without cushions (Pl 1, fig. 7).

**Dimensions**

| | |
|---|---|
| *Overall size* | 290-325 × 247-299 μm (dry condition); 325 × 312 μm (wet condition); 390 × 312 μm (after mounting in canada balsam). |
| *Thickness of exine* | 36 μm (wet condition); 16 μm (after mounting in canada balsam). |
| *Size of mesosporium*: | 260 × 221 μm (wet condition); 221 × 221 μm (after mounting in canada balsam). |

## DISCUSSION

The plant fossil assemblage of the Lohpiti Seam comprising *Glossopteris shailae, Araucarioxylon kumarpurensis* and *Noniasporites harrisii* is similar to that reported from Kumarpur Sandstone, Raniganj Formation, Raniganj Coalfield by Maheshwari and Bajpai (1984), Bajpai and Singh (1986) and Bajpai (1986). On the basis of data at hand, the floral assemblage associated with the Lohpiti Seam apparently is similar to that of the shale sequence slightly above the Kajora Seam of Kumarpur Sandstone. Thus, palaeobotanically also Lohpiti Sandstone Member of Jharia Coalfield is correlatable with Kumarpur Sandstone Member of Raniganj Coalfield, as earlier commented upon by Gee (1932) on the basis of field evidences.

## ACKNOWLEDGEMENT

We thank Dr Hari K. Maheshwari for helpful suggestions.

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# Palaeobotany and climate around Marhwas area, Sidhi District, South Rewa Gondwana Basin during Upper Permian

Shaila Chandra, A. K. Srivastava & Kamal J Singh

Chandra, Shaila, Srivastava, A. K & Singh, Kamal J. 1990 Palaeobotany and climate around Marhwas area, Sidhi District, South Rewa Gondwana Basin during Upper Permian. *In* : Jain, K. P. & Tiwari, R. S. (eds)— *Proc. Symp 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** 49-54.

Fossil plant asssemblages around Marhwas area in Sidhi District are represented by one species each of *Trizygia*, *Neomariopteris* and *Scutum*, a fern and 24 species of *Glossopteris*. Floristic composition indicates Raniganj-Kamthi affinities and a warm-temperate climate. High percentage of small-sized leaves and poor representation of pteridophytes in the flora suggest drier conditions and low humidity

**Key-words**—Megafossils, Palaeoclimate, Gondwana, Upper Permian (India)

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## सारॉंश

### उपरि परमी काल में दक्षिण रीवा गोंडवाना द्रोणी के सिधी जनपद में मड़वास क्षेत्र के आस-पास की पुरावनस्पति एवं जलवायु

शैला चन्द्रा, अश्विनी कुमार श्रीवास्तव एवं कमलजीत सिंह

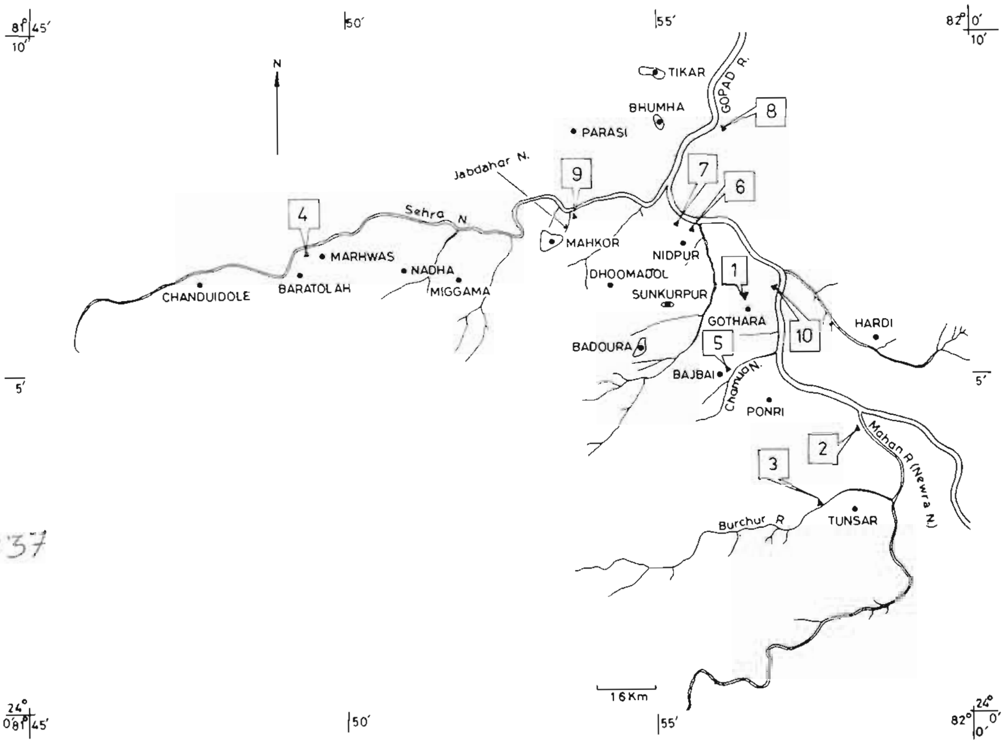
सीधी जनपद में मड़वास के आस-पास के अश्मित पादप समुच्चयों से **ट्राइजीजिया निओमेरिऑप्टेरिस** एवं **स्कूटम** में प्रत्येक की एक जाति, एक फ़र्न तथा **ग्लॉसाप्टेरिस** की 24 जातियाँ उपलब्ध हुई हैं। अश्मित वनस्पतिजात कुल मिलाकर रानीगंज-कामथी सजातीयता एवं उष्ण-शीतोष्ण जलवायु प्रदर्शित करता है। उक्त वनस्पतिजात में छोटे आकार की पत्तीयों की अधिकता तथा टेरीडोफ़ाइटी पौधों की कम संख्या से शुष्क परिस्थितियों एवं कम आर्द्रता का होना इंगित होता है।

THE Sidhi District is the eastern part of the great South Rewa Gondwana Basin. The principal river Gopad (Gopat in topo-sheet) flows from south to north and is the tributary of the Son. The localities covered in this area are exposed mostly in the nala and river cuttings in the villages around Gopad River

Hughes (1881) mapped the area and collected plant fossils from Bajbai, Chanduidol, Parasi and few localities adjacent to Mahan (also spoken as Mohan) River Section. Feistmantel (1882) after making exhaustive studies assigned an Upper Permian age to these beds. Ahmad (1955) and Raja Rao (1983) also suggested the age equivalent to Raniganj to these beds on the basis of lithological features, which was further supported by palaeontological evidences (Tripathi, 1962).

Satsangi (1964) discovered a so-called *Dicroidium* bearing bed alongwith typical Permian assemblage bearing beds in the Gopad River Section near the village Nidhpuri The presence of *Dicroidium* like fronds lead him to postulate occurrence of a Triassic horizon in the area. This was further supported by Srivastava (1974). Banerji *et al.* (1976) collected plant megafossils from three exposures, in close vicinity to each other, along the Gopad River and hesitantly dated two of the exposures as Triassic while the third one was definitely dated as Upper Permian. Again the former dating was done merely on the basis of a few specimens of poorly-preserved indeterminate specimens of *Dicroidium* like leaves.

In recent years extensive collections of plant fossils have been made by us from a number of



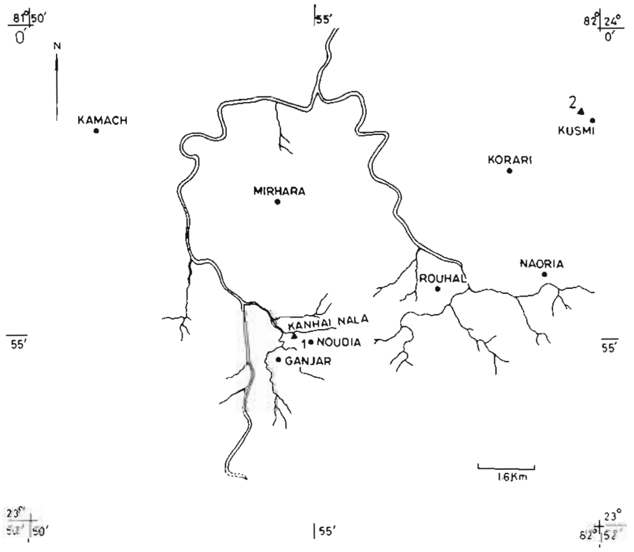
**Map 1**—Fossil locality map of Sidhi District, South Rewa Gondwana Basin. **1**, Gothara Hill; **2**, Mahan River Section near Gopad-Mahan confluence; **3**, Burchur River Section near Tunsar Village; **4**, Sehra Nala Section near Marhwas Village; **5**, Chamua Nala Section near Bajbai Village; **6**, **7**, Gopad River Section near Nidhpuri Village; **8**, Gopad River Section near Bhumha Village; **9**, Jabdahar Nala Section near Mahkor Village; **10**, Gopad River Section near Gothara Village.

localities around Marhwas in Sidhi District (Map 1 and 2), Majority of the exposures are found in the vicinity of Gopad River. Few of them are exposed in the Mahan River and the nalas joining these two rivers from various villages. All the specimens have been deposited in the Birbal Sahni Institute of Palaeobotany Museum.

## PALAEOBOTANY

The specimens are preserved as impressions on arenaceous and argillaceous shales. Carbonised crust is present over specimens from the Burchur River Section but has not yielded cuticle. Bulk maceration of the rock samples also did not yield identifiable organic matter. Plant fossils in general are fragmentary and rarely complete. The specimens are generally well preserved and hence could be identified up to the specific level.

The distribution of plant fossils, represented by pteridophytes and gymnosperms, in different



**Map 2**—Showing fossil locality. **1**, Kanhai Nala Section near Noudia Village, and **2**, Tilangana Ghat Section near Kusmi Village.

**Table 1—Distribution of plant fossils in different localities of Sidhi District, Madhya Pradesh**

| *Name of the fossils* | Gothara Hill | Mahan River section near Gopad-Mahan confluence | Burchur River section near Tunsar Village | Sehra Nala section near Marhwas Village | Chamua Nala section near Bajbai Village | Gopad River section near Nidhpuri Village (A) | Gopad River section near Nidhpuri Village (B) | Gopad River section near Bhumha Village | Jabdahar Nala section near Mahkor Village | Gopad River section near Gothara Village | Kanhai Nala section near Noudia Village | Tilangana Ghat section near Kusmi Village |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Trizygia speciosa* | | | + | | | | | | | | | |
| *Scutum sahnii* | | | + | | | | | | | | | |
| *Neomariopteris hughesii* | | | | + | + | | + | | | | + | + |
| Fern sp. | | | | + | | | | | | | | |
| *Glossopteris communis* | + | + | + | + | + | + | + | + | + | + | + | |
| *G. indica* | + | | + | + | + | + | | + | + | + | + | + |
| *G. pandurata* | | + | | | | | | | | | + | |
| *G. emarginata* | | | | | | | | | | + | | |
| *G. browniana* | + | | + | | | | + | | | | + | |
| *G. angustifolia* | + | + | | + | + | | | + | + | + | | |
| *G. stricta* | | | | + | | | | + | + | | | |
| *G. tenuifolia* | | | | + | | | | | + | | | |
| *G. retifera* | | | + | | + | | + | + | | | | |
| *G. taeniensis* | | | | | | | + | | | | | |
| *G. damudica* | + | | + | | | | + | | | | | |
| *G. conspicua* | | | + | | | | + | | | | + | |
| *G. stenoneura* | | | | | | | + | | | | | |
| *G. nimishea* | | | + | | | | | + | | | | |
| *G. formosa* | | | + | | | | | | | | | |
| *G. intermedia* | | | + | | | | + | | | | + | |
| *G. linearis* | | | | | + | | | | | | | |
| *G. gigas* | | | | | + | | | + | | | | |
| *G. leptoneura* | | | | | | | | | | + | | |
| *G.* cf. *searsolensis* | | | + | | | | | | | | | |
| *G. gondwanensis* | | | + | | | | | | | | + | |
| *G. spatulata* | | | + | | | | | | | | | |
| *G. varia* | | | | | + | | | | | | | |
| *G. zeilleri* | | | | + | | | | | | | | |
| *Vertebraria indica* | | | | | | | | + | | + | | |
| Stem axis | | + | + | + | + | | | + | + | + | + | + |
| Equisetalean axis | | | + | | + | | + | + | + | | + | |

localities of Sidhi District is shown in Table 1. Qualitatively the plant types are fairly well-represented.

*Floristic comparison*—All the localities show the dominance of *Glossopteris*. Pteridophytes have been recovered from Burchur River, Kanhai Nala, Chamua Nala, Sehra Nala, Tilangana Ghat and Gopad River near Nidhpuri B sections, but they are poorly represented. Total absence of *Gangamopteris* and *Noeggerathiopsis* in all the localities exclude the possibility of its being Lower Permian in age. Comparison with the known floristic data from the Raniganj Coalfield (Srivastava, 1956; Maheshwari, 1965; Pant & Gupta, 1968, 1971; Pant & Singh, 1971), Rajmahal Hills (Maheshwari & Prakash, 1965) and Auranga Coalfield (Srivastava, 1979) indicates a close similarity with the Raniganj flora.

The specific analysis of various *Glossopteris* species in the Sidhi assemblages also indicates Raniganj affinities (Chandra & Surange, 1979). *Glossopteris* species which are frequently found in the Raniganj strata, e.g., *G. retifera, G. conspicua, G. formosa, G. intermedia, G. angustifolia* and *G. linearis* are also dominant elements in Sidhi

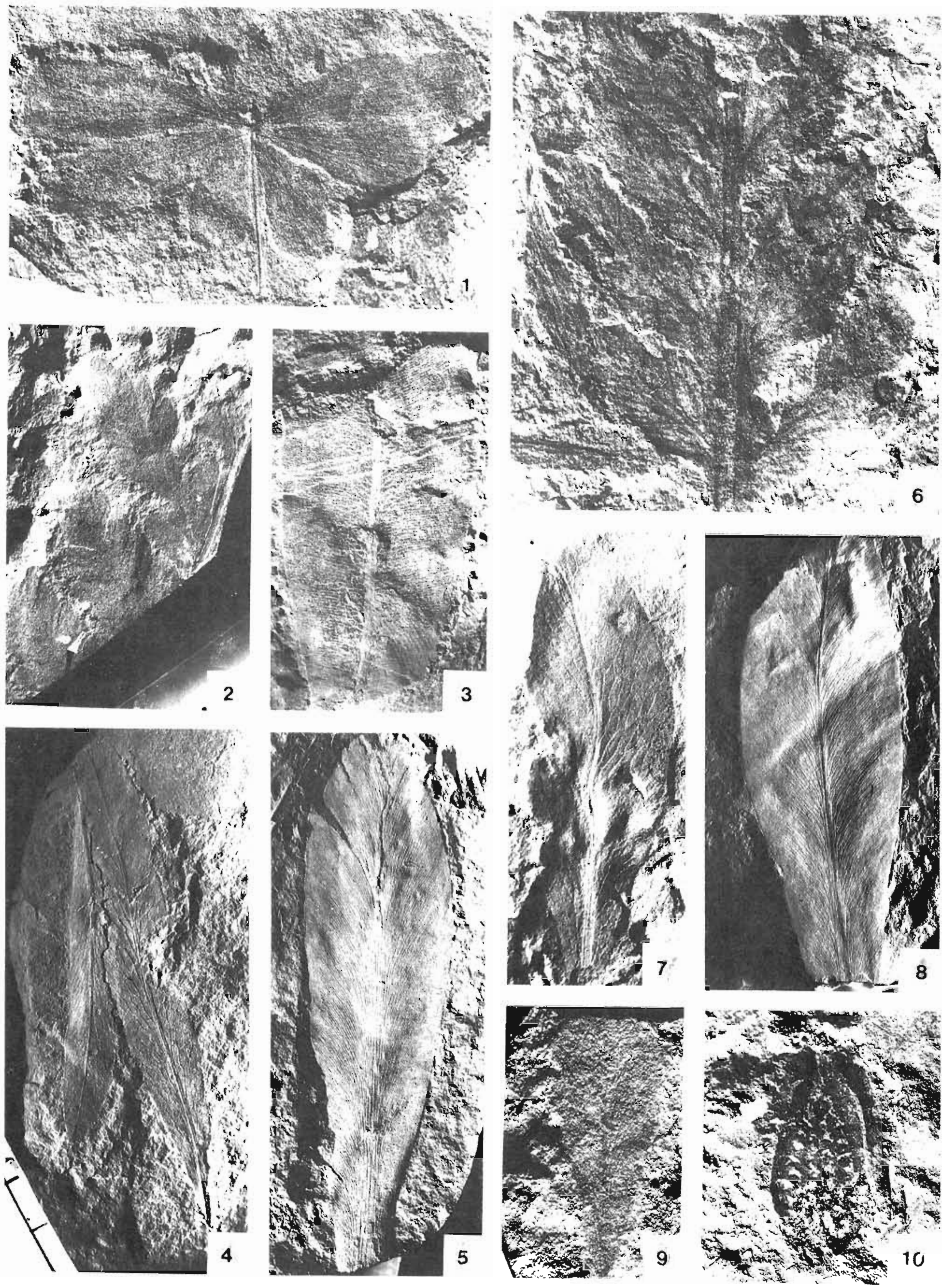


PLATE 1

assemblages. These are also well-represented in the Raniganj Coalfield, Rajmahal Hills and Auranga Coalfield

The distribution of *Glossopteris* species in the Kamthi flora has been analysed by Chandra and Prasad (1987). It was observed that in general the *Glossopteris* species are same as are found in Raniganj flora Some species, however, are characteristic to the Kamthi flora. The significant species of the Kamthi flora are *G. stricta, G. musaefolia* and *G. leptoneura* (Bunbury, 1861, Chandra & Prasad, 1987) The presence of *G. stricta* and *G. leptoneura* alongwith other typical Raniganj species indicates that the Sidhi assemblages could as well represent a transitional flora. The smaller size of the leaves and narrow elongate shapes of the leaves in general in Sidhi assemblages also point towards Kamthi affinities. A typical form, which we have provisionally identified as a fern because of lack of specimens, may turn out to be the same plant earlier identified as *Dicroidium*-complex by Srivastava (1974) and Banerji *et al.* (1976) Collective evidence and analysis of the Sidhi flora suggest affinities both with Raniganj and Kamthi floras and an uppermost Permian age

## PALAEOCLIMATE

Plant fossils recovered from the Upper Permian sediments of Marhwas area indicate the presence of lush-green forests dominated by *Glossopteris* plants of varying habits associated with a few pteridophytes. The climatic conditions were favourable for the development of plant communities but were not suitable for coal formation. Low percentage of pteridophytes also suggests that the conditions were drier as compared to the conditions prevailing during the same period in the Raniganj Basin. Preservation of leaves in different thin sediments also suggests that the plants were deciduous. The leaves in general are broken indicating disturbed conditions during their deposition.

Thus it can be inferred from the available data that the Permian forests around Marhwas were growing under warm temperate conditions with low humidity.

## REMARKS

The record of a *Glossopteris* dominated flora in the Marhwas area of Sidhi District, from exposures almost juxtaposed to the well-known Nidhpuri Section and often presumed to be of Triassic age, mediates a reassessment of the age of the fossil flora from the latter locality There is enough evidence to indicate that the Nidhpuri flora, too, may be of Upper Permian age (Chandra & Maheshwari, 1988).

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## PLATE 1

1 *Trizygia speciosa,* Specimen no. BSIP 36397 × 2.
2. *Neomariopteris hughesii.* Specimen no. BSIP 36398. × 2.
3. *Glossopteris nimishea,* Specimen no. BSIP 36399. × 1
4. *G gondwanensis,* Specimen no. BSIP 36400. × 1.
5. *G spatulata.* Specimen no. BSIP 36401. × 1
6. Fern sp. Specimen no. BSIP 36402. × 4
7 *Glossopteris conspicua,* Specimen no. BSIP 36403. × 2.
8. *G indica.* Specimen no. 36404. × 1
9. *G pandurata,* Specimen no BSIP 36405. × 1
10. *Scutum sahnii.* Specimen no BSIP 36406. × 2.

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# Occurrence of *Benlightfootia* from the Ib-River Coalfield, Orissa

Kamal J. Singh & Shaila Chandra

Singh, Kamal J. & Chandra, Shaila 1990. Occurrence of *Benlightfootia* from the Ib-River Coalfield, Orissa. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 55-57

*Benlightfootia* Lacey & Huard-Moine has been reported from the Kamthi Formation of Belpahar area, Ib-River Coalfield, Orissa. It is characterised by non-petiolate, cordate, bifid leaves having a deep apical notch. The venation is open, dichotomous, arising from a single thick vein at the base of the leaf. A new species, *B. indica*, has been proposed.

**Key-words**—Megafossils, Sphenophyllales, Ib-River Coalfield, Upper Permian (India).

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## साराँश

### इब नदी कोयला-क्षेत्र (उड़ीसा) से बेनलाइटफ़ुटिया की प्राप्ति

कमलजीत सिंह एवं शैला चन्द्रा

उड़ीसा में इब नदी कोयला-क्षेत्र में बेलपहाड़ क्षेत्र के कामथी शैल-समूह से **बेनलाइटफ़ुटिया** लैसे व हार्डमॉयनें अभिलिखित किया गया है। यह पत्ती वृंतहीन, हृदयाकार, द्विशाखित एवं अग्रस्थ कटान युक्त है। इस पत्ती के आधार से एक मोटी शिरा निकलती है जो द्विभाजित एवं खुला शिरान्यास बनाती है। **बेनलाइटफ़ुटिया इंडिका** नामक एक जाति प्रस्तावित की गई है।

THE genus *Benlightfootia* was proposed by Lacey and Huard-Moine 1966 for certain unique bifid leaves from the Wankie beds, Zimbabwe. Earlier, such leaves were identified as *Glossopteris* or *Sphenophyllum*. Lacey and Huard-Moine (1966) found that these leaves belong neither to *Glossopteris* nor to *Sphenophyllum*, and thus instituted a new genus—*Benlightfootia*.

The type species *B. mackii* is characterised by non-petiolate, bifid, cordate leaves occuring singly or in apparent clusters. A deep apical notch exists between the two apical lobes. The venation of the leaf is open, dichotomous, arising from a single, thick vein at the base of the leaf. The veins by repeated dichotomy reach the margins and extremities of the lobes which are slightly rounded having smooth margins. The venation of two halves of the leaf is completely distinct from near the base.

## MATERIAL AND METHODS

The material was collected from the outcrops of the Kamthi Formation in Ib-River Coalfield, Orissa, near Belpahar railway station. The specimens are impressions on light reddish-brown to reddish-grey, fine-grained, calcareous shales. There is no carbonised matter on the specimens.

## DESCRIPTION

### Genus—*Benlightfootia* Lacey & Huard-Moine 1966

### *Benlightfootia indica* sp. nov.

Pl. 1, figs 1, 2; Text-fig. 1

*Diagnosis*—Leaves bifid, sessile, occuring in a cluster of two or three; spreading out at 45°-55° from a common middle portion; shape basically cordate with a deep apical notch; venation open, dichotomous, arising from a thick, one or two veins at the base of the leaf; vascular system of the two halves of leaf completely distinct from near the base. Apices of lobes sharp and somewhat acute in shape with 3-4 slight depressions along the margins.

*Holotype*—Specimen no. BSIP 36387; Kamthi Formation, near Belpahar railway station, Ib-River Coalfield; Upper Permian.

*Description*—In all, there are three specimens in the collection, out of which, the best preserved specimen has two leaves. Leaves are cordate, 3.8 to 4.2 cm long and 2 to 2.2 cm wide at their widest part with a 1 to 1.2 cm deep terminal notch. The L:W ratio is 2 : 1. The leaves are sessile. Each lobe is 1 to 1.1 cm in width at the widest part of the leaf. The apices of lobes are sharp and acute having 3-4 slight depressions along the margin. A single major vein enters the base of the leaf and soon divides into two which by repeated dichotomy form two separate sets of veins (about 20-22 veins at the widest part of each lobe) supplying to each half of the leaf. The bases of leaves are acute-cuneate. All the three leaves are directed towards a common point suggestive of a part of a whorl.

## COMPARISON

*Benlightfootia indica* superficially resembles *Parasphenophyllum crenulatum* Maithy 1978 and *Sphenophyllum utkalensis* Pant *et al.* 1985 as they

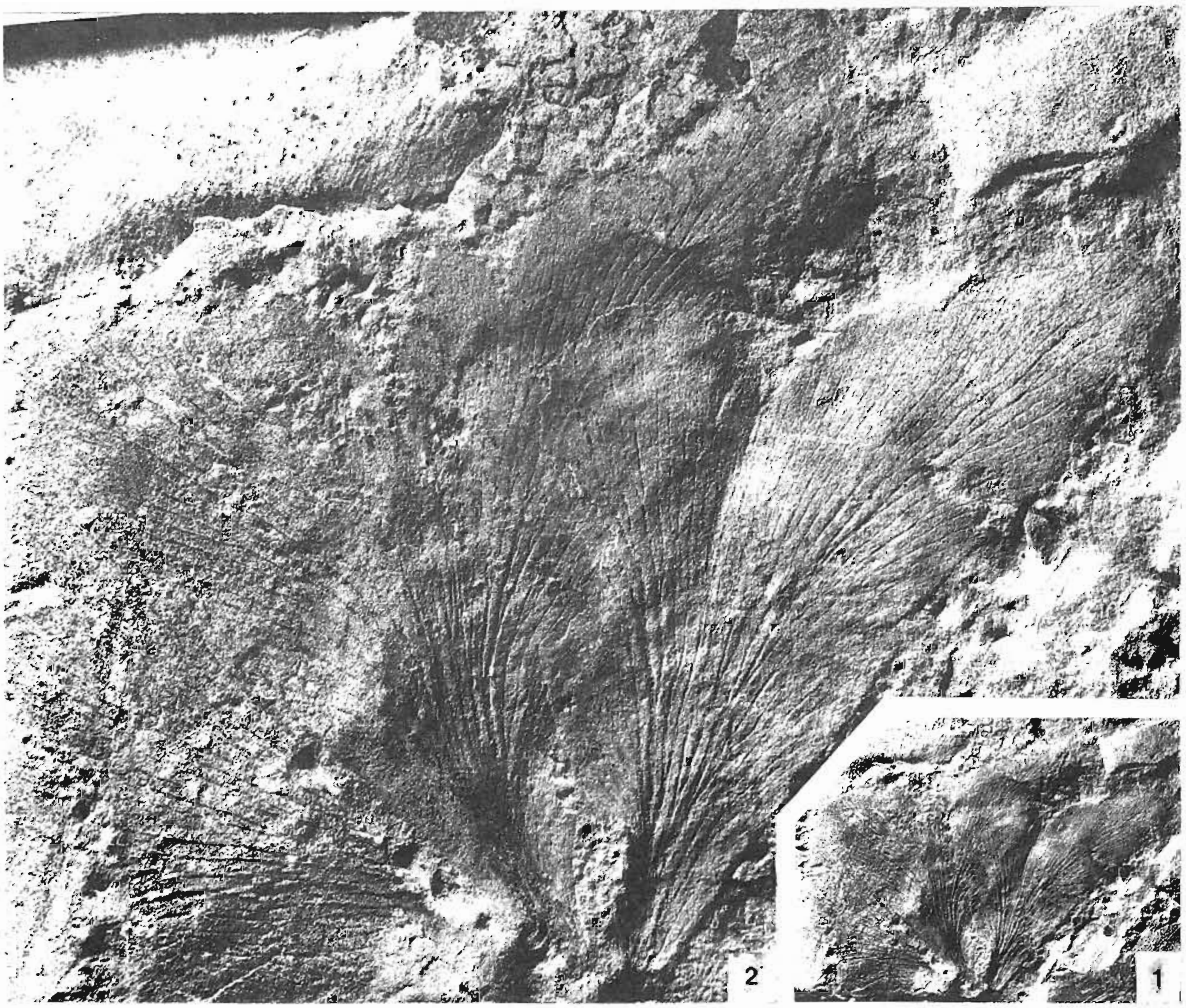
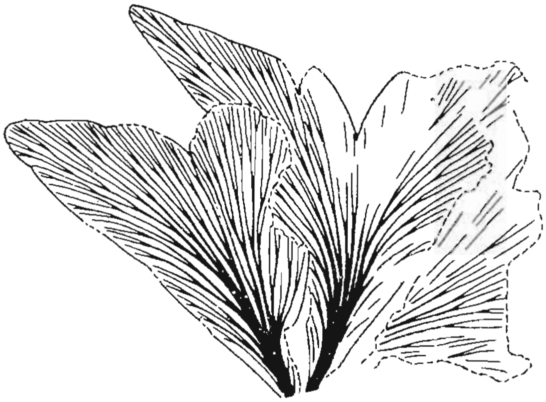


**PLATE 1**

1. *Benlightfootia indica* sp. nov., holotype showing two sessile bifid and cordate leaves. Specimen no. BSIP 36387. × 1.
2. Leaves in fig. 1 enlarged to show the deep terminal notches, acute apices having depressions along the margins and one or two major veins at the base in each leaf dichotomise to form two separate sets of veins supplying each half of the leaf. × 3.5.



**Text-figure 1**—*Benlightfootia indica* sp. nov · The sessile, bifid and cordate leaves showing terminal notches, acute apices with depressions along the margins and one or two thick veins at the base dichotomise to form two separate sets of veins supplying each half of the leaf; Specimen no BSIP 36387 × 2.

have bifid leaves and apical notches. *B. indica* further resembles *S. utkalensis* in its sessile nature and sharp acute apices. The apices in *S. utkalensis* are comparatively more pointed. *B. indica* differs from *S. utkalensis* in having 3-4 depressions in the apices along the margins of lobes and in having two separate sets of main veins supplying each half of the leaf. It seems that the vascular supply of the two halves in *B. indica* is completely separate from the base itself The apical margins in *S. utkalensis* are smooth and its venation is also different from *B. indica*.

The apical margins of both *Benlightfootia indica* and *Parasphenophyllum crenulatum* have crenulations but the shape of the leaves is different. In *B. indica* the leaf is cordate and sessile whereas the leaf of *Parasphenophyllum crenulatum* is triangular and petiolate The vascular system in both the genera are also distinctly different.

*Benlightfootia indica* may, however, be compared with some northern species of *Sphenophyllum* in having apically notched leaves. The comparable northern species are *Sphenophyllum longifolium, S majus, S oblongifolium, S. orbicularis, S. sarrensis, S. saxonicum* and *S. seuardii* (in Boureau, 1964). All these species are different from *Benlightfootia indica* in having variously toothed apical margins and usual sphenophyll venation

*Benlightfootia indica* differs from the type species *B. mackii* in having sharp and acute apices and 3-4 depressions along the margins of lobes, whereas the apices in *B. mackii* are obtuse, or somewhat rounded, and the margins of the apical lobes are smooth

## DISCUSSION

Lacey and Huard-Moine (1966) placed *Benlightfootia* under *incertae sedis* as they could not ascertain its affinity; they, however, opined that *Benlightfootia* could be a ginkgoalean leaf of a non-petiolate form, comparable with *Ginkgoidium, Ginkgoites, Baiera*, or *Psygmophyllum*. In the absence of any fertile part, it is difficult to place it under any known group of plants. However, its close external morphological resemblance with the known Sphenophyllales inadvertently includes it under this group. *Benlightfootia* must have been a small plant like *Raniganjia, Sphenophyllum* and *Lelstotheca* with leaves borne at the nodes in clusters.

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# Evolutionary pattern of striations and taeniae in the Indian Gondwana saccate pollen

Vijaya

Vijaya 1990. Evolutionary pattern of striations and taeniae in the Indian Gondwana saccate pollen. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** 83-91.

Striations and taeniae are genetically controlled morphographic characters of *sporae dispersae*. The sequential pattern of evolution in striations through Lower Gondwana has revealed that the earliest Permian is the starting plane for these characters which proliferate to a diversified and complex mosaic, in the subsequent time, culminating in Late Permian. The global occurrence of striations and taeniae in saccate pollen of Permian-Triassic times is an episode of evolution in organisation which appears to attain the fittest situation for exine protection, germination gates, or moisture regulators.

**Key-words**—Palynology, Morphography, Permian Gondwana (India).

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## सारॉंश

### भारतीय गोंडवाना के कोष्ठीय परागकणों में धारीयों एवं टीनीयों का वैकासिक स्वरूप

विजया

विकीरित बीजाणु-परागकणों की धारीयाँ एवं टीनीयाँ आनुवंश द्वारा नियंत्रित आकारिकीय लक्षण हैं। अधरि गोंडवाना में धारीयों में विकास के अनुक्रमिक स्वरूप से व्यक्त होता है कि ये लक्षण प्रारम्भिक परमी कल्प से विकसित हुए हैं तथा बाद में अनंतिम परमी कल्प में इनमें और अत्याधिक परिवर्तन एवं विकास हुआ। विश्व में परमी-त्रिसंघी काल में कोष्ठीय परागकणों में धारीयों एवं टीनीयों की उपस्थिति विकास की एक घटना है जब वे बाह्यचोल रक्षक, अंकुरण छिद्र, अथवा नमी नियंत्रक के रूप में अपनी भूमिका निभाने में अपने को तदनुरूप विकसित कर रहे थे।

STUDY of palynofossils from the Indian Gondwana sediments reveals a range of variability in their morphographic characters in kind as well as number. Phylogenetic studies (Heslop-Harrison, 1971) of spore-pollen complexes indicate that the major qualitative patterns are genetically controlled. In course of evolution each event is followed by a set pathway, e.g., an organisation in any form starts with simpler and less diversified level—the base line, and enters progressively into more complex and diversified levels. Thus, there is a *Starting plane* at which the appearance of a trait is recognised which, in time, is accompanied by experimental diversification in its nature. In course of diversification, variations attain their maxima, and normally no further alteration appears to be acquired. This phase is a *Stabilizing plane*. In the ultimate phase the proliferation of characters starts declining. Such a change may occur gradually, or all of a sudden. This last phase of existence of a particular character is the *Dying-out plane*, and is always accompanied with the starting plane of other character. Such sequence of changes is noted in the Gondwana palynofossils through time.

Saccate pollen constituting the major share of Lower Gondwana palynofloras bear a central body and two sacci attached juxtaposed to each other on either side of the central body, or a monosaccus attached to the body in various modes. A variation is generally found in saccus-body relationship.

Saccus is the isolated sexine from nexine which gets blown up resulting into a bladder-like organ. This sexinal layer appresses the nexine of body and covers it in various degrees. The proximal surface of this part of a pollen is either without any mark or furrows (Pl. 1, figs 1, 15, Text-fig. 2A, M), or with linear grooves or irregular furrows (Text-fig. 2B), giving rise to ribbon-shaped elevations (Pl. 1, fig.

10) arranged in an array of patterns to produce distinctive feature for group identification in the dispersed pollen (Text-fig. 2A-R).

## MORPHOLOGY

Presence of regular linear grooves (striations) or irregular furrows (resulting into taeniae) on the body of a pollen is recorded only in fossils, that too mainly of Permian and Triassic times; obviously this span of geological time is unique in respect of global phenomenon of the occurrence of "striate pollen". Word *striation* is derived from *Stria* (Pl. -*ae*, Latin, a furrow). This term has been defined in different ways by various workers, such as, "elongated ridges" by Thomson and Pflug (1953), "grooves between elongated sculpturing elements in striate grains" by Faegri and Iversen (1950); very fine "parallel microridges" by Kosanke (1950) and linear of "finger print pattern" by Harris (1955). In its objective meaning, however, the term striae is used most commonly in the sense of "furrows".

The manifestations of simple linear grooves (Pl. 1, fig. 5; Text-fig. 2B) result in various arrangement. Branching of horizontal striations is one line of variability leading to an increase in their number. Vertical partitions or connections in between these striations is another path of diversification which leads to brick-work pattern and then to reticuloid arrangement (Pl. 1, figs 3, 7; Text-fig. 2C, D, E, G, H, N, P, Q).

Another line of diversity in simple striations has been observed where sexine in between two striations become more flabby and relatively loose (Text-fig. 2F). In other words, the sexine is relatively more developed between the area delimited by two striations. The groove which is linear in normal case becomes somewhat irregular in width (Pl. 1, figs 8, 9). This appears to be a bridging phase in between the conditions of "striations and taeniae". Beside this, there is a group of pollen where striations have been found to be very faint and feeble; they cannot be traced all along their lengths (Pl. 1, fig. 4; Text-fig. 2I) but their presence can be marked.

As understood during the present analysis, the striations are defined here as linear, extremely narrow ($< 0.5 \mu$), uniformly wide, simple grooves running on the body forming various patterns of arrangements, such as—parallel, sub-parallel, simple, bifurcated, polygonal, brick-work, reticuloid, etc. These may be simple or branched, with or without vertical partitions. In between these grooves, sexine could be variously structured or sculptured (Bharadwaj, 1962; Kar, 1968; Tiwari, 1974; Lele, 1975).

Another major line of distinction in saccate pollen is the presence of taeniae (*taenia*, Pl.-*ae*; Latin, a ribbon-like strip). These are structured sexinal bands on proximal face of the body of saccate pollen leaving unstructured exinal region of uneven width in between two bands (Pl. 1, figs 10, 13; Text-fig. 2L). A number of genera are on record which bear such structure, e.g., *Lueckisporites, Lunatisporites* (Leschik, 1955; Potonié, 1970; Scheuring, 1970, 1978) and *Kamthisaccites* (Srivastava & Jha, 1986). Recently a species of bisaccate pollen is identified which bears striations on taeniae (Vijaya *et al*., 1988). This might represent a stage of an experiment in the course of evolution (Pl. 1, fig. 14; Text-fig. 2K). In few palynotaxa instead of several bands of sexine only two such bands are present on both the lateral regions of the body, leaving a wide unstructured area free in the centre of the body (Pl. 1, fig. 6; Text-fig. 2J).

From the above discussed conventional usage of terms it becomes evident that striations and taeniae are two different characters; striations represent linear furrows—like grooves, in which sexine is least

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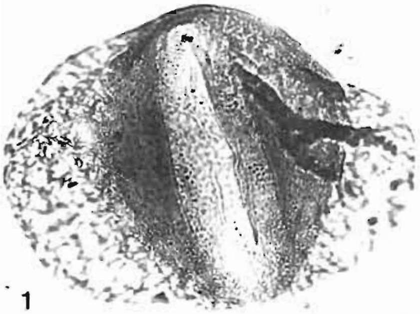
## PLATE 1

(All photomicrographs. × 500)

1. *Satsangisaccites* sp. : Non-striate bisaccate pollen.
2. *Striatopodocarpites* sp. : Horizontal striations bifurcated at places.
3. *Rhizomaspora* sp. : Reticuloid striations.
4. *Striatopodocarpites* sp. Faint, incomplete striations.
5. *Crescentipollenites* sp. : Simple horizontal striations.
6. *Lueckisporites* sp. : Two sexinal bands (Taeniae) on lateral region of central body.
7. *Lahirites* sp. : Vertical partitions in between striations at places.
8. *Striatites* sp. : Striations loosing its linear nature, becoming somewhat irregular spaces.
9. *Lunatisporites* sp. : Elevated sexinal bands tending to be taeniae.
10. *Lunatisporites* sp. : Distinct irregular sexinal bands (Taeniae).
11. *Striatites* sp. : Flabbiness in sexine, transforming towards taeniae organization.
12. *Striomonosaccites* sp. : Horizontal striations, bifurcated at places.
13. *Kamthisaccites* sp. : Elevated irregular sexinal bands (Taeniae).
14. *Lunatisporites* sp. : Taeniae, bearing striations on them.
15. *Parasaccites* sp. : Non-striate monosaccate pollen.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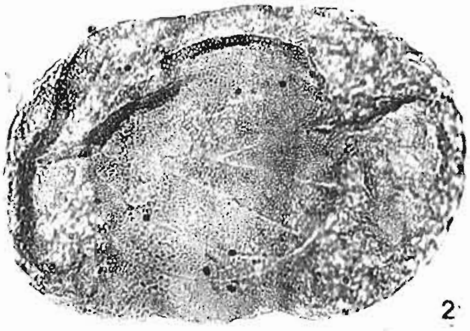
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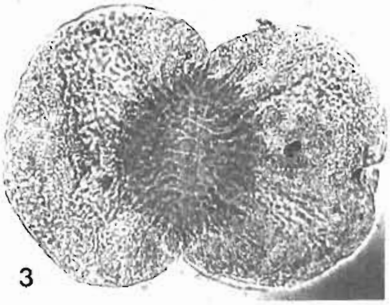
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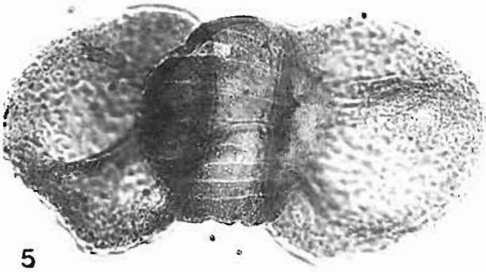
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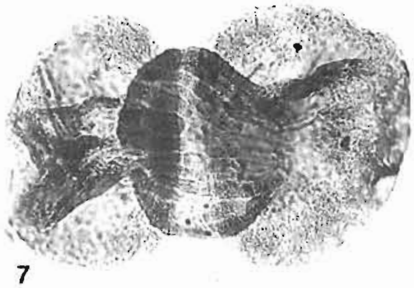
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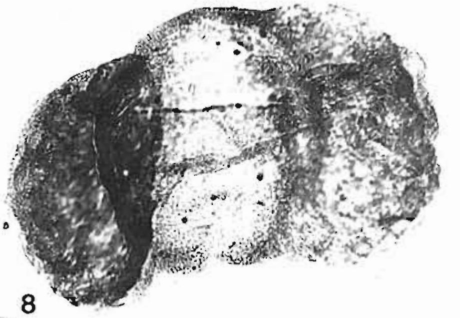
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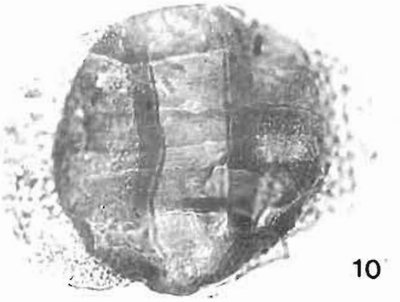
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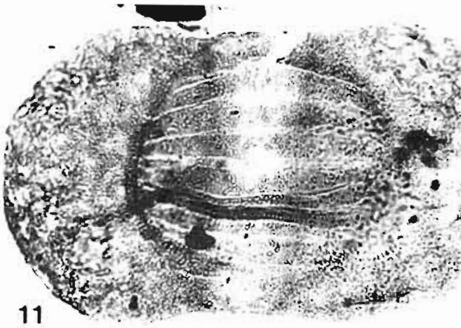
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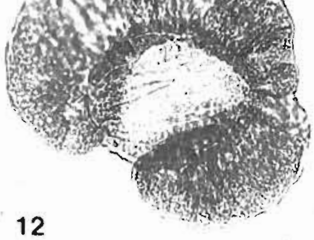
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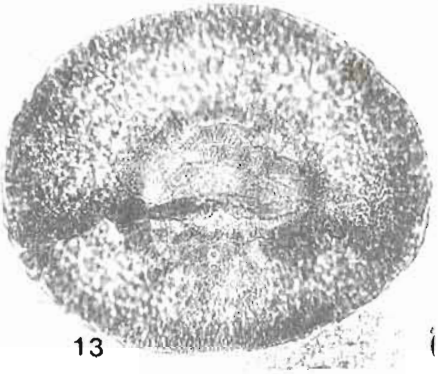
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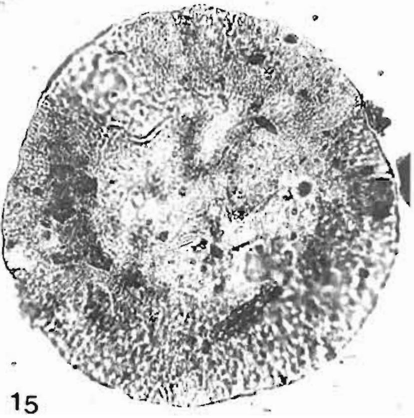
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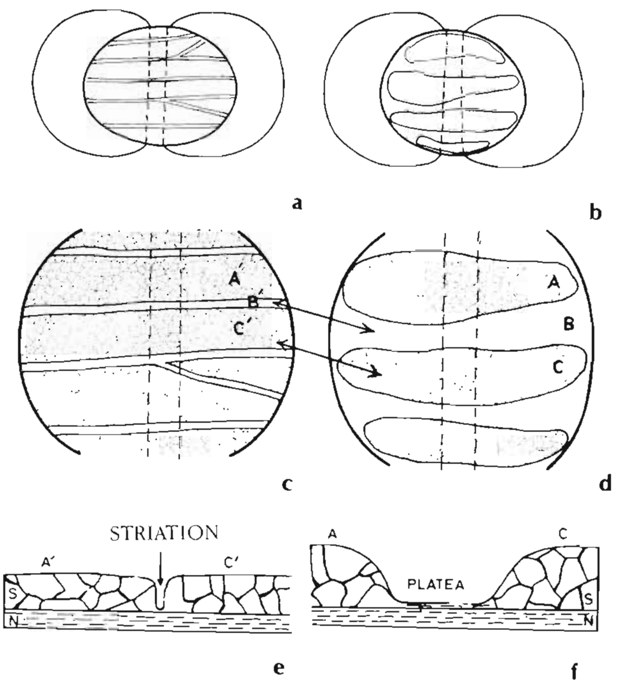
PLATE 1



**Text-figure 1**—Suggested terms for the distributional pattern of sexine on the body surface on saccate pollen. **a.** Simple linear furrows, striations; **b.** Well-developed sexinal bands, taeniae; **c.** A' & C'—Uniformly wide, broad, inter-striation spaces of structured sexine termed as Plaga; B'-linear, narrow furrows of unstructured sexine, termed as striations; **d.** A & C-Structured sexinal bands termed as Taeniae; B-irregularly wide unstructured sexinal inter taeniate space termed as platea; **e, f.** Schematic representation of sectional view of the exine layer along lateral axis of body. **e.** passing across striations and. f. across taeniae. A', C'—Plagae and striation; A, C-Taeniae and platea.
Section of mature exine consisting of inner lamellated nexine (N) and structured sexine (S). Arrows indicate reduced sexine in a striation (e) and a platea (f).

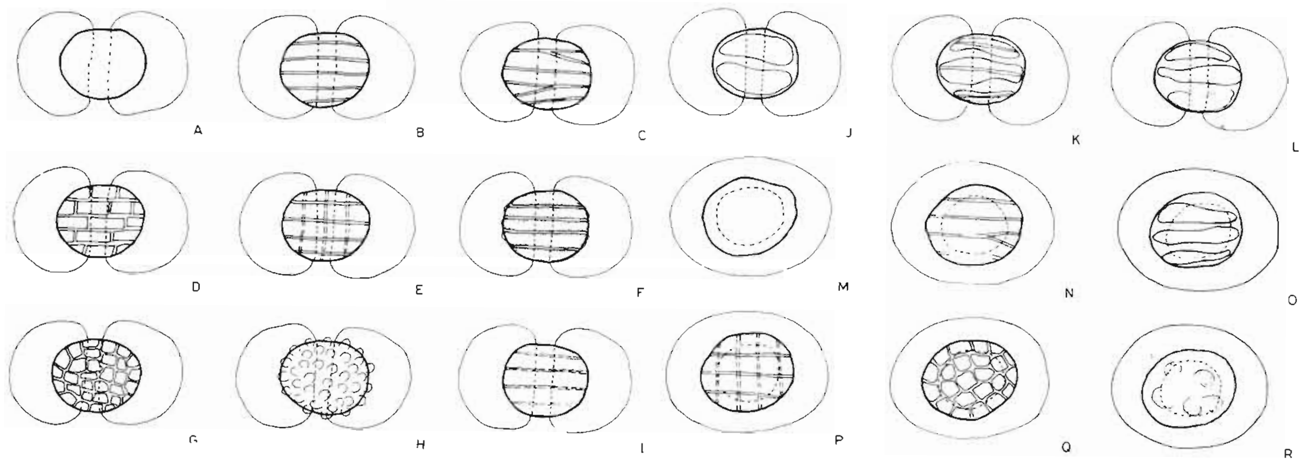
developed while taeniae are tape-worm-like bands having well-developed sexine (Text-fig. 1a, b). These descriptive terms are not mutually homologous. These two populations of pollen are entirely different from each other and, hence, the practice of their being clubed together as "striate pollen" is not acceptable. In view of these derivations, it is proposed here to term the inter-taeniate spaces as *Platea* (Latin-street, pl.-*ae*), and inter-striation space as *Plaga* (Latin-flat surface, tract; pl.-*ae*). The platea is the space irregularly wide along its length between two taeniae, having minimal development of sexine, in which no distinct structure has developed. The plaga is the inter-striation region, having fair development of sexine above the nexine layer exhibiting structure of various kinds (Text-fig. 1c, d). Thus, taeniae delimit the plateae and plagae delimit the striations; the *striations* are homologous to *plateations* and *taeniae* to *plagae*.

During the ontogeny of sporoderm (Taylor, 1982; Taylor *et al.*, 1984), at an advance stage the differentiation of sexine and nexine is relative and also variable in different parts of the pollen body. It is supposed that in the areas of grooves or scars, further development of sexinal part does not occur, leaving thinner areas, probably to provide elasticity to the body. Such situation exists in the case of striations and the plateae. Although both nexine and sexine layers are present in these regions, the latter does not develop the internal structures and remains a least developed homogeneous layer (Text-fig. 1e, f.).

## Sequential pattern of evolution

*Talchir*—The oldest palynofloras of the Indian Gondwana sediments are known from Talchir Formation (Early Permian in age) described by Lele and Makada (1972), Chandra and Lele (1979) and Lele (1984). It has been established that generally simple horizontal grooves (striations) are present at this level in bisaccate pollen only. The striations are simple mostly unbranched and merging at their ends with the body outline (e.g. *Faunipollenites*, Text-fig. 2B). In the younger horizon within the Talchir itself, one more variation is observed where the ends of striations meet with each other at the terminal side of the body forming a circum-striate pattern (e.g. *Circumstriatites*). In this horizon few monosaccate pollen are also recorded which show reticuloid, tuberculoid type of pattern on body (e.g. *Tuberisaccites*, Text-fig. 2R). Thus, it is concluded that simple striate pattern appeared in Talchir which later on showed only a little variation in disaccate pollen The appearance of monosaccate pollen with reticuloid grooves, or islands of sexine to give rise to a tuberculoid mosaic, is independent of the path of disaccate pollen This level is identified as line of appearance of striations—*a starting plane* (Text-fig. 3a).

*Karharbari*—In the later part of Early Permian (Karharbari Formation), few pollen with slight diversified variation in characters occur, i.e., the number of striations increases and vertical partitions in between these, at places, start appearing. Few bisaccate pollen having reticuloid-type of striations (e.g. *Rhizomaspora*) also make their appearance. Such forms may have their lineage of origin from monosaccate pollen which bear comparable characters of older horizon, i.e., Talchir Formation These variations take place in gradual pace among the pollen of Early Permian time. The divergence



**Text-figure 2**—Pattern of variations in striations and taeniae: **A.** Non striate bisaccate pollen (*Platysaccus*); **B.** Simple horizontal striations (*Faunipollenites*); **C.** Bifurcation in horizontal striations (*Striatites*); **D.** Brick-work pattern of striations (*Lahirites*); **E.** Striations on both the faces of central body (*Distriatites*); **F.** Flabbiness of sexine in between striations (*Striatites*); **G.** Reticuloid pattern in bisaccate pollen (*Rhizomaspora*); **H.** Tuberculoid pattern (*Tumeripollenites*); **I.** Faint striations (*Crescentipollenites*); **J.** Two prominent taeniae (*Leuckisporites*); **K.** Taeniae which bear striations (*Lunatisporites*); **L.** Taeniae with platea in between them (*Lunatisporites*); **M.** Non-striate monosaccate pollen (*Parasaccites*); **N.** Simple and bifurcated horizontal striations in monosaccate pollen (*Striomonosaccites*); **O.** Striations on both the faces of central body (*Distriomonosaccites*); **P.** Taeniate monosaccate pollen (*Kamthisaccites*); **Q.** Reticuloid pattern in monosaccate pollen (*Barakarites*); and **R.** Tuberculoid pattern in monosaccate pollen (*Tuberisaccites*).

and proliferation in character under study are foreshadowed at the Karharbari level. The most significant event which took place at Karharbari level is the appearance of vertical partitions and then its manifestation into the reticuloid pattern (Text-fig. 3a).

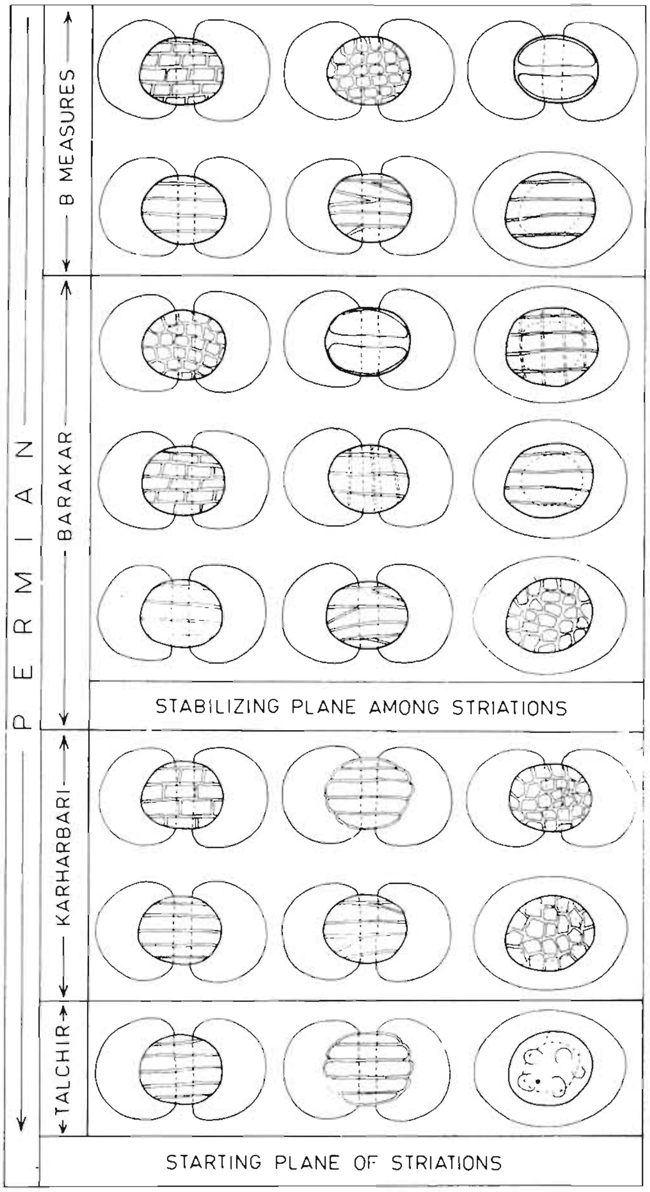
*Barakar*—Maximum proliferation in the quantity and quality of striations is found among the disaccate and monosaccate pollen grains of Barakar palynofloras. Hence, this level is identified as *Line of maximum proliferation* where the *stabilizing plane* starts, and preponderance of striate pollen is marked in having all kinds of striation patterns—simple, branched, vertical partitions, brick-work and reticuloid (Tiwari, 1965; Bharadwaj & Tripathi, 1981). Beside these, few monosaccate pollen are also recorded for the first time which bear perfect striations on one of the faces of the body (*Striomonosaccites*, Pl. 1, fig. 12), or even on both the sides (*Distriomonosaccites*, Text-fig. 2 O). One more kind of diversification is observed, i.e., the presence of two structured sexinal bands on body, leaving a wide, unstructured part in between. These sexinal bands are described as taeniae, as in *Lueckisporites*. Thus in the true sense of morphography, the bi-taeniate pollen staged at the Barakar level (Text-fig. 3a).

*Kulti*—In Kulti Formation of Late Permian, further variations in the kind of striations are not seen. However, an increase in the number of vertical partitions has been noted (Kar, 1968). Such an arrangement leads to the close brick-work pattern which appears as an irregular arrangement on periphery (Text-fig. 3a). In any case, the brick-work pattern is not secondary in origin.

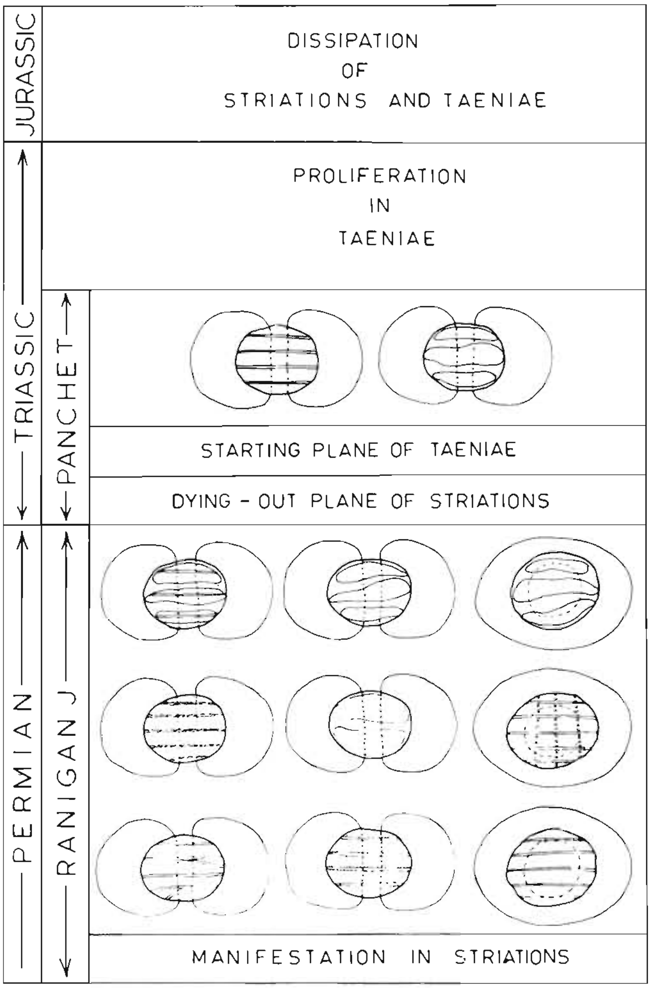
*Raniganj*—In Raniganj Formation (Late Permian), different diversifications take place, both in bisaccate as well as monosaccate pollen (Text-fig. 3b). These are given below:

(i) Flabbiness of plagae (sexinal bands between striations) transgresses towards the taeniate organisation (Pl. 1, fig. 11).
(ii) Beginning of development of irregular platae (space in between two structured sexinal bands); in other words, striations losing their linear nature and stepping towards the plateation (Pl. 1, fig. 8).
(iii) Existence of faint, incomplete grooves indicating a disappearing phase of striations (Pl. 1, fig. 4).
(iv) Prominent taeniae (sexinal bands) and well-defined platae (irregular unstructured areas in between them) forming taeniate organization (*Lunatisporites, Kamthisaccites*; Pl. 1, figs 10, 13).
(v) Taeniae, which bear striations on them (Pl. 1, fig. 14).
(vi) Tuberculoid pattern developed because of sexinal islands on body (Text-fig. 2R).

*Panchet*—Early Triassic pollen flora in Panchet



**Text-figure 3a**



**Text-figure 3b**

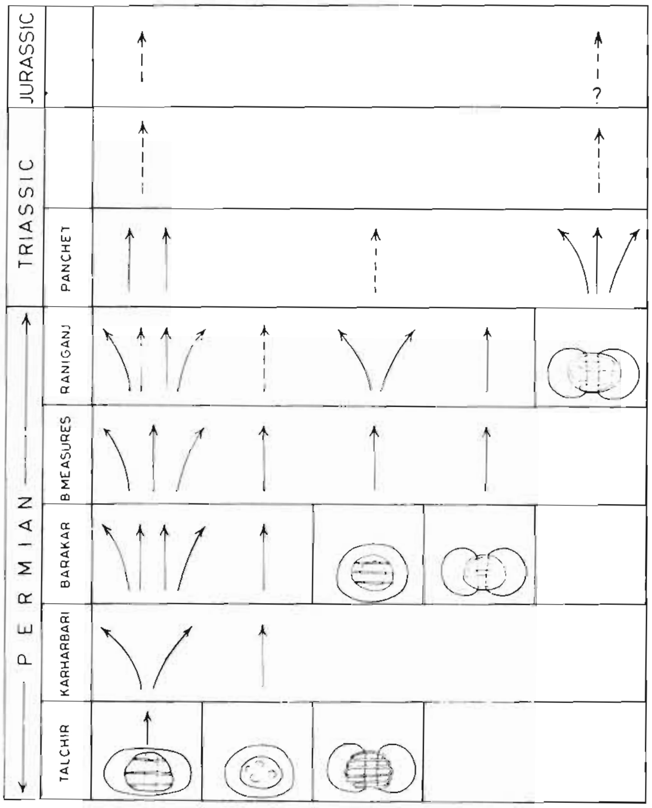
**Text-figure 3 a, b**—Relative complexity in nature of striations and taeniae in different palynological assemblages of the Indian Gondwana formations.

Formation (Maheshwari & Banerji, 1975; Bharadwaj & Tiwari, 1977; Tiwari & Rana, 1980, 1981) opens another chapter in the course of evolution of striations and plateations (Text-fig. 1), as it heralds the era of diversification in nature of taeniae on one hand and declination phase of striations on the other. Therefore, it makes the *Starting plane* of taeniae and *Dying-out plane* for striations (Text-fig. 3b).

## Derivations

The trends of complexity and paths of variability followed by striations, platae and allied characters (Text-figs 2, 3a, b) in saccate pollen through Gondwana horizons can be summed up (Text-fig. 4) as below:

1. Few, simple linear horizontal grooves (striations) in bisaccate pollen are recorded within the oldest palynofloras of Early Permian age. Also, bi-taeniate pollen are recorded.
2. Proliferation in quantitative and qualitative nature of striations begins at the level of late Early Permian time (Lower Barakar Palyno-sequence). Such diversification involves increase in number of striations, with bi- or trifurcation, presence of numerous vertical partitions, formation of brick-work, reticuloid pattern and other arrangement.
3. At the level of Late Permian/Early Triassic times, number of vertical partitions between horizontal striations declines. In some cases, striations become faint probably indicating the *dying-out plane* of that character.
4. The multi-taeniate nature scantily appears in the late Late Permian palynofloras but diversifies into several lines of variability in the Early Triassic.



**Text-figure 4**—Pattern of diversification and proliferation in striations and taeniae through Indian Gondwana formations.

5. Both, the striations and taeniae tend to die out in the Late Triassic, the former precedes the latter. In the Upper Mesozoic almost every line of striation-taeniae character disappears in the saccate pollen.

## CLIMATIC RELATIONSHIP

With the accumulation of data for palaeoclimatic inferences in variously related disciplines, viz., lithology, sedimentology and palaeogeography, it is evidenced that the earliest Permian (Talchir) sediments are glacigene in nature. The palynoflora is the simplest and primitive in its diversification which indicates a result of extreme cold climate with low humidity during Early Permian. Such inferences are also supported from the studies conducted by Suttner and Dutta (1986) on mineralogical analysis.

During late Early Permian (Karharbari) the climate ameliorated. Also, an increase in humidity was favourable for producing luxurient vegetation which contributed to the formation of coal. As discussed in preceding pages, at the level in geological sequence, the evolutionary paths of striations initiated several new experiments; the reticuloid pattern, vertical partitions and bifurcation of simple linear grooves made their appearance. This kind of variability seems to be related with the relatively higher humidity and rise in temperature.

With the commencement of late Early Permian time (Lower Barakar), maximum diversification is recorded in the nature of striations, with several lines of manifestations. The acme of qualitative preponderance in striations is exhibited at this level, which persisted throughout the Barakar Formation. Such a state of complexity in striations appears to have a direct relationship with increasing precipitation, temperate climate and moderately warm condition. It is also supported by the studies of Dutta and Suttner (1986) and Tiwari and Tripathi (1988).

During the time of deposition of Kulti Formation (Barren Measures; early Late Permian), the climate had been interpreted to be warm with low to medium humidity (Lele, 1976; Chandra & Chandra, 1988). However, existence of diversified palynoflora does not support dry or arid conditions. The continuity in the complexity of striations from Barakar Formation to Barren Measures can be corroborated with the results of heavy-mineral analysis of these sediments (Kar *et al.*, 1964) which suggests a tropical to subtropical humid climate.

Later part of Late Permian was a warmer period with very high humidity; such a condition is represented through the whole span of Raniganj Formation. However, the decline of temperature and humidity in the upper most Permian is indicated. The reticuloid and brick-work pattern of striations decline during Raniganj. Simple striations with lesser frequency of bifurcations are in prominence. Two new trends have been observed in the nature of these striations at this level (a) vanishing-phase of striations is depicted by the presence of faint grooves on central body, (b) flabbiness of plagae (sexine in between two striations) tending towards taeniate construction.

In Early Triassic time, there are evidences for change in climate, but the desertic or arid conditions were not existing because luxuriant vegetation thrived as implied by the diversified and rich spore-pollen populations. Diminishing trend of striation-complexity and diversification in taeniae characterise the Early Triassic saccate pollen group. The warming up of climate thus appears to be linked with thickening of several strips in the form of taeniae. Recently Suttner and Dutta (1986) on the basis of mineralogical and oxygen isotope studies have inferred that the climate gradually changed to warmer and moderately semi-arid in Upper Panchet with seasonal fluctuations rather than extreme aridity. Abundance of taeniae and their maximum complexity are indicative of severe seasonal fluctuations with drier intervals than those experienced during Late Permian time.

## FUNCTIONS

Functions of striations and plateations are still a mystery. Direct attempt to link climate with these characters does not lead to conclusion because similar climatic conditions existed at several different levels of geological period where such characters did not develop. But, if their appearance, dominance and disappearance are taken as events of evolutionary phenomenon in a particular time period, they may have an expression of climate during that span of time.

Appearance, existence and disappearance of striations and taeniae during Permian through Triassic is a global phenomenon. The cause of moisture-content-variability may be attributed to these grooves and furrows, so as to accommodate the shrinkage of exine during the loss of moisture and to save the mother cell from destruction. This factor of harmomegathy might give rise to some similar pattern in exine of pollen grain but the striations and plateations are very regular, well organized and systematic features: the reticuloid pattern, the vertical partitions, the irregularly wide space between thick sexinal strips and an array of other arrangements do not evidence the functionality of these grooves as accommodative safty-valves.

It has also been opined that the striations and the plateae might act as emergency tenuitates for germination (Tiwari, 1982). This appears to be a plausible explanation for their existence because after the shifting of germinal pole, multiple probable sites for germination could prove to be an asset for the cell. However, the striations and plateations are not made up of nexine alone but contain a thin layer of sexine also. Therefore, evidence must be sought for such a proposition. It appears that occurrence of striations and plateations in saccate pollen is nothing but an episode in the course of evolution of organisation with several paths of experimentation in nature for the search of fittest situation during the Permian and Triassic times. In any case they are not without mechanism meaning—they could play a role of exine protector, providing volume compensation, germination gates, or moisture regulators.

## ACKNOWLEDGEMENTS

This paper is the result of encouragement given by Dr B. S. Venkatachala, Director, BSIP, who initiated informal group discussions on the evolutionary aspects of Gondwana palynology. The author is grateful to him for his valuable suggestions during the progress of this work. Thanks are extended to Dr R. S. Tiwari, for useful discussions and critically going through the manuscript.

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# Permian-Triassic palynofloral transition in Godavari Graben, Andhra Pradesh

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Srivastava, Suresh C. & Jha, Neerja 1990. Permian-Triassic palynofloral transition in Godavari Graben, Andhra Pradesh. *In* Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany'. Palaeobotanist* **38** : 92-97

Palynological investigation of bore hole GAM 7 from Mailaram area (Paloncha Neck) in Godavari Graben has revealed five assemblages. Assemblages I to IV represent late Permian, being dominant in striate disaccate pollen. Assemblage V denotes an Early Triassic age in view of the preponderance of *Lunatisporites pellucidus* and *Verrucosisporites.* The changeover from striate-disaccate to taeniate phase is quick and sharp indicating a palynological break. The transition from Permian to Triassic in this part of Godavari Graben occurs in a paraconformable sequence The Permian Triassic boundary passes within a gap of 12 m and a definite presence of Panchet palynoflora is established.

**Key-words**—Palynology, Godavari Graben, Permian-Triassic (India).

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## सारॉंश

### आँध प्रदेश में गोदावरी द्रोणिका में परमी-त्रिसंघी परागाणुवनस्पतिजातीय परिवर्तन

सुरेश चन्द्र श्रीवास्तव एवं नीरजा झा

गोदावरी द्रोणिका में मेलारम क्षेत्र (पलौंचा नेक) से वेध-छिद्र जी-ए-ऍम०-7 के परागाणविक अन्वेषण से पाँच समुच्चय व्यक्त हुई हैं। रेखीय-द्विकोष्ठीय परागकणों से भरपूर समुच्चय एक से चार तक अनंतिम परमी आयु इंगित करती हैं। पाँचवीं समुच्चय **ल्यूनाटिस्पोराइटिस पेल्यूसिडस** एवं **वेरुकोसिस्पोराइटिस** की उपस्थिति के कारण प्रारम्भिक त्रिसंघी आयु प्रस्तावित करती है। रेखीय द्विकोष्ठीय से टीनिएट अवस्था में तीव्र परिवर्तन से परागाणविक अनिरंतरता व्यक्त होती है। गोदावरी द्रोणिका के इस भाग में परमी से त्रिसंघी परिवर्तन विशेष क्रम में हुआ है। परमी-त्रिसंघी सीमा 12 मीटर के अन्दर ही प्रेक्षित की गई है तथा इसमें पंचेत परागाणुवनस्पतिजात की स्पष्ट उपस्थिति स्थापित की गई है।

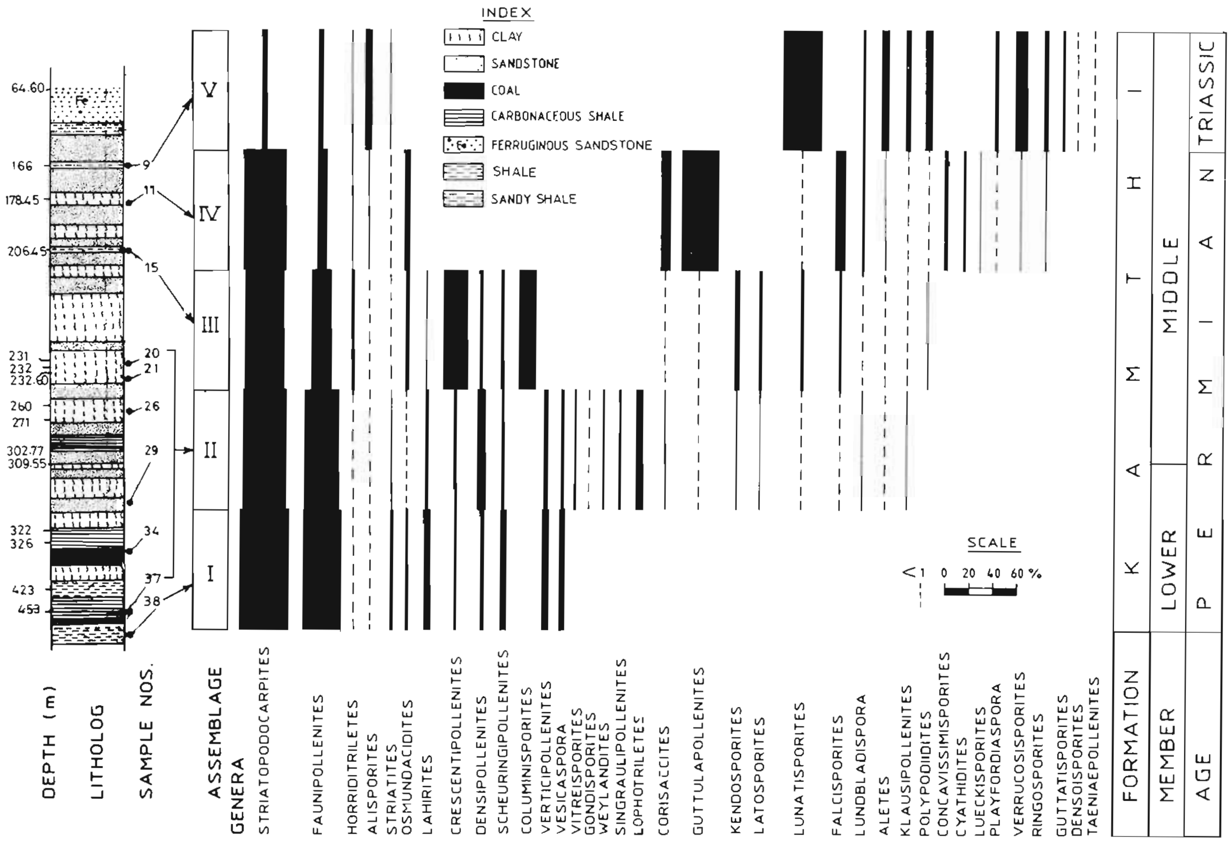
THE Gondwana outcrops in Godavari Graben extend over a length of about 350 km with an average width of 55 km. There is a well-defined constriction in the Paloncha-Kothagudem area where the average width narrows down to about 6 km. The bore-hole GAM7 studied here was drilled in Mailaram area (Paloncha Neck) by the Geological Survey of India.

## PALYNOASSEMBLAGES

The vertical distribution of various quantitatively significant palynotaxa in bore-hole GAM7 is shown in Histogram 1. In all, five palynoassemblages have been demarcated as under:

*Assemblage I*—This assemblage, recorded at 453 m depth, is dominated by striate-disaccate pollen, chiefly *Striatopodocarpites* (40%) and *Faunipollenites* (32%). Other important genera are *Verticipollenites* (4%) and *Labirites* (5%). *Densipollenites* (2%) and *Crescentipollenites* (2%) appear in low percentage while the trilete spores are very rare.

*Assemblage II*—Recorded between 423 to 231 m, this assemblage is characterised by the dominance of *Striatopodocarpites* (35%) and *Faunipollenites* (29%). *Densipollenites* increases up to 12 per cent at 423 m but the average value remains around 6 per cent. *Crescentipollenites* (2%) still remains insignificant. *Lunatisporites, Vitreisporites, Kendosporites, Guttulapollenites, Lundbladispora, Falcisporites, Klausipollenites,* etc. appear for the first time. In addition, *Gondisporites, Weylandites,* and



**Histogram 1**—Distribution of important palynotaxa in bore-hole GAM 7, Mailaram area, Godavari Graben.

*Singraulipollenites* occur in low percentage only. The percentage of trilete spores also increases as *Lophotriletes* occurs up to 13 per cent between 260-271.75 m depth level.

*Assemblage III*—At the depth of 206.45 m, striate disaccate pollen are still the dominant elements of the palynoflora (*Striatopodocarpites* 32% + *Faunipollenites* 17%). *Crescentipollenites* rises to 20 per cent. *Columinisporites* (14%) has a restricted distribution. *Kendosporites* (4%) and *Lunatisporites* record a slight increase.

*Assemblage IV*—This association is recorded at 178.45 m. The striate-disaccate (*Striatopodocarpites* 33%) pollen continue to dominate the palynoflora. Here, the subdominance is formed by *Guttulapollenites* (29%). *Corisaccites* and *Falcisporites* (8% each) also increase in percentage. The genera, like *Phidiaesporites, Triquitrites, Iraquispora, Cyathidites, Concavissimisporites,* are restricted to Assemblage IV. *Osmundacidites* attains its maximum value at 178.45 m.

*Assemblage V*—It is recorded at 166 m depth level. The striate-disaccate pollen show a sharp decline and are replaced by taeniate pollen genus *Lunatisporites* (32%); *Verrucosisporites* (10%) exhibiting a fair rise in frequency. *Taeniaepollenites* and *Guttatisporites* (3%) are restricted to Assemblage V. *Klausipollenites* (4%), *Playfordiaspora* (3%), *Ringosporites* (4%), *Polypodiidites* (6%) and *Alisporites* (7%) increase in percentage. Aletes (10%) also mark a significant increase.

## DISCUSSION

Five palynoassemblages demarcated in bore-hole GAM-7 essentially fall under two groups:

1. Assemblages I to IV are chiefly dominated by striate-disaccate pollen.
2. Assemblage V shows a dominance of taeniate pollen, alongwith cingulate-cavate trilete spores.

The dominance of disaccate pollen in Assemblages I-IV is comparable to the Late Permian palynofloras known from various basins of India. However, the occurrence of the following genera in the present sequence has been observed for the first time in Godavari Graben.

1. *Kendosporites* appears in Assemblage II and becomes significant in Assemblage III in Godavari Graben, whereas in Singrauli (Tiwari & Srivastava, 1984) and Raniganj (Singh & Tiwari, 1982) coalfields this genus occurs sporadically.

2 *Columinisporites* is well-represented in Assemblage III. The only other record in India, though low in percentage, is from Raniganj Coalfield (Singh & Tiwari, 1982) from where similar forms have been described as *Striatosporites*. This genus has been recorded from Baralaba Coal Measures of Australia (Foster, 1979), Late Permian of Africa (Jardine, 1974; Anderson, 1977) and Autunian of France (Alpern & Doubinger, 1973).

3 Presence of *Triquitrites, Iraquispora, Phidiaesporites* in Assemblage IV and *Taeniaepollenites* in Assemblage V forms the first record from the Indian subcontinent. *Ringosporites, Kraeuselisporites, Cyathidites* and *Concavissimisporites* present in Assemblage IV are also recorded from Panchet Formation of Raniganj Coalfield (Tiwari & Singh, 1983) but the percentage is low as compared to the Godavari Graben. Most of the above genera present in Assemblage IV along with *Guttulapollenites* and *Corisaccites* bear a close comparison with the assemblage recorded from Chhidru Formation in Salt Range (Balme, 1970). The common taxa in Assemblage IV of Godavari Graben and Chhidru Formation of Salt Range (West Pakistan) are: *Leiotriletes* sp., *Lophotriletes* sp., *Cyathidites* sp., *Cyclogranisporites arenosus, Osmundacidites senectus, Triquitrites proratus, Iraquispora labrata, Polypodiidites* sp., *Polypodiisporites* sp., *Playfordiaspora cancellosa* (= *Guthoerlisporites cancellosus*), *Lunatisporites noviaulensis* (= *Taeniaesporites noviaulensis*), *Vitreisporites pallidus, Falcisporites stabilis, Klausipollenites schaubergeri, Striatopodocarpites* (= *Protohaploxypinus*) *microcorpus, Ringosporites* (= *Nevesisporites*) *fossulatus, Verrucosisporites narmianus, Densipollenites indicus, Schizosporis* sp.

Assemblage IV also compares with the *Protohaploxypinus microcorpus* Zone (*Falcisporites* Superzone) of Australia in view of the common occurrence of *Protohaploxypinus* (= *Striatopodocarpites*), *Falcisporites* and *Playfordiaspora* (Rigby *et al.*, 1987). The Late Permian palynoflora of Madagascar (Goubin, 1965) also compares with Assemblage IV in view of the occurrence of *Guttulapollenites hannonicus* and *G. gondwanensis.*

Assemblage V, the youngest palynozone in bore-hole GAM7, records the conclusive evidence of the presence of Lower Triassic in Godavari Graben. This assemblage compares with *Lunatisporites* and *Verrucosisporites* Assemblage from the Panchet Formation of Raniganj Coalfield (Tiwari & Singh, 1983).

The palyno-assemblage from Budharam Area (Srivastava & Jha, 1988) in Godavari Graben is older than the Assemblage V recorded here in view of higher percentage of *Lundbladispora* and

→

## PLATE 1

(All co-ordinates refer to Leitz Laborlux D microscope and all photographs are magnified × 500).

1 *Playfordiaspora cancellosa*, Slide no. BSIP 10013; Coordinates 106.4 × 53.2.

2. *Striatopodocarpites microcorpus*, Slide no. BSIP 10003 Coordinates 102.9 × 41.8.

3. *Densoisporites* sp., Slide no. BSIP 100064; Coordinates 98.6 × 61.9.

4. *Cyathidites* sp., Slide no. BSIP 9999, Coordinates 97.5 × 52.8.

5 *Triquitrites* sp., Slide no. BSIP 10004; Coordinates 109 × 40

6,7. *Columinisporites* sp., Slide no. BSIP 10009; Coordinates 113.5 × 44.

8. *Concavissimisporites* sp., Slide no. BSIP 10005; Coordinates 99 × 52.9.

9. *Vitreisporites pallidus*, Slide no. BSIP 10006; Coordinates 108.8 × 65.8.

10. *Ringosporites fossulatus*, Slide no. BSIP 10007; Coordinates 111.4 × 62.3.

11. *Phidiaesporites* sp.

12. *Klausipollenites* sp., Slide no. BSIP 10008; Coordinates 99 × 71.0.

13. *Osmundacidites* sp., Slide no. BSIP 10007; Coordinates 111.4 × 56.

14. *Kendosporites* sp., Slide no. BSIP 10010; Coordinates 99 × 52.9.

15. *Lunatisporites* sp., Slide no. BSIP 10013; Coordinates 103.3 × 68.2.

16. *Polypodiidites* sp., Slide no. BSIP 10015; Coordinates 109 × 62.8.

17 *Taeniaepollenites* sp., Slide no. BSIP 10012; Coordinates 96.5 × 65.6.

18 *Lundbladispora* sp., Slide no. BSIP 10014; Coordinates 104 × 67.9.

19. *Guttulapollenites* sp., Slide no. BSIP 9999; Coordinates 109 × 44.5.

20. *Guttulapollenites* sp., Slide no. BSIP 10002; Coordinates 104.6 × 58.

21. *Guttatisporites* sp., Slide no. BSIP 10003; Coordinates 101 × 45.5.

22. *Lunatisporites* sp., Slide no. BSIP 10011; Coordinates 105 × 56.6.

23. *Verrucosisporites* sp., Slide no. BSIP 10003; Coordinates 101 × 60.

24. *Falcisporites* sp., Slide no. BSIP 10003; Coordinates 108.2 × 60.5.

25. *Lunatisporites* sp., Slide no. BSIP 10011; Coordinates 111 × 58.4.

26. *Iraquispora* sp., Slide no. BSIP 10003; Coordinates 105 × 55.8.

27. *Verrucosisporites trisectus.*, Slide no. BSIP 10001; Coordinates 98.7 × 52.

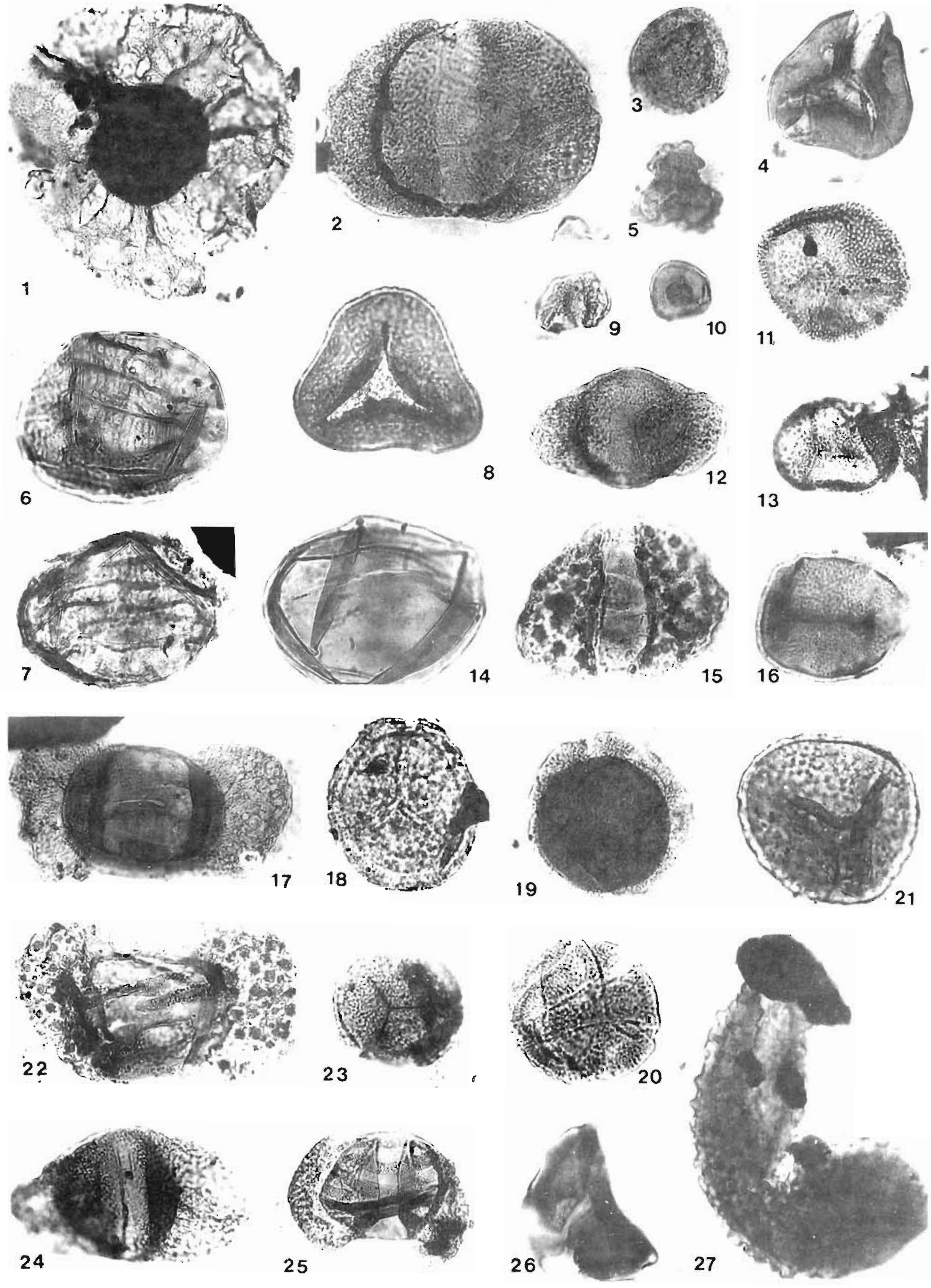


PLATE 1

*Densoisporites* which precedes the taeniate phase in Damoder Graben. The increase in percentage of *Klausipollenites, Ringosporites, Playfordiaspora, Lundbladispora, Polypodiidites* and *Alisporites* further indicates its affinity with Lower Triassic palynofloras. *Taeniaepollenites*, another rare taeniate genus in the present assemblage, and *Guttatisporites* restricted to Assemblage V only are also known from the Triassic of the Netherlands (Visscher, 1966). *Guttatisporites* has also been observed in low percentages in Panchet Formation of Damoder Valley Coalfield, India (Tiwari & Singh, 1983).

*Lunatisporites pellucidus* Zone (*Falcisporites* Superzone) of Australia (Rigby *et al.*, 1987) compares with Assemblage V in view of the common occurrence of *Lunatisporites pellucidus*. Similarly, the assemblage of Mianwali Formation, Salt Range (Balme, 1970) is comparable in having *Lunatisporites pellucidus* zone. The species common in the presently identified Assemblage V and Mianwali Formation, Salt Range are *Osmundacidites senectus, Ringosporites* (= *Nevesisporites*) *fossulatus, Ringosporites ringus, Densoisporites playfordii, Kraeuselisporites* sp., *Playfordiaspora cancellosa* (= *Guthoerlisporites cancellosus*), *Lunatisporites* (= *Taeniaesporites*) *pellucidus, L.* (= *Taeniaesporites*) *noviaulensis, Falcisporites stabilis, Klausipollenites schaubergeri, Verrucosisporites narmianus*.

The present palynological evidence indicates that Assemblages I-IV belong to Late Permian while Assemblage V conclusively shows Early Triassic affinity. The change-over from Late Permian to Early Triassic between 178-166 m is sharp and well-defined which is evident from a sudden change of striate-disaccate dominant assemblage to taeniate disaccate dominant assemblage. This conclusion is further substantiated by the study of palynofloral succession from Raniganj Coalfield (Tiwari & Singh, 1986) while a complete succession of Late Permian palynofloras is present in bore hole GAM7 up to 178 m, there is a distinct absence of two palynoassemblages (P-I *Striatopodocarpites* + *Klausipollenites*; P-II *Verrucosisporites* + *Callumispora*) which should precede the present *Lunatisporites* + *Verrucosisporites* Assemblage. This indicates a palynological break, though minor, in the palynological succession of bore core GAM7 between 178 to 166 m. The above palynological assemblage has not been recorded in the present study.The 12 meter strata which consists of greenish grey sandstones, did not yield microfossils.

Lithostratigraphically, the sediments up to 453 m in bore-hole GAM7 represent the Lower and Middle members of the Kamthi Formation (*sensu* Raja Rao, 1982). The Lower Member, between 272.75-453 m, is rich in carbonaceous shale and coal, alternating with white sandstone. The overlying greenish-grey sandstone with greenish-grey shales/clay up to 136 m depth are devoid of coal. The sediments above 136 m are represented by coarse-grained, ferruginous cross-bedded sandstone and alternating sandy shales. The entire sequence above 272.75 m is normally considered to represent the Middle Member of the Kamthi Formation.

Recently, Ramanamurthy and Rao (1987) have reconsidered the lithostratigraphic succession of the Lower Gondwana sediments in Ramagundam area of Godavari Graben and have raised the status of Lower Member and the lower part of the Middle Member to be equivalent to Raniganj Formation while the upper part of the Middle Member (represented by an alternate sequence of red/brown, sandy, calcareous clays and cross bedded sandstones) to be equivalent to the Panchet Formation. However, lithology attributed to Panchet Formation by Ramanamurthy and Rao (1987) in Godavari Graben does not conform to the lithology of Panchet Formation of the Damoder Basin—the type area. The present palynological finding in bore-hole GAM7 also shows that Panchet palynoflora commences much earlier within the green sandstone and clay sequence. Thus the Permian-Triassic boundary transgresses in the upper part of the Middle Member of Kamthi Formation (*sensu* Raja Rao, 1982) and Upper Raniganj (*sensu* Ramanamurthy & Rao, 1987).

Lithozone 3 of the Infra-Kamthi Formation (Kutty *et al.*, 1988), encompasses the Middle Member of the Kamthi Formation of earlier workers. This zone contains the *Endothiodont-Cistecephallus* fauna representing Late Permian-?late Early Permian. The lithological attributes of lithozone 3 may represent a part of the sequence studied in bore-hole GAM7 where the palynological transition has been observed. In view of the above discussion, it now appears certain that the younger part of Middle Member of the Kamthi Formation (*sensu* Raja Rao, 1982), represented by green sandstone and clay, and the overlying coarse-grained ferruginous sandstone with alternating sandy shale should represent the Panchet Formation in Godavari Graben. The first appearance of prevalent red colour of sandstones and clay representing Panchet Formation, as opined by Ramanamurthy and Rao (1987), does not corroborate with the present investigation. However, it appears difficult to demarcate a lithological boundary between the Raniganj and Panchet formations in bore-hole GAM7 as the sandstones and shales with greyish-green tint continue downwards having Late Permian assemblages and, therefore, the contact between Upper Permian and Lower Triassic sediments is considered to be represented by a paraconformity.

## CONCLUSION

Palynological analyses record the presence of definite Lower Triassic sediments in bore-hole GAM7, Mailaram Area (Paloncha Neck), Godavari Graben. The Permian-Triassic boundary is located within Middle Member of the Kamthi Formation. The palynofloral transition from *Protohaploxypinus* (= *Striatopodocarpites*) *microcorpus* to *Lunatisporites pellucidus* Zone indicates a palynological break, though minor in the succession. The palynofloral change-over from Permian to Triassic does not commensurate a lithological change, hence the lithological Permian/Triassic boundary remains to be established. It is further suggested that the Permian-Triassic change-over occurs in a paraconformable sequence.

The sediments containing *Lunatisporites-Verrucosisporites* assemblage may be equivalent to the sediments containing Assemblage PIII A in Damoder Valley. Thus the lithic attributes of the Panchet Formation in Godavari Graben could be represented by greyish-green sandstone and clays overlain by predominantly coarse to medium-grained, cross-bedded sandstone and sandy, calcareous shale which are present in bore-hole GAM7 from the surface up to 166 m depth. Assemblage IV and V, which have a close comparison with a similar succession in Salt Range, impart a palaeogeographic provincialism during the period.

## ACKNOWLEDGEMENT

We sincerely thank the authorities of the Coal Wing, Geological Survey of India for valuable help rendered during the collection of bore-core samples.

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# *Rostrumaspermum venkatachalae* gen. et sp. nov., an archegoniate seed from Triassic of Nidpur, India

Shyam C. Srivastava & S. R. Manik

Srivastava, Shyam C. & Manik, S. R. 1990. *Rostrumaspermum venkatachalae* gen. et sp. nov., an archegoniate seed from Triassic of Nidpur India. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 98-104.

Some carbonized seeds recovered from plant-bearing Nidpur beds are assigned to *Rostrumaspermum venkatachalae* gen. et sp. nov. Evidence of archegonia with short tubular neck favours identity with conifers and settles precisely pineaceous affiliations.

**Key-words**—Megafossil, Archegoniate seed, Morphology, Triassic (India)

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## साराँश

### निदपुर (भारत) के त्रिसंघी कल्प से एक स्त्रीधानीयुक्त बीज : रोस्ट्रमास्पर्मम वेंकटाचालाइ नव प्रजाति व जाति

श्याम चन्द्र श्रीवास्तव एवं सुरेन्द्र राघोबा माणिक

निदपुर अश्मित-पादप धारक संस्तरों से उपलब्ध कुछ कार्बनी बीजों को **रोस्ट्रमास्पर्मम वेंकटाचालाइ** नव प्रजाति व जाति से नामाँकित किया गया है। छोटी नालाकार गर्दन युक्त स्त्रीधानी की उपस्थिति के कारण ये कोनिफरों से सजातीयता इंगित करते हैं और इनमें भी पाइनेसी कुल से।

CONTINUED investigations of plant-bearing Nidpur beds have yielded a number of carbonized seeds. One of these structurally preserved seeds which is characterized by the occurrence of tubular archegonia at the micropylar end of megaspore sac has constituted the matter for this paper. Of the reported seed taxa (Pant, 1978; Manik, 1988) from Nidpur, namely *Rugaspermum, Savitrispermum, Nidispermum, Pyriformispermum, Rotundaspermum* and *Pantiaspermum*, none has revealed any such feature. However, among the various fossil gymnosperms, only a few members of Glossopteridales, Pteridospermales, Bennettitales (= Cycadeoidales) and Cordaitales have shown archegonia at the apical end of megaspore sac. To add, all living members of gymnosperms are also characterized by the presence of archegonia with an exception of *Welwitschia* and *Gnetum* (Maheshwari & Sanwal, 1963).

Renault (1879) figured archegonia in *Cycadinocarpus angustodunensis* from Permian of France. Since then, Brongniart (1981, in: Seward, 1919) described a definite megaspore membrane surrounding prothallus tissue bearing two archegonia. Later, Seward (1919) dealt in detail the structural features of *Cardiocarpus sclerotesta* Brongniart and showed a well-developed pollen chamber. Below the chamber, the prothallus tissue is prolonged as a blunt, short tentpole along which on each side two small archegonia are located. He also instituted a seed taxon *Rhabdospermum cyclocarpon* and reported the presence of single archegonium through illustrations of megaspore sac (Seward, 1919, fig. 501-C, p. 340). Long (1944) observed three archegonia towards the apical end of female gametophyte around the tentpole in a Palaeozoic pteridospermous seed—*Lagenostoma ovoides* Williamson 1877. Long (1959, 1960) opined that Lower Carboniferous seeds are the first known to contain archegonia, with three archegonia being the most common number. Taylor and Millay (1979) marked a well-developed archegonial cavity in *L. ovoides.*

Since the discovery by Long was highlighted,

**Text-figure 1**—*Rostrumaspermum venkatachalae* gen. et sp. nov., reconstruction of seed depicting overall shape, various cutinized membranes associated with archegonia; in mid-cut-open to show a part of megaspore sac Ca × 50.

Neely (1951) described *Taxospermum undulatum* and depicted the megagametophyte with one spherical or elliptical archegonium on either side of the low tentpole. In this Pennsylvanian seed, Taylor and Millay (1979) identified a megagametophyte which is well-differentiated into a tentpole and archegonium containing cytoplasmic remnant. The gametophyte of *Pachytesta hexangulata* Stewart 1951 consisted of short tentpole with three archegonia around it. Andrews and Felix (1952) reported tentpole and a two jacketed archegonia in the female gametophytes of *Cardiocarpus spinatus* Graham 1935. Andrews (1961, fig. 13-3B) figured a Lower Carboniferous seed, *Sphaerostoma ovale* Benson 1914, where archegonia can be clearly marked but the author has made no mention of it in the description.

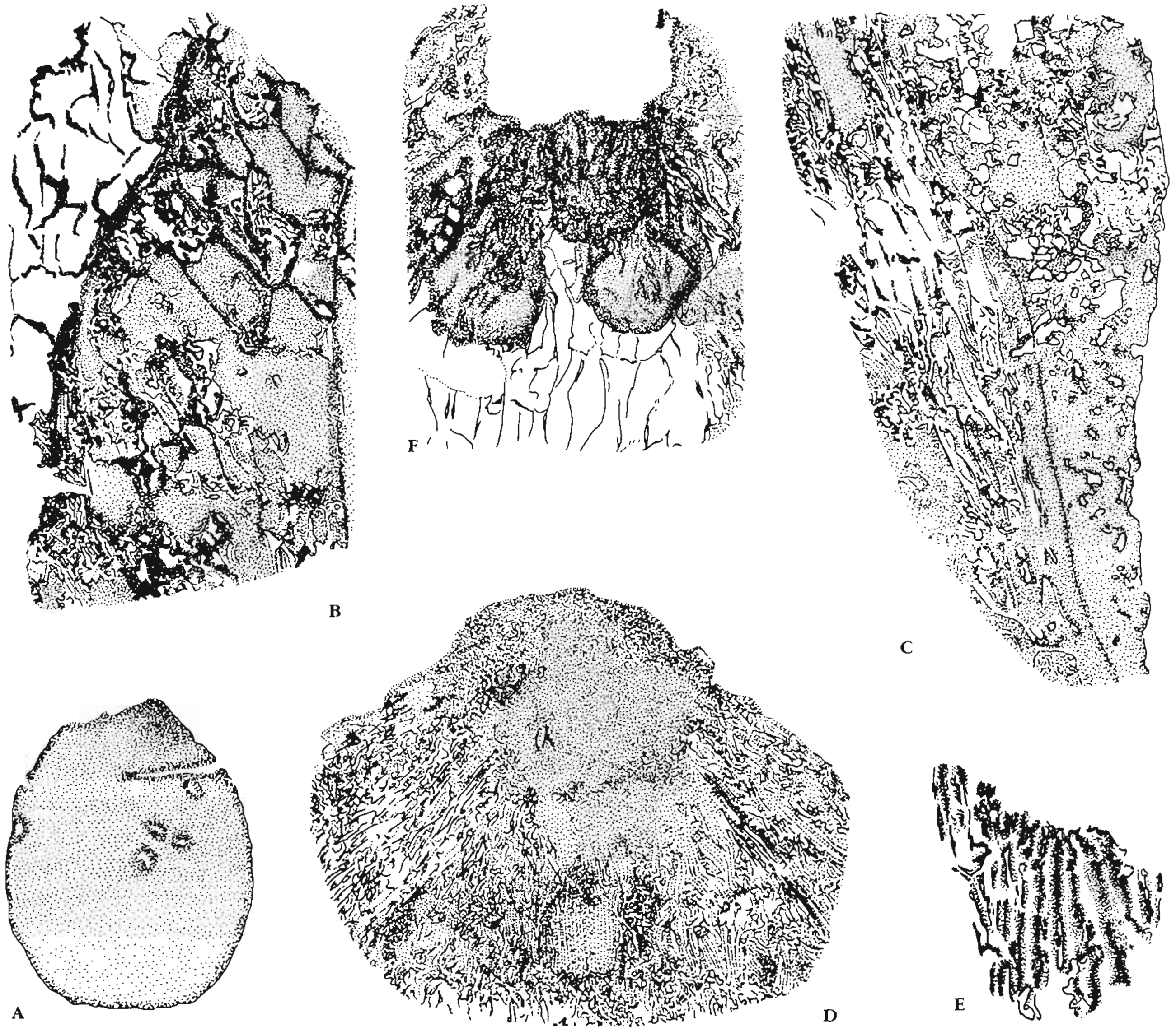
In addition, Rothwell (1971) reported ovoid cavities at the micropylar end of the megaspore sac of *Callospermarion pusillum* Eggert and Delevoryas 1960 and interpreted them to be archegonial cavities. However, in *Callospermarion undulatum,* described by Rothwell (1981), the definitive archegonia could be marked with tubular necks. But distinct number of archegonia could not be marked. In this character of tubular neck, *C. undulatum* approaches closest to the seed described here. Apart from this, Stidd and Cosentino (1976) were able to make out neck canal cells in the sunken archegonia of Carboniferous ovule *Nucellangium* Andrews 1949.

Other than these Palaeozoic seeds from northern hemisphere, interesting records of archegonia have also been made by Pant *et al.* (1985) from the Permian sediments of India. The two seed-genera described are: *Collospermum* and *Palaeocarpus* in which megaspore membrane is raised and prolonged into a tentpole-like structure. Under the surrounding depression, two or three spherical dark bodies are seen which are presumed to be archegonia on the basis of the presence of similar spherical archegonia found in cordaitalean and ginkgoalean seeds. From Late Permian of Bowen Basin, Queensland, Australia, Gould and Delevoryas (1977) have reported glossopteridean megasporophyll bearing seeds containing megagametophyte with one archegonium.

The aforesaid records have demonstrated varied archegonia in petrifactions and compressions of Palaeozoic seeds, but from Mesozoic not much is known. The first record came to light when Lignier (1911) in a reconstruction of *Cycadeoidea (Bennettites) morieri* (Lower Cretaceous of France) illustrated the presence of archegonia in the apical part of endosperm. However, Seward (1919) raised doubt regarding the occurrence of archegonia because the seed of *C. morieri* contains a well developed embryo. Since then, the occurrence of archegonia remained unknown till Sharma (1979), observed 2-3 archegonia in the apical part of endosperm of *Williamsonia*—ovules described from the Mesozoic of Rajmahal Hills, Bihar.

### *Rostrumaspermum* gen. nov.

*Diagnosis*—Seed ovate, tapering apically somewhat like a snout, micropylar end appearing flattened, integument in outer region thin on flanks and base, tending to be highly developed at apex, forming an outer integument characterized in extremities by radially disposed spaces; cellular structure of integument contorted revealing surface wall interspersed with pits, outer integument closely abutted to nucellus; nucellar membrane thin,



**Text-figure 2**—*Rostrumaspermum venkatachalae* gen. et sp. nov., **A.** Seed (alkali treated) showing overall outline and chalazal end, Slide no. BSIP 10272, × 25; **B.** A portion of megaspore sac adhered at places with nucellar membrane, Slide no. BSIP 10270, × 250; **C.** A part of micropylar end showing radially disposed spaces interspersed with irregular pits, Slide no. BSIP 10270, × 250; **D.** Apical region of seed exhibiting intensively cutinized flattened micropylar end, Slide no. BSIP 10271, × 150; **E.** A piece of outer integument showing cellular details, Slide no. BSIP 10270, × 250; **F.** Apical region of megaspore sac showing two distinct archegonia, Slide no. BSIP 10270, × 150.

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## PLATE 1

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*Rostrumaspermum venkatachalae* gen. et sp. nov.

1, 7 Carbonized seeds immersed in glycerine showing overall outline, micropylar and chalazal end (Holotype); Slide nos. BSIP, 10270, × 10; 10271, × 10.

2. Acid-treated seed depicting differentiation of cutinized membranes, specimen no. BSIP 10270, × 50.
3. Macerated seed after complete processing showing megaspore sac bearing two archegonia occupying almost entire space of nucellus, Slide no. BSIP 10270, × 25.
4. A portion of seed showing radially disposed spaces interspersed with irregular pits, Slide no BSIP 10270, × 150.
5. Apical end of seed magnified to show two spherical archegonia and distinctly differentiated radially disposed spaces, Slide no. BSIP 10270, × 50.
6. Megaspore sac highly magnified to show two distinct archegonia having tubular neck, Slide no. BSIP 10270, × 300.
8. Seed showing flattened top of micropylar end, Slide no. BSIP 10271, × 50.
9. Terminal portion of seed exhibiting distinctly differentiated nucellar depression, Slide no. BSIP 10272, × 50.


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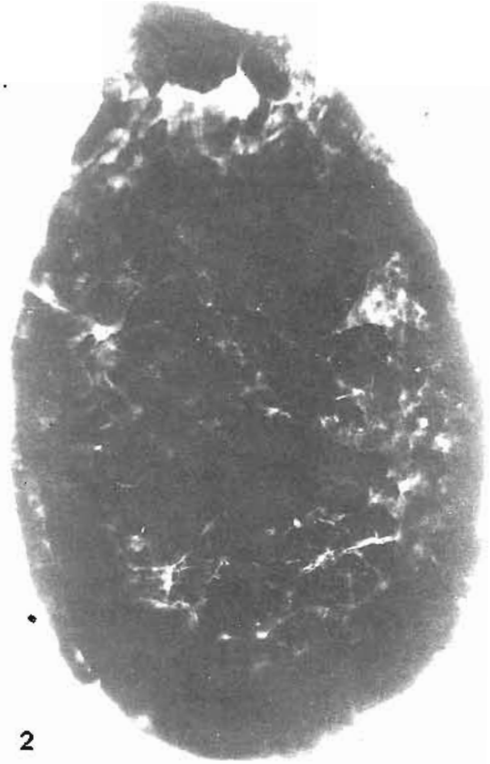
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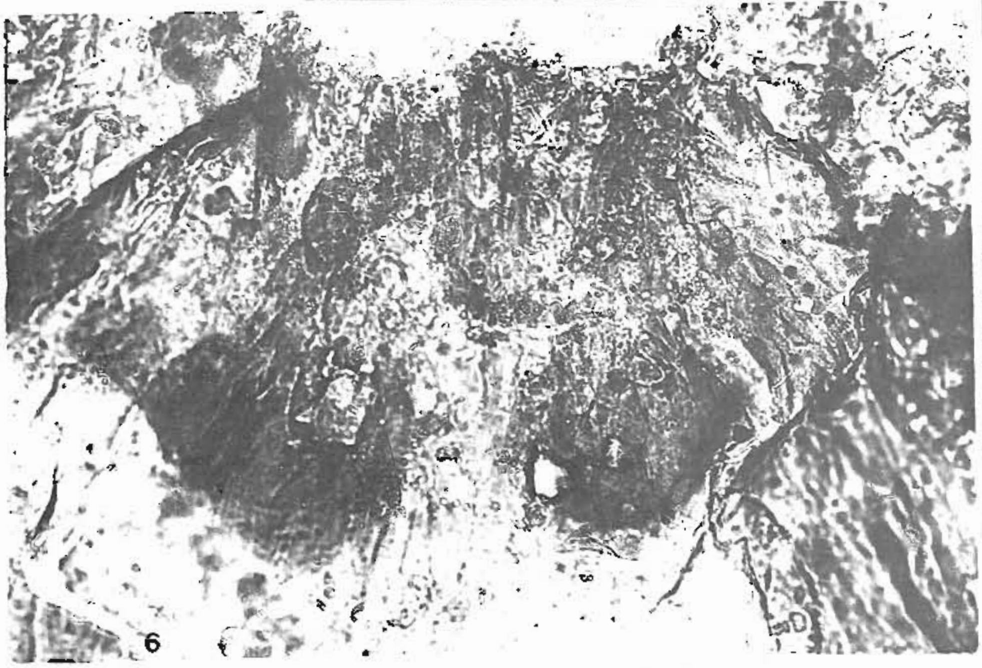
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4

PLATE 1

confluent to megaspore membrane, free from outer integument at its apex; megaspore membrane bearing two archegonia, occupying almost entire space of nucellus, forming ovoid to ovate sac.

*Type species—Rostrumaspermum venkatachalae* sp. nov.

*Discussion*—In its overall shape the present seed taxon differs from all the known seed genera described from Nidpur plant beds in bearing characteristic apical snout. Further, it stands apart from *Rostrumaspermum* because of lack of archegonia in their megaspore sac. In the striking features of archegonia, *Rostrumaspermum* compares with detached petrified seeds mostly known from Palaeozoic sediments of northern hemisphere but the present taxon being compressed, obviously seed lacks vascular supply and the other anatomical details and thus it can be easily differentiated from all such seeds. The two taxa preserved as petrifactions, viz., *Aetheotesta elliptica* Renault 1896, and *Rhabdospermum tunicatum* Seward 1919, possessing radially disposed spaces and apical snout, have exhibited close identity with the genus *Rostrumaspermum* but in other characters, because of being in petrified state, these genera readily differ from *R. venkatachalae.*

The other petrified taxa, viz., *Lagenostoma ovoides, Pachytesta hexangulata, Cycadinocarpus angustodunensis, Cardiocarpus spinatus, Taxospermum undulatum*, markedly differ from *R. venkatachalae* in having two archegonia flanking a "tentpole" at the distal end.

The new genus also compares with the seed compressions: *Collospermum* and *Palaeocarpus* reported from Lower Gondwana (Karharbari Formation) of India (Pant *et al.*, 1985) in the presence of archegonia but *R. venkatachalae* distinguishes itself from the latter two genera in its tubular archegonia and distinctive apical snout. Also, the new genus lacks well-differentiated tentpole as has been exhibited in the aforesaid Permian seed-compressions.

Further, the occurrence of tubular archegonia in *R. venkatachalae* suggests that this seed might belong to plants which could be allied to Cordaitales or Ginkgoales. However, this possibility is remote because no fructifications referable to these groups have so far been recorded. Besides, in possessing short tubular archegonia *R. venkatachalae* is distinctive from *Ginkgo biloba* but in this feature the former comes closer to *Pinus laricio* and *P. sylvestris.*

### *Rostrumaspermum venkatachalae* sp. nov.

Pl. 1, figs 1-9, Text-fig. 1A-N

*Diagnosis*—Seed ovate, platyspermic, outline entire, measuring 2-3 mm in length and 1.5-2 mm in breadth; chalazal end broadly rounded, tapering towards micropylar end having flattened apex; somewhat looking like apical snout; integument consisting of outer region tending to be thin along flanks and base, highly developed at apex, forming outer integument characterized by radially disposed spaces; structurally outer integument composed of irregular cells with their surfaces interspersed with pits of varying sizes, pits frequently occurring in hemispherical disposed spaces, entire integumentary cellular organization appearing to be contorted, integument closely abutted to nucellus but free at apex; nucellar membrane confluent to megaspore membrane, composed of thin-walled, elongated, rectangular-polygonal cells distinctly marked over the megaspore body; micropylar opening ± rounded, intensively cutinized depicting radially elongated cells; megaspore obscured in cellular details, dark-brown in colour occupying maximum space of nucellus, more or less forming an ovoid to ovate sac; at the micropylar end of megaspore sac two dark spherical bodies bearing tube-like neck considered as to be archegonium present; archegonia highly cutinized, cell outlines not discernible; between the two archegonia a cutinized mass superposed by one of the archegonia somewhat rounded flattened in structure distinctly marked and interpreted as to be immature archegonium.

*Holotype*—Slide no. BSIP 10270.

*Locality*—Nidpur, Sidhi District, Madhya Pradesh.

*Age*—Middle Triassic.

*Remarks*—Nucellar cuticle is mostly fused with the megaspore membrane and occasionally cellular markings or imprints are seen over megaspore body. At times, because of over maceration, seed-cuticles split into pieces and the two layers of megaspore sac become evident which is indicative of double nature of megaspore membrane. Other seed specimens belonging to *R. venkatachalae* have not shown the presence of archegonia but the pits have been commonly observed in the radially disposed spaces. Absence of archegonia may be due to the fact that the development of archegonia might have been deferred until female gametophyte is completely cellular (Foster & Gifford, 1974).

*Comparison*—In characteristic features of snout-like structure and occurrence of archegonia at the micropylar end the present taxon can be clearly differentiated from the other genera, viz. *Rugaspermum, Savitrispermum, Nidispermum, Pyriformispermum, Pantiaspermum* and *Rotundaspermum*, reported from Nidpur fossiliferous beds. Further, in the nature of integument these taxa generally possess tough integument composed of varied cell shapes while in *R. venkatachalae* the outer integument is extremely thin and delicate having irregular-shaped cells.

Archegoniate seeds whether preserved as petrifaction or compression, markedly differ from *R. venkatachalae* in bearing distinct tentpole. Besides, these archegonia bearing seeds completely lack tubular neck and the archegonia can occasionally be located in sunken state towards the micropylar end. *Callospermarion undulatum* (Neely) Rothwell 1981 alone comes closer to archegoniate seeds of Nidpur in having tubular archegonia but the former at once contrasts from the latter because of being anatomically preserved form. In details of anatomy, the comparison between *R. venkatachalae* and *C. undulatum* is not possible because of the state of preservation. *Collospermum* and *Palaeocarpus* described by Pant *et al.* (1985) from Lower Gondwana of India also differ from *R. venkatachalae* in having archegonia without tubular neck.

Amongst the extant forms, in gymnosperms, there is a tendency of shortening of neck, and also archegonia are located in varied position. Conifers have been exception where archegonia show a lateral position; similarly *Ephedra* also shows laterally placed archegonia. But *Ephedra* stands apart from *R. venkatachalae* in having large neck. However, *R. venkatachalae* bears a tubular neck and in this particular character it comes closer to *Pinus laricio* and *Pinus sylvestris* (Foster & Gifford, 1974; Sporne, 1974) where the two archegonia are associated with a short tubular neck. Occasionally, in *P. sylvestris* varying number of archegonia have also been noticed.

In general organization of apical portion of megaspore sac, *R. venkatachalae* may be compared with *Ginkgo biloba* but in the latter, archegonia are quite distinctive because of rudimentary neck (Maheshwari & Sanwal, 1963). Also, in *G. biloba* the number of archegonia ranges from 2-4 while in the present new seed only two archegonia have been observed.

*Affinity*—The ongoing characteristics of the present taxon have led to the conclusion that its relationship is closer to Coniferophytes (Coniferales) than the other plant groups. The presence of archegonia with tubular neck settles its affiliations with the extant species, *Pinus laricio* and *P. sylvestris*. This resemblance is indicative of the occurrence of *Pinus*-like plants in Nidpur flora. This could be further substantiated by the findings of needle-like compressions from the same strata. However, this character is not suggestive that the family Pinaceae must have been originated during Triassic period. But certainly it can be inferred that such coniferous traits must have been differentiated during Triassic time because conifers were passing through transitional stage during Early Mesozoic (Bailey, 1933). Depiction of such pineaceous features in Triassic seed supports the view of Meyen (1974) that separation of modern conifers took place at this stage.

The conspicuous absence of pollen chamber and free nucellus from integument at its apex sufficiently strengthens the evidence for its relationship with coniferales.

## ACKNOWLEDGEMENT

Authors are grateful to Professor D. D. Pant, Allahabad and Dr B. A. Vagyani, Kolhapur for their useful suggestions.

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# Palyno-dating of Nidpur beds, Son Graben, Madhya Pradesh

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Tiwari, R. S. & Ram-Awatar 1990. Palyno-dating of Nidpur beds, Son Graben, Madhya Pradesh. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 105-121.

The Nidpur beds, located in Gopad River section near Nidpur Village, Sidhi District, Madhya Pradesh, have proved to be a treasure of plant fossils—mainly fructifications and leaf-structures. The occurrence of *Dicroidium* rich pteridospermic megaflora provides the basis for dating these beds as Triassic. The present study reveals that the Nidpur beds are bracketed between two faults, as a result of which they escaped the erosion. The other underlying plant beds exposed in Gopad river and its tributaries (Mahan River and Sehra Nala) are older than Nidpur beds, as they yielded latest Permian palyno-assemblages. Lithologically the Nidpur beds are classified within the Upper Pali Member, and their palyno assemblage containing *Playfordiaspora, Lundbladispora, Densoisporites, Araucariacites, Goubinispora, Klausipollenites, Lunatisporites, Trabeculosporites*, indicates a Triassic affiliation. The trailing striate-disaccates are the remainié of the Upper Permian flora. On the basis of mega- and microfossils it is suggested that they are of the Early Triassic age.

**Key-words**—Palynology, Palyno-dating, Nidpur beds, Early Triassic (India)

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## सारांश

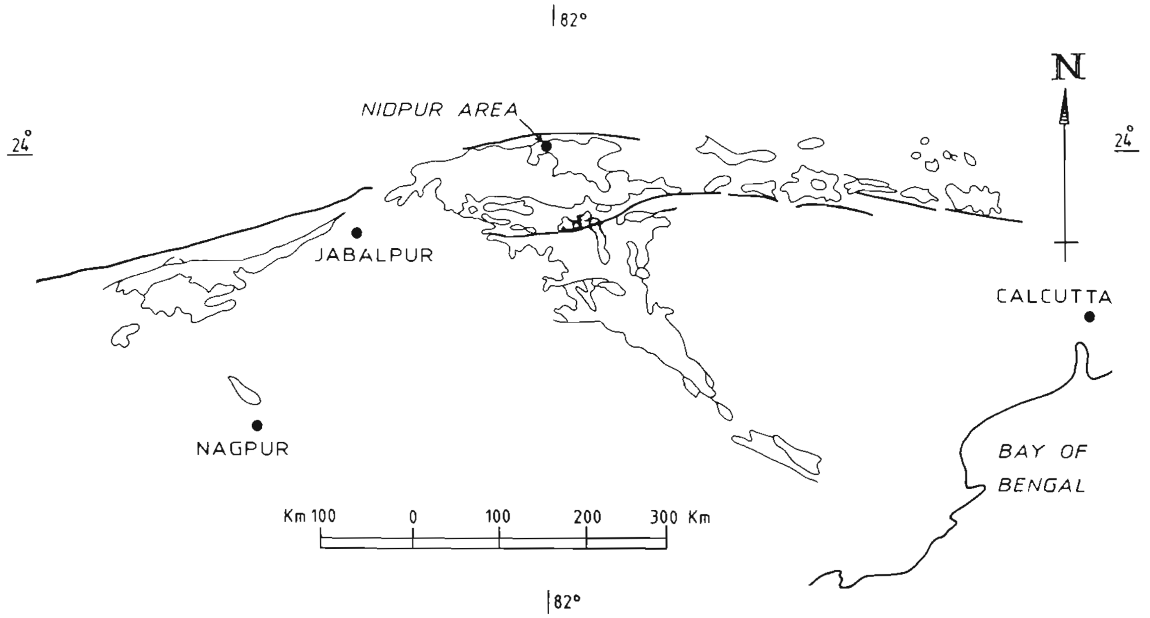
### मध्य प्रदेश में सोन द्रोणिका में निदपुर संस्तरों का परागाणविक कालनिर्धारण

राम शंकर तिवारी एवं राम अवतार

मध्य प्रदेश में सिधी जनपद में निदपुर गाँव के समीप गोपद नदी खंड में विद्यमान निदपुर अश्मित पादप-धारक संस्तरों से प्रचुर मात्रा में पादपाश्म मिले हैं जिनमें मुख्यतया फलन एवं पत्ती-संरचनायें हैं। **डाइक्रोइडियम्** से भरपूर टेरिडोस्पर्मी गुरुवनस्पतिजात के आधार पर इन्हें त्रिसंघी कल्प का आँका गया है। प्रस्तुत अध्ययन व्यक्त करता है कि निदपुर संस्तर दो भ्रंशों के बीच स्थित हैं जिसके फलस्वरूप ये नष्ट होने से बचे रहे। गोपद नदी तथा इसकी सहायक नदियों (महान नदी व सेहरा नाला) में निदपुर संस्तरों के नीचे विगोपित संस्तर इनकी अपेक्षाकृत अधिक पुरानी हैं चूँकि इनसे अर्नतिम परमी युगीन परागाणविक समुच्चय उपलब्ध हुई है। शैलविज्ञान की दृष्टि से, जिन्हें मध्य पाली सदस्य के अन्तर्गत वर्गीकृत किया गया है तथा जिनमें **प्लेफ़ोर्डियास्पोरा, लुन्ब्लाडिस्पोरा, डेन्सोइस्पोराइटिस, ॲराकेरियासाइटिस, गाउबिनिस्पोरा, क्लॉसिपोलिनाइटिस, ल्यूनाटिस्पोराइटिस, ट्रेबॅकुलोस्पोराइटिस** नामक परागाणुवर्गक विद्यमान हैं, त्रिसंघी कल्प का होना इंगित करते हैं। रेखीय-द्विकोष्ठीय परागकण उपरि परमी वनस्पतिजात के अवशेष हैं। शैल-स्तरविन्यास के आधार पर ये संस्तर उपरि पाली सदस्य के अन्तर्गत आती हैं। परन्तु गुरु- एवं सूक्ष्मपादपाश्मों के आधार पर इन्हें प्रारम्भिक त्रिसंघी आयु का प्रस्तावित किया गया है।

NIDPUR beds were discovered by Satsangi (1964) in the Gopad River section, western part of Singrauli Coalfield (Map 1), Sidhi District, Madhya Pradesh. Since then, they have attracted the attention of palaeobotanists, particularly because of well-preserved, abundant megafossils with varied fructifications found in these beds (Srivastava, 1975; Srivastava & Maheshwari, 1975; Pant & Basu, 1977, 1979). Also, a few palynological assemblages are recorded from these fossiliferous beds as well as other outcrops in the area (Chandra & Satsangi, 1965; Maheshwari, 1967; Bharadwaj & Srivastava, 1969; Trivedi & Misra, 1970). The tectonic set-up and the relative position of these beds, with mega- and microfossils, are of much interest for the age relationship of these beds.

Palynological dating of these beds makes the focal theme of the present paper. The sediments exposed on the left bank of Gopad River, at about 2 km north-east of Nidpur Village (24° 7′ : 81° 53′), between two faults ($F^2$ and $F^3$, Map 2) adjacently south of Sehra Nala confluence with Gopad River



**Map 1**—Showing pivotal positioning of Nidpur area in Son Valley Graben (southern arm) in relation to Damodar Graben (eastern arm) and Satpura Graben (western arm).

have been exclusively considered here as "Nidpur beds" and the area of study has been termed as "Marhwas area" (24°0′-24°10′ : 81°50′-82°0′) named after the Marhwas Village. As an essential suppliment for finer palyno-dating of these beds, several exposures is this area along Gopad River, Mahan River and Sehra Nala were also studied. A comparative assessment of assemblages recovered from *Dicroidium*-rich and *Glossopteris*-rich strata has been made. The data have been interpreted against the back-drop of geology, lithology and stratigraphy of the Pali Formation to which these sediments belong.

## GEOLOGY OF THE AREA

The Marhwas area is located in the Singrauli Basin, the extreme northern region of Son-Mahanadi Graben and the Nidpur beds are situated in the western most tongue of the Singrauli Basin. The situation of this part of the basin is very peculiar in that it occupies a point at the tri-junction of Damodar, Satpura and Son-Mahanadi grabens. Implicitly, the resemblance, in degrees, with these three grabens is expected in lithology and plant history (Map 1). In north, Pali Formation (Raniganj) and, at places, Parsora (Mahadeva) sediments are directly in contact with the Precambrian basement. The Gopad River traverses in south-north direction through this area. A shifting of basinal centre during sedimentation has been inferred with reference to the regional set-up of the basin (Raja Rao, 1983). The southern part of the area is bound by Parsora (Mahadeva) hillocks. The main country around Marhwas and Nidpur villages is a flat alluvial plain, excepting Gothra and Chakdahi hills, exposing mainly sediments of Pali Formation in river cuttings.

Majumdar (1981) gave a comprehensive account of the geological set-up of this area which has been modified as under on the basis of present palaeobotanical and palynological evidences.

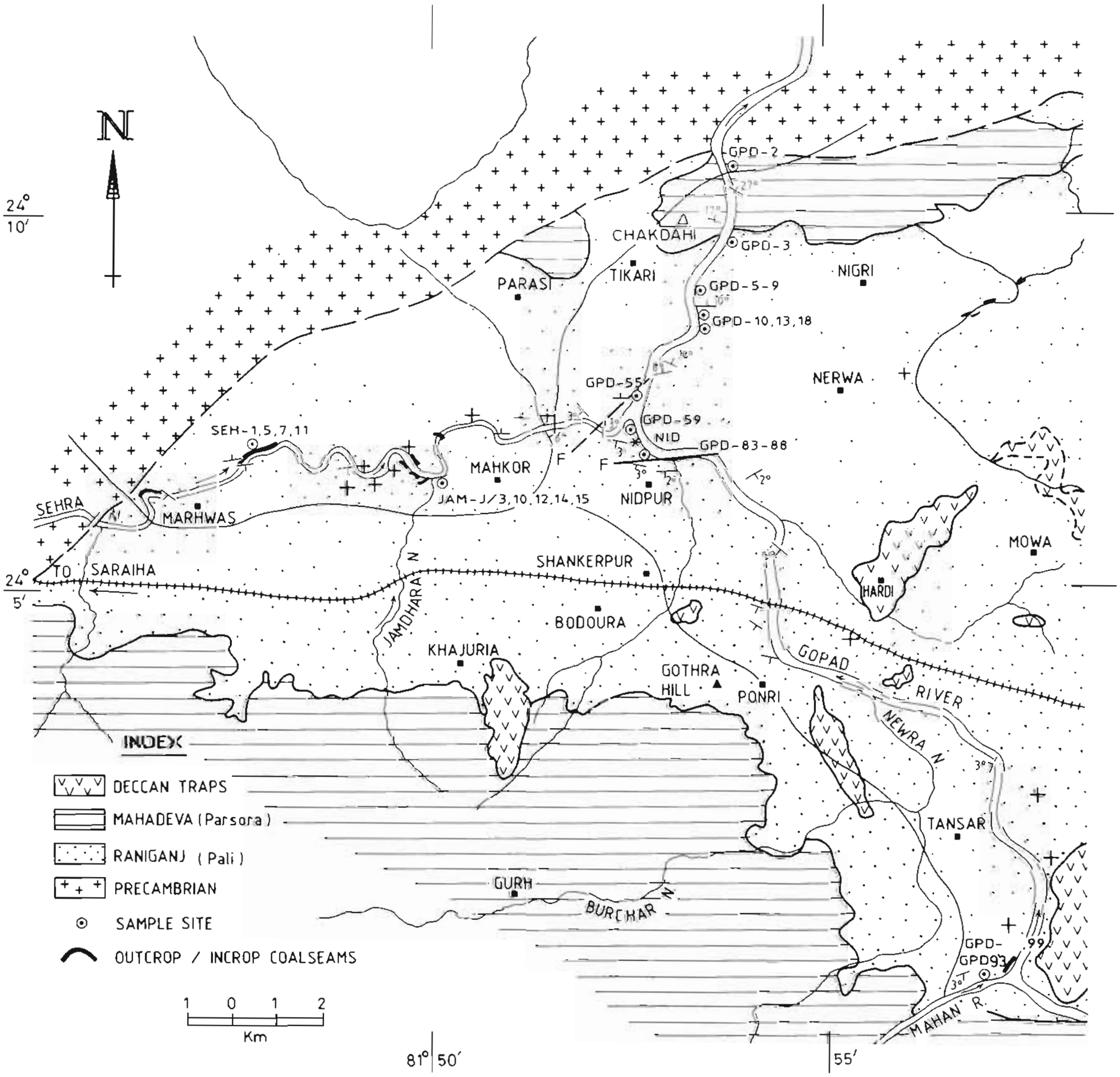
| | | |
|---|---|---|
| CRETACEOUS | DECCAN TRAP | DOLERITES AND BASALTS |
| Middle Triassic<br>Upper Triassic? | Parsora | Grey coarse to medium-grained sandstone with red to lilac coloured sandstone |
| | ............................Unconformity/Overlap and fault............................ | |
| Upper Permian to Lower Triassic | Middle and Upper Pali Formation | Grey feldspathic sandstone, shale, siltstone with carbonaceous shales, coal and siderite bands |
| | ................................Faulted................................ | |
| Precambrian | Precambrian | Slates, quartzites and metabasic granite schists, gneisses and granulites |

The Precambrian igneous- metamorphic complex forms a high scarp in the north and north-western part of the area. The younger sediments are separated from Precambrian by a prominent boundary fault.

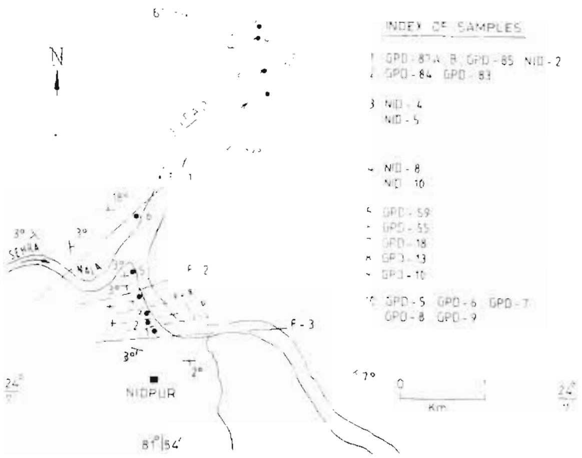
The Pali Formation is mainly composed of monotonous, multistoreyed arenaceous argillaceous rock assemblage and its lower contact faulted against the Precambrian complex. These suites of sediments are unconformably overlain by dominantly arenaceous beds with ferruginous violet-coloured, lilac-coloured sandstone, as seen in the Gopad River, north of Nidpur Village. Lithologically, the Pali Formation comprises sandstone, shale-siltstone, carbonaceous shale and coal sequence with minor calcareous intercalations and red shale-clay pockets. The Nidpur beds occupy the topmost part of the Pali sequence.

The Parsora Formation is exposed in the south and south-western part of the area (earlier marked as Mahadeva). Along the Gopad River, capping the Nidpur beds, coarse-grained sandstone with lilac colour intercalation have been noticed. In the northern-most region, the Parsora Formation is exposed in a overlap contact with the Pali Formation.

As is clear from the dip directions given in Map 2, a mild anticlinal structure trending east-west in the centre of the region is developed. Its axis runs along Marhwas-Nidpur alignment, more or less along the course of Sehra Nala which generally exposed horizontally along the strike. Near the confluence of Sehra nala with Gopad River, the situation has become complicated because of three faults (Map 2, 3). As defined above, the Nidpur beds exposed on the left bank of Gopad River, about 300 m south of Sehra-Gopad confluence, are bracketed between faults F-2 and F-3. In its turn, the sequence locked up between these two faults is also dissected by



**Map 2**—Geological map of north-west portion of Singrauli Coalfield showing Marhwas area where the Nidpur beds (asterisk) are situated. The yielding samples, marked by dot within a circle, are indicated along the traverses taken. NID (asterisk) indicates the position of sample nos. NID-4, 5, 8, 10, whose details are given in Map 3 (after Raja Rao, 1983).



**Map 3**—Gopad River section enlarged to show Nidpur beds—between Fault F2 and F3; location of yielding samples also depicted.

three minor faults, F-a, F-b and F-c, with 2 to 5 m differential down-throws. The Nidpur beds are more or less horizontally placed, and their displacements can be reconstructed on the basis of lateral extensions of lithological units.

Between faults F-1 and F-2, a distinct anticlinal fold structure is exposed in a faulted contact (F2) whose southern limb is dipping (6°) southwardly (Map 2, 4; Text-fig. 4). The sediments between faults F-1 and F-2 contain *Glossopteris-Vertebraria*-dominant magaflora and a typical Upper Permian palynoflora (present work); *per contra*, the Nidpur beds between faults F-2 and F-3 contain *Dicroidium*-bearing flora with distinctive palynofossils. The discontinuity of the Permian sequence with respect to Nidpur beds is thus evident The Permian sediments are exposed again at southern side of Nidpur beds with a faulted contact (Fault F-3)

## PALYNOSTRATIGRAPHY

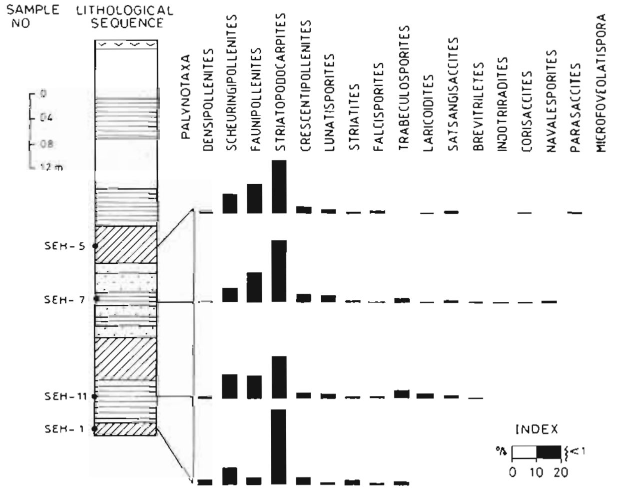
### I. Sehra Nala Section

A traverse was taken from west of Marhwas Village along the course of Sehra nala eastwards up to its confluence with Gopad River. The main lithology of the exposed sediments exhibits sandstones, shales, rarely thin coalseams of dull coal, carbonaceous shales and thin bands of fine clays. The sandstones are ferruginous with brick-red colour near Mahkor Village. The beds are gently dipping northwards, or horizontal (Map 2). Plant megafossils seen during the collection of samples are mainly *Glossopteris* leaves, *Vertebraria* and few unidentifiable twigs, but no *Dicroidium* was found. In all, 47 samples were collected, out of which 11 have yielded palynomorphs (Map 2). The details of these samples are as follows :

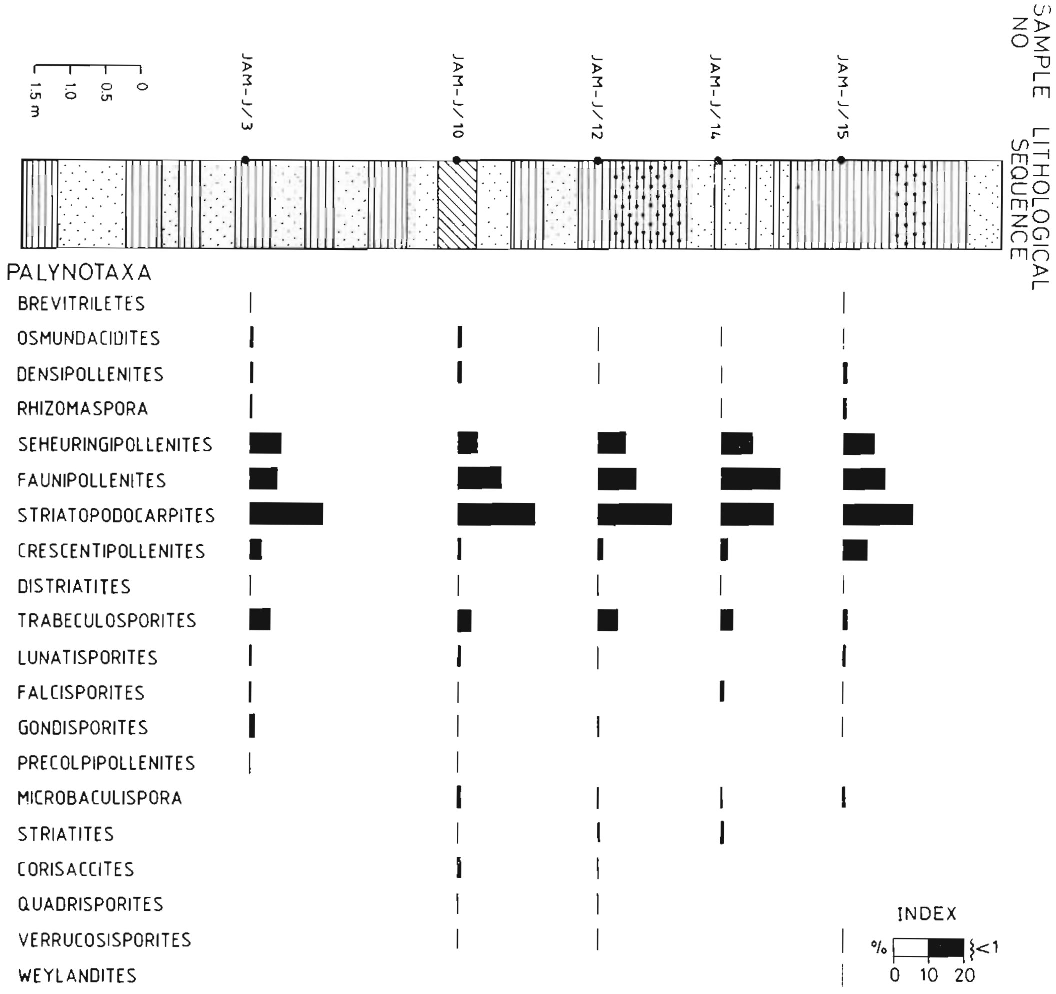
| Sample No. | Lithology | Geological horizon | Flora |
|---|---|---|---|
| SEH-5 | Black shale | Pali (Raniganj) | *Glossopteris* dominant |
| SEH-7 | Grey shale | | |
| SEH-11 | Shale | | |
| SEH-1 | Carbonaceous shale | | |
| JAM-J/3 | Grey shale | Pali (Raniganj) | *Glossopteris* dominant |
| JAM-J/10 | Black shale | | |
| JAM-J/12 | Black shale | | |
| JAM-J/14 | Ferruginous compact sandstone | | |
| JAM-J/15 | Ferruginous compact sandstone | | |

I-A. *Exposures near Marhwas Village*—About one kilometer north-east of Marhwas Village, a 6 m thick pile of horizontally placed black and grey shales and sandstones are exposed (Text-fig. 1) in the right bank of Sehra nala from where four samples proved to be rich in spores and pollen grains.

The assemblage is dominated by striate-disaccate genera : *Striatopodocarpites* and *Faunipollenites*, in association with non-striate genus *Scheuringipollenites*. Other taxa recorded are *Brevitriletes, Microfoveolatispora, Indotriradites, Guttulapollenites, Densipollenites, Crescentipollenites, Inaperturopollenites, Navalesporites* and *Striatites*. The genera—*Lunatisporites, Trabeculosporites* and the non-striate group consisting of *Satsangisaccites* and *Falcisporites* also



**Text-figure 1**—Frequency of palynotaxa in sequential samples collected from Sehra nala section (refer Map 2) near Marhwas.



**Text-figure 2**—Frequency of palynotaxa in sequential samples collected from Sehra nala section (refer Map 2) near Mahkor

appear inconsistently and sporadically in the assemblage.

No spore of *Lundbladispora-Densoisporites* group, or the genus *Weylandites* has been recorded. The overall composition indicates an uppermost Permian affinity for the assemblage. For such a conclusion, *Guttulapollenites* and *Navalesporites* have been taken into consideration with reference to the totality of assemblage.

I-B. *Exposures near Mahkor Village*—Thick exposures with low, northerly dips or horizontal strata are seen at the confluence of Jamdhara nala and Sehra nala. Further downstream of Sehra nala, near Mahkor Village massive deposits of compact, ferruginous, red sandstones are exposed. The intermittent shale bands within the sandstones, containing *Glossopteris* and *Vertebraria,* yielded spores and pollen.

Palynological assemblage recovered from this section (Map 2; Text-fig. 2) also resembles Marhwas assemblage in general, but the increased percentages of *Trabeculosporites* and occasional appearance of *Hamiapollenites, Weylandites* and *Osmundacidites* are indicative of changing trend towards a relatively younger aspect.

## II. Gopad River Section

The river was traversed from northern boundary fault, upstream up to the Mahan River junction (Map 2). All the prospective lithologies represented in about 150 samples were collected systematically (Map 2). The whole stretch of the area along Gopad River has been divided into following three parts.

II-A. *Section north of Nidpur plant beds*—The extent of this part runs from northern basement line up to fault F-2; 66 samples were collected for palynoanalysis, out of which only eleven have yielded.

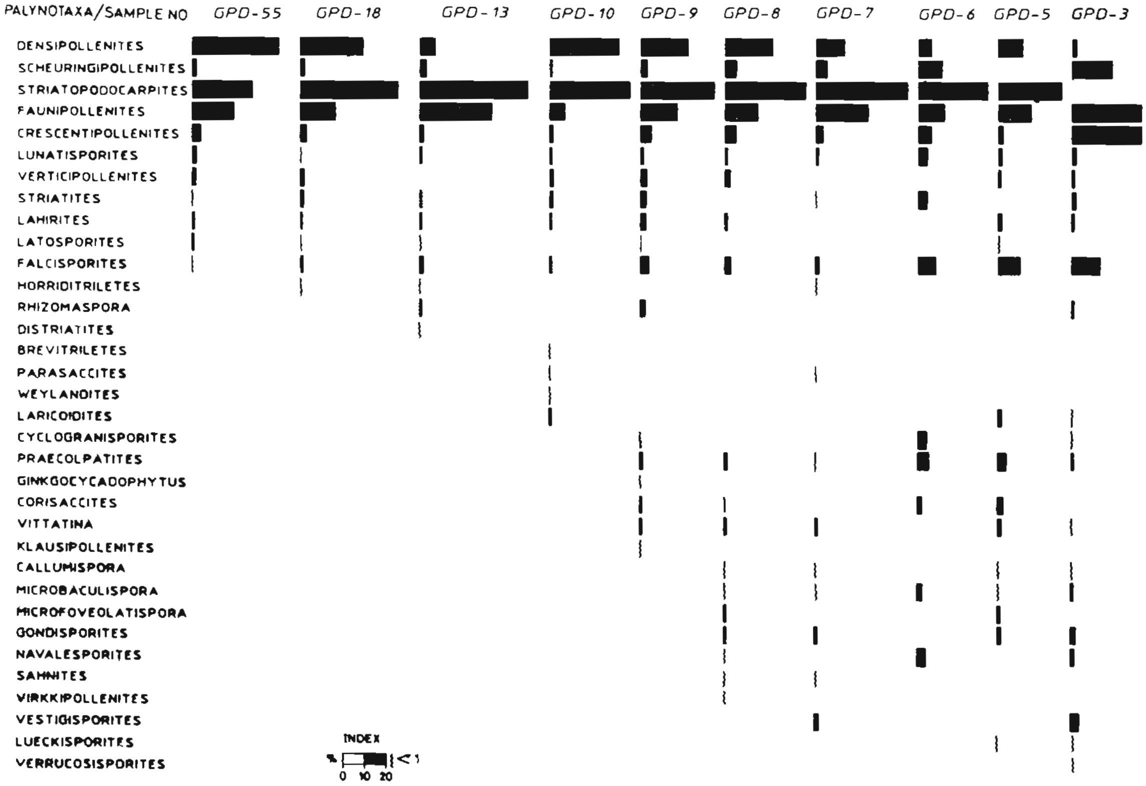
Adjacent to the south of metamorphics, massive, coarse, ferruginous, yellowish to reddish sandstone of Parsora (Mahadeva) Formation are exposed in the right bank of Gopad River. On the left bank, at this point, the Chakdahi Hill exposes a huge succession but none of the samples collected from scarpment proved to be positive.

Older to this strata, with a faulted contact, the Raniganj (Middle Pali) Formation is exposed; the main lithology of this sequence comprises fine-grained sandstones, siltstones, grey and black shales and rarely coaly-shale bands. Opposite to Bhumka Village, on the right bank of the river, a sequence of red ferruginous sandstone with large *Glossopteris* leaves is exposed. Even otherwise, the *Glossopteris, Vertebraria* and *Schizoneura* are commonly found The strata are low dipping towards north and north-east direction (Map 2).

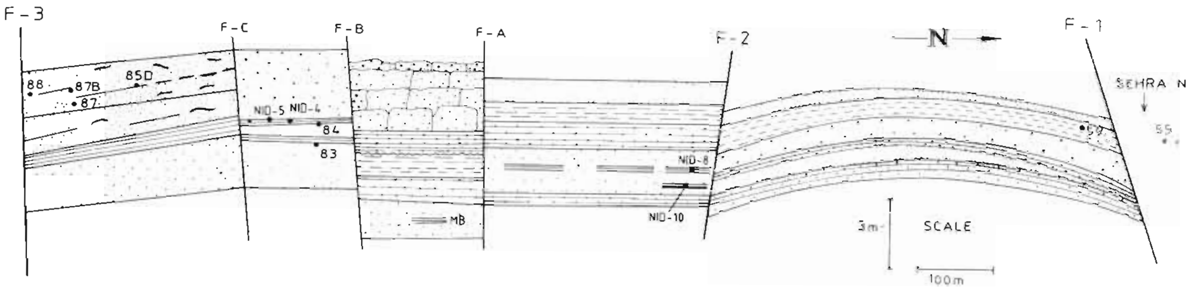
Sample no. GPD-2, a sandy shale-lense within the Mahadeva Sandstone, contains several dark brown taeniate-bisaccate pollen grains. Sample no. GPD-3, grey shale-band of 0.5 m thickness belonging to Raniganj (Pali) sequence, exposed just below Mahadeva sandstone contains a well preserved, diversified assemblage; it is in contrast with sample no. GPD-2 of Mahadeva Formation. Lithologically there is an abrupt change between GPD-3 and GPD-2 which is also reflected by palynofossils. This could represent a hiatus between Raniganj (Pali) and Mahadeva (Parsora). Sequential placement of yielding samples depicts a pattern of quantitative occurrence of various taxa, in Gopad River section, north of Nidpur fossiliferous beds (Text-fig.3).

*Striatopodocarpites, Faunipollenites* and *Densipollenites* are quantitatively important genera. Other characteristic forms are *Callumispora, Cyclobaculisporites, Microbaculispora, Crescentipollenites, Gondisporites, Lunatisporites, Falcisporites, Guttulapollenites, Verticipollenites* and *Navalesporites*. Absence of *Playfordiaspora, Trabeculosporites, Satsangisaccites, Weylandites* and *Goubinispora* is noteworthy as it reflects an older aspect of these beds than that of the palynoflora in the Nidpur beds discussed below. It is evident that the strata, exposed in Gopad River in the north of Nidpur beds, have an Upper Raniganj affinity.

II-B. *Section of Nidpur beds*—Fifty-two samples were collected from the bed exposed between fault F-2 and F-3 (Map 3), out of which 11 yielded pollen and spores. The yield was fairly rich in *Dicroidium*-bearing shales as well as in the carbonaceous bands in one of the sectors. Text-figure 4 depicts the section of this bed alongwith the location of yielding samples and Text-figure 5 gives the log of the sequence in this locality.

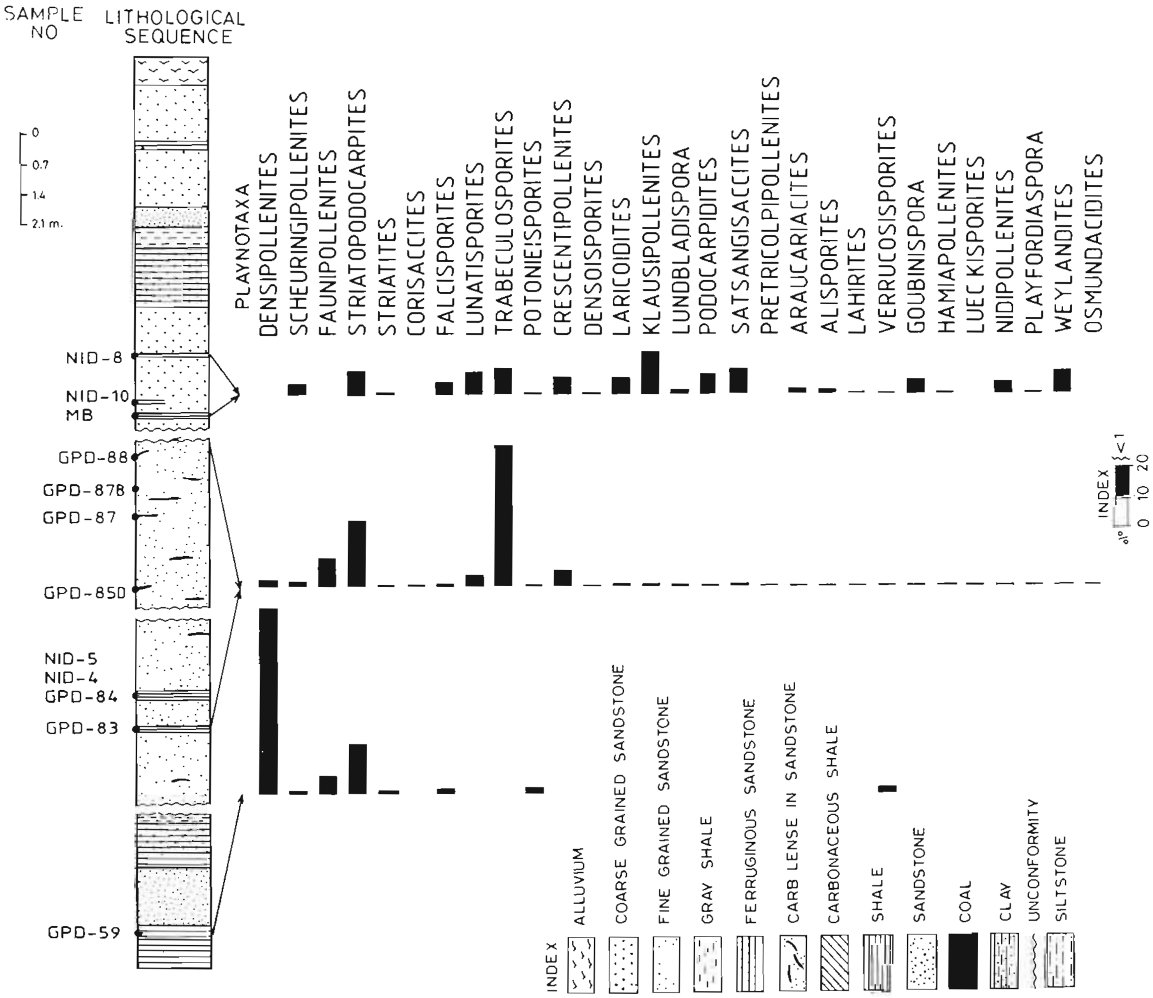


**Text-figure 3**—Percentage frequency of palynotaxa recovered from samples collected from north of Nidpur beds, in Gopad river (refer Map 2).



**Text-figure 4**—Generalised section of the Nidpur beds and associated sequence along Gopad River with location of palynologically productive samples (refer Map 3), F-1, F-2, F-3 major faults. F-A, F-B, F-C faults represented by minor dislocation (for Index see Text-fig 5).

The oldest strata in Nidpur beds are situated between fault F-c and F-3. This patch has distinctive lithology having dominantly coarse-grained sandstones with whitish greyish colour in the older level and ferruginous, pinkish-redish tint in the younger level. There are several carbonaceous shales, lenses and bands in sandstone units containing few fragments of *Glossopteris* leaves and unidentifiable dispersed plant remains. A number of samples (GPD-83, 84, 85D, 87, 87B, NID-4) have



**Text-figure 5**—Resolved super imposition of productive samples from Nidpur beds (between Faults F-1 and F-3. refer Map 2), and the percentage frequency of palynotaxa in productive samples. Similar assemblages have been clubed together, i.e., GPD-83 to GPD-88, and MB to NID-8.

yielded a taeniate disaccate (*Lunatisporites, Trabeculosporites*) dominating assemblage. Forms assignable to *Densipollenites* having diffused body are present (Type-A; Pl. 1, fig. 13) but species with distinct body are absent.

The *Dicroidium*-bearing shales of classical important beds are exposed just above the described carbonaceous-lense-bearing sandstone unit. This sequence is located between faults F-2 and F-c in which the general sequence, from bottom to top, starts with a grey, micaceous siltstone and grey shale which is full of carbonaceous matter comprising fructifications and profused *Dicroidium* leaves with allied forms, such as *Pteruchus, Savitrispermum* and *Lepidopteris*; fragmentary and rare *Glossopteris* leaves could be seen in some layers (see Srivastava, 1969). The thickness of this siltstone bed varies from 10 to 40 cm and, at places, because of the down thrusting, it remains submerged in the Gopad stream for most of the time during the year, except summer.

Above this *Dicroidium*-rich shale layer, a 1.5 m thick sandstone unit is present being fine to medium coarse grained in texture. It contains thin, 2-10 cm, lenses of grey, silty shale as well as siltstone, having imprints of *Dicroidium*. Palynology of the sample (MB, NID-8, NID-10) from this second horizon of *Dicroidium* shows an abrupt change in palynoflora where taeniate forms decline considerably.

Younger to the sandstone unit described above, there is another sandstone bed (1-2 m) containing thin layers of silty shale as well as siltstone but no mega-or microfossils have been found in them. This sandstone is capped by generally weathered, massive, red ferruginous sandstone of about 2 m thickness. Between these two sandstone layers a chocolate colour shale band (20-30 cm) is present which did not yield any microfossils.

The details of sequential set-up, thus, clearly reveal that the beds exposed between faults F-2 and F-a are horizontally placed exhibiting *Dicroidium*-bearing shales in the lower sandstone. The slice between faults F-a and F-b has suffered a subsidence so that the layers rich in *Dicroidium* have submerged in water. Sediments between faults F-b and F-c are again down-thrusted. The beds between fault F-c and F-2 represent more or less similar lithology, but those between F-c and F-3 are different, where the dips turn southwardly. No sediments are exposed after fault F-3 for quite some distance, beyond which the Pali (Raniganj) sediments are again exposed.

In this succession two palynological zones have been delimited between faults F-2 and F-3. The productive samples are grouped in sequential order as under·

| SAMPLE NO. | LITHOLOGY | REMARKS |
|---|---|---|
| **ZONE II** | | |
| NID-8 | Greenish shale | Faint prints of fossils |
| NID-10 | Grey siltstone | *Dicroidium* present |
| M.B. | Grey shale | (Master bed)<br>Rich in fructifications *Dicroidium*; poor *Glossopteris* |
| **ZONE I** | | |
| GPD-88 | Carbonaceous shale | Fragmentary fossils; *Glossopteris* |
| GPD-87B | Grey micaceous shale | Fragmentary fossils |
| GPD-87 | Grey silty shale | *Glossopteris* poor<br>?*Dicroidium* Poor |
| NID-5 | Carbonaceous shale | Specks of plant material |

*Contd.*

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## PLATE 1

(All photomicrographs are enlarged, × 500; orthoplan microscope no. 851393)

1. *Navalesporites spinosus* Sarate & Ram-Awatar 1984; Slide no. BSIP 10237, Coordinate 7 × 97.
2. *Scheuringipollenites maximus* (Hart) Tiwari 1973; Slide no. BSIP 10240A, Coordinate 22 × 98 (Leitz No. 512794/067053).
3. *Trabeculosporites* (Trivedi & Misra 1970); Slide no. BSIP 10243B, Coordinate 30 × 105.
4. *Tiwariasporis indicus* Srivastava, 1970; Slide no. BSIP 10240, Coordinate 9 × 93.
5. *Striatopodocarpites* Soritsch & Sedova emend. Bharadwaj 1962; Slide no. BSIP 10244, Coordinate 25 × 105.
6. *Lahirites raniganjensis* Bharadwaj 1962; Slide no. BSIP 10245, Coordinate 28 × 105.
7. *Lahirites* sp. (Tiwari 1965); Slide no. BSIP 10240A, Coordinate 6 × 112 (Leitz. no. 512794/067053).
8. *Densipollenites invisus* Bharadwaj & Salujha 1964; Slide no. BSIP 10240A, Coordinate 10 × 95 (Leitz. no. 512794/067053).
9. *Gondisporites raniganjensis* Bharadwaj 1962; Slide no. BSIP 10245, Coordinate 30 × 105.
10. *Striatites sewardii* (Virkki) Bharadwaj 1962; Slide no. BSIP 10237A, Coordinate 19 × 99.
11. *Lunatisporites* sp. (Goubin in: Maheshwari & Banerji 1975); Slide no. BSIP 10247; Coordinate 33 × 93.
12. *Densipollenites indicus* Bharadwaj 1962; Slide no. BSIP 10239, Coordinate 7 × 103.
13. Alete type-A; Slide no. BSIP 10241, Coordinate 38 × 107.
14. *Verticipollenites secretus* Bharadwaj 1962; Slide no. BSIP 10239, Coordinate 34 × 105.
15. *Corisaccites alutas* Venkatachala & Kar 1966; Slide no. BSIP 10243A, Coordinate 12 × 116.
16. *Crescentipollenites fuscus* (Bharadwaj) Bharadwaj, Tiwari & Kar 1974; Slide no. BSIP 10238, Coordinate 13 × 105.


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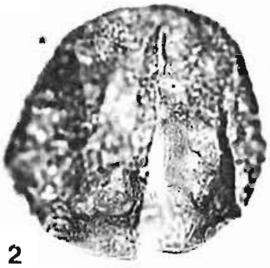
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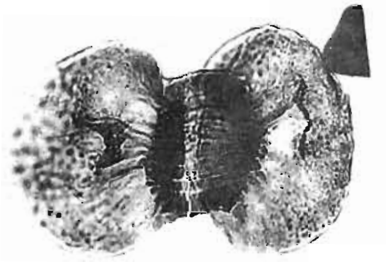
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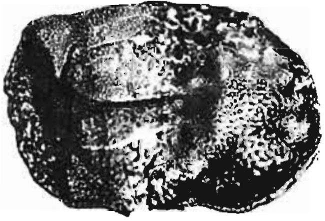
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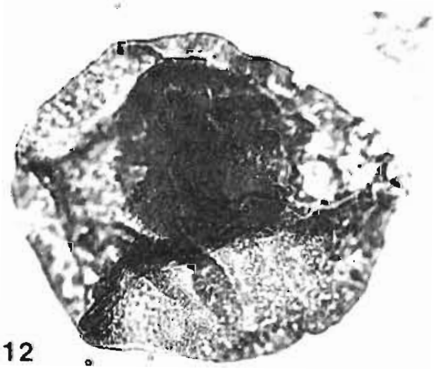
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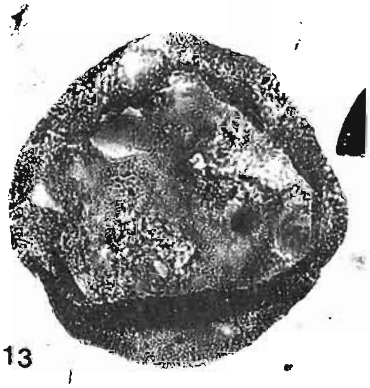
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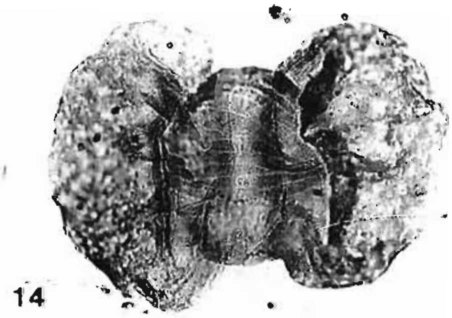
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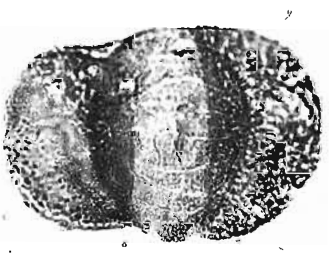
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PLATE 1

| | | |
|---|---|---|
| NID-4 | Carbonaceous shale | |
| GPD-85 D | Carbonaceous. shale lenses in coarse grained sandstone | Fragmentary fossils; dispersed plant matter |
| GPD 84 | Sandstone | |
| GPD 83 | Grey shale | |

## Zone I : Palyno-assemblage

The genus *Trabeculosporites* dominates in this zone The genera *Striatopodocarpites, Faunipollenites, Scheuringipollenites, Crescentipollenites* and *Guttulapollenites* are also significant.

The suite of qualitatively important taxa include *Callumispora, Verrucosisporites, Densoisporites, Lundbladispora, Alisporites, Klausipollenites, Falcisporites, Lunatisporites, Goubinispora, Inaperturopollenites, Playfordiaspora, Vitreisporites, Araucariacites, Satsangisaccites, Nidipollenites, Weylandites*, etc.

The Permian striate pollen enlisted above are the significant remains of the lot and stradded into this level, but the suite of qualitatively important taxa, however, confirms a major change at this level.

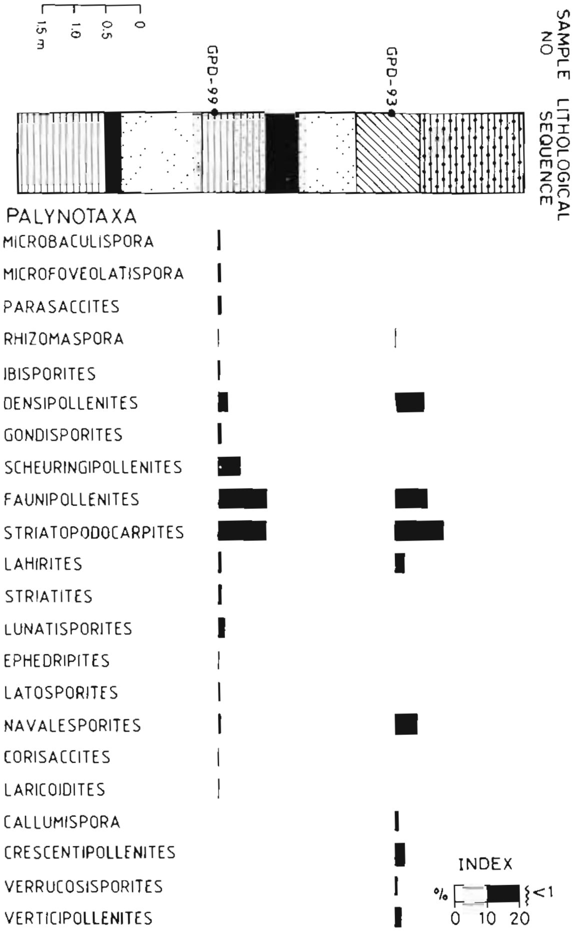
## Zone II : Palyno-assemblage

This zone is younger to Zone I. The palynoflora remarkably changes at this level. The taeniate pollen suddenly decline in Zone II, and the remanant of Permian genera (e.g. *Striatopodocarpites, Faunipollenites, Scheuringipollenites*) are at their low ebb. A better representation of *Nidipollenites, Satsangisaccites, Weylandites, Goubinispora, Densoisporites, Klausipollenites, Falcisporites, Podocarpidites* and *Alisporites* is depicted in this zone as compared to Zone I.

A broader aspect of continuity of Zone I and Zone II palyno-assemblages is evident from this analysis, but a floral change is well marked and significant because lithological changes are also distinct between these strata.

II-C. Section south of Nidpur beds—After the fault F-3, the strata are mostly covered under alluvium. Several samples were collected from the exposures near the railway bridge (Map 2), but none of them yielded microfossils. Only two samples (GPD-99 and GPD-93) collected from the confluence of Mahan and Gopad rivers were found to be productive. Thin coal seam with prominent shale layers is also exposed in this region.

The succession at Mahan-Gopad meeting point, on the left bank, exposes mainly micaceous, fine-grained sandstone, siltstone, grey shale, coaly shale and coal (Text-fig. 6). This bed contains distinct *Glossopteris* leaves and few needle-shaped indistinct plant debris. No *Dicroidium* has been seen in this section.



**Text-figure 6**—Frequency of important genera in two samples at Mahan-Gopad confluence (refer Map 2).

Sample no. GPD-99 exhibits the prominence of *Striatopodocarpites, Faunipollenites* and *Scheuringipollenites*. Other rare but qualitatively important genera are: *Cyclobaculisporites, Indotriradites, Microbaculispora, Microfoveolatispora, Densipollenites, Gondisporites, Lahirites, Lunatisporites, Navalesporites, Guttulapollenites*, etc. The other sample GPD-93 is younger to GPD-99 in the sequence; there is a subtle change in the assemblage of this sample when compared to the latter. Striate-disaccate pollen are in prominence, but two genera, i.e., *Densipollenites* and *Navalesporites*, increase considerably; *Crescentipollenites* is also present in this assemblage.

A clear Upper Raniganj affinity for these two assemblages is depicted. Quantitative differences are, however, evident amongst these two shale horizons.

## RELATIONSHIP OF NIDPUR BEDS

The sediments exposed in Gopad River and Sehra nala sections have been mapped earlier as Raniganj (Hughes, 1881). Recently, Raja Rao (1983), although delimited the area as Raniganj on the base map, commented that the Nidpur beds are of Triassic age. Tripathi (1963) reported the presence of *Rhinesuchus wadiai*—a labyrinthodont remain, from near Marhwas Village, indicating the age of sediments as Late Permian. The present palynological results from the same region (Marhwas assemblage) also support this conclusion.

Sequel to the report of *Dicroidium* by Satsangi (1964) from Nidpur, continuous efforts to analyse the flora of the area have resulted in the wealthy record of cuticles, fructifications and *in situ* pollen from this bed (Srivastava, 1975). Besides, reports of rich floral elements by Bose and Srivastava (1970, 1971, 1972, 1973), Pant and Basu (1973, 1977, 1979), Srivastava and Maheshwari (1975), and Pant and Pant (1987) made this bed a classical example of preservation and diversification. Because of the presence of characteristic *Dicroidium*-rich flora with other pteridospermic, ginkgoalean and coniferalean groups of plants, the assignment of Triassic age has been supported by these workers for the Nidpur beds.

In 1965, Chandra and Satsangi in a preliminary report of spores and pollen illustrated non-striate and taeniate disaccate pollen and few pteridophytic spores; the trisaccate pollen documented are referable to *Goubinispora* and the 'pteridophytic spores having ribs or striations belonging probably to Schizaeaceae' (Chandra & Satsangi, 1965) could be the specimens of the genus *Weylandites*. Although this bed bears *Dicroidium* imprints (Chandra & Satsangi, 1965), its stratigraphic position with reference to different units of this section, as known now, is not certain. However, in all probability, it belongs to the bed designated here as Master Bed (MB).

Maheshwari (1967) enlisted a palynoflora recovered from a shale, about 2 km south-east of Nidpur in Gopad River, near the railway bridge (Map 2). Although the stratigraphic location of this shale is not controlled, the prominence of striate-disaccates, *Densipollenites* and *Scheuringipollenites* suggests an Upper Permian affinity. This shale contained *Glossopteris* leaves but no *Dicroidium* is known from this locality.

Probably unaware of the detailed palynological studies of 'Nidpur plant beds' by Bharadwaj and Srivastava (1969), Trivedi and Misra (1970, pp. 14, 15) published an assemblage from the same area comprising the abundance of taeniate, striate pollen and *Weylandites*. Presence of few cingulate, monocolpate and *Falcisporites, Satsangisaccites* complex is also noticed.

Bharadwaj and Srivastava (1969) found a rich palynoflora in a "6 inch thick bed of highly carbonaceous shale which overlies the basal fine grey sandstone" The positioning of these shales has been determined now to be between faults F-2 and F-3 as numbered in the present work (Srivastava *pers. comm.*, 1986), and stratigraphically, this shale lies below the grey siltstone facies. It is not carbonaceous but contains rich carbonised plant matter as well as *Dicroidium* fossils. We have also recovered a comparable palynoassemblage in the grey siltstone facies younger to (i.e. 1.5 m above) the shale analysed by Bharadwaj and Srivastava (1969), however, the taxa, viz., *Densipollenites densus* and *D. indicus* with clearly defined central body, and some of the striate-disaccate species are not found in our assemblage. Except for this, the whole flora has been reproduced in the grey shale and siltstone which bear *Dicroidium*. The lithological observations as well as palynological contents indicate that the palynoflora described by Bharadwaj and Srivastava (1969) was obtained from a relatively older shale bed from inside the pit, with carbonaceous rich contents. The presently analysed grey siltstone also contains *Dicroidium* but has no *Densipollenites* with well-defined body. A fresh set of slides recently given to us by Srivastava (*pers. comm.*, 1988) made from *Dicroidium*-bearing grey siltstone and grey shale also contains an assemblage which does not have *Densipollenites* species with sharply defined central body.

## AGE CONNOTATION

The Upper Permian and Lower Triassic palynofloral sequences are well understood for Damodar Valley basins (Bharadwaj & Tiwari, 1977; Bharadwaj, Tiwari & Anand-Prakash, 1979; Tiwari & Rana, 1984; Tiwari & Singh, 1983, 1986; Vijaya & Tiwari, 1988). Tagged with lithological changes from Raniganj to Panchet formations in the Raniganj Coalfield, the assemblage R-I and P-I respectively qualify for the latest Permian and earliest Triassic (Tiwari & Singh, 1986). When compared with this model of Damodar Graben, the palynoassemblages recovered from the Sehra nala section and north as well as south of Nidpur beds in Gopad River (Text-figs 1, 2, 3, 6) match with the R-I and R-II assemblages of Late Permian (Tiwari & Singh, 1986). On the basis of the occurrence of *Corisaccites* and *Navalesporites* it can be compared with Sukhtawa assemblage in Satpura Basin (Bharadwaj, Tiwari & Anand-Prakash, 1978) which is considered to be latest Permian in age. Besides, the palynofossils from Gopad River, Mahan River and Sehra nala (except Nidpur beds) have also an akinness with the assemblages known from Middle Member of Pali Formation in Birsinghpur Pali Coalfield (Tiwari & Ram-Awatar, 1986, 1987b).

As discussed above, the palynoflora in the Nidpur beds contains *Lunatisporites*, *Trabeculosporites* (taeniate-complex), *Playfordiaspora*, *Densoisporites*, *Lundbladispora*, *Klausipollenites*, *Falcisporites*, *Araucariacites* and *Goubinispora* as the basic components indicating a Triassic age affiliation of these beds.

No Permian palynoflora in the peninsular India is known to possess such a composition of taxa, while the established Triassic palynofloras exhibit closely comparable trends in fundamental elements (Vijaya & Tiwari, 1988).

In Damodar Basin, the assemblage from Panchet Formation is mainly associated with high percentage of cavate spore genera *Lundbladispora* and *Densoisporites*, while these forms are rare in the Nidpur beds. In Zone-1, there are fairly large number of specimens assignable to the genus *Densipollenites* (Type-A, Pl. 1, fig. 13; Pl. 2, fig. 14) but none of them possesses a sharply defined central body. However, species with or without distinct body have been recorded from Upper Raniganj as well as Lower Panchet palynofloras of the Raniganj Coalfied (Vijaya & Tiwari, 1988).

When compared with the Australian Permian-Triassic assemblages (Helby *et al.*, 1987), there seems to be a factor of provinciality which plays a vital role in shaping the Triassic palynofloras of two regions. Thus, *Aratrisporites*, *Triplexisporites*, *Duplexisporites*, *Craterisporites*, etc., are some of the forms which are not well-represented in the so far known Indian assemblages. On the basis of taeniate dominance, the Nidpur assemblages are comparable with *Protohaploxypinus samoilovichii* Zone (in *Falcisporites* Super Zone : Helby *et al.*, 1987) but in other components the comparisons are not befitting. The genus *Trabeculosporites*, characteristic of the Nidpur fossiliferous bed, does not appear in any of the zones in Australia; it seems most plausible that *Trabeculosporites*-complex is related with *Infernopollenites* type of pollen having Anisian age aspect.

The evidences are accumulating to suggest strongly that the Son Valley basins have distinctive vegetational as well as depositional history during Permian and Triassic time (Raja Rao, 1983). A fairly marked deviation of palynological succession between Damodar River Basin and South Rewa Basin is also evident (Tiwari & Rana, 1980; Tiwari & Singh, 1986; Tiwari & Ram-Awatar, 1986, 1987 a, b) which reflects the influence of different floral components.

In South Rewa Basin, the Barakar Formation was overlain by uninterrupted deposition of thick sequence of Pali Formation, which is divisible into three units—Lower, Middle and Upper. The Lower Pali Member is equated with Barren Measures. The Middle Pali Member contains coal seams and carbonaceous layers with rich floral assemblage of Upper Permian affinity. The palynoflora of this horizon has been described by Tiwari and Ram-Awatar (1986) from Johilla Coalfield. In this assemblage, beside typical Upper Permian components, some forms such as taeniate genera *Trabeculosporites* and *Haemiapollenites* start appearing, which further increase in Nidpur beds. There is a fair degree of resemblance between the

## PLATE 2

→

1. *Crescentipollenites* Bharadwaj, Tiwari & Kar 1974; Slide no. BSIP 10248, Coordinate 31.5 × 96.5.

2, 13. *Trabeculosporites* Trivedi & Misra 1970; Slide nos. BSIP 10248, 10246A, Coordinates 47 × 101.5 & 41 × 103.

3. *Lunatisporites pellucidus* (Goubin) Maheshwari & Banerji 1975; Slide no. BSIP 10248, Coordinate 43 × 91.5.

4. *Distriatites bilateralis* Bharadwaj 1962; Slide no. BSIP 10246A, Coordinate 40 × 97

5. *Satsangisaccites nidpurensis* Bharadwaj & Srivastava 1969; Slide no. BSIP 10248, Coordinate 15.5 × 104.

6. *Araucariacites* (Cookson, 1947 ex Couper 1953); Slide no BSIP 10246A, Coordinate 41 × 103.

7, 8. *Playfordiaspora* Maheshwari & Banerji 1975; Slide nos. BSIP 10246, 10242; Coordinates 35 × 110 & 22 × 92.

9. *Falcisporites* Leschik emend. Klaus 1963; Slide no. BSIP 10248, Coordinate 22 × 108.

10. *Klausipollenites* Jansonius 1962; Slide no. BSIP 10244A, Coordinate 22 × 94 (Leitz. no. 512794/067053).

11. *Lundbladispora brevicula* Balme 1970; Slide no. BSIP 10245, Coordinate 21 × 109 (Leitz. no. 512794/067053).

12. *Densoisporites* Weyland. & Krieg. emend. Dettmann 1963; Slide no. BSIP 10244B, Coordinate 32 × 98.

14. Alete Type-A, Slide no. BSIP 10243, Coordinate 25 × 102.

15. *Goubinispora morondavensis* Tiwari & Rana 1980; Slide no. BSIP 10242, Coordinate 32.5 × 91.

16. *Weylandites indicus* Bharadwaj & Srivastava 1969; Slide no BSIP 10247A, Coordinate 13 × 102.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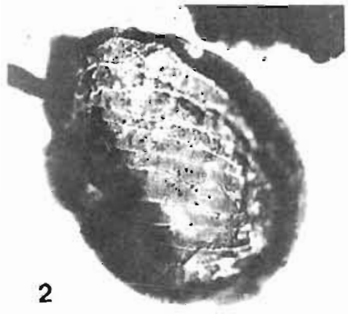
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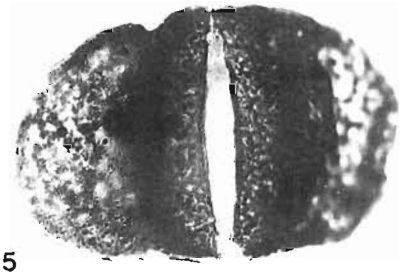
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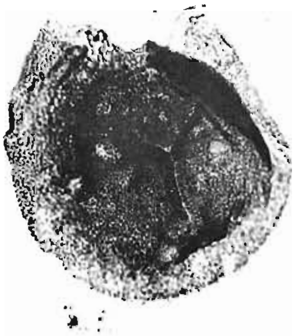
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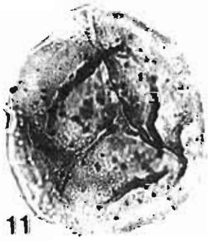
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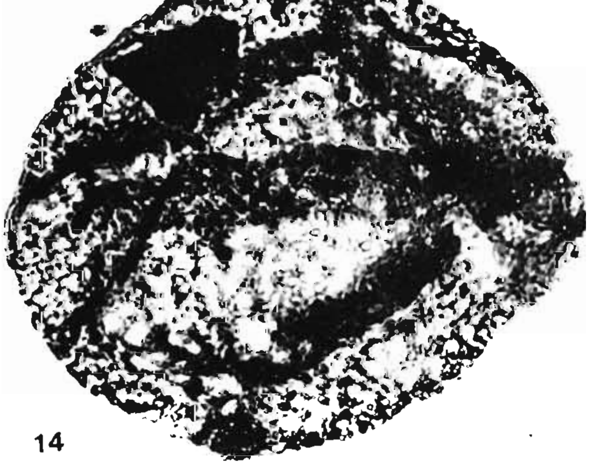
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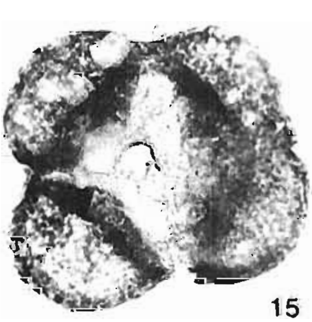
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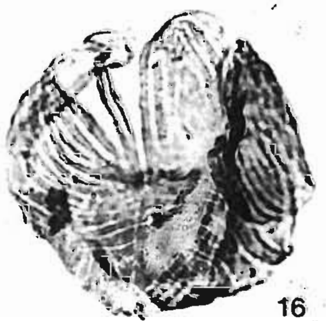
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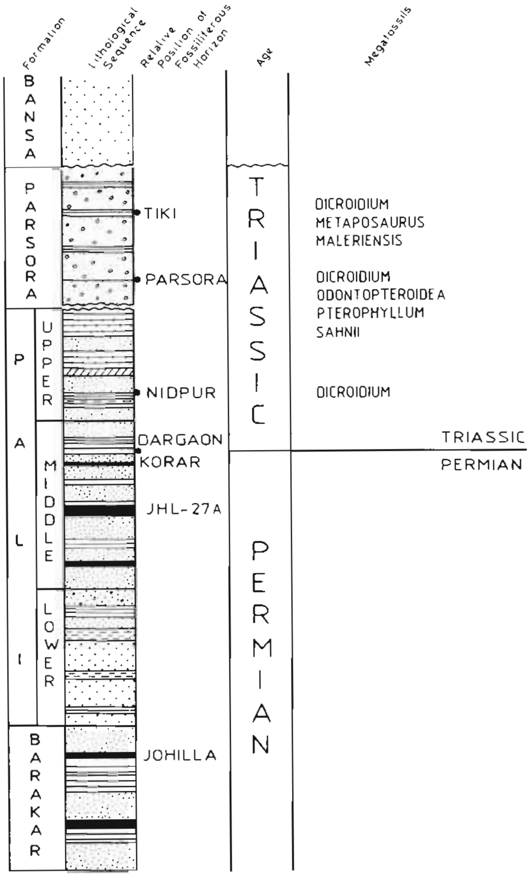
**PLATE 2**

Middle Pali palynoflora described by Tiwari and Ram-Awatar (1986) and those recovered in the assemblages from Gopad River Section (except Nidpur beds), Mahan River and Sehra nala studied here. Lithologically too, the latter sediments contain coal bands, grey shales and red facies with *Glossopteris* and *Vertebraria* fossils; therefore, they exhibit a relationship with Middle Pali. On the basis of mega- and microflora studied here. A latest Permian age is assigned to these beds. It is remarkable that the palynofloras in these beds are relatively younger to the assemblage described from bore-hole JHL-27A (Tiwari & Ram-Awatar, 1986). Besides, two assemblages from Korar Coalfield (in bore-hole UKD-8) are also recorded (Tiwari & Ram-Awatar, 1987b) ranging from Upper Permian to Lower Triassic. A still younger aspect has been noticed in the assemblage from beds exposed in Johilla River Section between Dargaon and Salaia villages (Tiwari & Ram-Awatar, 1987a). Earlier this portion was mapped in the Parsora Formation but now it is considered as a part of Pali Formation (Ram-Awatar, 1988). The sediments outcroping at Dargaon-Salaia villages have a well-preserved Late Permian/Early Triassic palynoflora. The palynoflora recovered from Nidpur bed is still younger than the Dargaon-Salaia assemblage of Johilla River having the predominance of taeniate pollen, and the *Playfordiaspora-Lundbladispora* components.

There is a continuity of some forms in all the four assemblages discussed above (Text- fig. 7), but the Nidpur assemblage is distinctive as well as younger than the remaining three. Lithologically, the sediments containing the palynological Zone I in 'Nidpur plant beds' show affinity with the Middle Pali Member in having carbonaceous layers in sandstone, but the palynological Zone II comes from a distinct suite of rocks where grey shale and siltstone are interbedded in sandstone which passes on to chocolate, red shale facies and lilac-coloured massive sandstone. The latter suite of lithology does not belong to Middle Pali Member; on the otherhand, it has a trend of similarity with the Upper Pali and Parsora Formation. Since both the palynological zones of Nidpur beds, i.e., Zone I and Zone II, have Triassic affinity, it becomes evident that the P/T boundary lies in the upper part of the Middle Pali Member but not at the Middle/Upper Pali level. Thus the lithology continues to transgress the P/T boundary.

Palynofloristically, Nidpur beds are older than the Tiki Bed (Kumaran & Maheshwari, 1980; Maheshwari & Kumaran, 1979), and much younger than the beds exposed in Johilla River between Dargaon and Salaia (Tiwari & Ram Awatar, 1987a).



**Text-figure 7**—Generalized sequence of sediments of Barakar, Pali and Parsora formations in Son Valley. Relative positioning of various fossiliferous horizons and their age relationship. Palynofossils known from all the beds marked except Parsora.

The Tiki beds are dated as Carnian to Early Norian on the basis of animal remains, such as *Metaposaurua maleriensis, Pachygonia incurvata* (amphibian), and *Phytosaurus maleriensis* (reptilean), etc. (Chatterjee & Roy Chowdhury, 1974). The Dargaon-Salaia Bed do not contain animal fossils, but palynologically it represents a P/T boundary zone (Tiwari & Ram-Awatar, 1987a). The Parsora Formation, exposed near Parsora Village, overlies the Upper Pali Formation and considered here older to the Tiki Bed. Lithologically, the Parsora Formation includes medium to coarse-grained sandstone, pebbly intercalations, violet to lilac-coloured shales and massive sandstones. The strata capping the *Dicroidium*-bearing beds near Nidpur show resemblance with Parsora-type of lithology. The plant megafossils found in the Parsora Formation include *Dicroidium odontopteroidea, Pterophyllum sahnii* and *Marattiopsis* sp. (Lele, 1955, 1961, 1962); the age of this formation is considered to be Late Triassic.

## DISCUSSION

The Nidpur fossiliferous beds are trapped between two faults at the anticlinal axis zone of the Middle Pali beds, and they have been down thrusted resulting into an escape from erosion. There is no continuity of sequence between the *Glossopteris*-dominant beds and the *Dicroidium*- dominant bed in the Gopad River.

The fragmentary glossopterid remains may occur sporadically in the Nidpur plant beds but overwhelming number of *Dicroidium* leaves and varied fructifications of pteridospermic affinity strongly suggest a major floral break at this level, with relation to other plant beds in Gopad River. The scope of this paper does not permit a discussion whether the *Dicroidium* leaves found in Nidpur beds are "true" *Dicroidium*, as they do not possess a forked rachis (cf. Townrow, 1957). Notwithstanding, it is certain that such leaves and other pteridospermic remains have never been reported from Sehra nala, Mahan River, Gopad River or any of the Upper Permian strata in peninsular India, including the type area of Raniganj Formation; obviously they do not indicate a Permian relationship. On the contrary, several reports of the occurrence of *dicroidium* are on record from the post-Permian horizon of India (Lele, 1962; Saksena, 1962; Bose & Banerji, 1976; Banerji & Bose, 1977; Pal, 1984). It could be that the forked and unforked rachis-bearing leaves were the constituents of the closely related population of plants. Nevertheless, it seems more probable that this leaf-taxon is an organ of the plant which thrived in the Triassic time rather than the Permian, because not a single specimen has been recorded so far from the rich megafossil zone of well-established Upper Permian in India.

Palynologically, the high incidence of taeniate pollen and variable representation of the genera *Playfordiaspora, Lundbladispora, Densoisporites, Klausipollenites, Goubinispora, Falcisporites, Araucariacites, Alisporites, Podocarpidites,* etc., directly corroborate with the Triassic palynofloras known from the Indian Gondwana. It may be that several Permian pollen continue to occur in the Nidpur beds, but this phenomenon is true for other Lower Triassic strata also. The remainié of Permian have always stradded up into the Triassic. It may be mentioned here that there are certain common species between Nidpur beds and the marine controlled Lower and Middle Triassic or even younger strata of Madagascar, e.g., *Striomonosaccites morondavensis, Protohaploxipinus ovatus, Vitreisporites pallidus, Cuneatisporites radialis, Platysaccus* cf. *leschiki, Sulcatisporites prolatus, Araucariacites australis* (original names after Goubin, 1965). A degree of close similarity between the two may be drawn from this observation.

As mentioned earlier, a sample (Sample no. GPD-2) collected from a shale in Mahadeva sandstone exposed in the Gopad River near northern boundary fault, yielded several taeniate-disaccate pollen. This is an important control-point because the Mahadeva are Triassic in age; it strongly suggests a Triassic affinity for Nidpur plant beds which also have abundant taeniate pollen.

From amongst the known assemblages of Tethys Himalayan sequence, the Kalapani Limestone and Kuti Shale (Anisian to Norian) have several elements of pollen which are common with the palynoflora of Nidpur beds (Tiwari *et al.*, 1984; Vijaya *et al.*, 1988). The Kalapani assemblage, in particular, possesses *Lundbladispora brevicula, Playfordiaspora cancellosa, Klausipollenites schaubergerii, Satsangisaccites nidpurensis, Alisporites landianus, Falcisporites stabilis, Nidipollenites monoletus*; these species are on record from the Nidpur beds.

The Permian and Triassic palynofloras from Salt Range are well known (Balme, 1970) but their comparison with that of Nidpur Bed is restricted as well as qualified because of the variance in diversity and regional influences on the former. Amongst the important taxa—*Navalesporites (Polypodiidites)* sp. and *Corisaccites-Guttulapollenites*-complex characterise the Permian formations of the Salt Range. These two genera are absent from the Nidpur beds but they are recorded in the *Glossopteris*-bearing sediments exposed in Sehra nala, Gopad River and Mahan River, which have been dated here as latest Permian. The taxa *Playfordiaspora (Guthoerlisporites) cancellosa, Lundbladispora brevicula* and *Falcisporites stabilis* (resembling *Satsangisaccites*), *Alisporites* spp. and *Densoisporites* spp. mainly qualify the late Lower and Middle Triassic of the Salt Range. Thus, their occurrence in Nidpur palynoflora is an indicator of Triassic relationship.

The *Paravittatina lucifer* in the Permian of Salt Range and *Weylandites indicus* in Nidpur palynoflora are different specific groups, hence their matching for dating cannot be done. So also the specimens referred to *Falcisporites nuthallensis* characterise the Permian of salt Range, but they are not comparable with the types found in Nidpur.

## CONCLUSIONS

The possibility of Nidpur fossiliferous beds being of Permian age is ruled out because:

1. they contain fossils of *Dicroidium, Pteruchus, Lepidopteris,* etc;
2. *Dicroidium*, even it is mostly of unforked-rachis-type, is not found in any of the well-established Upper Permian of India; on the other hand, it is frequent in the Triassic sequence;
3. a feeble continuation of the occurrence of *Glossopteris* in the Nidpur beds is not abnormal because such reports are on record from the Panchet Formation of the Raniganj Coalfield also. Remainié of the dominant plant group in Permian always stradded accross the P/T boundary;
4. Nidpur beds occur in a down-thrusted block as a result of which they escaped erosion. They are the youngest beds in the sequence of Pali Formation exposed in Gopad River;
5. they are capped by a lilac-coloured shale, clays and pinkish coarse-grained sandstones which resemble the litho-suite of Parsora Formation;
6. Nidpur beds are in faulted contact, to the north and south, with the Upper Permian strata which bear profused glossopterid plant fossils, but no *Dicroidium.*

Palynologically, it resembles the Lower Panchet Formation. The fair and consistent presence of *Falcisporites, Lunatisporites* (and taeniate complex), *Densoisporites, Laricoidites, Klausipollenites, Lundbladispora, Satsangisaccites, Araucariacites, Goubinispora, Nidipollenites, Playfordiaspora, Weylandites* and *Alisporites* brings the Nidpur beds very close to the palynological zone P-I of the Panchet in the type area (table 1 in: Tiwari & Singh, 1986).

The R-I and R-II palynozones belonging to uppermost Raniganj Formation (Tiwari & Singh, 1986) record the presence of *Gondisporites, Striatosporites, Indospora, Ephidripites, Verticipollenites, Thymospora, Hindipollenites, Welwitschiapites*, etc., which are not present in the Nidpur beds. Although an inconsistent and highly sporadic occurrence of some of the elements of P-I zone is recorded in R-I and R-II zones of the Upper Raniganj Formation (Tiwari & Singh, 1986) but their presence only suggests of foreshadow of the floral change. In totality of generic prominence and that of the fairly high incidence of the marker palynotaxa of Panchet (i.e. P-I to P-IV assemblage; Tiwari & Singh, 1986) the palynoflora of the Nidpur beds ascertains an Early Triassic age for the *Dicroidium*-rich horizon.

## ACKNOWLEDGEMENTS

The authorities of the Coal Division, Geological Survey of India have been the source of inspiration for us during last eight years to take up P/T boundary problem based on palynology; the present work is the outcome of such an attempt. We are thankful to them for their help. To Sri P. Satsangi and Sri Gopal Singh of the Palaeontology Division, G.S.I., Lucknow we are grateful for critically going through the manuscript and for useful discussion and suggestions. To Dr N. D. Mitra and Sri Mantu Majumdar, G.S.I., Calcutta, our thanks are extended for making available his experience of field study of the area through discussion and valuable suggestions. To Dr B. S. Venkatachala, Director, BSIP, we owe our sincere thanks for initiating the discussion on Nidpur and constant encouragement by his valuable comments and suggestions during the progress of this work.

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# Plant fossils from Dubrajpur Formation, Bihar and their significance in stratigraphy

Jayasri Banerji

Banerji, Jayasri 1990. Plant fossils from Dubrajpur Formation, Bihar and their significance in stratigraphy. *In*: Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** 122-130.

The paper deals with the plant fossils of Dubrajpur Formation exposed at Khatangi Hill in the Rajmahal Basin, Bihar. The assemblage is dominated by cycadophytes, though pteridophytes are quite frequent. Conifers are poorly represented. The genera *Onychiopsis, Ctenis, Taeniopteris* and *Pagiophyllum* are recorded for the first time. In view of the present finding the age of the Khatangi sediments is discussed. The dominance of cycadophytes and poor representation of conifers indicate subtropical to tropical climate prevailing at that time.

**Key-words**—Megafossils, Pteridophytes, Cycadophytes, Conifers, Dubrajpur Formation, Upper Jurassic (India).

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## साराँश

### बिहार में दुबराजपुर शैल-समूह से पादप-अवशेष तथा स्तरविन्यास में इनका महत्व

जयश्री बैनर्जी

बिहार में राजमहल द्रोणी में खातगी पहाड़ी में अनावरित दुबराजपुर शैल-समूह से उपलब्ध पादपाश्मों का वर्णन किया गया है। हाँलाकि टेरीडोफ़ाइटी पौधे इस समुच्चय में काफ़ी अधिक संख्या में मिलते हैं, साइकेडोफाइटी पौधों की बाहुल्यता है। कोनिफरी पादपाश्म अल्प संख्या में पाये गये हैं। **ओनाइकिऑप्सिस, टीनिस, टीनिऑप्टेरिस** एवं **पेजिओफिल्लम्** नामक प्रजातियाँ इस समुच्चय से पहली बार अभिलिखित की गई हैं। इन पादपाश्मों के आधार पर खातंगी अवसादों की आयु की विवेचना की गई है। साइकेडोफ़ाइटीयों की बाहुल्यता तथा कोनिफरों की अल्प संख्या से निक्षेपण के समय उपोष्णकटिबन्धीय से उष्णकटिबन्धीय जलवायु का होना इंगित होता है।

OLDHAM (1863 *in*: Oldham & Morris, 1963) first recognised Dubrajpur beds as a distinct horizon and named it after the village Dubrajpur in the Rajmahal Hills. Ball (1877) mapped this area and reported *Ptilophyllum* fronds from Dubrajpur beds. Later, Srivastava (1958), Sah (1965) and Sen Gupta (1988) recorded various fossil assemblages from Dubrajpur Formation exposed at Khatangi Hill near Kharikasol Village, Rajmahal Hills, Bihar (see Table 1) and proposed various ages for the *Ptilophyllum*-bearing beds of Dubrajpur Formation

Sah and Shah (1974) made two biozones within Dubrajpur Formation. The basal zone-A, comprising *Glossopteris communis, G. ampla, G. retifera, G. parallela* and *Vertebraria indica* of Upper Permian affinity and the upper zone-B consisting of *Marattiopsis macrocarpa, Gleichenites gleichenoides, Ptilophyllum acutifolium, Nilssonia princeps, Macrotaeniopteris lata* and *Williamsonia* sp. of early Middle Jurassic age. Sen Gupta (1984, 1985) carried out extensive work on Khatangi Hill section as well as the designated type section of Dubrajpur Formation at Sarwan Pahar near Dubrajpur Village. According to him, basal zone-A of Sah and Shah (1974), i.e., *Glossopteris-Vertebraria* assemblage, belongs to the Barakar Formation and the upper zone-B comprising *Ptilophyllum-Gleichenites* assemblage belongs to Dubrajpur Formation (Lower Jurassic). Sukh-Dev (1988) assessed an Early Cretaceous age for the latter assemblage. Tiwari *et al.* (1983) recognized six palynoassemblage zones from the subsurface sequence of Dubrajpur Formation as well as Intertrappean beds. They dated palynoassemblage zones A-C as Carnian-Norian, and zones D-F as Late Jurassic/Early Cretaceous, Singh and Venkatachala (1988) reassigned zones D-F to be Early Cretaceous.

The present investigations are based on plant fossils collected from Khatangi Hill. These plant remains are preserved as impressions on greyish-white shales. All the specimens have been deposited at the Birbal Sahni Institute of Palaeobotany Museum.

## DESCRIPTION

### Filicales

**Genus—*Gleichenites* Goeppert 1836**

*Gleichenites gleichenoides* (Oldham & Morris) Seward & Sahni 1920
Pl. 1, fig. 1

*Remarks*—In gross morphological features, the present specimens are similar to those of *Gleichenites gleichenoides* (Oldham & Morris) Seward & Sahni 1920.

**Genus—*Culcitites* Appert 1973**

*Culcitites madagascariensis* Appert 1973

1965 *?Thinnfeldia* sp., Sah, p. 219, pl. 1, fig. 3.
1965 *Microphyllopteris* sp., Sah, p. 219, pl. 1, fig. 5.
1988 *Thinnfeldia khatangiensis*, Sen Gupta, p. 75, pl. 12, fig. 32; pl. 15, fig. 40; text-fig. 17 (for details see Banerji, 1988).

### Unclassified ferns

**Genus—*Onychiopsis* Yokoyama 1889**

*Onychiopsis* sp.
Pl 1, figs 2, 3; Text-fig. 1A

*Description*—Fronds probably tripinnate, best available specimen about 2.5 cm in length. Ultimate pinnae sub-oppositely attached at an angle of 60°-

**Table 1—Plant fossil assemblages recorded by different authors from Dubrajpur Formation at Khatangi Hill**

| Srivastava, 1958 | Sah, 1965 | Sen Gupta, 1988 | Present assemblage |
|---|---|---|---|
| FILICALES:<br>*Gleichenites* sp.<br>*Marattiopsis* sp. | FILICALES:<br>*Gleichenites gleichenoides* (Oldham & Morris) Seward & Sahni | FILICALES:<br>*Gleichenites gleichenoides* (Oldham & Morris) Seward & Sahni | FILICALES:<br>*Gleichenites gleichenoides* (Oldham & Morris) Seward & Sahni<br>*Culcitites madagascariensis* Appert |
| UNCLASSIFIED FERNS:<br>*Cladophlebis* sp.<br>*Sphenopteris* sp.<br>*Pecopteris* sp. | UNCLASSIFIED FERNS:<br>*Cladophlebis indica* (Oldham & Morris) Sahni & Rao<br>*Cladophlebis* sp.<br>*Microphyllopteris* sp. | UNCLASSIFIED FERNS:<br>*Cladophlebis indica* (Oldham & Morris) Sahni & Rao | UNCLASSIFIED FERNS:<br>*Cladophlebis indica* (Oldham & Morris) Sahni & Rao<br>*Onychiopsis* sp. |
| CYCADALES:<br>*Nilssonia* sp. | PTERIDOSPERMALES:<br>*?Thinnfeldia* sp. | PTERIDOSPERMALES<br>*Thinnfeldia khatangiensis* sp. nov. | |
| BENNETTITALES:<br>*Otozamites* sp. | BENNETTITALES:<br>*Pterophyllum* sp.<br>*Williamsonia* sp.<br>*Ptilophyllum acutifolium* | BENNETTITALES:<br>*Ptilophyllum acutifolium* Morris<br>*Pterophyllum fissum* Feistmantel | BENNETTITALES:<br>*Ptilophyllum cutchense* Morris<br>*Ptilophyllum acutifolium*<br>*Williamsonia* sp.<br>*Pterophyllum distans* Morris<br>*Pterophyllum* sp. cf. *P. footeanum* Feistmantel |
| | CYCADALES:<br>*Nilssonia princeps* (Oldham & Morris)<br>*Nilssonia* sp.<br>*Macrotaeniopteris lata* (Oldham & Morris) Sahni | CYCADALES:<br>*Taeniopteris crenata* McClelland | CYCADALES:<br>*Nilssonia* sp.<br>*Ctenis rajmahalensis* n. sp.<br>*Taeniopteris* sp. cf. *T oldhamii* Bose & Banerji<br>*Taeniopteris* sp. |
| | CONIFERALES:<br>*Elatocladus conferta* (Oldham & Morris) Sahni | | CONIFERALES:<br>*Pagiophyllum* sp. |

70°, linear to lanceolate in shape, largest ultimate pinna 1 cm long and 2.5 mm broad. Pinnule-lobing towards base complete but towards distal end lobing incomplete at places. Pinnules oblanceolate to elliptical in shape, measuring 1.5-2 × 1-1.5 mm, margin entire, apex subacute to obtuse, attached by broad decurrent base. Venation mostly inconspicuous. Proximal pinnules with forked or unforked veins; rest, at places, showing keeled midvein appearing to be fertile.

*Remarks*—Five frond fragments have been recovered but their fertile nature is uncertain. The specimens are comparable with *Onychiopsis elongata* (Geyler) Yokoyama (1889, pl. 12, fig. 10) in size and shape of sterile pinnules. Sukh-Dev (1970) considered *O. elongata* and *O. paradoxus* Bose & Sukh-Dev 1959 as junior synonyms of *O. psilotoides* (Stokes & Webb) Ward but Kimura and Aiba (1986) maintain *O. elongata* as the type species of this genus.

#### Genus—*Cladophlebis* Brongniart 1849

*Cladophlebis indica* (Oldham & Morris) Sahni & Rao 1933
Pl. 1, fig. 4

*Comparison*—*Cladophlebis indica* is common in the assemblage. These forms are similar to the sterile frond of *Todites indicus* (Oldham & Morris) Bose & Sah described from various other localities of Rajmahal Basin. But due to lack of fertile fronds from this locality, they are being placed provisionally under *Cladophlebis indica* (Oldham & Morris) Sahni & Rao 1933.

### Bennettitales

#### Genus—*Ptilophyllum* Morris 1840

*Ptilophyllum cutchense* Morris 1840
Pl. 1, fig. 6

*Remarks*—According to Sen Gupta (1988, p. 103) *Ptilophyllum cutchense* Morris is restricted to *Cladophlebis indica-Dictyozamites indicus* assemblage zone of Middle to Upper Jurassic and absent in *Ptilophyllum acutifolium-Gleichenites gleichenoides* zone of Khatangi Hill.

*Ptilophyllum acutifolium* Morris 1840
Pl. 1, fig. 9

*Remarks*—A few specimens resembling *P. acutifolium* are present in the collections.

#### Genus—*Williamsonia* Carruthers 1870

*Williamsonia* sp.
Pl. 1, figs 5, 7

*Description*—Flower large, incomplete, about 10-14 cm in length and 7 cm in width; base of the flower probably rhomboidal, gradually tapering towards apex, bracts numerous, more than 12 in number, 5-6 mm broad, surface of bracts striate, proximal portion of bracts hairless but distal portion hairy; hairs up to 8 mm long.

*Comparison*—Only two specimens are found, one (Pl. 1, fig. 5) showing proximal part with hairless bracts and the other (Pl. 1, fig. 7) showing distal part of bracts with profuse hairs. Although both the specimens are described here as *Williamsonia* sp., there is a possibility of existence of two different species.

In their large size, the present specimens resemble *Williamsonia indica* Seward 1917 and *W. sahnii* Gupta 1943. But the specimen with profuse hairy bracts resembles *W. sahnii* and the other one compares with *W. indica* having hairless bracts.

#### Genus—*Pterophyllum* Brongniart 1828

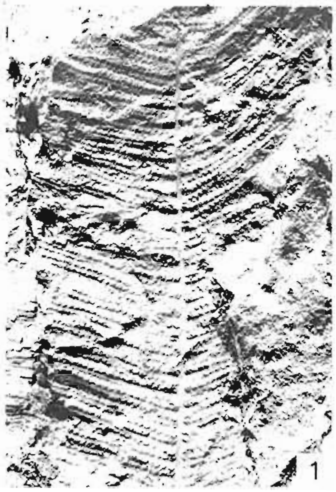
*Pterophyllum distans* Morris 1863
Pl. 1, fig. 10

*Comparison*—The specimen of *Pterophyllum distans* from Khatangi Hill, except for smaller pinnae is similar to those of the same species from Kutch

### PLATE 1

→

1. *Gleichenites gleichenoides* (Oldham & Morris) Seward & Sahni, a fragment of frond bearing small deltoid pinnules, Specimen no. BSIP 36244, × 1
2. *Onychiopsis* sp. a frond fragment, Specimen no. BSIP 36245B, × 2.
3. *Onychiopsis* sp., a frond with sterile and probable fertile pinnules at the distal end, Specimen no. BSIP 36245, × 2.
4. *Cladophlebis indica* (Oldham & Morris) Sahni & Rao, pinnule showing venation pattern, Specimen no. BSIP 36246A, × 2.
5. *Williamsonia* sp., a large incomplete flower showing overlapping bracts without hairs, Specimen no. BSIP 36250, × 1
6. *Ptilophyllum cutchense* Morris, showing overlapping pinnate leaves, Specimen no. BSIP 36262 A, × 1.
7. Distal portion of *Williamsonia* flower with hairy bracts, Specimen no. BSIP 36249, × 1.
8. *Ptilophyllum acutifolium* Morris, frond showing pinnae with acuminate apex, Specimen no. BSIP 36262 B, × 1.
9. *Pterophyllum* sp. cf. *P. footeanum*, Specimen no. BSIP 36252, × 1.
10. *Pterophyllum distans* Morris, pinnate leaf showing distantly placed pinnae, Specimen no. BSIP 36251, × 1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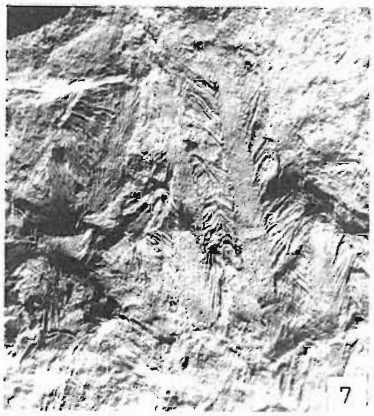
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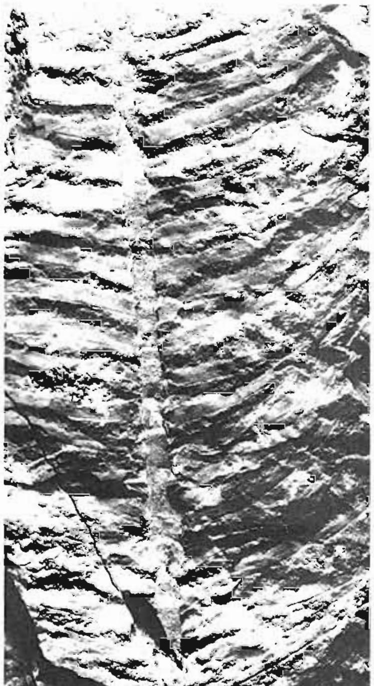
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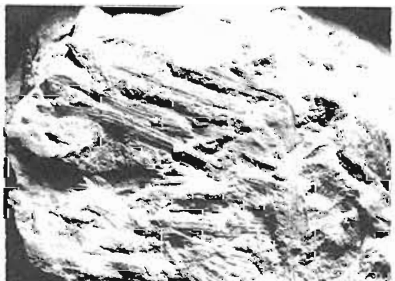
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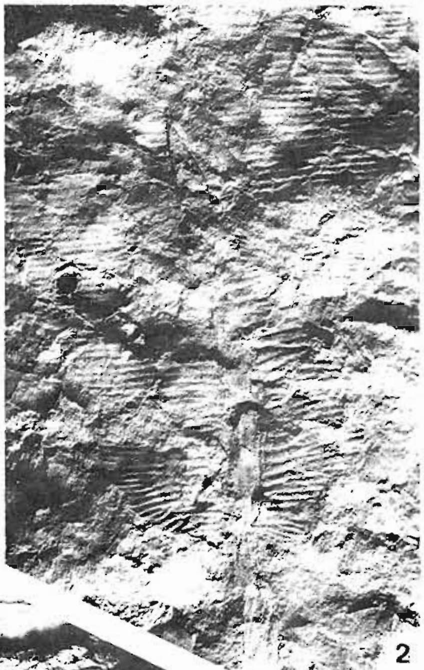
PLATE 1


1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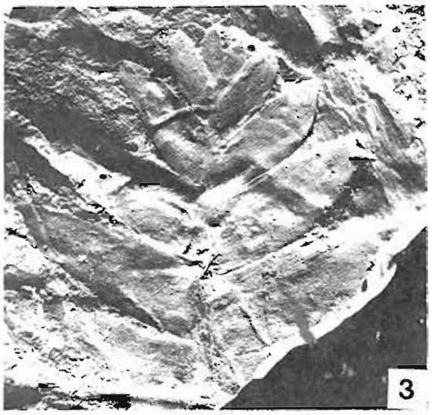
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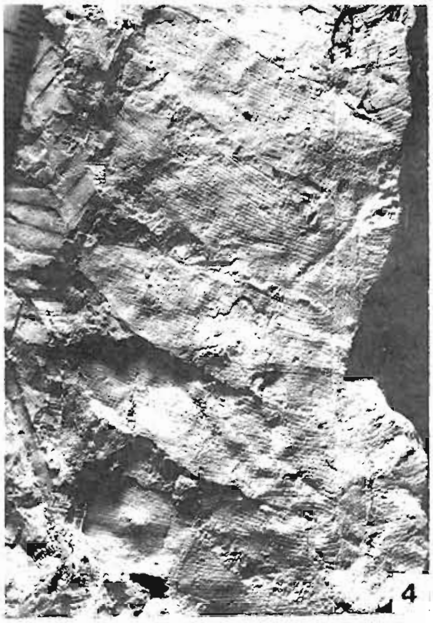
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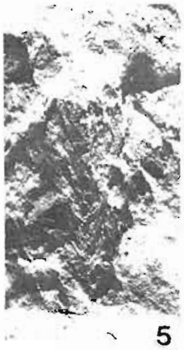
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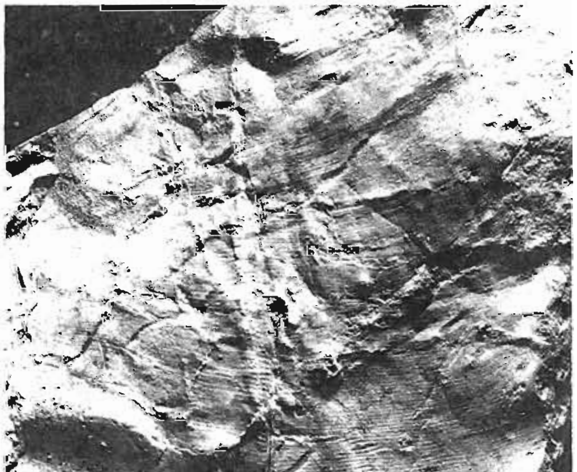
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PLATE 2

(Bose & Banerji, 1984). The Khatangi specimen probably represents a juvenile leaf.

*Pterophyllum* sp. cf. *P. footeanum* Feistmantel 1879
Pl. 1, fig. 9; Text-fig. 1B

*Description*—Specimens incomplete, 3.5 cm long; rachis 1 mm broad, finely striate. Pinnae alternate to sub-opposite, attached on lateral sides of rachis at angles of 80°-90°, linear, largest pinna fragment about 3.5 cm in length and 3-4 mm in width, apex mostly not preserved but in one specimen it seems to be obtuse; base broad, acroscopic and basiscopic basal margins turned upwards and downwards respectively and perhaps jointed with the bases of adjacent pinnae of same side; veins 3-8 per pinna, mostly forked at various levels.

*Remarks*—The specimens resemble *Pterophyllum footeanum* Feistmantel 1879 except for less concentration of veins.

## Cycadales

### Genus—*Nilssonia* Brongniart 1825

*Nilssonia* sp.
Pl. 2, figs 6, 7; Text-fig. 1C

*Description*—Leaves simple, incomplete, largest 20 cm in length and 9 cm in width, elongate, oblanceolate to spathulate. Rachis 0.6 cm broad near base. Lamina rather delicate with flecks of resin, corrugated, occasionally divided into irregular rectangular segments in middle region. Segments with lateral margin truncated and straight, slightly wavy at places. Apex obtuse, lamina gradually tapering towards base. Veins mostly simple, arising at right angle and running straight across lamina, slightly curved upwards towards apex, 20-30 veins/cm at margin.

*Remarks*—In most of the specimens studied, the attachment of lamina is not clear. A specimen (Pl. 2, fig. 7) shows lamina which almost covers the midrib leaving a narrow groove. Another specimen shows flecks of resin (Pl. 2, fig. 6), which is also a characteristic feature of the genus *Nilssonia*; veins are mostly unforked. Though the stomatal features are not known, yet the concentration of veins is unlike the genus *Pterophyllum* Brongniart.

*Comparison*—*Nilssonia orientalis* Heer described by Jacob and Shukla (1955) from Saighan Series of Afganistan is nearest to the present specimens in gross features and vein concentration, but differs by its less-segmented lamina.

### Genus—*Ctenis* Lindley & Hutton 1834

*Ctenis rajmahalensis* sp. nov
Pl. 2, figs 3, 4; Text-fig. 1D

*Diagnosis*—Fronds paripinnate, more than 12 cm in length and 10.7 cm in width. Rachis up to 6 mm broad, smooth or finely striate. Pinnae laterally attached at angles of 80°-90°, 0.6-5.8 cm in length, 2.5-2 cm in breadth, attached by broad base, margin entire, apex subacute to obtusely rounded, basal basiscopic and acroscopic margins extended upward and downwards on the rachis joining the adjacent pinnae. Rarely at places basal basiscopic margin slightly constricted and upper one straight. Veins arising at wide angles, forking at various levels, sub-parallel throughout the lamina with slight divergence towards lateral margins, 10-12 per cm at base, 16-18 per cm in middle region and 20-25 per cm towards distal end.

*Holotype*—Pl. 2, fig. 4, Specimen no. BSIP 36259.

*Remarks*—All the specimens are incomplete and show either apical or middle portion of the frond. Cross-connections between veins are rarely visible *Ctenis rajmahalensis* is somewhat comparable to *Ctenis imjhiriensis* Bose & Zeba-Bano 1979 in having rare cross-connections but the Khatangi Hill specimens differ by smaller pinnae and decurrent basal margins. In *Ctenis imjhiriensis* basiscopic and acroscopic margins are contracted.

### Genus—*Taeniopteris* Brongniart 1828

*Taeniopteris* sp. cf. *T. oldhamii* Bose & Banerji 1981
Pl. 2, fig. 1; Text-fig. 1E-G

*Description*—Leaf petiolate, petiole incomplete, 1-2.5 mm broad. Lamina ovate, 2.2-6 cm in length

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## PLATE 2

1. *Taeniopteris* cf. *T oldhamii* Bose & Banerji showing leaves with cordate bases, Specimen no. BSIP 36253, × 1.
2. *Taeniopteris* sp., incomplete leaf showing coarse nature of lateral veins, Specimen no. BSIP 36254, × 1
3. *Ctenis rajmahalensis* sp. nov. showing paripinnate nature of leaf, Specimen no. BSIP 36260, × 1.
4. *C. rajmahalensis* sp. nov. holotype showing venation pattern, Specimen no. BSIP 36259, × 1.
5. *Pagiophyllum* sp., Specimen no. BSIP 36258, × 1.
6. *Nilssonia* sp., showing corrugated irregularly segmented lamina of leaf with simple parallel lateral veins and fleck of resin, Specimen no. BSIP 36257, × 1.
7. Another specimen of *Nilssonia* sp. showing middle region of lamina fully covering the rachis except for a narrow median groove, Specimen no. BSIP 36256, × 1.

**Text-figure 1—A,** *Onychiopsis* sp. showing elliptical pinnules with forked or unforked veins, specimen no. B.S.I.P. 36261, × 4; **B**, *Pterophyllum* sp. cf. *P. footeanum*, linear pinnae showing venation, specimen no. B.S.I.P. 36252 × 1; **C**, *Nilssonia* sp., lamina almost covers the midrib except a narrow median groove and lateral veins are mostly unforked, specimen no. 36259, × 1; **D**, *Ctenis rajmahalensis* sp. nov., holotype showing shape and venation pattern of pinnae, specimen no. 36259, × 1; **E-G**, *Taeniopteris* sp. cf. *T oldhamii* Bose & Banerji—E. leaf showing cordate base and venation pattern, specimen no. B.S.I.P. 36253, × 1. **F-G.** small leaf of the above species showing emarginate apex and cordate base, specimen nos. 36247, 36247 (C.P.), × 1.

and 2.2-4 cm in width, margin appears to be entire, apex probably emarginate, base cordate. Midrib 1-2 mm thick, distinct up to apex, veins arising at 60°-80° angles, simple or forked, forking at various levels; vein concentration near midrib region 8-14 per cm and towards margin 13-20 per cm.

*Remarks*—The specimens though resemble *T. oldhamii* Bose & Banerji 1981 in general, yet differ in having emarginate apex and more or less entire margin. *Taeniopteris emarginata* Oishi 1940 has emarginate apex, but is distinguished by an obovate-elliptical shape and high concentration of veins.

### *Taeniopteris* sp.
Pl. 2, fig. 2

*Description*—Leaf incomplete, petiolate, 9.6 cm long, maximum width 6.2 cm. Petiole 2.6 cm long, 0.5 cm broad, surface showing wrinkles. Lamina probably thin, base constricted, margin entire. Petiole continued as midrib of the lamina. Lateral veins coming out almost at right angles to midrib, mostly bifurcated once in middle region, concentration of veins 7-10 per cm near midrib and 10-14 per cm near margin.

*Comparison*—*Taeniopteris* sp. resembles *T. buskoghatensis* Bose & Banerji 1981 in coarse nature of lateral veins.

## Coniferales

### Genus—*Pagiophyllum* Heer 1881

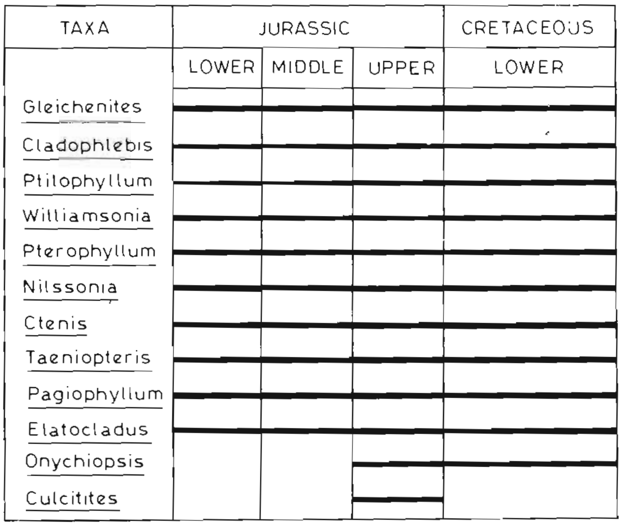
### *Pagiophyllum* sp.
Pl. 2, fig. 5

*Description*—Twig 2.5 cm long, 3 mm wide, leaves spirally disposed at angles of 30°-45°, linear to falcate, 4 × 0.5 mm, apex acute, margin entire, acroscopic basal margin straight, basiscopic basal margin decurrent, medianly keeled. Keel distinct up to apex.

*Remarks*—*Pagiophyllum* has been recorded from Khatangi Hill for the first time. The specimen compares best with *Pagiophyllum araucaroides* Vishnu-Mittre 1959, but the latter is based on anatomical details.

## DISCUSSION

In Dubrajpur Formation at Khatangi Hill, the cycadophytes are represented by nine species belonging to six genera. *Ptilophyllum* is the most dominant element. *Nilssonia* and *Ctenis* are quite frequent, whereas *Pterophyllum* and *Taeniopteris* are meagrely represented. Lycopsids and sphenopsids are absent in this assemblage. Ferns are represented by *Gleichenites, Culcitites, Onychiopsis* and *Cladophlebis*. Conifers are extremely rare and represented by a fragment of *Pagiophyllum* and *Elatocladus conferta*. The assemblage is characterised by frequent occurrence of *Culcitites, Onychiopsis, Ctenis* and *Nilssonia* along with the preponderance of *Ptilophyllum* and *Gleichenites*. Frequent occurrence of *Onychiopsis* along with abundance of *Gleichenites* indicates a Lower Cretaceous affinity. However, unlike other Lower Cretaceous assemblages the conifers are relatively infrequent. An Upper Jurassic affinity cannot be ruled out as the flora is dominated by cycadophytes and contains an Upper Jurassic marker genus *Culcitites* (Text-fig. 2). The overall dominance of cycadophytes over the conifers depicts that a tropical to subtropical climate was prevailing at the time of deposition.



**Text-figure 2**—Distribution of various taxa in Khatangi Hill, Dubrajpur Formation

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# The evolution of angiospermid pollen characteristics: conjectures and queries

G. Vasanthy, B. S. Venkatachala & S. A. J. Pocock

Vasanthy, G., Venkatachala, B. S. & Pocock, S. A. J. 1990. The evolution of angiospermid pollen characteristics: conjectures and queries. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany' Palaeobotanist* **38** : 131-146.

The origin and evolution of different exine layers of palynofossils is analysed in the light of accumulating ultrastructural data. Semi-diagrammatic illustrations based on the published TEM results of various exine types representing a cross section of extinct and extant plant groups are given for easy reference and comprehension. Some of the important palynological questions and issues discussed in the present work are: imprecise use, to describe the infra-tectum of pollen, of the flexible term "granular" that often leads to erroneous derivations and conclusions; ontogenetic differences between the apparently similar complexly alveolate columellate sexine types of gymnosperms and angiosperms respectively; independent evolution of columellar complexity in unrelated taxa; role of ubiquitous white lines in the exines of extinct and extant spores and pollen and adaptive rather than phylogenetic significance of sacci in progymnosperms, gymnosperms and angiosperms. Despite recognition of angiospermid pollen characteristics especially in tectally reticulate and columellate pollen of Triassic (Cornet, 1979, 1985, 1989; Pocock & Vasanthy, 1988; Pocock, Vasanthy & Venkatachala, 1988) the pre Cretaceous origin of angiosperm still remains an open question.

**Key-words**—Comparative analysis, Exine ultrastructure, Angiosperm evolution.

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## सारॉश

### आवृतबीजी परागकणों के लक्षणों का विकास : धारणायें एवं प्रश्न

जी० वासन्थी, बेंगलूर श्रीनिवासा वेंकटाचाला एवं ऍस० ए० जे० पोकोक

परासंरचनात्मक ऑकड़ों के आधार पर अश्मित परागकणों की विभिन्न बाह्यचोल तहों का उद्भव एवं विकास विश्लेषित किया गया है। वर्तमान एवं विलुप्त पादप समूहों के विभिन्न प्रकार के बाह्यचोल की अनुप्रस्थ काटों पर प्रकाशित पारगमन इलेक्ट्रॉन सूक्ष्मदर्शी के परिणामों पर आधारित अर्ध-चित्रित चित्र भी प्रस्तुत किये गये हैं। इस शोध-पत्र में विवेचित कुछ परागाणविक प्रश्न एवं विषय इस प्रकार हैं 'कणिकीय' शब्द, जिससे प्राय: त्रुटिपूर्ण व्याख्यायें एवं निष्कर्ष निकाले गये हैं, का अत्यन्त सीमित प्रयोग; क्रमश: अनावृतबीजीयों एवं आवृतबीजीयों के सदृश जटिल कूपिकीय/स्तंभिक सेक्साइनों के विभिन्न प्रकारों में उद्भवात्मक विभिन्नताएँ; असम्बद्ध वर्गकों में स्तंभी जटिलता का स्वतंत्र विकास; विलुप्त एवं वर्तमान परागकणों एवं बीजाणुओं के बाह्यचोल पर विद्यमान सर्वव्यापी सफेद रेखाओं की भूमिका तथा पूर्वअनावृतबीजी, अनावृतबीजी एवं आवृतबीजीयों 'कोष्ठकों' के जातिवृत्तीय महत्व के बजाय आनुकूलिक। त्रिसंघी कल्प (कॉर्नेट, 1979, 1985, 1989; पोकोक व वासन्थी, 1988; पोकोक, वासन्थी व वेंकटाचाला, 1988) के मुख्यतया स्तंभी एवं सततछदी जालिकावत् परागकणों में आवृतबीजी परागकणों के लक्षणो को मान्यता देने के बजाय आवृतबीजी पौधों का पूर्व-क्रीटेशी उद्भव अभी भी एक खुला प्रश्न है।

"POLLEN characters are subject to parallelism, convergence and possible reversal and the study of fine structural details of fossil pollen opens up possibilities of new sources of phylogenetic evidence" (Davis & Heywood, 1963). This paper is a follow-up of our recent contributions (Pocock & Vasanthy, 1988; Pocock, Vasanthy & Venkatachala, 1988; Vasanthy, Venkatachala & Pocock, 1988; Pocock, Vasanthy & Venkatachala, 1990) which emphasise the need for detailed palynological descriptions and critical analyses of exine characteristics of pre-Cretaceous palynofossils.

Light microscopic studies and SEM observations of various spore-pollen types have already amply discussed and hypothesised the evolution of germinal apertural types through ages. The objective of our present study was to trace the phylogenetic relationships with the aid of published ultrastructural details of palynofossils from Palaeozoic through Cretaceous. For easy reference and comprehension we have included in this paper the semi-diagrammatic illustrations of 56 TEM pictures of exine types. Legends of these Text-figures include our comments, conjectures and queries chiefly pertaining to basic palynology, which may aid palynologists to appreciate the new dimensions of palyno-phylogeny.

From an analysis of ultrastructural data of palynofossil and pollen types we infer that : (i) the polyplicate pollen morphotypes of *Equisetosporites, Ephedripites, Ephedra* and *Spathiphyllum* (Araceae) are infrastructurally different, thus negating any phylogenetic relationship among them; (ii) pre-Cretaceous *Equisetosporites chinleanus* and *Cornetipollis reticulata* are columellate, like Cretaceous angiosperms (cf. Pocock & Vasanthy, 1988); (iii) prevalence of saccus in many non-angiospermous plant groups and in primitive angiosperm Lactoridaceae is not a good character to link angiosperms with gymnosperms; (iv) columellar complexity might have risen independently in extant Coniferae, Circumpolles, some Eocene fossils and many taxa of angiosperms; (v) the tripartite nexine of *Equisetosporites chinleanus* with lamellate inter-bedded, mid-zone may be representative of a transitional evolutionary stage, intermediate between lamellate gymnospermous and non-lamellate angiospermous nexine; and (vi) as myriads of exine-types have been imprecisely described as "granular" and "spongy", one ought to be very discreet while grouping these types to draw phylogenetic inferences.

## GRANULAR INFRATECTUM : FACTS AND FALLACIES

In pollen morphological descriptions, the term granular is used in its broadest sense : to describe the sexinal or tectal surface sculpture (cf. Kremp, 1965, p. 61); the infra-tectal interstitial structure and sometimes even the nexine. Van Campo and Lugardon (1973) defined granular structure as sporopollenin organised into spherical grains, more or less densely distributed under the tectum and generally discernible under the electron microscope. The "synonyms" of granular infratectum—a network of rods of various size, poorly developed columellae, columellae formed of small granules, granular layer of endosexine and others—have been discussed in their informative review on granular exine.

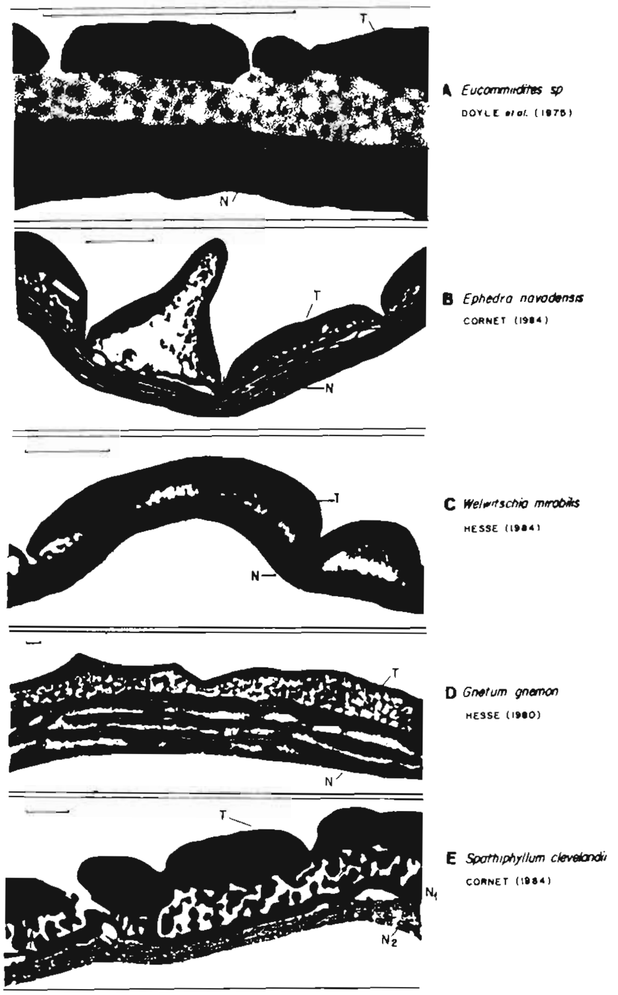
"Granular" exines that occur both in gymnosperms and angiosperms, have been hypothetically derived from "atectate" exines (Doyle, Van Campo & Lugardon, 1975; Walker & Skvarla, 1975). Crane (1985; table 9) while reviewing the occurrence of granular exine in various plant groups (e.g. *Archaeopteris*, Corystospermales, Bennettitales, Gnetales and many angiosperms) accepted the hypothesis that granular pollen wall stratification is primitive within angiosperms (cf. Doyle, 1978).

Ultrastructure of "granular" types of exines in fossil and extant gymnospermous pollen has been the subject of many palynological papers. Foster and Price (1981) described the Permian palynofossil *Praecolpatites sinuosus* (Text-fig. 3 A) as "incipiently alveolate" and even compared its "cavitate" or "granular" exoexine to the "granular" exine of certain Magnoliaceae. Zavada (1984) considered the exine of *Praecolpatites* as a granular form. Should we then infer that the terms "granular" and "incipiently alveolate" are synonyms or equivalents? If so, the exine of Middle Jurassic Corystosperm *Pteruchus dubius* (Zavada & Crepet, 1985; Text-fig. 5 C) could be described as either granular or incipiently alveolate. The ultrastructure of another gymnospermid Mesozoic palynofossil *Eucommiidites* (Doyle *et al.*, 1975; Text-fig. 1 A) reveals an anastomosing granular infratectum (prelude to columellar evolution?). Although Zavada (1984) described the infratectum of bisaccate pollen of Triassic, Jurassic and Cretaceous as granular, the Cenomanian *Granabivesiculites* sp. cf. *G. inchoatus* and the Albian vestigial saccate pollen (Text-fig. 3 B, C) look complexly columelliform (anastomosing rods) rather than granular. Likewise the dispersed monosulcate pollen from the Cenomanian Dakota Formation (Zavada & Dilcher, 1988) are apparently columellar or distinctly columelloid (e.g. Text-fig. 5 D-F) but not granular.

Amongst the extant gymnosperms, the exines of *Agathis alba* (Araucariaceae) and *Cupressus arizonica* (Cupressaceae) have granular ultrastructure (Van Campo & Lugardon, 1973). But in the latter (Text-fig. 3 D) the granular infratectum tends to be columelloid. Granular pollen development in *Cunninghamia lanceolata* (Taxodiaceae) has been investigated (Kurmann, 1988). The pollen wall of Gnetales is generally classified under granular type (Text-fig. 1 B, C, D). The inter-crestal infratectum of *Ephedra navadensis* (Cornet, 1985) and *E. distachya* (Van Campo & Lugardon, 1973) is columelloid unlike the granuliform infra-tectum of arched summit of the ridges. In *Welwitschia mirabilis* (Gullvag, 1966; Hesse, 1984), the interstitium is granulo-reticuloid (tending to be columelloid?). The infratectum of the inter-spinular areas in *Gnetum* spp. (Gullvag, 1966; Zavada, 1984) tends to be columelloid unlike the crowded granules of the domed infra-spinular interstitium. Some of the aforementioned examples may be possibly or probably indicative of granulo-columellar transitional stages of infratectum in non-angiosperms.

The prevalence of granular exine in angiosperms (e.g. Juglandaceae, Betulaceae, Amborellaceae, Annonaceae, Canellaceae, Magnoliaceae) has been discussed by Crane (1985). Granulo-columellar layer is characteristic of the Lower Eocene Normapolles (Kedves & Stanley, 1976) and of the Eocene *Granotricolporites miniverrucatus* (Kedves, 1986). Superimposition of granules in columellae of *Mischogyne elliotianum*, Annonaceae (Le Thomas, 1980), secondarily granulate columellae in *Calliandra viscidula*, Mimosoideae (Guinet & Barth, 1967), anastomosed granules orienting into columellae in *Vigna longifolia*, Papilinoideae (Horvat & Stainier, 1980) and the columellae secondarily reversing to granuliform infratectum accompanied by loss of footlayer in the Orchidaceae (Burns-Baloch & Hesse, 1988) are a few examples (Text-fig. 2) supportive of the hypothesis that granulo-columellar transition is a reversible and/or an atavistic trend.

In sum, the so-called granular infratectum is composed not only of spherical bodies (*sensu stricto*) but also of variously anastomosed patterns (*sensu lato*): incipiently alveolate, granulo-reticuloid, columelloid, imperfectly columellate, complexly columelliform and other transitional forms. In other words, the vague term "granular" has been commonly used to describe the exine types which differ from the typical alveolate columellate



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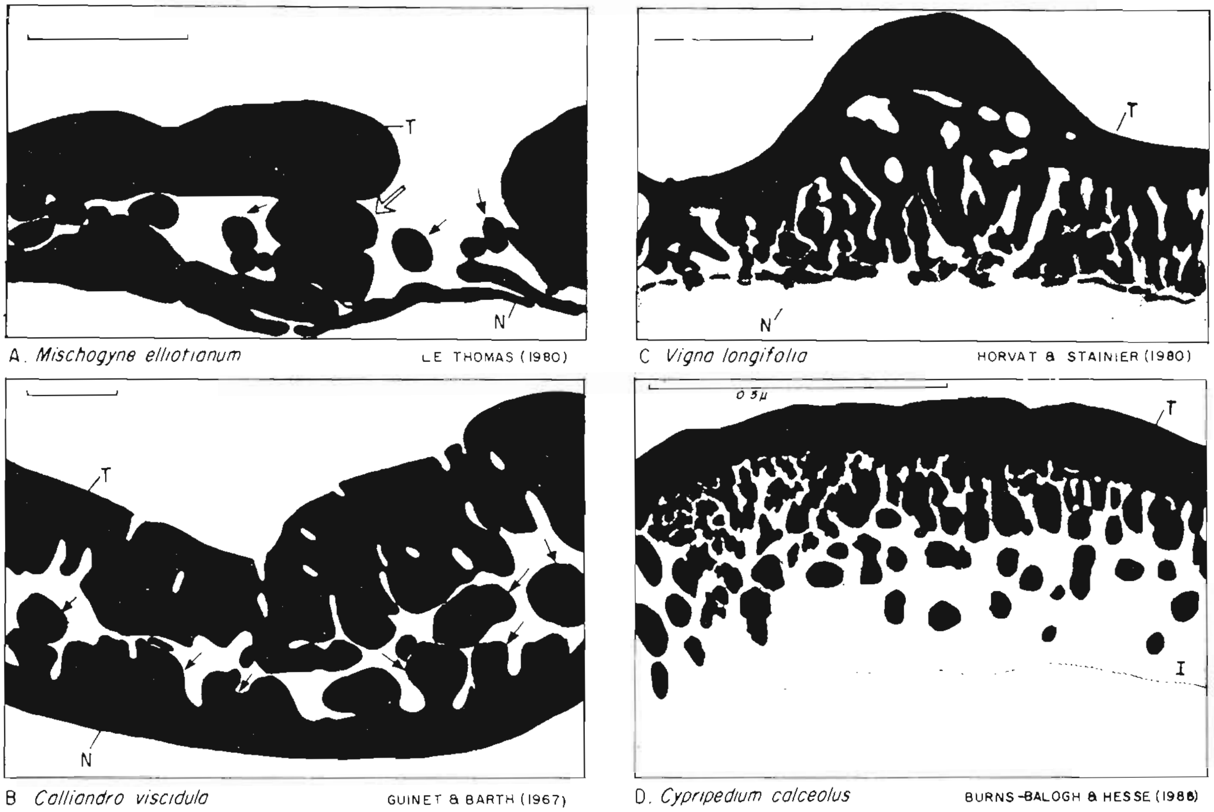
**Text-figure 1—A,** *Eucommiidites* sp., **Gymnosperm** *vs.* **Angiosperm affinity**. Aptian or Lower Albian? (Doyle *et al.*, 1975): Infra-tectal layer granular, spheroidal granules appear to be surficially apposed to the adjacent ones (prelude to the evolution of columella?), endexine laminated; **B,** *Ephedra navadensis,* **Gnetales** (Cornet, 1985): In the inter-crestal parts the thick tectum is not curved (cf. SEM by Ueno, 1978; pl. 46), it is linked with the lamellate nexine by columelliform structures (white arrows). Beneath the arched/domed/coniform tectum (cf. TEM pollen-sections of *Ephedra monosperma* by Gullvag, 1966, of *E. distachya* by Van Campo & Lugardon 1973 and of *E. californica* in Zavada, 1984) there is concentration of granules: few interlinked, the upper ones "hanging" from the tectal interior, lower ones dissociating from the nexinal boundary, and many crowded within the "cavus" (formed of tectal curvature during ontogeny?); **C,** *Welwitschia mirabilis,* **Gnetales** (Hesse, 1984): Beneath the thick tectum of ridges occurs the granulo-reticuloid interstitium; nexine lamellate (cf. TEM of *W. mirabilis* pollen by Gullvag, 1966); **D,** *Gnetum gnemon,* **Gnetales** (Hesse, 1980): Infra-tectum granulo-reticuloid; nexine lamellate (cf. TEM pollen-sections of *Gnetum gnemon, G. montanum* and *G. ula* by Gullvag, 1966, of *Gnetum* sp. by Zavada, 1984—wherein the "domed" infra-tectum of the medially-cut-spinules is infilled with interconnected granuloid structure and the inter-spinular area is narrow as the tectum is almost linked with the nexine by a row or two of granules); **E,** *Spathiphyllum clevelandii,* **Araceae** (Cornet, 1985): The anastomosing granulo-columellar infra-tectal structure is obviously complex.

**"Granular" is an imprecise term. Is there any correlation between "granulo-reticuloid" and "granulo-columellar" structures and tectal curvature and ridging?**

*Abbreviations* : **T** : tectum, faint tectum (Ueno, 1978) or the delimiting sexinal layer
**N** : footlayer (nexine-1) and endexine (nexine-2) either lamellate or non-lamellate.
**C** : columellae;
**S** : spine or spinules.
*Scale lines* : representing 1.0 micron unless otherwise specified.

Notes concerning Text-figures: All the figures are semi-diagrammatic transmission electron micrographs, published (except a few) in various works. Authors' names and years of publication are given against the taxa of all figures.



A. *Mischogyne elliotianum* LE THOMAS (1980)

C *Vigna longifolia* HORVAT & STAINIER (1980)

B *Calliandra viscidula* GUINET & BARTH (1967)

D. *Cypripedium calceolus* BURNS-BALOGH & HESSE (1988)

**Text-figure 2—A.** *Mischogyne elliotianum*, **Anonaceae** (Le Thomas, 1980): Infra-tectum with numerous free or agglomerated "granules" (short arrows) and coarse "columellar" elements (white arrow) formed of superimposition(?) of "granules"; **B,** *Calliandra viscidula,* **Mimosoideae** (Guinet & Barth, 1967): Section of distal face of a monad The inner face of thick tectum is irregularly undulated, wavy or sinuous and the (granuliform?) columellae of unequal size (short arrows) are basally fused with the nexine; **C,** *Vigna longifolia*, **Papilionoideae** (Horvat & Stainier, 1980): The "granulated-orientated" ("grenu-orienté") and anastomosed infra-tectal type-intermediate between *"grenu non-orienté"* type and *"grenu-columellaire"* type, i.e., the "granules" upon fusion are oriented more perpendicularly to the pollen surface and less in other directions; **D,** *Cypripedium calceolus,* **Orchidaceae** (Burns-Baloch & Hesse, 1988): Beneath the tectum are the hanging columelliform "stalactite globules," i.e., the cross-sectioned remnants of columellae are sunken in the exintine (I), nexine absent (step toward fragmentation of columellae).

**Granules ——→ Columellae (e.g. Annonaceae; Papilionoideae)**
**Columellae ——→ Granules (e.g. Mimosoideae; Orchidaceae)**
**Is granulo-columellar transition a reversible trend? (cf. Doyle, 1978).**

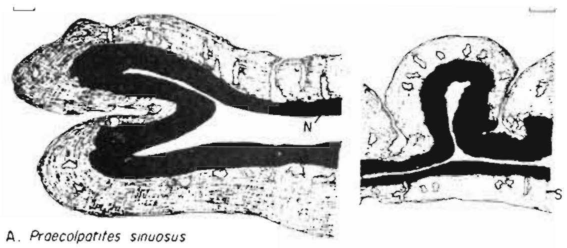
exines (Text-figs 3, 4, 5, 9). In general, alveolar exines characterize the gymnosperm and columellar exines the angiosperms, but granular exines have been reported to occur in primitive and advanced taxa of both extant gymnosperms and angiosperms (Doyle *et al.*, 1975).

We thus conclude that knowledge of developmental patterns (comparative analysis of ontogeny) of all known granular exine types may throw light on their phylogenetic relationship and the evolutionary stages of angiospermid exine characters in the pre-Cretaceous palynofossils.

## ARE COMPLEXLY ALVEOLATE AND COLUMELLATE EXINES ONTOGENETICALLY DIFFERENT?

Alveolar structure between the tectum and nexine consists of a more or less complex spongy or honeycomb-like system of alveolae (*L. alveolus* -a hollow) delimited by partitions attached at oblique or right angles to the inner surface of the tectum (Doyle *et al.*, 1975). The alveolar structures of gymnosperms are fundamentally different from the reticulate simple exine and the pseudoreticulate complex exines of angiosperms (Text-figs 3, 4, 7, 9) although some of these angiospermous and gymnospermous exines look "spongy" (another imprecise term like "granular"). Various alveolar types are broadly divided into cycad type in Cycadales, Medullosaceae and pinaceous type in Podocarpaceae and Pinaceae, Cordaites and saccate seed ferns.

The ultrastructure of multichambered or multitiered exines of pteridospermous pollen have been well-illustrated by Taylor (1971, 1973, 1978, 1980, 1982) and Kurmann and Taylor (1984) while

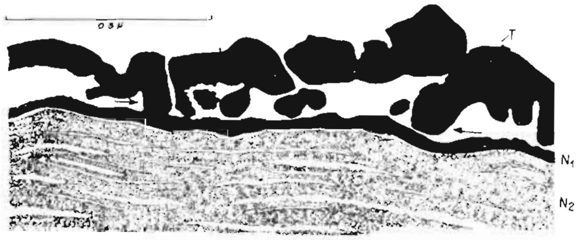


A. *Praecolpatites sinuosus*

FOSTER & PRICE (1981)

B. *Granobivesiculites inchoatus* ZAVADA (1984)

C Pollen with vestigial saccus



D. *Cupressus arizonica* VAN CAMPO & LUGARDON (1973)

E. *Picea abies* ERDTMAN (1965)

**Text-figure 3—A,** *Praecolpatites sinuosus*, **Gymnospermid?** Permian (Foster & Price, 1981) An inner weakly laminated darker "intexine" (N) and an outer incipiently-alveolate "exoexine" enclosing cavities, **B,** *Granabivesiculites inchoatus*, **Gymnospermid?** Cenomanian (Zavada, 1984): Bisaccate pollen with "granular" (or complexly columelliform or alveolate?) infra-tectal structure; saccus (*) resulting from a build-up of exinal material; **C,** Vestigial saccate pollen, Albian (Zavada, 1984): "Granular" (or complexly columelliform or alveolate?) infra-tectal structure; **D,** *Cupressus arizonica*, **Cupressaceae** (Van Campo & Lugardon, 1973): The infra-tectum is granulo-columellar(?) or tending to be columelliform (arrows)?, nexine lamellate; **E,** *Picea abies*, **Pinaceae-Abietoideae** (Erdtman, 1965): Complexly alveolate infra-tectum appearing like branched columellae; nexine lamellate.

**Incipiently-alveolate (A), complexly-alveolate (E), "granular" or complexly alveolate/columelliform (B&C), complexly-alveolate (E) and granulo-columelliform (D). Of these which is akin to the columellate exine?**

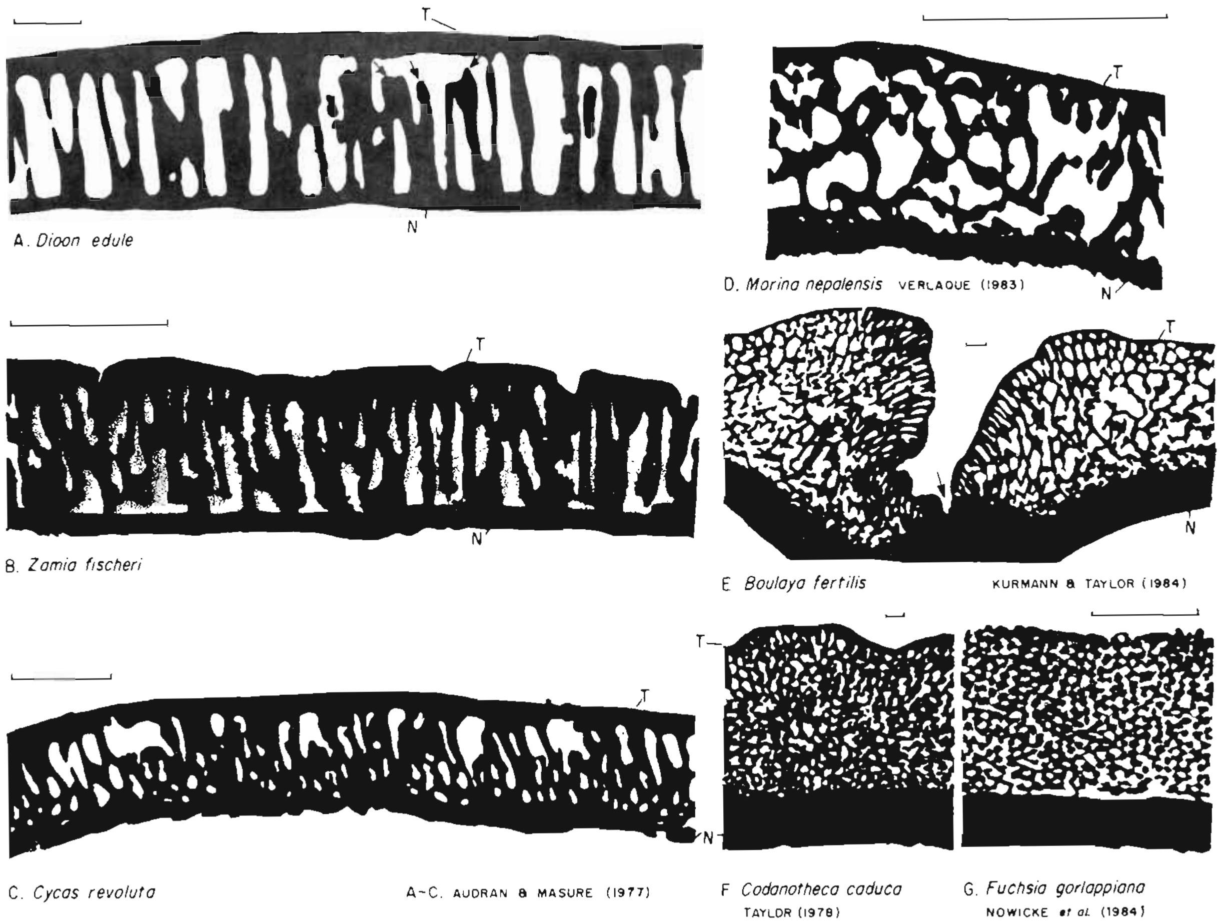
discussing their functional significance and adaptations These "alveolar" exine types are considered precursors to tubularly alveolate Cycadales. According to Zavada (1983) pollen wall development of cycads is identical with that of *Pinus* (Dickinson & Bell, 1970: Willemse, 1971) and *Podocarpus* (Vasil & Aldrich, 1973). Taylor (1982) even attempted to compare certain stages of pollen-wall development of *Monoletes* with those of Cycadales. Absence or scanty deposition of a primexine and limited secretory phase of tapetum during the free spore period differentiates the gymnospermous pollen ontogeny exemplified by *Zamia* (Zavada, 1983) from the angiosperm pollen ontogeny Whereas in the latter the gametophytically derived primexine or exine-template and an extremely active tapetum of free spore phase are the distinguishing characteristics.

Although it is tempting to compare the morphological peculiarities of complexly alveolate exines of *Boulaya fertilis* (Kurmann & Taylor, 1984) and *Codonotheca caduca* (Taylor, 1978; Text-fig. 4 E, F) with those of complexly columellate dicotyledonous *Morina nepalensis*, Morinaceae (Verlaque, 1983) and *Fuchsia garlappiana*, Onagraceae (Nowicke *et al.*, 1984; Text-fig. 4 D, G), it is now clear that some ontogenetic or developmental differences have played important roles in the formation of complex sexine types. Hence we may infer that pollen ontogenetic dissimilarities are not supportive of any phylogenetic relationship among the morphologically "similar" forms.

## COLUMELLAR COMPLEXITIES IN UNRELATED TAXA : ATTRIBUTABLE TO INDEPENDENT EVOLUTION?

Ektexine in most angiosperms comprises radial, rod-like columnar "columellae" which are sandwiched between the outer tectal layer and the basal footlayer nexine-1 (Faegri & Iversen, 1975) The distally and basally branched columellar complex forms are believed to have been derived from simple columellae (Text-fig. 9). Columellar infratectal organization in angiospermous pollen is supposed to be the culmination of adaptive trends facilitating the conveyance of sporophytic substances (Heslop-Harrison, 1979) and the equalised distribution of bending stresses over the exine surface (Muller, 1979).

It is a widely accepted hypothesis that the occurrence of columellae is an exclusively angiospermous character. The reversible granular-columellar transition (cf. Doyle, 1978) and

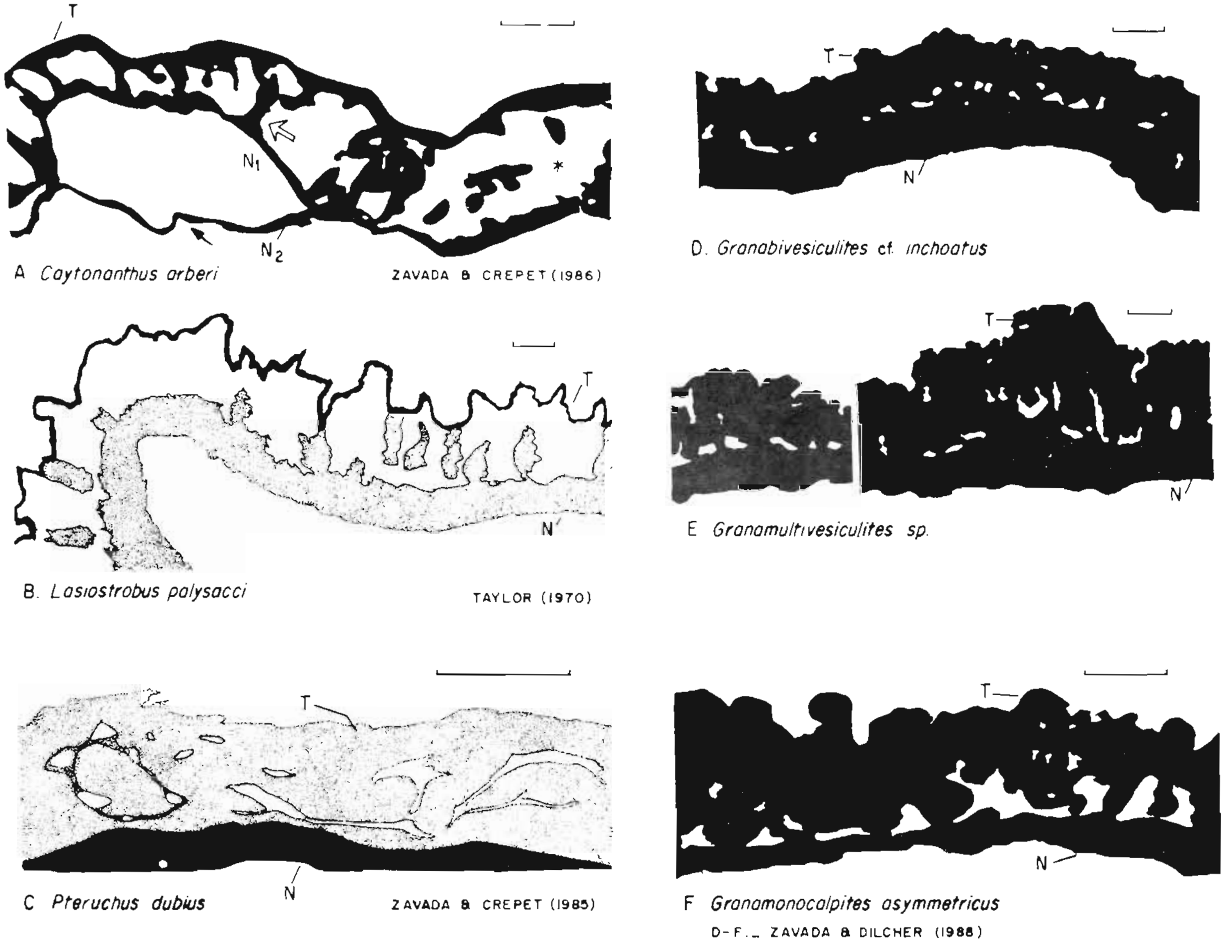


**Text-figure 4—A,** *Dioon edule*, **Cycadinae** (Audran & Masure, 1977): Exine section of lateral side; branched columellae like two dimensional view of septa or partitions of "alveolae"; **B,** *Zamia fischeri*, **Cycadinae** (Audran & Masure, 1977): Exine section of lateral side; very much branched columellae like two dimensional view of sectioned anastomosing septa of "alveolae"; **C,** *Cycas revoluta*, **Cycadinae** (Audran & Masure, 1977): Basally complexified "alveolar" infra-tectal structure of exine of prothallial pole. **D,** *Morina nepalensis*, **Morinaceae** (Verlaque, 1983): Sectioned portion of polar exine, infratectum "spongy" or complexly columellate resembling complex alveolar exine?; **E,** *Boulaya fertilis*, **Medullosales—Pteridosperms** (Kurmann & Taylor, 1984): An inner homogeneous nexine and an outer sculptured sexine composed of a series of anastomosing net work of muri of the interconnected chambers (apparently "spongy"), sexine diminishing over the proximal suture (arrow); **F,** *Codonotheca caduca*, **Monoletes-Pteridosperms** (Taylor 1978): Multichambered sexine and non-lamellate nexine; **G,** *Fuchsia garlappiana*, **Onagraceae** (Nowicke *et al.*, 1984): The ektexine is not differentiated into tectum, columellae and foot layer units but consisting of a "spongy" or para-crystalline layer which is united with the endexine at numerous points along the ektexine-endexine surface (or complexly columelliform beneath the granulo rugulately sculptured tectum?).

**Various grades of the alveolar complexity of Cycadinae pollen (e.g. A,B,C). The apparent similarity of the multichambered sexine of the Pteridosperms (e.g. E,F) with some complex sexine types of the Dicotyledons (e.g. D,G) is striking.**

complexly anastomosing granulo-columellar structures in angiosperm exines have already been discussed. Before considering the columellar complexity of angiosperms, it is necessary to discuss the columelloid structures and sexinal complexity in non-angiospermous palynofossils.

Although "granular" and alveolate types of exine are prevalent in living gymnosperms we may discern a small degree of granulo-columellar transition in *Cupressus arizonica*, Cupressaceae (Van Campo & Lugardon, 1973, Text-fig. 3 E). Columelloid structures of infratectum are apparent in the Cretaceous bisaccate *Granabivesiculites inchoatus*, rugulo-saccate *Granamultivesiculites* sp. (Zavada & Dilcher, 1988) as well as in Carboniferous *Lasiostrobus polysacci* (Taylor, 1970; Text-fig. 5). Sexinal complexity ("granular") is discernible in Cenomanian bisaccate *Granabivesiculites inchoatus* and a vestigially saccate pollen (Zavada, 1984; Text-fig. 3 B, C). The sexinal complexity of *Classopollis* and other Circumpolles bears some resemblance or analogous to the columellar complexity in some advanced taxa of dicotyledons (Pettitt & Chaloner, 1964, Burger, 1965, Pocock, Vasanthy &



A *Caytonanthus arberi* ZAVADA & CREPET (1986)

D. *Granabivesiculites* cf. *inchoatus*

B. *Lasiostrobus polysacci* TAYLOR (1970)

E *Granamultivesiculites sp.*

C *Pteruchus dubius* ZAVADA & CREPET (1985)

F *Granamonocolpites asymmetricus*

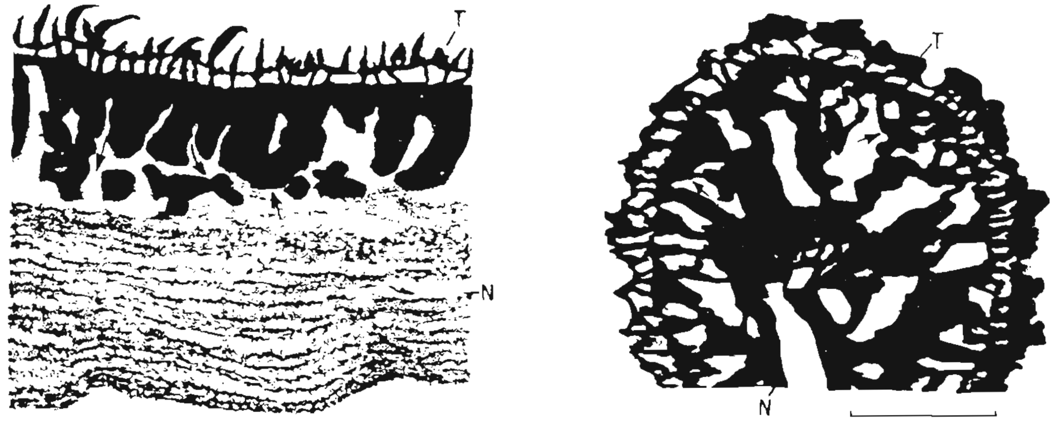
D-F._ ZAVADA & DILCHER (1988)

**Text-figure 5—A,** *Caytonanthus arberi,* **Caytoniales-Pteridosperms**, Carboniferous Middle Pennsylvanian (Zavada & Crepet, 1986). Monosulcate, bisaccate; in the saccus region (*) inwardly directed stout partitions and rods beneath the tectum are separated from the basal layer, in the cappus region of corpus the infra-tectum (white arrow) is alveolar (apparently columellar in sectional view), in the sulcus region (curved arrow) there is no tectum nor infra-tectal layer: **B,** *Lasiostrobus polysacci,* **Gymnospermid**?, Carboniferous-Upper Pennsylvanian (Taylor, 1970) An exine of three distinct layers, thin tectum, and uniformly thick nexine are linked by vertically oriented "columellae" (non alveolar and saccate!). **C,** *Pteruchus dubius.* **Corystospermales-Pteridosperms**. Middle Jurassic (Zavada & Crepet, 1985) Exine structure in the saccus region has two layers, the upper lightly staining layer encloses irregularly shaped processes separated by lacunae (non alveolate or incipiently alveolate granulate?) and the lower thin darker staining layer (N). **D,** *Granabivesiculites* cf. *inchoatus.* Monosulcate, bisaccate, exine structure of the proximal face: tectum thick, imperforate: infratectal layer thin "granular" (columellae?) and basal layer thick. **E,** *Granamultivesiculites* sp.: Monolete, with numerous small ruguloid sacci, exine structure of the proximal hemisphere, tectum thick, micro perforate, infra-tectal layer of irregular rods and columelliform structures and "granules" basal layer thick. **F,** *Granamonocolpites asymmetricus*: Monosulcate, asaccate, tectum thick, occasionally traversed by small perforations; infra tectal layer comprising small spherical or irregular shaped "granules" and "columellae" and a basal layer. **D—F,** Affinity? Cenomanian Cretaceous (Zavada & Dilcher, 1988)

**Alveolate exine in Carboniferous Pteridosperms (A-bisaccate) non-alveolate (granuliform?); in Middle Jurassic Pteridosperms (C-Asaccate) and columellate (!) in Carboniferous gymnospermid palynomorph (B-polysaccate). D-F: Distinctly "columelloid" infratectum in Cenomanian pollen!**

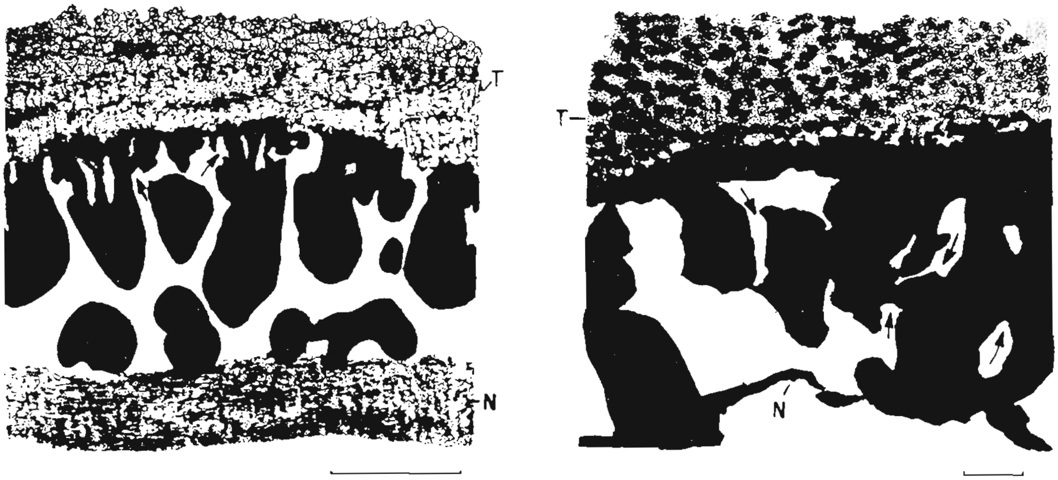
Venkatachala, 1990). Pocock *et al.* (1988) even surmised that if the evolution of complex feature is an intricate process resulting from simple forms, then could the sexine complexus of Circumpolles be regarded as culmination of structural evolution of Mesozoic Cheirolepidiaceae prior to their extinction during the Upper Cretaceous. This type of sexinal complexity in Circumpolles is not expressed in modern gymnosperm pollen (no regaining of lost character?).

Sexinal complexity, usually involving columellar or granulo-columellar complexification, at times accompanied by tectal complexity (Vasanthy, 1978, 1985) has been encountered in unrelated taxa of angiosperms, for example, Alismataceae (Argue, 1976), Araceae (Trevisan, 1980; Cornet, 1985),



C. *Classopollis sp.*
TAYLOR & ALVIN (1984)

D. *Classoidites glandis*
MEDUS (1977)



B . *Classopollis harrisii*
MEDUS (unpubl.)

A *Classopollis classoides*
ROWLEY & SRIVASTAVA (1986)

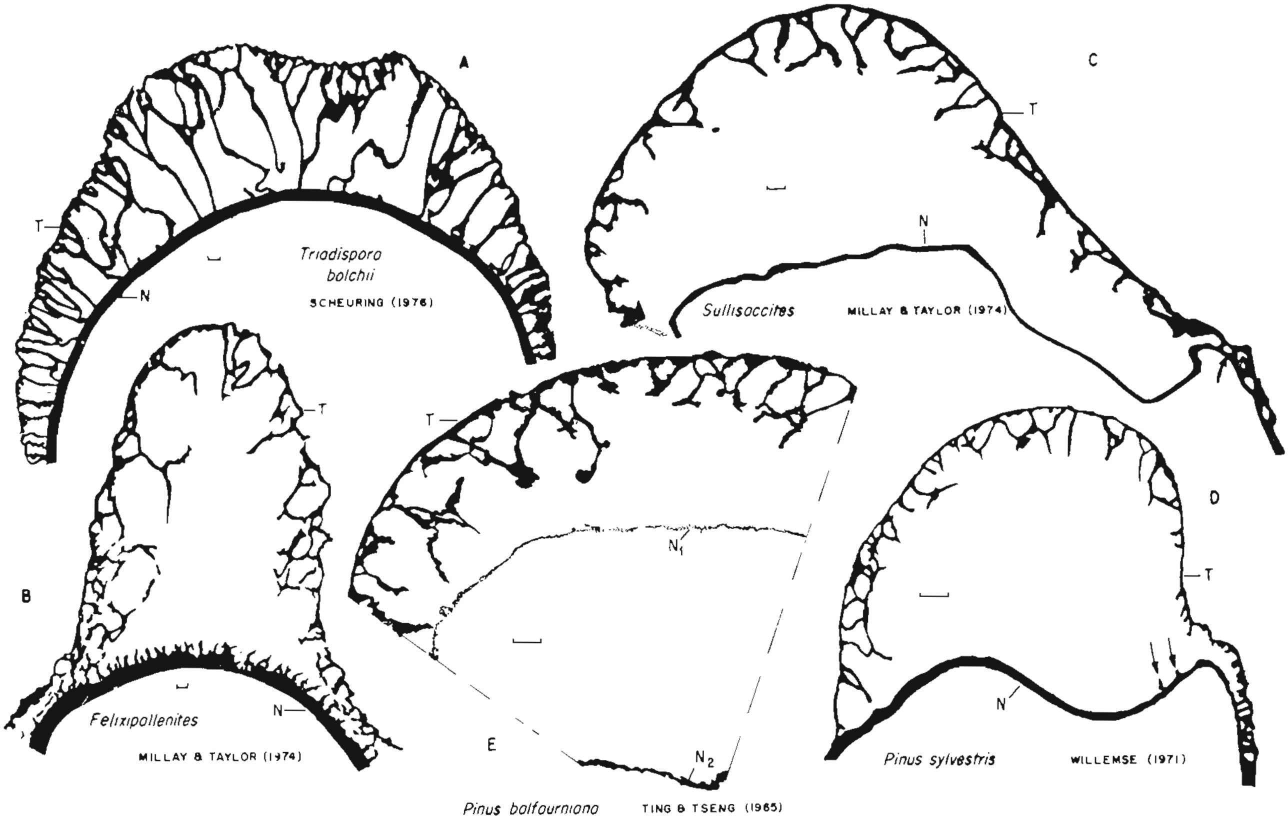
**Text-figure 6—A,** *Classopollis classoides*. Oxfordian-Upper Jurassic (Rowley & Srivastava, 1986): Tectum thick (complex?), infra-tectal rods or complexly columellate structures(?) manifesting lateral adnation (arrows), nexine lamellate, **B,** *C. harrisii*, Rhaeto-Liassic; Triassic-Jurassic (Médus, unpubl.) **C,** *Classopollis* sp., Barremian-Lower Cretaceous (Taylor & Alvin, 1984): Tectum echinulate, complex enclosing inter-tectal rods (short arrows, infra-tectal columelloid elements showing small degree of adnation (arrows); nexine lamellate; **D,** *Classoidites glandis*, Turonian—Upper Cretaceous (Médus, 1977): The "columellae" beneath the tectal complex are distally ramified; nexine lamellate.

**Are the infra-tectal complex structures of the extinct Circumpolles similar to the angiosperm columellae (Chaloner, 1976) or were these derived from the reduced muri of a subtectate alveolar system of *Triadispora* spp.? (Scheuring, 1976).**

Juglandaceae (Stone *et al.*, 1979), Haloragaceae (Praglowski, 1970), Morinaceae (Verlaque, 1983), Asteraceae (Skvarla & Larson, 1965), Dipsacaceae (Text-fig. 9) and many others. Even some Eocene pollen manifest sexinal or rather columellar complexity: *Caryopollenites triangulus* and *Subtriporopollenites constans* subsp. *constans* (Kedves & Stanley, 1976; text-fig. G, I) and *Interporopollenites endotriangulus* (Kedves, 1986). Detailed pollen developmental studies, for example *Artemisia vulgaris*, Asteraceae by Rowley and Dahl, 1977, are required to draw conclusions on the evolution, distinctiveness and inter-relationship of complex sexines in various taxa. Wanting ontogenetic data we may surmise that columellar complexity might have evolved independently in different plant groups and taxa.

## DO THE "SACCI" IN PROGYMNOSPERMS, GYMNOSPERMS AND ANGIOSPERMS SIGNIFY ANY PHYLOGENETIC RELATIONSHIP?

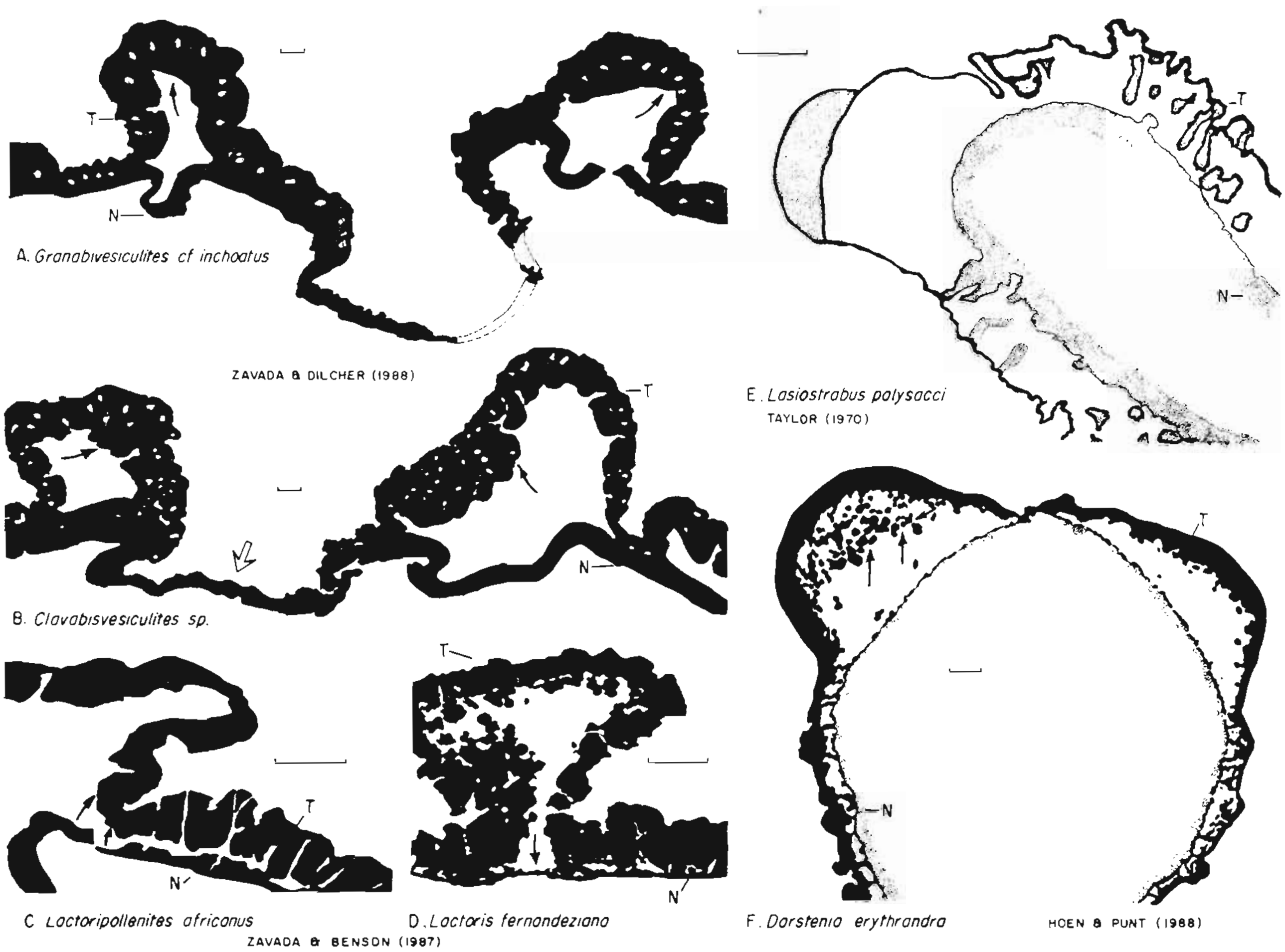
A saccus is an exoexinal expression, often showing a separation of sexine from nexine ("eusaccate") and seldom with the attachment of the infrareticulum of saccus to the nexine of corpus ("protosaccate") Protosaccate type (*Triadispora bolchii, Protodisaccitrilete*, Scheuring, 1974) and various types of "eusaccate" forms (monosaccate *Felexipollenites* and *Sullisaccites* (Millay & Taylor, 1974, bisaccate *Pinus sylvestris* and *P balfouriniana*, Willemse, 1971, Ting & Tseng, 1965 respectively) have been illustrated in Text-figure 7 Numerous forms of mono- or perisaccate, pseudo-saccate (*Rhabdosporites*), and bisaccate palynofossils have been elaborately illustrated and discussed by Millay and Taylor, 1970, 1974, 1976), Pant (1987) and Tiwari and Tripathi (1988). Crane (1985) tabulated the saccate spore-pollen bearing groups: Aneurophytalean progymnosperms, Carboniferous lycopods, Medullosan *Parasporites, Callistophyton, Glossopterids, Caytonia*, corystosperms and extant coniferae. The polysaccate condition in "non-alveolate" (columelloid?) palynofossil of Pennsylvanian Carboniferous *Lasiostrobus polysacci* is a unique phenomenon (Taylor, 1970). Zavada and



**Text-figure 7—A,** *Triadispora bolchii.* **Protodisaccitrileti**, Triassic (Scheuring, 1976): The infrasaccate "alveolar" system is divided into levels of different chamber size—the smallest underneath the tectum; all the elements of radially arranged infrastructure of the protosaccus reach the central body on the same sectional plane (i.e. apophysis-like structures near the central body); **B,** *Felixipollenites*, **Monosaccites**, Lower Pennsylvanian Carboniferous (Millay & Taylor, 1974): Laterally bulged infrasaccate alveolar system seemed to have broken away from the "apophyses" which are arising from the nexine; **C,** *Sullisaccites*, **Monosaccites**, Lower to lower-middle Pennsylvanian-Carboniferous (Millay & Taylor, 1974): Saccus intrareticulum is finer near region of distal saccus-corpus attachment (arrow) and saccus alveolae are dissociated from the saccus-floor within the lateral bulgings; **D,** *Pinus sylvestris*. **Pinaceae** (Willemse, 1971): In the saccus, the nexine is dissociated from the alveolar reticulation as in the lateral bulges of saccus in *Sullisaccites*: A few "apophyses" remnants (short arrows)?; **E,** *Pinus balfourniana*, **Pinaceae** (Ting & Tseng, 1965): Beneath the tectum are hanging the alveolar reticulation of the bladder, unlike in *Pinus sylvestris* there is a separation of nexine into two layers (N-1 and N-2).

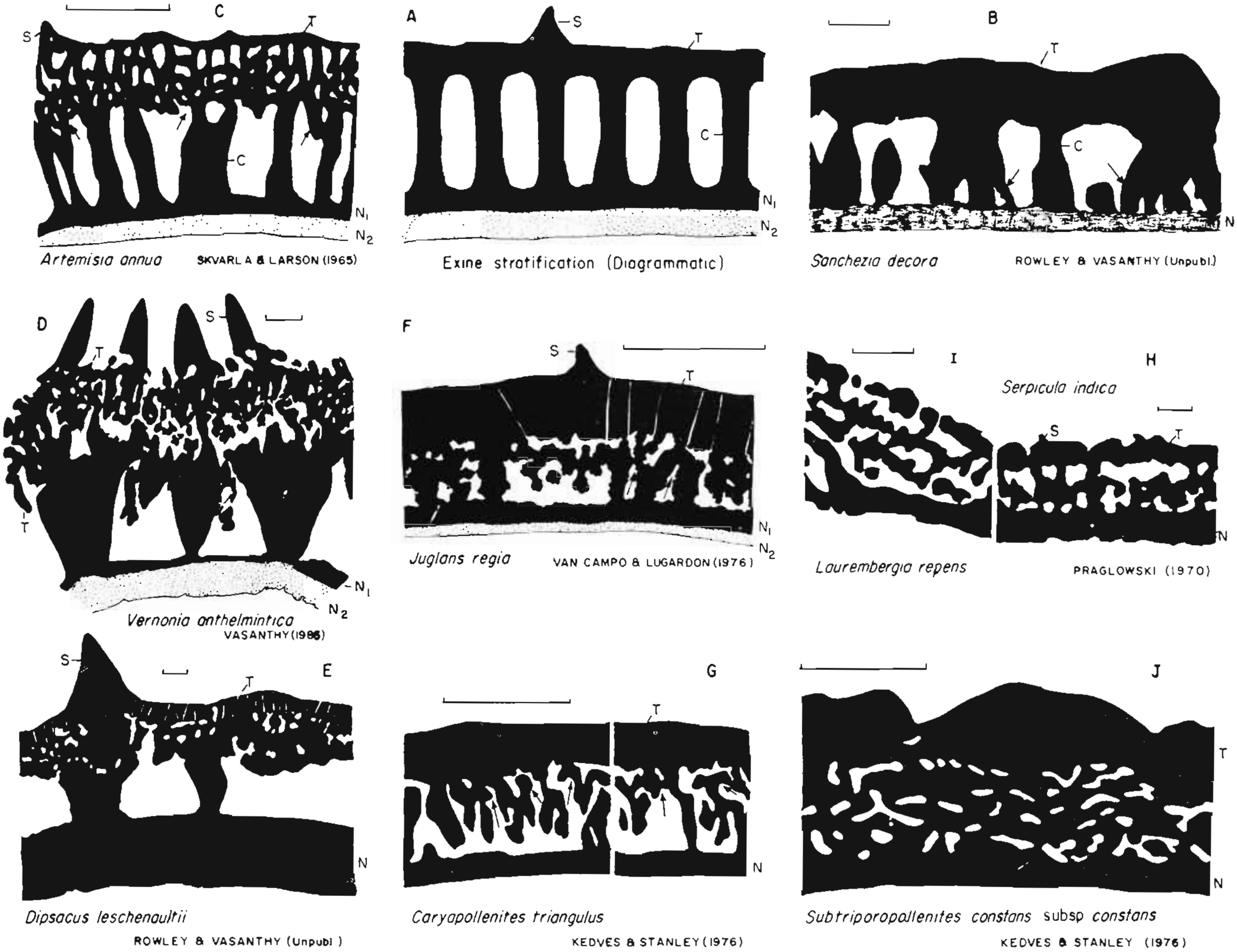
**Irrespetive of the differences (mono-or disaccate; proto-or eusaccate), the saccus infra-tectum both in the fossil and extant taxa is alveolate.**

Dilcher (1988) have reported the ruguloid sacci on the distal surface of bisaccate Cenomanian *Clavabivesiculites* sp. (Aff.?). The epithet " subsaccate" (cavate, pouched, rugulosaccate, vesiculate, winged, cf. Kremp, 1965, p. 161) has been used by Erdtman (1952, fig. 208) to describe the separation of "stalactiform" columellae from nexine in pollen of *Grevillea pinnatifida*, Proteaceae. The "polysacci" of *Lasiostrobus* bear a small degree of resemblance to the verrucae of *Dorstenia erythrandra*, Moraceae and the sections of its verrucae (Hoen & Punt, 1988) are partly comparable with radial sections of ridge-summits of *Ephedra navadensis* rather than that of *Lasiostrobus polysacci* (Text-figs 1 B, 8 E, F) Monosulcate pollen from the Albian-Cenomanian (e.g. *Granabivesiculites* sp. cf. *G. inchoatus, Clavabivesiculites* sp., Zavada & Dilcher, 1988) although flanged by two small sacci (non-alveolate but columelliform infratectum differing from proto and eusaccate intra-reticulate alveolar infratectum) are considered akin to the "saccate" tetrads of the Turonian *Lactoripollenites*



**Text-figure 8—A,** *Granabivesiculites* cf. *inchoatus*, Aff.?, Cenomanian-Cretaceous (Zavada & Dilcher, 1988): Monosulcate, bisaccate; the sulcus is flanged by two flange-like sacci; the sacci are formed by a separation of the tectum, infrastructural layer and part of the footlayer (arrows) from the rest of the nexine(N); **B,** *Clavabivesiculites* sp., Aff.?, Cenomanian-Cretaceous (Zavada & Dilcher, 1988): Two sacci and many small ruguloid sacci on the distal surface, in the flange like sacci on either side of the sulcus (white arrow) there is a separation of "granules"/columelloid structures (curved arrows) from the nexine; **C,** *Lactoripollenites africanus*, Turonian-Cretaceous (Zavada & Benson, 1987): Anasulcate, in tetrads, the "saccus" is formed by a separation of the sexine from the nexine (arrows); **D,** *Lactoris fernandeziana*, **Lactoridaceae** (Zavada & Benson, 1987): Tectum thick microperforate, nexine relatively thin and infra-tectum with columelliform structures; the conspicuous ridge or saccus adjacent to the aperture is formed by a separation of the sexine from the nexine (arrow); **E,** *Lasiostrobus polysacci*, **Gymnospermid?** Pennsylvanian-Carboniferous (Taylor, 1970): Exine stratification and distal thickened area of a "saccus", the tectum extends out from the body to form "sacci" often from the equatorial region, absence of columellae (!) in the saccal infra-structure; **F,** *Dorstenia erythrandra*, **Moraceae** (Hoen & Punt, 1989): Medial (left) and sub-medial sections of verrucae (partly "polysacci"-like?), note the crowded "granules" (short arrows) in the "caveate" infra-tectum of medially-cut verruca (cf. TEM of *Ephedra navadensis* in Text-fig. 1B)

### Non-alveolate infratectal structure of "saccus"-types!



**Text-figure 9—A,** Exine stratification—Diagrammatic: A "typical" and simple exine form is composed of a tectal layer, an infra-tectal layer of unbranched simple columellae (*columellae simplicea*) which is supported by Nexine-1 (footlayer). The footlayer differs in stainability from the basal layer, Nexine-2, (endexine). Tectum may be perforate or imperforate and may bear sculptural elements (spines, verrucae, bacula, etc.); **B,** *Sanchezia decora,* **Trichanthereae-Acanthaceae** (Rowley & Vasanthy, unpubl.): The columellae (C) appear in radial section, basally branched (*columellae conjunctae?*); **C,** *Artemisia annua,* **Anthemideae-Asteraceae** (Skvarla & Larson, 1965): The columellae in radial section appear distally bifurcated (arrows) or branched ("*Columellae digitatae*"). The distal columellar "off-shoots" seem to intrude into the complex network of tectum; **D,** *Vernonia anthelmintica,* **Vernonieae-Asteraceae** (Vasanthy, 1985): Note the distally digitating columellar complex and the "off-shoots" intruding into the downwardly descending tectal net; supratectal spines (S) are many; **E,** *Dipsacus leschenaultii,* **Dipsacaceae** (Rowley & Vasanthy, unpubl.): Note the distal complexity of infratectal columellar layer, micro-channelled tectum and the sunken base of tectal spine; **F,** *Juglans regia,* **Juglandaceae** (Van Campo & Lugardon, 1973): Tectum micro-channelled, spinulate; the "granulo-columellar" infra-tectum ("anastomosing rods") manifests distal complexity (arrows); **G,** *Caryopollenites triangulus,* Lower Eocene (Kedves & Stanley, 1976): A "granular"-columellar layer (or complexly anastomosing rods) resembles that of Juglandaceous pollen (Text-fig. F); **H,** *Serpicula indica* & **I** *Laurembergia repens,* **Haloragaceae** (Praglowski, 1970): Note the distal and proximal complexification of columellar layer; **J,** *Subtriporopollenites constans* subsp. *constans,* Lower Eocene (Kedves & Stanley, 1976)-cf. *Interporopollenites endotriangulus* (Kedves, 1986; pl.VI:1): Intergerminal exine; very rough tectum, a relatively thick granular-columellar layer (complexly anastomosed) and a thinner footlayer.

**Did columellar complexity evolve independently in different groups and taxa?**

*africanus* (Zavada & Taylor, 1986). The latter palynofossil is shown to bear some resemblance to the pollen tetrads of the primitive angiosperm *Lactoris fernandeziana* Phil. of Lactoridaceae. The conspicuous ridge adjacent to the aperture is formed by the separation of the footlayer (nexine) and the outer portion of the ektexine (sexine), forming a saccus (figs 2-6 in Zavada & Benson, 1987). However, the wavy tectal granular surface, and spheroidal stalactiform granular infratectum of "sacci" in *Lactoris fernandeziana* differ from tectal surface and columelloid saccus infratectum of

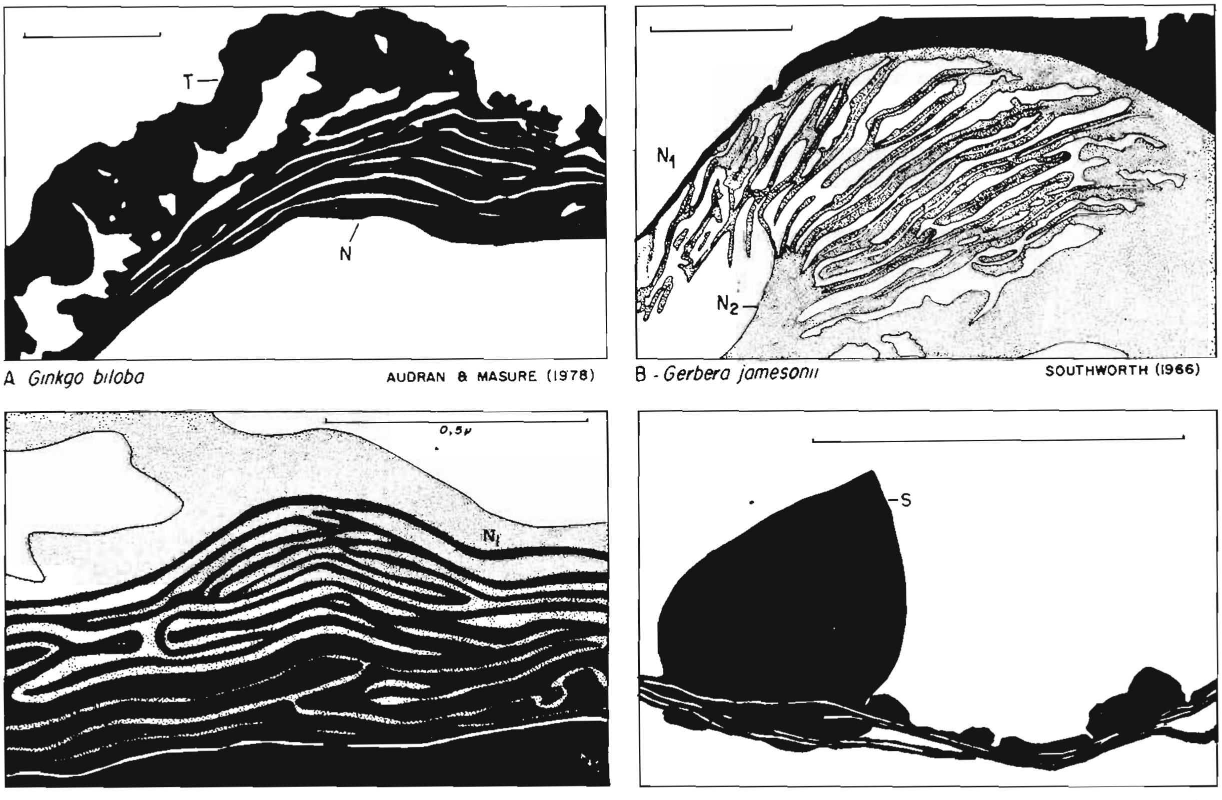
*Lactoripollenites africanus* (Text-fig. 8 C, D).

It may be inferred from these data that the exinal structural dissimilarity does not support the hypothetical evolution of sacci in the pollen tetrads of the Lactoridaceae from the sacci of gymnospermous monads.

## THE ROLE OF WHITE-LINES IN THE EVOLUTION OF SPORE-POLLEN EXINES

White-lines of the nexine layer have been primarily recognised as electron lucent ribbons of unit membrane dimension (50-60A) bound laterally by two dark zones. Reviews on various aspects of white-line-centered lamellations, by Rowley & Dahl (1977), Stone *et al.* (1979) and Guédès (1982) are pertinent to this discussion. While analysing the functional aspects of *Epilobium* endexine, Rowley (1988) hypothesised that a single form of white-line was an image produced by a tubule not a lamella at all and these are visible during the fundamentally active state of endexine development (in dicotylendons?); white-lines are the junction planes between groups of tuft-units within the endexine and also between units of ectexinal processes and tuft-units of endexine. Published information relative to the occasional occurrence of erect or convolute lamellae rather than periclinal, in the developing ectexine is discussed by Guédès (1982). Linear orientation of ectexinal infratectal granules preceding columellar organization is attributable to the presence of radially oriented lamellae (Le Thomas & Lugardon, 1976).

The omnipresence of white-lines in bryophytic and pteridophytic spores as well as in pollen of gymnosperms, monocotyledons and dicotyledons (Text-fig. 10) is of both ontogenetic and



A *Ginkgo biloba* AUDRAN & MASURE (1978) B - *Gerbera jamesonii* SOUTHWORTH (1966)

D. *Equisetosporites chinleanus* POCOCK & VASANTHY (1988) C. *Heliconia nutans* STONE *et al.* (1979)

**Text-figure 10—A,** *Ginkgo biloba*, **Ginkgoales** (Audran & Masure, 1978): Axial section of the edge of the furrow showing the large lamellated nexine; sexine tripartite enclosing a middle zone of irregular pits (columelloid layer?); **B,** *Gerbera jamesonii*, **Mutisieae-Asteraceae** (Southworth, 1966): Lamellated Nexine (endexine) in a young stage (microspore period) of pollen grain; **C,** *Heliconia nutans*, **Heliconiaceae** (Stone *et al.*, 1979): White-line formation prior to disappearance of the callose wall, segments of the initial white-lines probably develop beneath the spinule-precursors, the protosporopollenin from microspore layer down on a template of 4-5 white-lines (?); **D,** *Equisetosporites chinleanus*, **Proto-angiospermid**? Late Carnian-Triassic (Pocock & Vasanthy, 1988; pl IV): Polyplicate or ridged pollen, tectum discontinuous in furrows; columellae simple, of variable orientation, nexine three layered with an intermediate lamellate, transitional layer of interstratified nexine-1 and nexine-2 (?).

**Are the "white-lines" indispensable for (n)exine formation?**

phylogenetic significance in exine evolution (Guédès, 1982; Kedves, 1986; Gabaraeva, 1987; Pocock, Vasanthy & Venkatachala, 1990). Stainability, chemical make-up and persistence vs disappearance of lamellae are some of the criteria generally used to differentiate the gymnospermous nexine from the angiospermous endexine.

The statement of Guédès (1982) that the primitive condition in angiosperm pollen is characterised by an exine with an endexine, probably laminated and continuous with an overlying ectexine sounds logical and helps in our interpretation of the tripartite nexine of the tectate, columellate pollen of *Equisetosporites chinleanus* Daugherty (Triassic). Although we have already discussed the peculiarity of its nexine (Pocock & Vasanthy, 1988; Pocock, Vasanthy & Venkatachala, 1988), we outline it again briefly, here its nexine peculiarity (Text-fig. 10 D): the unique nexine of *E. chinleanus* possesses a distinct, continuous but undulate, lamellate zone, apparently sandwiched between the non-lamellate parts of nexine-1 (footlayer) and nexine-2 (endexine). The lamellae (endexinal) and interlamellae (ectexinal?) of varying thickness (grading into "white-lines" and eventually becoming indistinguishable from the underlying endexine), are interstratified (transitional zone?). We may therefore infer that this tripartite nexine construction in a columellate-tectate exine could be representative of one stage in the exine evolution of proto-angiosperms.

## CONCLUDING REMARKS

As greater importance had already been given to the apertural characters in the context of phylogeny and evolution, we are dealing with some of the extra-apertural pollen characteristics, in our present analysis of evolution of exines. Let us first consider the infra-tectal features which are generally believed to be of phylogenetic significance. The hypothetical precursors of incipiently columellate/alveolate exines are supposed to be the granular exines that should have resulted from the formation of cavities and their interlinkage (Walker & Skvarla, 1975; Walker & Walker, 1984) in primeval solid sporoderm or pollen-wall. According to Walker (1976) the columellar structure of cycads and saccate conifers represent divergent specializations *via* granular intermediates from homogeneous structure in the first gymnosperms. But his assumption on gymnosperm pollen evolution is wanting fossil evidence (cf. Doyle, 1976). It is relevant to quote Ehrendorfer (1976) here: "The prominent differences in chromosome patterns between various gymnosperm and angiosperm groups are clear expressions of different cytogenetic potentials and different phases of the evolutionary development of these groups. ......... it appears that gymnosperms and angiosperms have followed different evolutionary strategies".

We have already discussed in this work the use of vague or ambiguous term "granular" in its broadest sense. Truly granular form (*sensu stricto*-does it exist?) ought to be a transitory or evolving character and progressive evolution of granuloid structure should have resulted in the formation of columelloid structure, simple to composite columellar infra-tectum and their derivatives. On the other hand, retrogressive evolution or secondary simplification of columellae has been supposed to have thrown back the granular infra-tectal character. As the granulo-columellar types occur in both gymnosperms and angiosperms (Zavada, 1984; Pocock & Vasanthy, 1988 and examples discussed in this work) the origin of angiospermid pollen characteristics cannot be easily elucidated from palynological data alone (Zavada, 1984). A hypothesis contradictory to the above view is that the "granular" exines in Magnoliidae represents survivals of a pre-columellar state linking angiosperm pollen with gymnosperm pollen (e.g. Foster & Price, 1981).

Stress-tensibility (Muller, 1979) and efficient conveyance of sporophytic substance (Heslop-Harrison, 1979) of columellar organization, an exclusively angiospermous character (Van Campo, 1971) and the evolution of angiospermy during the Cretaceous (e.g. Hughes, 1976; Doyle & Hickey, 1976) are points of great interest in palynology and palaeo-palynology. The significant lower Cretaceous pollen types *Clavatipollenites hughesii* Couper, *Asteropollis asteroides* Hedlund & Norris, *Stephanocolpites fredericksburgensis* Hedlund & Norris, *Retimonocolpites dividuus* Pierce and *Stellatopollis barghoornii* Doyle have well-developed columellae (Walker & Walker, 1984). Cornet (1979) first reported the angiosperm-like pollen with tectate, columellate wall structure from the Upper Triassic and Jurassic of the Newark Super Group (U.S.A.). His subsequent unpublished report (1985) on the Triassic pollen with angiosperm affinities is adequately illustrative (LM, SEM & TEM) of columellate exine types. Cornet's recent work (1989) on the Late Triassic angiosperm-like pollen from the Richmond rift basin of Virginia describes only the Crinopolles group consisting of six genera and eleven species of angiospermid sulcate pollen. Of these, *Dicropollis operculatus, Monocrinopollis doylei, M. microreticulatus, M. mulleri,* *Polycolpopollis magnificus, Tricrinopollis minutus* and *T. olsenii* have dimorphic reticulum supported by columellae. Despite their close resemblance or morphological similarity to lower Cretaceous *Liliacidites* (Walker & Walker, 1984), Cornet (1989) was partly reluctant to attribute their affinity either to monocotyledons or to any angiosperms. This nebulous conclusion from Cornet, one of the staunch proponents of pre-Cretaceous angiosperm origin directs us to a logical analysis of views on angiospermid-pollen-characteristics: What do these three words mean? Could we equate the similarities or correspondences between angiosperm pollen and pre-Cretaceous pollen fossils to homologies or analogous convergences? Is not the combination of tectal reticulum and columellate infra-tectum a typical angiospermous character (cf. Van Campo, 1971)? However, Doyle (1978) remarked that the Triassic reticulate columellate monosulcate pollen reported by Cornet like the conifer *Classopollis* was indicative of the remarkable complexity of exine structure attained by the early Mesozoic seed plants, thus ruling out the conventional belief that earliest pollen should have the simplest structure. This statement is well-supported by the occurrence of columellar complexities in unrelated taxa (e.g. Text-figs 6, 9) and even in primitive families like Magnoliaceae (*Manglietia insignis* and *Magnolia acuminata*, Praglowski, 1973; fig. 1 b, c; fig. 7 g) and Annonaceae (*Uvariostrum pynaertii*, Le Thomas, 1980; Pl. 12, 3, 4) possess complexly granulo-columellate exine ultrastructure. Pocock and Vasanthy (1988) have inferred the angiospermic affinity on the basis of exine ultrastructure of two columellate upper Triassic palynomorphs: psilately banded *Equisetosporites chinleana* Daugherty and reticulately banded *Cornetipollis reticulata* Pocock & Vasanthy, 1988. Lacking data to bridge the gap between the Triassic "angiospermid" pollen and the Cretaceous angiosperm pollen types, may we conclude in accordance with Muller (1984) that the "angiospermid" pollen characters of Triassic were lost (due to extinction?) and reappeared in lower Cretaceous?

Alveolar complexity of Cycadinae and Pteridosperms in two dimensional view bear some resemblance to complex sexine types of dicotyledons (Text-fig. 4). It is intriguing to note the simplification of "alveolate" layer in *Boulaya fertilis*, Pteridosperms (Kurmann & Taylor, 1984, pl. 1, fig. 5) and that of columellate layer in *Artemisia vulgaris*, Asteraceae (Rowley & Dahl, 1977, pl. 23, fig. 3) over the apertural regions. Could we account for any exine substructural (e.g. Rowley *et al.*, 1981) similarity between these complexly alveolar and columellar sexine types?

Endexine evolution has been variously hypothesised by many palynologists (e.g. Guédès, 1982; Crane, 1985; Zavada & Dilcher, 1988; Cornet, 1989). Ubiquity of white-lines in exines of all plants either during development or their persistence after maturation is probably indicative of their significant role in (n)exine formation. The exine of *Equisetosporites chinleana* (Pocock & Vasanthy, 1988; pl. 4) distinguishes itself from most of the known types of exines by its tripartite nexine (Text-fig. 10 D) and inter-stratification or inter-bedding of nexine-1 and nexine-2 layers. According to Cornet (1989) the intermediate stage of nexinal development in *E. chinleana* is suggestive of progenesis: early or accelerated maturity of endexine.

Exinal inflation as an adaptation to pollen dispersal may have led to the formation of different types of sacci (e.g. Text-figs 7, 8). In other words, occurrence of sacci in spore-pollen bearing groups could be accounted rather for their functional significance (harmomegathic or pollen-export) than phylogenetic.

Having discussed some of the basic conjectures and queries relative to angiosperm ontogeny in the context of exine structural evolution, may we conclude our present work with the following quotation :

> ***"We never stop investigating. We are never satisfied that we know enough to get by. Every question we answer leads on to another."***
>
> —Desmond Morris

## ACKNOWLEDGEMENTS

We dedicate this paper to the memory of (Late) Prof. Dr P. Legris (Former Director of the French Institute, Pondicherry, and also CEGET, C.N.R.S., France) who was instrumental for our collaborative palynological researches. We thank Prof. Thomas Taylor and Dr Michael Zavada for sending reprints of several of their contributions consulted for this review. Thanks are due to all authors cited in the Text-figures. Our grateful acknowledgements go to Mr M. Kessavane and Mr Rene Anandam for drafting the Text-figures and Mr S. Aravajy for typing the manuscript.

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# Fossil flora of Gollapalle Formation

Neeru Pandya & Sukh-Dev

Pandya, Neeru & Sukh-Dev 1990. Fossil flora of Gollapalle Formation. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 147-154.

The plant megafossil assemblage of Gollapalle Formation, Andhra Pradesh is enriched and updated. The flora is chiefly constituted of *Cladophlebis, Sphenopteris, Marattiopsis, Pachypteris, Taeniopteris, Ptilophyllum, Dictyozamites, Pterophyllum, Williamsonia, Bucklandia, Elatocladus, Pagiophyllum, Brachyphyllum* and *Araucarites*. Conifers and cycadophytes are dominant; pteridophytes and pteridosperms are poorly represenred. Early Cretaceous age is supported for the Gollapalle flora.

**Key-words**—Fossil flora, Gollapalle Formation, Krishna-Godavari Basin, Early Cretaceous (India).

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## सारॉंश

### गोलापल्ली शैल-समूह का अश्मित वनस्पतिजात

नीरू पाँडया एवं सुखदेव

आँध प्रदेश में गोलापल्ली शैल-समूह से प्राप्त गुरुपादपाश्म समुच्चय के वर्तमान स्वरूप की विवेचना की गई है। यह अश्मित पादप-वनस्पतिजात मुख्यतया **क्लेडोफ़्लेबिस**, **स्फ़ीनॉप्टेरिस**, **मैरेट्टिऑप्सिस**, **पेकिप्टेरिस**, **टीनिऑप्टेरिस**, **टाइलोफ़िल्लम्**, **डिक्टियोजेमाइटिस**, **टेरोफ़िल्लम्**, **विलियमसोनिया**, **बुकलेन्डिया**, **इलेटोक्लेडस**, **पेजियोफ़िल्लम्**, **ब्रेकिफ़िल्लम्** एवं **ॲराकेराइटिस** नामक प्रजातियों से लक्षणित है। इसमें कोनिफरों एवं साइकेडोफ़ाइटीयों की बाहुल्यता है तथा टेरीडोफ़ाइटीयों एवं टेरीडोस्पर्मों की काफ़ी कम संख्या है। इस गोलापल्ली अश्मित वनस्पतिजात की प्रारम्भिक क्रीटेशी आयु प्रस्तावित की गई है।

THE Gollapalle Formation was named after the village Gollapalle (16°43″ : 85°58″) by King in 1880. It rests unconformably over the Chintalpudi sandstone (Permian) and underlies the Raghavapuram Formation. The Gollapalle sediments are exposed between the deltas of Godavari and Krishna rivers extending from Rajamundary to Eluru, consisting of conglomerate at the base, followed by medium to fine-grained, orange to brown, ferruginous and micaceous sandstone, grit and conglomerates, soft claystones and at places limestones. King (1880) equated this formation with the Rajmahal Formation. Later, it was studied in detail by Sarma (1957, 1958, 1960) who also described plant fossils. Baksi (1964) added more information on plant fossils from two localities—Kannapuram and Gopalapuram.

## DESCRIPTION

### Unclassified Ferns

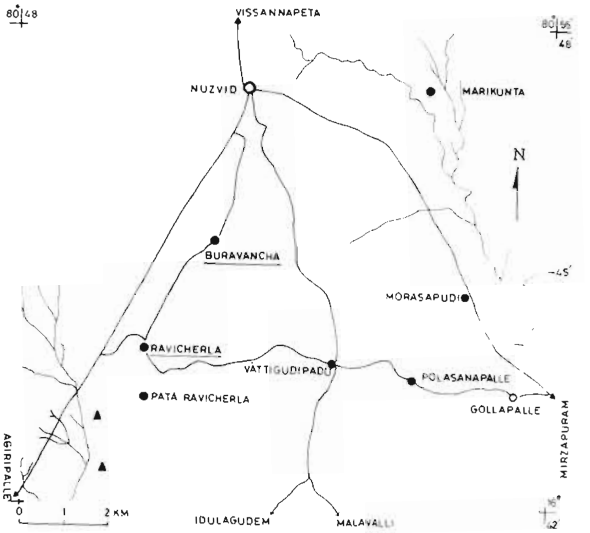
**Genus—*Cladophlebis* Brongniart 1849**

*Cladophlebis* sp. A

Pl. 1, figs 1, 2; Text-fig. 1A

*Description*—Pinnae fragmentary, 0.5-0.8 cm in length, 0.6-1.0 cm in width. Pinnules subopposite to alternate, measuring 5-7 mm in length and 3 mm in width at the broadest point, attached by entire broad base at an angle of 30°-70°, falcate, acroscopic basal margin joining basiscopic margin of upper pinnule; margin entire; apex acute or subacute; midrib persisting up to apex; lateral veins forked once.

*Collection*—Specimen nos. BSIP 36355 and 36356.



**Map 1**—Showing plant fossil localities in Krishna District, Andhra Pradesh.

*Comparison*—*Cladophlebis* sp. A is comparable to sterile pinnae of *Todites indicus* (Oldham & Morris) Bose & Sah 1968 in shape and size of pinnules but differs in venation pattern and pinnule margin. Lateral veins forked once are present in *C. kathiawarensis* Roy 1968 as in *Cladophlebis* sp A. However, the former is distinguished by crenulate or dentate margin of pinnules.

## GYMNOSPERMS

### Pteridospermales

### Family—Corystospermaceae

**Genus—*Pachypteris* Brongniart 1828**

*Pachypteris indica* (Oldham & Morris) Bose & Roy 1968
Pl. 1, fig. 3; Text-fig. 1C

*Remarks*—*Pachypteris indica* has been reported for the first time from the Gollapalle Formation.

### Cycadales

**Genus—*Taeniopteris* Brongniart 1832**

*Taeniopteris spatulata* McClelland 1850
Pl. 1, fig. 4; Text-fig. 1B

### Bennettitales

### Family—Williamsoniaceae

**Genus—*Ptilophyllum* Morris 1840**

*Ptilophyllum acutifolium* Morris 1840
Pl. 1, figs 7, 8

*Ptilophyllum cutchense* Morris 1840
Pl. 1, figs 5, 6; Pl. 2, fig. 1

**Genus—*Williamsonia* Carruthers 1870**

*Williamsonia blandfordii* Feistmantel 1876
Pl. 1, fig. 10

*Remarks*—The female flower of *Williamsonia blandfordii* is comparatively larger in size having 20 bracts and showing faintly marked longitudinal striations. This species has been reported for the first time from the Gollapalle Formation. So far, *W. blandfordii* has been reported from Kera and Kakadbhit localities of Kutch and Jandameta, Krishna-Godavari Basin (Raghavapuram Formation).

*Williamsonia kakadbhitensis*
Bose & Banerji 1984
Pl. 1, fig. 9; Pl. 2, fig. 2

1877 *Williamsonia* comp. *gigas* carr. : Feistmantel, p. 181, pl. 7, figs 1-4.

*Description* (Based on description and photographs given by Feistmantel 1877 and present specimens)—Flowers broadly rounded to oval, mostly onion shaped, measuring more than 9.0 cm in length and 7.3 cm in width. Bracts 18-24, arranged around receptacle, 1.9-13.4 cm in length and 0.5-1.0 cm in width, narrow at base, gradually broadening

→

### PLATE 1

1. *Cladophlebis* sp., specimen no. BSIP 36355, × 1.
2. *Cladophlebis* sp., specimen no. BSIP 36356, × 2.
3. *Pachypteris indica* (Oldham & Morris) Bose & Roy, specimen no. BSIP 36357, × 1
4. *Taeniopteris spatulata* McClelland, specimen no. BSIP 36358, × 1.
5. *Ptilophyllum cutchense* Morris, specimen no. BSIP 36382, × 1.
6. *P. cutchense*, specimen no. BSIP 36359, × 1
7. *P. cutchense* specimen no. BSIP 36360, × 1.
8. *Ptilophyllum acutifolium* Morris, specimen no. BSIP 36361, × 1.
9. *Williamsonia kakadbhitensis* Bose & Banerji, specimen no. BSIP 36364, × 1.
10. *Williamsonia blandfordii* Feistmantel, specimen no. BSIP 36362, × 1.
11. A microsporophyll, specimen no. BSIP 36365, × 1.
12. *Bucklandia* sp., specimen no. BSIP 36366, × 1.
13. *Elatocladus confertus* (Oldham & Morris) Halle, specimen no. BSIP 36367, × 1.
14. *Pagiophyllum* sp. cf. *P. grantii* Bose & Banerji, specimen no. BSIP 36375, × 1.
15. *Pagiophyllum gollapallensis* sp. nov., specimen no. BSIP 36372, × 1.
16. *Brachyphyllum* sp., specimen no. BSIP 36378, × 1.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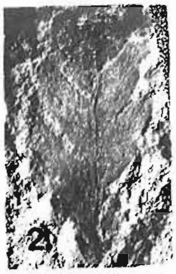
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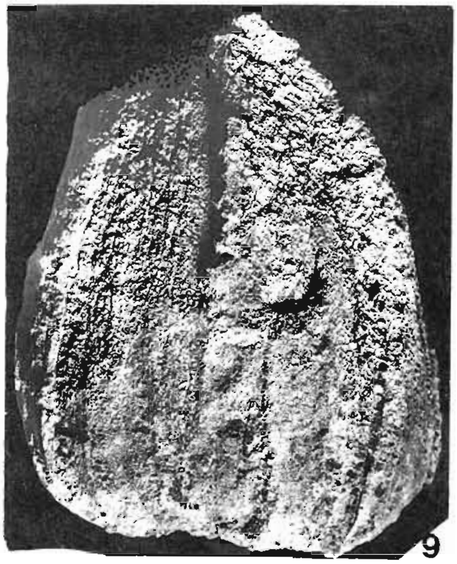
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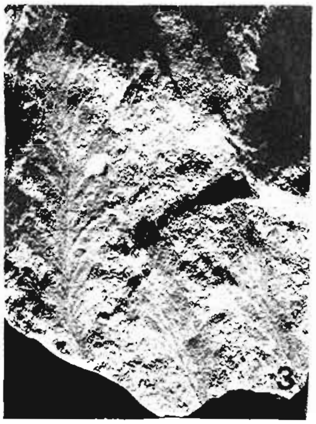
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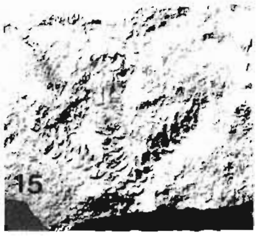
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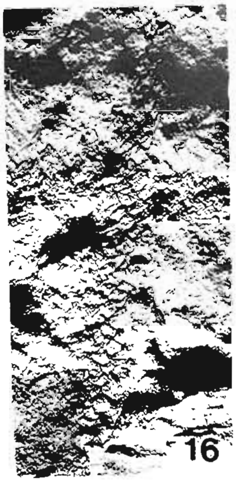
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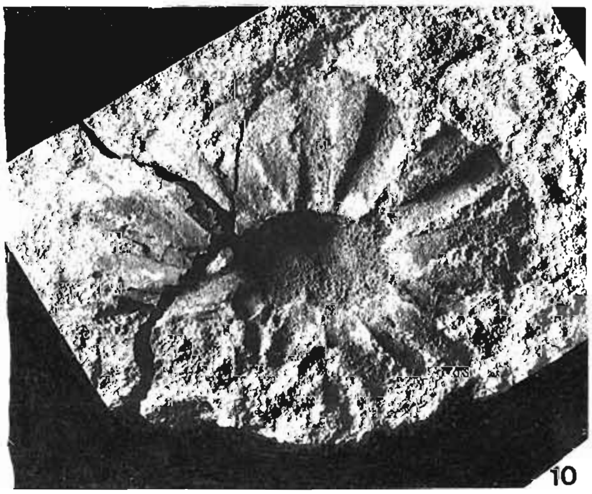
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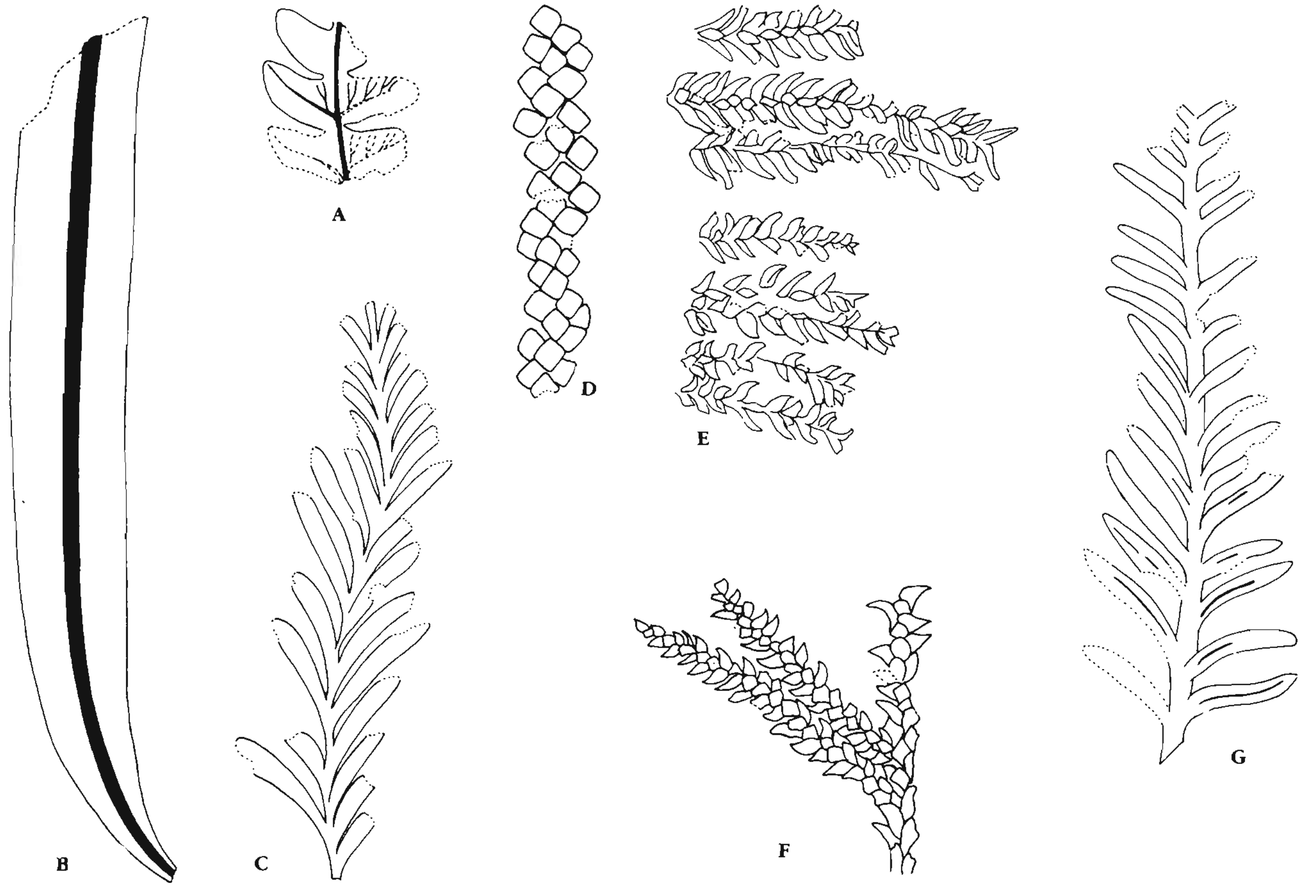
**PLATE 1**



**Text-figure 1—A.** *Cladophlebis* sp., specimen no. BSIP 36355, × 2; **B.** *Taeniopteris spatulata* McClelland, specimen no. BSIP 36358, × 1; **C.** *Pachypteris indica* (Oldham & Morris) Bose & Roy, specimen no. BSIP 36357, × 2; **D.** *Brachyphyllum* sp., specimen no. BSIP 36378, × 2; **E.** *Pagiophyllum* sp. cf. *P. grantii* Bose & Banerji, specimen no. BSIP 36373, × 1; **F.** *Pagiophyllum gollapallensis* sp. nov., Holotype, specimen no. BSIP 36371, × 2; **G.** *Elatocladus confertus* (Oldham & Morris) Halle, specimen no. BSIP 36370, × 2.

higher up and then again narrowing towards apex, compactly or rather loosely arranged. Longitudinal striations and hair present on the surface of bracts.

*Collection*—Specimen nos. BSIP 36363, 36364, 126/2711 and 161/2711.

*Remarks*—This is the first report of *Williamsonia kakadbhitensis* from the Gollapalle Formation. The specimens from the Ravicherla area are comparatively bigger in size.

### Microsporophyll
Pl. 1, fig. 11

*Description*—Fragmentary microsporophyll, 2 × 0.3 $\text{cm}^2$ in size, distal portion having two rows of small ?fertile appendages, tubular in shape, 3-4 mm long and 1 mm broad.

*Collection*—Specimen no. BSIP 36365.

*Remarks*—Only a single fragmentary microsporophyll bearing fertile appendages comparable to *Weltrichia santalensis* Sitholey & Bose 1971 is obtained; fragmentary nature of fossil precludes detailed comparison.

## Genus—*Bucklandia* Presl 1825

### *Bucklandia* sp. A
Pl. 1, fig. 12

*Description*—Fragmentary stems measuring 3.0-6.7 cm in length and 3.0-4.2 cm in width. Leaf-bases more or less rhomboidal, decurrent, measuring 1.2-2.2 × 0.8-1.0 cm, spirally and sparsely placed.

*Collection*—Specimen nos. BSIP 36366 and 1756/2711.

*Comparison*—*Bucklandia* sp. A apparently resembles some of the specimens of *Bucklandia sahnii* Bose (1953, pl. 1, fig. 4) and *Bucklandia* sp. (Sharma, 1974, pl. 1, fig. N) from Rajmahal Hills, Bihar. Anatomical details of the present specimens are not known and hence no comparison is attempted.

## Coniferales

### Family—Podocarpaceae

**Genus—*Elatocladus* Halle 1913**

*Elatocladus confertus* (Oldham & Morris) Halle 1913
Pl. 1, fig. 13; Pl. 2, figs 3, 4; Text-fig. 1G

*Remarks*—Feistmantel (1877) described this species under the name *Palissya conferta.* The swept back nature of leaves confirms its identification as *E. confertus.* Halle (1913) described this species from Grahamland and Sahni (1928) and Bose and Banerji (1984) from India.

### Family—Araucariaceae

**Genus—*Pagiophyllum* Heer 1881**

*Pagiophyllum gollapallensis* sp. nov.
Pl. 1, fig. 15; Pl. 2, figs 6, 7; Text-fig. 1F

1877 *Cheirolepis* comp. Münsteri: Feistmantel, p. 185, pl. 8, fig. 8.

1928 *Brachyphyllum expansum* (Sternberg): Sahni, p. 20, pl. 2, figs 28, 29.

*Diagnosis*—Leafy-twigs branched, maximum available length 8.5 cm and width 7.4 cm. Branches irregular but laterally appressed in one plane, 1.4-3.9 cm long and 0.3-0.4 cm wide, making an angle of 45°-75°. Leaves spirally borne, small, 1-3 × 1-2 mm, keeled, directed forward or laterally, slightly falcate, arising from a rhomboidal leaf-base cushion. Margin entire. Apex acute.

*Holotype*—Specimen no. BSIP 36371; Pl. 2, fig. 6.

*Comparison—Pagiophyllum gollapallensis* resembles *Pagiophyllum rotzoanum* (Massalongo) Wesley 1956 reported from Veneto, Italy, in morphological characters of leaves and their compact arrangement. However, the latter species is distinguished by lax branching system. Individual leaf-branch of *P. gollapallensis* is comparable to *P. chawadensis* Bose & Banerji 1984 and *P. sherensis* and *P. satpuraensis* (Maheshwari & Kumaran, 1976) in gross features but it differs from them in having compactly arranged larger leaves and the absence of 'Phytolemma'.

*Pagiophyllum* sp. cf. *P. grantii*
Bose & Banerji 1984
Pl. 1, fig. 14; Pl. 2, fig. 5; Text-fig. 1E

*Description*—leafy twigs, branched or unbranched, branching irregular, maximum available length 5.4 cm and width 0.7 cm. Leaves spirally borne, closely arranged at an angle of 20°-60°, straight or falcate, directed forward or laterally, measuring 2.5 × 1-1.5mm, arising from a rhomboidal leaf-base cushion. Margin entire. Apex acute.

*Collection*—Specimen nos. BSIP 36373, 36374, 36375, 53/2976 and 56/2976.

*Comparison—Pagiophyllum* sp. cf. *P. grantii* resembles *P. grantii* Bose & Banerji 1984 reported from Kutch in gross features but in the present specimens cuticular features are lacking.

**Genus—*Brachyphyllum* Brongniart 1828**

*Brachyphyllum regularis* Borkar & Chiplonkar 1973
Pl. 2, fig. 9

*Remarks*— A single leafy-twig of *Brachyphyllum regularis* Borkar & Chiplonkar 1973 known from Early Cretaceous of Songad, Kathiawar is identified here for the first time. This species has also been reported from Athgarh Formation.

*Brachyphyllum sehoraensis* Bose & Maheshwari 1973
Pl. 2, fig. 8

*Remarks*—The present specimen of *Brchyphyllum sehoraensis* is larger in size than that of Sehora. The phytolemma is not preserved in the present specimen. So far this species has been reported only from Sehora. Recently, Sukh-Dev and Rajanikanth (1988) have reported some isolated leaves from Gangapur Formation.

*Brachyphyllum* sp. A
Pl. 1, fig. 16; Pl. 2, fig. 10; Text-fig. 1D

*Description*—Leafy-twigs branched, branching at an angle of 60°, 4.5-6.2 cm in length and 0.4-0.5 cm in width. Leaves rhomboidal, closely appressed, 1.5-3.0 mm in length and width, arising from a rhomboidal leaf-base cushion. Margin entire. Apex subacute.

*Collection*—Specimen nos. BSIP 36378 and 23/2711.

*Comparison—Brachyphyllum* sp. A resembles *B. rhombicum* (Feistmantel) Sahni 1928 and *B. sehoraensis* Bose & Maheshwari 1973 in form and closely appressed nature of leaves. However, the former is comparable to *B. brevifolia* and *B. rhomboidales* Srivastava *et al.* 1984 in shape and size of leaves but differs in the absence of phytolemma.

**Genus—*Araucarites* Presl 1838**

*Araucarites cutchensis* Feistmantel
Pl. 2, fig. 11

## DISCUSSION

The floral assemblage of Gollapalle Formation is dominated by conifers and cycadophytes followed by pteridophytes and pteridosperms. Pentoxyleae and Ginkgoales have not been recorded so far. The following species are reported for the first time from this formation: *Cladophlebis* sp., *Pachypteris indica, Ptilophyllum acutifolium, P. cutchense, Williamsonia blandfordii, W. kakadbhitensis*, a microsporophyll, *Bucklandia* sp., *Elatocladus confertus, Pagiophyllum gollapallensis* sp. nov., *Pagiophyllum* sp. cf. *P. grantii, Brachyphyllum regularis, B. sehoraensis, Brachyphyllum* sp. and *Araucarites cutchensis.*

The Gollapalle floral assemblage is similar to that of Sehora of the Jabalpur Formation, Narsinghpur District, Madhya Pradesh, in common presence of *Pachypteris, Ptilophyllum, Elatocladus, Pagiophyllum, Brachyphyllum* and *Araucarites.* Further, in both *Weichselia* and *Cycadopteris* are lacking and there is also paucity of ferns. Palynologically the sediments of Sehora are dated as Late Jurassic/Early Cretaceous (Bharadwaj *et al.*, 1972; Singh, 1966). However, Sharma *et al.* (1977) and Venkatachala and Sinha (1986) have carried out palynological studies of the Gollapalle Formation from the subsurface samples which contain *Microcachrydites, Trilites, Sphaeropollenites, Leptolepidites, Podosporites, Klukisporites, Aequitriradites, Kraeuselisporites, Impardecispora* and *Crybelosporites* indicating an Early Cretaceous age. Recently, Singh and Venkatachala (1988) reassessed the Jurassic-Cretaceous palynofloras of India and suggested an Early Cretaceous age for the Sehora and Gollapalle sediments.

The Gangapur floral Assemblage-1 (represented by Butermal Nala flora) is closely comparable to Gollapalle flora in general composition (Sukh-Dev, 1988). In both, *Pachypteris, Taeniopteris, Ptilophyllum, Dictyozamites, Elatocladus, Pagiophyllum, Brachyphyllum,* particularly *B. sehoraensis* and *Araucarites* are common (Sukh-Dev & Rajanikanth, 1988). However, the Gangapur Assemblage-2 is distinguished chiefly by the presence of *Equisetites, Gleichenia, Hausmannia, Cycadites, Anomozamites, Otozamites, Allocladus,* etc.

The Early Cretaceous flora of Assemblage Zone-8 of *Dictyozamites Pterophyllum-Anomozamites*

**Table 1—Distribution of plant fossils in the Gollapalle Formation**

| *Taxa/Area* | *Buravancha/ Ravicherla* | *Musanur* | *Kunnapuram* | *Gopalapuram* |
|---|---|---|---|---|
| *Cladophlebis* sp. | + | + | | |
| *Sphenopteris* sp. | | | + | |
| *Marattiopsis macrocarpa* | + | | | |
| *Pachypteris indica* | + | | | |
| *Taeniopteris ensis* | + | | | |
| *T. spatulata* | + | | | |
| *Ptilophyllum acutifolium* | + | | + | + |
| *P. cutchense* | + | | | |
| *Dictyozamites feistmantelii* | + | | | |
| *Pterophyllum kingianum* | + | | | |
| *Williamsonia blandfordii* | + | | | |
| *W. kakadbhitensis* | + | | | |
| Microsporophyll | + | | | |
| *Bucklandia* sp. | + | | | |
| *Elatocladus confertus* | + | | | |
| *Pagiophyllum gollapallensis* sp. nov. | + | | | |
| *Pagiophyllum* sp. cf. *P. grantii* | + | | | |
| *Brachyphyllum regularis* | + | | | |
| *B. sehoraensis* | + | | | |
| *Brachyphyllum* sp. A | + | | | |
| *Araucarites cutchensis* | + | | | |
| *A. macropterus* | + | | | |

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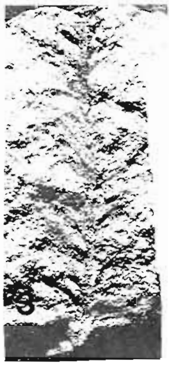
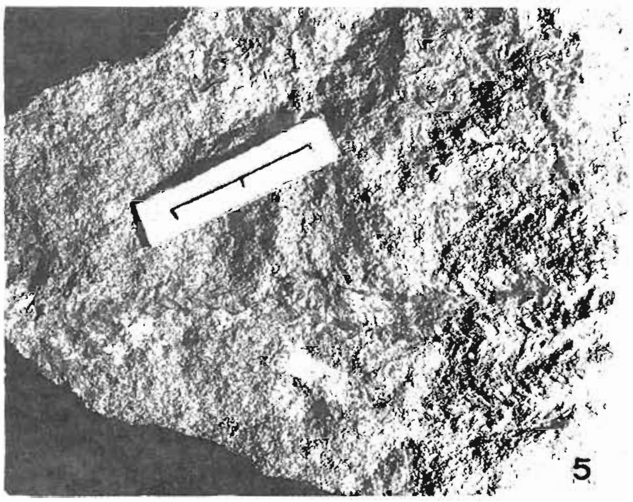
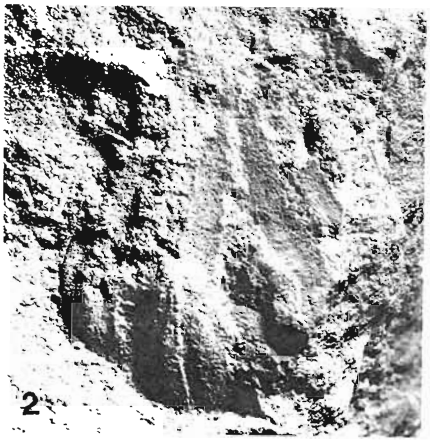
→

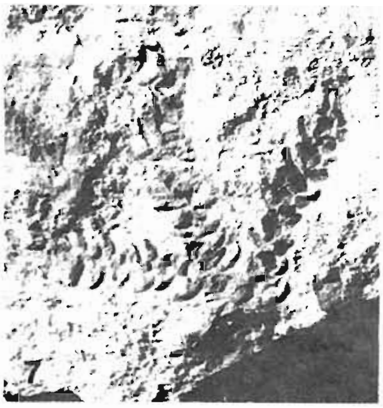
### PLATE 2

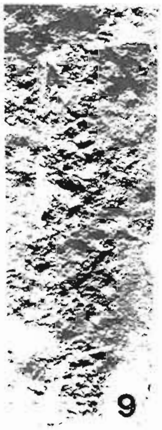
1. *Ptilophyllum cutchense* Morris, specimen no. BSIP 36381, × 1.
2. *Williamsonia kakadbhitensis* Bose & Banerji, specimen no. BSIP 36363, × 1.
3. *Elatocladus confertus* (Oldham & Morris) Halle, specimen no. BSIP 36370, × 1
4. *E. confertus*, specimen no. BSIP 36368, × 1
5. *Pagiophyllum* sp. cf. *P. grantii* Bose & Banerji, specimen no. BSIP 36373, × 1.
6. *Pagiophyllum gollapallensis* sp. nov., holotype, specimen no. BSIP 36371, × 1.
7. *P. gollapallensis*, specimen no. BSIP 36372, × 1.
8. *Brachyphyllum sehoraensis* Bose & Maheshwari, specimen no. BSIP 36377, × 1
9. *Brachyphyllum regularis* Borkar & Chiplonkar, specimen no. BSIP 36376, × 1.
10. *Brachyphyllum* sp., specimen no. BSIP 36378, × 2.
11. *Araucarites cutchensis* Feistmantel, specimen no. BSIP 36380, × 1

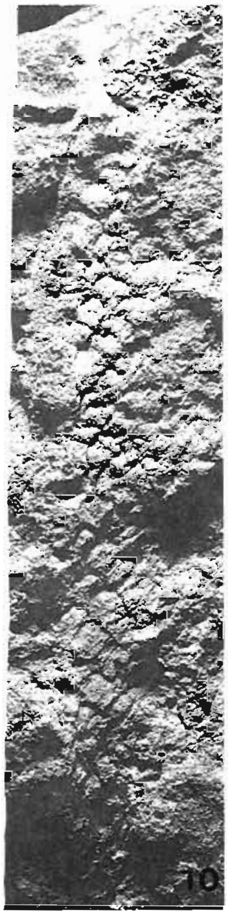












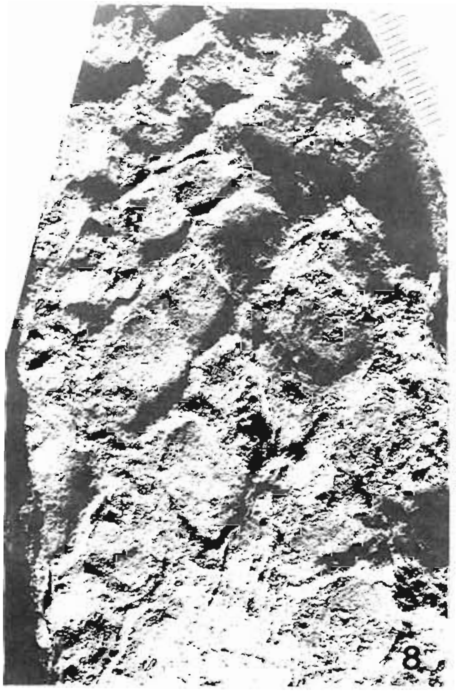


PLATE 2

(Sukh-Dev, 1988) is considered to be less diversified because of the preponderance of broad-leaved cycadophytes, viz., *Ptilophyllum, Pterophyllum, Dictyozamites, Anomozamites, Ctenis* and *Taeniopteris*. Besides pteridophytes, e.g., *Equisetites, Gleichenites* and *Hausmannia* are also present.

The Gollapalle flora is comparatively less varied than the Bansa flora of Jabalpur Formation, constituted by *Weichselia-Onychiopsis-Gleichenia*, Assemblage Zone-10 (Sukh-Dev, 1988), which is characterised by the richness of pteridophytes and conifers and reduction of cycadophytes and pteridosperms.

The faunal evidences from the Gollapalle Formation are meagre, only *Amobaculites, Ammodiscoides, Ammodiscus* and *Haplophragmoides* are known (Sastri *et al.*, 1973). Stratigraphically the Gollapalle Formation unconformably overlies the Chintalpudi sandstone (Permian) and unconformably underlies the Raghavapuram Formation which is dated Early Cretaceous (Barremian) on palaeontological evidences (Bhalla, 1969, 1972; Singh & Ghosh, 1977).

The flora of the Gollapalle Formation though representing Assemblage Zone no. 9 (Sukh-Dev, 1988) also shows close affinity with the flora of Gangapur Assemblage-1 (Butermal Nala) in having broad-leaved cycadophytes, like *Dictyozamites* and *Pterophyllum*. The Gollapalle flora is younger than the Chaugan floral assemblage (Zone no. 9) and older than the Bansa floral assemblage (Zone no. 10, Sukh-Dev, 1988).

In view of the present findings the Lower Cretaceous age of Gollapalle megaflora is supported.

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# Palynology of Mesozoic outcrops of Athgarh Formation exposed near Talbast, Orissa

B. N. Jana

Jana, B. N. 1990. Palynology of Mesozoic outcrops of Athgarh Formation exposed near Talbast, Orissa. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 155-162.

The palyno-assemblage recovered from Athgarh Formation, near Talbast region, Orissa contains 23 genera and 33 species. This assemblage, the first record from southern part of Athgarh outcrops in the region, is characterized by the dominance of the genus *Murospora*, and the palynofloral composition, as a whole, shows its affinity with Upper Jurassic/Lower Cretaceous palynological assemblages.

**Key-words**—Palynology, Athgarh Formation, Mahanadi Basin, Upper Jurassic/Lower Cretaceous (India)

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## साराँश

### उड़ीसा में तलबस्त के समीप अनावरित अथगढ़ शैल-समूह के मध्यजीवी दृश्यांशों का परागाणविक अध्ययन

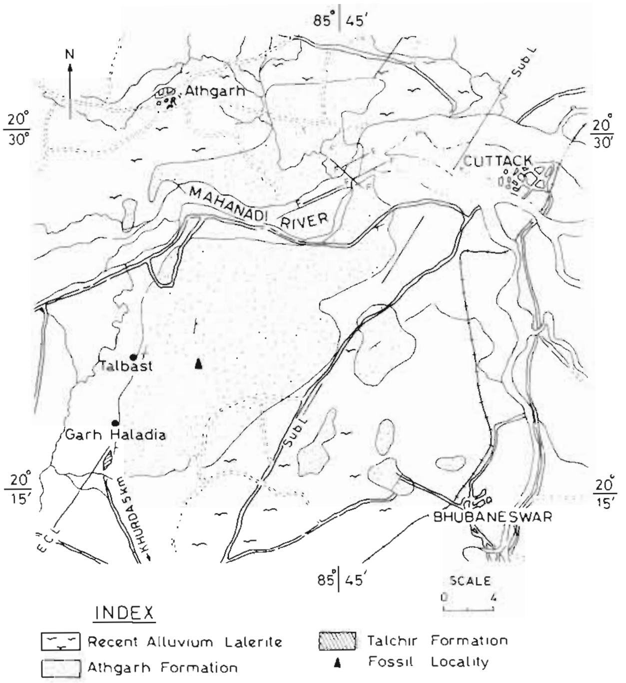
ब्रजेन्द्र नाथ जाना

उड़ीसा में तलबस्त क्षेत्र के समीपस्थ अथगढ़ शैल-समूह से उपलब्ध परागाणविक समुच्चय में 23 प्रजातियाँ एवं 33 जातियाँ विद्यमान हैं। इस क्षेत्र में अथगढ़ दृश्यांशों के दक्षिणी भाग से उक्त समुच्चय का यह पहला अभिलेख है तथा यह **मुरोस्पोरा** नामक प्रजाति की बाहुल्यता से अभिलक्षणित है। कुल मिलाकर यह उपरि जुरेसिक-अधरि क्रीटेशी परागाणविक समुच्चयों से सजातीयता व्यक्त करती है।

THE Athgarh Formation, usually known as "Athgarh Sandstones" constitutes a part of sedimentary sequence of Mahanadi Basin. It is the northernmost exposure of East Coast Gondwana of the Indian peninsula. The outcrops are exposed in the west and southwest of Cuttack city and encompasses an area of about 600 sq km. The sedimentary sequence of this formation is mostly covered by laterite and alluvium. The Athgarh Formation constitutes a part of Upper Gondwana sequence; it was known to lie unconformably over Precambrian basement rocks, but recently the palaeopalynological investigation by Tiwari *et al.* (1987) has revealed the presence of Talchir palynofossils in the olive-green shales which are lying below the Athgarh sandstone exposed near Garh-Haladia Village. Thus, as in other East Coast Gondwana basins, the Mesozoic sediments in Mahanadi Basin also lie unconformably over the Permian sediments.

The main lithological constituents of this formation are conglomerates, grits, sandstones and ferruginous shales (Ball, 1877; Adyalkar & Rao, 1963; Patra, 1980). Also, the occurrence of carbonaceous shales and coal-bands is known from Sidheshwar Hill. The palynological information from this formation is very meagre. So far, the records are known only from Sidheshwar Hill (Maheshwari, 1975; Jana & Tiwari, 1986) and Jagannath Prasad Quarry (Maheshwari, 1975). The paucity of palynological data is mainly because of unfavourable lithology of this formation for the preservation of spores and pollen. Maheshwari (1975) recorded an *Araucariacites*-rich assemblage containing 29 genera and 45 species from Sidheshwar Hill, Cuttack District and Jagannath Prasad Quarry, Puri District. Jana and Tiwari (1986) further made a detailed analysis of the sediments exposed in Sidheshwar Hill and reported the presence of 35 genera and 48 species in which *Araucariacites* is dominant, followed by the genus *Callialasporites*.

It is rather difficult to recover palynofossils from the sediments of Athgarh Formation; yet through



**Map 1**—The geological map of a part of Athgarh Basin showing the location of Mesozoic outcrops studied (after Ball, 1877; partly revised by P. K. Dutta, 1978, G. S. I. DOCD No. 4/79).

consistent efforts, new palynological information has recently been derived which forms the subject matter of the present paper.

## MATERIAL

The samples were collected by the author from Talbast region during a field trip in 1987. In Talbast area, the sediments of Athgarh Formation are mostly covered under dense vegetation; however; they are exposed in the open cast quarry of "Fire Clay".

The productive samples are from Fire Clay Mine which is about 350 m east of Tata's Fire Clay Mine Guest-House (Map 1). In the mine, the top is covered by alluvium and the base is not exposed; the section consists of alternate bands of sandstone and clay. The thickness of rock units and location of samples are as under:

| LITHOLOGY | THICKNESS (in m) | SAMPLE NO. |
|---|---|---|
| Alluvium cover | | |
| Sandy clay band-IV | 0.94 | 3<br>(16-18) |
| Ferruginous fine grained sandstone | 3.48 | |
| Sandy clay-band (discontinuous) | 0.15 | 1<br>(15) |
| Ferruginous coarse-grained sandstone | 2.84 | |
| Clay band | 00.63 | 3<br>(12-14) |
| Ferruginous sandstone | 1.26 | |
| Clay band -II | 0.63 | 3<br>(9-11) |
| Coarse-grained ferruginous sandstone | 2.20 | |
| Clay band-I | 2.20 | 8<br>(1-8) |
| (Base not exposed) | | |
| Total | 14.33 | 18 |

## CHECK LIST OF SPORE-POLLEN TAXA

The palynological assemblage recovered from Athgarh sediments is listed below:

Genus—*Cyathidites* Couper 1953
*C. australis* Couper 1953
*C. minor* Couper 1953
*C. concavus* (Bolkhovitina) Dettmann 1963
Genus—*Deltoidospora* Miner 1935
*Deltoidospora* sp.
Genus—*Todisporites* Couper 1958
*T major* Couper 1958
Genus—*Dictyophyllidites* Couper emend. Dettmann 1963
*Dictyophyllidites* sp.
Genus—*Concavisporites* Pflug emend. Delcourt & Sprumont 1955
*Concavisporites* sp.
Genus—*Osmundacidites* Couper 1953
*O. wellmanii* Couper 1953
*Osmundacidites* sp.
Genus—*Lycopodiacidites* Couper emend. Potonie 1956
*Lycopodiacidites* sp.
Genus—*Concavissimisporites* Delcourt & Sprumont emend. Delcourt, Dettmann & Hughes 1963
*Concavissimisporites* sp.
Genus—*Impardecispora* Venkatachala, Kar & Raza 1969
*I. apiverrucata* (Couper) Venkatachala, Kar & Raza 1969
*I. indica* Venkatachala 1969
Genus—*Klukisporites* Couper 1958
*K. scaberis* Couper 1958
*K. variegatus* Couper 1958
*Klukisporites* sp.
Genus—*Ischyosporites* Balme 1957
*I. crateris* Balme 1957
Genus—*Murospora* Somers 1952
*M. florida* Pocock 1961
*Murospora* sp.

Genus—*Laevigatosporites* Ibrahim 1933
- *Laevigatosporites* sp.

Genus—*Aequitriradites* Delcourt & Sprumont emend. Cookson & Dettmann 1961
- *Aequitriradites* sp.

Genus—*Callialasporites* Dev 1961
- *C. dampieri* (Balme) Dev 1961
- *C. segmentatus* (Balme) Srivastava 1966

Genus—*Alisporites* Daugherty 1941
- *A. grandis* (Cookson) Dettmann 1963

Genus—*Abiespollenites* Thiergart in Raatz 1937
- *Abiespollenites* sp.

Genus—*Podocarpidites* Cookson *ex* Couper 1953
- *Podocarpidites ellipticus* Cookson 1947
- *Podocarpidites* sp.

Genus—*Cycadopites* Wodehouse ex Wilson & Webster 1946
- *C. couperi* Kumar
- *Cycadopites* sp.

Genus—*Ginkgocycadophytus* Samoilovitch 1953
- *Ginkgocycadophytus* sp.

Genus—*Inaperturopollenites* Thomson & Pflug 1953
- *Inaperturopollenites* sp.

Genus—*Araucariacites* Cookson ex Couper 1953
- *A. australis* Cookson 1947

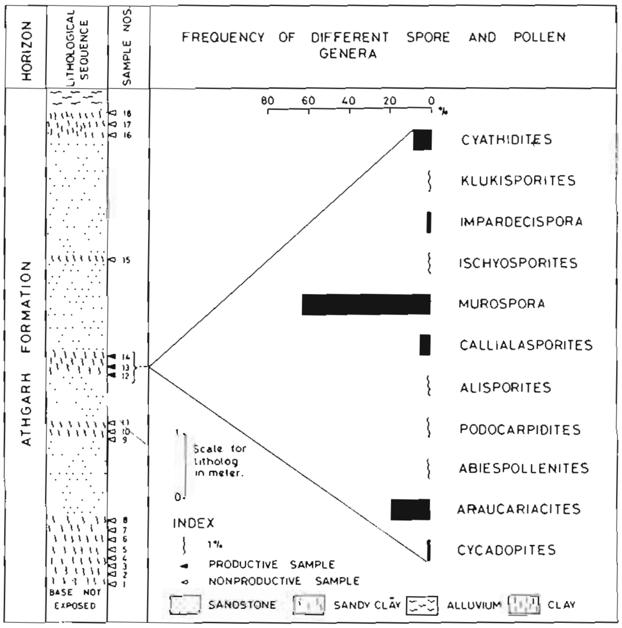
Genus—*Araucariapollenites* Reyre 1970
- *Araucariapollenites* sp.

Some of the important spores and pollen of this assemblage are illustrated in Plate 1 and Plate 2. The genus *Murospora*, being the major component, shows wide morphographical variations in this assemblage.

## QUANTITATIVE ANALYSIS AND COMPARISON

In this assemblage 11 genera out of 23 were encountered in counting (Text-fig. 1). The genus *Murospora* is the dominant (61%) spore. The representation of other elements is as follows: *Cyathidites* (9%), *Klukisporites* (0.5%), *Impardecispora* (1.5%), *Ischyosporites* (0.5%), *Callialasporites* (5%), *Alisporites* (0.5%), *Abiespollenites* (0.5%), *Podocarpidites* (0.5%), *Cycadopites* (1%) and *Araucariacites* (20%). The trilete group, as a whole, constitutes 72.5 per cent of the total assemblage.

This assemblage markedly differs from other assemblages described from Athgarh Formation in having the dominance of trilete group. It is important to note that the genus *Murospora* is dominant in the present assemblage but was not recorded earlier (Maheshwari, 1975; Jana & Tiwari, 1986). The alete genus *Araucariacites* is the dominant taxon in the assemblages of Sidheshwar Hill and Jagannath Prasad Quarry. The disaccate group which constitutes 15 per cent of the total assemblage (Maheshwari, 1975) is poorly represented in the present assemblage.



**Text-figure 1**

It is obvious that the assemblages from Sidheshwar Hill, Jagannath Prasad Quarry and Talbast do not match with each other. Lithostratigraphically their relative position in a sequence is difficult to assess because the dips are mostly rolling and most of the sediments are concealed. Palynologically the Sidheshwar Hill palynoflora is the richest among the three. The Talbast assemblage shows some indication of its being relatively younger to Sidheshwar Hill assemblage because *Murospora* qualifies for an younger affinity (Filatoff, 1975).

The present palynological assemblage shows resemblance with other known palynological assemblages recovered from Cauvery Basin, Palar Basin and Krishna-Godavari Graben. The palynological assemblages from Cauvery Basin (Venkatachala & Jain, 1970; Venkatachala & Sharma, 1974; Venkatachala, Sharma & Jain, 1972) have many genera in common with the present assemblage but the former is distinguishable from the latter in having *Cicatricosisporites, Contignisporites, Cooksonites, Coptospora, Triporoletes, Microcachrydites*, etc. However, the dominance of *Murospora* marks the difference. Inspite of several common genera with present assemblage, the Palar Basin assemblage (Ramanujam & Varma, 1981) is distinguishable from the present one in having *Cicatricosisporites, Cooksonites, Coptospora* and in the nature of dominant element. The palynological assemblages from Krishna-Godavari Graben (Sharma, Jain & Venkatachala, 1977) have several elements common with present assemblage but the former has several other genera, such as *Appendicisporites, Crybelosporites, Sestrosporites, Staplinisporites, Coronatispora, Cooksonites, Coptospora*, etc. in the assemblage.

The present assemblage closely resembles the palynological assemblage known from Katrol sediments of Kutch Basin (Venkatachala, Kar & Raza, 1969) but the latter differs in having *Araucariacites* as the dominant element.

The palynological assemblages from Satpura Basin (Kumar, 1973; Maheshwari & Gupta, 1983; Gupta, 1988) also have several common genera but they possess *Cicatricosisporites, Cooksonites*, etc. Moreover, the dominant genus is *Araucariacites* in the assemblage of Satpura Basin.

The present assemblage is also comparable to *Callialasporites dampieri* Super Zone of Upper Jurassic horizon of Australia (Helby *et al.*, 1987). Out of four Oppel Zones under *C. dampieri* Super Zone, the present assemblage resembles most the *Murospora florida* Oppel Zone in having *M. florida* and several species, such as *Klukisporites scaberi, Aequitriradites* sp., *Callialasporites dampieri*. However, the *M. florida* Oppel Zone of Helby differs from the present assemblage in having a variety of trilete spores, such as—*Stereisporites antiquaporites, Rogalskisporites canaliculus, Antulsporites varigranulatus, Staplinisporites telatus, Neoraistrickia densata, Lygodiumsporites circulumenus, Dictyotosporites complex, D. speciosus, Contignisporites cooksonii, Gleicheniidites senonicus, Lycopodiacidites asperatus* which are not recorded in Talbast assemblage.

The Upper Jurassic palynoflora of western Canada (Pocock, 1970) resembles the present assemblage in having several common genera. These are *Deltoidospora, Todisporites, Concavisporites, Concavissimisporites, Klukisporites, Murospora*, etc. But the Canadian palynological assemblage differs in having rich and varied trilete forms and in the nature of dominant element.

In the Talbast palynological assemblage, the stratigraphically important palynotaxa are *Impardecispora apiverrucata, Klukisporites scaberi, Ischyosporites crateris, Murospora florida* and *Aequitriradites* sp. These forms are known from Upper Jurassic as well as Lower Cretaceous horizons of India (Singh *et al.*, 1964; Venkatachala, 1967, 1969 a, b; Venkatachala *et al.*, 1969; Tiwari *et al.*, 1984; Ramanujam & Srisailam, 1974 etc.), Australia (Filatoff, 1975; Helby *et al.*, 1987; Dettmann, 1963), The Netherlands (Herngreen *et al.*, 1980), Canada (Pocock, 1964, 1967). So also the representation of genera like *Impardecispora, Aequitriradites*, etc. started in the Upper Jurassic but their qualitative variations and quantitative richness are seen in Lower Cretaceous horizons.

The present palynological assemblage is also unique in having trilete genus *Murospora* as the dominant element. So far, no playnological assemblage is known from the Upper Jurassic and Lower Cretaceous horizons of the Indian

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## PLATE 1

(All photomicrographs are magnified ca × 500. Coordinates refer to Leitz Laborlux Microscope no. 067063)

1, 2. *Cyathidites australis* Couper, Slide nos. BSIP 10276, Coordinates: 49 × 105.6; BSIP 10277, Coordinates: 33 × 98.

3. *Todisporites major* Couper, Slide no. BSIP 10276, Coordinates: 37 × 101.

4. ?*Concavisporites* sp., Slide no. BSIP 10277, Coordinates: 30.5 × 102.7.

5, 6, 7 *Osmundacidites wellmanii* Couper, Slide nos. BSIP 10279, Coordinates: 38 × 103.8; BSIP 10276, Coordinates: 71 × 79.5; BSIP 10278, Coordinates: 64 × 101.5.

8. *Murospora florida* Pocock, Slide no. BSIP 10282, Coordinates: 42 × 106.

9, 10. *Klukisporites variegatus* Couper, Slide nos. BSIP 10280, Coordinates: 39 × 93.4; BSIP 10277, Coordinates: 49.6 × 103.7.

11. *Ischyosporites* sp., Slide no. BSIP 10282, Coordinates: 60.8 × 98.8.

12. *Impardecispora* sp., Slide no. BSIP 10278, Coordinates: 50 × 110.4.

13. *Impardecispora apiverrucata* (Couper) Venkatachala, Kar & Raza, Slide no. BSIP 10283, Coordinates: 37.6 × 99.7

14. *Lycopodiacidites* sp., Slide no. BSIP 10284, Coordinates: 66 × 100.5.

15. *Aequitriradites* sp., Slide no. BSIP 10279, Coordinates: 46.5 × 105.5.

16. *Klukisporites scaberis* Couper, Slide no. BSIP. 10281, Coordinates: 60.8 × 98.8.

17, 18. *Murospora florida* Pocock; 17, BSIP 10284, Coordinates: 66 × 100.5; 18, BSIP 10284, Coordinates: 66 × 100.

19. *Impardecispora indica* Venkatachala, Slide no. BSIP 10281, Coordinates: 46 × 104.

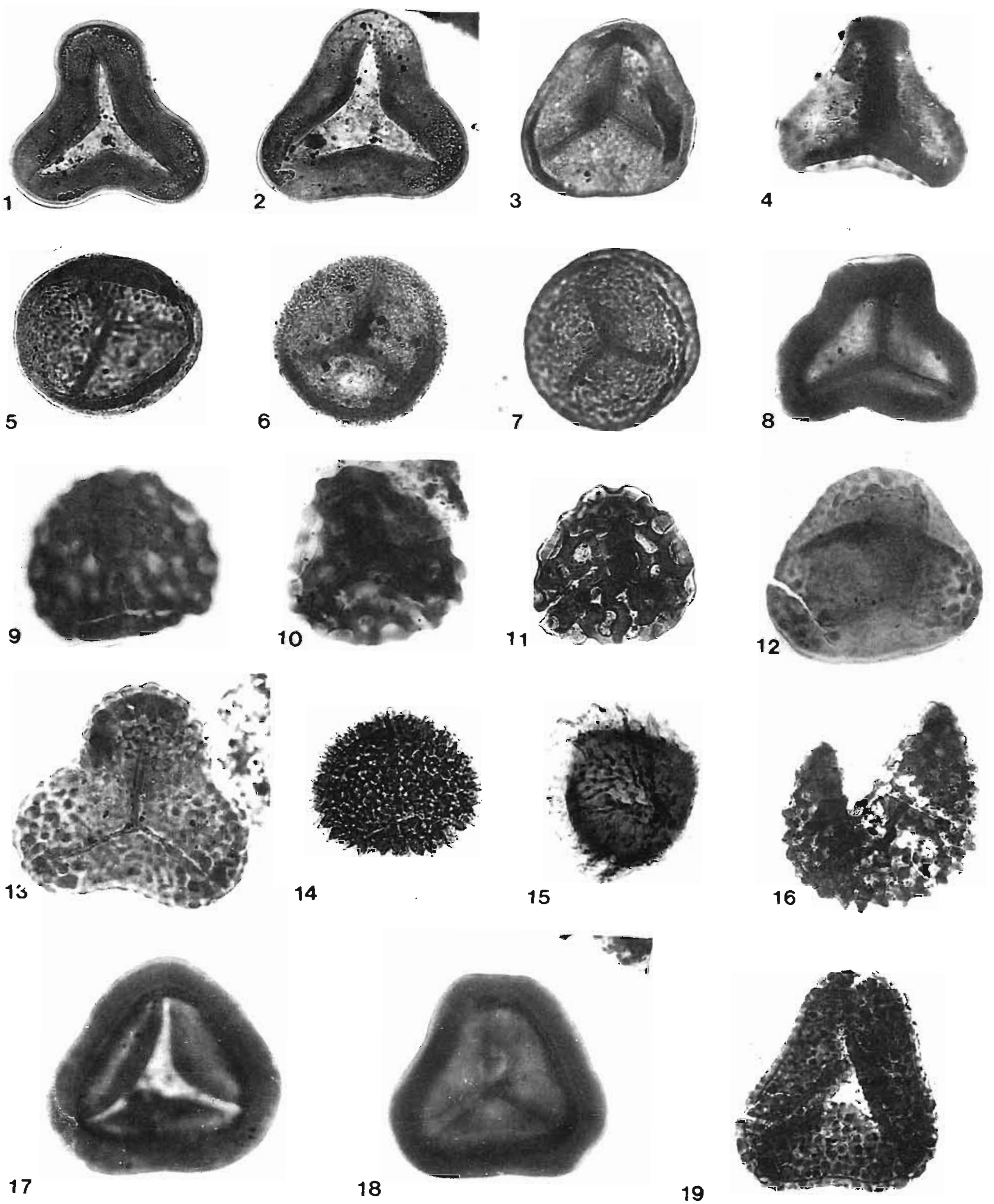
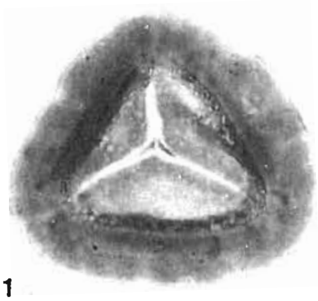


**PLATE 1**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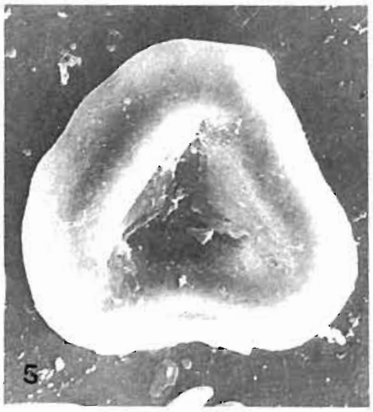
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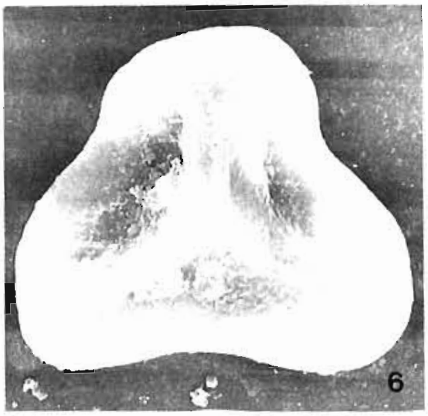
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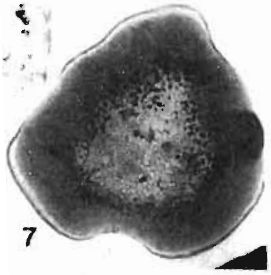
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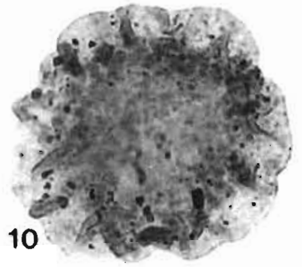
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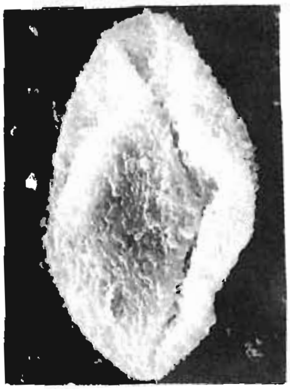


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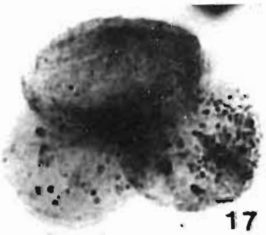
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PLATE 2

subcontinent where trilete group of spores constitutes the overall dominance. Analysing the overall composition of the present assemblage it is assumed that the pteridophytes producing *Murospora*-type of spores were growing nearby or at the depositional site.

## ACKNOWLEDGEMENT

I am thankful to Dr R. S. Tiwari for showing keen interest, various suggestions and critically going through the manuscript. I am also thankful to Sri B. Misra, Agent, Tata Refractories Ltd., Talbast, Orissa for permitting me to collect samples from the Fire Clay Mine and necessary facilities.

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## PLATE 2

(All photomicrographs are magnified ca × 500 unless otherwise stated. Coordinates refer to the stage of Leitz Laborlux Microscope no. 067063).

1-3. *Murospora florida* Pocock, Slide nos. 10285, Coordinates: 43 × 95; BSIP 10276, Coordinates: 49.5 × 106; BSIP 10278, Coordinates: 59 × 59.5.

4-6. *Murospora florida* Pocock, SEM photomicrographs, × 600.

7. *Murospora* sp., Slide no. BSIP 10286, Coordinates: 49 × 106.6.

8. *Laevigatosporites* sp., Slide no. BSIP 10278, Coordinates 62 × 96.5.

9, 10. *Callialasporites dampieri* (Balme) Dev, Slide nos. BSIP 10278, Coordinates: 59.5 × 97; BSIP 10287, Coordinates: 47.5 × 107.7

11 *Podocarpidites ellipticus* Cookson, Slide no. BSIP 10286, Coordinates: 67 × 107.

12 14. *Cycadopites couperi* Kumar, Slide nos. BSIP 10281, Coordinates: 53 × 106.4; BSIP 10276, Coordinates: 37 × 101; SEM photomicrograph. × 600.

15. *Cycadopites* sp. A, Slide no. BSIP 10287, Coordinates: 43 × 103.6.

16. *Cycadopites* sp. B, Slide no. BSIP 10283, Coordinates: 39 × 107.7.

17 *Abiespollenites* sp., Slide no. BSIP 10276, Coordinates: 70 × 89.

18. *Podocarpidites* sp., SEM photomicrographs. × 600.

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# Morphology of Bennettitalean fructifications

B. D. Sharma

Sharma, B. D. 1990. Morphology of Bennettitalean fructifications. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 163-170.

The Bennettitales dominated the vegetation throughout the world during Mesozoic Era. In external morphology they were cycad-like, but had distinct type of fertile parts. Fructifications were monosporangiate or bisporangiate. In seed-bearing fructifications a compact layer of fertile and sterile scales surrounded the conical/hemispherical receptacle. On the basis of ontogeny and anatomy, both types of scales are described as appendicular structures and derived the fructification from *Cordaianthus*. Bisexual fructifications resemble cycadeoideas. Male fructifications are unique and can be correlated neither with any known extinct nor extant plant. Bennettitales originated independently from protoseminales, a plexus which also gave rise to cordaitales and pteridosperms. Bennettitales ended abruptly.

**Key-words**—Morphology, Bennettitales, Fructifications, Mesozoic (India)

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## साराँश

### बैन्नेटाइटेली फलनों की आकारिकी

बी० डी० शर्मा

मध्यजीवी महाकल्प में समस्त विश्व में बैन्नेटाइटेली पौधों की बाहुल्यता थी। बाह्य आकार में ये साइकेडों की भांति थे, परन्तु अबन्ध्य अंगों में द्विबीजाणुधानीय थे। बीज्-धारक फलनों में अबन्ध्य एवं बन्ध्य शल्क-पत्रों की एक सघन तह से शंक्वाकार/अर्धगोलाकार धानी चारों ओर से घिरी है। पादपवृत्त एवं शारीर के आधार पर दोनों ही प्रकार के शल्क पत्रों को उपांगीय संरचनाओं के रूप में वर्णित किया गया है। उभयलिंगी फलन साइकेडिऑइडियों से अनुरूपता प्रदर्शित करते हैं। नर फलन विशिष्ट प्रकार के हैं तथा इन्हें किसी भी वर्तमान अथवा अश्मित पौधे से सम्बद्ध नहीं किया जा सकता। बैन्नेटाइटेल्स प्रोटोसेमीनेल्स से विकसित हुए हैं और इन्हीं से ही कोर्डेटेल्स एवं टेरिडोस्पर्मी पौधों का विकास हुआ है। बैन्नेटाइटेली पौधे अचानक ही विलुप्त हो गये।

THE bennettitalean plants dominating the vegetation during the Mesozoic were cycad-like in external appearance and anatomy, but their fertile parts had a distinct morphology from the latter. Some of the bennettitalean fructifications were bisexual, e.g., *Wielandiella* Nathorst 1880, *Williamsoniella* Thomas 1915, *Sturianthus* (*Sturiella*) Kräusel 1948 and *Amarjolea* Bose *et al.* 1984, while others had either seed-bearing fertile parts, e.g., *Williamsonia* Carruthers 1870 and *Bennettiticarpus* Harris 1932, or the fructification was microsporangiate, e.g., *Weltrichia* Braun 1849. The Cycadeoidales had the fructifications quite similar to those of the Bennettitales except that they were lateral, bisexual and embedded in the cortex of the trunk (Wieland, 1906, 1916), whereas in Bennettitales the fructifications were terminal and of exposed type. In the present paper the morphology of the bennettitalean fructifications is discussed.

Since the publication of Williamson (1868) on *Zamites gigas* Lindley & Hutton, a number of interpretations have been published on the morphology of fructifications of bennettitalean plants (Carruthers, 1870; Lignier, 1907; Arber & Parkin, 1907; Nathorst, 1909; Arber, 1919; Krässer, 1919; Sahni, 1932; Delevoryas, 1968; Harris, 1969; Sitholey & Bose, 1971; Sharma, 1969, 1982). On the basis of recent investigations, the interpretations suggested by earlier authors are rediscussed in this paper.

A typical bennettitalean seed-bearing fructification consists of a small pedicel provided with spirally arranged, linear, flat bracts which protect the conical/hemispherical receptacle. The receptacle is either completely covered with a compact layer of seminiferous (fertile) and interseminal (sterile) scales, e.g., *W sewardiana* Sahni 1932, *Williamsonia guptai* Sharma 1968, *W. harrisiana* Bose 1968, or the apical portion of receptacle is naked, e.g., *Williamsonia gigas* Carruther (Harris, 1967), *Williamsoniella coronata* Thomas 1911. The fertile scales bear orthotropus ovules, while the distal ends of sterile scales are swollen and fleshy, 5-8 sterile scales surround a fertile scale. In bisexual fructifications, a whorl of approximately 20 microsporophylls is present surrounding the central receptacle, e.g., *Amarjolea dactylota* and *Williamsoniella coronata*. Bose (1968) and Harris (1969) suggested that the microsporangiate fructifications be included under the genus *Weltrichia* Braun 1843. In a male fructification there are approximately 20 pinnate microsporophylls in a whorl. Microsynangia are produced on pinnae or on finger-like appendages. The presence of a whorl of bracts surrounding the whorl of microsporophylls (Sharma, 1969), or its absence (Sitholey & Bose, 1971) in *Weltrichia santalensis* Sitholey & Bose 1971 is a controversial problem and has been discussed in the present paper in the light of new collections and recent observations.

## MATERIAL AND METHODS

The material for the present paper was collected from different places throughout the Rajmahal Hills. Impressions of *Weltrichia* occur frequently at Sakrigalighat and Dhokuti, while petrified materials of seed-bearing Williamsonias occur in the fossiliferous localities of Amarjola, Chilgujari and Hiranduba. Epidermal structures of bracts were studied by using an adhesive 'Quickfix'; for anatomical details slides were prepared by the usual method of cutting, grinding and polishing. Because of the fragile nature of Amarjola material, it was boiled in Canada balsam prior to sectioning with the help of a wire band saw. Slides were mounted in Canada balsam.

## DESCRIPTION

*Seed-bearing Williamsonias*—They are of two types, i.e., 'Open type' and 'Close type' (Gupta 1958). In open type the bracts are large and spread, while the central conical receptacle is comparatively smaller and possesses a narrow layer of fertile and sterile scales (*Williamsonia sahnii* Gupta 1943). Gupta (1943) suspected the presence of a whorl of microsporophylls surrounding the central receptacle, but no such structure could be seen in the specimens present in his collection.

At the fossiliferous locality of Amarjola, the petrified seed-bearing Williamsonias of close type occur in three forms, i.e., complete fructifications covered with bracts (Pl. 1, figs 1-7, 9-12, 14-23), bractless fruits (Pl. 1, fig. 13) and the naked receptacles (Pl. 2, fig. 1). These are bulbous, oval, globose in shape and ranging in size from 2.5 × 2 to 12 × 10 cm (Pl. 1, figs 1-23). However, at the bases of all these forms, a circular depression is present (Pl. 1, figs 2, 4, 6, 7, 13) representing the point of detachment of the fructification from the peduncle (parent plant). The bracts are linear, curved structures (Pl. 1, figs 3, 4, 6) bearing stomata on their outer surfaces. Epidermal cells are squarish to rectangular and nonsinuous; stomata are typical syndetocheilic (Sharma, 1968; Bose & Kasat, 1969). Anatomy of the receptacle shows a large number of inverted vascular bundles arranged in a ring surrounding a wide pith. Loss of secondary wood and invertion of bundles take place in the peduncle of the fructification (Sharma, 1973). Sharma (1970a) described a receptacle to be the two-noded structure. Vascular supply in scales (fertile & sterile scales) originates indirectly from vascular bundles of the receptacle.

Leaving aside a few exceptions (*Williamsonia gigas, Williamsoniella coronata*), in majority of bennettitalean fructifications the scales are arranged in basipetal manner and cover the entire surface of the receptacle. In the basal portion of the receptacle there is no differentiation of fertile and sterile scales, and all the scales are identical. Sharma (1974a) described the ontogeny of scales and ovules. The body of a mature ovule may be divided into three portions, i.e., stalk, swollen body and long micropyle (Pl. 2, fig. 4). The stalk has a distinct cordate base. A narrow nucellar stalk (Pl. 2, fig. 9) is surrounded by 4-5 cell-thick layer of integument which gradually becomes narrower towards the distal side so much so that in the body portion it remains only 1-2 cell-thick layer (Pl. 2, fig. 10). A

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### PLATE 1

1-23. Petrified seed-bearing Williamsonias from Amarjola, Rajmahal Hills. Note variations in shape and sizes. All possess a definite circular detachment point at the basal end, × 3/4.


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**PLATE 1**

poorly developed vascular strand enters the base of nucellar stalk and travels up to its distal end. In the body region of ovule the nucellar stalk expands into an oval/globose nucellus. It is closely adhered with the integument and bears a deep pollen chamber (Pl. 2, fig. 5) in its distal end (Sharma, 1974b). Micropyle is long and lined by a 3-5 cell-thick layer of integument (Pl. 2, figs 2-4). The innermost layer of cells are modified and look similar to the interlocking cells of *Gnetum* (Sharma, 1970, 1980). In a seed, the micropylar canal is blocked (Pl. 2, figs 8, 10) by the nucellar plug (Sharma, 1976).

The distal portion of nucellus is made up of elongated cells (Pl. 2, fig. 7). A megaspore mother cell is differentiated in the nucellus which divides by meiosis and forms 4 cells in a linear tetrad. The lowermost cell acts as functional megaspore. Endosperm is produced by free nuclear divisions of the functional megaspore. Wall formation begins from the micropylar end (Sharma, 1974a). Three or four archegonia (Pl. 2, fig. 6) are produced in the upper portion of endosperm (Sharma, 1979). The seed (Pl. 2, fig. 10) is dicotyledonous (Sharma, 1970b). With the formation of seeds, the compact layer of scales also gets detached from the receptacle. However, individual seed could never be collected as it remains encircled by the surrounding interseminal scales. The seed-bearing fertile parts are identical in all the bennettitalean fructifications, viz., *Williamsonia, Williamsoniella, Wielandiella, Sturianthus* and *Amarjolea*. In bisexual fructifications the microsporophylls show wide variations in their structures. In *Amarjolea* the microsporophylls are well-developed and have been compared with that of the *Cycadeoidea* (Delevoryas, 1968; Bose *et al.*, 1984). In *Williamsoniella* (Thomas, 1915; Harris, 1969), the microsporophylls are comparatively lesser developed than *Amarjolea*, while in *Wielandiella* the microsporophylls are much reduced and do not possess the pollen-bearing structures. Pollination mechanism is yet to be understood in these fructifications.

The microsporangiate bennettitalean fructifications were comparatively larger and open type of flowers. *Weltrichia santalensis* Sitholey & Bose 1971 is one of the best known male fructification. They suggested the presence of a single whorl of microsporophylls surrounding a cup-shaped receptacle. Sharma (1969) described two whorls, the outer of sterile bracts (Pl. 3, fig. 2) and inner of microsporophylls (Pl. 3, fig. 1). The microsporophylls were twisted, bearing two rows of appendages on abaxial side in the proximal portion (Pl. 3, figs 3, 4) and one row on adaxial side in the distal portion. Two parallel rows of microsporangia were produced adaxially on the midrib of each appendage (Pl. 3, figs 5, 6). Sitholey and Bose (1971) did not agree with the interpretations of Sharma (1969). On the basis of the study of additional collections from Sakrigalighat earlier interpretations of the author get confirmed. A specimen collected from Dhokuti possesses a whorl of only bracts, and microsporophylls are absent in it.

*Weltrichia (Williamsonia) companulatiformis* Sharma 1969 is another species of microsporangiate bennettitalean flower. Sitholey and Bose (1971) treated it to be a junior synonym of *W. santalensis*. The author, however, disagrees with them and considers it a distinct species.

## DISCUSSION

Bennettitales were peculiar plants which resemble primitive gymnosperms in vegetative features (Cycads) while their fertile parts had the characters of advanced gymnosperms (Gnetales) and angiosperms (Wieland, 1906, 1916; Arber & Parkin, 1907; Pearson, 1929; Seward, 1917; Arber, 1919). The presence of a definite abscission point at the base of young fructification suggests its detachment from the parent plant, a condition identical to the ovule of the extant genus *Ginkgo* (Chamberlain, 1935). Probably similar to *Ginkgo*, in bennettitalean plants too the fertilization and formation of embryo took

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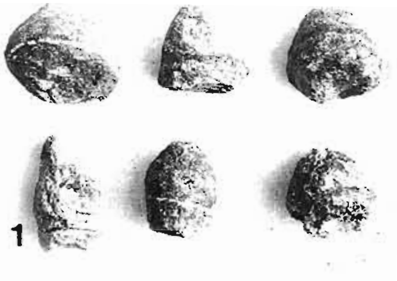
## PLATE 2

1-10. Seed-bearing Williamsonias.
  1. Naked receptacles from Amarjola, × 1/4.
  2, 3. Cross section—Compact layer showing circular micropyles and surrounding interseminal scales.
  4. Longitudinal section—Compact layer showing an ovule with long micropylar canal and interseminal scale. × 40.
  5. Same, pollen chamber in upper portion of nucellus, × 150.
  6. Archegonia chamber with 3-4 archegonia in upper portion of endosperm, × 200.
  7. Nucellus with elongated cells, × 200.
  8. Mature ovule with nucellar plug in micropyle, × 50.
  9. Distal portion of nucellar stalk is seen dividing into two and the surrounding integument, × 50.
  10. Upper portion of seed, × 30.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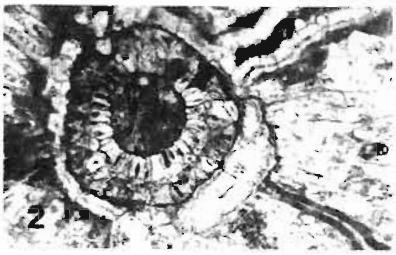
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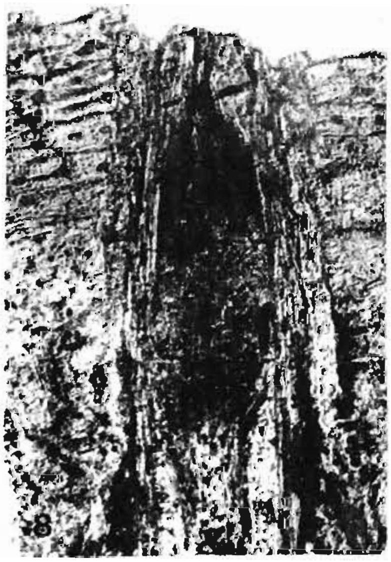
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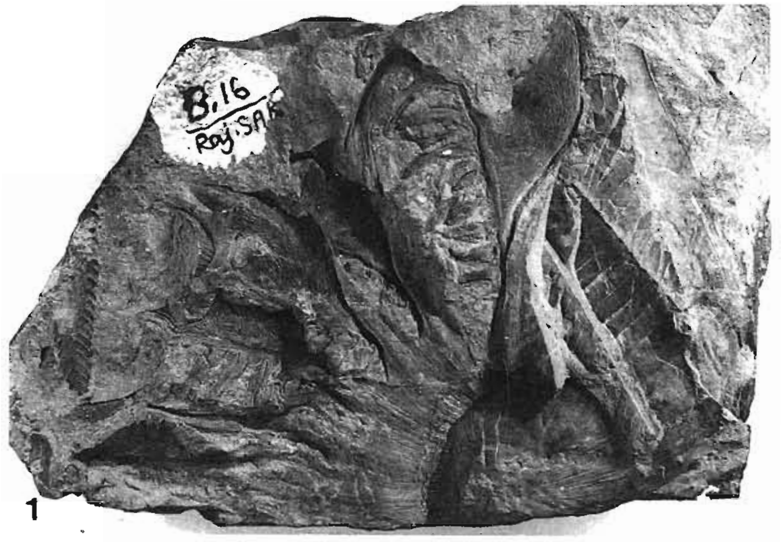
PLATE 2



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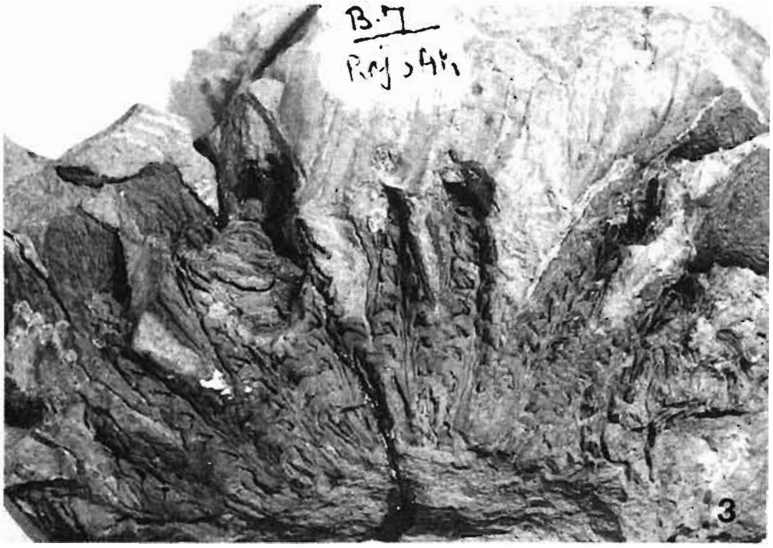

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**PLATE 3**

place on the ground and not on the parent plant. However, in morphology, *Ginkgo* ovule is distinct from the bennettitalean fructification.

The anatomy of receptacle suggests a mixture of primitive and advanced features. Though, there are large number of vascular bundles in the vascular cylinder, they are inverted with exarch protoxylem points; secondary growth is absent. There is no direct vascular supply to the scales from bundles of the vascular cylinder. Seminiferous and interseminal scales get independent vascular supply from the peripheral vascular strands of receptacle (Sharma, 1970) suggesting appendicular nature of scales, a view contrary to that of Lignier (1908) who believed seminiferous scales axillary to interseminal scales.

In seed-bearing Williamsonias there is no distinction of fertile and sterile scales at the basal portion of receptacle, i.e., in ontogeny both kinds of scales are identical (Sharma, 1974a). Formation of ovule begins from periphery to inner side, i.e., the micropyle is differentiated first and the funiculus develops quite late. Integument originates as a circular unit, unlike that of pteridosperms (Lyginopteridales & Medullosales; Meyen, 1987).

Sharma (1982) derived bennettitalean seed-bearing fructification from *Cordaianthus* as a result of reduction and swelling of inflorescence axis to receptacle and modification of the axillary buds-bearing megasporophylls and scales to seminiferous and interseminal scales. However, in ovule ontogeny *Cordaianthus* and bennettitalean fructifications are different from each other.

The bisporangiate bennettitalean fructifications show similarities with that of the Cycadeoidales. However, in the former the microsporophylls are comparatively less developed. A gradual sequence may be drawn from monosporangiate to bisporangiate, i.e., *Williamsonia, Wielandiella, Williamsoniella, Amarjolea* to *Cycadeoidea*, or vice versa. It is difficult to say which of the two conditions—monosporangiate or bisporangiate, is primitive. However, in geological time, unisexual Williamsonias appeared earlier than bisexual Cycadeoideas. The microsporangiate bennettitalean fructifications show similarities with pteridosperms in the presence of pollen-bearing organs as microsporangia and their direct association with the microsporophylls. The microsporophylls were pinnate structures in which the pinnae modified into finger-like appendages. In gross morphology, the microsporangiate bennettitalean fructifications can neither be related with any extinct nor extant group of plants.

Mehra (1988) derived Bennettitales independently from Protoseminales, a plexus which gave rise to Cordaitales and Pteridosperms. Bennettitales achieved maximum evolutionary development in a short geological span from Upper Triassic to Lower Cretaceous and then ended abruptly.

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## PLATE 3

1-6. Male fructification *Weltrichia santalensis*

1. A portion of fructification with microsporophylls and bracts surrounding a circular receptacle, × 3/4.
2. A whorl of sterile bracts, × 3/4.
3. A whorl of twisted microsporophylls, × 3/4.
4. Twisted microsporophylls with two rows of markings of appendages, × 2.

5 6. Finger-like appendages, each with two rows of microsporangia, × 2.

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# *Cauveridinium*, a new Gv-type dinoflagellate cyst from Trichinopoly Formation, Cauvery Basin, India

Khowaja-Ateequzzaman & K. P. Jain

Khowaja-Ateequzzaman & Jain, K.P. 1990. *Cauveridinium*, a new Gv-type dinoflagellate cyst from Trichinopoly Formation, Cauvery Basin, India. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 171-179.

Some lenticular dinoflagellate cysts with process ornamentation restricted to circumferential border zone, characterized by proximal process connections through ridges, have been recovered from the limestone unit of Trichinopoly Formation, Cauvery Basin. These Gv-cysts have been described under a new genus, *Cauveridinium*. Three new species, viz., *C. indicum, C. intermedium* and *C. longispinosum*, are proposed. A detailed comparison with other Gv-Cyst taxa has been attempted.

**Key-words**—Fossil dinoflagellate, Morphology, Cauvery Basin, Turonian-Santonian (India).

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## सारौंश

### कावेरी द्रोणी (भारत) में त्रिचनापल्ली शैल-समूह से एक नई जी-वी० प्रकार की घूर्णीकशाभ पुटी : कावेरीडीनियम

खोवाजा-अतीकुज्ज़माँ एवं कृष्ण प्रसाद जैन

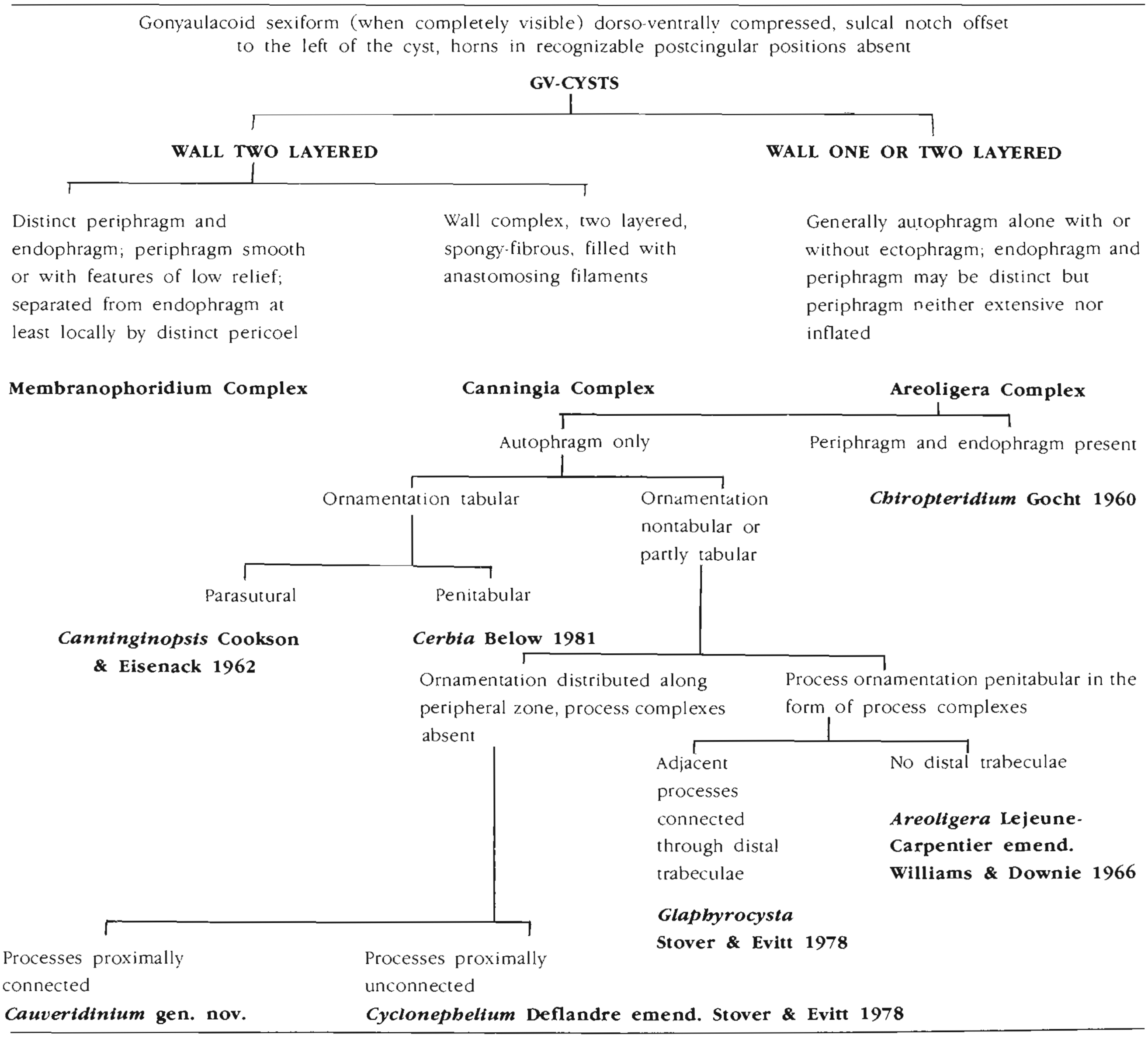
कावेरी द्रोणी की चूनापत्थर इकाई के परिवृत्तीय सीमा क्षेत्र, जो कि कटकों द्वारा निकटस्थ प्रवर्ध संयोजनों से युक्त है, से सीमित प्रवर्ध अलंकरण से युक्त कुछ मसूराकार घूर्णीकशाभ पुटीयाँ उपलब्ध हुई हैं। ये जी-वी० प्रकार की पुटीयाँ **कावेरीडीनियम** नामक नई प्रजाति के अन्तर्गत वर्णित की गई हैं। **कावेरीडीनियम इंडिकम्, का० इन्टरट्रेपियम्** एवं **का० लौंगिस्पाइनोसम** नामक तीन नई जातियाँ प्रस्तावित की गई हैं। अन्य विदित जी-वी० प्रकार के वर्गकों से इनकी विस्तृत तुलना का प्रयास किया गया है।

A GROUP of skolochorate type of lenticular dinoflagellate cysts lacking horns in recognizable postcingular positions and having an apical archaeopyle has been recovered from Shell Limestone unit of Trichinopoly Formation, exposed near Kunnam and Kullakkanatham villages in Cauvery Basin, southern India. On palaeontological evidence this formation has been assigned Turonian-Santonian age.

Recently Evitt (1985, p. 171) grouped the known dinoflagellate cyst genera into 17 major morphological categories. The criterion is based on consideration of morphological features of the cysts, for example, shape, wall relationship, wall features, paratabulation and archaeopyle. One of these is the Gv-Cyst category, mainly characterized by lenticular body, apical archaeopyle, sulcal notch offset to the left of the cyst and absence of horns. Keeping in view the above characters, Evitt (1985) further recognized three complexes, viz., *Areoligera* complex, *Membranophoridium* complex and *Canningia* complex, distinguishing each other on wall structure and surface ornamentation (Table 1).

Out of these three complexes, the *Areoligera* complex is differentiated from the other two complexes in that smooth or low to high relief features of autophragm. In view of the above summary of Gv-Cysts, it is apparent that the present dinoflagellate cysts are assignable to *Areoligera* complex which at present consists of six genera, viz., *Areoligera* Lejeune-Carpentier emend. Williams & Downie 1966, *Canninginopsis* Cookson & Eisenack 1962, *Cerbia* Below 1981, *Chiropteridium* Gocht 1960, *Cyclonephelium* Deflandre & Cookson emend. Stover & Evitt 1978 and *Glaphyrocysta* Stover & Evitt 1978.

**Table 1—Key to identify Gv-Cyst genera of *Areoligera* Complex**



All type and figured slides are housed in the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow. All coordinates refer to Olympus (BH-2) microscope no. 02939.

## SYSTEMATIC PALYNOLOGY

### *Cauveridinium* gen. nov.

Type Species—*Cauveridinium indicum* sp. nov.

*Diagnosis*—Cyst skolochorate, lenticular, subcircular; apex obtusely angular; antapex with two unequal prominences separated by a concavity; autophragm ornamentation elaborate with processes along circumferential border zone but modified on central dorsal and central ventral areas; processes solid or hollow, mostly connected proximally through ridges, rarely distally fused; archaeopyle apical, type (4A), operculum simple, polyplacoid, free.

**PLATE 1** →

(All photomicrographs in differential interference contrast, × 750)

1-6. *Cauveridinium indicum* sp. nov.

1-3. In dorsal high to dorsal low views respectively.

4,5. In ventral low and ventral high views respectively; slide no. BSIP 10273; Coordinates: 3.0 × 146.9 (holotype).

6. Detached operculum; slide no. BSIP 10273; Coordinates: 14.0 × 162.1.

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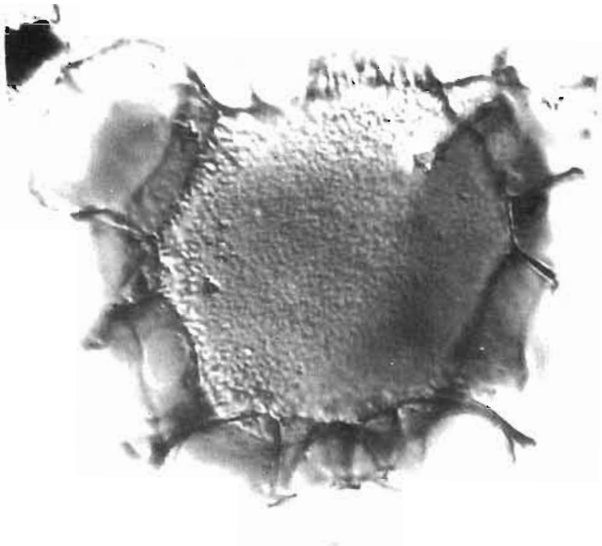

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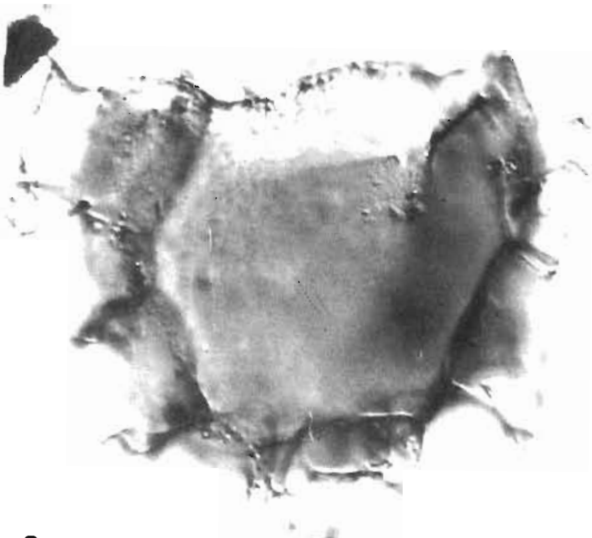

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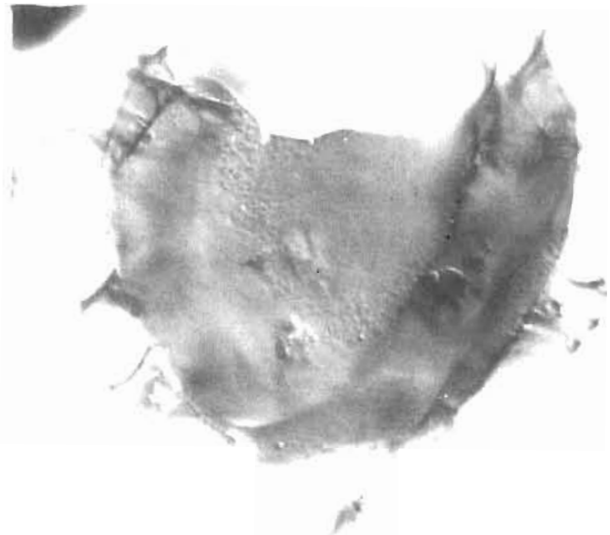

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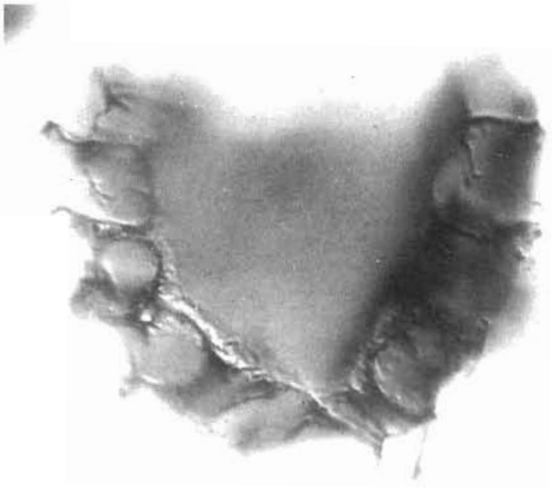

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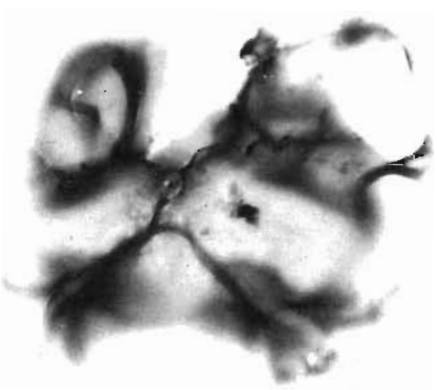

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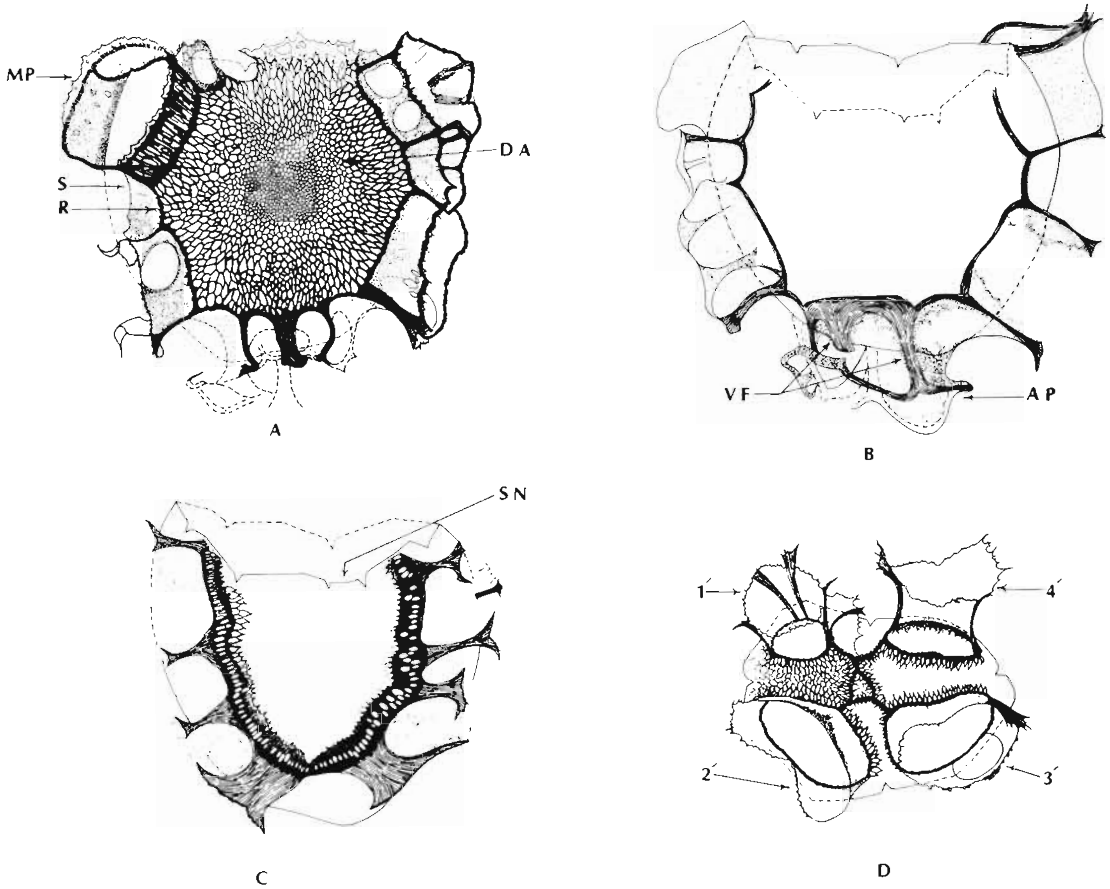
**PLATE 1**



**Text-figure 1**—*Cauveridinium indicum* sp. nov : **A,** Dorsal high view showing differentiated autophragm (DA), membranous processes (MP), ridge (R) and septum (S) connecting adjacent processes; **B,** Ventral high view showing vertical fibres (VF) of antapical process (AP); **C,** Ventral low view showing sulcal notch (SN) offset to the left of the cyst and process distribution; **D,** Detached operculum showing proximal connections of apical processes in a definite pattern; all × ca. 1000.

*Remarks*—A perusal of dinoflagellate cyst literature indicates that the development of ridges, septa or trabeculae, connecting processess, is an important character for generic identification. A few examples supporting the above statement are the distinction between *Glaphyrocysta/Cyclonephelium, Peridictyocysta/Prolixosphaeridium, Distatodinium/Tanyosphaeridium, Hystrichosphaerina/Perisseiasphaeridium, Emmetrocysta/Systematophera, Achomosphaera/Spiniferites*, etc.

Dinoflagellate cysts described under a new genus *Cauveridinium* are, in general, of *Cyclonephelium* morphology but are distinguished from the latter in characteristic development of ridges connecting the adjacent processes proximally. The other genera of *Areoligera* complex are compared and differentiated here (Table 1).

*Cauveridinium indicum* sp. nov.

Pl. 1, figs 1-6; Pl. 2, fig. 6; Pl. 3, figs 5, 6; Text-fig. 1A-D

*Holotype*—Pl 1, figs 1-5; Text-fig. 1A-C; Slide no. BSIP 10273; Coordinates: 3.0 × 146.9; Trichinopoly Formation, Kunnam, Cauvery Basin, Turonian-Santonian.

*Diagnosis*—Cyst skolochorate, lenticular,

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**PLATE 2**

→

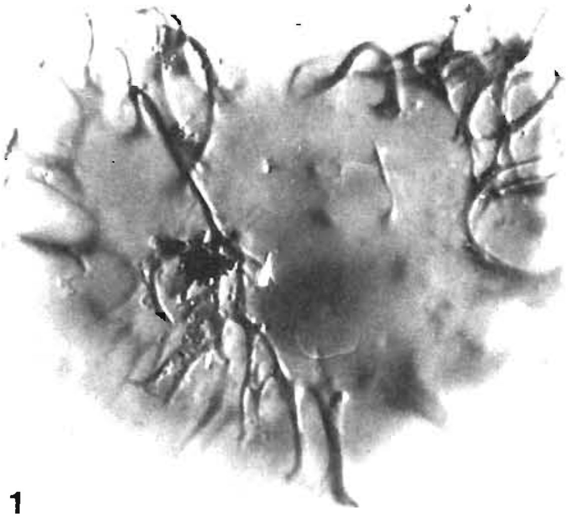
(All photomicrographs in differential interference contrast, × 750)

1-5. *Cauveridinium intermedium* sp. nov.

1-3. In dorsal high to dorsal low views respectively.

4,5. In ventral low and ventral high views respectively; slide no. BSIP 10274; Coordinates: 17.6 × 159.1

6 *Cauveridinium indicum* sp. nov.—detached operculum; slide no. BSIP 10273; Coordinates: 2.1 × 162.5.



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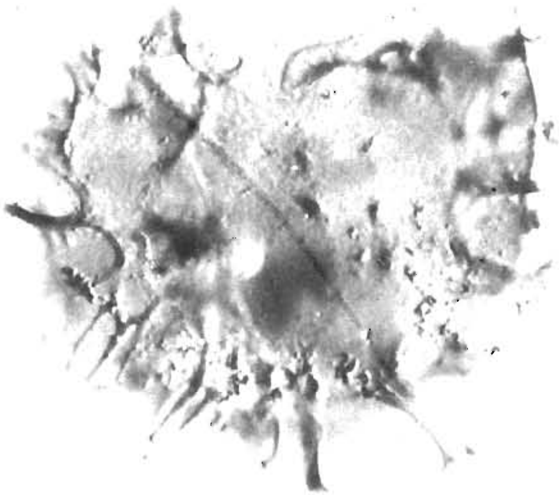

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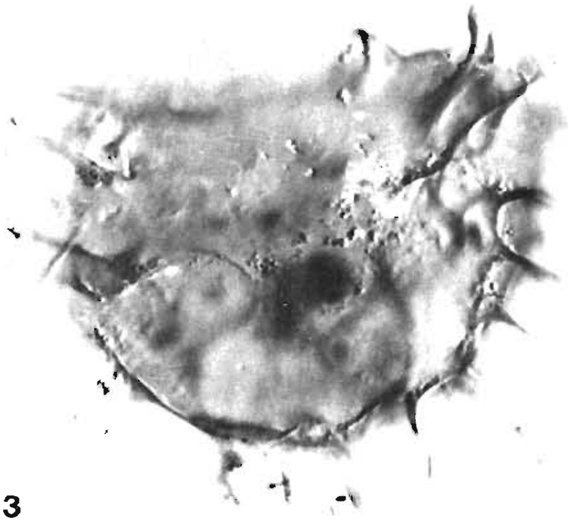

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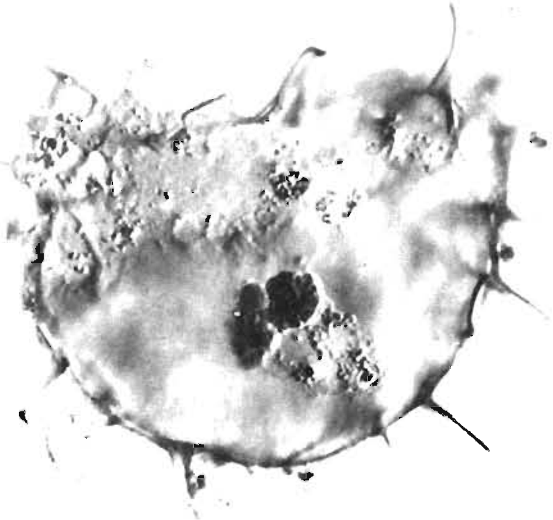

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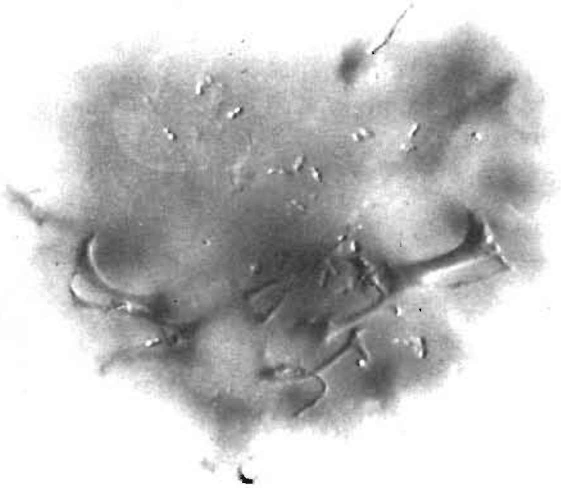

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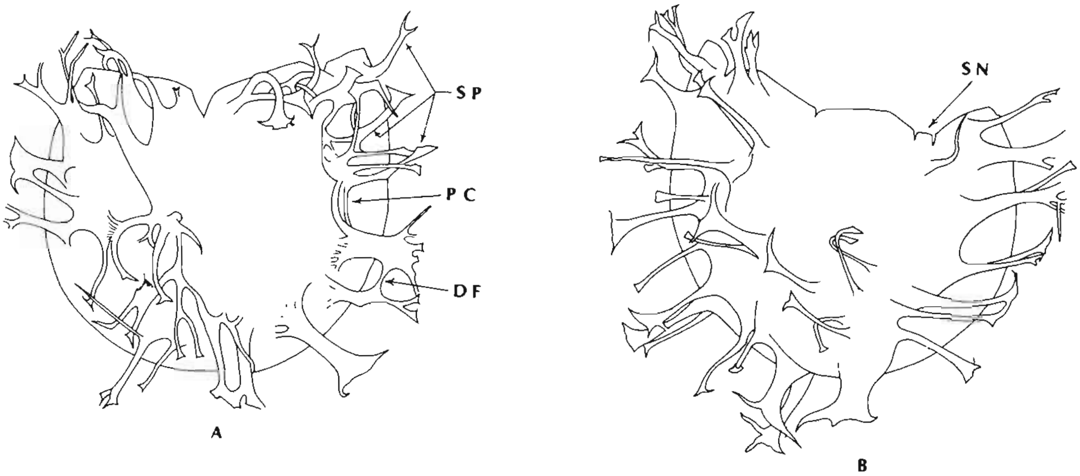
PLATE 2



**Text-figure 2**—*Cauveridinium intermedium* sp. nov. : **A,** Dorsal view showing general distribution, shape, proximal connections (PC) and distal fusions (DF) of solid processes (SP); **B,** Ventral view showing sulcal notch (SN) offset to the left of the cyst and process distribution; all × ca. 1000.

subcircular; apex obtusely angular; antapex with two unequal prominences separated by a concavity; autophragm differentiated (*sensu* Evitt, 1985); processes restricted to circumferential border zone, absent on central dorsal and central ventral areas, short, broad, membranous, fenestrate, supported by vertical fibres; processes proximally connected through thick ridges and a few mostly on dorsal surface also laterally connected through septa; archaeopyle apical, type (4A), operculum simple, polyplacoid, free; apical processes four, one per paraplate, proximally connected to a triangular structure formed at pre-apical paraplate position through ridges.

*Description* :

*Shape*—Cyst dorso-ventrally compressed, subcircular, sulcal notch offset to left of cyst (Text-fig. 1B,C); apical margin obtusely angular, antapex with two unequal prominences separated by a concavity.

*Wall relationship*—Autophragm only.

*Wall features*—No parasutural features; fibrous, spongy, fibre-like elements arise from process bases and ridges which merge with others, packing density of these elements increases inwardly, becoming quite continuous, homogeneous and less spongy towards center (Text-fig. 1A); ornamented with processes; processes restricted to circumferential border zone, covering more areas on ventral than dorsal side (Text-fig. 1C), central dorsal and central ventral areas free of processes; processes short, broad, membranous, fenestrate, distal margins irregular, serrate, supported by vertical fibres, adjacent processes on each side proximally connected through a ridge, some laterally connected through septa (Text-fig. 1A); apical processes proximally connected through ridges to a triangular structure at pre-apical paraplate position in a definite pattern, processes of 2′ and 3′ directly connect but of 1′ and 4′ first join together and then connect through a common ridge (Text-fig. 1D).

*Paratabulation*—Indicated by archaeopyle alone.

*Archaeopyle*—Apical, type (4A), operculum simple, polyplacoid, free (Text-fig. 1D).

| *Dimensions* | *Holotype* | *Range* |
|---|---|---|
| Size of body | 70 × 80 μm | 70-80 × 65-82 μm |
| Length of processes | 6-12 μm | 6-20 μm |

*Remarks*—The details of apical processes and operculum type mentioned for *C. indicum* sp. nov. are based on two well preserved dispersed specimens which possess identical differentiated autophragm and process type characteristic of the cyst.

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**PLATE 3** →

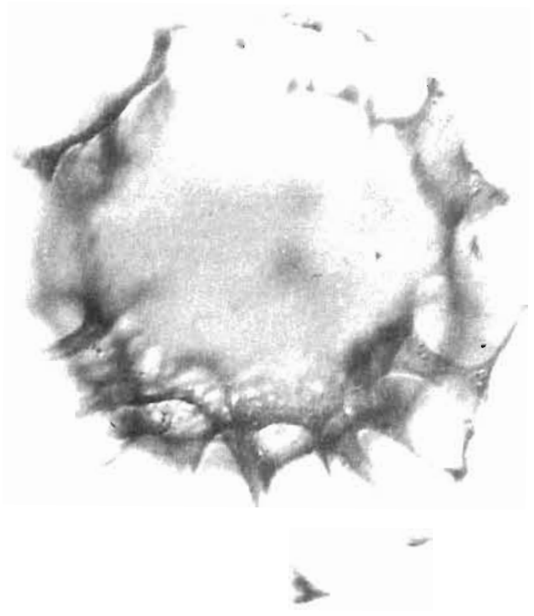
(All photomicrographs in differential interference contrast, × 750)

1-4. *Cauveridinium longispinosum* sp. nov.

1-3. In dorsal high to dorsal low views respectively.

4. In ventral view; slide no. BSIP 10275; Coordinates: 13.0 × 159.5 (holotype)

5,6. *Cauveridinium indicum* sp. nov.—detached opercula; slide no. BSIP 10273; Coordinates: 14.0 × 162.1 and 2.1 × 162.5 respectively.



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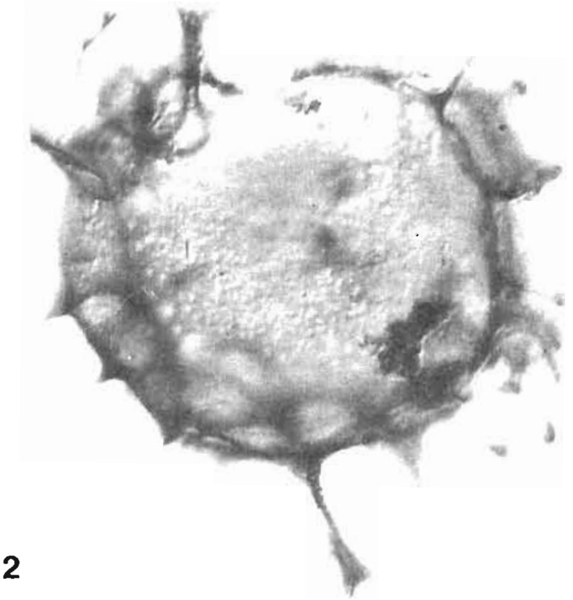

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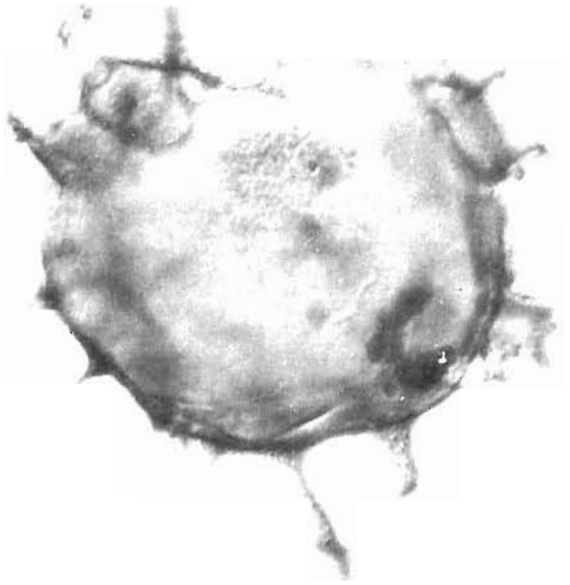

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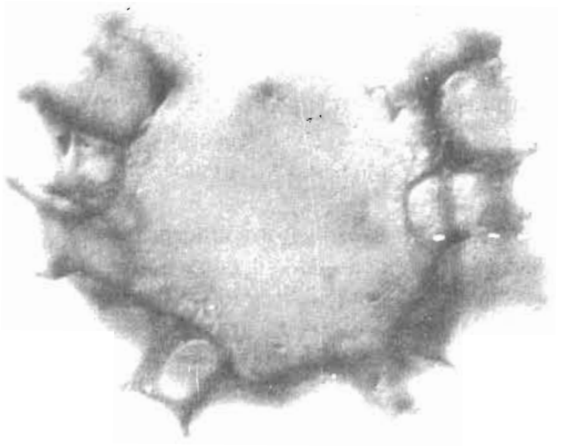

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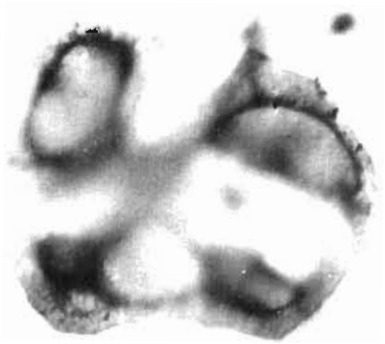


5

6

PLATE 3

### *Cauveridinium intermedium* sp. nov.
### Pl. 2, figs 1-5; Text-fig. 2A-B

1962 *Cyclonephelium distinctum* Deflandre & Cookson—In Cookson & Eisenack, p. 494; pl. 5, figs 8-11.

1978 *C. distinctum* Deflandre & Cookson—In Morgan, p. 923; pl. 10, fig. 3.

1978 *C. distinctum* sub sp. *longispinatum* Davey, p. 894; pl. 3, figs 4, 7, 8.

*Holotype*—Pl. 2, figs 1-5; Text-fig. 2A-B; Slide no. BSIP 10274; Coordinates: 17.6 × 159.1; Trichinopoly Formation, Kullakkanatham, Cauvery Basin, Turonian-Santonian.

*Diagnosis*—Cyst skolochorate, lenticular, subcircular; apex obtusely angular; antapex with two reduced, unequal prominences, separated by a concavity; autophragm smooth, ornamented with processes; processes restricted to circumferential border zone, absent on central dorsal and central ventral areas, solid, branched, variable in length and breadth, proximally connected, a few distally fused; archaeopyle apical, type (4A), operculum free.

*Description* :

*Shape*—Cyst dorso-ventrally compressed, subcircular, sulcal notch offset to left of cyst (Text-fig. 2B), apical margin obtusely angular; antapex with two reduced, unequal prominences separated by a concavity.

*Wall relationship*—Autophragm only.

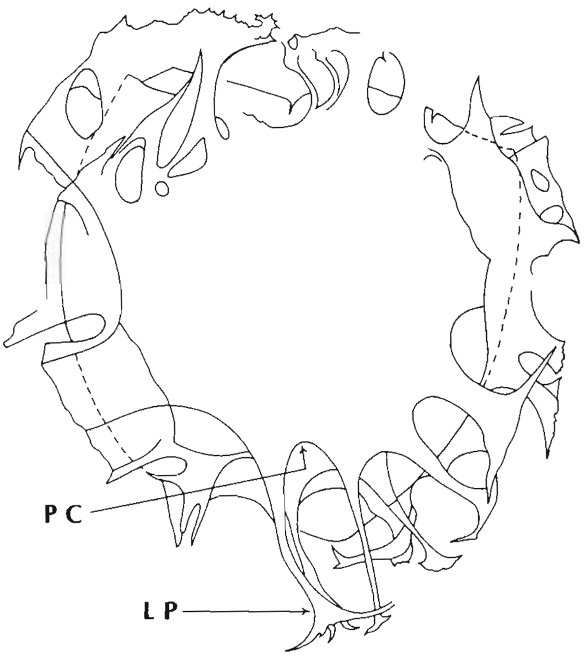
*Wall features*—No parasutural features, autophragm smooth, ornamented with processes restricted to circumferential border zone, absent on central dorsal and central ventral areas; processes solid, branched, variable in size, mostly proximally connected through ridges; others single, unconnected; some distally fused (Text-fig. 2A).

*Paratabulation*—Indicated by archaeopyle alone.

*Archaeopyle*—Apical, type (4A), operculum free.

| *Dimensions* | *Holotype* | *Range* |
|---|---|---|
| Size of body (without operculum) | 58 × 64 $\mu$m | 55-75 × 52-64 $\mu$m |
| Length of processes | 8-20 $\mu$m | 6-22 $\mu$m |

*Comparison*—*Cauveridinium intermedium* sp. nov. is an interesting species having features of both *Cyclonephelium distinctum* Deflandre & Cookson 1955 and its own. The occurrence of simple and unconnected processes suggests comparison with *C. distinctum* but proximally connected adjacent processes through a ridge differentiate it from *Cyclonephelium*. The other two species, *Cauveridinium indicum* sp. nov. and *C. longispinosum* sp. nov., differ from *C. intermedium* in that differentiated autophragm.



**Text-figure 3**—*Cauveridinium longispinosum* sp. nov.: Dorsal view showing long processes (LP) with proximal connections (PC); × ca. 1000.

### *Cauveridinium longispinosum* sp. nov.
### Pl. 3, figs 1-4; Text-fig. 3

*Holotype*—Pl. 3, figs 1-4; Text-fig. 3; Slide no. BSIP 10275; Coordinates: 13.0 × 159.5; Trichinopoly Formation, Kunnam, Cauvery Basin; Turonian-Santonian.

*Diagnosis*—Cyst skolochorate, lenticular, subcircular, apex obtusely angular; antapex with two unequal, reduced prominences separated by a concavity; autophragm differentiated, ornamented with processes; processes restricted to circumferential border zone, absent on central dorsal and central ventral areas, variable in size, adjacent processes connected proximally through ridge; archaeopyle apical, type (4A), operculum free.

*Description* :

*Shape*—Cyst dorso-ventrally compressed, subcircular, sulcal notch offset to left of cyst, apical margin obtusely angular; antapex with two unequal prominences separated by a concavity.

*Wall relationship*—Autophragm only.

*Wall features*—No parasutural features; autophragm fibrous, spongy; fibre-like elements arise from process bases and ridges which merge with others, packing density of these elements increases inwardly, becoming quite continuous, homogeneous and less spongy toward centre, ornamented with processess, processes restricted to circumferential border zone, absent on central dorsal and central ventral areas, long, variable in length and breadth, constricted in middle but flared and fenestrate distally; adjacent processes of each side of cyst proximally connected through a ridge (Text-fig. 3), larger in size on dorsal than ventral side.

*Paratabulation*—Indicated by archaeopyle alone.

*Archaeopyle*—Apical, type (4A), operculum free.

| *Dimensions* | *Holotype* | *Range* |
|---|---|---|
| Size of body (without operculum) | 56 × 66 μm | 55-68 × 60-70 μm |
| Length of processes | 9-26 μm | 8-35 μm |

*Comparison*—*Cauveridinium longispinosum* sp. nov. differs from *C. intermedium* sp. nov. in having differentiated autophragm and from *C. indicum* sp. nov. in that long, non-membranous processes.

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# Palynofacies, maturation and source rock potential in Krishna-Godavari Basin, India

M. S. Rawat & C. M. Berry

Rawat, M. S. & Berry, C. M. 1990. Palynofacies, maturation and source rock potential in Krishna-Godavari Basin, India. *In* Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 180-187

Studies on palynofacies and thermal alteration index (TAI) were carried out in the subsurface sequence encountered in nine drilled locations of Krishna-Godavari Basin for source rock evaluation of the Late Cretaceous-Tertiary sediments. The dispersed organic matter, as a whole, is considered mostly land-derived. The composition of the organic matter is dominantly mixed type. A higher degree of sapropelization is recorded in Late Cretaceous-Palaeogene sequence as compared to Neogene. The organic maturation as suggested by TAI values indicates that the maturation level of 'Oil Window' (TAI = 2.5) reached in the Late Palaeocene (53-60 Ma) in A, B, F and E locations. Younger levels of maturation are noted as Middle Eocene (43-49 Ma) in C and D and Early Miocene (13-16 Ma) in G, H and I locations. It is further observed that the occurrence of youngest level of 'Oil Window' maturation lies between 80°-100°C, which appears the effective cooking temperature for the kerogen in the basin. Based on palynofacies development and TAI values, the sediments within the mature zone are considered to possess good source rock quality to generate mixed type of hydrocarbons in the maturation range of TAI 2.5 to 3.0.

**Key-words**—Biodiagenesis, Palynofacies, Krishna-Godavari Basin, Late Cretaceous/Tertiary (India).

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## साराँश

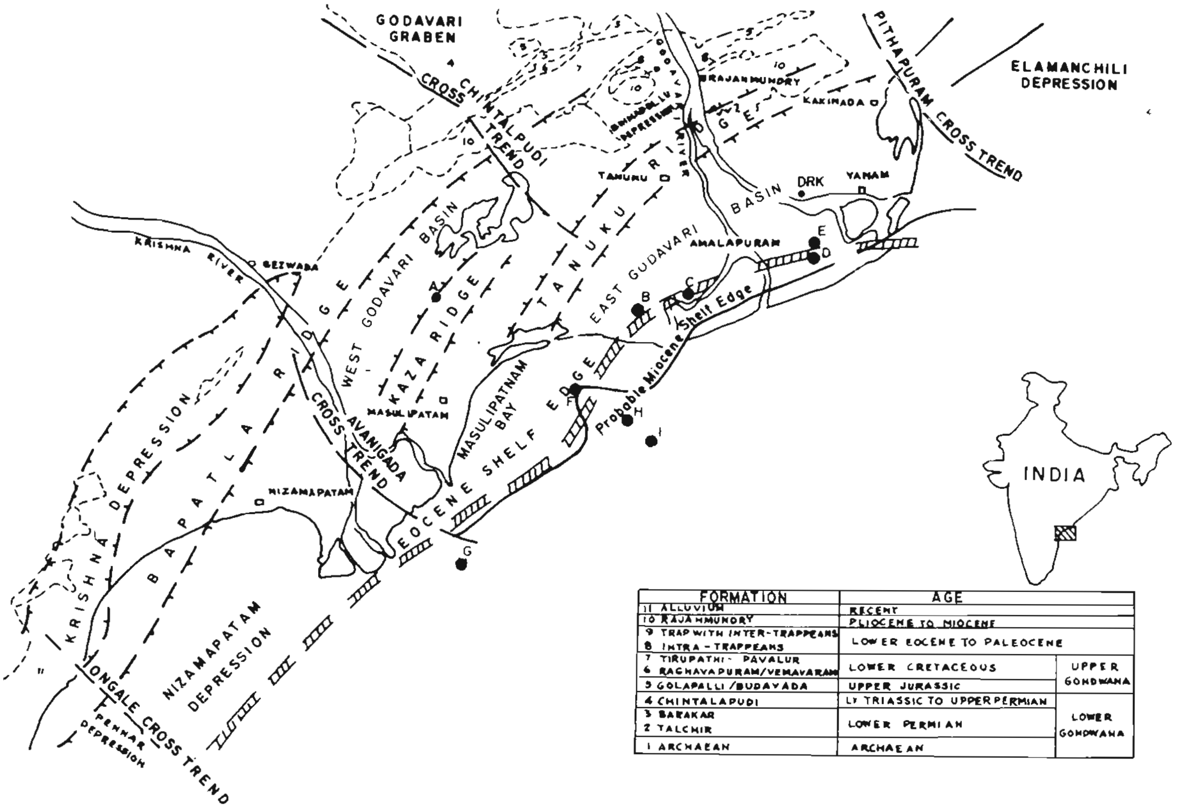
### भारत में कृष्णा-गोदावरी द्रोणी में परागाणु-संलक्षणी, परिपक्व एवं सम्भाव्य स्रोत चट्टान

ऍम० ऍस० रावत एवं सी० ऍम० बेरी

अनंतिम क्रीटेशी अवसादों की स्रोत चट्टान का मूल्याँकन करने के लिए कृष्णा-गोदावरी द्रोणी में नौ विभिन्न स्थानों पर की गई ड्रिलों से उपलब्ध उपसतही अनुक्रम का परागाणविक-संलक्षणी एवं तापीय परिवर्तन सूचक अध्ययन किया गया। कार्बनिक पदार्थ की संरचना मिश्रित प्रकार की है। नवनूतन की अपेक्षाकृत अनंतिम क्रीटेशी-पुरानूतन कालीन अनुक्रम में उच्चतर डिग्री को सैप्रोपेलाइजन अभिलिखित किया गया है। तापीय परिवर्तन सूचक मानकों द्वारा प्रस्तावित कार्बनिक परिपक्वता से प्रदर्शित होता है कि 'ऑयल विन्डो' की परिपक्वता अनंतिम पुरानूतन कल्प में ए०, बी०, ऍफ़० एवं ई० नामक स्थानों पर पूर्ण हो गई थी। जी०, ऍच० एवं आई० स्थानों पर प्रारम्भिक मध्यनूतन में तथा सी० एवं डी० में मध्य-मध्यनूतन कल्प में कम परिपक्वता स्तर प्रेक्षित किया गया है। यह भी प्रेक्षित किया गया है कि 'ऑयल विन्डो' का सबसे कम परिपक्वता स्तर 80°×100° सेन्टीग्रेड के बीच विद्यमान है और यही तापक्रम द्रोणी में केरोजन को पक्व करने में प्रभावकारी लगता है। परिपक्व मंडल के अन्दर के अवसादों में 2.5 से 3.0 के मध्य तापीय परिवर्तन सूचक के परिपक्वता-विस्तार में मिश्रित प्रकार के हाइड्रोकार्बनों का निर्माण करने के लिए स्रोत चट्टानी गुणता विद्यमान है।

THE paper embodies the results of source rock palynological study of Late Cretaceous-Neogene sedimentary sequence encountered in the subsurface of onshore and offshore areas of Krishna-Godavari Basin. Drilling in this basin was started in 1978 by Oil and Natural Gas Commission and, so far, over 50 locations have been drilled. This study has been taken up in view of the increasing exploratory activities for commercial hydrocarbons in both onshore and offshore areas.

Earlier palynological studies in the basin are mostly confined to the palynostratigraphy (Sharma *et al.*, 1977; Venkatachala & Sharma, 1982, 1984; Ramanujam *et al.*, 1986; Rawat *et al.*, 1986). Palynofacies and maturation studies, which have attained significant interest in source rock evaluation for hydrocarbons, have not been attempted seriously. Venkatachala (1984) published a short account on organic matter types and maturation in Narsapur well and initiated such studies in this



| FORMATION | AGE | |
|---|---|---|
| 11 ALLUVIUM | RECENT | |
| 10 RAJAHMUNDRY | PLIOCENE TO MIOCENE | |
| 9 TRAP WITH INTER-TRAPPEANS<br>8 INTRA-TRAPPEANS | LOWER EOCENE TO PALEOCENE | |
| 7 TIRUPATHI - PAVALUR<br>6 RAGHAVAPURAM/VEMAVARAM | LOWER CRETACEOUS | UPPER GONDWANA |
| 5 GOLAPALLI/BUDAVADA | UPPER JURASSIC | |
| 4 CHINTALAPUDI | LT TRIASSIC TO UPPER PERMIAN | LOWER GONDWANA |
| 3 BARAKAR<br>2 TALCHIR | LOWER PERMIAN | |
| 1 ARCHAEAN | ARCHAEAN | |

**Text-figure 1**—Location and geological map of Krishna-Godavari Basin.

basin. A few unpublished records are those of Berry *et al.* (1984), Sharma and Berry (1984) and Rawat *et al.* (1986). Regional synthesis of palynofacies and maturation data in the basin has not been attempted to-date; this study forms such an attempt on this problem.

## GEOLOGICAL SETTING OF KRISHNA-GODAVARI BASIN

Krishna-Godavari Basin occupies most of the coastal plains of Andhra Pradesh on the east coast of India and extends into the coastal water of Bay of Bengal. It covers an area of about 15,000 sq km in onland and 25,000 sq km in the offshore up to 1,000 m isobath. Tectonically, the basin is of the type of divergent continental margin associated with initial rifting and basin filling, then covered by platform-type carbonates and in the final stage, superimposed by the delta system. It is a composite basin comprising various ridges and depressions (Text-fig. 1).

The Archaean and metamorphic complex forms the basement and delimits the basin towards the west and north-west. The basement exhibits the ENE-WSW to NE-SW trend, which is in conformity with dominant trends of Eastern Ghats. Outcrop sedimentary rocks, ranging in age from Permian to Holocene, mainly remain covered under alluvium.

The onland subsurface sequence includes Cenozoic, Mesozoic and Palaeozoic strata. The latter has been encountered in one well of Draksharama area. The Mesozoic sediments of the area have also been penetrated scantily but the Cenozoic sequence is profusedly drilled. Generally, the Late Cretaceous claystones are overlain by a Palaeogene sequence of sandstone-shales and occasional limestones. This is followed by a sand and clay sequence in the Neogene. In the offshore areas, few locations have gone down to Late Cretaceous. A thick, more than 3,000 m sedimentary sequence of Miocene-Recent in the offshore have been found to be composed of siltstone, sands, shaly sands, shales and clays.

The present study is based on the subsurface data of nine locations drilled by Oil and Natural Gas Commission in Krishna-Godavari Basin (Text-fig. 1). The tentative representative locations are as under:

*West Godavari Basin*

1. Location A (Late Cretaceous-Neogene)

*East Godavari Basin*

2. Location B (Late Cretaceous-Neogene)

3. Location C (Late Cretaceous-Neogene)
4. Location D (Late Cretaceous-Neogene)
5. Location E (Palaeocene-Neogene)

*Masulipatnam Bay Area*

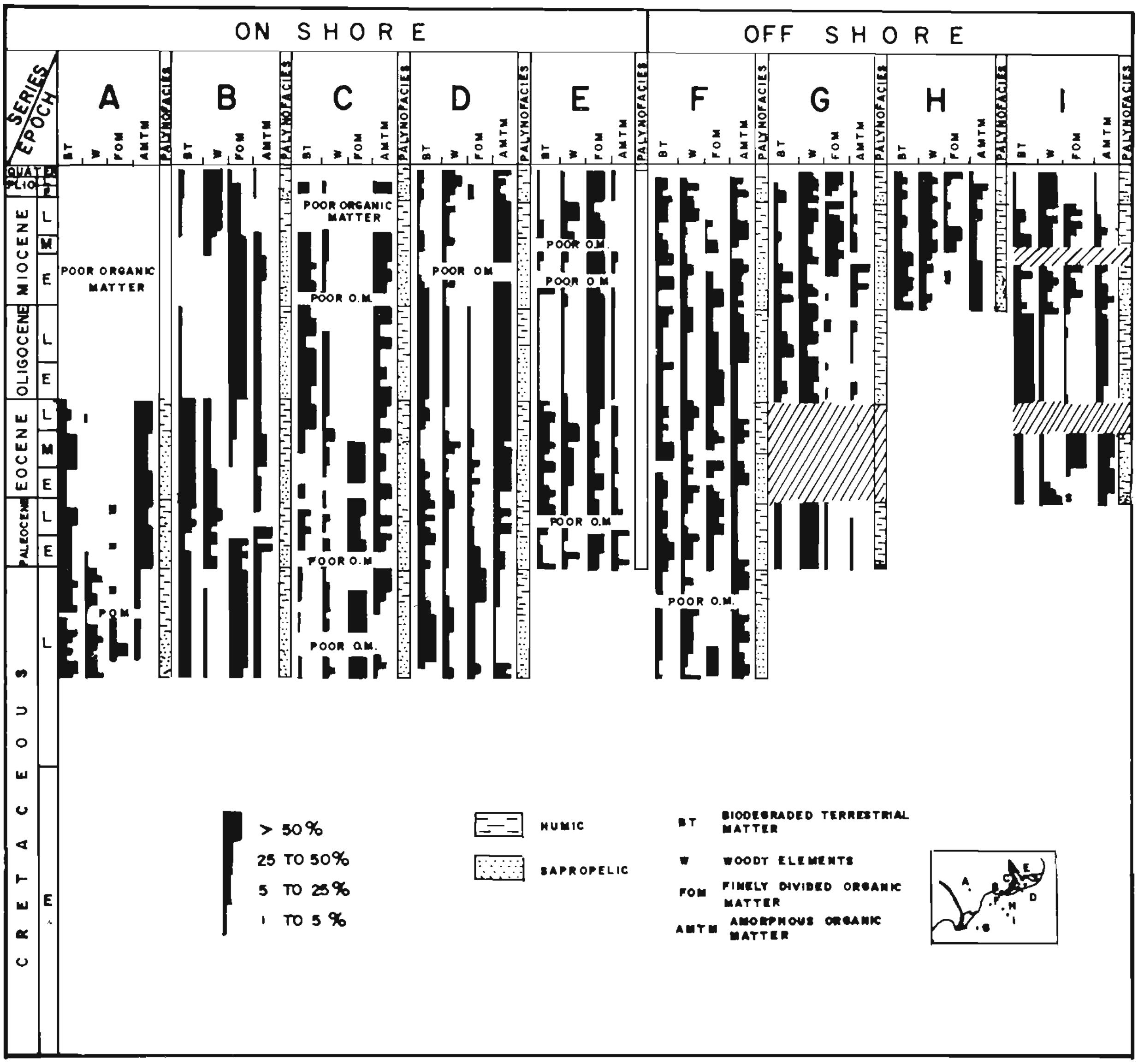
6. Location F (Late Cretaceous-Neogene)
7. Location G (Palaeocene-Neogene)
8. Location H (Neogene-Recent)
9. Location I (Palaeocene-Recent)

## METHODS

Based on visual examination, various types of organic matter, as detailed and classified by Masran and Pocock (1981) and Venkatachala (1984), are recorded. However, for the purpose of this study, the total organic matter has been conveniently grouped into four principal types, viz., (i) biodegraded terrestrial organic matter (BT), (ii) woody components (W), (iii) amorphous organic matter (AMTM), and (iv) finely divided organic matter (FOM). These groups are considered of prime interest to interpret the type and potential of organic matter in the source bed for hydrocarbons.

In addition, organic matter types and their quantitative analysis are made according to the method of Terry and Chilinger (1955). To show relative abundance (volume percentage) of organic matter types in the studied sequence and as depicted in Text-figure 2 the following four categories have been considered:

Abundant (A) : 50% or
Common (C) : 25-50%



**Text-figure 2**—Organic matter types in Krishna-Godavari Basin.

**Table 1—Principal organic matter types in Krishna-Godavari Basin**

| AGE | ORGANIC MATTER | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|---|
| PLIOCENE | BT | POOR ORGANIC MATTER | P | C | T – P | T | P – A | T – C | P – C | T |
| | W | | A | T | P – A | T | P – A | C – A | C – A | A |
| | FOM | | T – C | – | P | A | – | P – A | T – A | – |
| | AMTM | | T | A | T – A | T | P – A | T – P | T – A | T |
| | FACIES | | H > S | H : S | H > S | S > H | H > S | H > S | H > S | H > S |
| MIOCENE | BT | | T | C – A | T – C | T – A | T – A | T – A | P – A | T – A |
| | W | | P – A | T – P | T – C | T – A | T – A | P – A | P – A | P – A |
| | FOM | | C – A | – | – | P – A | T – A | T – A | T – A | ▨<br>P – A |
| | AMTM | | P – C | A | A | T – P | T – A | T – A | P – C | T – A |
| | FACIES | | S > H | H : S | S > H | S > H | S : H | H : S | H > S | H > S |
| OLIGOCENE | BT | | T | P – A | C | T | P – A | P – A | | A |
| | W | | – | P | P | T | P – C | P – A | | T |
| | FOM | | A | – | T | A | P – A | T – P | | P – C |
| | AMTM | | P | P – A | A | T | P – A | T – P | | T |
| | FACIES | | S > H | H > S | S > H | S > H | S > H | H > S | | H > S |
| EOCENE | BT | P – A | A | P – A | T – C | P – A | P – A | ▨ | | ▨ |
| | W | T | P – C | T – C | T – A | P – A | P – A | ▨ | | ▨<br>C |
| | FOM | – | T – P | A | T – C | P – A | P – A | ▨ | | P – A |
| | AMTM | C – A | T – C | P – A | P – A | T – P | P – A | ▨ | | P – A<br>C – A |
| | FACIES | S > H | H > S | S > H | S > H | H > S | S : H | ▨ | | S : H |
| PALEOCENE | BT | P – A | P – A | P – C | P – A | T – A | P – A | ▨ | | |
| | W | T | P – A | T – P | P – C | T – A | T – A | A | | |
| | FOM | P | C – A | C – A | T – C | C – A | P – A | T | | |
| | AMTM | C – A | P – A | P – A | P – A | P – A | P – A | T | | |
| | FACIES | S > H | H > S | S > H | S : H | S > H | S : H | H > S | | |
| LATE CRETACEOUS | BT | P – A | C | T | P – A | | T – P | | | |
| | W | P – A | T | T – C | T – C | | T – A | | | |
| | FOM | P – A | C – A | A | P – A | | C | | | |
| | AMTM | P | P | T – A | P – A | | P – A | | | |
| | FACIES | H > S | S > H | S > H | S : H | | S > H | | | |

LEGEND

BT : BIODEGRADED TERRESTRIAL MATTER
W : WOODY ELEMENTS
FOM : FINELY DIVIDED ORGANIC MATTER
AMTM : AMORPHOUS ORGANIC MATTER

A : ABUNDANT (>50%)
C : COMMON (25-50%
P : PRESENT (5-25%)
T : TRACES (<5%)
S : SAPROPELIC
H : HUMIC

Present (P) : 5-25%
Traces (T) : 1-5%

Thermal Alteration Index (TAI) values were worked out on 1-5 scale of Staplin (1969) based on the colours of spores and pollen. Mature/immature facies were demarcated according to the scheme suggested by Staplin (1977, fig. 10). Accordingly, in the assessment of the maturation, TAI value of 2.5 has been taken to demarcate the youngest level of mature facies.

'Humic facies' comprising terrestrially sourced biodegraded matter and woody elements are dominantly gas-prone which mature at higher level of thermal index as compared to the 'Sapropelic facies' (amorphous and finely divided organic matter) sourced from marine as well as terrestrial organic matter which yield hydrocarbons at comparatively lower level of thermal maturity. These two major organic facies are very significant from the source potential view point.

## PALYNOFACIES AND MATURATION

The type of dispersed organic matter from different sequences in the studied locations is recorded under various stages of biodegradation and sapropelization. Based on the occurrence and the relative abundance of four principal categories, the dominant organic facies are determined as shown in Table 1 and depicted through a composite palynofacies diagram (Text-fig. 2).

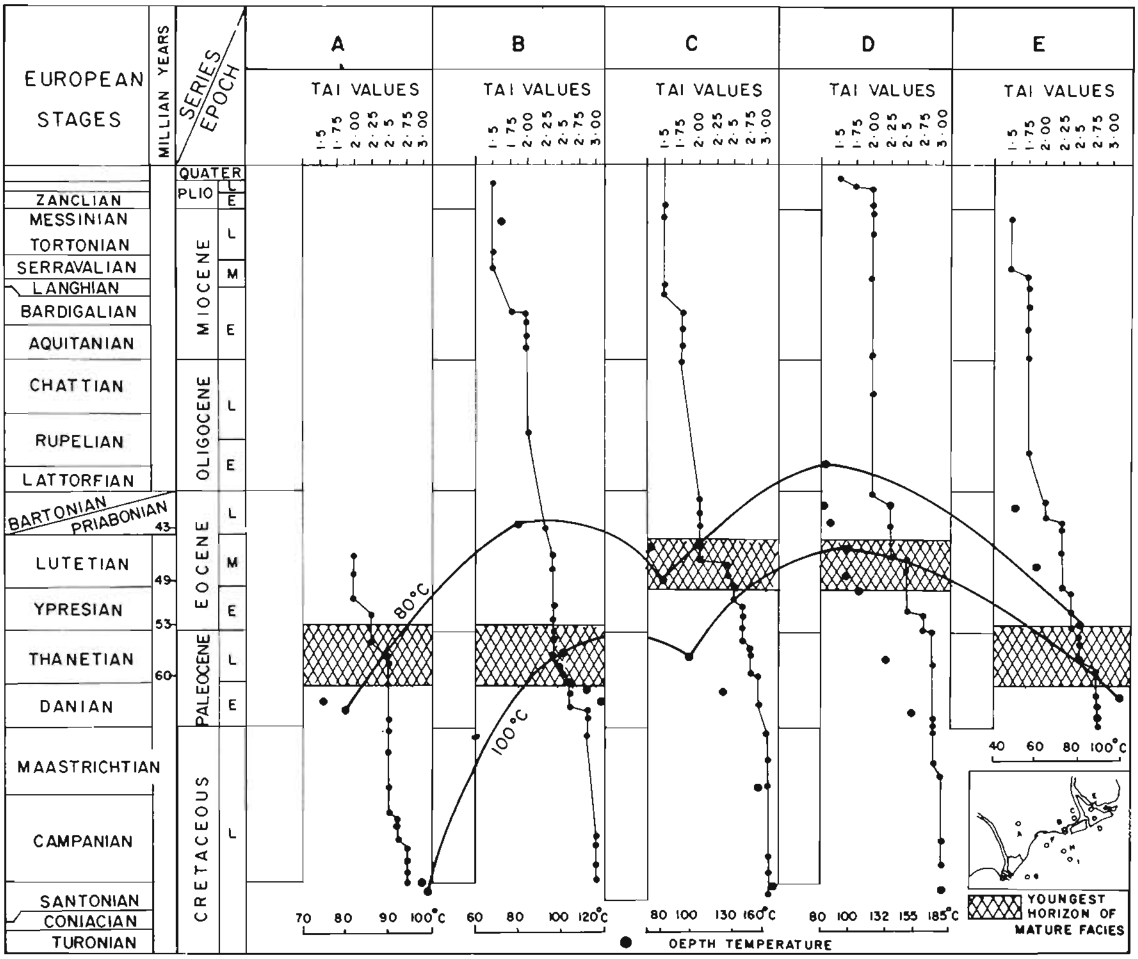
The thermal maturation levels as evaluated by TAI values of fossil pollen grains are depicted through maturation profiles (Text-figs 3, 4). The bottom hole temperatures are also incorporated along the TAI values (Text-figs 3, 4). The data is effectively used to delineate the thermally mature organic facies. The characteristics of organic matter and its maturation in the area of present study are discussed below:

## PLIOCENE SEQUENCE

*Palynofacies*—Humic organic facies dominates; however, a better degree of sapropelization occurs at certain intervals in the onshore region, particularly in the Bhimanapalli area (Text-fig. 2).

*Thermal maturation*—The low TAI values of 1.25-2.0 would suggest an immature thermal facies.

*Source potential*—The Pliocene sequence from potential view point is relatively unimportant.



**Text-figure 3**—TAI maturation profile in the onshore locations of Krishna-Godavari Basin.

## MIOCENE SEQUENCE

*Palynofacies*—The sequence contains a mixed organic facies comprising both humic and sapropelic matter; however, a better humic yield is observed in locations G, H and I (Text-fig. 2).

*Thermal maturation*—The TAI values range from 1.5 to 2.75. The sequence in Narsapur-Bhimanapalli area on the onland parts shows low TAI values of 1.5-2.0 indicating immature facies. However, TAI values show increasing trends in the locations studied beyond the Miocene shelf edge in the offshore. Based on TAI values, the youngest level of mature facies is recorded in Early Miocene in G, H, I locations (Text-fig. 4).

*Source potential*—Miocene source potential in onshore locations—A, B, C, D, E and F in the offshore above Miocene shelf-edge, is considered poor due to low maturation. In contrast, the occurrence of higher TAI values of maturation in locations G, H and I, beyond the Miocene shelf edge, as discussed above, is significant and points towards a good source rock maturation in Early Miocene (13-16 Ma) capable of generating hydrocarbons, mostly gaseous ones.

## PALAEOGENE SEQUENCE

*Palynofacies*—The sequence contains organic matter suite dominated essentially by sapropelic matter, though humic matter is also recorded in appreciable amount and forms dominant component at certain intervals in B, C and G areas (Table 1; Text-fig. 2).

*Thermal maturation*—The TAI values range from 1.75 to 2.75$^{+}$. Based on TAI data, the youngest levels of mature facies are delineated in A, B, C, D, E and F areas during Late Palaeocene-Middle Eocene time (Text-figs 3, 4).

*Source potential*—Based on palynofacies and maturation data, a good source rock development is postulated up to Middle Eocene in C and D locations

(Text-fig. 3) and up to Late Palaeocene in A, B, F and E areas. A general enrichment of sapropelized organic matter in A, C, D, E, F areas would indicate a better source potential for both liquid and gaseous hydrocarbons, as compared to B and G areas where sapropelization is not so prominent.

## LATE CRETACEOUS

*Palynofacies*—Late Cretaceous organic matter recorded in A, B, C, D and F areas is classified as sapropelic-humic. Sapropelic type constitutes the major part of the organic matter, although humic elements are also common and form a sizable percentage in A area.

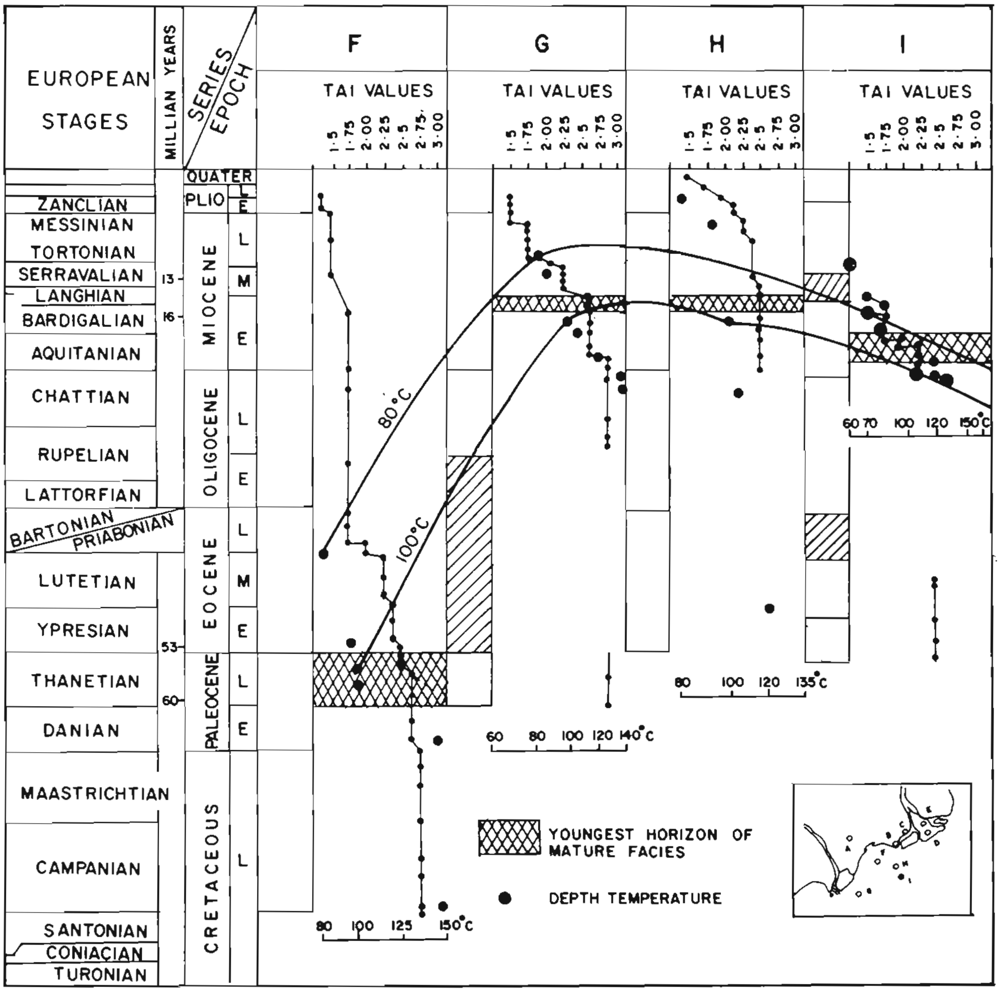
*Thermal maturation*—The TAI values range from 2.5 to 3.0 showing adequate maturity.

*Source potential*—The general enrichment of sapropelized matter and adequate thermal maturity would indicate ideal source rock potential for hydrocarbons.

## REMARKS AND CONCLUSION

*Organic matter*—The vegetal dispersed organic matter is considered mostly land-derived. However, occurrence of associated structured marine remains would indicate that a sizable fraction of amorphous matter belongs to marine source. The composition of organic matter is dominantly of mixed type and varies from sapropelic dominant to humic dominant. At times, both humic and sapropelic facies are observed to be nearly in equal proportions.

A comparatively thicker Miocene-Pliocene sedimentary sequence in locations, viz., G, H, and I beyond the Miocene shelf edge, shows dominance of humic organic matter, in contrast to sapropelized type commonly occurring in the areas, such as, B, C, D, E in East Godavari Basin and F situated above the Miocene shelf edge in Masulipatnam Bay. Apparently, the rapid burial of sediments in the areas beyond the Miocene shelf edge has slowed degradation of organic matter reaching the sea



**Text-figure 4**—Maturation profile in the offshore locations of Krishna-Godavari Basin.

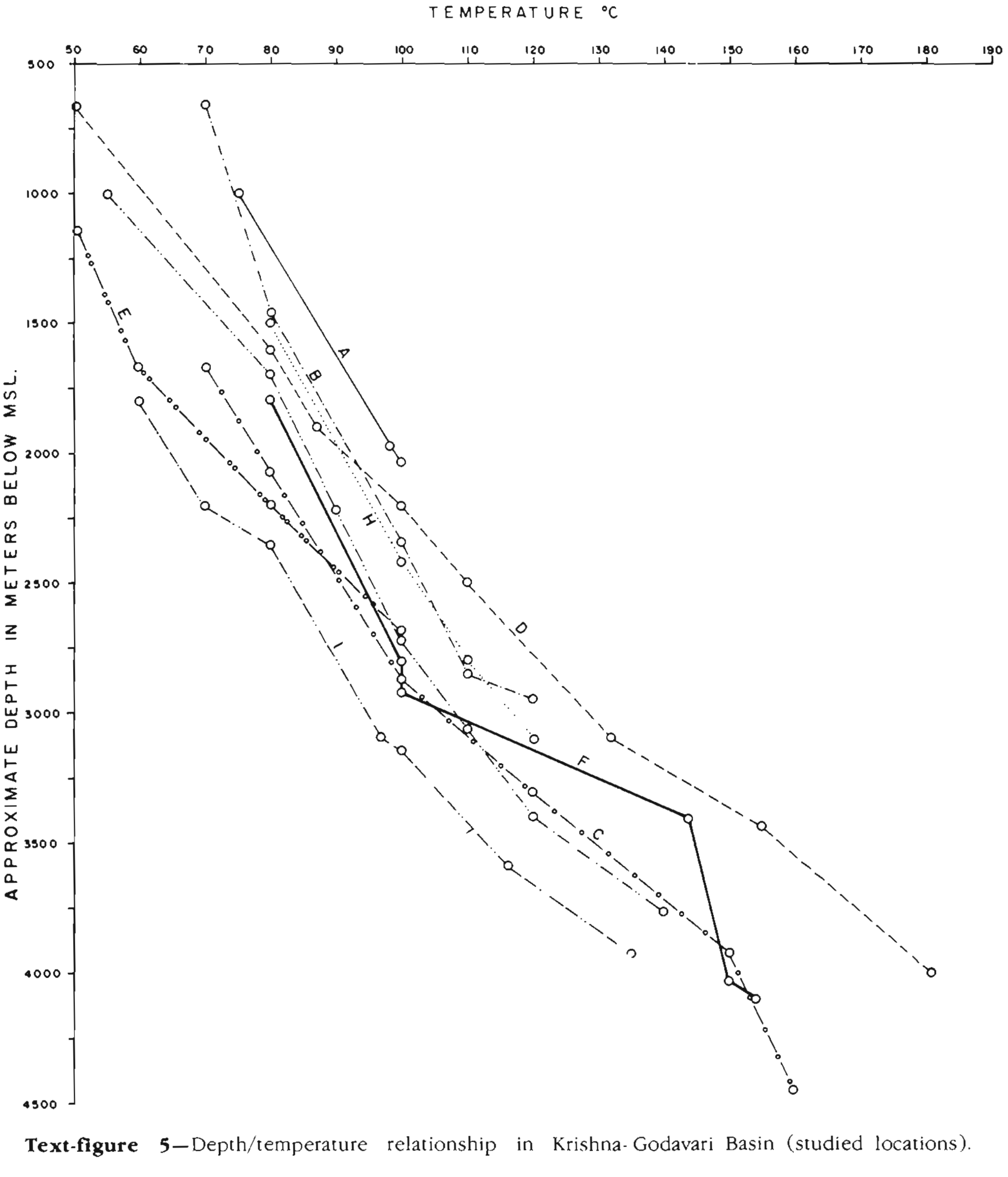
bottom. On the similar line, one may explain a higher degree of sapropelization in the Cretaceous-Palaeogene sequence where sedimentation rate is usually slow.

*Maturation*—The organic maturation as suggested by Thermal Alteration Index (TAI) values (Text-figs 3, 4) of the organic matter studied in the nine locations indicate the youngest level of mature facies (oil window) at various burial depths in A, B, C, D, E, F, G, H and I locations and has three distinct horizons, restricting the maturation (Text-figs 3, 4).

In certain areas, like A, B, F, E, which are apparently west of Eocene shelf edge, the maturation has reached up to Late Palaeocene (observed intervals: 53-60 Ma). In two of the locations, i.e., C, D, which are below the Eocene shelf edge and above the Miocene shelf edge, the youngest horizon of maturation falls in the Middle Eocene (Interval: 43-49 Ma) (Text-fig. 3).

In the third set of locations, i.e., G, H and I, the youngest level of mature facies reached in the Early Miocene between 13-16 Ma (Text-fig. 4).

The above observations show a quantum jump in time in response to the studied locations *vis-a-vis* the shelf edge. The latter is a plane of active tectonic leverage. It is presumed that the tectonic setting of the locations in their respective positions has affected the maturation history. It is for this reason that the locations beyond the Miocene shelf edge having a chance of continuous sedimentation and



**Text-figure 5**—Depth/temperature relationship in Krishna-Godavari Basin (studied locations).

continuous heat flow from the basement, mature up to Early Miocene. In the locations between Eocene shelf edge and Miocene shelf edge, the maturation reaching up to Middle Eocene suggests partial loss of heat at some unconformity levels. Further to the west, in the locations above the Eocene shelf edge, the heat loss at the unconformity gaps (hiatuses) resulted into a further lowering of the maturation level in the geochronologic scale.

Another factor associated with the leverage on account of shelf edge is the rapid subsidence and accumulation of sediments in deeper area of the basin. This has resulted into rapid burial of the deeper basin sediments and accentuated the maturation process in the deeper part. The geothermal gradient of this basin (Text-figs 3-5) is more or less consistent as a whole, however, there are local variations, e.g., in H and I (Text-fig. 5) which have gone to affect the maturation within the reasonable limits of time.

A regular feature of maturation, temperature and TAI relationships is the occurrence of youngest horizon of mature facies in the studied locations, which lies almost between 80°-100°C. It would appear that this temperature range is the effective cooking temperature for the kerogen in the basin.

*Source potential*—The palynofacies development of Krishna-Godavari Basin is largely sapropelic in the Late Cretaceous-Palaeogene and humic in Neogene. The maturation analysis, as discussed above, in the studied locations indicates that maturation level of 'oil window' reached in Late Palaeocene in A, B, F and E, Middle Eocene in C and D and Early Miocene in G, H and I areas. Viewed in terms of organic matter types and maturation, the sediments within the mature zone in the studied area are considered to possess good source potential to generate mixed type of hydrocarbons.

## ACKNOWLEDGEMENTS

The authors are indebted to Shri S. C. Roychoudhury, Regional Director, KDMIPE, Oil & Natural Gas Commission, for according permission to present this paper in the Symposium 'Vistas in Indian Palaeobotany', at the Birbal Sahni Institute of Palaeobotany, Lucknow. They are thankful to Shri A. Ranga Rao, Dy General Manager (Geology) and Shri Y. K. Mathur, Superintending Palynologist, KDMIPE for encouragements received during the course of this study. The authors would also like to acknowledge the help made available to them by the unpublished ONGC reports of Dr D. S. N. Raju and Chidambaram, C. M. Berry *et al.*, K. D. Sharma and C. M. Berry and Rawat *et al.* The views expressed in this paper are those of the authors and not necessarily of ONGC.

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# Spectrofluorimetric study of some resinites from Indian coals and lignites

B. K. Misra, Rakesh Saxena & Anand-Prakash

Misra, B. K., Saxena, Rakesh & Anand-Prakash 1990. Spectrofluorimetric study of some resinites from Indian coals and lignites. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 188-195.

Spectral fluorescence measurements were carried out on three common resinite types—with greenish-yellow, yellow, and orange fluorescence colours, from the Tertiary (Eocene) lignites of Matanomadh and Panandhro Lignite fields of Kutch, and Permian (Lower Gondwana) coals from Raniganj Coalfield. The analysis revealed a distinct shift in their maximum fluorescence intensity (λ max.) towards higher wavelength and increase in red/green (650/500 nm) quotient (Q) corresponding with increase in the age of the deposit. The resinite types from Tertiary lignites show λ max. at 500-510 nm for type-1, 520-530 nm for type-2 and 540 nm for type-3 with corresponding Q values of 0.17-0.29, 0.38-0.49 and 0.69, respectively. Whereas, the Permian coals have λ max. at 580, 600 and 610 nm and Q values of 0.59, 1.47 and 1.9, respectively for greenish-yellow, yellow, and orange fluorescing resinite types.

**Key-words**—Spectrofluorimetry, Resinites, Lignites, Permian, Eocene (India).

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## साराँश

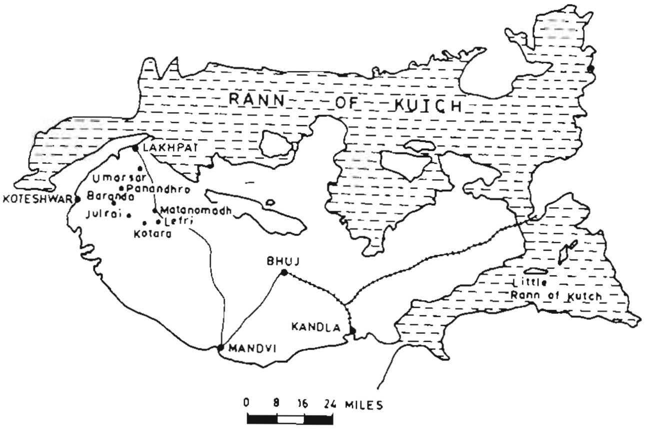
### भारतीय कोयलों एवं लगुडांगारों से प्राप्त कुछ रेज़िनाइटों का वर्णप्रतिदीप्ति अध्ययन

बसन्त कुमार मिश्रा, राकेश सक्सेना एवं आनन्द प्रकाश

कच्छ के मातानोमढ़ एवं पनान्धो लगुडांगार क्षेत्रों के तृतीयक युगीन (आदिनूतन) लगुडांगारों तथा रानीगंज कोयला-क्षेत्र से परमी (अधरि गोंडवाना) युगीन कोयले के तीन सामान्य रेज़िनों का वर्णप्रतिदीप्ति अध्ययन किया गया। उक्त विश्लेषण से उच्चतर तरंगदैर्ध्य की ओर अधिकतम प्रतिदीप्ति तथा निक्षेपों की आयु बढ़ने के साथ लाल/हरे (650/500 एँन-एँम०) विभाग में भी वृद्धि व्यक्त होती है। तृतीयक लगुडांगारों के रेज़िनाइटों की अपेक्षाकृत परमी युगीन कोयलों में लेमडा अधिकतम का मान तथा विभाग का मान दोनों ही अधिक प्रेक्षित किये गये हैं।

FLUORESCENCE microscopy, a relatively recent innovation for organic petrography, employed in the study of peat, lignite, bituminous coal, oil shale and dispersed organic matter, has been found quite successful and acceptable, particularly in identification, characterization and quantification of liptinite macerals. It is better suited for rank or maturity assessment than reflectivity measurements in cases where huminite/vitrinite maceral is not present in sufficient quantity or it is unsuited for reflectivity measurements, e.g., sapropelic coals, oil shales and dispersed organic matter.

Quantitative monochromatic fluorescence measurement on coal macerals was carried out by Jacob (1964, 1974). Polychromatic UV fluorescence spectral measurement was initiated by van Gijzel (1967, 1967a, 1975) and Ottenjann *et al.* (1975). The technique was later refined and perfected by Ottenjann (1980, 1982). Fluorescence characteristics, being an overall reflection of chemical composition of an organic matter, are related with its rank (maturity) and age (Teichmüller, 1982; Ottenjann, 1982; Teichmüller & Durand, 1983). Macerals, sporinite, alginite, cutinite and suberinite have been studied most, whereas, resinite has not been studied in detail to that extent because of their varying fluorescence properties in a single coal or lignite sample. Characterization and classification of resinites maceral have been carried out by Crelling *et al.* (1982), Crelling and Bensley (1983), Dobell *et al.* (1984) and Teerman *et al.* (1987). Mukhopadhyay and Gormly (1984) found



**Text-figure 1**—Location map of Matanomadh and Panandhro Lignite field, Kutch, Gujarat.

variation in hydrogen content of resinites with variation in fluorescence colour and property. Recently, Misra (1989, in press) categorized resinites of Panandhro lignite into five types based on their fluorescence spectral characteristics. Therefore, we purposefully selected the resinite maceral from resinite-rich Tertiary (Eocene) lignite and Lower Gondwana (Permian) coal to ascertain possible relationship between the resinite types and their fluorescence properties and age.

## LIGNITE-BEARING AREA : KUTCH BASIN

The lignite deposit in Kutch Basin of Gujarat State occurs at several places, viz., Umarsar, Panandhro, Akri-Mota, Matanomadh, Lefri, etc. associated with Palaeocene-Eocene sedimentary sequence lying over the basement of Deccan basalt of Late Cretaceous-Palaeocene (Text-fig. 1). The sequence containing lignite is represented by the sediments of Matanomadh (Palaeocene) and Naredi (Eocene) formations. The Matanomadh Formation is characterized dominantly by gritty, coarse-grained sandstones and shales with occasional, uneconomic, impure lignite occurring as thin streaky or lensoid bands. Whereas the Naredi Formation overlying the Matanomadh Formation comprises shales, carbonaceous shales, sandstones and lignite. The formation houses most of the commercially exploitable lignite present in Kutch Basin, particularly the deposit of the Panandhro Lignite field. The lignite of the Matanomadh area is distributed in eight to nine impersistent to persistent seams, varying in thickness from 0.15 to 4.00 m. In the area of Panandhro Lignite field, the lignite deposit is the largest in the basin. It is represented by three to five persistent seams varying in thickness between 0.10 to 10.51 m being associated with shale, carbonaceous shale and clay beds. The seams show splitting and merging tendency and become contaminated with other sediments towards south-west (for detailed geology and lithostratigraphy please refer to Biswas & Raju, 1973).

The lignite samples collected from both Matanomadh and Panandhro are from the Naredi sediments. However, the local names have been used in the text mainly because of their occurrence close to the famous Matanomadh temple and the Panandhro Village of the area, respectively.

## COAL-BEARING AREA : RANIGANJ COALFIELD, DAMODAR GRABEN

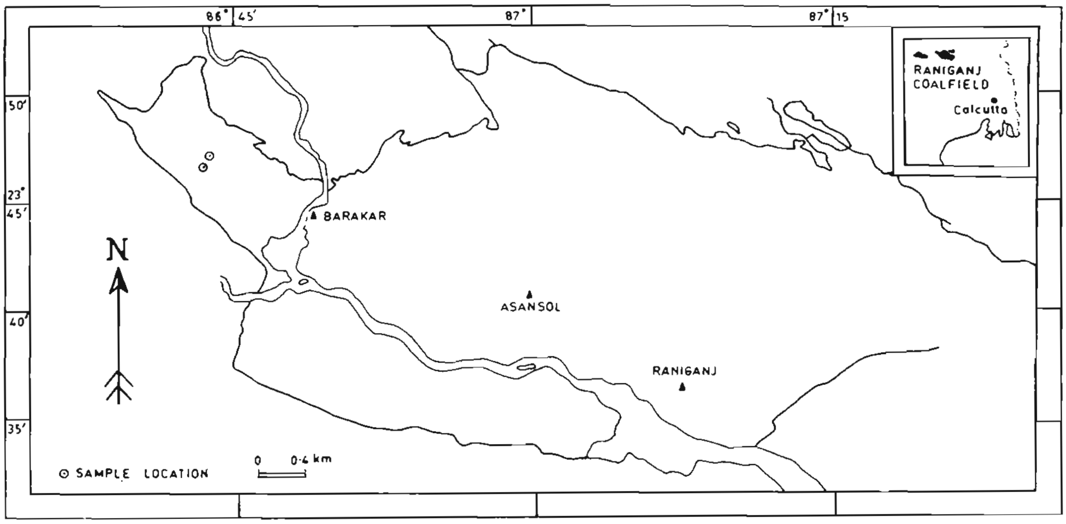
The Lower Gondwana (Permian) sediments of Barakar and Raniganj formations from Raniganj Coalfield of Damodar Graben belong to Damuda Group (Text-fig. 2). The sediments of both the formations are very well developed in this coalfield which represent their type area. The Barakar Formation essentially comprises medium-grained whitish-grey sandstones, shales, carbonaceous shales and low rank non-coking coals, whereas, the overlying Raniganj Formation is characterized by fine-grained sandstones, shales, carbonaceous shales and low to medium rank coking coals. The Raniganj sediments are relatively more argillaceous in nature than that of the Barakar Formation. The coal seams in both the formations generally vary in thickness between 1.50 to 6.00 metres.

For the present study the Barakar coal from Gopinathpur, Chanch-Begunia and Brindabanpur seams and Raniganj coal from Koithi and Handal seams have been selected as they contain fair amount of resinite maceral for spectral fluorescence measurement.

## MATERIAL AND METHOD

Eighteen representative channel samples from Matanomadh (3 samples) and Panandhro (10 samples) lignite and Barakar (3 samples) and Raniganj (2 samples) coals have been used for the present investigation. Particulate pellets from crushed and sieved (± 18 mesh, 1.00-2.00 mm grain size) lignite and coal samples were prepared by cold embedding in Epoxy resin. The particulate pellets were ground and polished following international standard methods. The descriptive terminology and quantitative assessment of coal and lignite macerals (microconstituents) are according to I.C.C.P. recommendations (I.C.C.P., 1971, 1975).

Spectral fluorescence measurements on resinite



**Text-figure 2**—Location map of Raniganj Coalfield, West Bengal.

were carried out between 400 to 750 nm, with 10 nm interval using 150 watt xenon lamp as the illumination source on Leitz MPV-3 unit. NPL Fluotar oil objective of 25 magnification (0.75 numerical aperture) was used with fluorescence-free immersion oil. A Littrow type grating monochromator (12001/mm) on emission side (λ 2), central control panel and a bench-top Hewlett-Packard 85B computer was attached to the MPV-3 unit. Monochromator drive, shutters and measurements were controlled by central control panel or the computer (one at a time). Scanning of samples was done in blue light (420-490 nm, violet blue excitation), whereas UV excitation filter was used (340-380 nm) for quantitative spectral measurement. Correction factor from calibration spectrum was obtained using Planck's colour temperature distribution (at 3000° K) of stabilized 12 volt 100 watts tungsten halogen lamp in transmitted mode (Reuter *et al.*, 1976; Ottenjann, 1980). All measurements (background & calibration of sample spectra) and calculations (background substraction, correction factor, spectral corrections, λ max, and red/green quotient) were performed with the help of the attached computer including print-out of the result and curve. For operating the MPV-3 and computer, operating manual and programmed cassette for spectral measurement were supplied by Leitz. All necessary precautions were taken during measurements, e.g., selection of site for background measurement and object for spectral measurement avoiding alteration and weathering effects. Erroneous results due to any possible source were rejected.

A minimum of ten measurements were carried out on each resinite type. Individual fluorescence spectral data were averaged and normalized to 100 per cent (λ max.) and average curve for resinite was drawn manually.

## MEGA- AND MICROSCOPIC CHARACTERS OF LIGNITES AND COALS

*Lignite*—The lignite from both the Matanomadh and Panandhro areas of Kutch are dark-brown in colour, sparingly banded in nature and amorphous in texture. However, Matanomadh lignite is much inferior in quality as compared to the Panandhro lignite. They contain frequent globular or lensoid bodies and bands of yellow and red-coloured resins,

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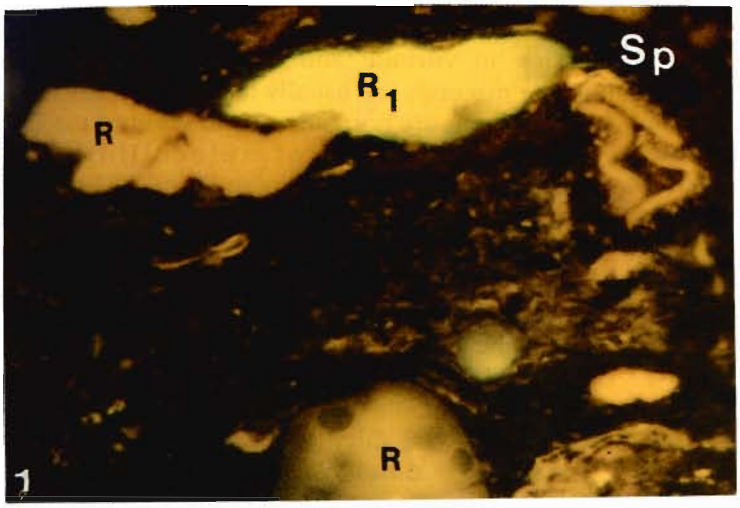
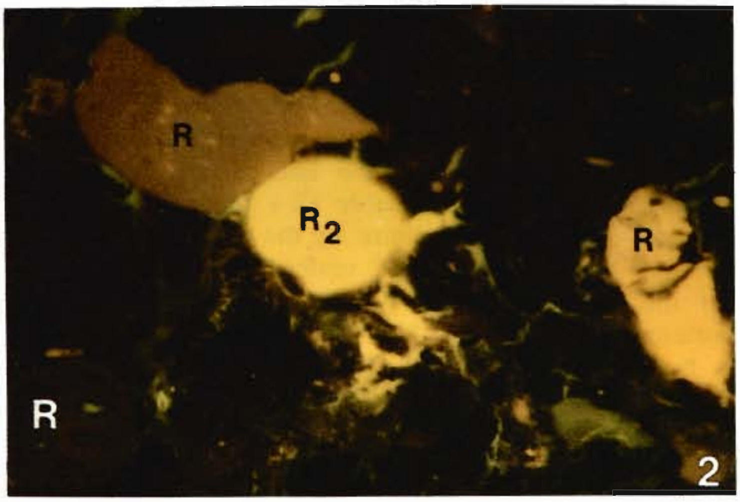
## PLATE 1

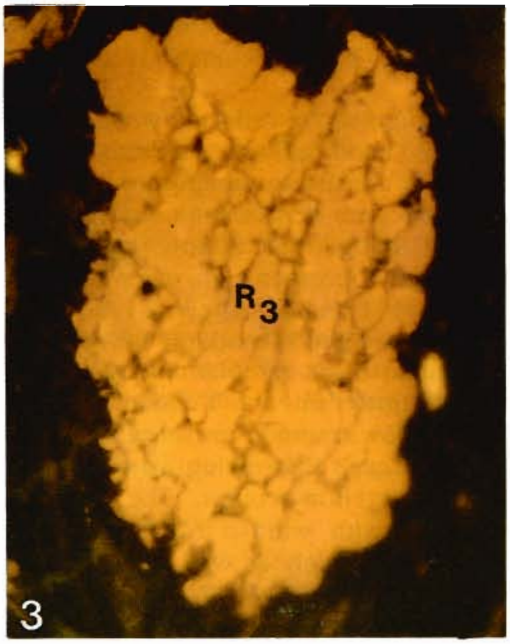
→

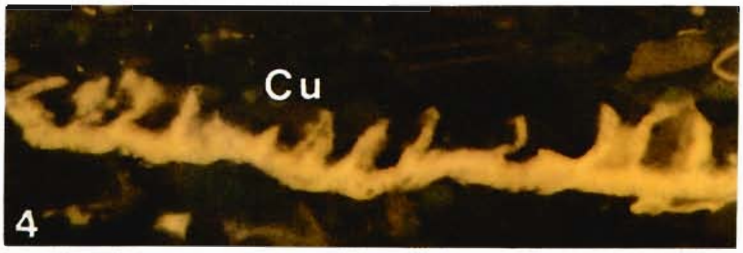
(All photomicrographs are under blue light excitation)

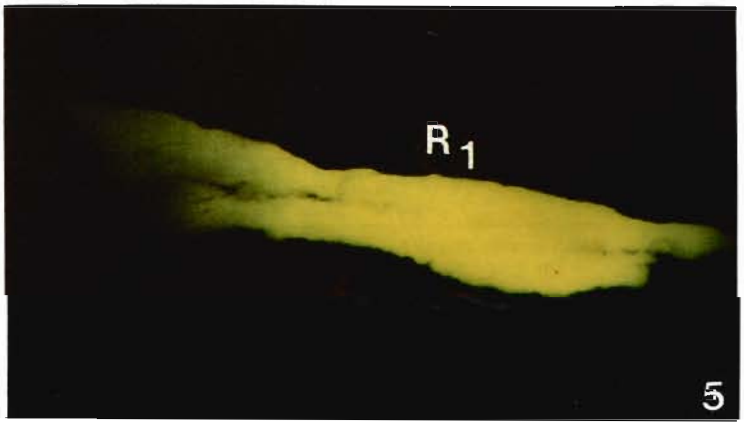
1. Resinite type-1 (greenish-yellow) in Panandhro lignite (R—other resinite types, Sp.—pollen grain), × 672.
2. Resinite type-2 (bright yellow) in Matanomadh lignite (R—other resinite types), × 672.
3. Resinite type-3 (orange) in Panandhro lignite, × 576.
4. Cutinite with yellowish-orange fluorescence colour in Panandhro lignite, × 672.
5. Resinite type-1 (greenish yellow) in Permian coals, × 576.
6. Resinite type-2 (bright yellow) in Permian coals (Sp.—Sporinite), × 416.
7. Bright yellow fluorescing sporinite (Sp.) in Permian coals, × 672.

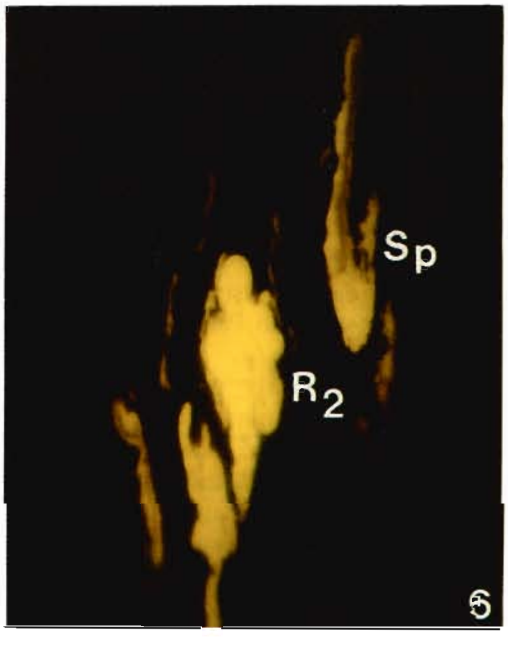












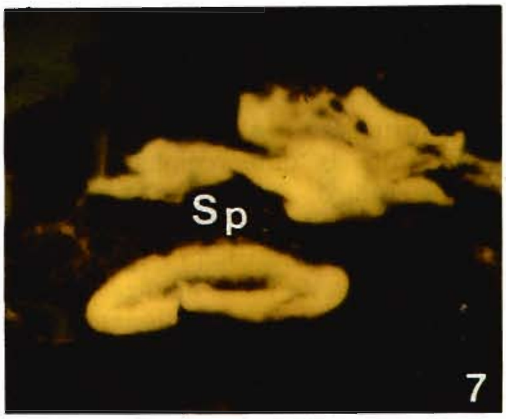


**PLATE 1**

dispersed throughout the seams. Biogenic (framboidal) pyrite is commonly associated with the lignite.

The lignites, in reflected white light, are rich in huminite and liptinite macerals. The inertinite macerals, consisting chiefly of semifusinite and sclerotinite, are less in amount. The mineral matter content is generally low to moderate, but occasionally becomes high, when lignite turns shaly in nature. Framboidal pyrite and calcite (both concretionary and secondary) are common, whereas argillaceous black granular mineral matter is usually in subordinate amount. Under blue light both the lignites show common presence of maceral alginite (*Botryococcus*) fluorescing with bright, greenish-yellow to yellow colour. The sporinite maceral fluoresces with whitish to yellow colour and is distributed sparsely as well as in occasional dense patches (Pl. 1, figs 1, 6, 7). Cutinite is common to quite common and fluoresces with orangish-brown, orange, yellowish-brown, or brown colour (Pl. 1, fig. 4). Suberinite maceral is sporadic to common fluorescing with weak yellowish or orangish-brown to brown colour. The macerals fluorinite and exudatinite are only sporadic. The maceral liptodetrinite is quite common in most of the samples studied. Among the macerals of liptinite group, resinite is the abundant maceral in both Matanomadh and Panandhro lignites.

The resinite in these lignites, occurs as primary globular, oval or elliptical discrete bodies, primary cell filling and as remobilized lumpy or irregular elongated bodies. It shows brown, shades of grey and dark reddish-brown colour under normal reflected light. Under blue light excitation some of the resinites display droplet or vesicle structures and cracks. The resinites show yellowish-green, greenish-yellow, orangish-yellow, yellowish-orange, orange, brownish-orange, orangish brown, yellowish-brown to brown fluorescence colours. However, for the pesent study only yellowish-green to greenish-yellow (resinite type-1), yellow (resinite type-2) and yellowish-orange to orange (resinite type-3) fluorescing resinites as classified by Misra (1989, in press) from Panandhro lignites have been selected.

*Coal*—The coals of Barakar and Raniganj formations from Raniganj Coalfield are banded in nature. The Barakar coals have frequent and prominent dull bands alternating with impersistent semi-bright and bright bands. The Raniganj coals, on the contrary, have persistent bright and semi-bright bands with thin, dull bands. Both the coals are hard and compact in nature and break with uneven fracture

Under reflected white light, the Barakar coals are rich in vitrinite and inertinite macerals. The liptinite macerals are usually less in proportion. The Raniganj coals are normally rich in vitrinite macerals, chiefly consisting of telocollinite and desmocollinite. The liptinite macerals, particularly resinites, are more common than the Barakar coals. The inertinite macerals mainly comprising semifusinite, fusinite and inertodetrinite are seldom represented by more than 25.00 per cent by volume. In both the Barakar and Raniganj coals, cell lumens of semifusinite and fusinite are often filled with argillaceous or calcareous minerals. In general, these coals have high amount of mineral matter consisting mainly of black granular matter (argillaceous mineral matter). Calcite and siderite minerals are common and may become occasionally high. The Raniganj coals, in this area, are characterized by finely disseminated and crack-filling pyrite occurrences.

Under blue light excitation, the liptinitic contents in both the Barakar and Raniganj coals increase considerably (2-4 times). The sporinite, resinite and cutinite are the most common liptinite macerals observed under fluorescence light. The exsudatinite is common and suberinite is usually sporadic in Barakar coals. However, the coals from Raniganj Coalfield are characterized by the presence of liptodetrinite and relatively high proportion of resinite macerals. The sporinite and cutinite show yellowish-orange and orange fluorescence colours. The resinite fluorescing with green, greenish-yellow, bright yellow, yellowish-orange, orange, orangish-brown and brown colours occur as primary globular, oval or elliptical discrete bodies as well as remobilized crack and fissure fillings.

## RESULTS

The averge spectral parameters of resinite type-1 (yellowish-green to greenish-yellow), type-2 (yellow) and type 3 (yellowish-orange to orange) recorded in Tertiary lignites and Permian coals are listed as follows (Text-figs 3-8):

| Samples | λ Max. | Red/Green Quotient (Q) |
|---|---|---|
| Matanomadh resinite | | |
| MR-1 | 500 | 0.17 |
| MR-2 | 530 | 0.379 |
| Panandhro resinite | | |
| PR-1 | 510 | 0.29 |
| PR-2 | 520 | 0.49 |
| PR-3 | 540 | 0.69 |

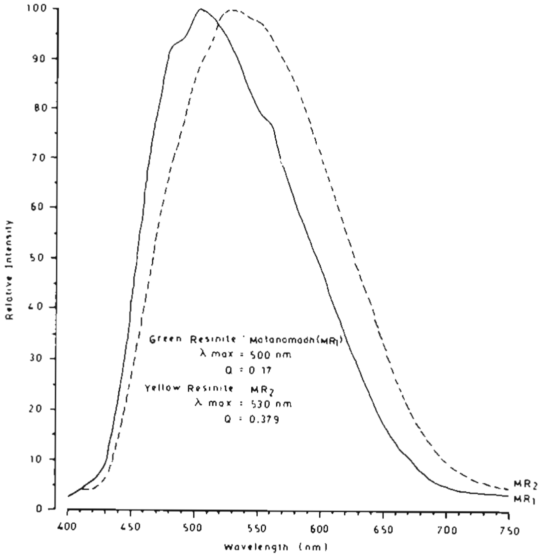
| | | |
|---|---|---|
| Permian resinite | | |
| LR-1 | 570 | 0.588 |
| LR-2 | 590 | 1.29 |
| LR-3 | 610 | 1.90 |

The description of qualitative and spectral fluorescence characteristics of resinite types is as follows:

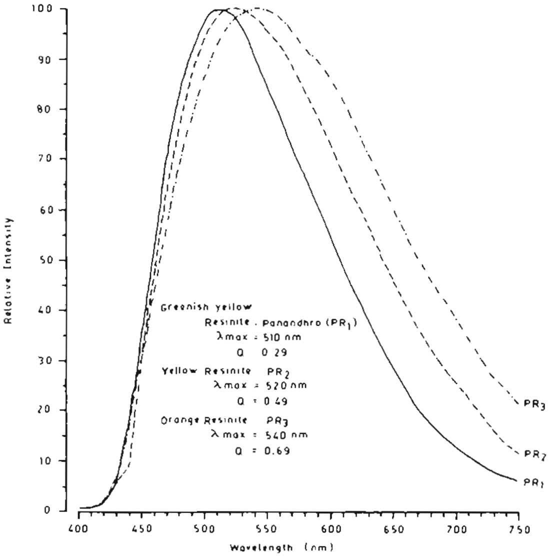
*Resinite Type-1* (Pl. 1, figs 1, 5)—The resinite type-1 (yellowish-green to greenish-yellow) occurs as oval, elliptical or globular discrete bodies distributed sparsely with other resinite types. This resinite is less common in Tertiary lignites and sporadic in Lower Gondwana coals. In lignites these resinites are translucent in appearance under blue light excitation. They do not show droplet or vesicled structures; however, occasionally they are cracked.

The average λ max. of resinite type-1 in lignites from Matanomadh and Panandhro has been recorded at 500 and 510 nm with Q values of 0.17 and 0.29, respectively. For Permian coals the λ max. has been found at 570 nm with red/green quotient (Q) of 0.558.

*Resinite Type-2* (Pl. 1, figs 2, 6)—The resinite type-2 (yellow) is common in Tertiary lignites and Permian coals. It commonly occurs as discrete bodies (like type-1) and also as infillings in cell lumens of humotelinite in lignites. In Lower Gondwana coals cell filling resinite type-2 has not



**Text-figure 3**



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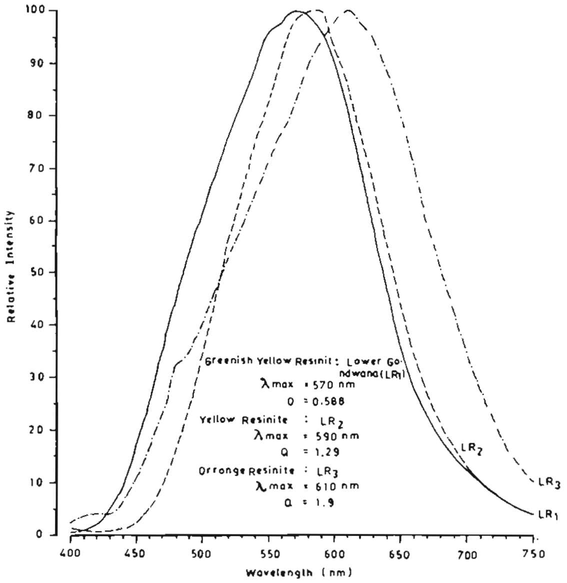
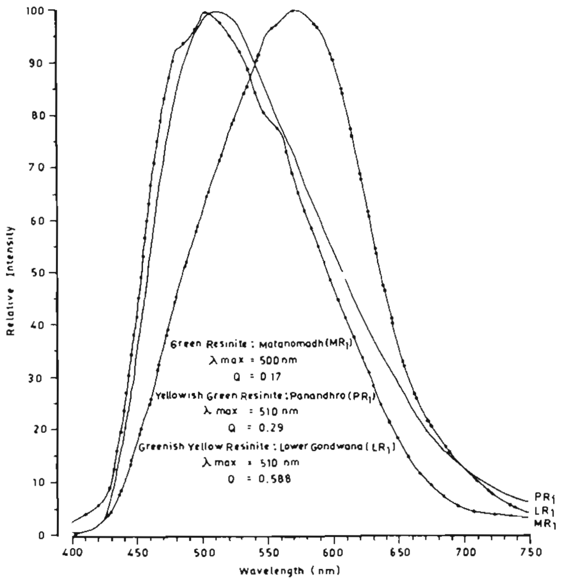
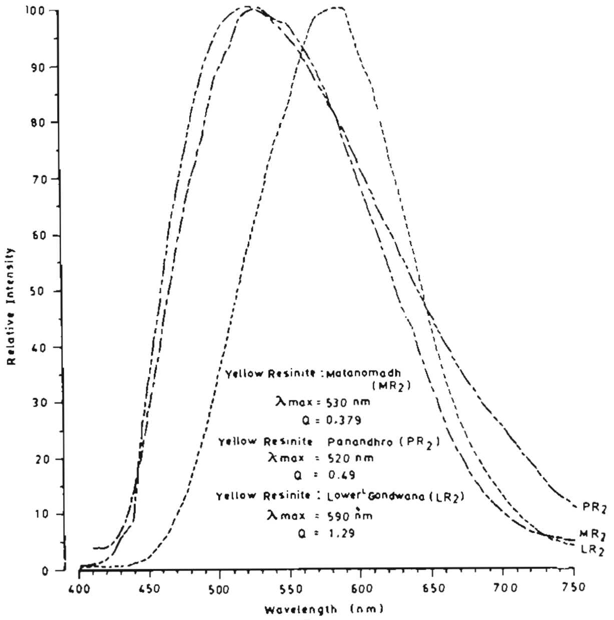


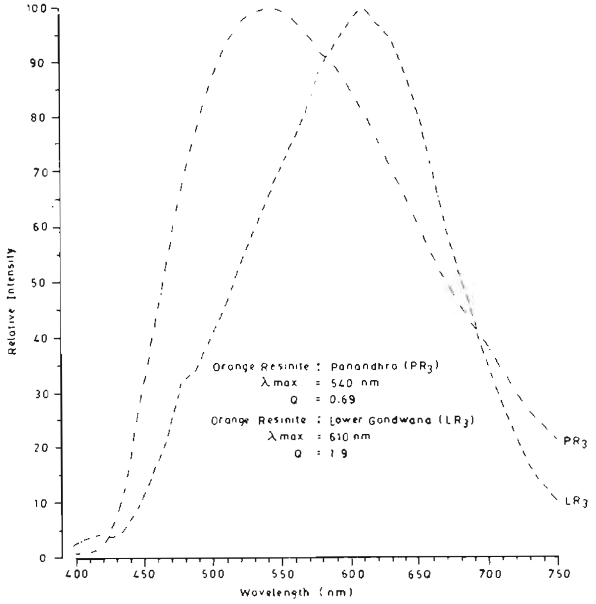
**Text-figure 5**



**Text-figure 6**



**Text-figure 7**



**Text-figure 8**

**Text-figures 3 to 8**—Spectral fluorescence pattern of: **3**, Green (MR$_1$) and yellow (MR$_2$) resinite types from Matanomadh Lignite, Kutch; **4**, Greenish yellow (PR$_1$), yellow (PR$_2$) and orange (PR$_3$) resinite types from Panandhro lignite, Kutch; **5**, Greenish yellow (LR$_1$), yellow (LR$_2$) and orange (LR$_3$) resinite types from Lower Gondwana coals, Raniganj Coalfield, West Bengal; **6**, Resinite type-1 from Matanomadh and Panandhro lignites and Permian coals; **7**, Resinite type-2 from Matanomadh and Panandhro lignites and Permian coals; **8**, Resinite type-3 from Panandhro lignite and Permian coals.

been recorded. In lignites, this resinite type appears translucent. In coals, its fluorescence intensity is weaker than those of the lignites. Cracks and droplet structures on these resinites are uncommon.

The average maximum intensity (λ max.) of the resinite type-2 occurs at 530 nm for Matanomadh, 520 nm for Panandhro and 590 nm for Lower Gondwana coals with red/green quotient of 0.379, 0.49 and 1.29, respectively.

*Resinite Type-3* (Pl. 1, fig. 3)—The resinite type-3 (yellowish-orange to orange) is common in Tertiary lignites and quite common in Permian coals. It occurs as discrete bodies, like type 1 and 2, and also as irregular lumps. In lignites it is rarely found as cell fillings. In lignites, this resinite type under blue light excitation commonly shows cracks and droplet structure. In Permian coals droplet structure on resinites has not been observed. These resinites are occasionally transluscent in lignites. The fluorescence intensity of these resinites is weaker than type 1 and 2.

The average maximum intensity (λ max.) of the resinite type-3 occurs at 540 nm in Panandhro lignite and at 610 nm in Permian coals. The corresponding red/green quotients are 0.69 and 1.90, respectively.

## DISCUSSION

The three resinite types in Tertiary lignites of Matanomadh and Panandhro, and Permian coals of Raniganj Coalfield, Damodar Graben are distinguishable using two spectral parameters—λ max. and red/green (650/500 nm) quotient (Table 1). The three resinite types (only two from Matanomadh lignite) of lignites and coals separately show only small differences in their spectral parameters (Text-figs 3-5). They may represent a continuous series as expressed by Teerman *et al.* (1987) and Misra (1989, in press).

Certain physical characters, viz., droplet (uncollapsed gas bubbles) or vesicle (collapsed bubbles) structures and transluscency in resinites, have not been observed in the Permian coals. Absence of these features in Permian coals and their presence in lignites is possibly related to the vegetal precursors which form lignite and coal. The resinites in Tertiary lignites originated chiefly from angiospermic vegetation and those in Permian coals were produced from gymnospermic plants (Stach *et al.*, 1982). The absence of transluscency in resinites of Permian coals may also be related with their older age and higher rank.

Comparison of spectral curves of the individual resinite type with each other (Text-figs 6-8) distinctly shows a shift in maximum fluorescence intensity (λ max) towards higher wavelength with corresponding increase in red/green quotients. The resinite types from lignites, being of identical age (Eocene), appear to be closely related with each other (Text-figs 6-8) by virtue of similarities in their spectral pattern, λ max. and red/green quotients. However, certain minor differences in their spectral characteristics may have been caused by the differences in rank, conditions of coalification and tectonic history of the two lignite deposits. Thus, the evident shift of λ max. towards higher wavelength along with increase in red/green quotient in each of the resinite types from Tertiary to Permian times corresponds fairly well with age of the lignite and coal deposits.

## CONCLUSIONS

The spectral fluorescence characteristics of the three resinite types, type-1 (yellowish-green to greenish-yellow), type-2 (yellow), and type-3 (yellowish-orange to orange) recorded in Tertiary lignites from Matanomadh and Panandhro areas of Kutch and Lower Gondwana (Permian) coals from Raniganj Coalfield of Damodar Graben suggest that:

(i) the three resinite types from different areas show gradational spectral characteristics among themselves and may represent a continuous series;

(ii) the Palaeocene-Eocene resinite types in Matanomadh and Panandhro lignites being identical in age are also closely related on the basis of their spectral pattern and other parameters;

(iii) the three resinite types from Tertiary lignites and Permian coals show a distinct shift in their maximum fluorescence intensity (λ max.) towards higher wavelength and corresponding increase in red/green quotients. The distinctly higher λ max. and higher red/green quotients of the three resinite types of Permian coals vis-a-vis those of the resinite types of Tertiary lignites appear to be related with the age of the deposits.

## ACKNOWLEDGEMENTS

The authors wish to thank Mr V. P. Singh for preparing the illustrations.

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# A new *Crinum*-like pseudostem from Deccan Intertrappean beds of Mohgaonkalan, India

G. V. Patil & E. V. Upadhye

Patil, G. V & Upadhye, E. V 1990. A new *Crinum*-like pseudostem from Deccan Intertrappean beds of Mohgaonkalan, India. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany' Palaeobotanist* **38** : 209-211

A new petrified *Crenum*-like pseudostem, *Crinum eocenum* sp. nov., comparable to modern *Crinum asiaticum* L. of Amaryllidaceae has been described from the Intertrappean beds of Mohgaonkalan, Madhya Pradesh.

**Key-words**—Petrified pseudostem, Deccan Intertrappean beds (India).

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## सारांश

### भारत में मोहगाँवकलाँ की दक्खिन अन्तर्ट्रैपी संस्तरों से एक नया क्रिनम-सदृश आभासी तना

जी० वी० पाटिल एवं ई० वी० उपाध्ये

मध्य प्रदेश में मोहगाँवकलाँ की दक्खिन अन्तर्ट्रैपी संस्तरों से अमेरिल्लीडेसी कुल के वर्तमान **क्रिनम् एशियाटिकम** एल० से तुलनीय एक नया अश्मीभूत **क्रिनम-**सदृश आभासी तना वर्णित किया गया है। इस तने को **क्रिनम् ईओसेनिकम्** नव जाति से नामांकित किया गया है।

THE specimen under investigation, a broken piece of chert, was recovered from the Deccan Intertrappean beds of Mohgaonkalan, Madhya Pradesh. The anatomical study has been made through serial peel sections taken along transverse and longitudinal planes.

The pseudostem and leaf sheaths belonging to Musaceae (Rao & Menon, 1963; Jain, 1964; Trivedi & Verma, 1972); Cannaceae (Trivedi & Verma, 1971) and Gramineae (Paradkar, 1975; Patil & Singh, 1984) are well known from the Deccan Intertrappean beds exposed around Mohgaonkalan, Madhya Pradesh.

### Genus—*Crinum* L.

### *Crinum eocenum* sp. nov.

*Diagnosis*—Axis small with four concentric leaf-sheaths; vascular bundles 4-5, collateral and closed, scattered in parenchymatous ground tissue, broad at one end and narrow at the other end; leaf-sheaths four, broad in centre and gradually become narrower towards margins; and lower epidermis distinct, cells compactly placed with stomata; vascular bundles in a row, collateral and closed; xylem elements 4-5 with protoxylem and metaxylem, having spiral thickening.

*Holotype*—Pl. 1, figs 1-7; Specimen no. MOH/GVP-EVU/14, Department of Botany, Institute of Science, Nagpur.

*Type locality*—Deccan Intertrappean beds, Mohgaonkalan, Madhya Pradesh, India.

*Age*—Eocene.

*Description*—Specimen 1.5 cm in length and 3.2-4.6 mm in diameter; central axis broader at one end and tapers at the other end (Pl. 1, figs 1, 6), measuring 120-610 μm in diameter; encircled by four leaf-sheaths arranged concentrically (Pl. 1, fig. 1), first leaf-sheath varies from 175-235 μm and second from 140-290 μm in thickness, both sheaths broader in the middle region, gradually thin out towards margins, third leaf-sheath 200-350 μm and fourth 165-360 μm in thickness; central axis epidermis single layered with compactly arranged

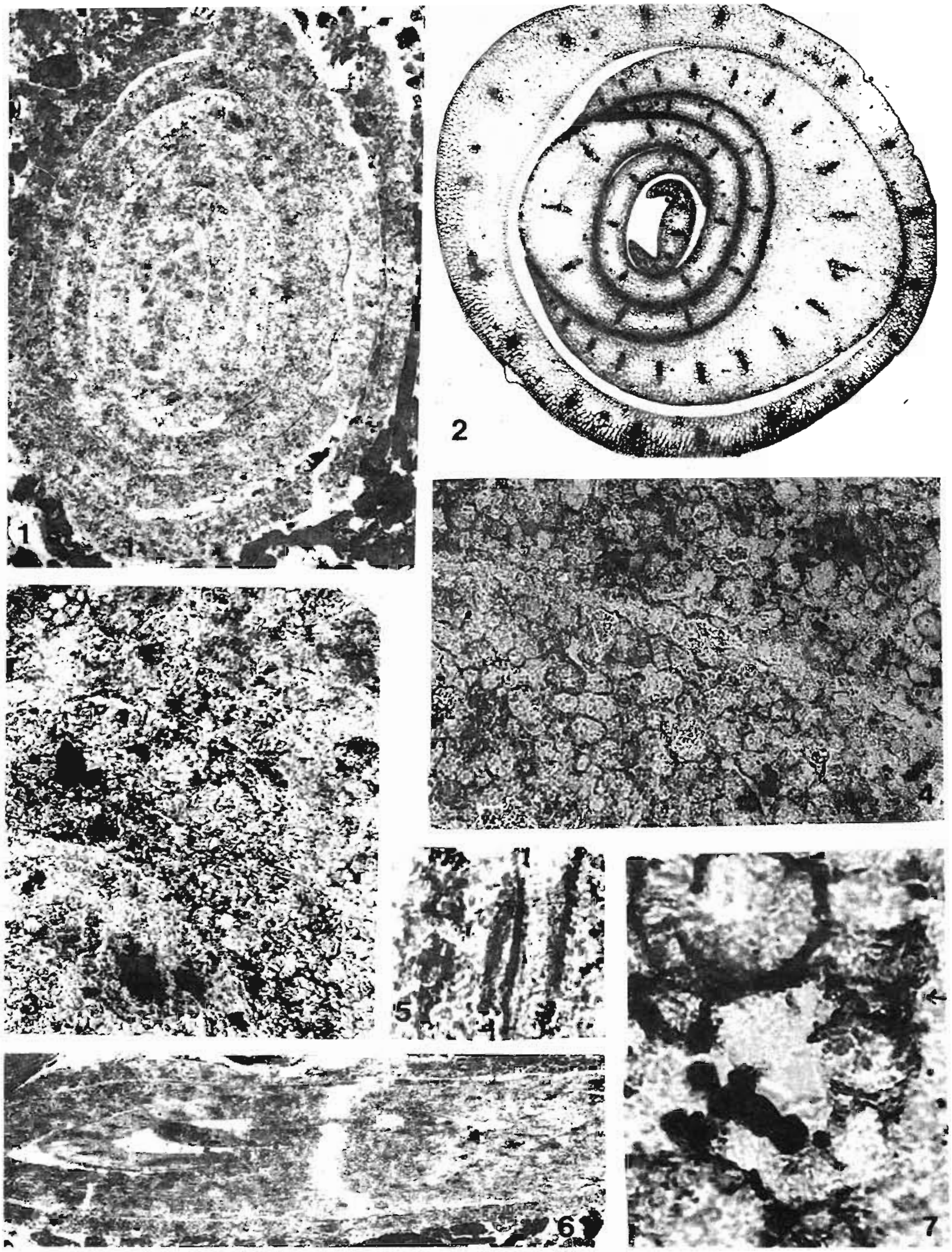

**PLATE 1**

1. Fossil pseudostem in transverse section showing four leaf-sheaths and axis, × 18
2. Transverse section of pseudostem of *Crinum asiaticum* showing four leaf sheaths, × 18.
3. Transverse section of fossil pseudostem showing three leaf-sheaths, × 90.
4. Mesophyll tissue of fossil leaf-sheaths showing loosely arranged parenchyma, × 150
5. Vessels in longitudinal section to show thickening in case of fossil, × 350
6. Longitudinal section of fossil pseudostem, × 9.
7. Epidermis with stoma and substomatal chamber, × 350.

cells; parenchymatous loosely arranged and without air chambers; vascular bundles 4-5 in number, embedded in irregular fashion in ground tissue, collateral and closed. Xylem vessels show spiral thickening (Pl. 1, fig. 5); due to bad preservation details of phloem could not be seen.

## DISCUSSION

The present fossil has been compared with pseudostem and leaf sheaths of living and fossil taxa of monocotyledons. Its structures have been compared with the pseudostems of *Crinum* species, *Pancratium maritinum, Amaryllis vittata* and *Zephyranthes tubispatha* of Amaryllidaceae. It closely resembles the pseudostem of *Crinum* L. The species of *Crinum*, viz., *C. giganteum, C. asiaticum* and *C. meldensia* of Amaryllidaceae were considered for comparison. A freshly cut section of pseudostem of *Crinum asiaticum* L. shows similar characters of the fossil, eg., four leaf-sheaths arranged concentrically (Pl. 1, fig. 2). They are 4.4-5.2 μm in diameter. First leaf-sheath is 175-350 μm thick, second 170-790 μm thick, third 280-1360 μm thick and fourth leaf-sheath is 640-980 μm thick. Outer leaf-sheaths are wider in middle and gradually become narrower towards margins. Mesophyll of leaf-sheath is parenchymatous without air chambers. Vascular bundles are collateral and closed. Xylem elements are 18-30 μm in diameter.

In view of the above, it is apparent that the present fossil closely resembles the pseudostem of *Crinum* L., particularly to *Crinum asiaticum* L. of Amaryllidaceae. But the size differences of various constituents of this pseudostem suggest its new specific status.

## ACKNOWLEDGEMENTS

The authors are thankful to the Director, Institute of Science, Nagpur, for laboratory facilities.

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# *Arecoidocarpon kulkarnii* gen. et sp. nov., an arecoid palm fruit from Mohgaon Kalan, Madhya Pradesh

S. D. Bonde

Bonde, S. D. 1990. *Arecoidocarpon kulkarnii* gen. et sp. nov., an arecoid palm fruit from Mohgaon Kalan, Madhya Pradesh. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist*, **38** : 212-216.

The paper describes a petrified palm fruit embedded in a chert from Mohgaonkalan, District Chhindwada, Madhya Pradesh. It is a single-seeded, ovoid drupe, whose wall is characterized by a thin epicarp, fibrous mesocarp and hard endocarp. Fibre-fibrovascular bundles and brachysclereides are restricted to the inner layers of the pericarp. Endosperm is homogeneous, covered with two-layered seed coat, the outer one with reduced vascular strands and inner with tanniniferous material. Embryo is apical and a shallow chalazal groove is protruding in the seed. Its affinity is suggested with non-ruminate arecoid palms.

**Key-words**—Megafossil, Palm fruit, Deccan Intertrappean beds (India).

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## साराँश

### मध्य प्रदेश में मोहगांवकलाँ से एक अरेकॉयडी ताड़ फल : अरेकॉयडीकार्पन कुलकर्णीई नव प्रजाति व जाति

ऍस० डी० बोंडे

मध्य प्रदेश में छिंदवाड़ा जनपद में मोहगांवकलाँ से एकत्र एक रामसैकाश्म से एक अश्मीभूत ताड़ फल का वर्णन किया गया है। यह एक बीज वाला अंडाकार बदरी फल है जिसकी भित्ति पतली बाह्यफलभित्ति, रेशेदार मध्यफलभित्ति तथा कठोर अन्त:फलभित्ति से अभिलक्षणित है। ये तन्तुवाही बंडल एवं ब्रेकिस्क्लेरीड फलभित्ति की अन्तस्थ तहों तक सीमित हैं। भ्रूणपोष समांगी तथा बीजचोल की दो तहों से ढका हुआ है। बाहरी तह में कम वाही बंडल हैं तथा अन्दर वाली तह टैनिनमय पदार्थ से युक्त है। भ्रूण अगस्थ है तथा बीज में एक हल्का सा खाँचा विद्यमान है। इस अश्मित फल की अरूमिनेट अँरेकॉयडी ताड़ों से सजातीयता प्रस्तावित की गई है।

PALM fruits from India have been described by Bande *et al.* (1982), Chitaley (1960, 1960a), Chitaley and Nambudiri (1969), Kaul (1951), Lakhanpal (1952), Mahabale (1950), Mehrotra (1987), Nambudiri (1966), Patil and Upadhye (1983), Prakash (1954, 1960), Rode (1933), Sahni (1937), Shete and Kulkarni (1985) and Trivedi and Chandra (1971). They have been assigned to *Cocos, Hyphaeneocarpon, Nypa* (*Nipa, Nipadites*) showing affinities with extant genera *Cocos, Hyphaene* and *Nypa*, respectively. However, a large number of fruit specimens, whose affinities are not clearly understood, are assigned to form genus *Palmocarpon* Miquel.

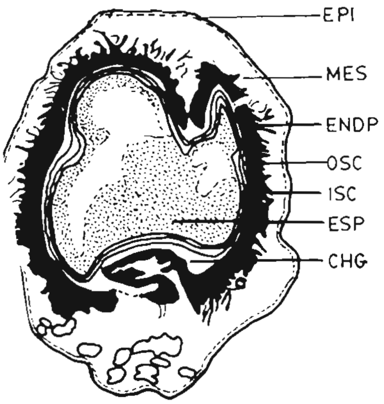
A single specimen found embedded in a reddish-brown chert in the Intertrappean Bed at Mohgaonkalan, district Chhindwara, Madhya Pradesh, has been studied. The specimen was examined by usual thin-ground method. The preservation was found to be excellent showing all the essential anatomical characters, enabling its identification.

## SYSTEMATIC DESCRIPTION

### Family—Palmae (Arecaceae)

### Genus—*Arecoidocarpon* gen. nov.

*Diagnosis*—Drupe unilocular, single seeded; pericarp thick, characterised by thin epicarp, fibrous mesocarp and hard endocarp; fibre-fibrovascular bundles and brachysclereides restricted to inner fruit wall layers; seed solitary, seed-coat two-zoned,



**Text-figure 1**—*Arecoidocarpon kulkarnii* gen. et sp. nov.—A longitudinal section of the fruit showing EPI-epicarp, MES-mesocarp, ENDP-endocarp, OSC-outer seed coat, ISC-inner seed coat, ESP-endosperm, and CHG-chalazal groove × 1.5.

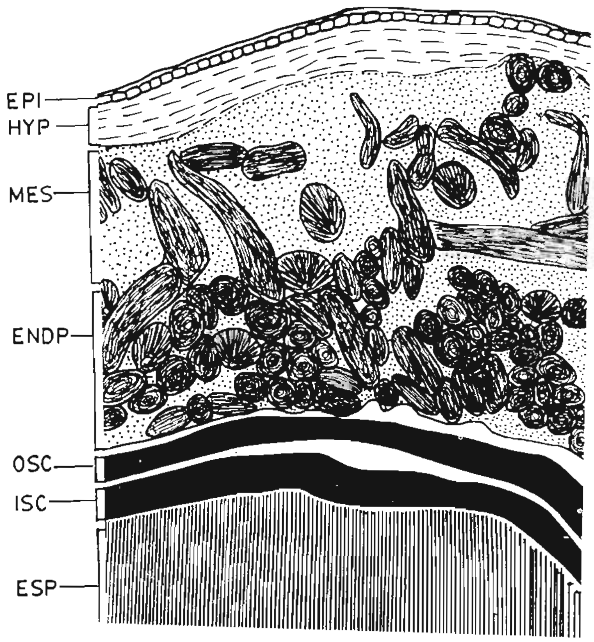
outer with reduced vascular strands, inner with tanniniferous material; endosperm homogeneous or ruminate; chalazal groove shallow, irregular.

Type species—*Arecoidocarpon kulkarnii* sp. nov.

*Arecoidocarpon kulkarnii* gen. et sp. nov.
Pl. 1, figs 1-4; Text-figs 1, 2

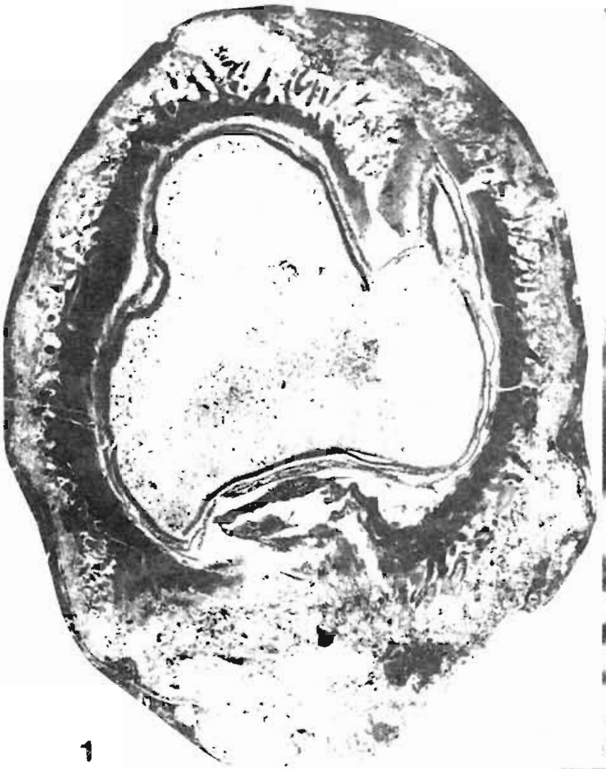
*Diagnosis*—A unilocular single-seeded, ovoid drupe; pericarp thick, divisible into epicarp, mesocarp and endocarp; epicarp 90-180 μm thick. Epidermis single-layered, made up of rectangular to cubical cells; hypodermis 4-6 layered with squarish to rectangular compact cells. Mesocarp thick, with fibre-fibrovascular bundles and brachysclereides. Ground tissue parenchymatous with rectangular cells. Endocarp hard, with 5-6 rows of compact arrangement of fibre-fibrovascular bundles and brachysclereides with intermittent islets of thick-walled parenchyma. Locular epidermis made up of sclerotic-palisade cells. Seed solitary. Seed coat two-layered; outer 63-76 μm wide, made up of thick-walled, rectangular, pitted cells traversed by a ring of reduced vascular strands; inner seed coat 63-85 μm wide, made up of thick-walled, rectangular cells filled with tanniniferous material. Endosperm homogeneous. Embryo cylindrical, apical. Shallow groove present at chalazal region.

*Description*—Fruit single seeded, ovoid drupe with rounded apex (Text-fig. 1; Pl. 1, figs 1, 2), 1.65 cm long and 1.2 cm wide. Persistent structures like perianth not observed at the base. Fruit wall 1520-2170 μm thick, 5580 μm thick at the chalazal region; differentiated into thin epicarp, fibrous mesocarp and hard endocarp. Epicarp 90-180 μm thick,



**Text-figure 2**—*Arecoidocarpon kulkarnii* gen. et sp. nov.—A portion of the fruit magnified to show EPI-epidermis, HYP-hypodermis, MES-mesocarp, ENDP-endocarp, OSC-outer seed coat, ISC-inner seed coat, and ESP-endosperm × 25

comprising a single layered epidermis made up of rectangular to cubical (13 × 17 μm) cells, covered with a thick cuticular layer and a 4-6 layered hypodermis. Hypodermal cells squarish to rectangular and compactly arranged. Mesocarp 900-1200 μm thick, composed of fibre bundles, fibrovascular bundles, brachysclereides in the thin-walled rectangular, parenchymatous cells. Fibre bundles 108 × 126–162 × 198 μm in size and rounded to elongated in shape. Fibrovascular bundles 198 × 234–288 × 396 μm, elongated to spindle-shaped with reduced vascular elements. Stegmata abundant. Endocarp very hard, 625–800 μm thick consisting of 5-6 rows of compactly arranged fibre-fibrovascular bundles and brachysclereides. Islets of thick-walled ground parenchyma cells present intermittently in this layer. Locular epidermis made up of sclerotic-palisade cells. Tanniniferous cells and raphide sacs present in all the three layers of the fruit wall (Text-figs 1, 2; Pl. 1, figs 1-3). Seed elongated, 11 × 9 mm, occupying entire fruit cavity except basal region; completely filled with endosperm tissue and covered with two-layered seed coat (Text-fig. 2; Pl 1, figs 3-4). Outer seed coat layer 63-76 μm thick, consisting of compactly arranged thick-walled, rectangular, pitted cells, traversed by a ring of reduced vascular strands (Pl. 1, fig. 4). Inner seed coat as thick as the outer layer, 63-85 μm, with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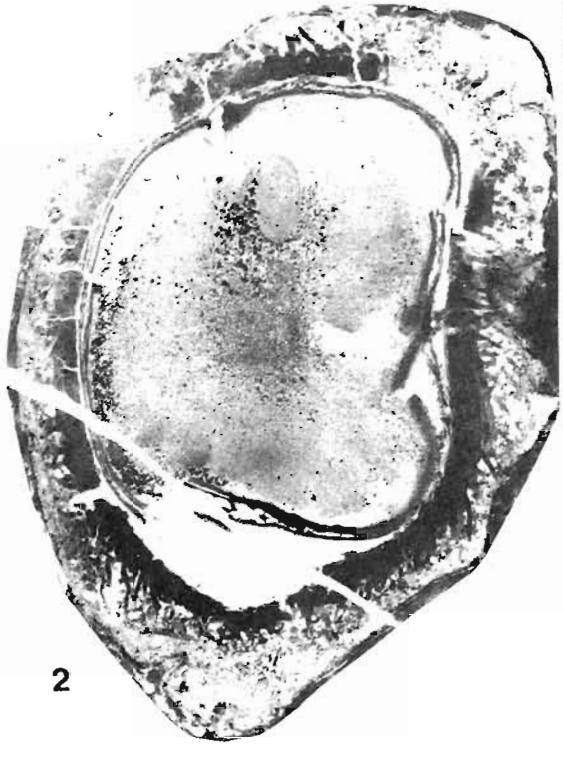
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PLATE 1

compact arrangement of thick-walled, rectangular cells filled with tanniniferous material. Endosperm homogeneous (non-ruminate), having 1-2 layers of outer squarish to rectangular cells. Radial files of inner cells converging into the centre of the seed (Pl. 1, figs 1-2). Cells thick-walled, reserve food material obscure. Embryo cylindrical, 1875 × 1000 μm in size with oval to elongated 12.6 × 21 μm cells, being present at the apical region of the seed (Pl 1, fig. 2). A shallow groove present at the chalazal region (Text-fig. 1; Pl. 1, fig. 1).

*Holotype*—Pl. 1, fig. 1; Slide nos. MK-26, MK-27, MK-28, Department of Botany, M.A.C.S. Research Institute, Pune.

*Type locality*—Mohgaonkalan, district Chhindwada, Madhya Pradesh, India.

*Type horizon*—Deccan Intertrappean beds.

*Age*—Early Eocene.

## DISCUSSION

The important characters of the present fruit are, (i) single seeded ovoid drupe, (ii) fruit wall differentiated into thin epicarp, fibrous mesocarp and hard endocarp, (iii) fibre-fibrovascular bundles and brachysclereides restricted to mesocarp and endocarp layers, (iv) locular epidermis made up of tangentially elongated sclerotic cells, (v) two-layered seed coat, outer with pitted cells and reduced vascular strands and inner with tanniniferous cells, (vi) homogeneous endosperm, and (vii) shallow chalazal groove These characters suggest its affinity with Arecoid group of palms.

*Comparison with living palms*—Guerin (1949), Murray (1973), Essig (1977), Essig and Young (1979), Padmanabhan and Regupathy (1981), Kulkarni and Pande (1983) and Reddy and Kulkarni (1985) have studied the anatomy of extant Arecoid palm fruits.

There are 760 species belonging to 88 genera in the Arecoid palms (Moore, 1973). Fibrovascular bundles with thick fibrous sheath, hard endocarp composed of fibre bundles and brachysclereides, irregular shallow chalazal groove and homogeneous endosperm suggest the affinity of presently described fruit with non-ruminate Arecoid palms, like *Areca triandra, Chrysalidocarpus, Rhopalostylis, Veitchia* and *Ptychosperma*. *Areca triandra* and *Chrysalidocarpus* species possess a sclerotic cylinder in the mesocarp formed by sclereides and brachysclereides. In *Rhopalostylis*, fibre bundles in the mesocarp are arranged in 2-3 concentric rows and the outer seed coat is massive. *Veitchia* and *Ptychosperma* differ from the fossil in having fibre bundles in the epicarp Moreover, the seed in *Ptychosperma* is angular

*Comparison with fossil palms*—The only palm fruit so far considered to bear any resemblance with the extant genus *Areca* or Arecoid palms is *Palmocarpon arecoides* Mehrotra 1987, however, the structure of seed coat, an important character to decide affinity with *Areca*, or with any other Arecoid palm, is not observed in the latter Moreover, it does not show compact arrangement of fibre-fibrovascular bundles constituting hard endocarp. Beside this, nothing is known about the endosperm in *P. arecoides*. Therefore, *P arecoides* cannot be considered to be a fruit of *Areca* or even any other Arecoid palm.

## ACKNOWLEDGEMENT

The author is thankful to Professor A. R. Kulkarni, University of Bombay for going through the slides and helpful suggestions. He is also thankful for making available his collection of anatomical preparations of extant palm fruits.

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## PLATE 1

*Arecoidocarpon kulkarnii* gen. et sp. nov.

1. Longitudinal section of fruit showing single seed, two-layered seed coat and fruit wall. Shallow groove is seen at the basal region of the seed × 6.
2. Longitudinal section of fruit showing small cylindrical embryo at the apical region and chalazal groove at the base of the seed × 6.
3. Longitudinal section showing epicarp, mesocarp, endocarp, two layered seed coat and endosperm × 30.
4. Longitudinal section showing outer seed coat with group of reduced vascular strands in the outer seed coat layer × 92.

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# Palynology of Langrin Coalfield, South Shillong Plateau, Meghalaya

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Singh, R. S. 1990. Palynology of Langrin Coalfield, South Shillong Plateau, Meghalaya. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 217-228.

Palynology of Langrin Coalfield, Khasi Hills, Meghalaya is reported here. The spore-pollen assemblage recovered from five coal seams associated with Tura Formation comprises 30 genera and 56 species. Presence of dinoflagellate cysts and fungal remains has also been observed. Five new species, viz., *Gemmamonocolpites dimorphous, Clavamonocolpites indicus, Spinizonocolpites indicus, S. wodehousei* and *S. bulbospinosus* are described. Quantitative assessment of the assemblages for each seam has been done. Pteridophytic spores dominate in coal seams 1 and 2 but gradually decrease in the upper seams, while angiospermic pollen behave in more or less *vice-versa* with that of pteridophytic spores. Ecological grouping of palynofossils suggests the occurrence of coastal swamp and brackish-water mangrove communities during the deposition of coal seams. Absence of gymnospermic pollen in the assemblage indicates a flat topography of the basin. Palaeocene age has been assigned to this palynological assemblage.

**Key-words**—Palynology, Langrin Coalfield, Tura Formation, Palaeocene (India).

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## सारॉंश

### मेघालय में दक्षिण शिलांग पठार में लैंग्रिन कोयला-क्षेत्र का परागाणविक अध्ययन

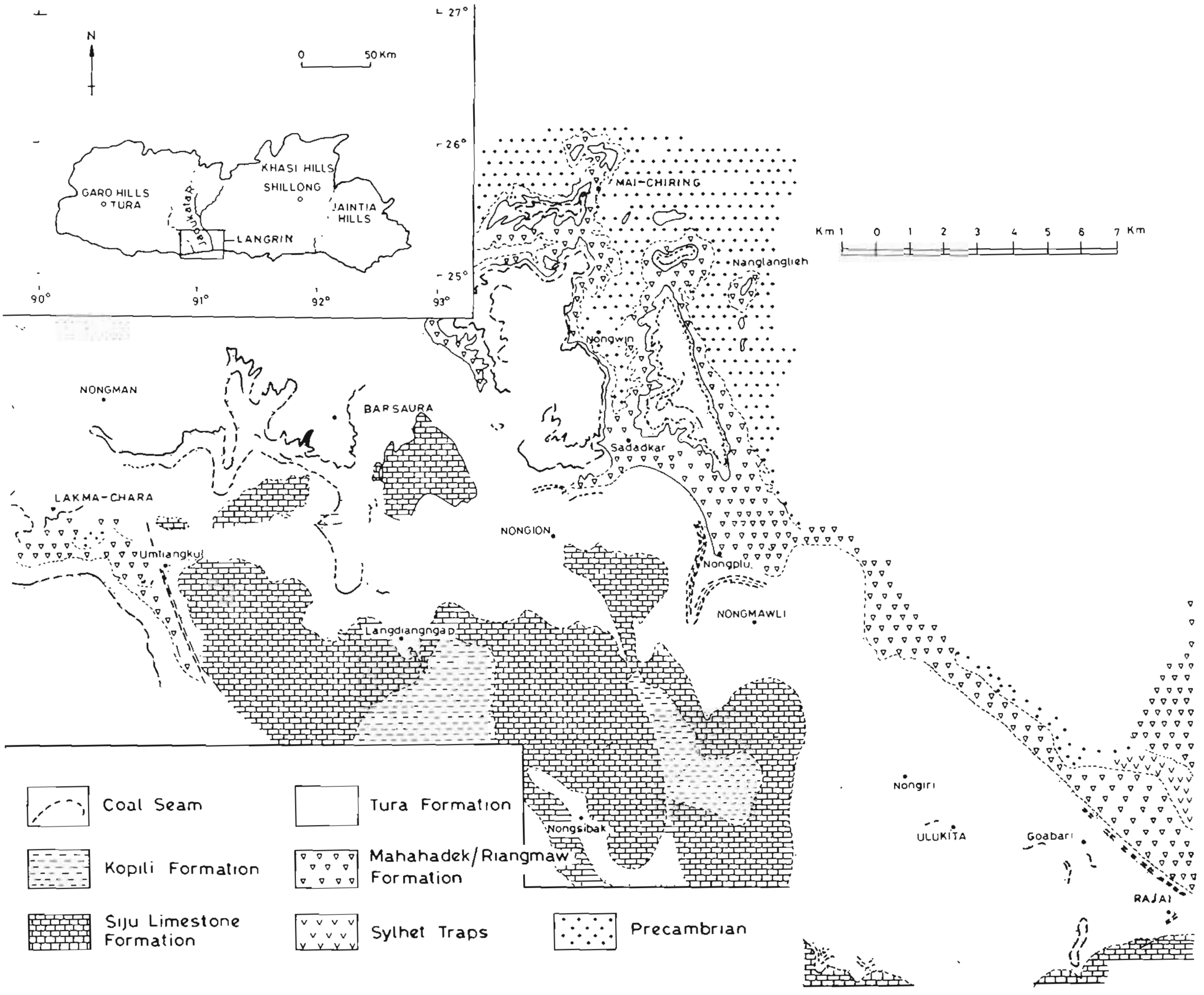
रमा शंकर सिंह

मेघालय में खासी पहाड़ियों में लैंग्रिन कोयला-क्षेत्र का परागाणविक अध्ययन किया गया है। तुरा शैल-समूह से सहयुक्त पाँच कोयला सीमों से उपलब्ध परागकण-बीजाणु समुच्चय में 30 प्रजातियाँ एवं 56 जातियाँ विद्यमान हैं। **जेमामोनोकॉल्पाइटिस डाइमोर्फस, क्लेवामोनोकॉल्पाइटिस इंडिकस, स्पाइनीजोनोकॉल्पाइटिस इंडिकस, स्पा० वॉडहाउसाई** एवं **स्पा० बल्बोसस** नामक पाँच नई जातियाँ वर्णित की गई हैं। प्रत्येक सीम का भारात्मक विश्लेषण किया गया है। कोयला-सीम 1 व 2 में टेरीडोफ़ाइटी बीजाणुओं की बाहुल्यता है लेकिन ऊपरी सीमों में ये शनैः शनैः कम हो जाते हैं जबकि आवृतबीजी परागकण इसके विपरीतं प्रवृत्ति व्यक्त करते हैं। अश्मित परागकणों के पारिस्थितिकीय समूहों से इन कोयला-समूहों के निक्षेपण के समय तटीय दलदली एवं खारे जल वाली मैंग्रोव वनस्पति का होना प्रस्तावित होता है। अनावृतबीजी परागकणों की अनुपस्थिति से चपटी द्रोणी का होना इंगित होता है। इस परागाणविक समुच्चय की पुरानूतन आयु प्रस्तावित की गई है।

LANGRIN Coalfield lies in the western extremity of Khasi Hills between latitudes 25° 12′ : 25° 19′ and longitudes 91° 0′ : 91° 14′, in the state of Meghalaya. Palynologically this coalfield was unattended so far but geologically it was studied by La Touch (1883), Medlicott (1869), Palmer (1924), Fox (1937), Ghosh (1940), Biswas (1962) and Rao (1981). The generalised rock succession in this coalfield is as follows (modified after Rao, 1981):

| AGE | FORMATION & LITHOLOGY |
|---|---|
| Eocene | Siju Limestone: Limestone, marls, silts & shales. |
| Palaeocene | Tura Formation: Sandstone, coal, shale & clay.<br>Unconformity |
| Late Cretaceous | Jadukata Formation. Sandstones conglomerate alterations.<br>Unconformity |
| Jurassic (?) | Sylhet Trap: Basalt, Alkali basalt rhyolite, acid tuff.<br>Unconformity |
| Pre-Cambrian | Coarse grained granite, granodiorites, banded gneiss & quartzite. |

The coal seams in Langrin Coalfield are associated with Tura Formation and are exposed in widely separated patches (Map 1). Rao (1981) reported six coal seams in this coalfield within a thickness ranging from 77 to 126 m, but in the present study only five coal seams could be traced In most part of the coalfield, the top portion of Tura Sandstone is being eroded away exposing seams no.

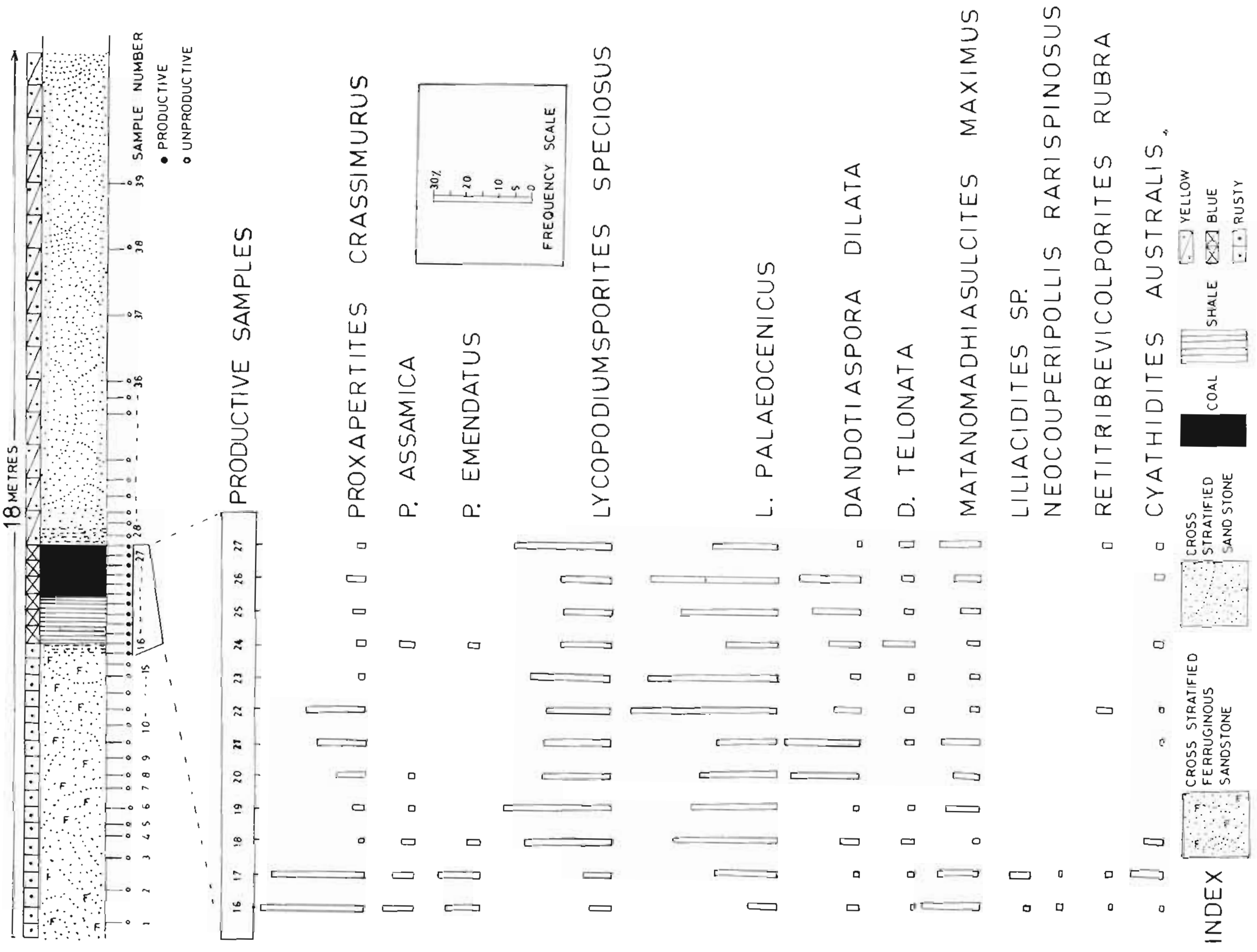


**Map 1**—Geology of Langrin Coalfield (after Rao, 1981).

3 and 4. Barsaura nala section containing five coal seams is considered to be a reference section whose lithology and location of each sample are plotted in Text-figures 1 to 5. Generally, the coal seams dip at an angle of about 35° south but in the reference section they are almost horizontal. In Jadukata area only one coal seam (seam 5) is encountered which is exposed near Rajai Village Seams 1 and 2 are also exposed near Goabari Village where they are 0.7-1.5 m thick respectively, with an intervening 40 m thick sandstone parting. In the eastern part, Lakma Chara section contains all the seams, except the bottom seam; here seam 3 is locally 3-3.6 m thick. In Mai-Chiring the lowermost coal seam occurs at about 50-60 m above the contact of Jadukata and Tura formations. The samples were collected from Rajai, Goabari, Mai-Chiring, Lakma-Chara and Barsaura (Map 1). The figured and type slides of palynotaxa are housed in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

## SPORE AND POLLEN CHECK-LIST

*Cyathidites australis* Couper 1953
*C. minor* Couper 1953
*Todisporites major* Couper 1958
*T minor* Couper 1958
*Dictyophyllidites kyrtomatus* Kar & Kumar 1986
*Lygodiumsporites lakiensis* Sah & Kar 1969
*Dandotiaspora dilata* Sah, Kar & Singh 1971
*D. telonata* Sah, Kar & Singh 1971
*D. plicata* (Sah & Kar) Sah, Kar & Singh 1971
*Lycopodiumsporites palaeocenicus* Dutta & Sah



**Text-figure 1**—Histogram illustrating relative abundance of spore-pollen species in coal seam 1.

1970

*L. speciosus* Dutta & Sah 1970

*L. umstewensis* Dutta & Sah 1970

*Pteridacidites robustus* Kar & Kumar 1986

*Schizaeoisporites crassimurus* Dutta & Sah 1970

*Polypodiisporites mawkmaensis* Dutta & Sah 1970

*Palmidites plicatus* Singh 1974

*P. aplicatus* Singh 1974

*Retimonosulcites ovatus* (Sah & Kar) Kar 1985

*Liliacidites* sp. in Kar & Kumar 1986

*Matanomadhiasulcites maximus* (Saxena) Kar 1985

*M. kutchensis* (Saxena) Kar 1985

*Clavamonocolpites indicus* sp. nov.

*Gemmamonocolpites dimorphous* sp. nov.

*Neocouperipollis kutchensis* (Venkatachala & Kar) Kar & Kumar 1986

*N. rarispinosus* (Venkatachala & Kar) comb. nov.

*N. echinatus* (Sah & Kar) Kar & Kumar 1986

*N. magnus* (Dutta & Sah) comb. nov.

*Proxapertites assamica* (Sah & Dutta) Singh 1975

*P. crassimurus* (Sah & Dutta) Singh 1975

*P. emendatus* (Sah & Dutta) Kar & Kumar 1986

*Spinizonocolpites echinatus* Muller 1968

*S. baculatus* Muller 1968

*S. intrarugulatus* Muller, de Di Giacomo & Van Erve 1987

*S. bulbospinosus* sp. nov.

*S. indicus* sp. nov.

*S. wodehousei* sp. nov.

*Spinizonocolpites* sp. A.

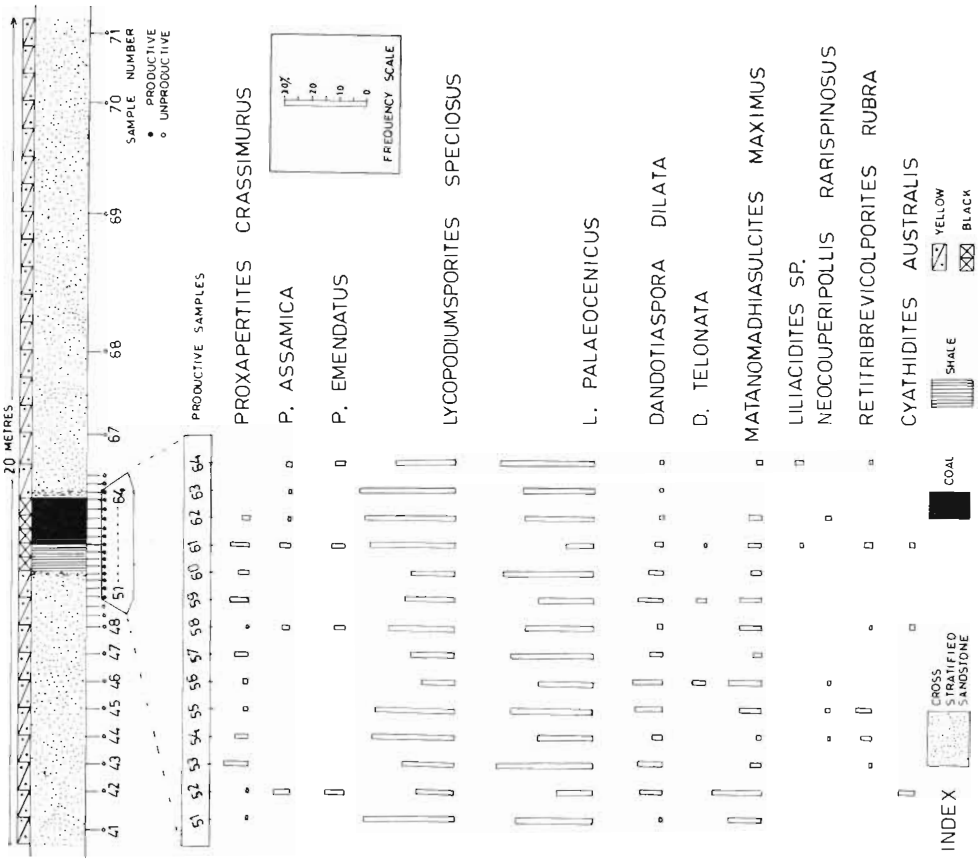
*Tricolpites reticulatus* Cookson 1947

*T. crassireticulatus* Dutta & Sah 1970

*T. baculatus* Kar & Jain 1981

*Sastriipollenites trilobatus* Venkatachala & Kar 1969

*Retistephanocolpites multirimatus* (Dutta & Sah)



**Text-figure 2**—Histogram showing relative abundance of spore pollen species in coal seam 2.

Saxena 1981
*Psilastephanocolporites psilatus* Kar & Kumar 1986
*Polymargocolporites mawlensis* Kar & Kumar 1986
*Retitribrevicolporites matanomadhensis* (Venkatachala & Kar) Kar 1985
*R. rubra* (Dutta & Sah) Kar & Kumar 1986
*Meliapollis navalei* Sah & Kar 1970
*M. minutus* Singh 1974
*Triangulorites bellus* (Sah & Kar) Kar 1985
*T pachyexinus* Kar & Kumar 1986
*Kielmeyerapollenites eocenicus* Sah & Kar 1972
*K. syncolporatus* Kar & Kumar 1986

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## PLATE 1

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(England Finder reading and magnification are given for each figure).

1,2. *Gemmamonocolpites dimorphous* sp. nov., Slide no. BSIP 9962, × 25/0, × 1000; Slide no. BSIP 9946, × 52/0, × 1000.

5. *Clavamonocolpites indicus* sp. nov., Slide no. BSIP 9968, Y40/2; × 1000; Slide no. BSIP 9969, 022/2, × 1000.

3,6. *Spinizonocolpites bulbospinosus* sp. nov., Slide no. BSIP 9946, × 044/0, 1000; Slide no. BSIP 9947, G49/3, × 1000.

7,8. *Diporites* sp. A, Slide no. BSIP 9949, W62/1, × 500; Slide no. BSIP 9978, T38/0, × 500.

9. *Lycopodiumsporites palaeocenicus* Dutta & Sah 1970, Slide no. BSIP 9988, P24/0, × 500.

10. *Proxapertites assamica* (Sah & Dutta) Singh 1975, Slide no. BSIP 9976, × 44/3, × 500.

11 *Tricolpites baculatus* Kar & Jain 1981, Slide no. BSIP 9957, E 49/1, × 500.

12. *Sastriipollenites trilobatus* Venkatachala & Kar 1969, Slide no. BSIP 10099, N42/1, × 500.

13. *Proxapertites emendatus* (Sah & Dutta) Kar & Kumar 1986, Slide no. BSIP 9967, D49/0, × 500.

14,15. *Spinizonocolpites wodehousei* sp. nov., Slide no. BSIP 9965, U46/2, × 1000; Slide no. BSIP 9965, F68/3, × 1000.

16. *Tricolpites crassireticulatus* Dutta & Sah 1970, Slide no BSIP 9977, J36/1, × 500.

17 *Triangulorites bellus* (Sah & Kar) Kar 1985, Slide no. BSIP 9965, G47/4, × 500.

18. *Retistephanocolporites multirimatus* (Dutta & Sah) Saxena 1981, Slide no. BSIP 9956, H43/3, × 500.


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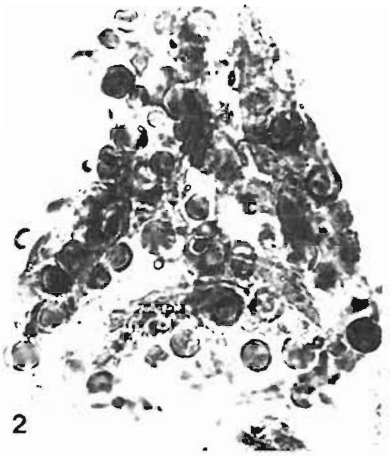
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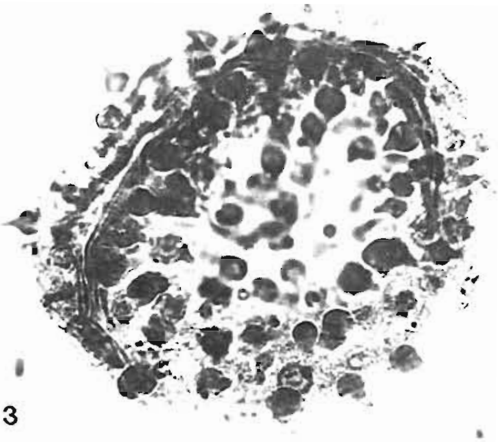
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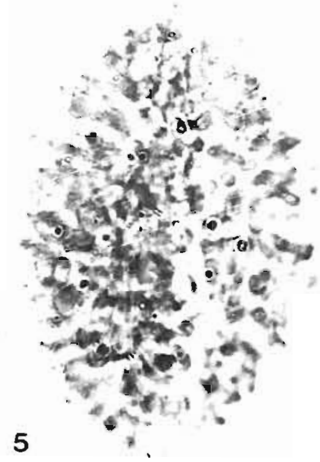
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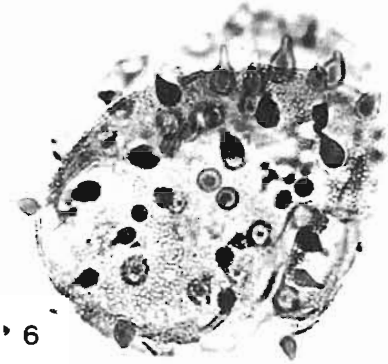
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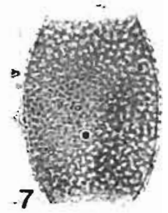
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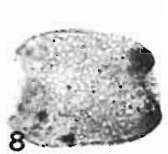
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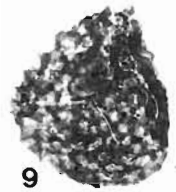
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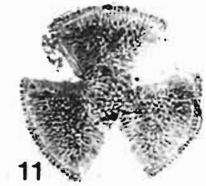
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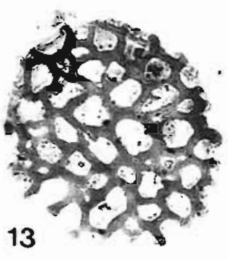
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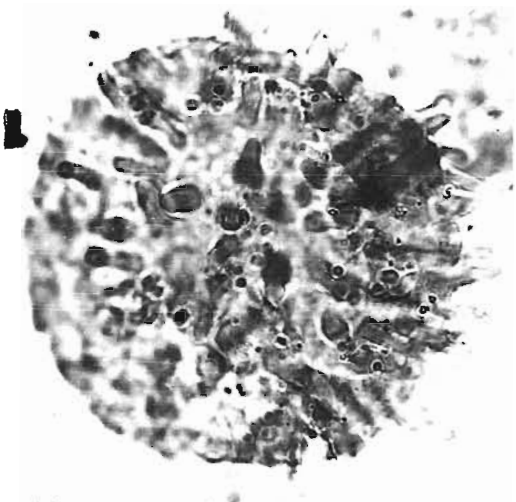
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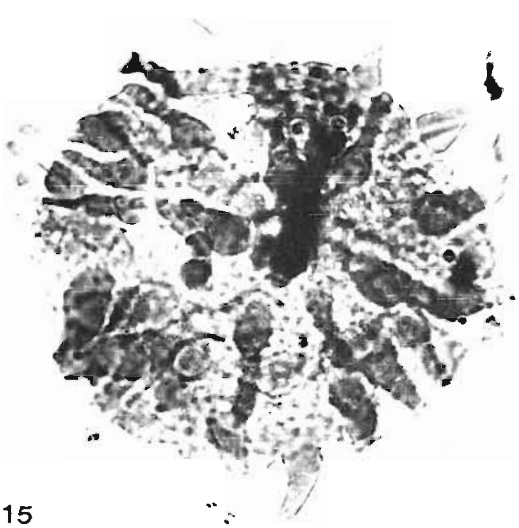
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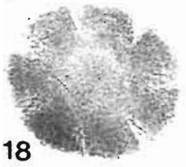
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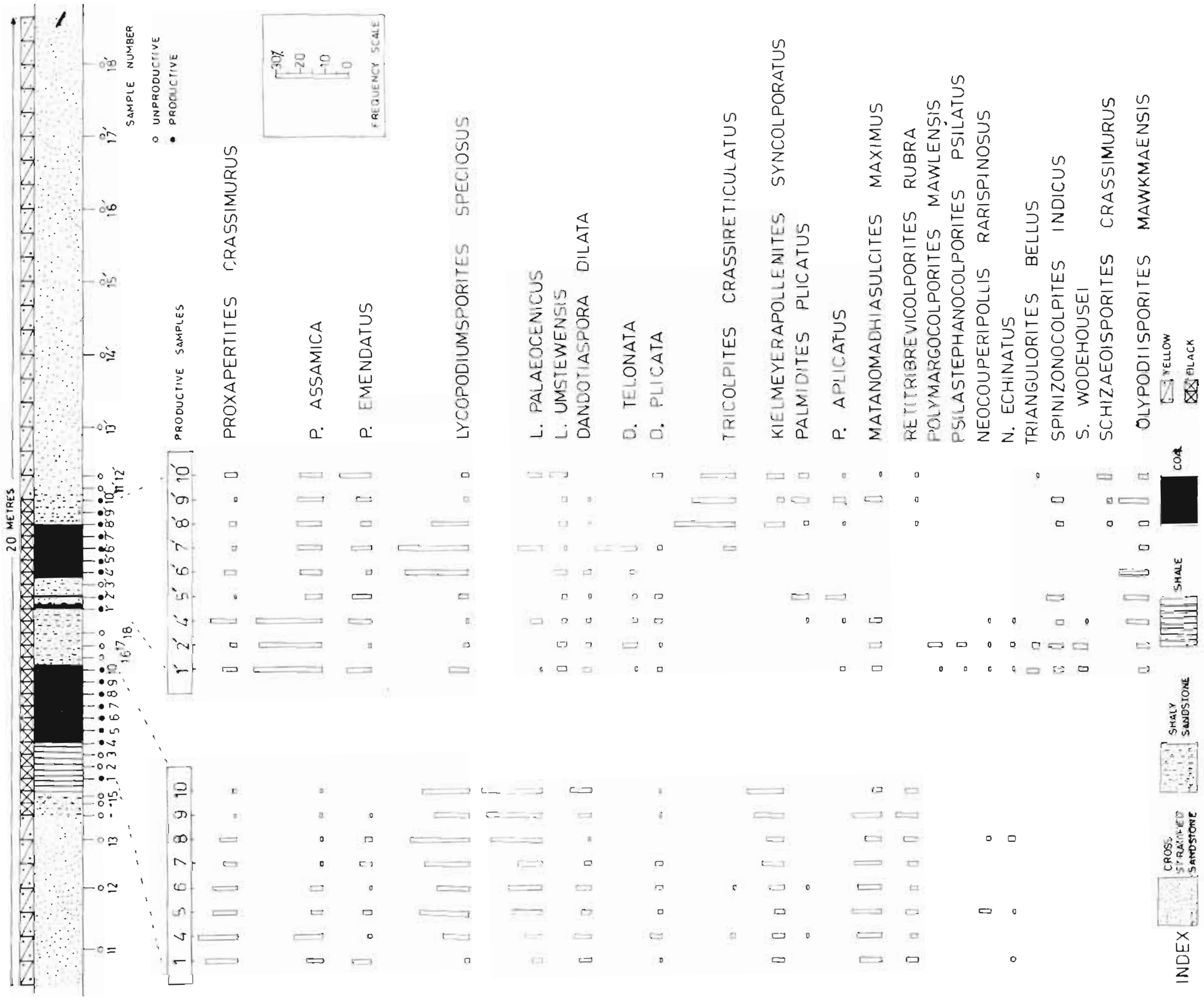
PLATE 1



**Text-figure 3**—Histogram illustrating relative abundance of spore pollen species in coal seams 3 and 4.

## PLATE 2

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1,2. *Spinizonocolpites indicus* sp. nov., Slide no. BSIP 9979, U33/0, × 1000; Slide no. BSIP 9980, S31 0, × 1000.
3. *Dandotiaspora dilata* Sah, Kar & Singh 1971, Slide no. BSIP 9983, Z45 3, × 500.
4. *Spinizonocolpites intrarugulatus* Muller, de Di Giacomo Van & Erve 1987, Slide no. BSIP 9973, O44 2, × 1000.
5. *Spinizonocolpites* sp. A, Slide no. BSIP 9986, × 47 4, × 1000.
6. *Neocouperipollis magnus* (Dutta & Sah) comb. nov., Slide no. BSIP 9972, H44 0, × 500.
7. *N. echinatus* (Sah & Kar) Kar & Kumar 1986, Slide no. BSIP 9966, H36/3, × 500
8. *Tricolpites baculatus* Kar & Jain 1981, Slide no. BSIP 9953, W 30 1, × 500.
9. Pollen type B, Slide no. BSIP 9949, R59/1, × 1000.
10. Dinoflagellate, Slide no. BSIP 10100, Y35/0, × 500.
11. *Cyathidites minor* Couper 1953, Slide no. BSIP 9970, D34 1, × 500
12. *Meliapollis minutus* Singh 1974, Slide no. BSIP 9971, Y 23 4, × 500.
13. *Retitribrevicolporites matanomadhensis* (Venkatachala & Kar) Kar 1985, Slide no BSIP 9959, E58/0, × 750.
14. *Neocouperipollis rarispinosus* (Sah & Dutta) comb. nov., Slide no. BSIP 9949, W61 0, × 1000
15. Pollen type-A, Slide no BSIP 9959, F28 2, × 1000.
16. *Spinizonocolpites echinatus* Muller 1968, Slide no. BSIP 9949, Q33 3, × 1000.

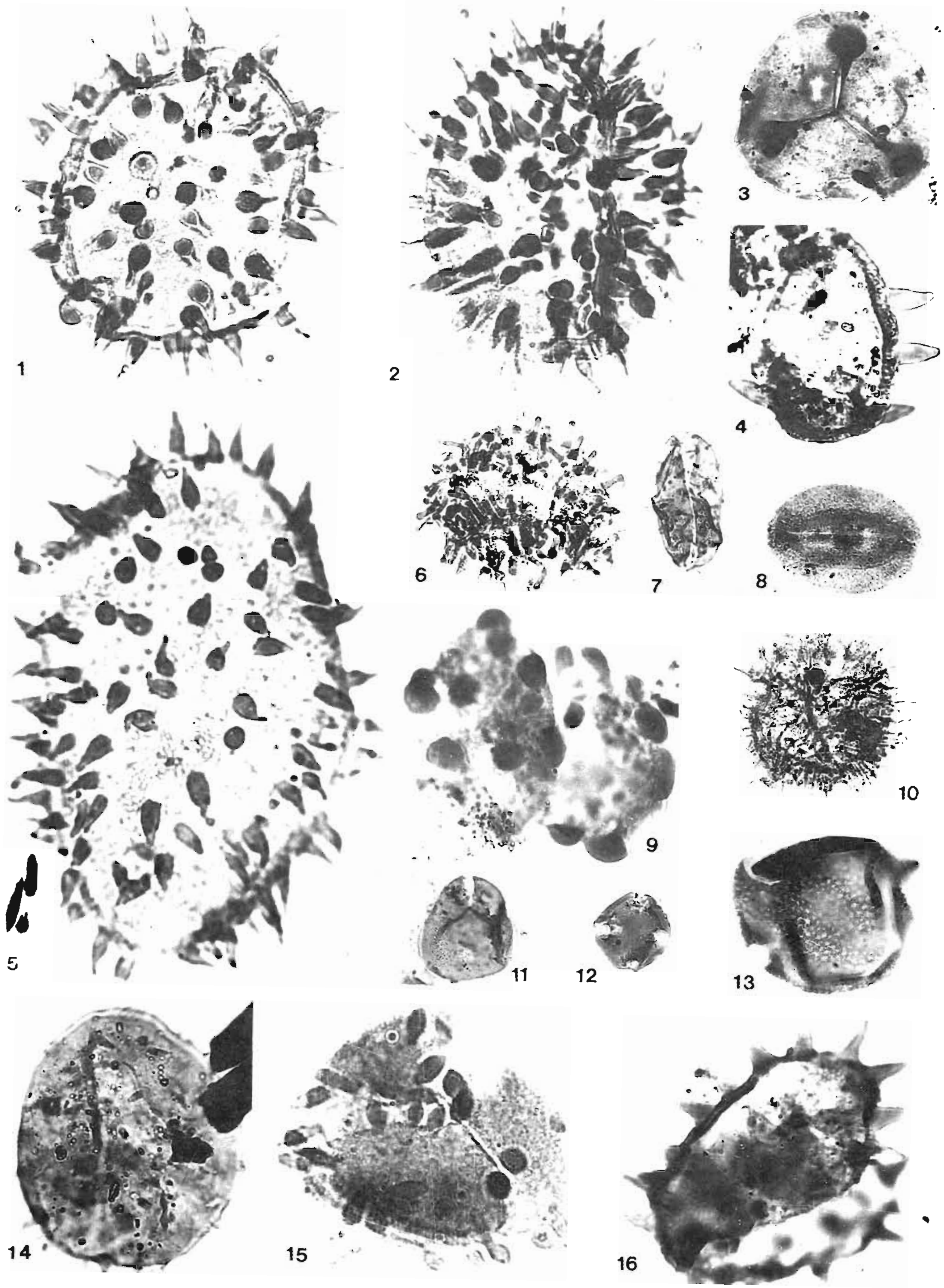


**PLATE 2**

*Diporites* sp. A

*Droseridites* sp. in: Kar & Kumar 1986

*Inapertusporites kedvesii* Elsik 1968

## SYSTEMATIC DESCRIPTION

### Genus—*Neocouperipollis* (Venkatachala & Kar) Kar & Kumar 1986

*Neocouperipollis rarispinosus* (Sah & Dutta) comb. nov.

Pl. 2, fig. 14

1966 *Monosulcites rarispinosus* Sah & Dutta, pl. 1, figs 26-28, p. 76.

1969 *Couperipollis rarispinosus* (Sah & Dutta) Venkatachala & Kar, p. 161.

*Neocouperipollis magnus* (Dutta & Sah) comb. nov

Pl. 2, fig. 6

1970 *Monosulcites magnus* Dutta & Sah, pl. 5, figs 1, 2, p. 28.

1986 *Couperipollis magnus* (Dutta & Sah) Kar & Kumar, pl. 4, figs 4, 5, p. 195.

*Remarks—Couperipollis* Venkatachala & Kar 1969 is *nomen nudum*. *Couperipollis rarispinosus* (Sah & Dutta) Venkatachala & Kar 1969 and *Couperipollis magnus* (Dutta & Sah) Kar & Kumar 1986 are transferred to *Neocouperipollis* Venkatachala & Kar emend. Kar & Kumar 1986.

*Gemmamonocolpites* Van der Hammen & Garcia 1965

*Gemmamonocolpites dimorphous* sp. nov.

Pl. 1, figs 1, 2

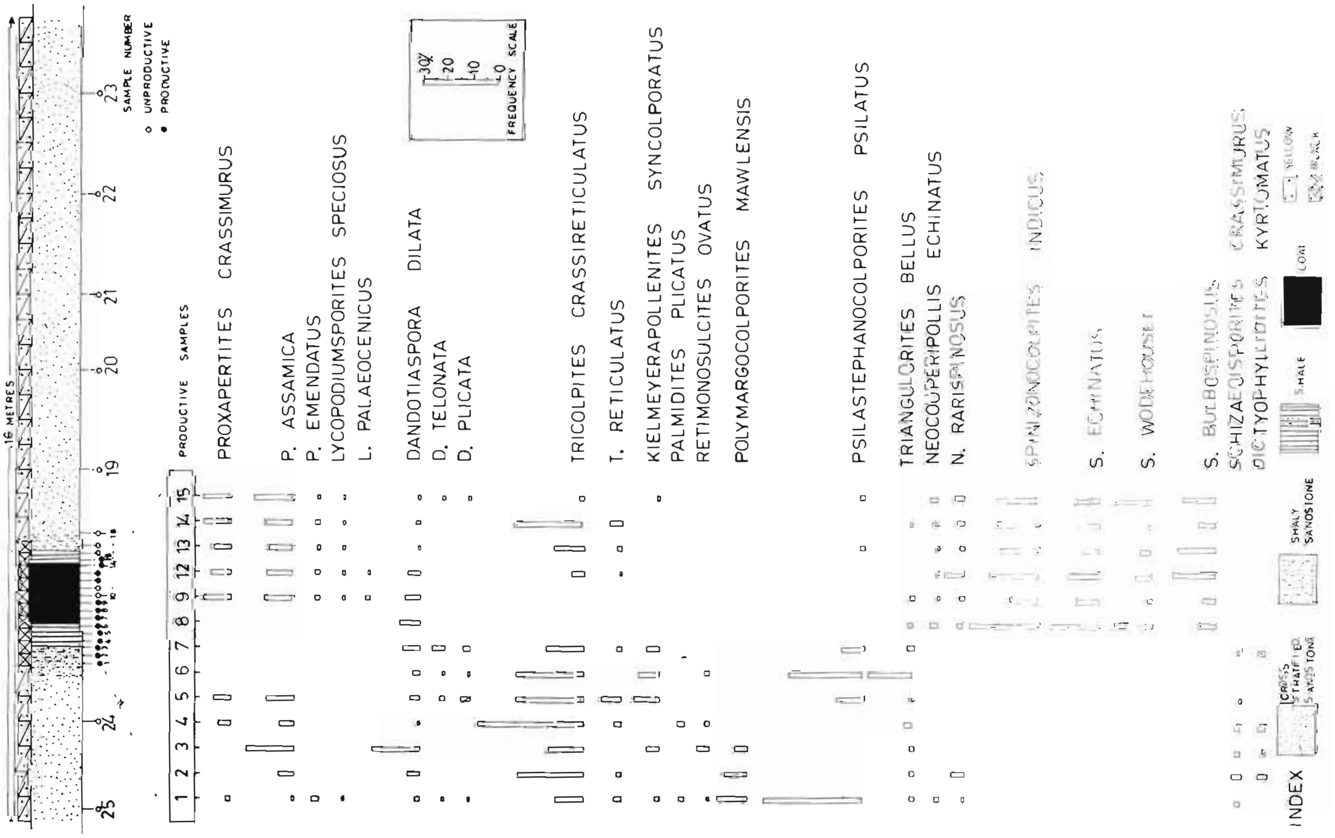
*Holotype*—Pl. 1, fig. 1; slide no. BSIP 9962.

*Type Locality*—Langrin Coalfield, Meghalaya.

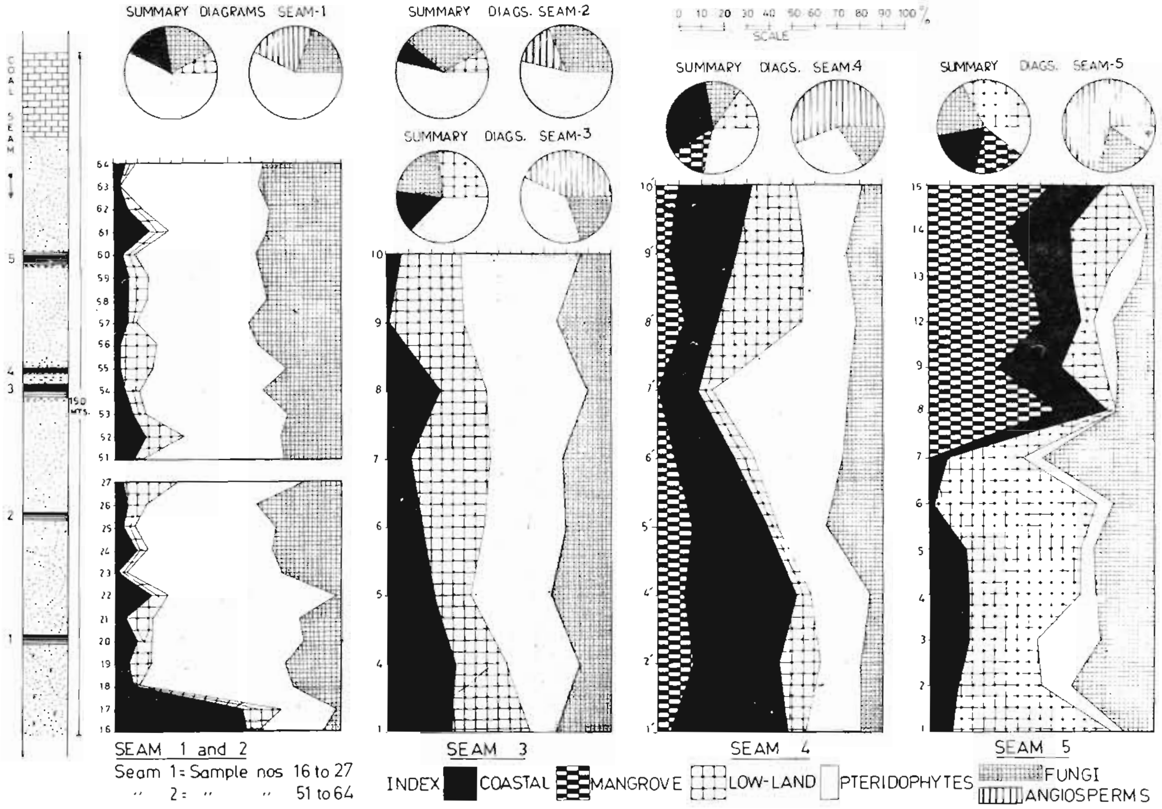
*Diagnosis*—Pollen monocolpate or trichotomocolpate, monocolpate grains oval, trichotomocolpate broadly triangular; exine gemmate, few gemmae with small accuminated tips; tectum finely reticulate, infratectum columellate.

*Description*—Monocolpate pollen 52-62 $\mu$m long, 40-48 $\mu$m wide, trichotomocolpate grains 49-55 $\mu$m long from corner to base. Colpus in both monocolpate and trichotomocolpate grains reaches up to equator or corner, distinct; exine between sculptural elements about 1 $\mu$m thick; gemmae 2-4 $\mu$m wide, few gemmae with about 1 $\mu$m long accuminated tips; tectum finely reticulate, lumina less than 0.5 $\mu$m wide.

*Remarks—Gemmamonocolpites gemmatus* Van der Hammen & Garcia 1965 and *G. barbatus*



**Text-figure 4**—Histogram illustrating relative abundance of spore-pollen species in coal seam-5.



**Text-figure 5**—Histograms showing ecological and botanical groups of palynomorphs in the assemblages of Langrin Coalfield.

Guzmán 1967 have much smaller gemmae. *G. amicus* Guzmán 1967 and *G. ovatus* Guzmán 1967 are smaller and have sparsely placed gemmae. The new species can be distinguished from all the other known species by accuminate tips on few gemmae and the mono-trichotomocolpate condition of the aperture.

### *Clavamonocolpites* Guzmán 1967

### *Clavamonocolpites indicus* sp. nov.

Pl. 1, figs 4, 5

*Holotype*—Pl. 1, fig. 4; slide no. BSIP 9968.

*Type locality*—Langrin Coalfield, Meghalaya.

*Diagnosis*—Pollen oval, monocolpate, colpus distinct; exine sculpture mixed with pila and clava, tectum scabrate.

*Description*—Pollen 58-70 $\mu$m long and 42-48 $\mu$m wide; colpus extending almost up to the equator; exine sculpture (ectexine) mixed with pila and clava but pila dominates, 2-3 $\mu$m long, head 1.5-2.0 $\mu$m wide; thickness of exine between sculptural elements 1-1.5 $\mu$m; interspinal area scabrate.

*Remarks*—*Clavamonocolpites terrificus* Guzmán 1967 differs by having only clavate exinal sculpture. The exinal sculpture with mixed pila and clava is the distinguishing feature of this species.

### *Spinizonocolpites* Muller 1968

### *Spinizonocolpites wodehousei* sp. nov.

Pl. 1, figs 14, 15

*Holotype*—Pl. 1, fig. 15; slide no. BSIP 9965.

*Type locality*—Langrin Coalfield, Meghalaya.

*Diagnosis*—Pollen subcircular, medium-sized, annulocolpate; exine sculpture spinose, spine long-beaked flask-shaped with swollen base and rounded apex; tectum microreticulate, infratectum columellate.

*Description*—Pollen more or less subcircular in meridional and polar views; 46-65 $\mu$m long at longer axis, 34-46 $\mu$m wide at shorter axis; tend to divide into two halves through colpus suture; spine 8-18 $\mu$m long, 4-7 $\mu$m wide at base, exine 1-1.5 $\mu$m thick between the spines; tectum microreticulate, lumina uniform, polygonal, 1-1.5 $\mu$m wide, muri 0.5 $\mu$m thick.

*Remarks*—*Couperipollis wodehousei* (Biswas) Venkatachala & Kar 1969 is described from the Tertiary of Meghalaya as monocolpate pollen having exinal characters similar to that of present species, but in this study no grain with such morphology was found to be monocolpate. *Spinizonocolpites baculatus* Muller 1968 is comparable with this new taxon but has baculate sculpture. *S. intrarugulatus*

Muller *et al.* 1987 is smaller in size and has 2.5-3 μm thick exine between the spines.

*Spinizonocolpites bulbospinosus* sp. nov.
Pl. 1, figs 3, 6

*Holotype*—Pl. 1, fig. 3; slide no. BSIP 9946.

*Type locality*—Langrin Coalfield, Meghalaya.

*Diagnosis*—Pollen subcircular, annulocolpate; exine sculpture bulbospinosus, spine with small accuminate protruding tips, tectum microreticulate, infratectum columellate.

*Description*—Pollen 47-63 μm long at longer axis and 33-51 μm wide at shorter axis; colpus annulate or partially attached over one-fourth of the circumference, grains tend to divide through colpus suture, spine base swollen like gemmae, small accuminate protruding apex, 3.5-6 μm long, 2-5 μm wide at base, apex 1-1.5 μm; exine between sculpture about 1 μm thick; lumina less than 1 μm wide, uniform, muri thin.

*Remarks*—*Gemmamonocolpites dimorphous* sp. nov. described above whose sculptural elements are dominantly gemmate with few transitional bulbospines is comparable with the new species in only sculptural morphology.

*Spinizonocolpites indicus* sp. nov.
Pl 2, figs 1, 2

*Holotype*—Pl 2, fig. 1, slide no. BSIP 9979.

*Type locality*—Langrin Coalfield, Meghalaya.

*Diagnosis*—Pollen subcircular, annulocolpate; exine sculpture spinose, spine base swollen with gradually tapering pointed apex, tectum microreticulate, infratectum columellate.

*Description*—Pollen 52-58 μm long at longer axis, 41-49 μm wide at shorter axis; colpus annulate, tend to divide into two halves through colpus suture. Exine sculpture spinose, spine base swollen with gradually tapering pointed apex, 7-15 μm long and 2-4 μm wide at base, exine 1-1.5 μm thick between spines; lumina 1 μm wide, uniform, polygonal, muri thin.

*Remarks*—*Spinizonocolpites echinatus* Muller 1968 can be easily distinguished by its sparsely placed spines which are conical in shape and rounded apex rather than bulbospinosus sculpture.

*Spinizonocolpites* sp. A
Pl. 2, fig. 5

*Description*—Pollen oval or subcircular in shape, 68-92 μm long, 60-80 μm wide; colpus annulate, exine sculpture (ectexine) spinose, spine completely echinate or mixed with bulbous spines, 3-10 μm long, 2-5 μm wide at base; exine 1-2 μm thick between sculptural elements; tectum microreticulate; lumina polygonal, about 1 μm wide, muri thin; infratectum columellate.

*Remarks*—*Spinizonocolpites echinatus* Muller 1968 is comparable but can easily be distinguished by its size-range and comparatively longer spines. *Nypa*-pollen have similar morphology but are smaller (45-60 μm) in size.

*Diporites* Van der Hammen 1954
*Diporites* sp. A
Pl. 1, figs 7, 8

*Description*—Pollen barrel-shaped, 40-50 μm long, 28-40 μm wide; diporate, ora meridionally on the opposite sides, wide openings; exine 1.5 μm thick, surface reticulate; lumina irregular, 1-2 μm wide, muri about 1 μm thick, infratectum columellate.

*Remarks*—The pollen resembles the pollen of *Calamus walkeri* Hance 1874.

Pollen type A
Pl. 2, fig. 15

*Description*—Pollen broadly triangular, 48-52 μm in size; trichotomocolpate; exine bulbospinosus with few gemmae; gemmae sparse, 4-8 μm long, 2-4 μm wide at base, accuminated tips less than 1 μm long; exinal wall about 1.5 μm thick; infratectum columellate.

*Remarks*—The general morphology suggests its affinity with palm; however, such grains are not yet described.

Pollen type B
Pl. 2, fig 9

*Description*—Pollen subcircular, 35-41 μm in size, annulocolpate, tend to divide into two halves through colpus; exine sculpture gemmate, gemmae 4-9 μm wide, sparse, wall 1.5-2 μm wide, tectum reticulate, infratectum columellate.

*Remarks*—Annulocolpate pollen with gemmate sculpture are unknown. It shows relationship with *Nypa*-pollen.

## DISCUSSION

The relative frequency of important palynotaxa based on frequency count for each sample is shown with the help of histograms. Coal seams 1 and 2 (Text-figs 1, 2) have similar microfloral composition marked by the dominance of *Lycopodiumsporites palaeocenicus, L. speciosus, Proxapertites* spp., *Dandotiaspora* spp., *Matanomadhiasulcites maximus* and *Retitribrevicolporites rubra.* Pteridophytic spores contribute more than half of the population of palynotaxa. In coal seam 3 (Text-fig. 3) the angiospermic pollen are slightly dominant over the pteridophytic spores, probably due to the dominant representation of *Kielmeyerapollenites*; however, the dominant taxa of seams 1 and 2 also continue to remain dominant in this assemblage. The assemblage of coal seam 4 (Text-fig. 3) is characterised by the dominance of angiospermic pollen over the pteridophytic spores. *Lycopodiumsporites umstewensis, Schizaeoisporites mawkmaensis, Spinizonocolpites indicus, S. echinatus, Psilastephanocolporites psilatus, Polymargocolporites mawlensis* and *Triangulorites bellus* appear for the first time. Some of the dominant species of seam 3, viz., *Lycopodiumsporites palaeocenicus, Kielmeyerapollenites syncolporatus, Matanomadhiasulcites maximus* and *Retitribrevicolporites rubra* are significantly reduced, though *Proxapertites* spp. and *Lycopodiumsporites speciosus* remain dominant as in seam 3. Coal seam 5 (Text-fig. 4) has more or less similar microfloral composition with that of seam 4, but the over-dominance of angiospermic pollen, particularly the species of *Spinizonocolpites*, makes the pteridophytic spores a minor constituent in the assemblage

Botanical grouping of the palynomorphs shows that the angiospermic pollen gradually increase from lower to upper coal seams, whereas the pteridophytic spores behave more or less *vice-versa* (Text-fig. 5). Assemblage of coal seams 1 and 2 are homotaxial, both quantitatively and qualitatively in which pteridophytic spores contribute about 55 per cent, angiospermic pollen about 20 per cent and rest are fungal spores. In coal seams 3, 4 and 5 the pteridophytic spores amount to 36, 29 and 9 per cent, and the angiospermic pollen contribute about 43, 57 and 70 per cent, respectively. Ecological grouping of the palynotaxa shows that during the deposition of lower three coal seams more or less similar ecological conditions prevailed. The pteridophytes contribute most in the assemblage; occurrence of coastal elements, viz., *Neocouperipollis, Proxapertites* and *Palmidites* in good number indicate near-shore swampy vegetation. Lowland tropical elements, viz., *Matanomadhiasulcites, Liliacidites, Retitribrevicolporites, Tricolpites crassireticulatus* and *Kielmeyerapollenites* with wide ecological niche indicates tropical climatic condition. It is interesting to observe that in the assemblages of upper two seams, *Nypa*-related pollen, *viz., Spinizonocolpites* occurs as a dominant element and also marine algae occur frequently which suggests a brackish-water mangrove type of floral community. The change from lower to upper seams from coastal swamp to mangrove type of vegetation is attributed to transgressive phase of the sea during the deposition of upper two coal seams. Dominant representation of fungal spores and fruiting bodies in the assemblages of all the coal seams indicates warm and humid climatic conditions. Absence of gymnosperms shows a low-land topographical feature of the sedimentary basin

Sah and Singh (1974) on the basis of subsurface samples of the Tura Formation in Garo Hills proposed *Dandotiaspora telonata* Cenozone for the coal seams. Singh, Singh and Sah (1975) further recognised four subzones, viz., *Polycolpites cooksonii* subzone, *Palmaeopollenites communis* subzone, *Lycopodiumsporites palaeocenicus* subzone and *Dandotiaspora telonata* subzone. In this study the assemblage shows more or less similar floral composition with that of Garo Hills (Sah & Singh 1974, Singh, 1977, Singh, Singh & Sah, 1975) but quantitatively the patterns are dissimilar. This assemblage interestingly is similar to that of the equivalent Palaeocene deposits, viz., Lakadong Sandstone and Therria Sandstone of Meghalaya (Baksi, 1962; Biswas, 1962; Sah & Dutta, 1967; Dutta & Sah, 1970; Kar & Kumar, 1986a). Palaeocene assemblage of Meghalaya and Matanomadh Formation (Saxena, 1978, 1980) of Kutch seems to be homotaxial with this assemblage, suggesting Palaeocene age to Langrin Coalfield assemblage.

## ACKNOWLEDGEMENTS

The author is grateful to Drs B. S. Venkatachala and R. K. Kar, Birbal Sahni Institute of Palaeobotany, Lucknow for guidance and helpful suggestions.

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# Palynological studies of the Barail Group (Oligocene) in the Type Area, Assam

R. K. Kar

Kar, R. K. 1990. Palynological studies of the Barail Group (Oligocene) in the type area, Assam. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 229-242.

The surface samples from Disang (Eocene), Laisong (Lower Oligocene), Jenam (Middle Oligocene), Renji (Upper Oligocene) and Bhuban (Lower Miocene) formations exposed along Silchar-Halflong road in the type area in Assam were palynologically investigated. Six samples studied from Disang are placed into *Striatriletes microverrucosus* Cenozone. Laisong palynological assemblage comprises 30 genera and 28 identifiable species and the entire assemblage is placed into *Osmundacidites wellmanii* Cenozone. The Jenam assemblage has 49 genera and 42 identifiable species and the assemblage is divisible into: (i) *Malayaeaspora costata* Cenozone, and (ii) *Striatriletes susannae* Cenozone. The Renji assemblage constitutes *Cyathidites minor* Cenozone. The Bhuban assemblage is placed into *Pinuspollenites crestus* Cenozone. The Disang palynological assemblage is distinguished from Laisong by the high representation of *Phragmothyrites eocaenicus* and *Striatriletes susannae*. Laisong is differentiated from Jenam by the dominance of *Cyathidites minor, Lygodiumsporites lakiensis, Striatriletes susannae* and *Striatriletes multicostatus*. In Renji Formation, *Cyathidites minor* reappears in a good percentage but frequency of *Polypodiaceaesporites tertiarus, Striatriletes susannae, Striatriletes multicostatus* and *Osmundacidites wellmanii* is considerably reduced. The Bhuban assemblage is distinguished from Renji by the abundance of *Pinuspollenites crestus* and *Podocarpidites khasiensis*.

**Key-words**—Palynology, Barail Group, Oligocene (India).

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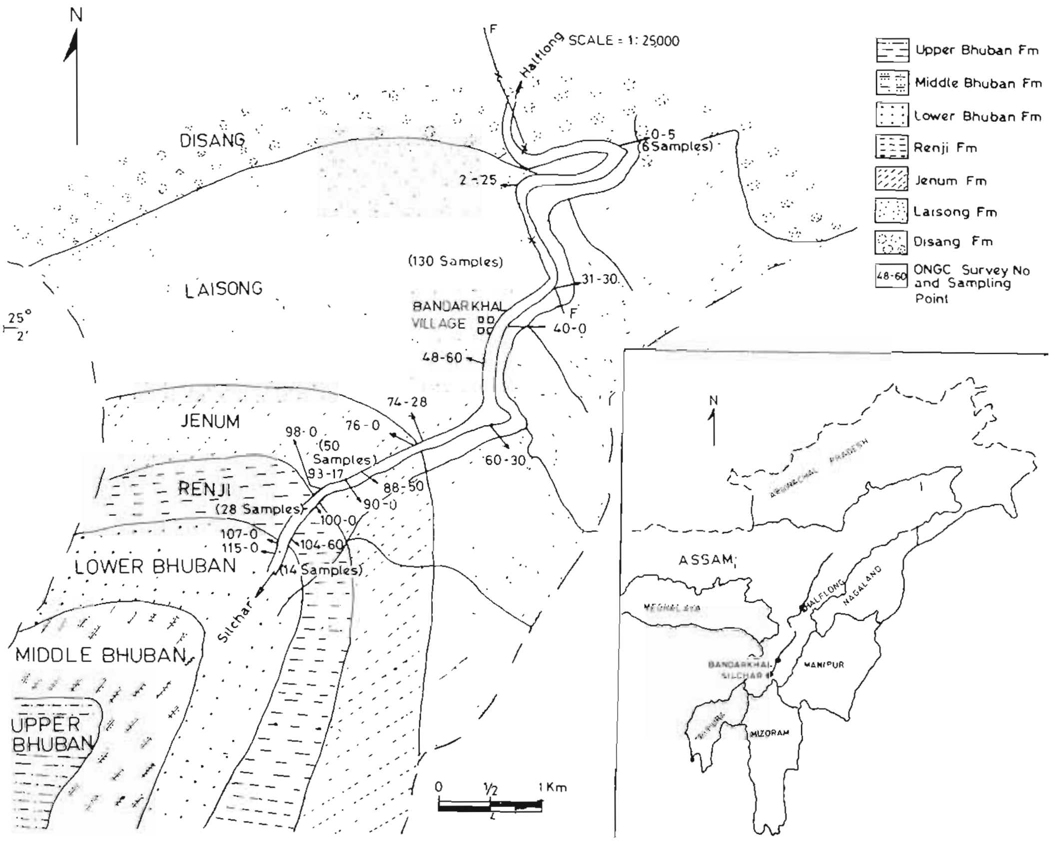
## साराँश

### असम में प्ररूप क्षेत्र में बैरेल समूह (पश्चनूतन) का परागाणविक अध्ययन

रंजीत कुमार कर

असम में प्ररूप क्षेत्र में सिल्चर हाफलौंग मार्ग के संग-संग विगोपित दिसाँग (आदिनूतन), लाइसोंग (अधरि पश्चनूतन), रेन्जी (उपरि पश्चनूतन) एवं भुबन (अधरि मध्यनूतन) शैल-समूहों का परागाणविक अन्वेषण किया गया है। दिसाँग से एकत्रित छः नमूनों को **स्ट्रआट्राइलिटीज़ माइक्रोवेरुकोसस** नवमंडल में रखा गया है। लाइसोंग परागाणविक समुच्चय में 30 प्रजातियाँ एवं 28 जातियाँ विद्यमान हैं तथा यह पूरी समुच्चय **ओस्मुन्डेसिडाइटिस वैलमैन्नाई** नवमंडल में रखी गई है। जेनम समुच्चय में 49 प्रजातियाँ एवं 42 जातियाँ विद्यमान हैं तथा इसे (i) **मलायाइयास्पोरा कोस्टेटा** नवमंडल में रखा गया है। रेन्जी समुच्चय में **स्याथिडाइटिस माइनर** नवमंडल प्रेक्षित किया गया है। भुबन समुच्चय **पाइनसपोलिनाइटिस क्रेस्टस** नवमंडल में रखी गई है। दिसाँग समुच्चय **फ्रेग्मोथाइराइटिस ईओसेनिकस** एवं **स्ट्रआट्राइलिटीस सुसान्न** की बाहुल्यता के कारण लाइसोंग समुच्चय से पृथक की जा सकती है। **स्याथिडाइटिस माइनर, लाइगोडियमस्पोराइटिस लाकीयेन्सिस, स्ट्रआट्राईलिटीस सुसान्न** एवं **स्ट्र० मल्टीकोस्टेटस** की प्रचुरता के कारण लाइसोंग को जेनम समुच्चय से पृथक किया जा सकता है। रेन्जी शैल-समूह में **स्याथिडाइटिस माइनर** पुनः अच्छी प्रतिशत मात्रा में मिलने लगता है परन्तु **पोलिपोडिएसिस्पोराइटिस टर्शियेरस, स्ट्रआट्राइलिटीस सुसान्न, स्ट्र० मल्टीकोस्टेटस** एवं **ओस्मुन्डेसिडाइटिस वैलमेनाई** पर्याप्त कम मात्रा में मिलते हैं। **पाइनसपोलिनाइटिस क्रेस्टस** एवं **पोडोकार्पिडाइटिस खासीयेन्सिस** की बाहुल्यता के आधार पर भुबन और रेन्जी समुच्चयों को एक दूसरे से पहचाना जा सकता है।

THE Barail Group is named after the Barail Range situated in Cachar and north Cachar Hill districts of Assam. The geosynclinal sediments of this group in Surma Valley are divided into Laisong, Jenam and Renji formations whereas in Upper Assam and Naga Hills, these are known as Naogaon, Baragolai and Tikak Parbat formations. To know the palynological assemblage of this group from the type locality, samples were collected from Silchar-Halflong road section (Lat. 25°2′ : Long. 92°45′) in collaboration with the Oil and Natural Gas Commission, Calcutta. In all, 228 samples were collected—6 samples from



**Text-figure 1**—Geological map of Silchar-Halflong road showing the distribution of Disang, Laisong, Jenam, Renji and Bhuban formations.

Disang, 130 samples from Laisong, 50 samples from Jenam, 28 samples from Renji and 14 samples from Bhuban (Text-fig. 1).

## GENERAL GEOLOGY

Silchar-Halflong road exposes Disang, Laisong, Jenam, Renji, Bhuban and Bokabil formations. Disang consists generally of shale with minor sandstone/siltstone. The shales are mainly black to dark, steel-grey, weathering to reddish-brown in most of the places. This is laminated, highly fissile to splintery, rarely concretionary and with small clots of carbonaceous coaly material at places. Disang shales are fluvial, non-marine flood-plain deposits formed in a narrow trough bounded by Barisal-

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## PLATE 1

(All photomicrographs, unless otherwise mentioned, are × 500)

1,2,5. *Malayaeaspora costata* Trivedi, Ambwani & Kar, × 1000; slide no. BSIP 10032, U20/1, M32/1, M16.

3,7,11. *Polypodiaceaesporites chatterjii* Kar; slide nos. BSIP 10265, M36/2; 10266, R28; 10054, V21/1

4,23. *Striatriletes multicostatus* Kar & Saxena; slide nos. BSIP 10264, F16/1; 10021, N39.

6. *Dictyophyllidites kyrtomatus* Kar & Kumar; slide no. BSIP 10021, R14/1

8. *Cyathidites minor* Couper; slide no. BSIP 10057, J37/2.

9,10. *Osmundacidites wellmanii* Couper; slide nos. BSIP 10027, Z45/3; 10079, W21

12. *Todisporites kutchensis* Sah & Kar; slide no. BSIP 10267, × 19.

13. *Phragmothyrites eocaenicus* Edwards emend. Kar & Saxena; slide no. 10037, O40/2.

14,15,20,21 *Klausipollenites sulcatus* Kar, Kieser & Jain; slide nos. BSIP 10045, P12; 10046, L26/3; 10047, L43; 10039, R32/4.

16. Spore mass; slide no. BSIP 10048, V43/2.

17. *Spinizonocolpites echinatus* Muller; slide no. BSIP 10269, V20/1.

18. *Laevigatosporites lakiensis* Sah & Kar; slide no. BSIP 10074, N25/4.

19. Tetracolporate pollen; slide no. BSIP 10023, D28/4.

22. *Platysaccus papilionis* Potonié & Klaus; slide no. BSIP 10079, M43.

24. *Abiespollenites cognatus* Kar; slide no. BSIP 10268, Z8/4.

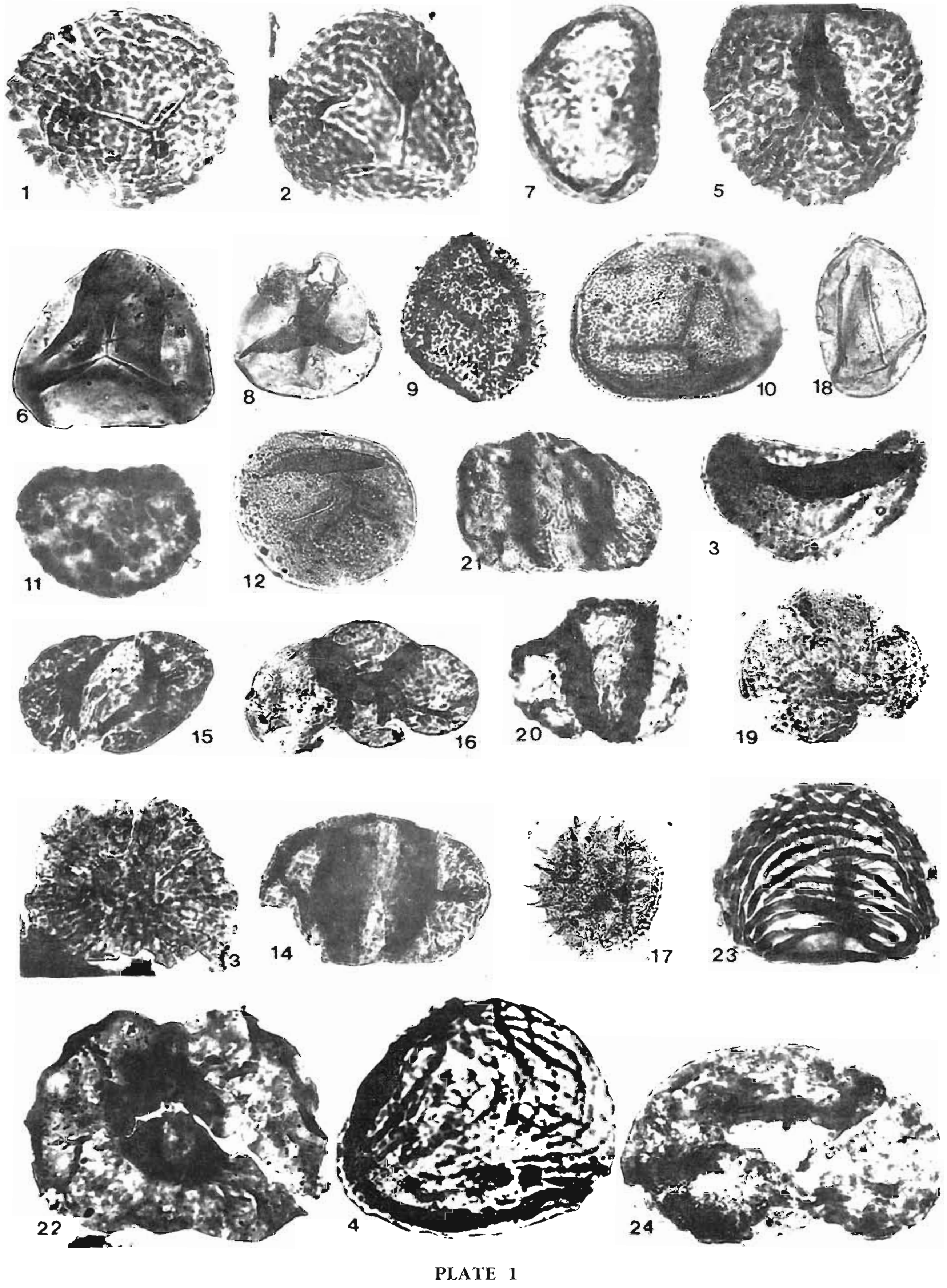


PLATE 1

Chandpur high in the west with ancestral Arakan-Yoma ridge in the east. Disang shales are not related to the shelf carbonate-clastic deposits of Khasi and Jaintia hills.

Disang is overlain by a conformable thick group of alternating hard sandstone and shale known as Barail Group. The Laisong is its basal formation and it generally consists of sandstones with occasional interbeds of shales and siltstones. The sandstones are grey to dark grey, weathering to reddish-brown, medium to coarse-grained, thick-bedded, hard and compact. Jenam, the middle unit of Barail Group, is essentially an argillaceous unit with shale and sandstone with minor alternation of fairly thick sandstone bands. In this section, the sandstones are more common and consist more or less equal proportion of sandstone and shale. The shales are dark grey to grey, laminated and carbonaceous at places. This formation shows conformable and gradational contact with the underlying Laisong Formation.

The topmost Renji Formation comprises entirely sandstone with occasional thin bands of highly fossile silty shale. The sandstones are dirty-grey to greenish-grey with tinge of violet, occasionally pinkish, weathering to yellowish-brown. The dicot leaf-impressions are mostly found in this formation. It is difficult to demarcate the contact of Jenam with overlying Bhuban, as the lower beds of Bhuban are highly arenaceous. However, the presence of frequent shales and conglomerate bands in Bhuban separates it with underlying Renji Formation.

## DISANG ASSEMBLAGE

Out of 6 samples collected and macerated from Disang, 5 samples yielded palynofossils. The samples are poor in spores and pollen grains. The following species are recorded:

*Cyathidites minor* Couper 1953
*Todisporites major* Couper 1958
*Dictyophyllidites dulcis* Kar 1985
*Intrapunctisporis intrapunctis* Krutzsch 1959
*Lygodiumsporites lakiensis* Sah & Kar 1969
*Striatriletes susannae* van der Hammen emend. Kar 1979
*S. paucicostatus* Kar 1985
*S. multicostatus* Kar & Saxena 1981
*S. microverrucosus* Kar & Saxena 1981
*Osmundacidites wellmanii* Couper 1953
*Polypodiaceaesporites chatterjii* Kar 1979
*P. tertiarus* Dutta & Sah 1970
*P. levis* Sah 1967
*Polypodiaceaesporites* sp.
*Polypodiisporites repandus* Takahashi 1964
*Psiloschizosporis psilata* Kar & Saxena 1981
*Podocarpidites khasiensis* Dutta & Sah 1970
*Pinuspollenites crestus* Kar 1985
*Piceapollenites excellensus* Kar 1985
*Klausipollenites sulcatus* Kar, Kieser & Jain 1972
*Taeniaesporites* sp.
*Hamiapollenites* sp.
*Neocouperipollis achinatus* (Sah & Kar) Kar & Kumar 1986
*Margocolporites tsukadai* Ramanujam 1966
*Pellicieroipollis langenheimii* Sah & Kar 1970
*Palaeomalvaceaepollis mammilatus* Kar 1985
*Phragmothyrites eocaenicus* Edwards emend. Kar & Saxena 1976
*Parmathyrites indicus* Jain & Gupta 1970
*Notothyrites setiferus* Cookson 1947
*Inapertusporites kedvesii* Elsik 1968
*Inapertusporites* sp.
*Diporisporites anklesvarensus* (Varma & Rawat) Elsik 1968
?*Sumatradinium* sp.

The reworked gymnospermous Mesozoic forms in the assemblage are: *Klausipollenites sulcatus* Kar, Kieser & Jain 1972, *Taeniaesporites* sp. and *Hamiapollenites* sp.

## Palynological Zonation

The Disang palynological assemblage is assigned to one palynological zone, named as *Striatriletes microverrucosus* Cenozone.

### *Striatriletes microverrucosus* Cenozone

*Type section*—Silchar-Halflong road section near Bandarkhal Village at the U-shape bend of the road (0-5, Text-fig. 1).

*Lithology*—Mostly highly fissile to splintery shales, generally with alternation of sandstone/siltstone.

*Lower contact*—Thin band of sandstone.

*Upper contact*—Hard sandstone.

*Distinguishing characters of Cenozone*—This zone is represented by the dominance of *Cyathidites minor, Striatriletes microverrucosus, Polypodiaceaesporites tertiarus, Pinuspollenites crestus* and *Phragmothyrites eocaenicus.*

*Palaeoecology*—The sediments were deposited mostly in fresh water condition.

*Age*—Late Eocene.

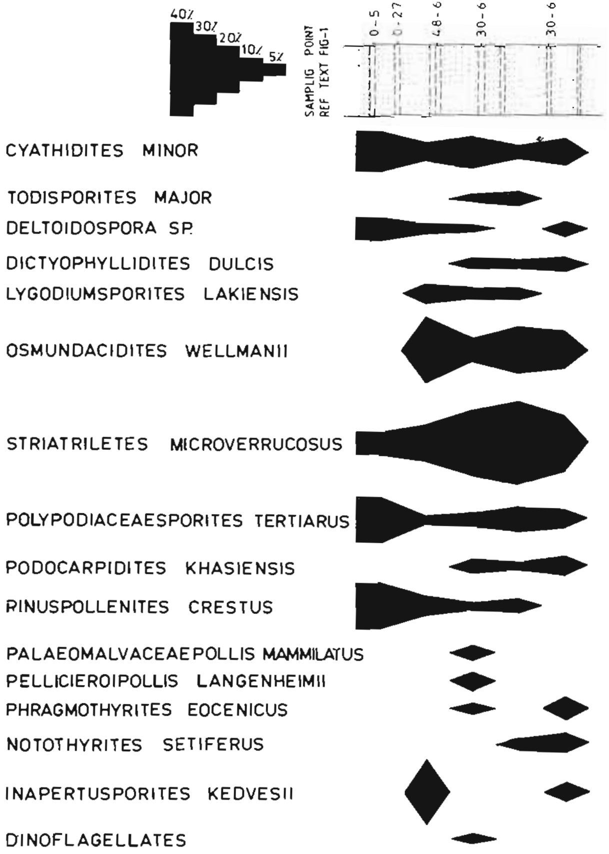
*Correlation with other cenozones*—This cenozone is not comparable to any of the known cenozones.

## LAISONG ASSEMBLAGE

This formation is well exposed along Silchar-Halflong road section. One hundred and thirty samples were macerated, out of which 70 samples yielded microfossils. Palynotaxa recovered from this formation are listed below:

*Cyathidites minor* Couper 1953
*Todisporites major* Couper 1958
*Dictyophyllidites dulcis* Kar 1985
*Lygodiumsporites lakiensis* Sah & Kar 1969
*Intrapunctisporis apunctis* Krutzsch 1959
*I. intrapunctis* Krutzsch 1959
*Lycopodiumsporites palaeocenicus* Dutta & Sah 1970
*L. globatus* Kar 1985
*Lycopodiumsporites* sp.
*Osmundacidites wellmanii* Couper 1953
*Striatriletes susannae* van der Hammen emend. Kar 1979
*S. paucicostatus* Kar 1985
*S. multicostatus* Kar & Saxena 1981
*S. microverrucosus* Kar & Saxena 1981
*Malayaeaspora costata* Trivedi, Ambwani & Kar 1981
*Deltoidospora* sp.
*Dandotiaspora telonata* Sah, Kar & Singh 1971
*Densoisporites* sp.
*Verrucosisporites* sp.
*Dulhuntyispora dulhuntyi* Potonié 1956
*Polypodiaceaesporites tertiarus* Dutta & Sah 1970
*P chatterjii* Kar 1979
*Polypodiisporites repandus* Takahashi 1964
*Podocarpidites khasiensis* Dutta & Sah 1970
*Pinuspollenites crestus* Kar 1985
*Klausipollenites sulcatus* Kar, Kieser & Jain 1972
*Neocouperipollis achinatus* (Sah & Kar) Kar & Kumar 1986
*Tetracolporites* sp.
*Monoporisporites* sp.
*Palaeomalvaceaepollis mammilatus* Kar 1985
*Inapertusporites kedvesii* Elsik 1968
*Phragmothyrites eocaenicus* Edwards emend. Kar & Saxena 1976
*Bicellaesporites* sp.
*Diporicellaesporites* sp.
*Spiniferites hypercanthus* (Deflandre & Cookson) Cookson & Eisenack 1974
*S. bulloideus* (Deflandre & Cookson) Sarjeant 1970
*Operculodinium* sp. cf. *O. centrocarpum* (Deflandre & Cookson) Wall 1967

In addition, 6 genera and 4 species are reworked palynofossils, viz., *Dandotiaspora telonata, Densoisporites* sp., *Verrucosisporites* sp., *Dulhuntyispora dulhuntyi, Klausipollenites sulcatus* and *Neocouperipollis achinatus* (Text-fig. 2).



**Text-figure 2**—Percentage of different spore-pollen species in Laisong Formation.

*Palynological zonation*—The assemblage is assigned to the *Osmundacidites wellmanii* Cenozone.

### *Osmundacidites wellmanii* Cenozone

*Type section*—Silchar-Halflong road section, opposite to Bandarkhal Village (40—0, Text-fig. 1).

*Lithology*—Hard sandstone with occasional layers of shale and siltstone.

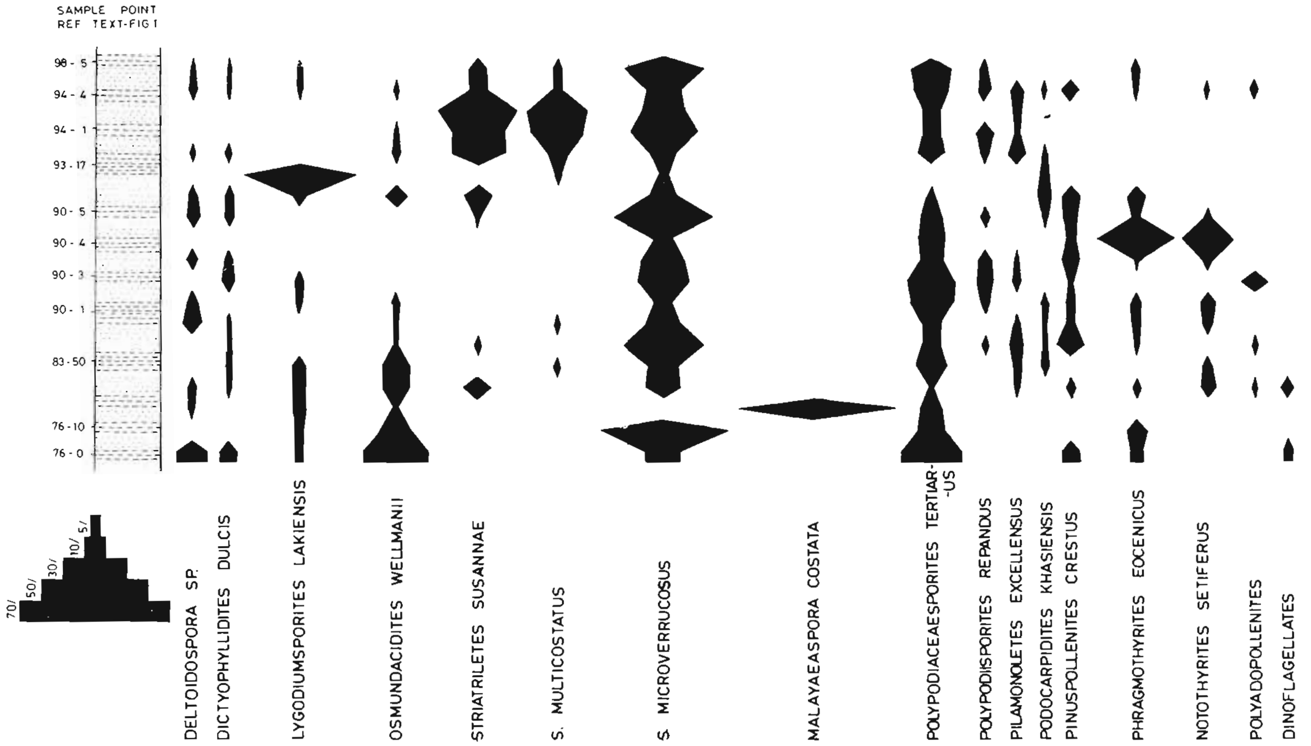
*Lower contact*—Hard sandstone.

*Upper contact*—Hard sandstone.

*Distinguishing characters of Cenozone*—It i recognized by good representation of *Cyathidite minor, Osmundacidites wellmanii, Striatrilete microverrucosus, Polypodiaceaesporites tertiaru Pinuspollenites crestus* and *Inapertusporites kedvesi*

*Palaeoecology*—The sediments were deposite in fluviatile conditions.

*Age*—Early Oligocene.



**Text-figure 3**—Percentage of different palynotaxa in Jenam Formation.

*Correlation with other cenozones*—This zone resembles *Striatriletes microverrucosus* Cenozone in the common presence of several forms but is distinguished by its high representation of *Osmundacidites wellmanii.*

## JENAM ASSEMBLAGE

Fifty samples from this formation was macerated and 38 samples yielded spores and pollen grains belonging to following 49 genera and 42 identifiable species (Text-fig. 3).

*Cyathidites minor* Couper 1953
*Todisporites major* Couper 1958
*Dictyophyllidites dulcis* Kar 1985
*Lygodiumsporites lakiensis* Sah & Kar 1969
*Deltoidospora* sp.
*Intrapunctisporis apunctis* Krutzsch 1959
*Alsophilidites* sp.
*Dandotiaspora plicata* (Sah & Kar) Sah, Kar & Singh 1971

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## PLATE 2

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(All photomicrographs, unless otherwise mentioned, are × 500)

1. *Polypodiaceaesporites levis* Sah; slide no. BSIP 10082, H26/4.

2,4. *Polypodiaceaesporites chatterjii* Kar; slide nos. BSIP 10083, R15 1, 10084, P34/1.

3,18,21 *Cyathidites minor* Couper; slide nos. BSIP 10021, T30; 10088, Z34; 10078, U22.

5,26. *Osmundacidites wellmanii* Couper; slide nos. BSIP 10083, P26/3; 10089, O26/3.

6. *Notothyrites setiferus* Cookson; slide no. BSIP 10036, H4 1

7,11. *Phragmothyrites eocaenicus* Edwards emend. Kar· slide nos. BSIP 10028, S36; 10037, O40 2

8. *Podocarpidites khasiensis* Sah & Kar; slide no. BSIP 10026; T30.

9. *Todisporites kutchensis* Sah & Kar; slide no. BSIP 10070, L22.

10. *Indotriradites sparsus* Tiwari; slide no. BSIP 10092, W45/3.

12. *Klausipollenites sulcatus* Kar, Kieser & Jain; slide no. BSIP 10029, R48.

13,14,15. *Polypodiaceaesporites haardti* Thiergart; slide nos. BSIP 10086, Q42/4; 10092, U12/4; 10093, G26.

16. *Biretisporites convexus* Sah & Kar; slide no. BSIP 10079, R34/2.

17,22,24. *Lygodiumsporites lakiensis* Sah & Kar; slide nos. BSIP 10021, R34; X23; 10094, R13/4.

19. *Parmathyrites indicus* Jain & Gupta; slide no. BSIP 10037, U44.

20. *Tsugaepollenites velatus* Kar; slide no. BSIP 10091, O7

23. *Lycopodiumsporites globatus* Kar; Slide no. BSIP 10096, H15/4.

25. *Triporoletes* sp; slide no. BSIP 10067, Y28.

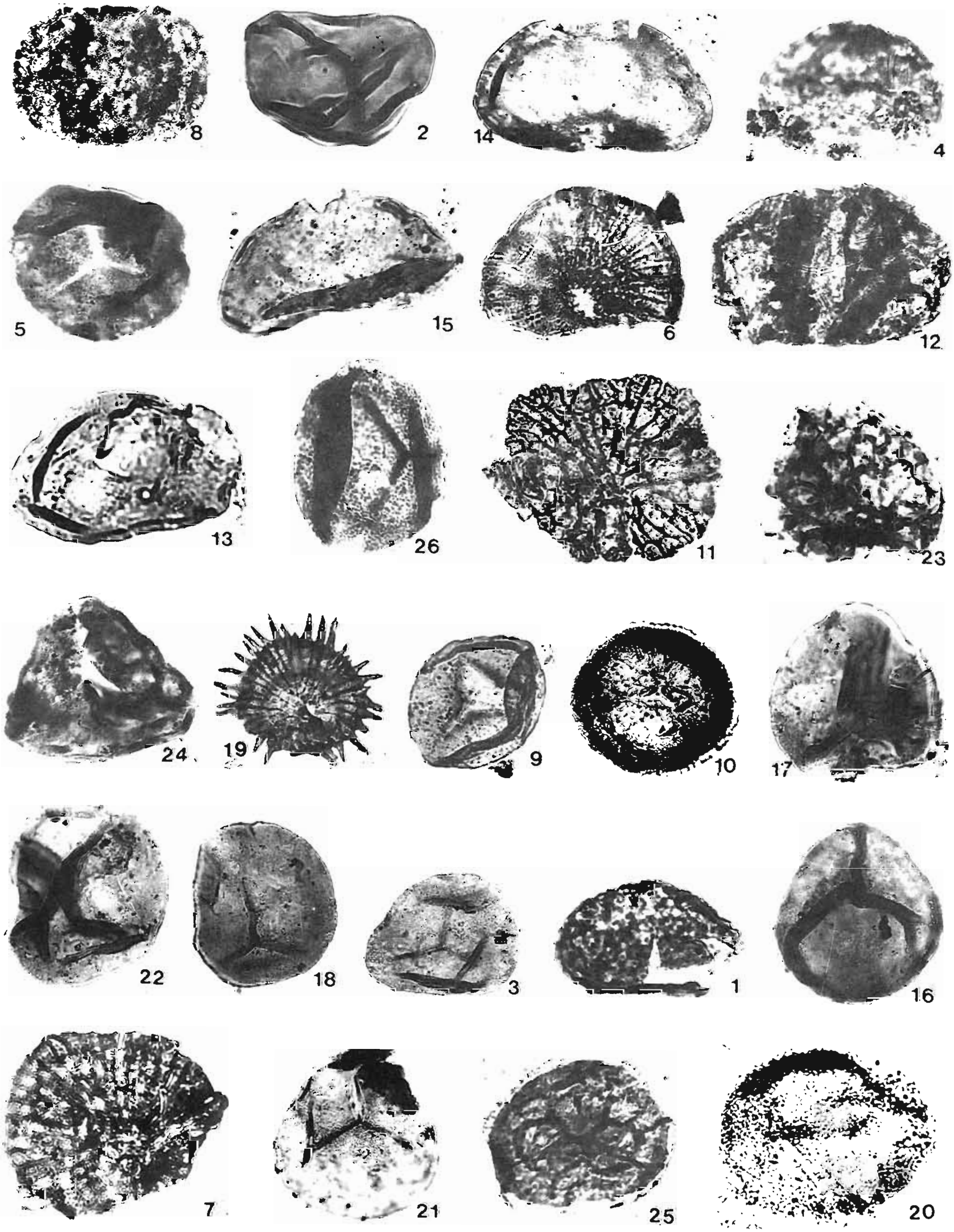


**PLATE 2**

*Neocalamospora* sp.
*Azolla aglochidia* Kar 1985
*Osmundacidites wellmanii* Couper 1953
*Lycopodiacidites* sp.
*Lycopodiumsporites globatus* Kar 1985
*Striatriletes susannae* van der Hammen emend. Kar 1979
*S. paucicostatus* Kar 1985
*S. multicostatus* Kar & Saxena 1981
*S. microverrucosus* Kar & Saxena 1981
*Cheilanthoidspora monoleta* Sah & Kar 1974
*Verrucosisporites* sp.
*Polypodiaceaesporites levis* Sah 1967
*P. tertiarus* Dutta & Sah 1970
*P. chatterjii* Kar 1979
*P haardti* Thiergart 1940
*Polypodiisporites repandus* Takahashi 1964
*P. ornatus* Sah 1967
*Tiwariasporis* sp.
*Pilamonoletes excellensus* Kar (MS.)
*Psiloschizosporis psilata* Kar & Saxena 1981
*Psiloschizosporis* sp.
*Podocarpidites khasiensis* Dutta & Sah 1970
*Abiespollenites cognatus* Kar 1985
*Pinuspollenites crestus* Kar 1985
*Piceapollenites excellensus* Kar 1985
*Klausipollenites sulcatus* Kar, Kieser & Jain 1972
*K. decipiens* Jansonius 1962
*Platysaccus* sp.
*Rhizomaspora radiata* Wilson 1962
*Tsugaepollenites velatus* Kar 1985
*Neocouperipollis kutchensis* (Venkatachala & Kar) Kar & Kumar 1986
*N. achinatus* (Sah & Kar) Kar & Kumar 1986
*Spinizonocolpites echinatus* Muller 1968
*Magnamonocolpites miocenicus* Kar 1985
*Tricolpites reticulatus* Cookson 1947
*Retitrescolpites* sp.
*Acanthotricolpites brevicolpus* Kar (MS.)
*Platoniapollenites iratus* Sah & Kar 1974
*Retistephanocolpites* sp.
*Tetracolporites* sp.
*Polyadopollenites* sp.
*Pellicieroipollis langenheimii* Sah & Kar 1970
*Palaeomalvaceaepollis mammilatus* Kar 1985
*Inapertusporites kedvesii* Elsik 1968
*Phragmothyrites eocaenicus* Edwards emend. Kar & Saxena 1981
*Notothyrites setiferus* Cookson 1947
*Monoporisporites* spp.
*Lacrimasporonites* sp.
*Bicellaesporites* sp.
*Pluricellaesporites* sp.
*Multicellaesporites* sp.

There are also few dinoflagellates in the assemblage. The above list includes reworked Palaeozoic, Mesozoic and older Tertiary forms, too. These are: *Neocalamospora* sp., *Klausipollenites sulcatus, Klausipollenites decipiens, Platysaccus* sp., *Rhizomaspora radiata, Neocouperipollis kutchensis, Neocouperipollis achinatus, Spinizonocolpites echinatus, Platoniapollenites iratus* and *Pellicieroipollis langenheimii.*

The assemblage is divisible into (i) *Malayaeaspora costata* Cenozone, (ii) *Polypodiaceaesporites tertiarus* Cenozone, and (iii) *Striatriletes susannae* Cenozone in ascending order.

### *Malayaeaspora costata* Cenozone

*Type section*—Silchar-Halflong road section between 76·0-88·50 points (Text-fig. 1).

*Lithology*—Mainly sandstone with occasional thin layers of carbonaceous shale.

*Lower contact*—Thick sandstone.

*Upper contact*—Thick sandstone.

*Distinguishing characters of Cenozone*—This has the dominance of *Malayaeaspora costata, Striatriletes microverrucosus, Osmundacidites wellmanii* and *Polypodiaceaesporites tertiarus.*

*Palaeoecology*—The deposition took place in fluviatile condition.

*Age*—Middle Oligocene.

*Correlation with other cenozones*—This cenozone compares well with the *Osmundacidites wellmanii* Cenozone of Laisong Formation in the representation of *Osmundacidites wellmanii, Striatriletes microverrucosus* and *Polypodiaceaesporites tertiarus.* However, insignificant contribution by *Cyathidites minor* and *Pinuspollenites crestus* and prominent representation of *Malayaeaspora costata* differentiate this cenozone.

### *Polypodiaceaesporites tertiarus* Cenozone

*Type section*—Silchar-Halflong road section between 90·0 to 90·20·5 points (Text-fig. 1).

*Lithology*—Hard, compact sandstone with alternation of shale.

*Lower contact*—A sandstone band.

*Upper contact*—A sandstone band.

*Distinguishing characters of Cenozone*—Abundance of *Polypodiaceaesporites tertiarus, Striatriletes microverrucosus, Phragmothyrites eocaenicus* and *Notothyrites setiferus.*

*Palaeoecology*—The sediments were deposited in fluviatile condition.

*Age*—Middle Oligocene.

*Correlation with other cenozones*—

*Malayaeaspora costata* Cenozone resembles this zone in the presence of *Striatriletes microverrucosus, Osmundacidites wellmanii* and *Polypodiaceaesporites tertiarus.* However, substantial contribution of *Phragmothyrites eocaenicus* and *Notothyrites setiferus* in this cenozone distinguishes it from the preceding one.

### *Striatriletes susannae* Cenozone

*Type section*—Silchar-Halflong road section between 93·17 to 98·0·5 points (Text-fig. 1)

*Lithology*—Mostly sandstone with thin partings of carbonaceous shale.

*Lower contact*—Thick sandstone.

*Upper contact*—A hard sandstone band.

*Distinguishing characters of Cenozone*—Fair presence of *Striatriletes susannae, Striatriletes multicostatus, Striatriletes microverrucosus, Lygodiumsporites lakiensis* and *Polypodiaceaesporites tertiarus.*

*Palaeoecology*—The sediments were deposited in fluviatile condition.

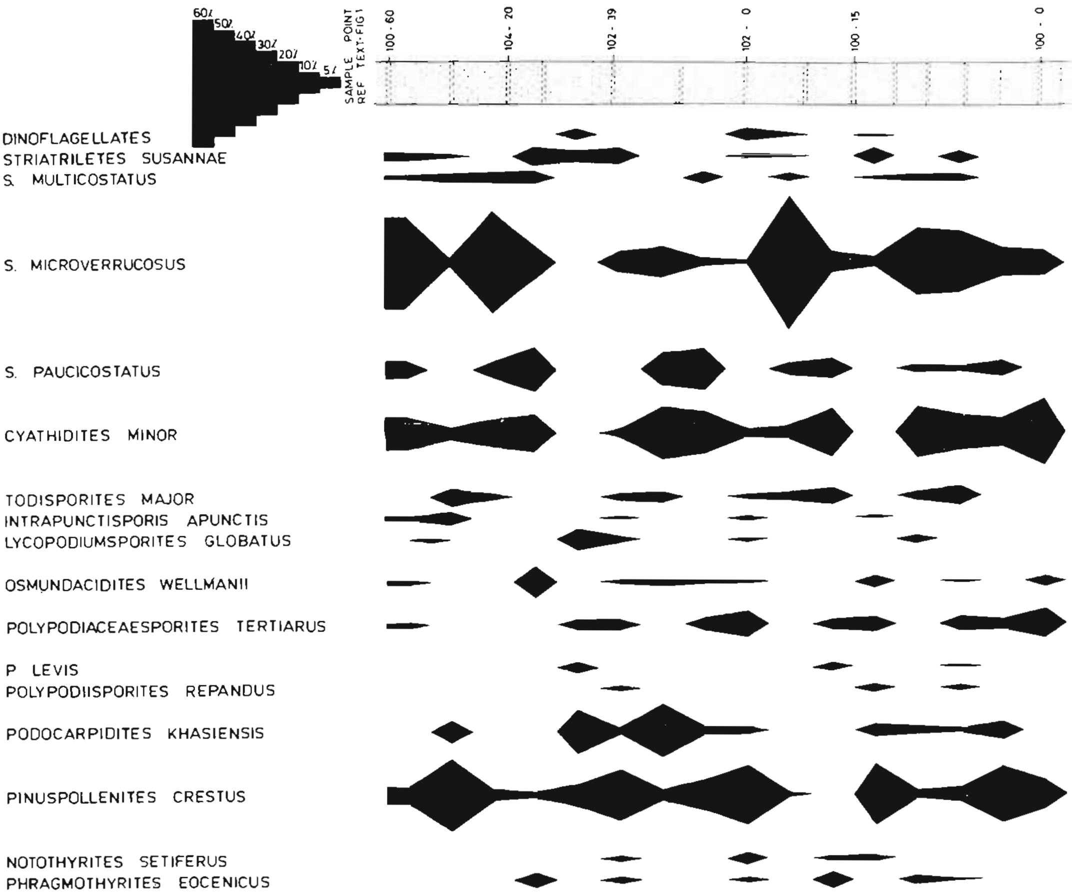
*Age*—Middle Oligocene.

*Correlation with other cenozones*—*Polypodiaceaesporites tertiarus* Cenozone is not correlatable with the present one. *Striatriletes susannae* Cenozone of Rokhia bore hole core no. 1, Gajalia 1 and Baramura 2 closely resemble this cenozone as the assemblage is dominated by *Striatriletes. Phragmothyrites eocaenicus* Cenozone of Lakwa bore hole core no. 22 resembles this cenozone in the representation of *Striatriletes susannae* but is differentiated by its ill-representation of *Phragmothyrites eocaenicus. Striatriletes susannae* Cenozone of Lakwa bore-hole core no. 22 compares well with this assemblage in the dominance of *Striatriletes susannae* but other constituents, e.g., *Inapertusporites kedvesii, Phragmothyrites eocaenicus* and *Tricolpites reticulatus* are not found in good percentage in the present cenozone.

## RENJI ASSEMBLAGE

Twenty-eight samples from this formation were macerated, out of which 17 samples yielded palynofossils.The following 47 genera and 52 species were recovered:

*Cyathidites minor* Couper 1953
*Deltoidospora* sp.
*Alsophilidites* sp.
*Todisporites kutchensis* Sah & Kar 1969
*T. major* Couper 1958
*Lygodiumsporites lakiensis* Sah & Kar 1969
*Lygodiumsporites* sp.
*Biretisporites convexus* Sah & Kar 1969
*Intrapunctisporis intrapunctis* Krutzsch 1959
*I. apunctis* Krutzsch 1959
*Dictyophyllidites dulcis* Kar 1985
*D. kyrtomatus* Kar & Kumar 1987
*Lycopodiumsporites globatus* Kar 1985
*Lycopodiacidites* sp.
*Osmundacidites wellmanii* Couper 1953
*Striatriletes susannae* van der Hammen emend. Kar 1979
*S. paucicostatus* Kar 1985
*S. multicostatus* Kar & Saxena 1981
*S. microverrucosus* Kar & Saxena 1981
*S. aidaensis* Kar 1985
*Neocalamospora rotunda* Bose & Kar 1976
*Densoisporites velatus* Weyland & Krieger 1953
*Microbaculispora gondwanensis* Bharadwaj 1962
*Verrucosisporites* sp.
*Dulhuntyispora dulhuntyi* Potonié 1956
*Laevigatosporites lakiensis* Sah & Kar 1969
*Polypodiaceaesporites levis* Sah 1967
*P. tertiarus* Dutta & Sah 1970
*P. chatterjii* Kar 1979
*Polypodiisporites repandus* Takahashi 1964
*Seniasporites* sp.
*Pilamonoletes moderatus* Kar (MS.)
*Psiloschizosporis psilata* Kar & Saxena 1981
*P. scabratus* Kar 1985
*Podocarpidites classicus* Salujha, Kindra & Rehman 1972
*Pinuspollenites crestus* Kar 1985
*Piceapollenites excellensus* Kar 1985
*Abiespollenites cognatus* Kar 1985
*Tsugaepollenites velatus* Kar 1985
*Cuneatisporites radialis* Leschik 1955
*C. reticulatus* Kar, Kiesser & Jain 1972
*Platysaccus papilionis* Potonié & Klaus 1954
*Klausipollenites sulcatus* Kar, Kieser & Jain 1972
*Lahirites raniganjensis* Bharadwaj 1962
*Striatopodocarpites diffusus* Bharadwaj & Salujha 1964
*Verticipollenites secretus* Bharadwaj 1962
*Rhizomaspora costa* Venkatachala & Kar 1968
*Palmaepollenites kutchensis* Venkatachala & Kar 1969
*Neocouperipollis kutchensis* (Venkatachala & Kar) Kar & Kumar 1986
*Neocouperipollis* sp.
*Retitrescolpites* sp.
*Minutitricolporites minutus* (Sah & Kar) Kar 1985
*Tetracolporites* sp.
*Pellicieroipollis langenheimii* Sah & Kar 1970
*Palaeomalvaceaepollis mammilatus* Kar 1985



**Text-figure 4**—Percentage of different species in Renji Formation.

*P. rudis* Kar 1985

*Polyadopollenites* sp.

*Phragmothyrites eocaenicus* Edwards emend. Kar & Saxena 1976

*Kutchiathyrites eccentricus* Kar 1977

*Inapertusporites kedvesii* Elsik 1968

*Pluricellaesporites* sp.

Dinoflagellates

The reworked Palaeozoic forms found in this assemblage are: *Neocalamospora rotunda*, *Microbaculispora gondwanensis*, *Verrucosisporites* sp., *Dulhuntyispora dulhuntyi*, *Platysaccus papilionis*, *Lahirites raniganjensis*, *Striatopodocarpidites diffusus*, *Verticipollenites secretus* and *Rhizomaspora costa*. Mesozoic reworked forms are not many; they are represented by *Densoisporites velatus*, *Cuneatisporites reticulatus* and *Klausipollenites sulcatus*. The older Tertiary species encountered in the assemblage are: *Palmaepollenites kutchensis*, *Neocouperipollis kutchensis*, *Neocouperipollis* sp., *Minutitricolporites minutus* and *Pellicieroipollis langenheimii* (Text-fig. 4).

## Palynological Zonation

This palynological cenozone is named as *Cyathidites minor* Cenozone.

### *Cyathidites minor* Cenozone

*Type section*—Silchar-Halflong road section between 100·0 to 104·60 points (Text-fig. 1).

*Lithology*—Sandstone with occasional thin bands of highly fissile silty shale.

*Lower contact*—A hard sandstone.

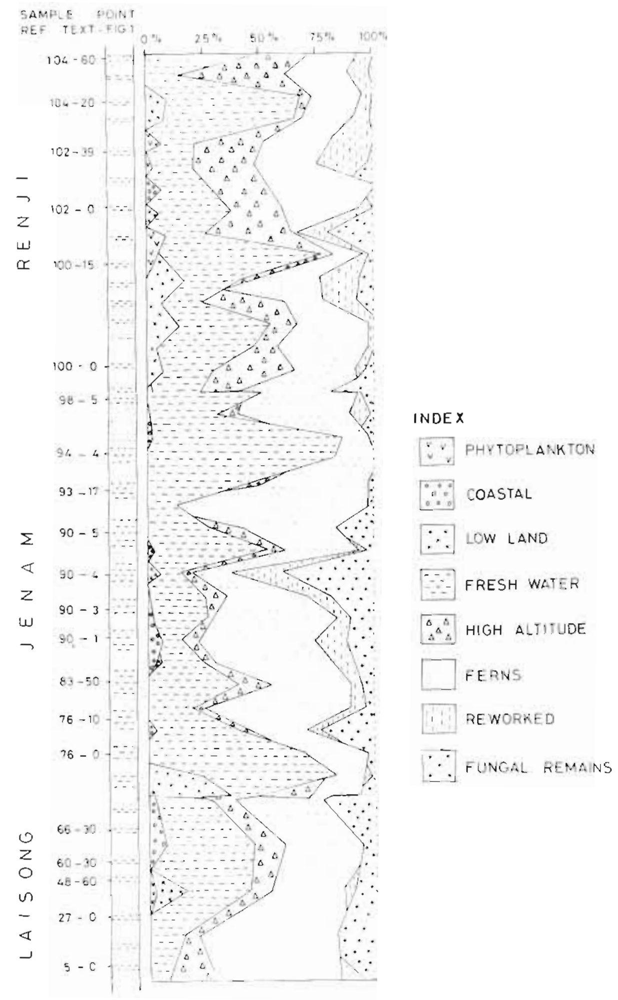
*Upper contact*—Sandstone.

*Distinguishing characters of Cenozone*—This shows the presence of *Cyathidites minor, striatriletes microverrucosus*, *Striatriletes paucicostatus*, *Pinuspollenites crestus* and *Podocarpidites khasiensis*.

*Palaeoecology*—The sediments were deposited in fluviatile environment.

*Age*—Late Oligocene.

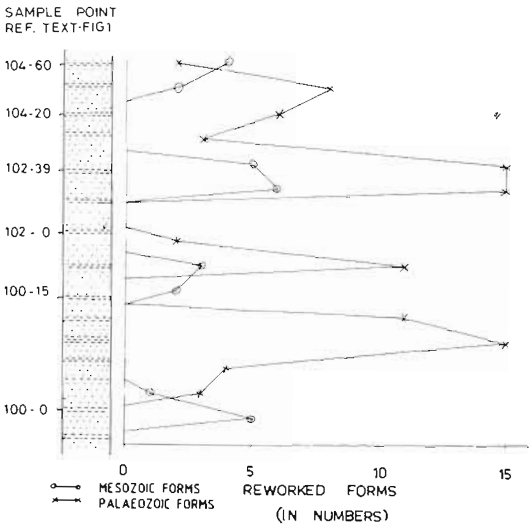
*Correlation with other cenozones*—*Striatriletes susannae* Cenozone—the topmost cenozone of



**Text-figure 5**—Summary diagram showing the representation of different ecological groups in Laisong, Jenam and Renji formations.

Jenam Formation, broadly resembles this cenozone in the abundance of *Striatriletes microverrucosus*. However, other dominant species of Jenam Formation, viz., *Striatriletes susannae, Striatriletes multicostatus* and *Polypodiaceaesporites tertiarus* though present in Renji Formation do not contribute much to the assemblage. Similarly, *Striatriletes susannae* Cenozone of Rokhia 1, Gajalia 1 and Baramura 2 proposed by Kar (MS) is only broadly comparable (Text-fig. 5).

*Cyathidites minor* Cenozone proposed for Lakwa bore-hole core no. 22 by Kar (MS) between the depth 3855-3390 m resembles this cenozone in the presence of *Cyathidites minor* in good numbers but the other dominant elements like *Polypodiisporites repandus, Polypodiaceaesporites* sp., *Striatriletes susannae* and *Phragmothyrites eocaenicus* are not found in appreciable percentage in this cenozone (Text-fig. 6).



**Text-figure 6**—Percentage of reworked Palaeozoic and Mesozoic spore-pollen in Renji Formation.

## BHUBAN ASSEMBLAGE

To distinguish the Upper Renji Formation from the Lower Bhuban at Silchar-Halflong road section, 14 samples were collected and macerated out of which 9 samples yielded the following palynological taxa:

*Cyathidites minor* Couper 1953
*Todisporites major* Couper 1958
*Deltoidospora* sp.
*Dictyophyllidites dulcis* Kar 1985
*Lygodiumsporites lakiensis* Sah & Kar 1969
*Intrapunctisporis apunctis* Krutzsch 1959
*Pteridacidites fistulosus* Sah 1967
*Azolla aglochidia* Kar 1984
*Osmundacidites wellmanii* Couper 1953
*Lycopodiumsporites globatus* Kar 1984
*Lycopodiacidites* sp.
*Striatriletes susannae* van der Hammen emend. Kar 1979
*S. paucicostatus* Kar 1985
*S. multicostatus* Kar & Saxena 1981
*S. microverrucosus* Kar & Saxena 1981
*S. aidaensis* Kar 1985
*Malayaeaspora costata* Trivedi, Ambwani & Kar 1981
*Indotriradities sparsus* Tiwari 1964
*Indotriradites korbaensis* Tiwari 1964
*Indotriradites* sp.
*Neocalamospora rotunda* Bose & Kar 1976
*Psilaplicates triangulus* Bose & Kar 1976
*Laevigatosporites lakiensis* Sah & Kar 1969
*Polypodiaceaesporites levis* Sah 1967
*P chatterjii* Kar 1979

*P baardti* Thiergart 1940
*Polypodiisporites repandus* Takahashi 1964
*P ornatus* Sah 1967
*Psiloschizosporis psilata* Kar & Saxena 1981
*Pilamonoletes moderatus* Kar (MS )
*Podocarpidites khasiensis* Dutta & Sah 1970
*Pinuspollenites crestus* Kar 1985
*Abiespollenites cognatus* Kar 1985
*Tsugaepollenites velatus* Kar 1985
*Klausipollenites sulcatus* Kar, Kieser & Jain 1972
*K. decipiens* Jansonius 1962
*Callialasporites monoalasporus* Dev 1961
*C. segmentatus* (Balme) de Jersey 1962
*Cuneatisporites reticulatus* Kar, Kieser & Jain 1972
*C. radialis* Leschik 1955
*Platysaccus papilionis* Potonié & Klaus 1954
*P queenslandi* de Jersey 1962
*Corisaccites alutas* Venkatachala & Kar 1969
*Lunatisporites* sp.
*Striatopodocarpites diffusus* Bharadwaj & Salujha 1964
*S. venustus* Bharadwaj 1962
*Rhizomaspora costa* Venkatachala & Kar 1969
*Faunipollenites varius* Bharadwaj 1962
*Limitisporites plicatus* Bose & Kar 1966
*Hindipollenites* sp.
*Elilasaccites elilaensis* Bose & Kar 1966
*Parasaccites korbaensis* Bharadwaj & Tiwari 1964
*Potonieisporites* sp.
*Plicatipollenites gondwanensis* Lele 1964
*Divarisaccus lelei* Venkatachala & Kar 1966
*Palaeomalvaceaepollis mammilatus* Kar 1985
*Polyadopollenites* sp.
*Notothyrites setiferus* Cookson 1947
*Phragmothyrites eocaenicus* Edwards emend. Kar & Saxena 1976
*Cordosphaeridium exilimurum* Davey & Williams 1966

The assemblage has a large number of reworked Palaeozoic and Mesozoic palynofossils. The Palaeozoic spores and pollen grains recovered are: *Indotriradites korbaensis, Indotriradites sparsus, Indotriradites* sp., *Neocalamospora rotunda, Psilaplicates triangulus, Cuneatisporites radialis, Platysaccus papilionis, Corisaccites alutas, Lunatisporites* sp., *Striatopodocarpites diffusus, Striatopodocarpites venustus, Faunipollenites varius, Limitisporites plicatus, Hindipollenites* sp., *Elilasaccites elilaensis, Parasaccites korbaensis, Potonieisporites* sp., *Plicatipollenites gondwanensis* and *Divarisaccus lelei.*

The Mesozoic forms found in the assemblage are: *Klausipollenites sulcatus, Klausipollenites decipiens, Callialasporites monoalasporus, Callialasporites segmentatus, Cuneatisporites reticulatus* and *Platysaccus queenslandii.*

It is to note here that no Palaeocene-Eocene palynofossils are met within the samples studied here. Such abundance of reworked Palaeozoic and Mesozoic forms in the assemblage is nowhere found in the section. This feature may be considered to distinguish it from the older formations. Perhaps the Himalayan upliftment continued to influence the deposition. The angiosperms are represented only by two genera and their contribution is also insignificant. However, the gymnosperms and the pteridophytes are well represented.

*Palynological zonation*—Fifteen species are well represented in the samples. The distribution pattern of these species are more or less same, therefore, only one cenozone, viz., *Pinuspollenites crestus* Cenozone is proposed for this formation.

### *Pinuspollenites crestus* Cenozone

*Type section*—Silchar-Halflong road section between 107 to 115-0 points (Text-fig. 1).

*Lithology*—Mainly sandy shale and sandstone.

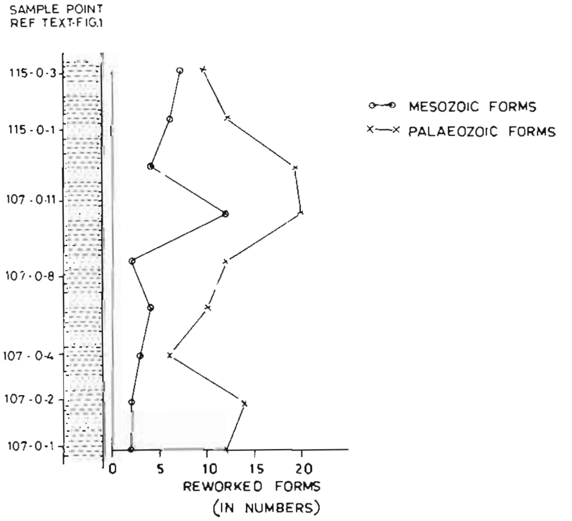
*Lower contact*—A hard sandstone band.

*Upper contact*—Sandstone.

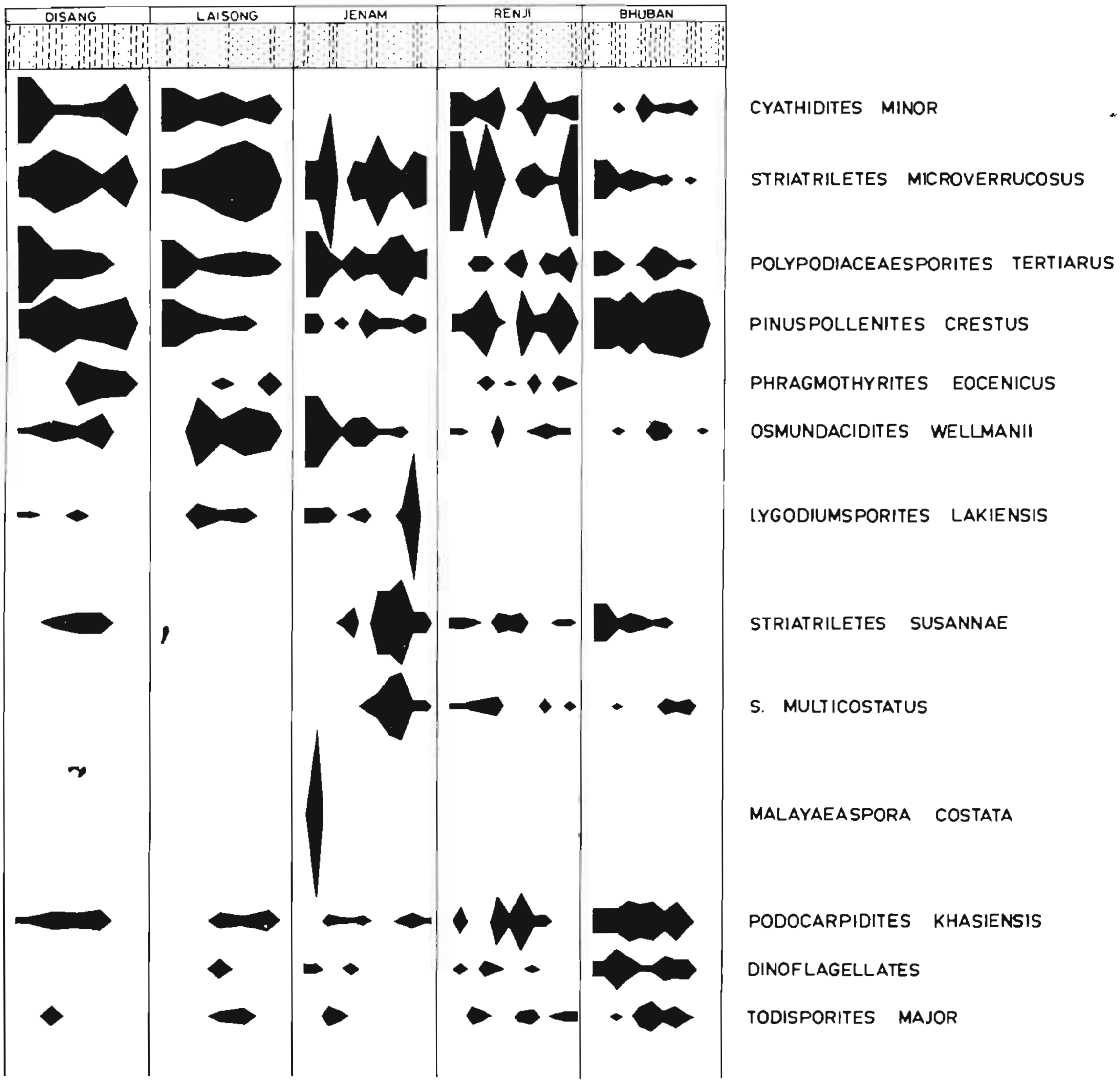
*Distinguishing characters of Cenozone*—Dominance of gymnospermous pollen grains represented by *Pinuspollenites crestus* and *Podocarpidites khasiensis* and presence of Palaeozoic and Mesozoic forms (Text-fig. 7).

*Palaeoecology*—The sediments were deposited in a flood plain.

*Age*—Miocene.



**Text-figure 7**—Distribution of reworked Palaeozoic and Mesozoic species in Bhuban Formation.



**Text-figure 8**—Distribution of stratigraphically important spore-pollen species in Disang, Laisong, Jenam, Renji and Bhuban formations.

*Correlation with other known Cenozones*—This cenozone resembles *Pinuspollenites crestus* Cenozone of Rokhia bore-hole core no. 1, Gajalia bore-hole core no. 1 and Baramura bore-hole core no. 2 by Kar (MS) The present one, however, slightly differs in the better representation of *Podocarpidites khasiensis* and in the absence of *Operculosculptites globatus*.

## DISCUSSION

Samples from Disang, Laisong, Jenam, Renji and Bhuban formations were investigated to distinguish the Disang (Upper Eocene) and Laisong (Early Oligocene) and to find out the finer differentiation of Barails and Renji (Late Oligocene) and Bhuban (Miocene) palynological boundary.

It has been observed that Disang and Laisong can be separated on the basis of palynofossils. In Disang *Phragmothyrites eocaenicus* and *Striatriletes susannae* are found in good percentage. In Laisong, these two species are hardly found and instead *Osmundacidites wellmanii* are very well represented. The contribution of *Polypodiaceaesporites tertiarus* is also comparatively reduced in the Laisong assemblage whereas that of *Striatriletes microverrucosus* is considerably increased (Text-fig. 8).

Laisong and Jenam formations are distinguished on the basis of the distribution of *Cyathidites minor, Lygodiumsporites lakiensis, Striatriletes susannae, Striatriletes multicostatus* and *Malayaeaspora costata*. In Laisong, *Cyathidites minor* is prominent but it is almost absent in Jenam Formation.

*Lygodiumsporites lakiensis, Striatriletes susannae, Striatriletes multicostatus* and *Malayaeaspora costata* are the dominant elements in Jenam, but are either ill-represented or totally absent in Laisong Formation.

Jenam and Renji formations, on the other hand, are distinguished on the basis of *Cyathidites minor, Polypodiaceaesporites tertiarus, Pinuspollenites crestus, Osmundacidites wellmanii, Malayaeaspora costata* and *Lygodiumsporites lakiensis. Cyathidites minor* reappears in Renji Formation in substantial percentage but the representation of *Polypodiaceaesporites tertiarus, Striatriletes susannae, Striatriletes multicostatus* and *Osmundacidites wellmanii* is reduced *Lygodiumsporites lakiensis* and *Malayaeaspora costata* are almost absent in Renji Formation.

Renji and Bhuban formations are easily demarcated by the proportionate occurrence of gymnospermous pollen grains. *Pinuspollenites crestus* and *Podocarpidites khasiensis* are present in both the formations, but in Bhuban their representation is maximum. Beside contribution of *Striatriletes microverrucosus, Cyathidites minor* also considerably dwindles but the percentage of dinoflagellates increases in Bhuban Formation. The reworked Palaeozoic and Mesozoic forms are also maximum in this formation.

Salujha and Kindra (1986) also worked out the Palynostratigraphy of the Silchar-Halflong road traverse and proposed 5 palynological zones for the Barail sediments. Of these, only the lower most and the third zones are moderately fossiliferous; others are poor in spores and pollen grains. All these zones are not comparable to the present ones as *Stephanoporopollenites validus, Tricolpites ovatus* and *Polyporina globosa* found in most of those zones as dominant forms are absent here. The assemblage recorded here is dominated by pteridophytic spores and the angiospermic pollen.

### Comparison with other cenozones of Barail Group

Saxena *et al.* (1987) proposed *Polysphaeridium subtile* and *Todisporites major* cenozones for Lower and Upper Laisong Formation exposed along Sonarpur-Badarpur road section, Jaintia Hills, Meghalaya. *Polysphaeridium subtile* Cenozone has abundance of phytoplanktons. *Osmundacidites wellmanii* Cenozone proposed here for Laisong does not exhibit resemblance as the Sonarpur-Badarpur assemblage is dominated by dinoflagellates. However, *Cyathidites minor* and *Lygodiumsporites lakiensis* are found as dominant species in both.

*Todisporites major* Cenozone has *Cordosphaeridium multispinosum, Cordosphaeridium fibrospinosum, Polysphaeridium subtile, Striatriletes susannae, Biretisporites oligocenicus, Todisporites major, Lygodiumsporites lakiensis, Lygodiumsporites eocenicus, Polyadopollenites sahnii* and *Echistephanocolpites meghalayaensis* as dominant elements. This cenozone resembles the present one by the dominance of pteridophytic spores and some of the dominant forms, like *Lygodiumsporites lakiensis* and *Todisporites major*, are also common.

Saxena *et al.* (1987) also proposed *Lygodiumsporites eocenicus* Cenozone for Jenam and Renji formations. This cenozone is characterized by the high frequency of pteridophytic spores mostly represented by *Striatriletes susannae, Striatriletes pachyexinus, Lygodiumsporites eocenicus, Lygodiumsporites lakiensis, Todisporites major, Polypodiaceaesporites tertiarus, Podocarpidites meghalayaensis, Laricoidites punctatus* and *Polyadopollenites sahnii.* Out of these, *Striatriletes susannae, Lygodiumsporites eocenicus, Lygodiumsporites lakiensis, Todisporites major* and *Polypodiaceaesporites tertiarus* are also found in Jenam and Renji, but the present assemblage is more diversified.

## ACKNOWLEDGEMENTS

The author is grateful to Dr B. S. Venkatachala, Director, BSIP for encouragement during the progress of this work. Sincere appreciation is expressed to the authorities of KDM Institute of Petroleum Exploration, Dehradun and the Central Region, Calcutta of the Oil & Natural Gas Commission for assisting in the field work by deputing Sri B. N. Srivastava, Superintending Geologist and Sri R. K. Singhal, Surveyor. The financial support rendered by the Oil Industry Development Board, New Delhi to complete the project is gratefully acknowledged.

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# Palynological investigation of Arthungal bore-hole, Alleppey District, Kerala

M. R. Rao

Rao, M. R. 1990. Palynological investigation of Arthungal bore-hole, Alleppey District, Kerala. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 243-255.

Palynological assemblage from the Arthungal bore-hole (Alleppey District, Kerala) consists of 49 genera and 65 species of pteridophytic spores and angiospermous pollen. Dinoflagellate cysts and fungal remains have also been reported. *Liliacidites keralaensis* and *Jacobipollenites arthungalensis* have been established as new species. The palynological succession has been divided into three cenozones, viz., *Triangulorites bellus* Cenozone, *Crassoretitriletes vanraadshooveni* Cenozone and *Malvacearumpollis bakonyensis* Cenozone. Palynological data depict a warm and humid tropical climate with plenty of rainfall during the time of deposition. Palynofossils belonging to lowland, fresh water swamp and water edge, back mangrove and coastal floras have been identified. Palynological succession ranges from Eocene-Early Miocene in age.

**Key-words**—Palaeopalynology, Palaeoecology, Eocene-Early Miocene (India).

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## साराँश

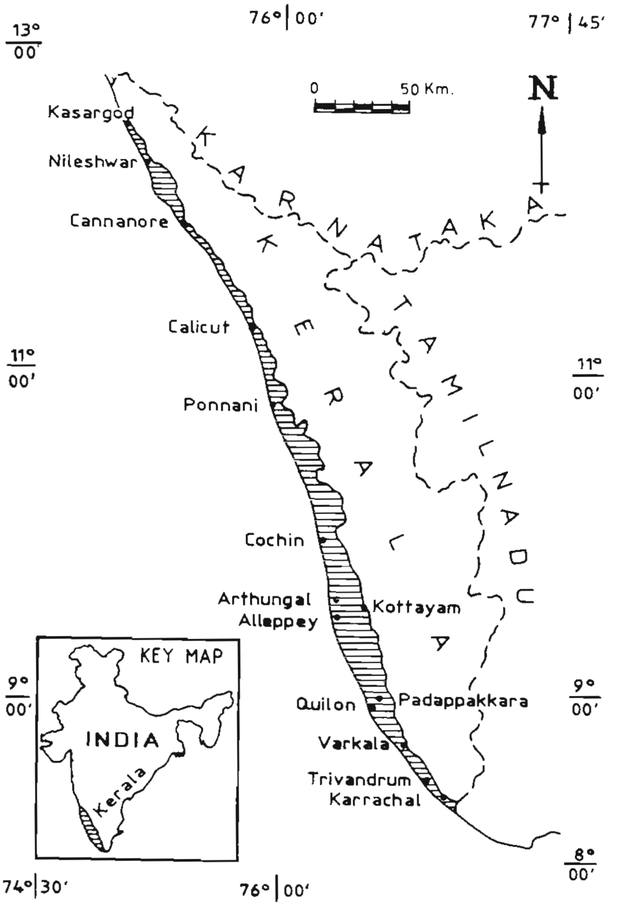
### केरल में अॅलेप्पी जनपद में आरथुंगल वेधछिद्र का परागाणविक अन्वेषण

मुलागलापल्ली रामचन्द्र राव

आरथुंगल वेध-छिद्र (अॅलेप्पी जनपद, केरल) से प्राप्त परागाणविक समुच्चय में टेरीडोफाइटी बीजाणुओं एवं आवृतबीजी परागकणों की 49 प्रजातियाँ एवं 65 जातियाँ मिली हैं। **लिलिएसीडाइटिस केरलायेन्सिस** एवं **जेकबिपोलिनाइटिस आरथुंगलेन्सिस** नामक नई जातियाँ बनाई गई हैं। परागाणविक अनुक्रम तीन नवमंडलों में विभक्त किया गया है। ये **ट्राइएंगुलोराइटिस बैल्लस** नवमंडल, **क्रेसोरेटिट्राइलिटीस वानराडशूवेनाई** नवमंडल एवं **माल्वेसियरमपॉलिस बेकॉनयेन्सिस** नवमंडल हैं। उपलब्ध परागाणविक आँकड़े निक्षेपण के समय अत्याधिक वर्षा के साथ-साथ उष्ण एवं नम उष्णकटिबन्धीय जलवायु प्रदर्शित करते हैं। निम्नभूमि, स्वच्छ जल वाली दलदल, पश्च मैंग्रोव एवं तटीय वनस्पतिजात के अश्मित परागकण अभिनिर्धारित किये गये हैं। उपलब्ध परागाणविक अनुक्रम आदिनूतन से प्रारम्भिक मध्यनूतन काल तक विस्तृत है।

PALYNOFOSSILS have been recovered from Arthungal (9° 39″ 32 : 76° 17″ 50) bore-hole (440.70 m depth) in Alleppey District, Kerala (Map 1) The area is covered by coastal alluvium composed of sand and sandy clay. This is underlain by a sequence of alternating beds of clays and sandstones with band of lignite. The lithological details of the samples are as follows:

| | Depth/range in m | Lithology |
|---|---|---|
| 1 | 430.70-442.70 | Carbonaceous sand |
| 2. | 418.70-430.70 | Clayey sand |
| 3. | 412.70-418.70 | Clayey sand |
| 4. | 409.70-412.70 | Clayey sand |
| 5. | 379.70-409.70 | Clayey sand |
| 6. | 322.70-379.70 | Carbonaceous sand |
| 7 | 274.70-322.70 | Coarse carbonaceous sand |
| 8. | 271.70-274.70 | Clayey sand |
| 9. | 268.70-271.70 | Lignite |
| 10. | 241.70-268.70 | Carbonaceous sandy clay |
| 11 | 205.70-241.70 | Carbonaceous sandy clay |
| 12. | 157.70-205.70 | Sandy clay |
| 13. | 151.70-157.70 | Sandy clay |
| 14. | 142.70-151.70 | Clayey sand |
| 15. | 124.70-142.70 | Clayey sand |
| 16. | 100.70-124.70 | Clayey sand |
| 17 | 91.70-100.70 | Clayey sand |
| 18. | 76.70- 91.70 | Clayey sand |
| 19. | 46.70- 76.70 | Sand |
| 20. | 31.70- 46.70 | Clayey sand |
| 21. | 22.70- 31.70 | Carbonaceous clayey sand |
| 22. | 16.70- 22.70 | Sand |
| 23. | 7.70- 16.70 | Sandy clay |
| 24. | 0.00- 7.70 | Coarse sand |



**Map 1**—Localities of Tertiary exposures in Kerala Basin.

The Tertiary sediments of Kerala coast are known as Warkalli and Quilon beds; they were first described by King (1882) and Foote (1883). The Quilon beds consist of fossiliferous limestones with intercalations of calcareous clays, carbonaceous clays and sands, while the Warkalli beds include variegated sandstone interbedded with white plastic and variegated clays, carbonaceous clays and seams of lignite or peaty lignite. The Tertiary sequence rests unconformably over the Archean crystalline complex and is succeeded by recent to subrecent marine and estuarine sediments (Poulose & Narayanaswami, 1968).

Palynological studies of the Tertiary sediments of Kerala have been done by Rao and Vimal (1953), Potonié and Sah (1960), Ramanujam (1977), Ramanujam and Rao (1971), Rao and Ramanujam (1978, 1982), Kar and Jain (1981), Varma, Ramanujam and Patil (1986) and Varma (1987). Raha, Rajendran and Kar (1987) for the first time reported Eocene-Early Miocene palyno-assemblages from 600 metres deep bore-hole near Ambalapuzha in Alleppey District, Kerala.

Out of 24 samples, 18 are productive. The palynofossils include 49 genera and 65 species of pteridophytic spores and angiospermous pollen. Dinoflagellate cysts and fungal remains are also present. The slides and negatives are deposited at the Birbal Sahni Institute of Palaeobotany, Lucknow.

The following spore-pollen species are present

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**PLATE 1** →

(All photomicrographs *ca.* × 500; Coordinates on Olympus Microscope no. 217267, BH. 2).

1, 2. *Liliacidites keralaensis* sp. nov., Slide no. BSIP 9909; Coordinates: 15.5 × 162.9 (Holotype); 19.3 × 136.5.

3. *Retipilonapites arcotense* Ramanujam, Slide no. BSIP 9910; Coordinates: 15.7 × 163.6.

4. *Longapertites hammenii* Rao & Ramanujam, Slide no. BSIP 9911; Coordinates: 8.5 × 143.8.

5. *Palmaepollenites kutchensis* Venkatachala & Kar, Slide no. BSIP 9912; Coordinates: 20.0 × 130.6.

6. *Palmaepollenites eocenicus* (Biswas) Sah & Dutta, Slide no. BSIP 9913; Coordinates: 8.8 × 145.2.

7. *Polypodiaceaesporites intrapunctis* Rao & Ramanujam, Slide no. BSIP 9914; Coordinates: 20.5 × 151.5.

8. *Laevigatosporites ovatus* Wilson & Webster, Slide no. BSIP 9915; Coordinates: 16.4 × 165.2.

9. *Clavainaperturites clavatus* v.d. Hammen & Wijmstra, Slide no. BSIP 9916; Coordinates: 8.5 × 163.6.

10. *Palmidites maximus* Couper, Slide no. BSIP 9913; Coordinates: 6.5 × 126.5.

11, 12. *Cheilanthoidspora monoleta* Sah & Kar, Slide nos. BSIP 9917; Coordinates: 8.5 × 127.8; 9918, coordinates 12.0 × 138.1

13. *Cheilanthoidspora mioceneca* Kar & Jain, Slide no. BSIP 9919; Coordinates: 20.0 × 141.2.

14. *Inaperturopollenites* sp. cf. *I. punctatus* Saxena & Bhattacharyya, Slide no. BSIP 9911; Coordinates: 10.1 × 133.7

15. *Palmaepollenites keralensis* Rao & Ramanujam, Slide no. BSIP 9920; Coordinates: 11.5 × 129.6.

16. *Quilonipollenites sahnii* Rao & Ramanujam, Slide no. BSIP 9921; Coordinates: 6.0 × 138.6.

17. *Polypodiisporites ratnamii* Rao & Ramanujam, Slide no. BSIP 9922; Coordinates: 11.2 × 135.0.

18. *Polypodiisporites miocenicus* Rao & Ramanujam, Slide no. BSIP 9923; Coordinates: 10.0 × 162.8.

19. *Crassoretitriletes vanraadshooveni* Germeraad *et al.*, Slide no. BSIP 9924; Coordinates: 18.5 × 152.3.

20, 21. *Lygodiumsporites padappakkarensis* Rao & Ramanujam, Slide nos. BSIP 9913; Coordinates: 10.0 × 138.6, 9916; Coordinates: 8.7 × 133.0.

22. *Intrapunctisporis intrapunctis* Krutzsch, Slide no. BSIP 9925; Coordinates: 21.5 × 163.4.

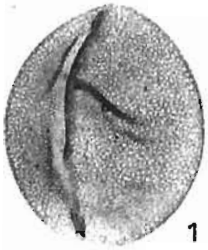
23. *Osmundacidites kutchensis* Sah & Kar, Slide no. BSIP 9913; Coordinates: 19.0 × 161.7.

24. *Verrucosisporites* sp., Slide no. BSIP 9926; Coordinates: 18.0 × 158.0.

25, 26. *Neocouperipollis (Couperipollis) kutchensis* (Venkatachala & Kar) Kar & Kumar, Slide nos. BSIP 9927; Coordinates: 15.5 × 164.5; 9925; Coordinates: 19.0 × 157.5.

27. *Foveotriletes* sp., Slide no. BSIP 9925; Coordinates: 8.7 × 167.7.

28. *Striatriletes susannae* v.d. Hammen emend. Kar, Slide no. BSIP 9928; Coordinates: 21.4 × 141.4.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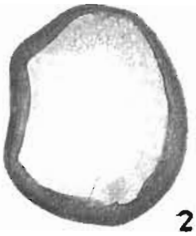
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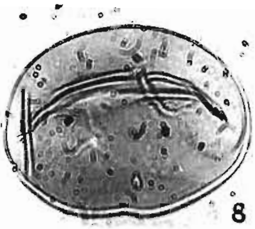
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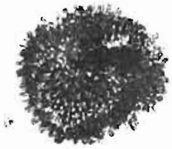
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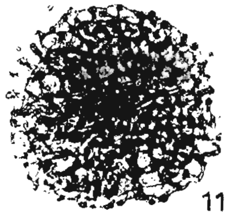
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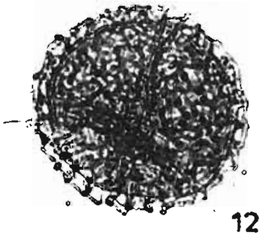
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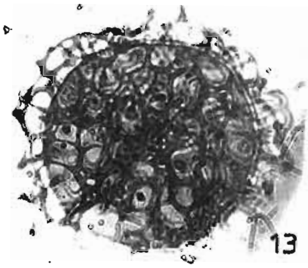
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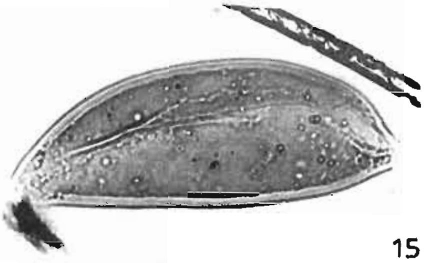
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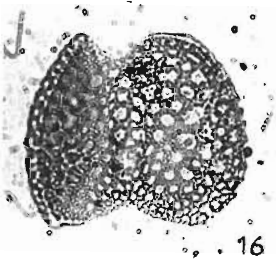
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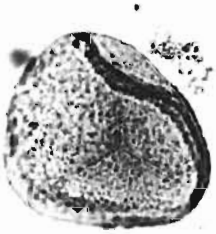
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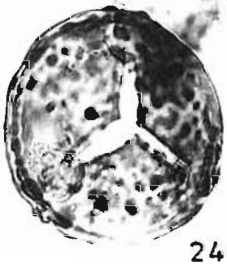
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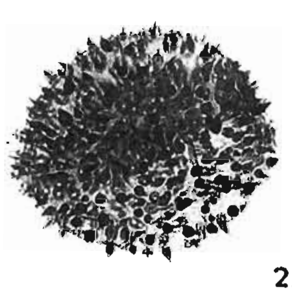
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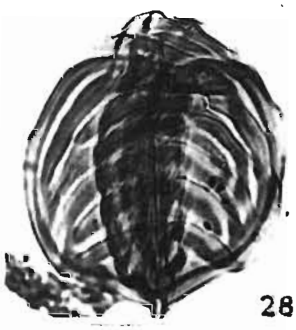
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**PLATE 1**

in the assemblage Palynotaxa marked with asterisks (*) are described in the text. The botanical affinities of the spore-pollen are given below:

*Schizaeaceae—Lygodiumsporites padappakkarensis* Rao & Ramanujam 1978 (Pl. 1, figs 20, 21), *Crassoretitriletes vanraadshooveni* Germeraad, Hopping & Muller 1968 (Pl. 1, fig. 19, Pl. 3, fig. 26).

*Osmundaceae—Osmundacidites kutchensis* Sah & Kar 1969 (Pl. 1, fig. 23).

*Parkeriaceae—Striatriletes susannae* van der Hammen emend. Kar 1979 (Pl. 1, fig. 28).

*Polypodiaceae—Laevigatosporites ovatus* Wilson & Webster 1946 (Pl. 1, fig. 8), *Polypodiaceaesporites intrapunctis* Rao & Ramanujam 1978 (Pl. 1, fig. 7), *Polypodiisporites miocenicus* Rao & Ramanujam 1978 (Pl 1, fig. 18), *P ratnamii* Rao & Ramanujam 1978 (Pl. 1, fig. 17).

*Potamogetonaceae—Retipilonapites arcotense* Ramanujam 1966 (Pl. 1, fig. 3), *Clavainaperturites clavatus* van der Hammen & Wijmstra 1964 (Pl 1, fig. 9).

*Palmae—Palmidites maximus* Couper 1953 (Pl. 1, fig. 10), *Palmaepollenites eocenicus* (Biswas) Sah & Dutta 1966 (Pl. 1, fig. 6), *P kutchensis* Venkatachala & Kar 1969 (Pl. 1, fig. 5), *P. keralensis* Rao & Ramanujam 1978 (Pl. 1, fig. 15), *Longapertites hammenii* Rao & Ramanujam 1978 (Pl. 1, fig. 4), *Neocouperipollis kutchensis* (Venkatachala & Kar) Kar & Kumar 1987 (Pl 1, figs 25, 26), *Quilonipollenites sahnii* Rao & Ramanujam 1978 (Pl. 1, fig. 16; Pl. 2, fig. 22), *Trilatiporites noremi* Ramanujam 1966 (Pl. 3, figs 2, 3).

*Liliaceae*—* *Liliacidites keralaensis* sp. nov. (Pl 1, figs 1, 2).

*Oleaceae—Retitrescolpites singularis* Rao & Ramanujam 1982 (Pl. 2, fig. 13).

*Ctenolophonaceae—Ctenolophonidites costatus* van Hoeken Klinkenberg 1966 (Pl. 2, figs 18, 19).

*Bombacaceae—Lakiapollis ovatus* Venkatachala & Kar 1969 (Pl. 2, fig. 29; Pl. 3, fig. 16).

*Euphorbiaceae—Tricolporopollis decoris* Dutta & Sah 1970 (Pl. 2, fig. 15).

*Meliaceae—Meliapollis ramanujamii* Sah & Kar 1970 (Pl. 2, fig. 28), *M. quadrangularis* (Ramanujam) Sah & Kar 1970 (Pl. 2, fig. 3).

*Caesalpiniaceae—Margocolporites tsukadai* Ramanujam 1966 (Pl. 2, fig. 27), *M. sahnii* Ramanujam 1966 (Pl. 2, figs 5, 6), *Trisyncolpites ramanujamii* Kar 1979 (Pl. 2, fig. 20).

*Rubiaceae—Retitricolporites crassioratus* Rao & Ramanujam 1982 (Pl. 2, fig. 7), *Favitricolporites magnus* Sah 1967 (Pl. 2, fig. 8).

*Polygalaceae—Polybrevicolporites karii* Rao & Ramanujam 1982 (Pl. 3, fig. 9).

*Apocynaceae—Psilodiporites hammenii* Varma & Rawat 1963 (Pl. 3, fig. 5).

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## PLATE 2

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(All photomicrographs *ca.* × 500; Coordinates on Olympus microscope no. 217267 : BH2)

1, 2. *Sastriipollenites trilobatus* Venkatachala & Kar, Slide nos. BSIP 9929; Coordinates: 6.0 × 160.4; 9930; Coordinates: 17.5 × 129.0.

3. *Meliapollis quadrangularis* (Ramanujam) Sah & Kar, Slide no. BSIP 9922; Coordinates: 6.0 × 171.0.

4. *Verrutricolpites* sp., Slide no. BSIP 9931; Coordinates: 12.0 × 135.0.

5, 6. *Margocolporites sahnii* Ramanujam, Slide no. BSIP 9932; Coordinates: 16.0 × 139.3.

7 *Retitricolporites crassioratus* Rao & Ramanujam, Slide no. BSIP 9930; Coordinates: 9.3 × 146.0.

8. *Favitricolporites magnus* Sah, Slide no. BSIP 9933; Coordinates: 6.4 × 168.0.

9. *Tricolporopollis rubra* Dutta & Sah, Slide no. BSIP 9919; Coordinates: 14.0 × 154.4.

10. *Polycolpites* sp., Slide no. BSIP 9921; Coordinates: 8.5 × 148.5.

11 *Retistephanocolpites* sp., Slide no. BSIP 9924; Coordinates: 20.0 × 140.2.

12. *Dermatobrevicolporites (Triorites) dermatus* (Sah & Kar) Kar, Slide no. BSIP 9934; Coordinates: 12.3 × 151.0.

13. *Retitrescolpites singularis* Rao & Ramanujam, Slide no. BSIP 9935; Coordinates: 11.0 × 131.5.

14. *Tricolpites retipilatus* Kar & Jain, Slide no. BSIP 9936; Coordinates: 8.3 × 161.5.

15. *Tricolporopollis decoris* Dutta & Sah, Slide no. BSIP 9921; Coordinates: 8.5 × 156.5.

16. *Tricolporopollis* (Venkatachala & Kar) *matanamadhensis* Tripathi & Singh, Slide no. BSIP 9928; Coordinates: 18.0 × 167.0.

17. *Gemmatricolpites* sp., Slide no. BSIP 9926; Coordinates: 16.0 × 130.6.

18, 19. *Ctenolophonidites costatus* (van Hoeken-Klinkenberg) Slide nos. BSIP 9916; Coordinates: 11.0 × 138.5; 9937; Coordinates: 18.5 × 158.4.

20. *Trisyncolpites ramanujamii* Kar, Slide no. BSIP 9915; Coordinates: 10.0 × 136.8.

21. *Tricolpites crassireticulatus* Dutta & Sah, Slide no. BSIP 9916; Coordinates: 9.0 × 155.2.

22. *Quilonipollenites sahnii* Rao & Ramanujam, Slide no. BSIP 9925; Coordinates: 9.0 × 155.2.

23. *Tricolpites retibaculatus* Saxena, Slide no. BSIP 9913; Coordinates: 20.3 × 164.0.

24, 25. *Triangulorites bellus* (Sah & Kar) Kar, Slide nos. BSIP 9929; Coordinates: 4.2 × 147.4; 9923; Coordinates: 14.5 × 137.2.

26. *Tricolpites matanomadhensis* Saxena, Slide no. BSIP 9924; Coordinates: 15.0 × 142.0.

27 *Margocolporites tsukadai* Ramanujam, Slide no. BSIP 9919; Coordinates: 11.6 × 156.9.

28. *Meliapollis ramanujamii* Sah & Kar, Slide no. BSIP 9930; Coordinates: 11.4 × 148.0.

29. *Lakiapollis ovatus* Venkatachala & Kar, Slide no. BSIP 9924; Coordinates: 14.4 × 165.0.

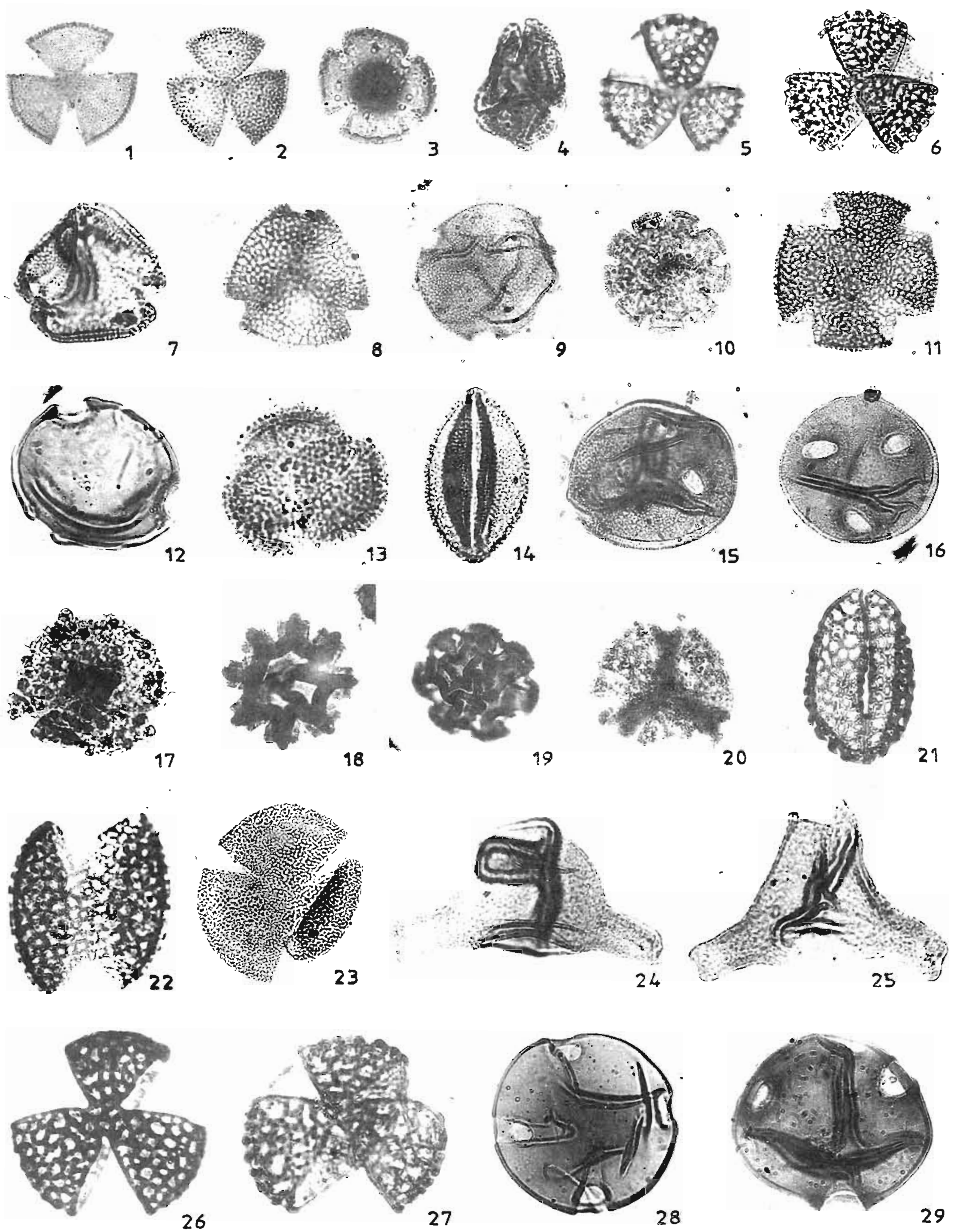

PLATE 2

*Moraceae—Triporopollenites minutus* Rao & Ramanujam 1982 (Pl. 3, fig. 4).

*Proteaceae—Proteacidites triangulus* Kar & Jain 1981 (Pl. 3, figs 17, 18), *P truncatus* Rao & Ramanujam 1982 (Pl. 3, fig. 7).

*Chenopodiaceae—Chenopodipollis miocenica* Kar & Jain 1981 (Pl. 3, fig. 6).

*Malvaceae—Malvacearumpollis bakonyensis* Nagy 1962 (Pl. 3, figs 22, 23).

*Uncertain affinity—Intrapunctisporis intrapunctis* Krutzsch 1959 (Pl. 1, fig. 22), *Foveotriletes* sp. (Pl. 1, fig. 27), *Verrucosisporites* sp. (Pl. 1, fig. 24), *Cheilanthoidspora monoleta* Sah & Kar 1974 (Pl. 1, figs 11, 12), *C. mioceneca* Kar & Jain 1981 (Pl. 1, fig. 13), *Inaperturopollenites* sp. cf. *I. punctatus* Saxena & Bhattacharyya 1987 (Pl. 1, fig. 14), *Tricolpites crassireticulatus* Dutta & Sah 1970 (Pl. 2, fig. 21), *T. retibaculatus* Saxena 1979 (Pl. 2, fig. 23), *T matanomadhensis* Saxena 1979 (Pl. 2, fig. 26), *T. retipilatus* Kar & Jain 1981 (Pl. 2, fig. 14), *Tricolpites* sp. (Pl. 3, fig. 21), *Verrutricolpites* sp. (Pl. 2, fig. 4), *Gemmatricolpites* sp. (Pl. 2, fig. 17), *Retistephanocolpites* sp. (Pl. 2, fig. 11), *Polycolpites* sp. (Pl. 2, fig. 10), *Tricolporopollis rubra* Dutta & Sah 1970 (Pl. 2, fig. 9), *T matanamadhensis* Tripathi & Singh 1985 (Pl 2, fig. 16), *Sastriipollenites trilobatus* Venkatachala & Kar 1969 (Pl. 2, figs 1, 2), *Dermatobrevicolporites dermatus* (Sah & Kar) Kar 1985 (Pl. 2, fig. 28), *Retitricolporites* sp. (Pl. 3, fig. 29), *Striacolporites ovatus* Sah & Kar 1970 (Pl. 3, fig. 28), *S. cephalus* Sah & Kar 1970 (Pl. 3, fig. 10), *Verrucolporites verrucus* Sah & Kar 1970 (Pl. 3, fig. 8), **Jacobipollenites arthungalensis* sp. nov. (Pl. 3, figs 11, 24), *Verrutriporites* sp. (Pl. 3, fig. 19), *Triangulorites bellus* (Sah & Kar) Kar 1985 (Pl. 2, figs 24, 25), *Polyporina multiporosa* Kar 1985 (Pl. 3, fig. 1) and *Ornatetradites droseroides* Rao & Ramanujam 1982 (Pl. 3, fig. 27).

The taxa designated as 'sp.' in the check list are distinct and hence could not be assigned to any of the known species. Detailed morphological study of these taxa will be carried out later.

### Genus—*Liliacidites* Couper 1953

Type species—*Liliacidites kaitangataensis* Couper 1953

#### *Liliacidites keralaensis* sp. nov.

Pl. 1, figs 1, 2

*Holotype*—Pl. 1, fig. 1, size 65 μm; Slide no. BSIP 9909.

*Type locality*—Arthungal bore-hole, Alleppey District, Kerala, depth range 322.70-377.70 m.

*Diagnosis*—Pollen oval-elliptical, size range 60-70 × 34-50 μm, monosulcate, sulcus distinct, 6 μm long, 4 μm wide extending from one end to other; exine up to 3.5 μm thick, sexine ca 2.5 μm, nexine

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## PLATE 3 →

(All photomicrographs *ca.* × 500; Coordinates on Olympus microscope no. 217267. BH-2)

1. *Polyporina multiporosa* Kar; Slide no. BSIP 9938; Coordinates: 17.0 × 132.2.
2,3. *Trilatiporites noremi* Ramanujam, Slide no. BSIP 9934, Coordinates: 16.6 × 135.0.
4. *Triporopollenites minutus* Rao & Ramanujam, Slide no. BSIP 9937; Coordinates: 8.0 × 148.1.
5. *Psilodiporites hammenii* Varma & Rawat, Slide no. BSIP 9930; Coordinates: 10.5 × 150.3.
6. *Chenopodipollis miocenica* Kar & Jain, Slide no. BSIP 9939; Coordinates: 15.0 × 156.1.
7. *Proteacidites truncatus* Rao & Ramanujam, Slide no. BSIP 9940; Coordinates: 11.4 × 169.0.
8. *Verrucolporites verrucus* Sah & Kar, Slide no. BSIP 9914; Coordinates: 4.0 × 160.0.
9. *Polybrevicolporites karii* Rao & Ramanujam, Slide no. BSIP 9931; Coordinates: 9.3 × 160.0.
10. *Striacolporites cephalus* Sah & Kar, Slide no. BSIP 9913; Coordinates: 17.4 × 160.0.
11, 24. *Jacobipollenites arthungalensis* sp. nov., Slide no. BSIP 9936; Coordinates: 15.0 × 165.0; 9941; Coordinates: 8.6 × 159.0 (Holotype).
12. *Operculodinium* sp., Slide no. BSIP 9911; Coordinates: 6.3 × 158.0.
13. *Heliospermopsis hungaricus* Nagy, Slide no. BSIP 9937; Coordinates: 7.0 × 165.4.
14. *Lirasporis intergranifer* Potonié & Sah emend. Kar & Jain, Slide no. BSIP 9928; Coordinates: 19.5 × 127.0.
15. *Collumosphaera* sp., Slide no. BSIP 9919; Coordinates: 19.5 × 127.0.
16. *Lakiapollis ovatus* Venkatachala & Kar, Slide no. BSIP 9911; Coordinates: 18.0 × 149.5.
17-18. *Proteacidites triangulus* Kar & Jain, slide no. BSIP 9910; Coordinates: 16.0 × 168.2.
19. *Verrutriporites* sp., Slide no. BSIP 9909; Coordinates: 11.0 × 149.0.
20. *Achomosphaera* sp., Slide no. BSIP 9916; Coordinates: 7.5 × 134.0.
21. *Tricolpites* sp., Slide no. BSIP 9933; Coordinates: 21.5 × 143.6.
22-23. *Malvacearumpollis bakonyensis* Nagy, Slide no. BSIP 9939; Coordinates: 5.0 × 162.0.
25. *Thallasiphora* sp., Slide no. BSIP 9941; Coordinates: 17.5 × 160.6.
26. *Crassoretitriletes vanraadshooveni* Germeraad *et al.*, Slide no. BSIP 9942; Coordinates: 10.5 × 164.0.
27. *Ornatetradites droseroides* Rao & Ramanujam, Slide no. BSIP 9934; Coordinates: 4.0 × 147.8.
28. *Striacolporites ovatus* Sah & Kar, Slide no. BSIP 9930; Coordinates: 14.0 × 133.0.
29. *Retitricolporites* sp., Slide no. BSIP 9943; Coordinates: 8.5 × 139.0.

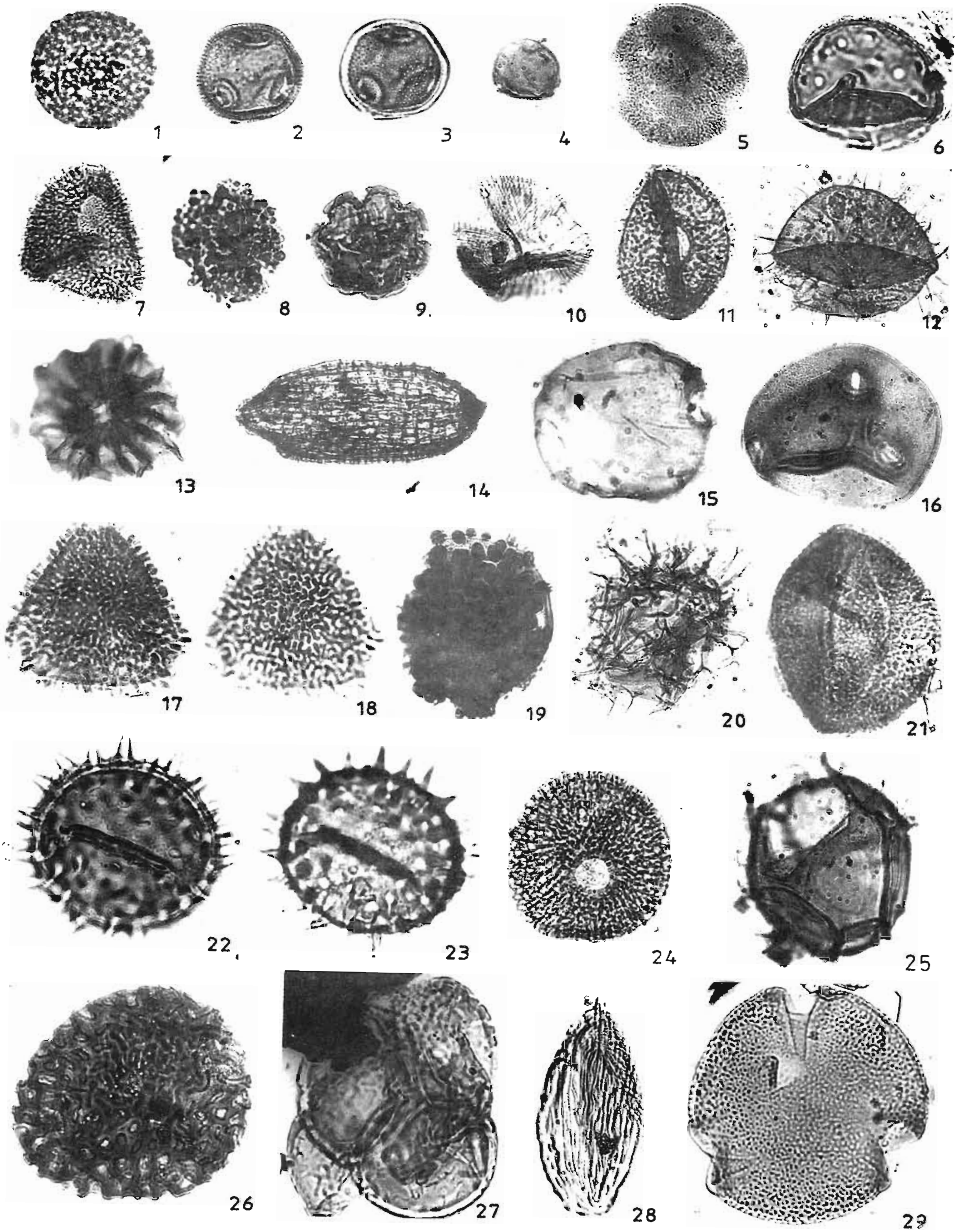
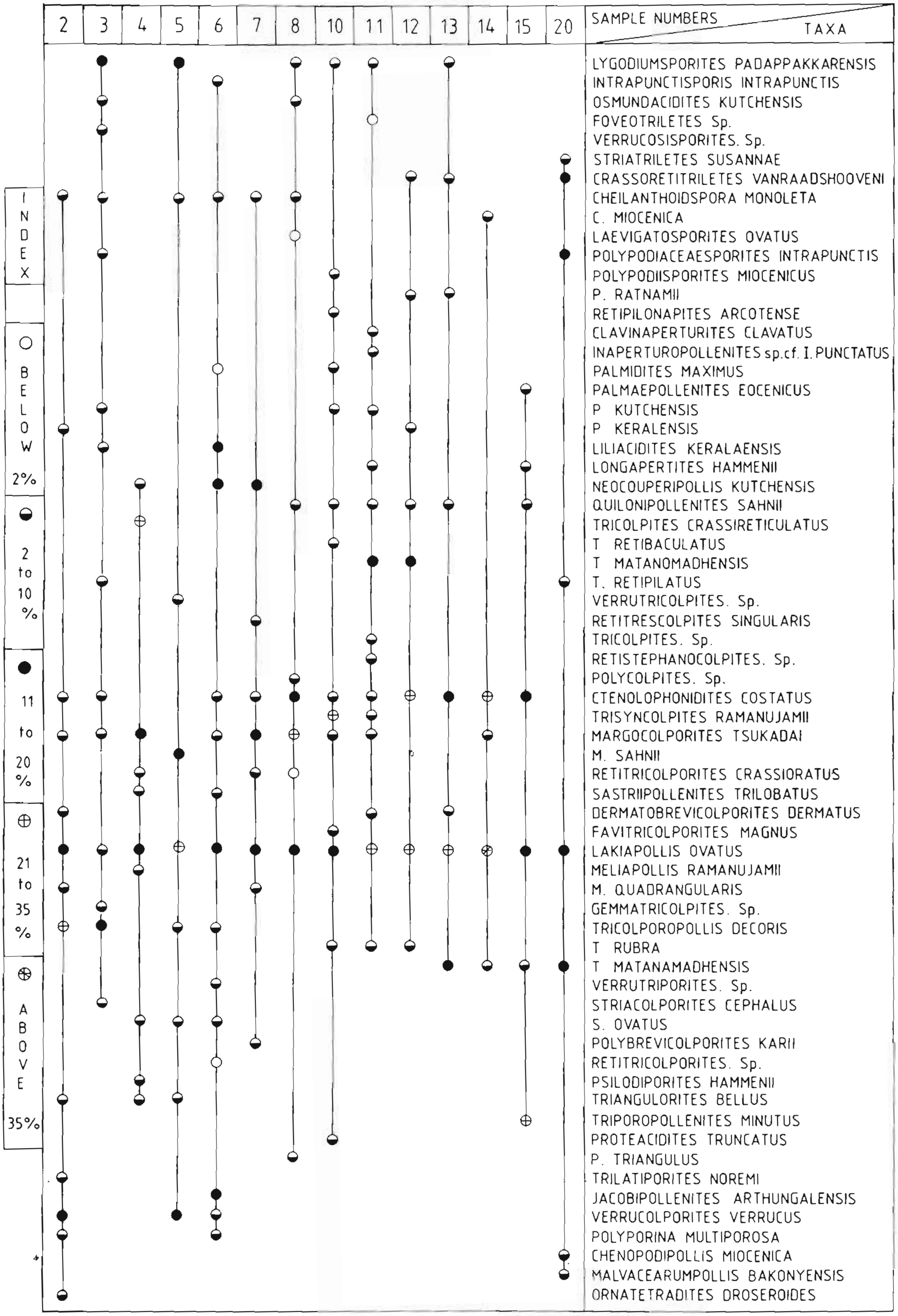


**PLATE 3**



**Text-figure 1**—Percentage frequency of palynotaxa in Arthungal bore-hole (frequency chart is based on samples where more than one hundred specimens could be counted).

*ca* 1 μm thick; surface finely reticulate, reticulum homobrochate, brochi up to 1 μm.

*Comparison—Liliacidites keralaensis* sp. nov. compares well with *L. kaitangataensis* Couper (1953) in its organization but the latter can be distinguished by its differential ornamentation pattern of the reticulate exine (lumina 5 μm at equator and 1 μm at poles). *L. baculatus* Venkatachala & Kar 1969 is distinguished by its funnel-shaped sulcus and intrabaculate exine. *L. ellipticus* Venkatachala & Kar 1969 is distinct by its boat-shaped sulcus and finely intrareticulate exine. *L. magnus* Jain, Kar & Sah 1973 is closely comparable by its ornamentation but the present species is differentiated by its tectate exine. *Liliacidites microreticulatus* Dutta & Sah 1970 is bigger in size (89 μm) and has differential ornamentation.

*Affinity*—Liliaceae.

### Genus—*Jacobipollenites* Ramanujam 1966

Type species—*Jacobipollenites magnificus* Ramanujam 1966.

*Jacobipollenites arthungalensis* sp. nov.
Pl. 3, figs 11, 24

*Holotype*—Pl. 3, fig. 24; size 60 μm; Slide no. BSIP 9941.

*Type locality*—Arthungal bore-hole, Alleppey District, Kerala, depth range 322.70-377.70 m.

*Diagnosis*—Pollen spheroidal, size 55-60 × 45-55 μm; monoporate, pore distinct, 10-12 μm wide, thick annulus present around pore; exine up to 4 μm thick, retipilate, surface showing retipilariate ornamentation.

*Comparison—Jacobipollenites arthungalensis* sp. nov. is closely comparable with *J. magnificus* Ramanujam 1966 in its general characters but the latter can be distinguished in having coarse reticulum and absence of annulus around pore.

*Affinity*—Unknown.

## PALYNOSTRATIGRAPHY

The three cenozones established are given below in ascending order (Text-fig. 2):

iii) *Malvacearumpollis bakonyensis* Cenozone
ii) *Crassoretitriletes vanraadshooveni* Cenozone
i) *Triangulorites bellus* Cenozone

### *Triangulorites bellus* Cenozone

*Type section*—Depth range 440.70-272.70 m.

*Lithology*—Mainly composed of sand and clayey sand, thickness 168 m.

*Nature of contact*—This cenozone constitutes the lowest biostratigraphic unit in the bore-hole. The sediments are conformably overlain by those which contain *Crassoretitriletes vanraadshooveni* Cenozone.

*Species restricted to this cenozone—Cheilanthoidspora monoleta, Liliacidites keralaensis, Neocouperipollis kutchensis, Tricolpites crassireticulatus, Polycolpites* sp., *Sastriipollenites trilobatus, Meliapollis ramanujamii, M. quadrangularis, Tricolporopollis decoris, Striacolporites cephalus, S. ovatus, Polybrevicolporites karii, Triangulorites bellus, Jacobipollenites arthungalensis* and *Verrucolporites verrucus.*

*Characteristic palynofossils—Ctenolophonidites costatus, Lakiapollis ovatus, Cheilanthoidspora monoleta, Liliacidites keralaensis, Neocouperipollis kutchensis, Polycolpites* sp., *Sastriipollenites trilobatus, Meliapollis ramanujamii, M. quadrangularis, Tricolporopollis decoris, Striacolporites cephalus, S. ovatus, Polybrevicolporites karii, Triangulorites bellus, Jacobipollenites arthungalensis* and *Verrucolporites verrucus.*

*Remarks*—The significant features of this cenozone are the restricted and common occurrence of *Tricolporopollis decoris* (20%), *Jacobipollenites arthungalensis* (18%), *Liliacidites keralaensis* (15%), *Neocouperipollis kutchensis* (11%) and restricted but rare representation of *Triangulorites bellus* (8%) and *Verrucolporites verrucus* (8%). *Lakiapollis ovatus* (25%) is the dominant taxon. *Tricolporopollis decoris* is abundant (26%) in the lower part but rare towards top (3%).

### *Crassoretitriletes vanraadshooveni* Cenozone

*Type section*—Depth range 271.70-151.70 m.

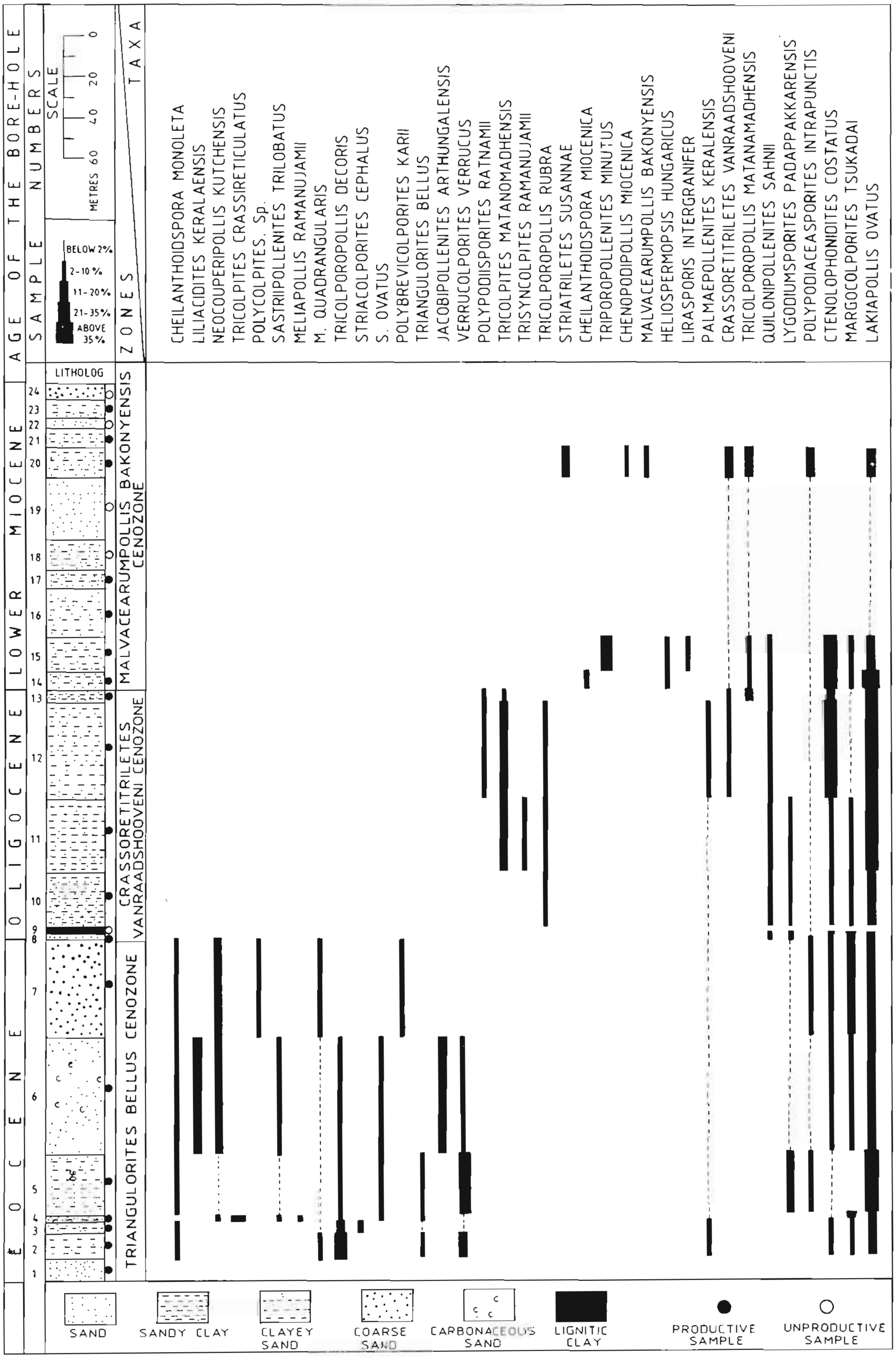
*Lithology*—Mainly sandy clay with a band of lignite; thickness 120 m.

*Nature of contact*—The upper part of the sediments which contains this cenozone is composed of sandy clay. It is conformably overlain by the clayey sand of *Malvacearumpollis bakonyensis* Cenozone.

*Species restricted to this cenozone—Polypodiisporites ratnamii, Tricolpites matanomadhensis, Tricolporopollis rubra* and *Trisyncolpites ramanujamii.*

*Characteristic palynofossils—Crassoretitriletes vanraadshooveni, Polypodiisporites ratnamii, Lygodiumsporites padappakkarensis, Polypodiaceaesporites intrapunctis, Ctenolophonidites costatus, Margocolporites tsukadai, Lakiapollis ovatus* and *Trisyncolpites ramanujamii.*

*Remarks*—The appearance of *Crassoretitriletes*



**Text-figure 2**—Palynostratigraphic zonation in Arthungal bore hole.
]

and *Trisyncolpites* is significant in these sediments. *Trisyncolpites* is restricted to this cenozone only. *Ctenolophonidites costatus* (49%) and *Lakiapollis ovatus* (25%) are the abundant taxa in this cenozone. *Lygodiumsporites padappakkarensis* (10%) is rare in the lower part and gradually decreases towards the top of the cenozone. Extinction of *Lakiapollis* and *Ctenolophonidites* at the post Eocene terminal event has been reported (Venkatachala *et al.*, 1989). However, their dominant occurrence in the Arthungal bore-hole (Eocene-Early Miocene) has been observed. The post Eocene appearance may be surmised either to reworking or to their continuation beyond Eocene.

*Malvacearumpollis bakonyensis* Cenozone

*Type section*—Depth range 151.70-7.70 m.

*Lithology*—Mainly clayey sand, upper part sandy clay alternating with sand, thickness 144 m.

*Nature of contact*—These sediments are overlain by carbonaceous sand and are devoid of palynofossils.

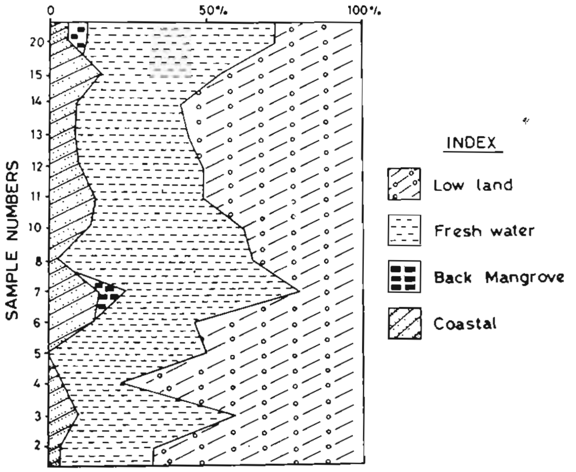
*Species restricted to this cenozone—Striatriletes susannae, Cheilanthoidspora mioceneca, Triporopollenites minutus, Chenopodipollis miocenica, Malvacearumpollis bakonyensis, Heliospermopsis hungaricus* and *Lirasporis intergranifer.*

*Characteristic palynofossils—Crassoretitriletes vanraadshooveni, Quilonipollenites sahnii, Polypodiaceaesporites intrapunctis, Ctenolophonidites costatus, Striatriletes susannae, Cheilanthoidspora mioceneca, Chenopodipollis miocenica, Malvacearumpollis bakonyensis, Heliospermopsis hungaricus, Lirasporis intergranifer* and *Lakiapollis ovatus.*

*Remarks*—This cenozone is characterized by the predominance of *Lakiapollis ovatus* (30%). *Malvacearumpollis bakonyensis* and *Chenopodipollis miocenica* appeared for the first time whereas *Lygodiumsporites padappakkarensis* and *Palmaepollenites keralensis* are absent. The relative increase in *Crassoretitriletes* and *Polypodiaceaesporites* has been recorded. *Ctenolophonidites costatus* is present only in the lower part of the cenozone and absent towards the top.

## PALAEOCLIMATE AND ENVIRONMENT OF DEPOSITION

The bore-hole assemblage is rich and diversified. These palynofossils can be divided into different ecological groups such as low-land, fresh-water swamp and water-edge, back-mangrove and coastal. The dinoflagellate cysts indicate shallow marine conditions. The frequency of different ecological groups has been given in Text-fig. 3.



**Text-figure 3**—Representation of different ecological groups in Arthungal bore-hole.

*Low-land flora*

| | |
|---|---|
| *Favitricolporites* | Rubiaceae |
| *Psilodiporites* | ?Apocynaceae |
| *Tricolporopollis* | Euphorbiaceae |
| *Lakiapollis* | Bombacaceae |

*Fresh-water swamp and water-edge flora*

| | |
|---|---|
| *Lygodiumsporites* | Schizaeaceae (*Lygodium*) |
| *Crassoretitriletes* | Schizaeaceae (*Lygodium*) |
| *Laevigatosporites* | Polypodiaceae |
| *Polypodiaceaesporites* | Polypodiaceae |
| *Polypodiisporites* | Polypodiaceae |
| *Striatriletes* | Parkeriaceae (*Ceratopteris*) |
| *Liliacidites* | Liliaceae |
| *Ctenolophonidites* | Ctenolophonaceae |
| *Margocolporites* | Caesalpiniaceae (*Caesalpinia*) |
| *Trisyncolpites* | Caesalpiniaceae |
| *Meliapollis* | Meliaceae |
| *Triporopollenites* | Moraceae |
| *Ornatetradites* | Droseraceae |
| *Retipilonapites* | Potamogetonaceae |
| *Clavainaperturites* | Potamogetonaceae |
| *Chenopodipollis* | Chenopodiaceae |

*Back-mangrove flora*

| | |
|---|---|
| *Meliapollis* | Meliaceae |
| *Malvacearumpollis* | Malvaceae |

*Coastal flora*

| | |
|---|---|
| *Trilatiporites* | Palmae (*Sclerosperma*) |
| *Palmaepollenites* | Palmae |

| | |
|---|---|
| *Quilonipollenites* | Palmae (*Eugeissonia*) |
| *Longapertites* | Palmae |
| *Neocouperipollis* | Palmae |

On the basis of the presence of spore/pollen of Schizaeaceae, Parkeriaceae, Osmundaceae, Liliaceae, Caesalpiniaceae, Meliaceae, Ctenolophonaceae, Oleaceae, Rubiaceae and Polygalaceae in the assemblage it has been inferred that the climate at the time of deposition was tropical.

The presence of fungal remains (*Phragmothyrites, Notothyrites, Multicellaesporites*, etc.) and the occurrence of ferns and representatives of tropical rain forest elements belonging to the families Ctenolophonaceae, Oleaceae and Moraceae confirm high degree of rainfall Thus, a humid and tropical climate with high rainfall has been inferred.

The presence of dinoflagellate cysts has been observed in the middle part (151.70-271.70 m) of the bore-hole which indicates that the sequence was deposited under shallow marine condition. The dinoflagellate cysts (*Operculodinium, Achomosphaera* and *Thallasiphora*) and the back mangrove flora suggest the existence of brackish water mangrove swamps The pollen types comparable to Potamogetonaceae (*Retipilonapites, Clavainaperturites*) and Droseraceae (*Ornatetradites*) are indicators of fresh-water lakes or ponds dotting the landscape. The prevailing near-shore conditions have been confirmed by the presence of palm pollen (*Palmidites, Palmaepollenites, Neocouperipollis* and *Quilonipollenites*).

## AGE OF THE SEDIMENTS

The *Triangulorites bellus* Cenozone ranges from 440.70 to 272.70 m. The genera restricted to this cenozone are usually found associated with the Eocene assemblages (Sah & Kar, 1970; Sah & Dutta, 1966; Dutta & Sah, 1970; Kar, 1985; Raha *et al.*, 1987). Hence this assemblage has been dated as Eocene.

The *Crassoretitriletes vanraadshooveni* Cenozone encompasses depth levels from 271.70-151.70 m. Germeraad, Hopping and Muller (1968) critically studied the occurrence and distribution of *Crassoretitriletes* in pantropical areas suggesting that this form appears for the first time in the Lower Oligocene sediments. In addition, Kar (1979) reported *Trisyncolpites ramanujamii* from the Oligocene sediments of Kutch and considered it a age-definitive. The first appearance of *Crassoretitriletes* and *Trisyncolpites* intermixed with the dominant elements like *Lygodiumsporites, Polypodiisporites, Margocolporites* and *Lakiapollis*, suggests Oligocene age.

The *Malvacearumpollis bakonyensis* Cenozone has been found to be distributed at depth levels ranging from 151.70-7.70 m. The genera are usually associated with the Miocene assemblages (Rao & Ramanujam, 1978, 1982; Kar & Jain, 1981; Venkatachala & Rawat, 1973; Rao *et al.*, 1985; Kar, 1985).

*Malvacearumpollis* is considered important for suggesting Early Miocene age. This genus occurs as a dominant element in the Khari Nadi Formation, Kutch (Kar, 1985) and Surma Group, Meghalaya and Assam (Rao *et al.*, 1985) though it is poorly represented in Kerala Basin. The first appearance of *Heliospermopsis* and *Lirasporis* and the predominance of *Crassoretitriletes* and *Quilonipollenites* coupled with *Striatriletes, Cheilanthoidspora mioceneca* and *Chenopodipollis miocenica* dates this assemblage as Early Miocene. From the above palynological data, it is inferred that the Arthungal bore-hole palynological succession ranges from Eocene to Early Miocene in age.

## CONCLUSIONS

1. The angiospermous pollen are qualitatively and quantitatively dominant elements of the Arthungal palynoflora.
2. The palynosequence in Arthungal bore-hole can be divided into three cenozones, viz., *Triangulorites bellus* Cenozone, *Crassoretitriletes vanraadshooveni* Cenozone and *Malvacearumpollis bakonyensis* Cenozone.
3. The palynoflora suggests a humid and tropical climate with plenty of rainfall during the deposition of these sediments.
4. The environment of deposition has been inferred as brackishwater mangrove swamps.
5. On the basis of palynological data, the sequence studied has been assigned Eocene-Early Miocene age

## ACKNOWLEDGEMENTS

I sincerely express my deep gratitude to Dr B. S. Venkatachala, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for constant encouragement and useful suggestions. The author is grateful to Dr H. P. Singh, Deputy Director, B.S.I.P. Lucknow for kindly going through the manuscript and giving useful suggestions. The author is thankful to the Director, Central Ground Water Board, Trivandrum for providing bore-hole samples.

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# Tertiary palynology of Kerala Basin—An overview

H. P. Singh & M. R. Rao

Singh, H. P. & Rao, M. R. 1990. Tertiary palynology of Kerala Basin—An overview. *In* Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 256-262.

In Kerala Basin the Tertiary sedimentary sequence is represented by Quilon and Warkalli formations. Palaeoassociations of upland, lowland, fresh-water, sandy beach and mangrove vegetations have been figured out. Composition of the palynological assemblages indicates the existence of tropical rain forests with a high degree of rainfall. Dinoflagellate cysts and pollen grains of *Barringtonia*, *Rhizophora*, *Nypa* and *Calamus* suggest deposition under brackish water mangrove swamps. The sandy beach conditions are indicated by *Palmidites*, *Palmaepollenites* and *Quilonipollenites*. Divergent views on the age of Quilon and Warkalli formations have been reconsidered on the basis of new palynological evidences.

**Key-words**—Palaeopalynology, Kerala Basin, Tertiary (India).

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## सारॉंश

### केरल द्रोणी का तृतीयक युगीन परागाणविक अध्ययन : एक पुनरीक्षण

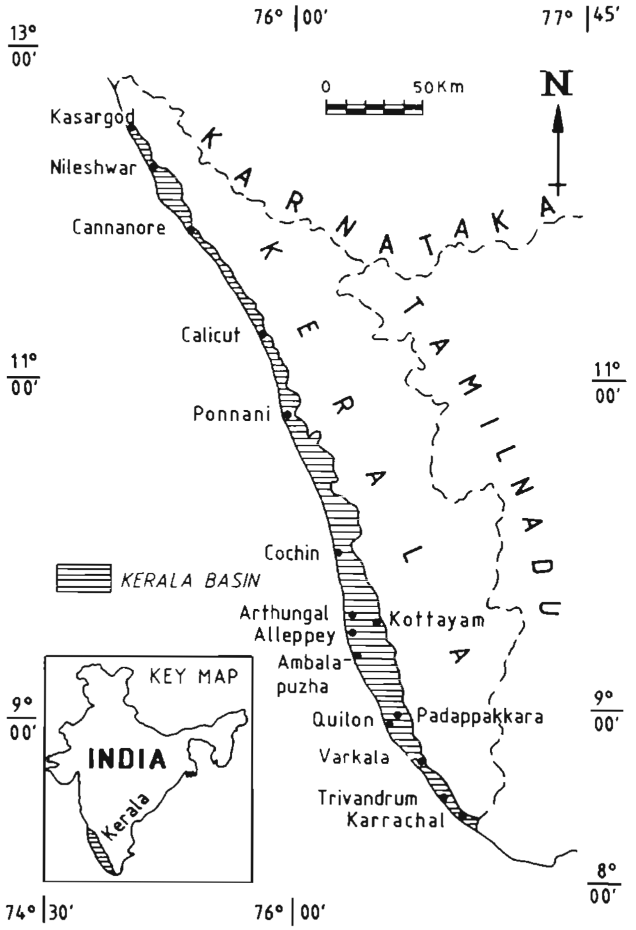
हरिपाल सिंह एवं मुलागलापल्ली रामचन्द्र राव

केरल द्रोणी में तृतीयक युगीन अवसादीय अनुक्रम क्वीलन एवं वरकली शैल-समूहों से निरूपित है। उपरिभूमि, निम्नभूमि, स्वच्छ जल, बलुई तट एवं मैंग्रोव वनस्पति के पुरासाहचर्य अभिलिखित किये गये हैं। परागाणविक समुच्चयों के पारस्परिक साहचर्य से अत्यधिक वर्षा वाले उष्णकटिबन्धीय वनों का होना इंगित होता है। घूर्णीकशाभ पुटीयाँ तथा **बैरिंग्टोनिया**, **राइजोफ़ोरा**, **नाइपा** एवं **कैलेमस** के परागकण खारे जल युक्त मैंग्रोव दलदली परिस्थितियों के अन्तर्गत निक्षेपण प्रस्तावित करते हैं। **पाल्मीडाइटिस**, **पाल्मीपोलिनाइटिस** एवं **क्वीलोनीपोलिनाइटिस** की उपस्थिति के कारण बलुई तट वाली परिस्थितियाँ व्यक्त होती हैं। नये परागाणविक प्रमाणों के आधार पर क्वीलन एवं वरकली शैल-समूहों की आयु पर उल्लिखित विभिन्न दृष्टिकोणों पर पुनर्विचार किया गया है।

MOST of the palynological studies on the Quilon and Warkalli formations (Kerala Basin) have not been related to stratigraphically located samples. They are confined only to a meagre number of grab samples. Thus the accrued palynological evidence cannot be considered authentic to draw a successional picture of the vegetational history though Ramanujam (1982) opined that the two formations pertain to a single time transgressive unit, being Early to Middle Miocene in age.

In the recent past, Raha, Rajendran and Kar (1987) and Rao (1989) have systematically studied palynology from the bore-holes of Ambalapuzha and Arthungal (Alleppey District, Kerala), respectively (Map 1). They have used palynology as the basis for assigning Eocene to Early Miocene age to the successions studied.

The present paper reassesses the available palynological data from the Tertiary sediments of Kerala Basin in the light of recent palynological advances made in this area, with a view to identify ecologically and stratigraphically significant palynotaxa as related to habitat and time. An attempt has also been made to reconstruct vegetation of the past so as to understand its possible impact on the evolution of the modern flora. Some important contributions made on the Tertiary palynology of Kerala Basin are: Rao and Vimal (1952), Vimal (1953), Potonié and Sah (1960), Ramanujam (1960, 1966, 1972, 1977, 1982, 1987), Ramanujam and Rao (1971, 1977, 1978), Jain and Kar (1979), Ramanujam and Srisailam (1978), Ramanujam, Srisailam and Reddy (1981), Rao and Ramanujam (1978, 1982), Kar and Jain (1981), Varma and Patil (1985), Varma,



**Map 1**—Kerala Basin showing localities of Tertiary exposures.

Ramanujam and Patil (1986), Raha, Rajendran and Kar (1987), Varma (1987) and Rao (1989).

## GEOLOGY

The Tertiary sediments of Kerala coast are well known as Warkalli and Quilon formations. These rocks were first described by King (1882) and Foote (1883). The Quilon Formation consists of limestones with intercalations of calcareous clays, carbonaceous clays and sand whereas the Warkalli Formation comprises variegated sandstones interbedded with white plastic and variegated clays, carbonaceous clays and seams of lignite or peaty lignite. The Tertiary sequence rests unconformably over the Archean crystalline complex. It is succeeded by recent to subrecent marine and estuarine sediments (Poulose & Narayanaswami, 1968). A recent study of the lithology based on some bore-hole information resulted in the institution of a third formation, viz., Vaikom Formation, underlying the Quilon Formation (Rao, 1975; Rao *et al.*, 1975). These beds are similar to Warkalli Formation but are more arenaceous and coarse-grained.

## PALYNOLOGY

The Quilon and Warkalli palynological assemblages consist of 135 genera and 165 species. Pteridophytic spores and angiospermous pollen constitute an important part of the assemblage. Dinoflagellate cysts and fungal remains are also commonly met with. On the basis of the morphological similarities, botanical affinities of some Quilon and Warkalli palynofossils have been tagged with modern families, as tabulated below:

### Pteridophytes

| | |
|---|---|
| *Verrucosisporites* | Lycopodiaceae (*Lycopodium*) |
| *Foveosporites* | Ophioglossaceae (*Ophioglossum*) |
| *Cibotiidites* | Dicksoniaceae |
| *Lygodiumsporites* | Schizaeaceae |
| *Crassoretitriletes* | Schizaeaceae |
| *Schizaeoisporites* | Schizaeaceae |
| *Gleicheniidites* | Gleicheniaceae (*Gleichenia*) |
| *Striatriletes* | Parkeriaceae |
| *Intrabaculisporis* | Schizaeaceae |
| *Cyathidites* | Cyatheaceae |
| *Alsophilidites* | Cyatheaceae |
| *Osmundacidites* | Osmundaceae |
| *Biretisporites* | ?Hymenophyllaceae |
| *Lycopodiumsporites* | Lycopodiaceae |
| *Pteridacidites* | Pteridaceae (*Pteris*) |
| *Laevigatosporites* | Polypodiaceae |
| *Polypodiaceaesporites* | Polypodiaceae |
| *Polypodiisporites* | Polypodiaceae |

### Angiosperms

### Monocotyledons

| | |
|---|---|
| *Retipilonapites* | Potamogetonaceae (*Potamogeton*) |
| *Palmaepollenites* | Arecaceae |
| *Arecipites* | Arecaceae |
| *Clavapalmaedites* | Arecaceae (*Oncosperma*) |
| *Langapertites* | Arecaceae |
| *Spinizonocolpites* | Arecaceae (*Nypa*) |
| *Quilonipollenites* | Arecaceae (*Eugeissonia*) |
| *Dicolpopollis* | Arecaceae (*Calamus*) |
| *Trilatiporites* | Arecaceae (*Sclerosperma*) |
| *Paravuripollis* | Arecaceae (*Salaca*) |

| | |
|---|---|
| *Iridacidites* | Iridaceae |
| *Liliacidites* | Liliaceae |

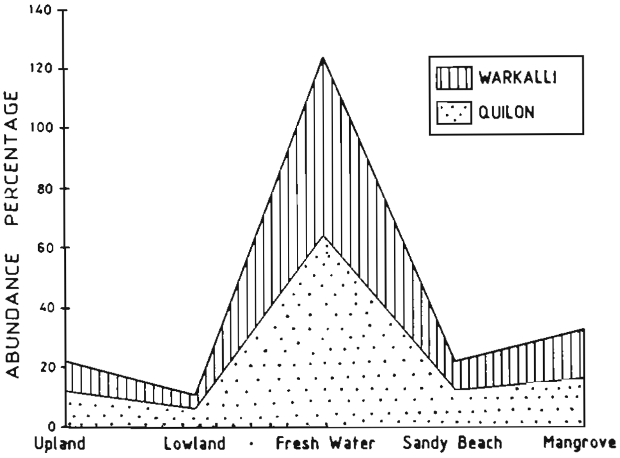
## Dicotyledons

| | |
|---|---|
| *Crotonoidaepollenites* | Euphorbiaceae |
| *Crototricolpites* | Euphorbiaceae |
| *Retitricolporites* | |
| *Dipterocarpoides* | Dipterocarpaceae |
| *Retitricolpites* (some spp.) | Oleaceae |
| *Heterocolpites* | Combretaceae |
| *Psilatricolpites* | Ebenaceae |
| *Loranthipites* | Loranthaceae (*Loranthus*) |
| *Gothanipollis* | Loranthaceae |
| *Palaeocoprosmadites* | Rubiaceae (*Coprosma*) |
| *Talisiipites* | Sapindaceae |
| *Cupaniedites* | Sapindaceae |
| *Araliaceoipollenites* | Araliaceae (*Aralia*) |
| *Symplocoipollenites* | Symplocaceae (*Symplocoa*) |
| *Zonocostites* | Rhizophoraceae (*Rhizophora*) |
| *Bombacacidites* | Bombacaceae |
| *Hippocrateaceaedites* | Hippocrateaceae (*Hippocratea*) |
| *Cauveripollis* | Caprifoliaceae |
| *Compositoipollenites* | Asteraceae |
| *Ctenolophonidites* | Ctenolophonaceae (*Ctenolophon*) |
| *Polycolpites* | Lamiaceae |
| *Retistephanocolpites* | Lamiaceae |
| *Meliapollis* | Meliaceae |
| *Sapotaceoidaepollenites* | Sapotaceae |
| *Myricipites* | Myricaceae |
| *Casuariniidites* | Casuarinaceae (*Casuarina*) |
| *Verrutriporites* | Sonneratiaceae |
| *Proteacidites* | Proteaceae |
| *Haloragracidites* | Haloragaceae (*Myriophyllum*) |
| *Triorites* | Onagraceae |
| *Anacolosidites* | Olacaceae (*Anacolosa*) |
| *Clavaperiporites* | Thymeliaceae |
| *Ornatetradites* | Droseraceae |
| *Droseridites* | Droseraceae (*Drosera*) |
| *Trisyncolpites* | Caesalpiniaceae |
| *Lakiapollis* | Bombacaceae (*Durio*) |
| *Sonneratiopollis* | Sonneratiaceae |
| *Malvacearumpollis* | Malvaceae |
| *Chenopodipollis* | Chenopodiaceae |
| *Polyporina* | Chenopodiaceae |
| *Caryophyllidites* | Caryophyllaceae |
| *Umbelliferoipollenites* | Apiaceae |
| *Neyvelipollenites* | Lentibulariaceae |
| *Myricaceoipollenites* | Myricaceae |
| *Cricotriporites* | Rubiaceae |
| *Lacrimapollis* | Tiliaceae |
| *Clavatricolporites* | Aquifoliaceae |
| *Warkallipollenites* | Plumbaginaceae |

## PALAEOECOLOGICAL ANALYSIS

Rao and Ramanujam (1982) and Varma (1987) brought out ecological significance of palynofossils from Quilon Formation and Tonakkal clays (Kerala State), respectively. The proposed ecological groups seem to be far more in number than necessary. We have fed the available data to the computer and prepared an area graph (Text-fig. 1). The qualitative aspect of palynological data and palaeogeographical locale of the Tertiary sequence of sediments of Kerala Basin in the Indian subcontinent do not confirm the presence of montane elements (Rao & Ramanujam, 1982; Varma, 1987). The terrestrial elements represented by upland (relief) and lowland floras rapidly merge with the fresh water elements which lose hold towards the vicinity of tidal mud flats and coastal shore-line.

Palynological data was thoroughly combed and ecologically significant palynotaxa were selected and segregated for identifying various habitats. The palynoflora of Quilon and Warkalli formations has been segregated under the following different ecological groups such as upland, lowland, fresh-water, sandy beach and mangrove.



**Text-figure 1**—Distribution of different ecological group of plants in Quilon and Warkalli formations.

### Upland elements

| | |
|---|---|
| *Umbelliferoipollenites* | Apiaceae |
| *Symplocoipollenites* | Symplocaceae (*Symplocoa*) |
| *Hippocrateaceaedites* | Hippocrateaceae |
| *Proteacidites* | Proteaceae |
| *Palaeocoprosmadites* | Rubiaceae (*Coprosma*) |
| *Clavaperiporites* | Thymeliaceae |
| *Compositoipollenites* | Asteraceae |

### Lowland elements

| | |
|---|---|
| *Lakiapollis* | Bombacaceae (*Durio*) |
| *Tricolporopollis* | Euphorbiaceae |
| *Favitricolporites* | Rubiaceae |

### Fresh water elements

| | |
|---|---|
| *Lycopodiumsporites* | Lycopodiaceae (*Lycopodium*) |
| *Lygodiumsporites* | Schizaeaceae (*Lygodium*) |
| *Crassoretitriletes* | Schizaeaceae (*Lygodium*) |
| *Schizaeoisporites* | Schizaeaceae (*Schizaea*) |
| *Pteridacidites* | Pteridaceae (*Pteris*) |
| *Polypodiisporites* | Polypodiaceae (*Polypodium*) |
| *Polypodiaceaesporites* | Polypodiaceae (*Polypodium*) |
| *Laevigatosporites* | Polypodiaceae |
| *Striatriletes* | Parkeriaceae (*Ceratopteris*) |
| *Liliacidites* | Liliaceae |
| *Marginipollis* | Lecythidaceae (*Barringtonia*) |
| *Psilatricolpites* | Ebnaceae |
| *Ctenolophonidites* | Ctenolophonaceae (*Ctenolophon*) |
| *Neyvelipollenites* | Lentibulariaceae |
| *Margocolporites* | Caesalpiniaceae (*Caesalpinia*) |
| *Trisyncolpites* | Caesalpiniaceae |
| *Sapotaceoidaepollenites* | Sapotaceae |
| *Meliapollis* | Meliaceae |
| *Triporopollenites* | Moraceae |
| *Anacolosidites* | Olacaceae (*Anacolosa*) |
| *Ornatetradites* | Droseraceae (*Drosera*) |
| *Retipilonapites* | Potamogetonaceae |
| *Araliaceoipollenites* | Araliaceae |
| *Haloragacidites* | Haloragaceae |
| *Cupaniedites* | Sapindaceae (*Cupania*) |

### Sandy Beach elements

| | |
|---|---|
| *Palmaepollenites* | Arecaceae |
| *Quilonipollenites* | Arecaceae (*Eugeissonia*) |
| *Longapertites* | Arecaceae |
| *Dicolpopollis* | Arecaceae |
| *Paravuripollis* | Arecaceae |
| *Spinizonocolpites* | Arecaceae (*Nypa*) |

### Mangrove elements

| | |
|---|---|
| *Meliapollis* (some spp.) | Meliaceae |
| *Intratriporopollenites* | Tiliaceae |
| *Rhoipites* | Anacardiaceae |
| *Alangipollis* | Alangiaceae (*Alangium*) |
| *Zonocostites* | Rhizophoraceae (*Rhizophora*) |
| *Retitricolporites* | Verbenaceae |
| *Heterocolpites* | Combretaceae |
| *Verrutricolporites* | Lythraceae |

The palms generally tend to remain away from the storm tide and dominate the sandy beach flora. The mangrove swamps are confined to littoral regions between low tide and high tide all along the estuaries of rivers and on low mud flats of the sea coast. The fresh-water elements are conspicuous and may be representing the lowland and upland elements of the flora. They dominate the assemblages at all levels characteristic of tropical rain forests.

The spores of Schizaeaceae, Parkeriaceae, Osmundaceae, Polypodiaceae and pollen of Arecaceae, Rhizophoraceae, Verbenaceae, Hippocrateaceae, Caesalpiniaceae, Combretaceae, Sapotaceae, Dipterocarpaceae, Meliaceae, Ctenolophonaceae, Oleaceae, Moraceae and Anacardiaceae in the palyno-assemblage of Quilon and Warkalli formations clearly indicate the prevalence of tropical climate at the time of deposition.

The presence of fungal remains, viz., *Phragmothyrites, Notothyrites, Parmathyrites, Multicellaesporites, Pluricellaesporites,* fern spores and tropical rain forest elements belonging to the families Ctenolophonaceae, Oleaceae, Dipterocarpaceae, Moraceae and Alangiaceae confirm high degree of rainfall.

Similar palaeoclimatic derivations have been made by Awasthi and Ahuja (1982) on the basis of fossil woods, viz., *Calophyllum, Drybalanops, Gluta, Swintonia, Terminalia, Diospyros, Litsea,* *Cynometra, Gonystylus* and *Leea* reported from the Neogene of Varkala in Kerala Coast.

Dinoflagellate cysts (*Operculodinium, Achomosphaera* and *Thalassiphora*) and pollen of *Barringtonia, Rhizophora, Lumnitzera, Nypa, Calamus,* Araliaceae, Sapindaceae, Meliaceae and Droseraceae indicate the existence of brackish water mangrove swamps. Pollen comparable to Potamogetonaceae, Haloragaceae and Droseraceae indicate the presence of fresh water lakes or ponds, dotting the inland landscape, away from the mangrove belt. The sandy beach conditions have been inferred by the presence of palm pollen (*Palmidites, Palmaepollenites* and *Quilonipollenites*).

## AGE OF QUILON AND WARKALLI FORMATIONS

On the basis of foraminifera, ostracod and mollusca evidences, the Quilon Formation is assigned an Early to Middle Miocene age (Jacob & Sastry, 1952; Dey, 1962). The Warkalli Formation overlying the Quilon Formation is considered to be Late Miocene to Pliocene in age (Poulose & Narayanaswami, 1968).

Ramanujam (1982) opined that a striking similarity exists between the assemblages of both the formations. He concluded (on the basis of surface and subsurface palyno-assemblages) that the entire Tertiary sequence of Kerala Basin constitutes a single time transgressive group being Early to Middle Miocene in age.

Raha, Rajendran and Kar (1987) on subsurface palynological data from Ambalapuzha, Alleppey District, Kerala, suggested Eocene to Early Miocene age to the sediments. Palynofossil taxa *Proxapertites, Polycolpites, Meliapollis, Verrutricolporites, Proteacidites* and *Striacolporites* with some palm pollen are suggestive of Eocene age. Oligocene age has been inferred by the presence of *Crassoretitriletes, Trisyncolpites* and *Bombacacidites*. The occurrence of *Malvacearumpollis, Hibisceaepollenites* and *Quilonipollenites* suggests Early Miocene age.

Recent palynological study of Arthungal bore-hole, Alleppey District, Kerala by one of us (Rao, 1989 *in this volume*) also provides cogent evidence that the palynoflora of Warkalli and Quilon formations may vary from Eocene to Early Miocene in age. The Arthungal bore-hole palynofloral succession has been divided into three distinct cenozones, viz., *Malvacearumpollis bakonyensis* Cenozone (Early Miocene), *Crassoretitriletes vanraadshooveni* Cenozone (Oligocene) and *Triangulorites bellus* Cenozone (Eocene). Each cenozone contains age definitive and ecologically important palynofossils, the details of which are given in the above mentioned paper. It is quite obvious from this palynological data that the Arthungal bore-hole penetrates through strata ranging in age from Eocene to Early Miocene.

Thus, on the basis of subsurface Arthungal palynofossils it is suggested that the entire Tertiary sequence of Kerala Basin may have to be restudied palynologically both from the surface and subsurface for finer resolution of the age before a tangible conclusion can be made.

## DISCUSSION

The Quilon and Warkalli formations of Kerala have yielded a variety of pteridophytic spores and angiospermous pollen (Table 1). Dinoflagellate cysts and fungal remains are also present whereas the gymnospermous pollen are poorly represented.

**Table 1**

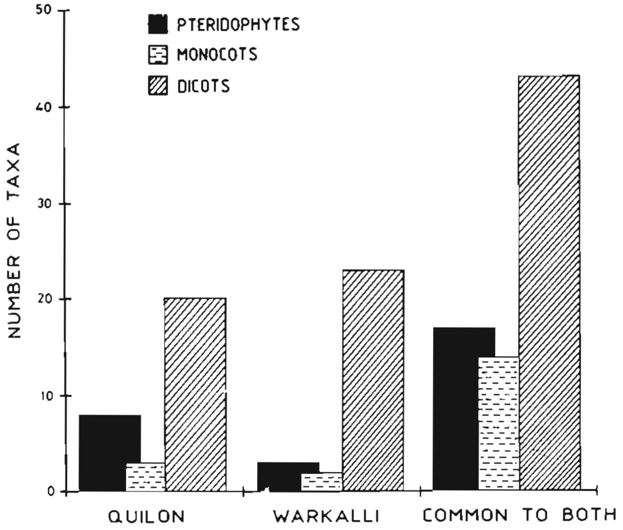
| Palynotaxa | Quilon Formation | Warkalli Formation | Common genera between two formations |
|---|---|---|---|
| *Lygodiumsporites* | + | | |
| *Intrabaculisporis* | + | | |
| *Gleicheniidites* | + | | |
| *Eximospora* | + | | |
| *Foveotriletes* | + | | |
| *Cingulatisporites* | + | | |
| *Cibotiidites* | + | | |
| *Laevigatosporites* | + | | |
| *Spinainaperturites* | + | | |
| *Clavainaperturites* | + | | |
| *Crotonisulcites* | + | | |
| *Monoporopollenites* | + | | |
| *Spinamonoporites* | + | | |
| *Crotonoidaepollenites* | + | | |
| *Foveotricolpites* | + | | |
| *Crototricolpites* | + | | |
| *Punctatricolpites* | + | | |
| *Bacubrevitricolpites* | + | | |
| *Clavasyncolpites* | + | | |
| *Meyeripollis* | + | | |
| *Costatipollenites* | + | | |
| *Talisiipites* | + | | |
| *Foveostephanocolporites* | + | | |
| *Padappakkarapollis* | + | | |
| *Polybrevicolporites* | + | | |
| *Triorites* | + | | |
| *Casuarinidites* | + | | |
| *Echitriporites* | + | | |
| *Tetrapollis* | + | | |
| *Inaperturotetradites* | + | | |
| *Haloragacidites* | + | | |

*Contd.*

| | | | |
|---|---|---|---|
| *Parsonsidites* | + | | |
| *Biretisporites* | – | + | |
| *Neyvelisporites* | – | + | |
| *Polypodiaceaesporites* | – | + | |
| *Iridacidites* | – | + | |
| *Disulcipollis* | – | + | |
| *Warkallipollenites* | – | + | |
| *Stephanocolpites* | – | + | |
| *Clavatricolpites* | – | + | |
| *Rhoipites* | – | + | |
| *Lacrimapollis* | – | + | |
| *Myrtaceidites* | – | + | |
| *Psilastephanocolporites* | – | + | |
| *Diporites* | – | + | |
| *Retitriporites* | – | + | |
| *Florschuetzia* | – | + | |
| *Myricaceoipollenites* | – | + | |
| *Trilatiporites* | – | + | |
| *Caryophyllidites* | – | + | |
| *Polyporina* | – | + | |
| *Ranunculacidites* | – | + | |
| *Clavatricolpites* | – | + | |
| *Intratriporopollenites* | – | + | |
| *Subtriporopollis* | – | + | |
| *Pseudonothofagidites* | – | + | |
| *Farsonsidites* | – | + | |
| *Periporopollenites* | – | + | |
| *Chenopodipollis* | – | + | |
| *Sparganiaceaepollenites* | – | + | |
| *Lycopodiumsporites* | – | – | + |
| *Osmundacidites* | – | – | + |
| *Cyathidites* | – | – | + |
| *Intrapunctisporis* | – | – | + |
| *Alsophilidites* | – | – | + |
| *Dandotiaspora* | – | – | + |
| *Seniasporites* | – | – | + |
| *Cicatricosisporites* | – | – | + |
| *Scantigranulites* | – | – | + |
| *Verrucosisporites* | – | – | + |
| *Foveosporites* | – | – | + |
| *Crassoretitriletes* | – | – | + |
| *Pteridacidites* | – | – | + |
| *Monolites* | – | – | + |
| *Cheilanthoidspora* | – | – | + |
| *Polypodiisporites* | – | – | + |
| *Schizaeoisporites* | – | – | + |
| *Retipilonapites* | – | – | + |
| *Palmaepollenites* | – | – | + |
| *Arecipites* | – | – | + |
| *Verrumonocolpites* | – | – | + |
| *Neocouperipollis* | – | – | + |
| *Palmidites* | – | – | + |
| *Proxapertites* | – | – | + |
| *Clavapalmaedites* | – | – | + |
| *Spinizonocolpites* | – | – | + |
| *Pararuripollis* | – | – | + |
| *Liliacidites* | – | – | + |
| *Longapertites* | – | – | + |
| *Quilonipollenites* | – | – | + |
| *Dicolpopollis* | – | – | + |
| *Retitricolpites* | – | – | + |
| *Retibrevitricolpites* | – | – | + |
| *Loranthipites* | – | – | + |
| *Marginipollis* | – | – | + |
| *Retistephanocolpites* | – | – | + |
| *Ctenolophonidites* | – | – | + |
| *Polycolpites* | – | – | + |
| *Lakiapollis* | – | – | + |
| *Tricolpites* | – | – | + |
| *Palaeosantalaceaepites* | – | | + |
| *Psilatricolporites* | – | – | + |
| *Heterocolpites* | – | – | + |
| *Retitricolporites* | – | – | + |
| *Cauveripollis* | – | – | + |
| *Araliaceoipollenites* | – | – | + |
| *Zonocostites* | – | – | + |
| *Compositoipollenites* | – | – | + |
| *Bombacacidites* | – | – | + |
| *Hippocrateaceaedites* | – | – | + |
| *Palaeocoprosmadites* | – | – | + |
| *Symplocoipollenites* | – | – | + |
| *Margocolporites* | – | – | + |
| *Gothanipollis* | – | – | + |
| *Cupaniedites* | – | – | + |
| *Sapotaceoidaepollenites* | – | – | + |
| *Meliapollis* | – | – | + |
| *Polygalacidites* | – | – | + |
| *Triporopollenites* | – | – | + |
| *Myricipites* | – | – | + |
| *Maculoporites* | – | – | + |
| *Verrutriporites* | – | – | + |
| *Graminidites* | – | – | + |
| *Jandufouria* | – | – | + |
| *Ornatriporites* | – | – | + |
| *Proteacidites* | – | – | + |
| *Thomsonipollis* | – | – | + |
| *Haloragacidites* | – | – | + |
| *Clavaperiporites* | – | – | + |
| *Anacolosidites* | – | – | + |
| *Ornatetradites* | – | – | + |
| *Droseriidites* | – | – | + |
| *Podocarpidites* | ? | + | – |

The distribution of different plant groups in Quilon and Warkalli formations alongwith the common elements between the two is given in Text-figure 2.

1. Ecological analysis of the Tertiary palynofossils



**Text-figure 2**—Distribution of different plant groups in Quilon and Warkalli formations.

from the Kerala Basin identifies upland, lowland, fresh water, sandy beach and mangrove elements occurring as constituents of tropical rain forests of semi-evergreen type. The terrestrial elements of upland relief flora and lowland vegetation tend to merge with the fresh water constituents and dominate the total assemblage. Luxuriant growth of palms seems to have been supported by the sandy beaches. Mangrove vegetation thriving on the tidal mud flats and dinocysts in the estuaries have also been richly contributing to the past vegetation.

2. The bore-holes penetrating through the Tertiary sediments of Kerala Basin have yielded palynological evidences which assign Eocene to Early Miocene age to the successions studied. In view of this newly emerged palynological information, concerted efforts are required to systematically restudy the entire sequence from the stratigraphically located samples. Therefore the contention of Ramanujam (1982) that the entire Tertiary sequence of Kerala Basin is a single time transgressive unit, being Early to Middle Miocene in age, needs to be confirmed.

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# Palynological investigation of the Ratnagiri beds of Sindhu Durg District, Maharashtra

R. K. Saxena & N. K. Misra

Saxena, R. K. & Misra, N. K. 1990. Palynological investigation of the Ratnagiri beds of Sindhu Durg District, Maharashtra. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 263-276.

A palynological assemblage consisting of 60 genera and 95 species has been recovered from the Ratnagiri beds of Sindhu Durg District, Maharashtra. Quantitatively, pteridophytic spores and fungal remains are dominant, sharing 44 and 40 per cent of the total assemblage respectively. These are followed by angiospermous pollen (16%). On the basis of comparative morphology, the palynofossils have been assigned affinities to extant genera or families. The present day distribution of such taxa suggests a tropical-subtropical climate (warm-humid) with plenty of rainfall. The environment of deposition has been interpreted as near-shore with sufficient fresh water supply.

**Key-words**—Palynology, Palaeoecology, Ratnagiri beds, Neogene (India).

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## सारॉंश

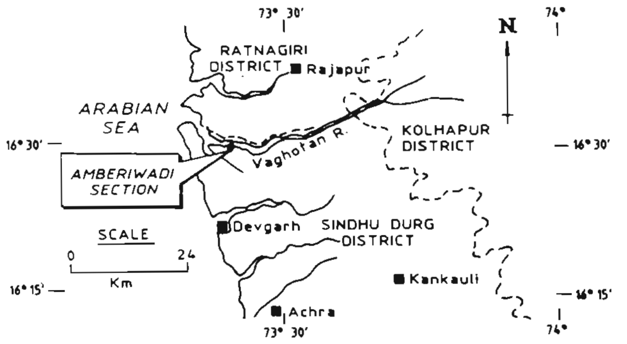
### महाराष्ट्र में सिन्धु दुर्ग जनपद के रत्नागिरी संस्तरों का परागाणविक अन्वेषण

रमेश कुमार सक्सेना एवं नरेन्द्र कुमार मिश्रा

महाराष्ट्र में सिन्धु दुर्ग जनपद के रत्नागिरी संस्तरों से उपलब्ध परागाणविक समुच्चय में 60 प्रजातियाँ एवं 95 जातियाँ मिली हैं। संख्यात्मक दृष्टि से टेरीडोफ़ाइटी बीजाणुओं एवं कवकीय अवशेषों की बाहुल्यता है जो कुल समुच्चय के क्रमश: 44 एवं 40 प्रतिशत हैं। इनके पश्चात् आवृतबीजी परागकणों का क्रम आता है। तुलनात्मक आकारिकी के आधार पर उपलब्ध अश्मित परागाणुओं की वर्तमान प्रजातियों एवं कुलों से सजातीयता प्रदर्शित की गई है। इन वर्गकों के वर्तमान वितरण से अत्याधिक वर्षा से युक्त उष्णकटिबन्धीय से उपोष्णकटिबन्धीय जलवायु का होना इंगित होता है। निक्षेपण-वातावरण पर्याप्त स्वच्छ जल आपूर्ति से युक्त तटीय प्रस्तावित किया गया है।

THE Ratnagiri beds were first reported by Wilkinson (1871) from a number of quarries and well sections along Ratnagiri coast, Maharashtra. The geological literature on these beds is rather meagre, mainly because of their poor exposure and less thickness. So far, the palynological studies on Ratnagiri beds are confined to the subsurface lignite samples collected from a well located 10 km south of Ratnagiri, near Third Dharamshala bus-stop on Ratnagiri-Pawas road (Phadtare & Kulkarni, 1980a, b, 1984a, b; Kulkarni & Phadtare, 1983; Kulkarni *et al.*, 1985). The cuticular studies on these beds have been published by Kulkarni and Phadtare (1980) and Dalvi and Kulkarni (1982). Phadtare and Kulkarni (1984c) described fossil woods of Anacardiaceae from these beds.

Saxena *et al.* (in press) made a lithostratigraphic study of these beds in a number of well, outcrop, cliff, road, mine and other sections in Ratnagiri and Sindhu Durg districts of Maharashtra. Of these, Amberiwadi section near Tirlot Village and Kalviwadi section near Tembhavli Village are outcrop sections. The present palynofloral investigation has been carried out on the Amberiwadi section located in Devgarh Taluk of Sindhu Durg District, Maharashtra (Lat. 16°30′20″N : Long. 73°23′20″E, Text-fig. 1). The base of the section is composed of grey clay followed by lignite (1 m), grey clay mixed with



**Text-figure 1**—Showing the location of Amberiwadi section in Sindhu Durg District, Maharashtra.

ferruginous matter (0.5 m) and ironstone (0.2 m). This is covered by about 9 m thick laterite (Text-fig. 2). Carbonized remains of wood and fragmentary leaves are also found in the lignite bed of this section.

## MATERIAL AND METHOD

A total of 24 samples were collected from clay and lignite beds of Amberiwadi section at a regular stratigraphic interval of 0.20 m. In order to obtain a rich and complete assemblage, samples were also collected laterally. Precautions were taken to collect samples only from fresh and unweathered surfaces, to avoid any kind of contamination.

Samples were treated with $HNO_3$ and HF followed by 5 per cent solution of KOH. The slides were prepared in polyvenyl alcohol and mounted in canada balsam Lietz Laborlux microscope has been used for the study and photomicrography. The material, slides and negatives of figured specimens have been deposited in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

## PALYNOFLORA

The palynotaxa recovered from the Ratnagiri beds are as follows:

### Pteridophytic spores

*Assamiasporites tertiarus* Mehrotra & Sah 1980 (Pl. 3, fig. 4)

*Cyathidites congoensis* Sah 1967

*Cyathidites minor* Couper 1953 (Pl. 1, fig. 1)

**Cyathidites giganticus* sp. nov. (Pl. 1, fig. 17)

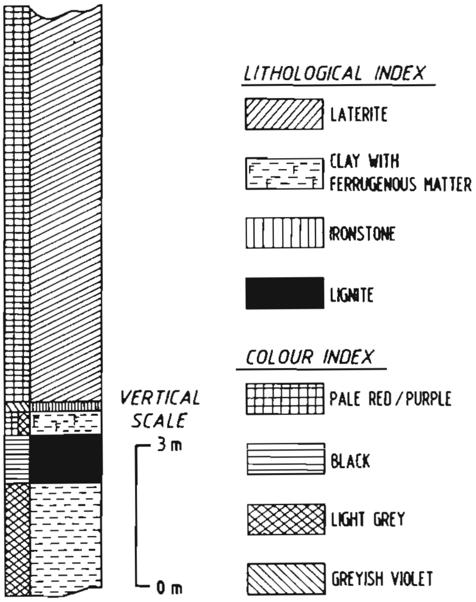
*Dictyophyllidites kyrtomatus* Kar & Kumar 1986

*Laevigatosporites lakiensis* Sah & Kar 1969

*Laevigatosporites ovatus* Wilson & Webster 1946

*Leptolepidites* sp. (Pl. 1, fig. 3)

*Lygodiumsporites lakiensis* Sah & Kar 1969 (Pl. 3, fig. 1)



**Text-figure 2**—Litholog of Amberiwadi section showing sequence of various strata of Ratnagiri beds.

*Lygodiumsporites pachyexinus* Saxena 1978

*Monolites mawkmaensis* Dutta & Sah 1970

*Monolites ovatus* Sah 1967

**Monolites amberiwadiensis* sp. nov. (Pl. 1, fig. 6)

*Osmundacidites cephalus* Saxena 1978 (Pl. 3, fig. 7)

*Osmundacidites microgranifer* Sah & Jain 1965 (Pl. 1, fig. 2)

*Polypodiaceaesporites levis* Sah 1967

*Polypodiaceaesporites tertiarus* Dutta & Sah 1970

*Polypodiisporites ornatus* Sah 1967

*Polypodiisporites repandus* Takahashi 1964

**Polypodiisporites minutiverrucus* sp. nov. (Pl. 1, fig. 5)

*Polypodiisporites* sp. (Pl. 1, fig. 4)

*Pteridacidites fistulosus* Sah 1967 (Pl. 3, fig. 6)

*Striatriletes susannae* Van der Hammen 1956 emend. Kar 1979 (Pl. 3, fig. 15)

*Todisporites minor* Couper 1958 (Pl. 3, fig. 3)

### Angiospermous pollen grains

*Arecipites punctatus* Wodehouse 1933

*Assamiapollenites* sp. (Pl. 3, fig. 5)

*Clavaperiporites jacobi* Ramanujam 1966

*Clavaperiporites* sp. (Pl. 2, fig. 6)

*Dermatobrevicolporites* sp. (Pl. 1, fig. 19)

*Dicolpopollis* sp. (Pl. 2, fig. 2)

*Favitricolporites retiformis* Sah 1967 (Pl. 3, fig. 10)

*Foveotricolpites prolatus* Rao & Ramanujam 1982

*Inaperturopollenites punctatus* (Saxena) Saxena & Bhattacharyya 1987
*Inaperturotetradites* sp. 1 (Pl. 2, fig. 7)
*Inaperturotetradites* sp. 2 (Pl. 2, fig. 3)
*Lakiapollis ovatus* Venkatachala & Kar 1969
*Lakiapollis* sp. (Pl. 1, fig. 13)
*Malvacearumpollis* sp. (Pl. 2, fig. 5)
*Paleosantalaceaepites dinoflagellatus* Biswas 1962 emend. Dutta & Sah 1970
*Palmidites maximus* Couper 1958
*Palmidites* sp. (Pl. 1, fig. 8)
*Pandaniidites* sp. (Pl. 1, fig. 14)
*Polyadopollenites* sp. (Pl. 1, fig. 16)
*Proxapertites microreticulatus* Jain *et al.* 1973 (reworked)
*Proxapertites* sp. (Pl. 1, fig. 12, reworked)
*Quilonipollenites ornatus* Rao & Ramanujam 1978
*Quilonipollenites* sp. (Pl. 1, fig. 9)
*Retipilonapites delicatissimus* Ramanujam 1966
*Retipilonapites* sp. (Pl. 3, fig. 9)
*Retitrescolpites splendens* Sah 1967
*Retitricolpites dipterocarpoides* Rao & Ramanujam 1982 (Pl. 3, fig. 2)
*Retitricolporites crassioratus* Rao & Ramanujam 1982
**Retitricolporites subcircularis* sp. nov (Pl. 1, fig. 11)
*Thomsonipollis* sp. (Pl. 1, fig. 10)
*Tricolpites reticulatus* Cookson 1947
*Tricolpites* sp. 1 (Pl. 2, fig.1)
*Tricolpites* sp. 2 (Pl. 1, fig. 15)
*Tricolporopollis matanamadhensis* (Venkatachala & Kar) Tripathi & Singh 1985
*Triporotetradites* sp. (Pl. 2, fig. 8)
*Verrualetes assamicus* Singh & Saxena 1984 (Pl. 1, fig. 20)
*Verrumonocolpites* sp. (Pl. 1, fig. 7)
**Verrutriporites grandioratus* sp. nov. (Pl. 1, fig. 18)

### Salt glands of Mangrove plants

**Heliospermopsis ankleshvarensis* (Srivastava 1967) comb. nov.
*Heliospermopsis hungaricus* Nagy 1965
*Heliospermopsis* sp. (Pl. 2, fig. 10)

### Fungal remains

*Basidiosporites fournierii* Elsik 1968
*Basidiosporites* sp. 1 (Pl. 3, fig. 12)
*Basidiosporites* sp. 2 (Pl. 3, fig. 8)
*Dendromyceliates splendens* Jain & Kar 1979
*Dicellaesporites fusiformis* Sheffy & Dilcher 1971
*Dicellaesporites popovii* Elsik 1968
**Diporicellaesporites wilkinsonii* sp. nov. (Pl. 3, fig. 13)
*Diporicellaesporites* sp. (Pl. 3, fig. 19)
*Dyadosporonites* sp. 1 (Pl. 2, fig. 11)
*Dyadosporonites* sp. 2 (Pl. 2, fig. 4)
*Fusiformisporites* sp. (Pl. 2, fig. 12)
**Inapertisporites kedvesii* Elsik 1968
*I. subovoideus* Sheffy & Dilcher 1971
*Involutisporonites wilcoxii* Elsik 1968
*Kutchiathyrites eccentricus* Kar 1979
*Lirasporis intergranifer* Potonié & Sah 1960 emend. Jain & Kar 1979
*Lirasporis* sp. (Pl. 3, fig. 18)
**Microthyriacites ramanujamii* sp. nov (Pl 2, fig. 13)
*Multicellaesporites elsikii* Kar & Saxena 1976
**Paramicrothallites konkanensis* sp. nov (Pl 2, fig. 9)
*Parmathyrites ramanujamii* Singh *et al.* 1986
*Parmathyrites* sp. (Pl. 3, fig. 17)
*Phragmothyrites assamicus* (Kar *et al.*) Saxena *et al.* 1984
*Phragmothyrites edwardsii* (Rao) Kar *et al.* 1972
*Phragmothyrites eocaenica* Edwards 1922 emend Kar & Saxena 1976
**Ratnagiriathyrites hexagonalis* gen. et sp. nov (Pl. 2, fig. 14, Pl. 3, fig. 11)
*Staphlosporonites* sp. 1 (Pl. 3, fig. 14)
*Staphlosporonites* sp. 2 (Pl 3, fig. 16)
**Trichothyrites amorphus* (Kar & saxena) comb. nov
**Trichothyrites setiferus* (Cookson) comb. nov

Taxa with asterisk (*) mark have either been described or commented upon herein. Plate and figure numbers given in the above list in parentheses refer to the illustration of the present paper. The spore/pollen types which could not be assigned to any known species and are represented by very few specimens have also been listed in the check-list (eg. *Leptolepidites* sp., *Lakiapollis* sp., etc.) and illustrated in the plates. However, their descriptions have not been given.

## SYSTEMATIC PALYNOLOGY

### Genus—*Cyathidites* Couper 1953

*Cyathidites giganticus* sp. nov.
Pl. 1, fig. 17

*Holotype*—Pl. 1, fig. 17, size 96 $\mu$m, Slide no. BSIP 10135, coordinates: 51.8 × 104.2.

*Type horizon & locality*—Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Spores triangular with concave interapical margin, size range 94-100 $\mu$m; trilete, rays extending up to the equator; exine 4.5-5.5 $\mu$m thick, slightly thicker at apices than at interapical region, laevigate.

*Comparison*—*Cyathidites australis* Couper 1953 (54-77 $\mu$m), *C. minor* Couper 1953 (31-45 $\mu$m, exine 1.5 $\mu$m thick) and *C. congoensis* Sah 1967 (32-46 $\mu$m, exine 1.5-2.5 $\mu$m thick) differ from the present species in having smaller size and thinner exine.

*Number of specimens studied*—13.

### Genus—*Monolites* Erdtman 1947 ex Potonié 1956

*Monolites amberiwadiensis* sp. nov.
Pl. 1, fig. 6

*Holotype*—Pl. 1, fig. 6, size 61 × 50 $\mu$m, Slide no. BSIP 10127; coordinates: 59.8 × 97.1.

*Type horizon & locality*—Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Spores circular to oval; size range 51-63 × 44-51 $\mu$m; monolete, ray extending more than half the longer axis; exine 2 to 2.5 $\mu$m thick, psilate, perine present, more or less punctate.

*Comparison*—The present species is distinguished from *M. ovatus* Sah 1967 and *M. mawkmaensis* Dutta & Sah 1970 by the presence of punctate perine, bigger size and thicker exine.

*Number of specimens studied*—17.

### Genus—*Polypodiisporites* Potonié 1934

*Polypodiisporites minutiverrucus* sp. nov.
Pl. 1, fig. 5

*Holotype*—Pl. 1, fig. 5, size 49 × 31 $\mu$m, Slide no. BSIP 10126; coordinates: 53.5 × 99.2.

*Type horizon & locality*—Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Spores bean-shaped, size range 49-59 × 29-50 $\mu$m; monolete, ray distinct, extending up to half the longer axis; exine 2.5 $\mu$m thick, verrucose, verrucae small, 3-4 $\mu$m in size, flat, closely placed.

*Comparison*—*Polypodiisporites* sp. (Saxena, 1978, pl. 2, figs 37, 38, p. 452) resembles present species in having small verrucae but differs in being bigger in size (68-92 × 58-68 $\mu$m).

*Number of specimens studied*—18.

### Genus—*Retitricolporites* Van der Hammen 1956 ex Van der Hammen & Wijmstra 1964

*Retitricolporites subcircularis* sp. nov.
Pl. 1, fig. 11

*Holotype*—Pl. 1, fig. 11, size 52 × 46 $\mu$m, Slide no. BSIP 10130; coordinates: 48.1 × 96.5.

*Type horizon & locality*— Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Pollen isopolar, circular to

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## PLATE 1

→

(All photomicrographs are *ca* ×750, unless otherwise stated. Coordinates refer to Leitz Laborlux microscope no. 512794/067304).

1. *Cyathidites minor* Couper, Slide no. BSIP 10122; coordinates: 35.2 × 96.4.
2. *Osmundacidites microgranifer* Sah & Jain, Slide no. BSIP 10123: coordinates 58.4 × 98.7.
3. *Leptolepidites* sp., Slide no. BSIP 10124; coordinates: 51.1 × 100.1.
4. *Polypodiisporites* sp., Slide no. BSIP 10125; coordinates: 60.3 × 96.8.
5. *Polypodiisporites minutiverrucus* sp. nov., Slide no. BSIP 10126; coordinates: 53.5 × 99.2 (Holotype).
6. *Monolites amberiwadiensis* sp. nov., Slide no. BSIP 10127; coordinates: 59.8 × 97.1 (Holotype).
7. *Verrumonocolpites* sp., Slide no. BSIP 10128; coordinates: 52.3 × 98.5.
8. *Palmidites* sp., Slide no. BSIP 10129; coordinates: 52.6 × 103.4.
9. *Quilonipollenites* sp., Slide no. BSIP 10130; coordinates: 52.2 × 94.1.
10. *Thomsonipollis* sp., Slide no. BSIP 10131; coordinates: 69.6 × 99.9.
11. *Retitricolporites subcircularis* sp. nov., Slide no. BSIP 10130; coordinates: 48.1 × 96.5 (Holotype).
12. *Proxapertites* sp., Slide no. BSIP 10132; coordinates: 48.2 × 100.2.
13. *Lakiapollis* sp., Slide no. BSIP 10133; coordinates: 42.0 × 106.9.
14. *Pandaniidites* sp., ×850, Slide no. BSIP 10134; coordinates: 51.4 × 99.8.
15. *Tricolpites* sp. 2, Slide no. BSIP 10122; coordinates: 31.5 × 99.1
16. *Polyadopollenites* sp., Slide no. BSIP 10126; coordinates: 51.8 × 103.7.
17. *Cyathidites giganticus* sp. nov., ×500, Slide no. BSIP 10135; coordinates: 51.8 × 104.2 (Holotype).
18. *Verrutriporites grandioratus* sp. nov., Slide no. BSIP 10136; coordinates: 51.2 × 94.2 (Holotype).
19. *Dermatobrevicolporites* sp., Slide no. BSIP 10137; coordinates: 39.8 × 103.1.
20. *Verrualetes assamicus* Singh & Saxena, Slide no. BSIP 10134; coordinates: 43.7 × 106.8.

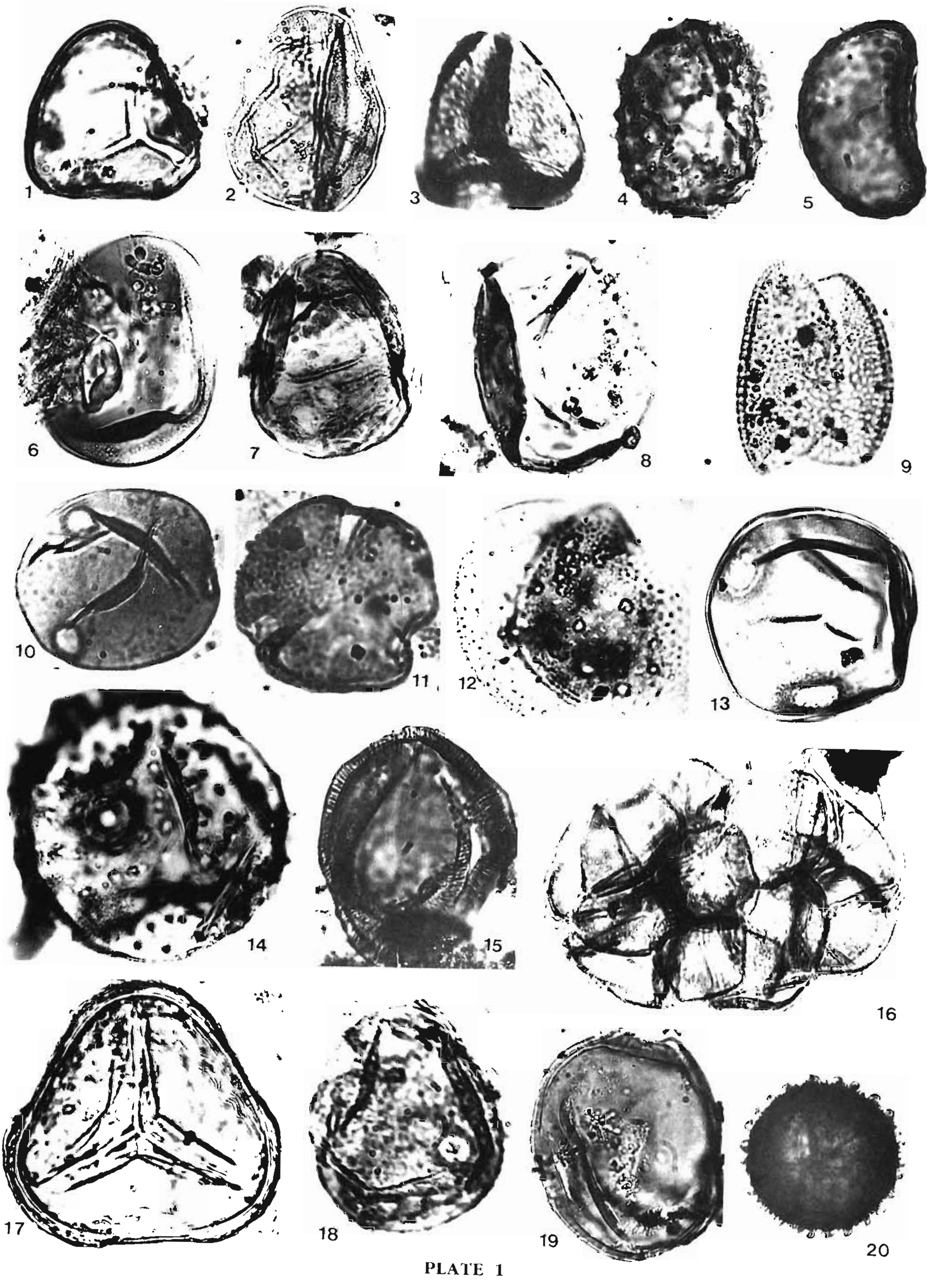

PLATE 1

subtriangular, 43-56 μm in size, tricolporate, zonicolporate, colpi deep, colpi margin thickened with ± blunt ends, pores distinct, oval, 8-10 × 4-6 μm in size, pore margin thickened; exine 2.5-3 μm thick, tectate, columella distinct, reticulate to foveoreticulate, lumina circular, *ca* 1 μm, sexine thicker than nexine.

*Comparison*—The present species is distinguished from *R. guianensis* Van der Hammen & Wijmstra 1964, *R. annulatus* Salard-Cheboldaeff 1978 and *R. crassioratus* Rao & Ramanujam 1982 by its bigger size, thickened ora and colpi margins and reticulate to foveoreticulate ornamentation.

*Number of specimens studied*—12.

### Genus—*Verrutriporites* Muller 1968

*Verrutriporites grandioratus* sp. nov.
Pl. 1, fig. 18

*Holotype*—Pl. 1, fig. 18, size 57 × 47 μm, Slide no. BSIP 10136; coordinates: 51.2 × 94.2.

*Type horizon & locality*—Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Pollen oval, size range 50-58 × 39-47 μm; triporate, pores oval, 7-9 × 3.5-6 μm, pore margin thickened, pores subequatorial in position; exine 1-1.5 μm thick, verrucate, verrucae small to large, closely placed and evenly distributed, folds present.

*Comparison*—*V. lundensis* Muller 1968 differs from present species in having smaller size (18-34 μm) and smaller pore diameter (2-3 μm).

*Number of specimens studied*—5.

### Genus—*Heliospermopsis* Nagy 1965

*Heliospermopsis ankleshvarensis* (Srivastava 1967) comb. nov.

*Basionym*—*Oudhkusumites ankleshvarensis* Srivastava 1967, *Rev. Micropaleontol.* **10**(1), pl. 1, figs 1-16, p. 38.

*Holotype*—Srivastava, 1967, pl. 1, fig. 1

## Fungal remains

### Genus—*Microthyriacites* Cookson 1947

*Microthyriacites ramanujamii* sp. nov.
Pl. 2, fig. 13

*Holotype*—Pl. 2, fig. 13, size 116 × 94 μm, Slide no. BSIP 10143; coordinates: 50.7 × 100.5.

*Type horizon & locality*—Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Ascostromata circular to subcircular, nonostiolate, size range 110-126 × 90-95 μm, hyphae radiating, forming pseudoparenchymatous, small, thickened central cells and larger, rectangular to squarish outer cells, cells nonporate, margin thin and wavy.

*Comparison*—The present species is distinguished from *Microthyriacites sahnii* Rao 1959, *M. cooksonii* Rao 1959 and *M. edwardsii* Rao 1959 by its thickened central cells and smaller size.

*Number of specimens studied*—5.

### Genus—*Ratnagiriathyrites* gen. nov.

Type species—*Ratnagiriathyrites hexagonalis* gen. et sp. nov.

*Diagnosis*—Ascostromata subcircular or irregular in shape, dark brown in colour, nonostiolate, cells not arranged radially, porate, pores generally distributed throughout stromata, cells hexagonal, bigger towards periphery than in the central region; margin thick, wavy.

*Comparison*—The present genus is

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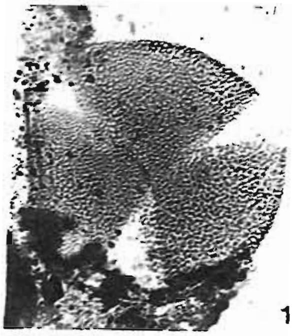
## PLATE 2

1. *Tricolpites* sp. 1 × 650, Slide no. BSIP 10122; coordinates: 37 × 105.4.
2. *Dicolpopollis* sp., Slide no. BSIP 10138; coordinates: 61.3 × 94.0.
3. *Inaperturotetradites* sp. 2, × 550, Slide no. BSIP 10139, coordinates: 43.7 × 99.4.
4. *Dyadosporonites* sp. 2, Slide no. BSIP 10140; coordinates: 39.4 × 98.2.
5. *Malvacearumpollis* sp., Slide no. BSIP 10130; coordinates: 62.7 × 98.9.
6. *Clavaperiporites* sp., Slide no. BSIP 10130; coordinates: 41.1 × 97.7.
7. *Inaperturotetradites* sp. 1, × 850, Slide no. BSIP 10141; coordinates: 51.8 × 108.2.
8. *Triporotetradites* sp., × 500; Slide no. BSIP 10142; coordinates: 69.0 × 93.8.
9. *Paramicrothallites konkanensis* sp. nov., × 500; Slide no. BSIP 10137; coordinates: 44.6 × 102.5 (Holotype).
10. *Heliospermopsis* sp., Slide no. BSIP 10140; coordinates 65.3 × 110.8.
11. *Dyadosporonites* sp. 1, Slide no. BSIP 10140; coordinates: 59.0 × 93.1.
12. *Fusiformisporites* sp., Slide no. BSIP 10142; coordinates: 50.5 × 105.2.
13. *Microthyriacites ramanujamii* sp. nov., Slide no. BSIP 10143; coordinates: 50.7 × 100.5 (Holotype).
14. *Ratnagiriathyrites hexagonalis* sp. nov., Slide no. BSIP 10126; coordinates: 38.3 × 104.7 (Holotype).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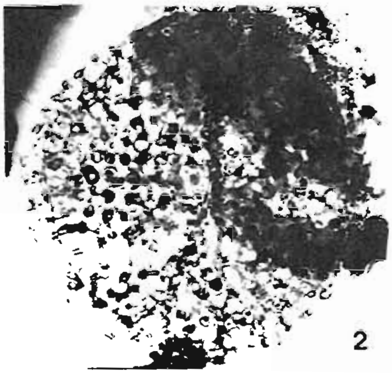
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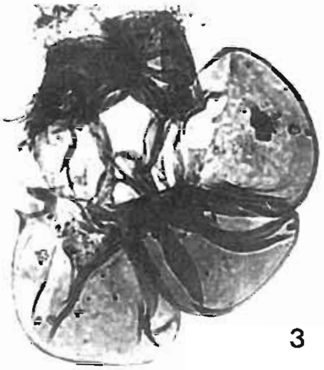
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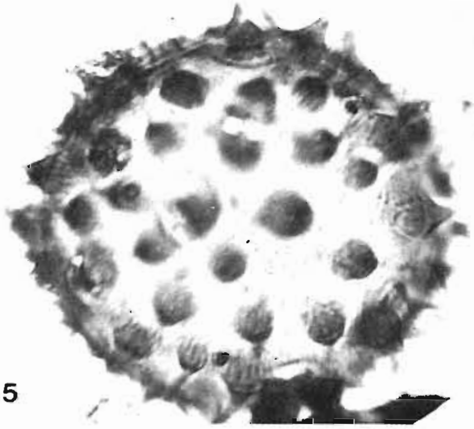
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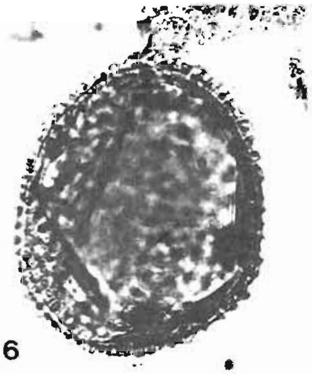
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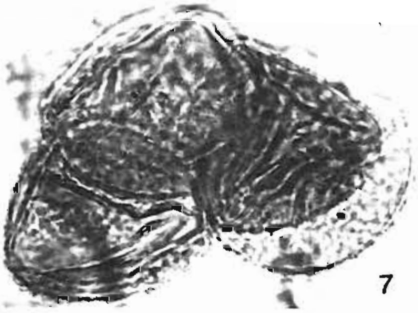
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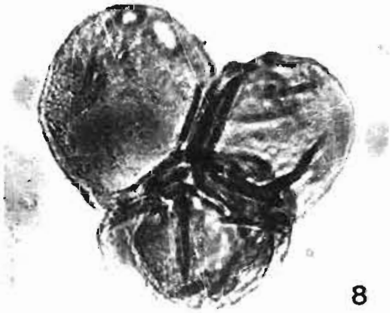
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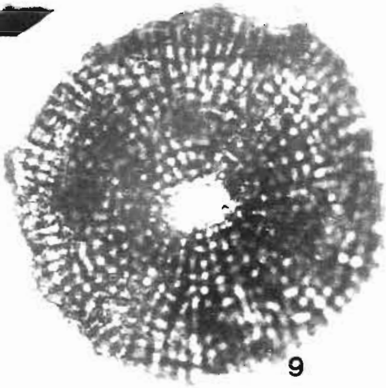
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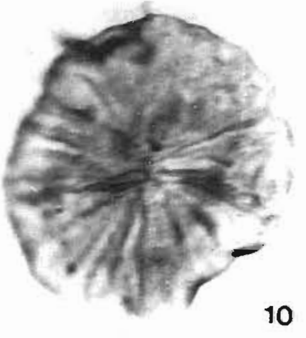
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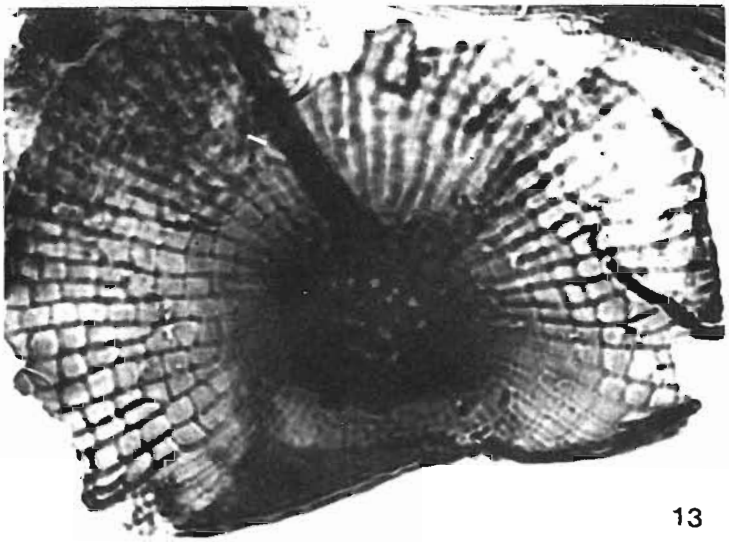
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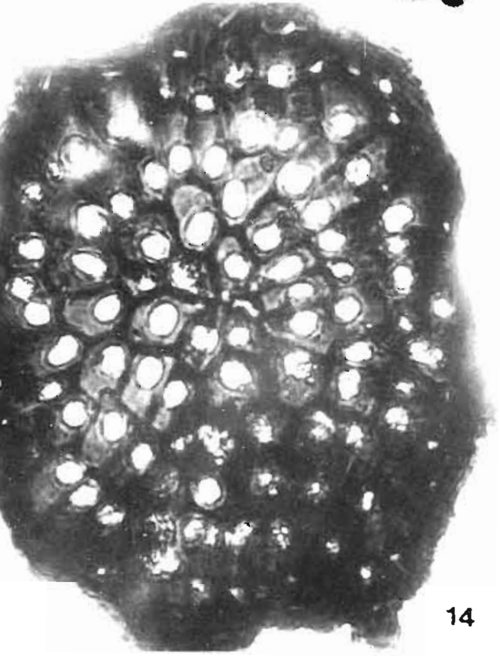
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PLATE 2

distinguished from *Phragmothyrites* Edwards 1922 emend. Kar & Saxena 1976 and *Microthyriacites* Cookson 1947 by its non-radiating and hexagonal, porate cells. *Siwalikiathyrites* Saxena & Singh 1982 resembles the present genus in having non-radial cells but differs in being nonporate.

*Ratnagiriathyrites hexagonalis* sp. nov.
Pl 2, fig. 14; Pl. 3, fig. 11

*Holotype*—Pl. 2, fig. 14, size 114 × 95 μm, Slide no. BSIP 10126; coordinates: 38.3 × 104.7.

*Type horizon & locality*—Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Ascostromata subcircular to irregular in shape, dark brown in colour, nonostiolate, size range 66-114 × 55.5-95 μm, cells not arranged radially, porate, pores mostly distributed throughout ascostromata, marginal cells nonporate, cells hexagonal, sometimes pentagonal, cells increasing in size towards periphery, margin thick, wavy.

*Number of specimens studied*—19.

### Genus—*Paramicrothallites* Jain & Gupta 1970

*Paramicrothallites konkanensis* sp. nov.
Pl. 2, fig. 9

1986 *Paramicrothallites menonii* Jain & Gupta *in* Singh *et al.*, Pl. 1, fig. 4, p. 96

*Holotype*—Pl. 2, fig. 9, size. 103 × 98 μm, Slide no. BSIP 10137; coordinates: 44.6 × 102.5.

*Type horizon & locality*—Ratnagiri beds; Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Ascostromata subcircular in shape, dark brown in colour, size range 94-103 × 90-98 μm, ostiolate, ostiole subcircular, *ca* 7-9 μm in diameter, unthickened, hyphae radiating, forming nonporate pseudoparenchymatous cells, central cells squarish, marginal cells rectangular, margin uneven.

*Comparison*—*Paramicrothallites menonii* Jain & Gupta 1970 reported by Singh *et al.* (1986, pl. 1, fig. 4) resembles the present species.

*Number of specimens studied*—16.

### Genus—*Trichothyrites* Rosendahl 1943

*Trichothyrites setiferus* (Cookson) comb. nov.

*Basionym*—*Notothyrites setiferus* Cookson 1947, *Proc. Linn. Soc. N.S.W.* **72**, pl. 11, figs 1-6, p. 209.

*Holotype*—Cookson, 1947, pl. 11, fig. 1.

*Trichothyrites amorphus* (Kar & Saxena) comb. nov.

*Basionym*—*Notothyrites amorphus* Kar & Saxena 1976, *Palaeobotanist* **23**(1), pl. 4, figs 44-45, p. 9.

*Holotype*—Kar & Saxena, 1976; pl. 4, figs 44-45.

### Genus—*Inapertisporites* Van der Hammen 1954 ex Rouse 1959 emend. Saxena & Bhattacharyya 1987

*Inapertisporites kedvesii* Elsik 1968

*Remarks*—The present specimens are bigger (44-54.5 × 39.2-53.2 μm) than those described by Elsik (1968, 28-38 μm) from the rockdale lignite (Palaeocene) of Texas. Kar and Saxena (1976, pl. 3, fig. 23; pl. 4, fig. 47) described similar but larger (27-72 μm) spores from the Matanomadh Formation (Palaeocene) of Kutch. The spores described by Chandra *et al.* (1984) from the sediment cores from

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## PLATE 3

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1. *Lygodiumsporites lakiensis* Sah & Kar, Slide no. BSIP 10126; coordinates: 53.4 × 93.6.
2. *Retitricolpites dipterocarpoides* Rao & Ramanujam, Slide no. BSIP 10144; coordinates: 61.7 × 98.4.
3. *Todisporites minor* Couper, Slide no. BSIP 10126; coordinates: 49 × 93.5.
4. *Assamiasporites tertiarus* Mehrotra & Sah, Slide no. BSIP 10144; coordinates: 31.6 × 109.8.
5. *Assamiapollenites* sp., Slide no. BSIP 10148A; coordinates: 43.8 × 106.8.
6. *Pteridacidites fistulosus* Sah, Slide no. BSIP 10132; coordinates: 38 × 95.4.
7. *Osmundacidites cephalus* Saxena, Slide no. BSIP 10145; coordinates: 49.3 × 107.3.
8. *Basidiosporites* sp. 2, Slide no. BSIP 10146; coordinates: 35.3 × 91.9.
9. *Retipilonapites* sp., Slide no. BSIP 10130; coordinates: 64.5 × 95.7.
10. *Favitricolporites retiformis* Sah, Slide no. BSIP 10134; coordinates: 62.8 × 92.3.
11. *Ratnagiriathyrites hexagonalis* sp. nov., Slide no. BSIP 10138; coordinates: 67.2 × 108.2.
12. *Basidiosporites* sp. 1, Slide no. BSIP 10147; coordinates: 45.6 × 107.4.
13. *Diporicellaesporites wilkinsonii* sp. nov., Slide no. BSIP 10122; coordinates: 70.5 × 104.6 (Holotype).
14. *Staphlosporonites* sp. 1, Slide no. BSIP 10132; coordinates: 43.2 × 97.5.
15. *Striatriletes susannae* van der Hammen emend. Kar, Slide no. BSIP 10134; coordinates: 41.2 × 91.7
16. *Staphlosporonites* sp. 2, Slide no. BSIP 10122; coordinates: 44.2 × 106.8.
17. *Parmathyrites* sp., Slide no. BSIP 10130; coordinates: 55.4 × 106.2.
18. *Lirasporis* sp., Slide no. BSIP 10130; coordinates: 49.9 × 103.5.
19. *Diporicellaesporites* sp., Slide no. BSIP 10148; coordinates: 39.8 × 101.5.

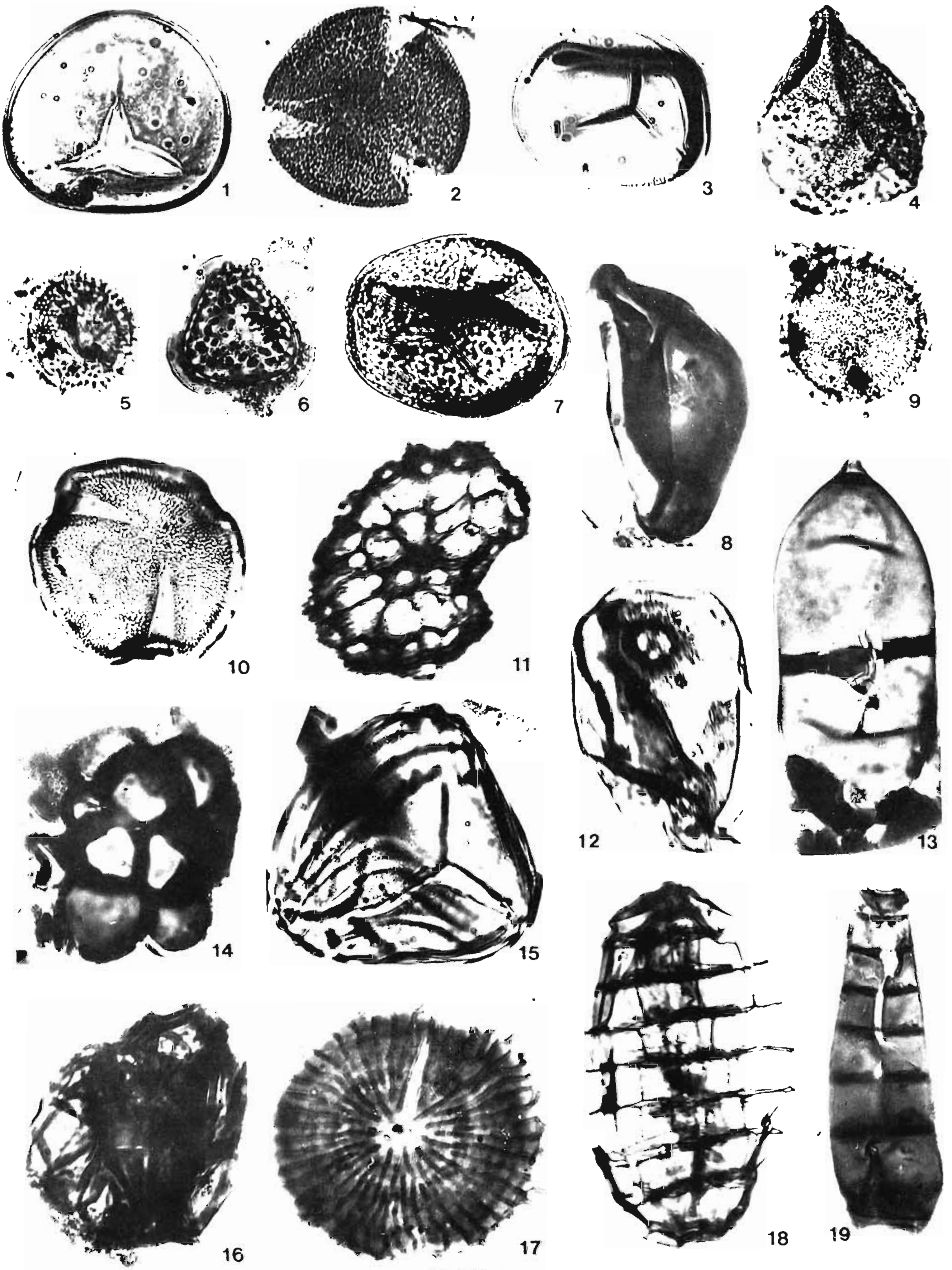


PLATE 3

Arabian Sea range from 14 to 88 μm in size

*Number of specimens studied*—47

**Genus—*Diporicellaesporites* Elsik 1968**

*Diporicellaesporites wilkinsonii* sp. nov
Pl 3, fig. 13

*Holotype*—Pl. 3, fig. 13, size 100 × 40 μm, Slide no. BSIP 10122; coordinates: 70.5 × 104.6.

*Type horizon & locality*—Ratnagiri beds, Amberiwadi section, Sindhu Durg District, Maharashtra.

*Diagnosis*—Fungal spores capsular in shape, size range 98-126 × 36-40 μm; tetracellate, middle septum complete, 2.5-3 μm thick, whereas other two septa incomplete, not covering full width of spore; diporate, pores apical, situated on protuberances, sometimes slightly offset; wall up to 1.0 μm thick, psilate.

*Comparison*—The present species is distinguished from *D. stacyii* Elsik 1968 and *D. acuminatus*, *D. puryearensis* and *D. tetralocularis* all instituted by Sheffy and Dilcher 1971 by its bigger size and two ill-developed and incomplete septa.

*Number of specimens studied*—17.

## DISCUSSION

The qualitative and quantitative analyses of the present palynofloral assemblage indicate that the fungal remains and pteridophytic spores are the dominant constituents, whereas the angiospermous pollen are poorly represented. The assemblage is devoid of algal, bryophytic and gymnospermous elements.

### Qualitative Analysis

The known botanical affinities of palynotaxa and present day distribution of the various families are given in table 1

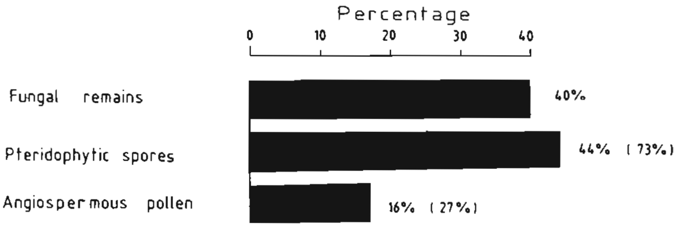
**Table 1**

| Botanical group/Family | Palynotaxa | Present day distribution of the family | Remarks |
|---|---|---|---|
| DIVISION-THALLOPHYTA | | | |
| Fungal fruiting bodies (Microthyriaceae) | *Parmathyrites ramanujamii*, *Parmathyrites* sp., *Phragmothyrites eocaenica*, *P. edwardsii*, *P. assamicus*, *Microthyriacites ramanujamii*, *Kutchiathyrites eccentricus*, *Ratnagiriathyrites hexagonalis*, *Lirasporis intergranifer*, *Lirasporis* sp., *Paramicrothallites konkanensis*, *Trichothyrites setiferus*, *T amorphus* | Warm and humid Tropical climate | |
| Fungal spores and mycelia (Ascomycetes, Basidiomycetes and Deuteromycetes) | *Inapertisporites kedvesii*, *I. subovoideus*, *Fusiformisporites* sp., *Dicellaesporites popovii*, *Dicellaesporites fusiformis*, *Multicellaesporites elsikii*, *Staphlosporonites* spp. 1 and 2, *Dendromyceliates splendens*, *Basidiosporites fournierii*, *Basidiosporites* spp. 1 and 2, *Involutisporonites wilcoxii*, *Dyadosporonites* spp. 1 and 2, *Diporicellaesporites wilkinsonii*, *Diporicellaesporites* sp. | | |
| DIVISION-PTERIDOPHYTA | | | |
| Cyatheaceae | *Cyathidites congoensis*, *Cyathidites minor*, *Cyathidites giganticus* | Tropical-subtropical | |
| Osmundaceae | *Osmundacidites micrograniter*, *O. cephalus*, *Todisporites minor* | Cosmopolitan | Shady places or swamps |
| Dicksoniaceae | *Dictyophyllidites kyrtomatus* | Tropical-subtropical | |
| Schizaeaceae (*Lygodium*) | *Lygodiumsporites lakiensis*, *L pachyexinus*, *Leptolepidites* sp. | Tropical-subtropical | |
| Lycopodiaceae | *Assamiasporites tertiarus* | Cosmopolitan | Humid shady habitat |
| Parkeriaceae (*Ceratopteris thalictroides*) | *Striatriletes susannae* | Tropical-subtropical | |

| | | | |
|---|---|---|---|
| Adiantaceae | *Pteridacidites fistulosus* | Cosmopolitan | Chiefly in damp and shady places |
| Polypodiaceae (*Polypodium*) | *Monolites ovatus, M maukmaensis, Monolites amberiwadiensis, Polypodiaceaesporites levis, P. tertiarus, Laevigatosporites ovatus, L. lakiensis, Polypodiisporites ornatus, P repandus Polypodiisporites* sp., Polypodiisporites *minutiverrucus* | Cosmopolitan | |
| DIVISION-SPERMATOPHYTA | | | |
| SUBDIVISION-ANGIOSPERMAE<br>CLASS-MONOCOTYLEDONAE | | | |
| Arecaceae | *Palmidites maximus, Palmidites* sp., *Dicolpopollis* sp., *Proxapertites microretienlatus. Proxapertites* sp. | Tropical-subtropical | |
| Arecaceae (*Syagrus*) | *Arecipites punctatus* | | |
| Arecaceae (*Eugeissona*) | *Quilonipollenites ornatus, Quilonipollenites* sp. | | |
| Potamogetonaceae (*Potamogeton*) | *Retipilonapites* sp., *R delicatissimus* | Cosmopolitan | Aquatic |
| Pandanaceae (*Pandanus*) | *Pandaniidites* sp. | Cosmopolitan | |
| CLASS-DICOTYLEDONAE | | | |
| Dipterocarpaceae (*Dipterocarpus*) | *Retitricolpites dipterocarpoides* | Tropical-Subtropical | |
| Gunneraceae | *Tricolpites reticulatus* | Cosmopolitan | |
| Rubiaceae | *Retitricolporites crassioratus* | Tropical-subtropical | |
| Oleaceae | *Retitrescolpites splendens* | Cosmopolitan | Chiefly tropical subtropical |
| Bombacaceae (*Durio*) | *Lakiapollis ovatus, Lakiapollis* sp. | Tropical-subtropical | |
| Gentianaceae | *Favitricolporites retiformis* | Cosmopolitan | |
| Thymeliaceae (*Wilkstroemia*) | *Clavaperiporites jacobi, Clavaperiporites* sp., | Cosmopolitan | |
| Malvaceae | *Malvacearumpollis* sp. | Tropical-subtropical | |
| Rhizophoraceae | *Paleosantalaceaepites dinoflagellatus* | Tropical-subtropical | |
| Mimosaceae | *Polyadopollenites* sp. | Tropical-subtropical | |
| Lamiaceae | *Tricolpites* spp. 1 and 2 | Cosmopolitan | |
| Sonnertiaceae | *Verrutriporites grandioratus* | Tropical-subtropical | |
| Sapotaceae | *Thomsonipollis* sp. | Tropical-subtropical | |
| Avicenniaceae (*Avicennia*) | *Retitricolporites subcircularis* | Tropical-subtropical | |

## Quantitative analysis

The Amberiwadi palynoflora comprises 60 genera and 95 species including fungal remains, pteridophytic spores, angiospermous pollen and salt glands of mangrove plants. The quantitative analysis has been done on the basis of frequency of various palynotaxa in a count of 100 specimens per sample. This revealed that fungal remains, being represented by 18 genera and 30 species constitute 40 per cent of the assemblage. The significant fungal taxa have been referred to *Phragmothyrites, Ratnagiriathyrites, Lirasporis, Trichothyrites* and *Inapertisporites.* The pteridophytic spores, represented by 13 genera and



**Text-figure 3**—Percentage of various botanical groups in the palynoassemblage of Amberiwadi section.

24 species, constitute 44 per cent of the assemblage. The dominant genera of pteridophytic spores are: *Cyathidites, Todisporites, Lygodiumsporites, Assamiasporites, Laevigatosporites, Monolites, Polypodiaceaesporites* and *Polypodiisporites.* The angiospermous pollen being represented by 28 genera and 38 species are poorly represented (16%). The significant angiospermous pollen taxa are: *Lakiapollis, Dermatobrevicolporites* and *Verrutriporites.* Not considering the fungal remains, the pteridophytic spores and angiospermous pollen come to 73 and 27 per cent, respectively (Text-fig. 3). The rich representation of local elements, viz., fungal remains and pteridophytic spores, appears to have masked the frequency of the angiospermous elements. The genera which are represented by more than 5 per cent are: *Phragmothyrites, Trichothyrites, Todisporites, Lygodiumsporites, Laevigatosporites, Polypodiisporites* and *Lakiapollis. Lakiapollis* is a dominant taxon constituting more than half of the angiospermous pollen assemblage.

### Palaeoclimate

The Amberiwadi assemblage consists of palynofossils having affinities with 25 extant families. Of these, 14 families are restricted to the tropical-subtropical climate, whereas others are cosmopolitan in distribution (Table 1). The prevalence of tropical-subtropical climate with heavy rainfall during the sedimentation of the Ratnagiri beds is evident from the composition of the assemblage and the present day distribution of their nearest extant families. The rich representation of fungal remains is also indicative of warm and humid climate.

### Environment of deposition

The present palynoflora contains elements belonging to various ecological groups, viz., montane, fresh water swamps and water edge, mangrove, back-mangrove and sandy beach.

Montane elements—*Clavaperiporites.*

Fresh-water swamps and water-edge elements—*Lygodiumsporites, Striatriletes, Pteridacidites, Laevigatosporites, Monolites, Polypodiisporites, Retipilonapites, Proxapertites.*

Back mangrove and mangrove elements—*Retitricolporites, Favitricolporites, Paleosantalaceaepites, Verrutriporites.*

Sandy beach elements—*Arecipites, Quilonipollenites, Dicolpopollis.*

The qualitative analysis of the Amberiwadi assemblage reveals that the presence of *Lygodiumsporites* and *Striatriletes* is indicative of fresh-water swampy environment. Pollen taxa referable to Potamogetonaceae show aquatic environment. The presence of family Rhizophoraceae (*Paleosantalaceaepites*), Avicenniaceae (*Retitricolporites*) and Gentianaceae (*Favitricolporites*) suggests mangrove vegetation. Back-mangrove elements belonging to family Sonneratiaceae (*Verrutriporites*) are also present in this assemblage. Coastal and shore line elements are represented by *Quilonipollenites, Arecipites, Palmidites* and *Dicolpopollis* related to family Arecaceae. The montane elements belonging to family Thymeliaceae (*Clavaperiporites*) appear to be derived from some distance. From the overall vegetational pattern the environment of deposition appears to be near-shore with sufficient fresh water supply or fresh water swamps nearby, or both.

## CONCLUSIONS

On the basis of foregoing account, the following conclusions have been derived:

1. Amberiwadi palynofloral assemblage consists of fungal remains (including spores and fruiting bodies), pteridophytic spores and angiospermous pollen. The bryophytic and gymnospermous elements are totally unrepresented.
2. The fungal remains (40%) are represented by 18 genera and 30 species. Of these, 9 genera and 16 species are of fungal spores.
3. The pteridophytic spores (44%) are represented by 13 genera and 24 species and have been assigned to Cyatheaceae, Osmundaceae, Dicksoniaceae, Schizaeaceae, Lycopodiaceae, Parkeriaceae, Adiantaceae and Polypodiaceae. The spores assigned to Cyatheaceae, Osmundaceae, Schizaeaceae and Polypodiaceae are dominantly present in the Amberiwadi assemblage.
4. The angiospermous pollen (16%) are represented by 28 genera and 38 species and are referable to Arecaceae, Potamogetonaceae, Pandanaceae, Dipterocarpaceae, Gunneraceae, Rubiaceae, Oleaceae, Bombacaceae, Gentianaceae, Thymeliaceae, Malvaceae, Rhizophoraceae, Mimosaceae, Lamiaceae, Sonneratiaceae, Sapotaceae, Avicenniaceae. The members of

Bombacaceae, being represented by *Lakiapollis* are dominant in the assemblage.

5. The palynoflora suggests a warm, humid (tropical-subtropical) climate with heavy rainfall during the deposition of Ratnagiri beds.
6. The environment of deposition has been interpreted as near-shore with sufficient fresh water supply or fresh water swamps nearby or both. The occurrence of a mixture of elements from various ecological groups could be possible only in such condition.

## ACKNOWLEDGEMENTS

The authors are grateful to Dr B. S. Venkatachala, Director, B.S.I.P., Lucknow for useful discussions. The present work has been carried out under a research project sponsored by C.S.I.R., New Delhi [Project no. 24 (171)/86-EMR-II]. One of the authors (N.K.M.) is grateful to C.S.I.R., New Delhi for the award of Junior Research Fellowship.

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# Some fossil woods from Tipam Sandstone of Assam and Nagaland

N. Awasthi & R. C. Mehrotra

Awasthi, N. & Mehrotra, R. C. 1990. Some fossil woods from Tipam Sandstone of Assam and Nagaland. *In* . Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 277-284.

The paper records four fossil woods, viz., *Koompassioxylon elegans* Kramer, *Bauhinia tertiara* sp. nov., *Bischofia palaeojavanica* Awasthi and *Laurinoxylon naginimariense* sp. nov. from the Tipam Sandstone of Assam and Nagaland. These show close resemblance with the woods of extant genera, viz., *Koompassia, Bauhinia, Bischofia* and Lauraceae, respectively. Occurrence of *Koompassia* in the Indian and southeast Asian Neogene sediments provides further evidence of a close phytogeographical link between Indian subcontinent and southeast Asia.

**Key-words**—Fossil woods, Fabaceae, Lauraceae, Bischofiaceae, Tipam Sandstone, Late Miocene (India).

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## साराँश

### असम एवं नागालैंड के तिपम बालुपत्थर से कुछ अश्मित काष्ठें

नीलाम्बर अवस्थी एवं राकेश चन्द्र मेहरोत्रा

असम एवं नागालैंड के तिपम बालुपत्थर से **कूम्पासिऑक्सीलान एलिगेन्स** क्रेमर, **बॉहीनिआ टर्शियॅरा** नव जाति, **बिस्कोफ़िआ पेलियोजावानिका** अवस्थी एवं **लॉरीनॉक्सीलॉन नगीनीमारीयेन्से** नव जाति नामक चार अश्मित काष्ठों का वर्णन किया गया है। ये काष्ठें क्रमशः वर्तमान **कूम्पासिआ, बॉहीनिआ, बिस्कोफ़िआ** नामक प्रजातियों तथा लॉरेसी कुल से घनिष्ठ समानता प्रदर्शित करते हैं। भारतीय एवं दक्षिण-पूर्व एशिया के पश्चनूतन कालीन अवसादों में **कूम्पासिआ** की उपस्थिति से इन दो उपमहाद्वीपों के बीच पादप-भौगोलिक सम्बन्ध व्यक्त होता है।

THE Neogene sediments belonging to the Tipam Group are well-developed throughout northeast India. They generally contain plant remains in the form of silicified and semicarbonised woods associated with coarse, loose, ferruginous, mottled sandstones, sandy clays and pebbles. Detailed anatomical studies of the fossil woods carried out by several workers (Chowdhury, 1936; 1938; Chowdhury & Ghosh, 1946; Chowdhury & Tandon, 1949; Ghosh, 1956; Eyde, 1963; Prakash, 1966; Prakash & Tripathi, 1969a, b, 1970a, b, 1972, 1974, 1975, 1976, 1977; Prakash & Awasthi, 1970, 1971; Prakash & Lalitha, 1978; Lalitha & Prakash, 1980; Prakash, Bande & Lalitha, 1986) from Assam and Nagaland have revealed the presence of a number of tropical dicotyledonous genera belonging to the families Flacourtiaceae, Clusiaceae (Guttiferae), Dipterocarpaceae, Celastraceae, Sterculiaceae, Elaeocarpaceae, Fabaceae (Leguminosae), Combretaceae, Lecythidaceae, Lythraceae, Sonneratiaceae, Sapotaceae, Ebenaceae, Verbenaceae, Lauraceae, Euphorbiaceae, and Moraceae. With the intention of updating the flora of Tipam Group and for better understanding of the palaeoenvironment and phytogeography, we have further carried out detailed investigation of fossil woods from these areas. Amongst them, the fossil woods showing close resemblance with the woods of extant *Koompassia, Bauhinia, Bischofia* and a lauraceous member, are described in the present paper.

## SYSTEMATIC DESCRIPTION

### Family—Fabaceae (Leguminosae)

#### Genus—*Koompassioxylon* Kramer 1974

*Koompassioxylon elegans* Kramer 1974
Pl. 1, figs 1, 4, 6

*Description*—*Wood* diffuse-porous (Pl. 1, fig. 1). *Growth rings* not seen. *Vessels* small to large, t.d. 72-240 μm, r.d. 52-280 μm, round to oval, solitary and in radial multiples of 2-6, rarely in tangential pairs, evenly distributed, 3-7 per sq mm (Pl. 1, fig. 1), perforations simple; vessel-members storied; intervessel pits bordered, alternate, 6-8 μm in diameter, vestured. *Parenchyma* paratracheal, aliform, confluent to confluent-banded, bands up to 5 cells thick (Pl. 1, fig. 1), strands storied. *Xylem rays* 1-3 (mostly 2) seriate, 6-8 per mm, storied (Pl 1, fig. 6); ray tissue heterogeneous; uniseriate rays 4-15 cells or 80-280 μm in height, composed wholly of procumbent cells; multiseriate rays 6-21 cells or 140-400 μm in height, mostly consisting of procumbent cells, sometimes with single row of upright or square cells at one or both the ends (Pl. 1, fig. 4). *Fibres* angular in cross section, 12-20 μm in diameter, about 560 μm in length, thick-walled, non-septate. *Ripple marks* present due to storied arrangement of vessel members, parenchyma strands and rays (Pl. 1, fig. 4).

*Affinities*—The above anatomical characters of fossil wood collectively indicate its close similarity with that of the Malayan *Koompassia malaccensis* and the fossil wood—*Koompassioxylon elegans* Kramer reported earlier from the Neogene of south-east Asia and Bengal (Kramer, 1974; Bande & Prakash, 1980).

*Figured specimen*—Museum specimen no. BSIP 36351.

*Locality*—Bimlapur, Dibrugarh District, Assam

### Genus—*Bauhinia* Linn.

*Bauhinia tertiara* sp. nov.
Pl. 1, figs 3, 8; Pl. 2, figs 1-3

Single piece of well-preserved secondary wood measuring about 13 cm in length and 3 cm in width.

*Description*—*Wood* diffuse-porous (Pl. 2, fig. 1). *Growth rings* not observed. *Vessels* small to large, mostly medium in size, t.d. 72-180 μm, r.d. 72-280 μm, mostly solitary, occasionally in radial multiples of 2-4, evenly distributed, 3-11 per sq mm, oval in shape when solitary, with flat contact walls when in multiples (Pl. 2, fig. 1); tyloses present; perforations simple; vessel-members 100-380 μm long with oblique to horizontal ends, storied (Pl. 1, fig. 3), intervessel pits bordered, alternate, 4-8 μm in diameter, almost circular in shape with lenticular apertures (Pl. 1, fig. 8). *Parenchyma* vasicentric, having 3-5-celled sheath completely enclosing vessels, mostly aliform to confluent, banded, joining several adjacent vessels (Pl. 2, fig. 1); parenchyma strands storied, cells 16-48 μm in width and 48-100 μm in length. *Xylem rays* 1-2 seriate, mostly uniseriate, 9-12 per mm, usually made up of procumbent cells, storied (Pl. 2, figs 2, 3); ray tissue weakly heterogeneous, rays 16-44 μm in width and 8-60 cells or 160-960 μm in height; procumbent cells 32-60 μm in radial length and 16-32 μm in tangential height; upright cells 44-48 μm in tangential height and 16-20 μm in radial length. *Fibres* moderately thick-walled, angular in cross section, 8-16 μm in diameter and 440-600 μm in length, non-septate (Pl. 2, figs 1, 3). *Ripple marks* present due to storied arrangement of vessel-members, parenchyma strands and rays (Pl. 2, figs 2, 3)

*Holotype*—Museum specimen no. BSIP 36352.

*Locality*—Naginimara Village, Kongan Coalfield, Mon District, Nagaland.

*Affinities*—Presence of ripple marks due to storied arrangements of vessel-members, parenchyma strands and xylem rays, tylosed vessels, vasicentric, aliform to confluent-banded parenchyma, predominantly uniseriate xylem rays and non-septate fibres indicate its affinity with *Bauhinia* Linn. of Fabaceae (Metcalfe & Chalk, 1950; Rao *et al.*, 1972). Wood slides of five species of *Bauhinia*, viz., *B. malabarica* Roxb., *B. mirandina* Pittier, *B. purpurea* Linn., *B. racemosa* Lam. and *B. variegata* Linn. were examined for comparison of the fossil wood; the descriptions and photographs of

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**PLATE 1** →

1. *Koompassioxylon elegans* Kramer 1974: Cross section showing shape, size and distribution of vessels and parenchyma pattern, × 45; Slide no. BSIP 36351-I.
2. *Koompassia malaccensis* Maing. ex Benth.: Cross section showing similar nature and distribution of vessels and parenchyma as in fossil, × 45.
3. *Bauhinia tertiara* sp. nov. Radial longitudinal section showing storied nature of vessel elements, × 100; Slide no. BSIP 36352-III.
4. *Koompassioxylon elegans* Kramer 1974: Tangential longitudinal section showing storied rays, × 45; Slide no. BSIP 36351-II.
5. *Koompassia excelsa* (Becc.) Taub.: Tangential longitudinal section showing similar storied rays, × 45.
6. *Koompassioxylon elegans* Kramer 1974: Tangential section showing details of ray cells, × 120; Slide no. BSIP 36351-II.
7. *Laurinoxylon naginimariense* sp. nov.; Radial longitudinal section showing oil cells in rays, × 120; Slide no. BSIP 36353-III.
8. *Bauhinia tertiara* sp. nov.: Intervessel pits, × 600; Slide no. BSIP 36352-III.
9. *Laurinoxylon naginimariense* sp. nov.: Intervessel pits, × 600; Slide no. BSIP 36353-II.

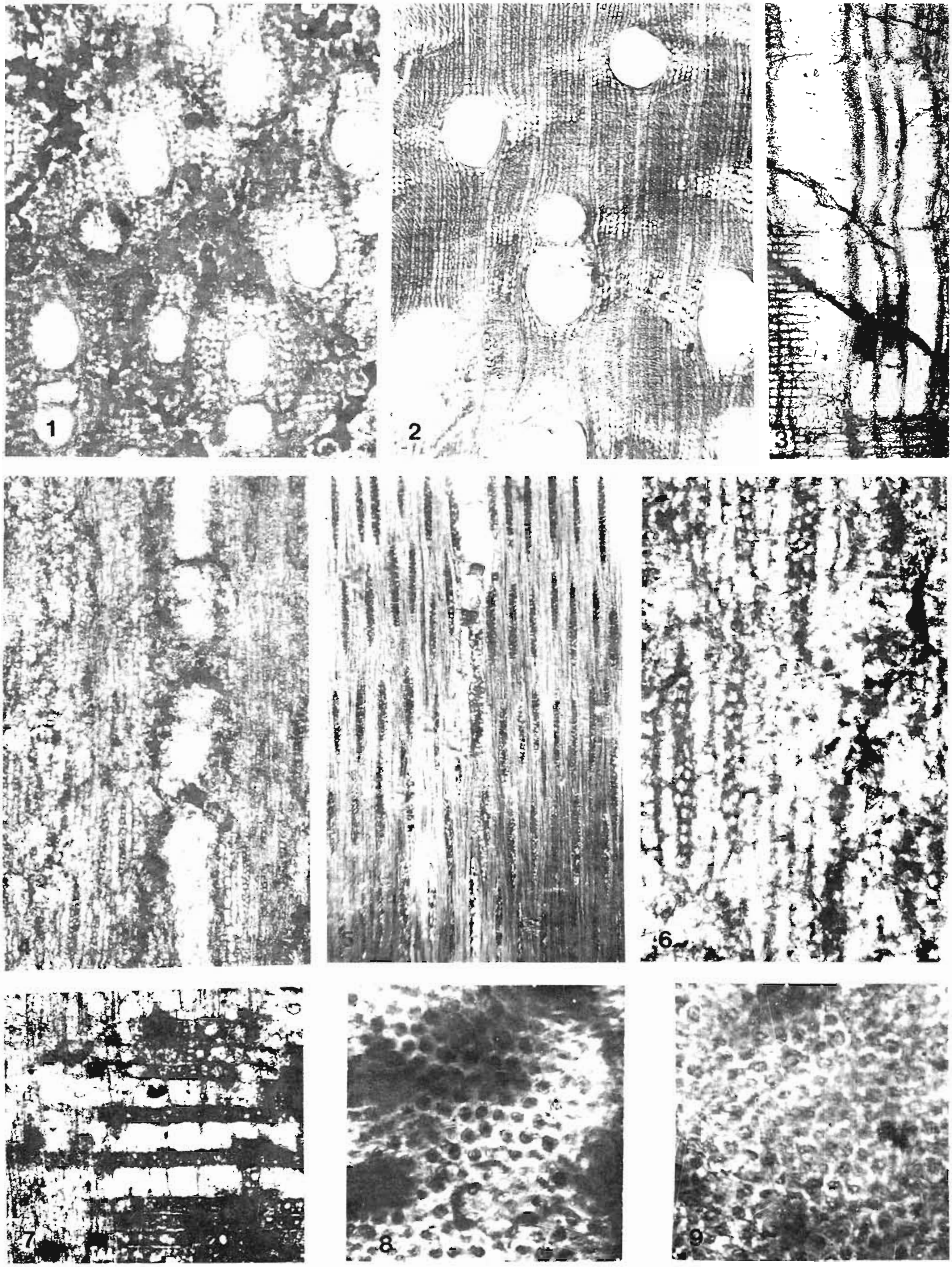

PLATE 1

two other species, *B. foveolata* Dalz. and *B. retusa* Ham. (Pearson & Brown, 1932; Rao *et al.*, 1972) were also consulted. It has been found that the present fossil wood shows closest resemblance with *B. racemosa* and differs from other species in several features. *B. purpurea* and *B. variegata* differ from the fossil in the absence of ripple marks. In *B. mirandina*, the parenchyma is relatively less (vasicentric) and the rays are broader (1-3 seriate). While in *B. foveolata, B. malabarica* and *B. retusa* the amount of parenchyma is more than in the present fossil wood.

The fossil woods of *Bauhinia* are of common occurrence in the Neogene deposits of India. They have been described as *Bauhinium miocenicum* Trivedi & Panjwani (1986) and *B. palaeomalabaricum* Prakash & Prasad (1984), both from the Siwalik beds of Kalagarh, Uttar Pradesh, cf. *Bauhinia* from the Cuddalore Series of Cauvery Basin (Ramanujam & Rao, 1966) and *Bauhinia deomalica* Awasthi & Prakash 1987 from the Namsang beds of Deomali, Arunachal Pradesh. Fossil woods cf. *Bauhinia* (Ramanujam & Rao, 1966), *Bauhinium miocenicum* and *B. palaeomalabaricum* differ from this Nagaland wood in having relatively broad and continuous parenchyma bands. Moreover, in *B. miocenicum* the xylem rays are broader. In *B. deomalica* the parenchyma is mostly banded, whereas in our fossil it is vasicentric to aliform-confluent. Therefore, the present fossil wood is assigned to *Bauhinia tertiara* sp. nov.

### Family—Lauraceae

#### Genus—*Laurinoxylon* Felix 1883

*Laurinoxylon naginimariense* sp. nov.
Pl. 1, figs 7, 9; Pl. 2, figs 4-6

This species is represented by a small piece of secondary wood measuring 7 cm in length and 2.5 cm in width.

*Description—Wood* diffuse-porous (Pl. 2, fig. 4). *Growth rings* indistinct. *Vessels* usually medium to large, occasionally small, rarely very small, t.d. 80-320 $\mu$m, r.d. 40-320 $\mu$m, mostly round to oval, sometimes flattened due to compression, usually solitary, occasionally in radial multiples of 2-3 (rarely up to 5), uniformly distributed, 2-6 per sq mm (Pl. 2, fig. 4); tyloses present; perforations simple; vessel-members 240-360 $\mu$m long with oblique to horizontal ends; intervessel pits bordered, alternate, minute, less than 4 $\mu$m in diameter, circular to oval in shape with linear apertures (Pl. 1, fig. 9). *Parenchyma* vasicentric to aliform, sometimes confluent joining adjacent vessels (Pl. 2, figs 4, 6); parenchyma cells 16-32 $\mu$m in diameter and 20-120 $\mu$m in length. *Xylem rays* 1-5 (mostly 2) seriate, 8-11 per mm, usually made up of procumbent cells; uniseriate rays 12-20 $\mu$m in width and 2-10 cells or 48-220 $\mu$m in height; multiseriate rays 24-72 $\mu$m in width and 5-25 cells or 88-340 $\mu$m in height (Pl. 2, fig. 5); ray tissue heterogeneous; rays homocellular to heterocellular (Pl. 1, fig. 7), consisting of procumbent cells and oil cells at one or both the ends; ray cells 40-80 $\mu$m in radial length and 16-40 $\mu$m in tangential height. *Fibres* moderately thick-walled, angular in cross section, 8-20 $\mu$m in diameter and 200-560 $\mu$m in length. *Oil cells* associated with xylem rays either in the middle portion or at the margins of rays, also present scattered among fibres either singly or in pairs, 44-60 $\mu$m in tangenital height and 40-52 $\mu$m in radial length (Pl. 1, fig. 7; Pl. 2, figs 4-6).

*Holotype*—Specimen no. BSIP 36353.

*Locality*—Naginimara Village, Kongan Coalfield, Mon District, Nagaland.

*Affinities*—In having mostly solitary vessels with occasional multiples, septate fibres, heterogeneous xylem rays, paratracheal parenchyma and oil cells, the present fossil wood shows resemblance with the members of the family Lauraceae.

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### PLATE 2

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1. *Bauhinia tertiara* sp. nov.: Cross section showing nature and distribution of vessels and parenchyma, × 40; Slide no. BSIP 36352-I.
2. *Bauhinia tertiara* sp. nov.: Tangential longitudinal section showing xylem rays, × 65; Slide no. BSIP 36352-II.
3. *Bauhinia tertiara* sp. nov.: Tangential longitudinal section showing ray cells and fibres, × 100; Slide no. BSIP 36352-IV.
4. *Laurinoxylon naginimariense* sp. nov.: Cross section showing nature and distribution of vessels and oil cells, × 25; Slide no. BSIP 36353-I.
5. *Laurinoxylon naginimariense* sp. nov. Tangential longitudinal section showing xylem rays, fibres and oil cells, × 80; Slide no. BSIP 36353-II.
6. *Laurinoxylon naginimariense* sp. nov.: Cross section showing paratracheal parenchyma and oil cells, × 70; Slide no BSIP 36353-I.
7. *Bischofia palaeojavanica* Awasthi 1990: Cross section showing nature and distribution of vessels, × 50; Slide no. BSIP 36354-I.
8. *Bischofia palaeojavanica* Awasthi 1990: Tangential longitudinal section showing xylem rays and septate fibres, × 90; Slide no. BSIP 36354-II.

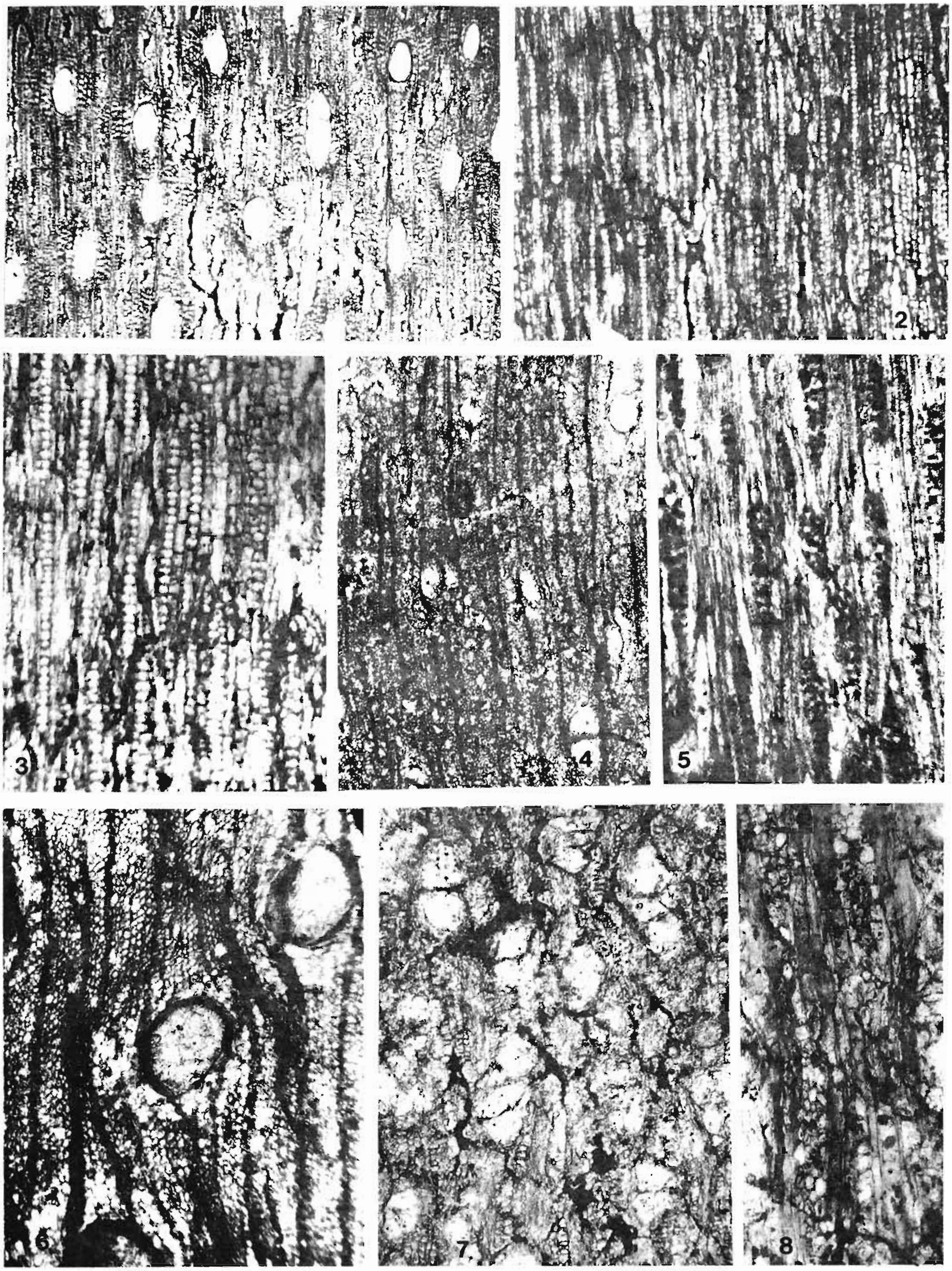

PLATE 2

The family Lauraceae is homogeneous in wood anatomy, thus on the basis of individual genus differentiation is difficult. Therefore, all the lauraceous fossil woods described so far from different parts of the world are placed under the genus *Laurinoxylon* Felix 1883. From India, four species of *Laurinoxylon* are known. They are *Laurinoxylon tertiarum* Prakash & Tripathi 1974 from Tipam Sandstone of Hailakandi, Assam; *L. namsangensis* Lakhanpal *et al.* 1981 and *L. deomaliensis* Lakhanpal *et al.* 1981 from Namsang beds of Deomali, Arunachal Pradesh and *L. varkalaensis* Awasthi & Ahuja 1982 from the Neogene of Varkala, Kerala. The important characters of these fossil woods are summarized in Table 1. *Laurinoxylon tertiarum* differs from the present

**Table 1—Important anatomical characters of *Laurinoxylon* Felix known from India**

| FOSSIL SPECIES | GROWTH RINGS | VESSELS | PARENCHYMA | XYLEM RAYS | FIBRES | OIL CELLS |
|---|---|---|---|---|---|---|
| *Laurinoxylon tertiarum* Prakash & Tripathi 1974 | Distinct | t.d. 60-152 μm, r.d. 80-200 μm, solitary and in radial multiples of 2-4; 8-10 per sq mm; tyloses present; perforations simple and scalariform | Scanty to vasicentric, forming 1-3 celled sheath, sometimes aliform, rarely confluent joining 2-3 adjacent vessels | 1-3 (mostly 2) seriate, 1-24 cells in height, enlarged upright cells at the margins | Non-libriform to semi-libri-form, septate | Present in xylem rays, parenchyma cells and fibres |
| *L. namsangensis* Lakhanpal *et al.* 1981 | Not seen | t.d. 75-300 μm, r.d. 75-405 μm, solitary and in radial multiples of 2-5, 8-10 per sq mm; tyloses profuse; perforations simple | Scanty paratracheal, rarely forming uniseriate sheath | 2 seriate (rarely 3 seriate), 5-22 cells in height, single row of marginal upright or square cells present | Thick-walled, septate | Present in xylem rays |
| *L. deomaliensis* Lakhanpal *et al.* 1981 | Present | t.d. 60-120 μm, r.d. 40-320 μm, solitary and in radial multiples of 2-5, occasionally up to 8, 12-44 per sq mm; tyloses present; perforations simple | Scanty paratracheal | 1-2 (mostly 2) seriate, 5-30 cells in height, single marginal row of upright or square cells present | Moderately thick-walled, septate | Abundant; scattered singly among fibres |
| *L. varkalaensis* Awasthi & Ahuja 1982 | Not seen | t.d. 80-240 μm, r.d. 128-280 μm, solitary and in radial multiples of 3-4, closely placed; tyloses profuse; perforations simple | Paratracheal, 2-3 seriate sheath around vessels, sometimes aliform | 1-3 (mostly 2) seriate, 12-45 cells high, 1-2 enlarged upright cells at the margins | Semi-libriform to libriform, septate | Present among fibres and at the margins of rays |
| *L. naginimariense* sp. nov. | Indistinct | t.d. 80-320 μm, r.d. 40-320 μm, solitary and in radial multiples of 2-5, 2-6 per sq mm; tyloses present; perforations simple | Vasicentric to aliform, sometimes confluent joining ȧdjacent vessels | 1-5 (mostly 2) seriate, homocellular to heterocellular, 5-25 cells in height | Moderately thick-walled, septate | Associated with xylem rays either in the middle portion or at the margins; also occuring as scattered cells among fibres |

fossil in having scalariform perforation plates. In *L. namsangensis* and *L. deomaliensis* the parenchyma is less, i.e., scanty paratracheal to uniseriate vasicentric than in the present fossil specimen. The parenchyma in *L. varkalaensis* is also scanty and the rays are narrower. Moreover, in the former the tyloses are abundant completely occluding the vessels.

In view of the above differences, the present fossil wood is placed under a new species, *Laurinoxylon naginimariense*. The specific name is derived after Naginimara, the type locality of the fossil wood.

### Family—*Bischofiaceae*

#### Genus—*Bischofia* Blume

*Bischofia palaeojavanica* Awasthi 1989
Pl. 2, figs 7, 8

*Wood* diffuse-porous (Pl. 2, fig. 16). *Growth rings* not seen. *Vessels* usually small to medium, rarely large, t.d. 68-240 $\mu$m, r.d. 52-200 $\mu$m, solitary and in radial multiples of 2-5, round to oval, evenly distributed, 6-14 per sq mm; tyloses abundant (Pl. 2, fig. 7); perforations simple; vessel-members 100-520 $\mu$m long with oblique to horizontal ends; intervessel pits bordered, alternate, large, 10-14 $\mu$m in diameter, circular to oval in shape with lenticular apertures. *Parenchyma* absent, or rarely 1-2 cells may be present associated with vessels (Pl. 2, fig. 7). *Xylem rays* 1-5 seriate, 5-8 per mm; ray tissue heterogeneous, uniseriate rays consisting of upright cells only, 24-52 $\mu$m in width and 4-9 cells or 220-720 $\mu$m in height; multiseriate rays made up of procumbent cells in the central portion and 1-6 rows of upright cells at one or both the ends, 40-140 $\mu$m in width and 7-29 (rarely 50) cells or 360-1120 (rarely 1720) $\mu$m in height (Pl. 2, fig. 8); sometimes ray to ray fusion observed. *Fibres* moderately thick-walled, angular in cross section, 20-40 $\mu$m in diameter, septate (Pl. 2, fig. 8).

*Affinities*—In its anatomical characters the fossil wood resembles extant *Bischofia javanica* Bl. Among known fossil woods it resembles *Bischofia palaeojavanica* described by Awasthi (1989) from the Namsang beds near Deomali, Arunachal Pradesh.

*Figured Specimen*—Specimen no. BSIP 36354.

*Locality*—Naginimara Village, Kongan Coalfield, Mon District, Nagaland.

## DISCUSSION

Of the four taxa added to the Tipam flora, the genus *Koompassia* is significant from the phytogeographical point of view as it does not exist in the Indian subcontinent today. However, it is represented by four species distributed only in the Malayan Peninsula, Borneo and New Guinea (Willis, 1973). *K. malaccensis* Maing. ex Benth. is a large tree, about 30-50 m tall, though buttressed at the base, occurring throughout the lowland forest in swampy ground and also on hill sides in Malayan Peninsula and Indonesia, especially in Sumatra (Ridley, 1922; Desch, 1957). The fossil woods of *Koompassia* are also known from the Neogene of Bengal and Malayan Peninsula (Kramer, 1974; Bande & Prakash, 1980) indicating its wider distribution during that time. Like *Koompassia*, a few other elements, viz., *Dryobalanops* (Awasthi, 1971; Schweitzer, 1958), *Anisoptera* (Prakash & Tripathi, 1970b), *Gluta* (Prakash & Tripathi, 1969b; Prakash, 1973), *Swintonia* (Prakash & Tripathi, 1969a; Prakash & Bande, 1980), *Afzelia-Intsia* (Prakash, 1973; Prakash & Tripathi, 1975), *Sindora* (Lalitha & Prakash, 1980), etc., known from the Neogene sediments of India, Mynmar and Malaysia are now confined to Mynmar and Malayan region where they still grow luxuriantly in the tropical evergreen forest. None of these genera has so far been found in Indian Palaeogene sediments. Thus, it is quite evident that they had originated in the Malayan region perhaps during the Early Tertiary. After the land connections between India and Southeast Asia were established towards the close of Oligocene, several Malayan tropical elements including the two legumes, *Koompassia* and *Sindora* entered the Indian subcontinent via Mynmar, and flourished there under equable climate till the end of Pliocene. The reason for their total disappearance from the Indian subcontinent after Pliocene could be due to gradual decrease in the mean annual temperature and precipitation caused by the Himalayan orogeny and northward drifting of the Indian Plate (Smith & Briden, 1979). Being sensitive to the changing environments, several such taxa which were growing luxuriantly in the Indian subcontinent under tropical and high humid conditions failed to regenerate thereafter.

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# Some new carbonised woods from Neogene of Kerala coast and their bearing on palaeoclimate

N. Awasthi & Rashmi Srivastava

Awasthi, N. & Srivastava, Rashmi 1990. Some new carbonised woods from Neogene of Kerala coast and their bearing on palaeoclimate. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 285-292.

Carbonised woods resembling extant species of *Hydnocarpus* (Flacourtiaceae), *Anisoptera* and *Hopea* (Dipterocarpaceae) and *Payena-Palaquium* (Sapotaceae) are recorded from the Neogene sediments of Varkala and Payangadi, Kerala coast. They have been named as *Hydnocarpoxylon keralaensis* sp. nov., *Anisopteroxylon varkalaensis* sp. nov., *Hopenium payangadiensis* sp. nov. and *Sapotoxylon prepayena* sp. nov., respectively. The modern equivalents of these woods are among the important elements of the tropical evergreen forest of Western Ghats, Burma and Malaysia indicating the prevalence of nearly equable warm climate and excessive humid conditions in the area at the time of their deposition during Mio-Pliocene.

**Key-words**—Carbonised woods, Dicotyledons, Kerala Coast, Neogene (India).

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## सारॉंश

### केरल तट के पश्चनूतन कल्प से कुछ नई कार्बनमय काष्ठें तथा पुराजलवायु में इनका महत्व

नीलाम्बर अवस्थी एवं रश्मि श्रीवास्तव

केरल तट पर वरकला एवं पयांगदी के पश्चनूतन अवसादों से **हिड्नोकार्पस** (फ़्लेकोर्शिएसी), **ऐंनाइसॉप्टेरा** एवं **होपिआ** (डिप्टेरोकार्पेसी) तथा **पयेना-पैलेक्वियम** (सैपोटेसी) की वर्तमान जातियों से मिलती-जुलती कार्बनमय काष्ठें अभिलिखित की गई हैं। इन्हें क्रमशः **हिड्नोकार्पोक्सीलॉन केरलायेन्सिस** नव जाति, **ऐंनाइसॉप्टेरॉक्सीलॉन वरकलायेन्सिस** नव जाति, **होपीनियम पयॉंगदीयेन्सिस** नव जाति एवं **सैपोटॉक्सीलॉन प्रीपयेना** नव जाति से नामांकित किया गया है। इन काष्ठों के वर्तमान वर्गक पश्चिमी घाट, बर्मा एवं मलेशिया के उष्णकटिबन्धीय सदाहरित वनों के मुख्य अवयव हैं जो मध्यनूतन-अतिनूतन कल्प में इनके निक्षेपण के समय उष्ण जलवायु एवं अत्याधिक आर्द्र परिस्थितियों का होना इंगित करते हैं।

THE sedimentary sequence along the Kerala coast, classified as Warkalli beds of Mio-Pliocene age, contain rich deposits of carbonised woods. These are generally found associated with lignite, carbonaceous clays, sandy clays and white plastic clays. A number of dicotyledonous woods have been described earlier as *Calophyllum, Gluta, Swintonia, Diospyros, Dryobalanops, Cynometra, Terminalia, Gonystylus, Canarium* and a lauraceous member closely comparable to *Cinnamomum-Litsea* complex from Varkala cliff section and Payangadi Super Clay Mine by Awasthi and Ahuja (1982), Awasthi and Panjwani (1984) and Awasthi and Srivastava (1990).

The main objective of this study is to generate additional data for reconstruction of palaeoflora and palaeoclimate of the region and to trace out the history of the tropical evergreen forests of Western Ghats. The carbonised woods investigated from Varkala and Payangadi show close resemblance with those of *Hydnocarpus, Anisoptera, Hopea* and *Payena-Palaquium* complex of Sapotaceae.

## SYSTEMATIC DESCRIPTION

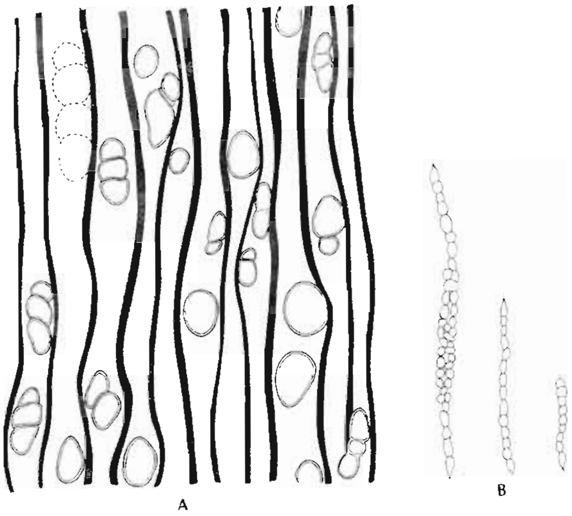
### Family—Flacourtiaceae

**Genus—*Hydnocarpoxylon* Bande & Khatri 1980**

*Hydnocarpoxylon keralaensis* sp. nov.

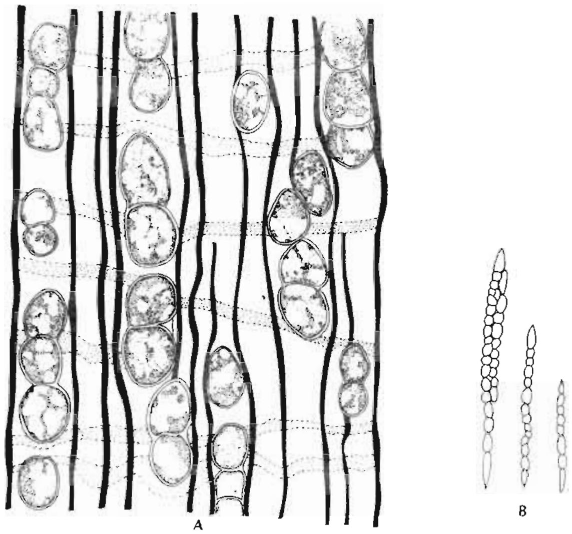
Pl. 1, figs 1-5; Text-figs A, B

*Description*—*Wood* diffuse-porous. *Growth rings* indistinct. *Vessels* solitary and in radial



**Text-figure 1**—*Hydnocarpoxylon keralaensis* sp. nov.—**A.** Cross section showing vessels, × 100; **B.** 1-3 Seriate heterocellular rays, × 100.

multiple of 2-3, occasionally more, mostly small, rarely medium in size, oval or flattened due to compression, t.d. 32-96 $\mu$m, r.d. 48-175 $\mu$m; evenly distributed, about 20-30 vessels per sq mm, profusely tylosed; perforations scalariform with 18-22 horizontal bars, sometimes branched; vessel-members 175-800 $\mu$m long; inter-vessel pits not observed. *Parenchyma* absent. *Rays* 1-3 (mostly 1-2) seriate; uniseriate rays consisting of mostly upright cells, sometimes a few procumbent cells also occur in between, multiseriate rays consisting of procumbent cells in the median portion with uniseriate marginal extensions of upright cells at both the ends 10-45 cells or 160-1280 $\mu$m in height, crystalliferous; upright cells 24-48 $\mu$m in tangential height and 20-32 $\mu$m in radial length; procumbent cells 16-20 $\mu$m in tangential height and 40-60 $\mu$m in radial length. *Fibres* aligned in radial rows, semilibriform, septate.



**Text-figure 2**—*Sapotoxylon prepayena* sp. nov.—**A.** Cross section showing distribution pattern of vessels tyloses in vessels and thin bands of apotracheal parenchyma, × 100, **B.** 1-2 seriate heterocellular rays, × 100.

*Affinities*—The present carbonised wood resembles closely that of the genus *Hydnocarpus* Gaertn. of the family Flacourtiaceae (Metcalfe & Chalk, 1950) in having important features, such as small to medium-sized tylosed vessels, scalariform perforations, absence of parenchyma, 1-3 (mostly 1-2) seriate, heterogeneous xylem rays and septate fibres. A detailed comparison of the fossil wood with a number of species of *Hydnocarpus* (Chowdhury & Ghosh, 1958; Desch, 1957; Pearson & Brown, 1932) revealed that it bears similarities with most of them. However, in having xylem rays 10-45 cells high and 18-20 bars in scalariform performation plates the fossil shows closest affinities with the wood of *Hydnocarpus sumatrana*.

There is only one species of fossil wood of *Hydnocarpus*, *Hydnocarpoxylon mandalaensis* Bande & Khatri 1980 known so far, which is reported

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## PLATE 1

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*Hydnocarpoxylon keralaensis* sp. nov.

1. Cross section showing nature and distribution of vessels, × 27; Slide no. BSIP 36383-I.
2. Cross section magnified to show shape and size of vessels, × 80; Slide no. BSIP 36383-I.
3. Scalariform perforation plate with bars in radial longitudinal section, × 340; Slide no. BSIP 36383-III.
4. Tangential longitudinal section showing rays, × 56; Slide no. BSIP 36383-II.
5. Radial longitudinal section showing heterocellular rays, × 86; Slide no. BSIP 36383-III.

*Anisopteroxylon varkalaensis* sp. nov.

6. Cross section showing nature and distribution of heavily tylosed vessels, × 30; Slide no. BSIP 36384-I.
7. Cross section magnified to show diffuse parenchyma, heavily tylosed vessels and solitary gum canals, × 85; Slide no. BSIP 36384-I(a).
8. Tangential longitudinal section showing multiseriate rays with sheath cells, × 120; Slide no. BSIP 36384-II.
9. Radial longitudinal section showing heterocellular rays, × 86; Slide no. BSIP 36384-III.

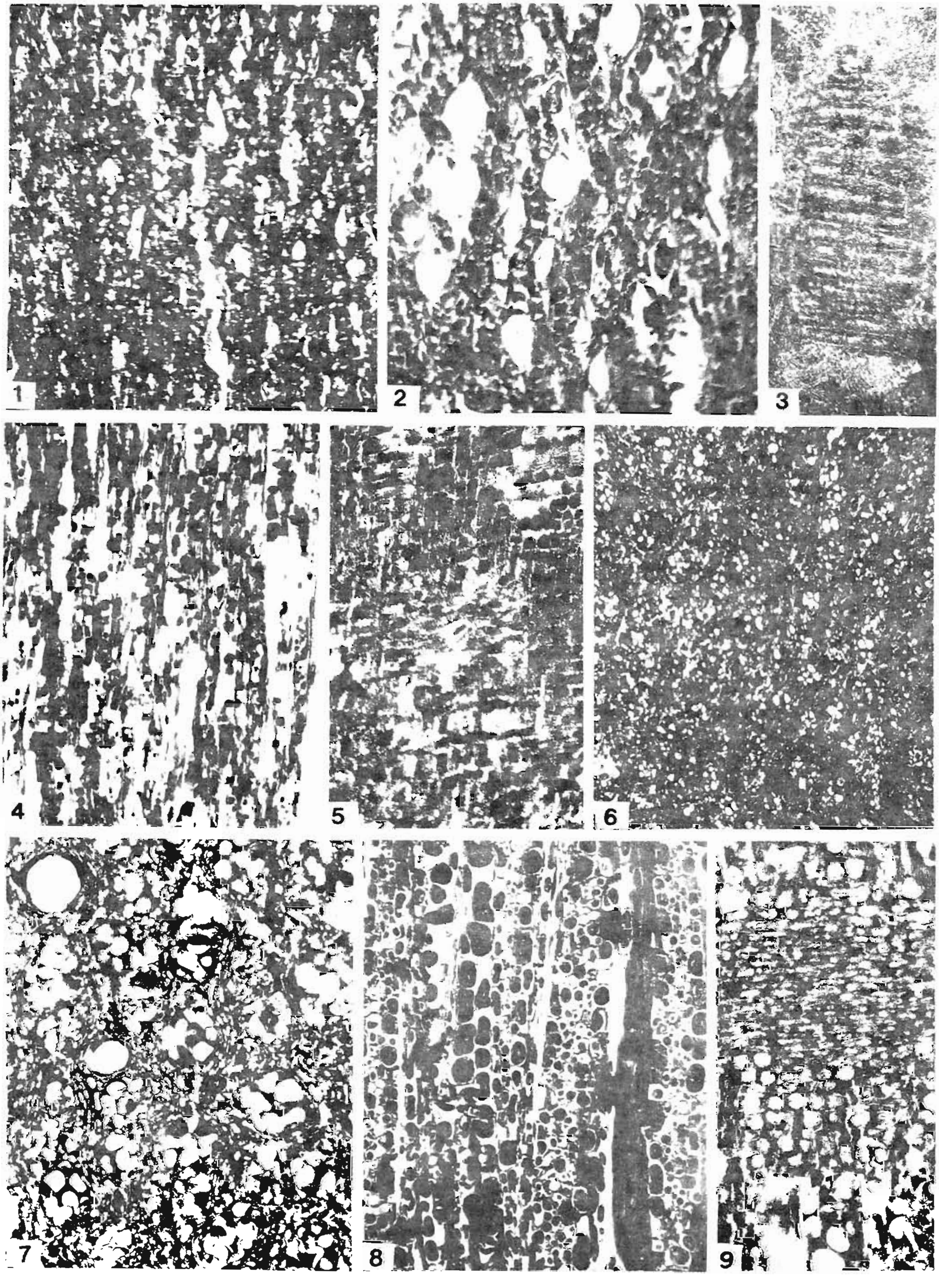

PLATE 1

from the Deccan Intertrappean beds of Mandla District. It differs from our fossil wood in having vessels in radial multiples of up to 11 with 40-60 per sq mm frequency. Besides, the height of xylem rays in *H. mandalaensis* is also more.

*Holotype*—Specimen no. BSIP 36383.

*Locality*—Varkala Cliff section, Varkala, Kerala.

## Family—*Dipterocarpaceae*

### Genus—*Anisopteroxylon Ghosh* & Kazmi 1958

*Anisopteroxylon varkalaensis* sp. nov.
Pl. 1, figs 6-9

*Description*—*Wood* diffuse-porous. *Growth rings* indistinct. *Vessels* mostly solitary, rarely in radial multiples of 2-3, small to medium in size, t.d. 80-160 μm, r.d. 64-192 μm, circular to oval, uniformly distributed, about 25-30 vessel per sq mm; heavily tylosed (Pl. 1, fig. 7); perforations simple; vessel-members 240-640 μm long with transverse to oblique septa; inter-vessel pits small to medium, alternate, 6-8 μm in diameter, vestured. *Vasicentric tracheids* present, intermingled with vasicentric parenchyma. *Parenchyma* paratracheal and apotracheal, paratracheal scanty; apotracheal parenchyma diffuse to diffuse-in-aggregate, sometimes forming uniseriate interrupted lines; cells 20 μm in diameter and 54-130 μm in length. *Rays* 1-7 (mostly 4-5) seriate, heterogeneous; uniseriate rays rare, 6-12 cells in height, consisting of upright cells only; multiseriate rays 2-7 cells or 40-160 μm broad and 16-120 cells or 350-2000 μm in height; heterocellular, consisting of procumbent cells and 2-10 marginal rows of square or upright cells at one or both the ends, sheath cells present, occurring throughout the flank of multiseriate rays; upright and square cells 20-44 μm in tangential height and 16-32 μm in radial length; procumbent cells 12-20 μm in tangential height and 20-32 μm in radial length. *Fibres* aligned in radial rows between two consecutive rays, 20-25 μm in diameter, nonseptate, libriform. *Gum canals* vertical, diffuse, mostly solitary, sometimes in pairs, 40-96 μm in diameter.

*Affinities*—Presence of vertical diffuse gum canals, heavily tylosed medium-sized vessels, paratracheal and apotracheal diffuse to diffuse-in-aggregate parenchyma, heterocellular xylem rays with upright cells completely sheathing multiseriate rays, suggests close similarity of the carbonised woods with that of the genus *Anisoptera* of Dipterocarpaceae. From a detailed comparison with a number of species of *Anisoptera* it was found that the anatomical features of the fossil wood collectively indicate its similarity with that of *A. polyandra* Bl.

Seven species of the genus *Anisopteroxylon* Ghosh & Kazmi are known from the Neogene sediments of India, viz., *Anisopteroxylon bengalensis* Ghosh & Kazmi, 1958 from west Bengal, *A. jawalamukhi* Ghosh & Ghosh 1958 from the Siwalik sediments near Jawalamukhi, *A. coromandalensis* Navale 1963 from the Cuddalore Sandstone near Pondicherry, *A. garoense* (Chowdhury) Prakash & Tripathi 1976 from the Tipam Sandstone of Hailakandi, Assam and Garo Hills, *A. kalagarhensis* Prakash 1978 and *A. oblongoides* Yadav 1989 from the Siwalik sediments of Kalagarh and *A. shantiniketanense* Ghosh & Roy 1980 from near Shantiniketan, west Bengal. Our fossil wood *A. varkalaensis* differs from all these species in having relatively smaller and more frequent vessels (t.d. 80-160 μm, r.d. 64-192 μm) and higher rays.

*Holotype*—Specimen no. BSIP 36384

*Locality*—Varkala Cliff section, Varkala, Kerala.

### Genus—*Hopenium* Awasthi 1980

*Hopenium payangadiensis* sp. nov.
Pl. 2, figs 1-4, 9

*Description*—*Wood* diffuse-porous. *Growth rings* distinct, crowding of vessels at regular intervals indicates beginning of annual growth increment (Pl. 2, fig. 2), *Vessels* solitary and in radial multiples of 2-3, small to medium in size, t.d. 48-240 μm, r.d. 64-220 μm, round to oval when solitary and flattened at places of contact when in radial multiples, heavily tylosed, 23-28 vessels per sq mm; perforations simple; inter-vessel pits medium, 5-8 μm in diameter, vestured. *Vasicentric tracheids* present, not easily recognisable from parenchyma in cross section. *Parenchyma* paratracheal, vasicentric, most probably forming sheath of 1-3 cells around vessels; apotracheal parenchyma diffuse to diffuse-in-aggregate, cells sometimes scattered among fibres (Pl. 2, fig. 3). *Rays* 1-4 (mostly 3-4) seriate; ray tissue heterogeneous; uniseriate rays 2-12 cells or 80-288 μm in height and 8-16 μm broad, composed wholly of upright cells; multiseriate rays 2-4 seriate or 48-96 μm broad, heterocellular, consisting of procumbent cells through the median portion and 1-4 marginal rows of upright cells at both the ends (Pl. 2, fig. 4), crystalliferous square or upright cells interspersed among procumbent cells (Pl. 2, fig. 4), 8-38 cells or 200-600 μm in height; square or upright cells 24-48 μm in tangential height and 24-30 μm in radial length; procumbent cells 20-28 μm in tangential height and 28-45 μm in radial length. *Fibres* aligned in radial rows between two consecutive rays (Pl. 2, fig. 3), 16-20 $\mu$m in diameter, non-septate, libriform *Gum canals* vertical, aligned in tangential rows forming concentric rings, circular to oval, 48-144 $\mu$m in diameter.

*Affinities*—Occurrence of vertical gum canals in concentric rings, heavily tylosed medium to small sized vessels, vasicentric tracheids, paratracheal as well as diffuse parenchyma and thick-walled fibres suggest its affinity with the woods of *Shorea, Parashorea, Pentacme, Balanocarpus* and *Hopea* of the family Dipterocarpaceae. However, in having crystalliferous upright or square cells interspersed among procumbent cells of multiseriate rays the carbonised wood resembles that of *Hopea* and can be differentiated from other genera.

Critical examination of wood slides of *Hopea plagata* Vidal, *H. pentanervia* Symington ex G. H. S. Wood, *H. intermedia* King, *H. parviflora* Bedd., *H. ferruginea* Parijs, *H. sangal* Korth., *H. beccariana* Burck and *H. mengarwan* Miq. has revealed that the present fossil resembles closely the wood of *H. parviflora*. The only difference between the two is that the vessels in *H. parviflora* are slightly smaller.

So far four species of fossil woods of *Hopea* are known, viz., *Hopenium pondicherriense* Awasthi 1980 from the Cuddalore Sandstone near Pondicherry; *H. neyveliense* Awasthi 1984 from the Neyveli lignite deposits, Tamil Nadu; *H. prenutansoides* Prasad & Prakash 1988 and *H. kalagarhensis* Prasad & Prakash 1988 from the Siwalik sediments, Kalagarh, Uttar Pradesh. All these species show some significant differences from our fossil wood *H. payangadiensis*. In *H. pondicherriense* and *H. neyveliense* the frequency of vessels is more, i.e., 25-75 and 30-50 vessels per sq mm respectively as against up to 30 vessels in our fossil. Moreover, in *H. neyveliense* the gum canals are exceptionally large and more frequent. The gum canals in *H. kalagarhensis* are also bigger and their concentric rings are closely placed. The vessels and gum canals in *H. payangadiensis* are relatively bigger than in *H. prenutansoides*.

*Holotype*—Specimen no. BSIP 36385.

*Locality*—Payangadi Super-Clay Mine, district Cannanore, Kerala.

## Family—Sapotaceae

### Genus—*Sapotoxylon* Felix 1882

*Sapotoxylon prepayena* sp. nov.
Pl. 2, figs 5, 8, 10; Text-figs A, B

*Description*—*Wood* diffuse-porous. *Growth rings* absent. *Vessels* small to medium-sized, solitary and mostly in radial multiples of 2-6, round to oval in shape, t.d. 48-96 $\mu$m, r.d. 64-160 $\mu$m, somewhat obliquely arranged in radial line, about 12-16 vessels per sq mm; tyloses abundant, completely plugging the vessels; perforations simple, vessel-members short 172-350 $\mu$m in height with truncate ends; inter-vessel pits small, 5-8 $\mu$m in diameter, bordered, alternate with minute aperture. *Vasicentric tracheids* present, intermingled with vasicentric parenchyma. *Parenchyma* both paratracheal and apotracheal, apotracheal parenchyma abundant, occurring in the form of 1-3 cells thick, wavy, continuous or broken lines, each separated by 6-15 rows of fibres, about 2-6 lines per mm. *Rays* fine, 1-2 (mostly uniseriate), heterocellular, consisting of both upright and procumbent cells, 2-27 cells or 250-380 $\mu$m in height, upright cells 30-35 $\mu$m in tangential height and 28-30 $\mu$m in radial length; procumbent cells 12-16 $\mu$m in tangential height and 32-64 $\mu$m in radial length. *Fibres* aligned in radial rows between two consecutive rays, interrupted by thin bands of apotracheal parenchyma; small, 10-12 $\mu$m in diameter, thick-walled; semilibriform, non-septate.

*Discussion*—The above features collectively indicate that the fossil wood belongs to the family Sapotaceae. The family Sapotaceae is homogeneous in wood structure and therefore on the basis of wood anatomy it is not always possible to easily distinguish most of its genera from each other. However, it can be done only in exceptional cases when all the xylotomical characters are taken into consideration collectively after critical assessment. Detailed anatomical studies of various sapotaceous woods from their description and photographs (Desch, 1954; Hayashi *et al.*, 1973; Henderson, 1953; Kribs, 1969; Metcalfe & Chalk, 1950; Miles, 1978; Normand, 1960; Pearson & Brown, 1932), as well as thin sections revealed that the present carbonised wood shows maximum similarity with those of *Palaquium* and *Payena*. Their similarity with each other can be seen in shape, size and distribution pattern and frequency of vessels and parenchyma lines. However, in having predominantly uniseriate rays the fossil appears to be more akin to *Payena*.

A number of fossil woods belonging to the family Sapotaceae are known from different parts of the world. These are: *Sapotoxylon taeniatum* (Felix, 1882) from the Tertiary of Bavaria, Germany; *Manilkaroxylon diluviale* (Hofmann, 1948) from the Quaternary deposits of South America; *M. crystallophora* and *Palaeosideroxylon flammula* (Grambast-Fessard, 1968) from Upper Miocene of Castellane in South East France; *Sapotoxylon pacltovae* and *Manilkaroxylon bohemicum* (Prakash *et al.*, 1974) from the Oligocene of Bohemia, Czechoslovakia; *Sapotoxylon multiporosum* (Prakash *et al.*, 1982) from the Mio-Pliocene of Blue Nile, Ethiopia; *Tridemostemon tertiarum* and *Chrysophyllum zairense* (Bande *et al.*, 1987) from the Miocene of Zaire, Africa; *Siderinium deomaliense* (Prakash & Awasthi, 1970) from the Mio-Pliocene of Deomali, Arunachal Pradesh; *Madhucoxylon cacharense* (Prakash & Tripathi, 1977) from the Tipam Sandstone, Assam and *Chrysophylloxylon pondicherriense* (Awasthi, 1977) from the Cuddalore Sandstone near Pondicherry.

In having xylem rays predominantly uniseriate to occasionally biseriate and vessel profusely tylosed, the present fossil wood can be easily differentiated from all the known species. It may be pointed out that in all the above species the xylem rays are always more than 2-seriate and the vessels are not so profusely tylosed.

Though the present carbonised wood has been shown to be similar to *Payena*, yet possibility of its being still closer to certain other species of *Palaquium*, particularly the Malayan species, cannot be ruled out. We may, therefore, regard it as a new sapotaceous wood having close similarity with those of *Payena* and *Palaquium*. Accordingly, it is placed under the genus *Sapotoxylon* Felix and named as *Sapotoxylon prepayena* sp. nov., indicating its affinity with *Payena*.

*Holotype*—Specimen no. BSIP 36386.

*Locality*—Payangadi Super-Clay Mine, district Cannanore, Kerala.

## PRESENT DISTRIBUTION AND PALAEOCLIMATIC IMPLICATIONS

Occurrence of *Hydnocarpus, Anisoptera, Hopea* and *Payena-Palaquium* in the Warkalli beds furnishes additional data for elucidating the climate at the time of their deposition. Early Tertiary marks the oldest occurrence of *Hydnocarpus* Gaertn. in India. At present as many as 40 species, distributed in the Indo-Malayan region, are known (Willis, 1973). In India, it is represented by 7 species (Santapau & Henri, 1973), occurring in the evergreen forests of Western Ghats, Assam and Andaman Island. *Hydnocarpus sumatrana*, the nearest living counterpart of the fossil, is found in Sumatra, Java, Borneo, Celebes and Philippines in rain forests (Sleumer, 1954).

The genus *Anisoptera* Korth. had wider distribution during Neogene, but has totally disappeared now from India. However, it continues to flourish luxuriantly in the evergreen forests of Chittagong to the east and southward to Burma, Thailand, Malay Peninsula, Sumatra and Borneo. *Anisoptera polyandra* Bl., a closely comparable species with carbonised wood, is known to occur in New Guinea in the evergreen forests (Hooker & Jakson, 1946). Like other dipterocarps, *Hopea* was also widely distributed in India during Neogene. At present, it is restricted to Western Ghats, Assam and the Andaman Island. *H. parviflora* with which the carbonised wood resembles most occurs in the evergreen forest of Western Ghats, from South Kanara to further south up to 1,100 m altitude, common in both the moist and dry forests in Malabar and Travancore up to an elevation of 900 m (Chowdhury & Ghosh, 1958).

Of the two sapotaceous genera *Palaquium* Bl. and *Payena* A. Dc., the former is represented in India by four species, occurring in the evergreen forests of Western Ghats, Garo Hills, Khasi Hills and Jaintia Hills, while the latter exists no more in India but is widely distributed in similar type of forests of Southeast Asia and Malayasia (Willis, 1973).

The living counterparts of the carbonised woods belonging to *Calophyllum, Dryobalanops, Canarium, Swintonia, Gluta, Cynometra, Terminalia, Diospyros, Leea, Gonystylus, Cinnamomum-Litsea* known from the same deposits have a similar distribution pattern in the Indo-

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## PLATE 2

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*Hopenium payangadiensis* sp. nov.

1. Cross section showing vertical gum canals in tangential row, × 27; Slide no. BSIP 36385-I(a).
2. Another cross section showing nature and distribution of vessels, × 27; Slide no. BSIP 36385-I(b).
3. Cross section magnified to show shape and size of vessels and distribution of parenchyma, × 86; Slide no. BSIP 36385-I(b).
4. Tangential longitudinal section showing heterocellular rays with upright cells interspersed amongst procumbent cells, × 86; Slide no. BSIP 36385-II.
9. Radial longitudinal section showing heterocellular xylem rays. × 86; Slide no. BSIP 36385-III.

*Sapotoxylon prepayena* sp. nov.

5. Cross section of carbonised wood showing distribution of vessels and parenchyma, × 80; Slide no. BSIP 36386-I.
6. Same section magnified to show shape and size of vessels and parenchyma, × 160; Slide no. BSIP 36386-I.
7 Tangential longitudinal section showing heterocellular uniseriate xylem rays, × 120; Slide no. BSIP 36386-II.
8. Radial longitudinal section showing heterocellular xylem rays, × 80; Slide no. BSIP 36386-III. 340.
10. Intervessel pits, × 340; Slide no. BSIP 36386-II.

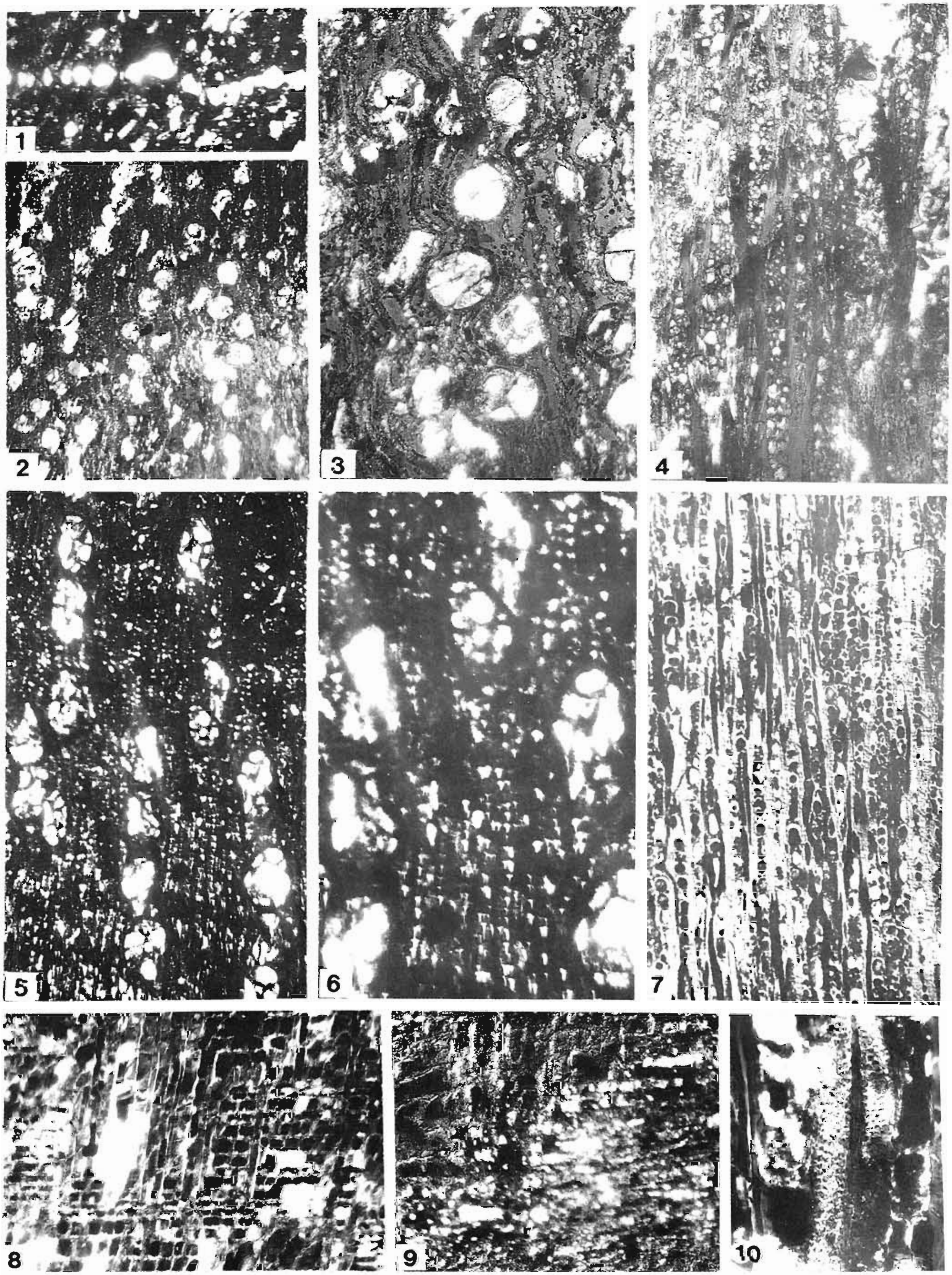

PLATE 2

Malayan region (Awasthi & Ahuja, 1982; Awasthi & Panjwani, 1984; Awasthi & Srivastava, 1989). Thus based on the collective evidence of the modern equivalents of megafossils, it may be inferred that the flora growing all along the Kerala coast during Mio-Pliocene was distinctly tropical with luxuriant forest vegetation dominated by evergreen elements. Further, presence of certain ecologically significant Malayan taxa, namely, *Dryobalanops, Anisoptera, Gonystylus, Payena* and certain species of *Hydnocarpus, Canarium, Swintonia* and *Leea* which totally disappeared from this region as well as from other parts of India during post Pliocene suggests the prevalence of excessive humid conditions as a result of higher rainfall throughout the year with a very short dry season. Disappearance of these taxa obviously reflects a considerable decrease in the annual precipitation, since in the tropical region it is mainly the rainfall which controls the distribution of plants.

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# Litho- and biostratigraphy of the Siwalik succession in Surai Khola area, Nepal

G. Corvinus

Corvinus, G. 1990. Litho- and biostratigraphy of the Siwalik succession in Surai Khola area, Nepal. *In* Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 293-297

The Surai Khola succession of Siwalik sediments comprises an uninterrupted body of molasse sediments of a thickness of 5,500 m, which have been divided into six lithological units. The sequence has yielded abundant vertebrate and invertebrate fossils, particularly of mammals. These indicate that the lower part of the Surai Khola succession belongs to the Chinji zone of the Lower Siwalik, while the rich fauna of the upper beds belong to the Tatrot and Pinjor faunal zones of the Upper Siwalik. Apart from the mammalian fauna, a wealth of plant fossils has come to light, particularly from the lower and middle part of the sequence. The finer clastics throughout the sequence yielded palynofossils.

**Key-words**—Lithostratigraphy, Biostratigraphy, Siwalik, Nepal Himalaya.

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## साराँश

### नेपाल में सुराई खोला क्षेत्र में शिवालिक अनुक्रम का शैल-एवं जैवस्तरविन्यास

गुदरून कोर्वाइनस

शिवालिक अवसादों के सुराई खोला अनुक्रम में 5,500 मीटर मोटे अबाधित अवसाद विद्यमान हैं जिन्हें छः शैलिकीय इकाईयों में विभक्त किया गया है। इस अनुक्रम से काफी रीढ़धारी एवं अरीढ़धारी अशिमत जन्तु मिले हैं जिनमें विशेषतया स्तनधारी जन्तु हैं। इनसे यह प्रदर्शित होता है कि सुराई खोला का निचला भाग अधरि शिवालिक के चिन्जी क्षेत्र से सम्बन्धित है जबकि ऊपरी संस्तरों का जन्तुजात उपरि शिवालिक के तत्रोत एवं पिंजौर मंडलों से समानता दर्शाता है। स्तनधारी जन्तुजात के अलावा पर्याप्त मात्रा में अशिमत पौधे भी मिले हैं, विशेषकर अनुक्रम के बीच के एवं निचले भाग से। पूरे अनुक्रम के बारीक खंडजों से अशिमत परागकण उपलब्ध हुए हैं।

UNDER the Geo-archaeological Project, University of Erlangen, financed by the German Research Council, the author carried out field as well as research work during the last five years in several areas in the Siwalik Hills of Nepal. The research includes stratigraphical and biogeographical investigations in the Miocene to Pleistocene deposits of the Siwalik ranges in the Dang area in western Nepal, particularly in the Surai Khola area and in the Kamla Nadi area in eastern Nepal (Corvinus, 1988a, b).

The Siwalik mountains being the youngest, of the Himalayan orogeny, form the foot-hills along the entire Himalaya margin from Pakistan to Assam. In Nepal alone they are ca 800 km in length, consisting of molasse sediments, sandstones, mudstones, shales and claystones of up to 8,000 m thickness. They are deposited during the last ca 15 million years as erosional debris from the rising Himalaya into the foredeep basin along the foot of the mountains; they are folded and thrusted against the Himalaya during the Middle Pleistocene, as the last phase of the Himalayan orogeny.

The movement and the mountain building are not terminated. India continues to be subducted underneath the Central Asian Block and neo-tectonic movements are going on. Earthquakes show that it is still a zone of unrest and unstability. One day the thick deposits of the Terai plains, all of which have been washed down from the Himalaya, too, will be subjected by these movements and folded against the Himalaya. The Siwalik deposits have once been very similar to the recent deposits of the Terai and the Gangetic plains. Driving east-westwards along the Terai one crosses river after river with wide, meandering flood-beds filled with sand, silt, and gravels. The rivers carry a tremendous amount of load into the plains each year, and the accumulation of erosional debris from the mountains into the Gangetic plains is estimated to be some 6,000 to 8,000 m thick.

The research has yielded results in many aspects. A detailed lithostratigraphy of almost 6,000 m could be established at the Surai khola, and owing to the abundance of *in situ* fossils, all bio geographical data could be recorded into the comprehensive stratigraphical column (Text-fig. 2).

In the course of investigations, a wealth of plant fossils in the form of megafossils and pollen has come to light which necessitated the author to collaborate with the Birbal Sahni Institute of Palaeobotany, Lucknow to study the Palaeobotanical aspects. Thus, the kind assistance and suggestions of the Director, Dr B. S. Venkatachala, resulted a joint research programme. Drs N. Awasthi and M. Prasad of BSIP are studying the plant megafossils, and Dr S. Sarkar is carrying out the palynostratigraphic analysis. In this way we will be able to build up a complete floristic succession from Lower to Upper Siwaliks in one area, in the Nepal Siwaliks as model (Reports of their work are published in this issue). This report deals with the litho- and biostratigraphical background of this multi-faceted research project, where every aspect plays an important role for the whole, and where palaeobotany is one aspect which reaches its fullest importance when combined with all the other aspects of the research.

## GEOGRAPHY AND MODERN ENVIRONMENT

Below the Siwalik foot-hills in south a flat, wide plain called the Terai stretches east-west which constitutes fertile farmland. Formerly, the flat land at the foot of the Himalaya was a thick belt of tropical forest, called the Bhabar zone, of mainly Saal and bamboo which was once one of the richest wild life areas of the world. But now most of these virgin forests are disappearing fast due to the continued cutting of trees and the wild life has disappeared completely.

The climate in the Terai is like in north India, with cool and dry winters, extreme hot summers and rather heavy monsoon seasons with rainfall between 1,600 to 2,000 mm/annum (more so in the east than in the west). The climate supports a tropical to sub-tropical, moist deciduous to dry deciduous vegetation.

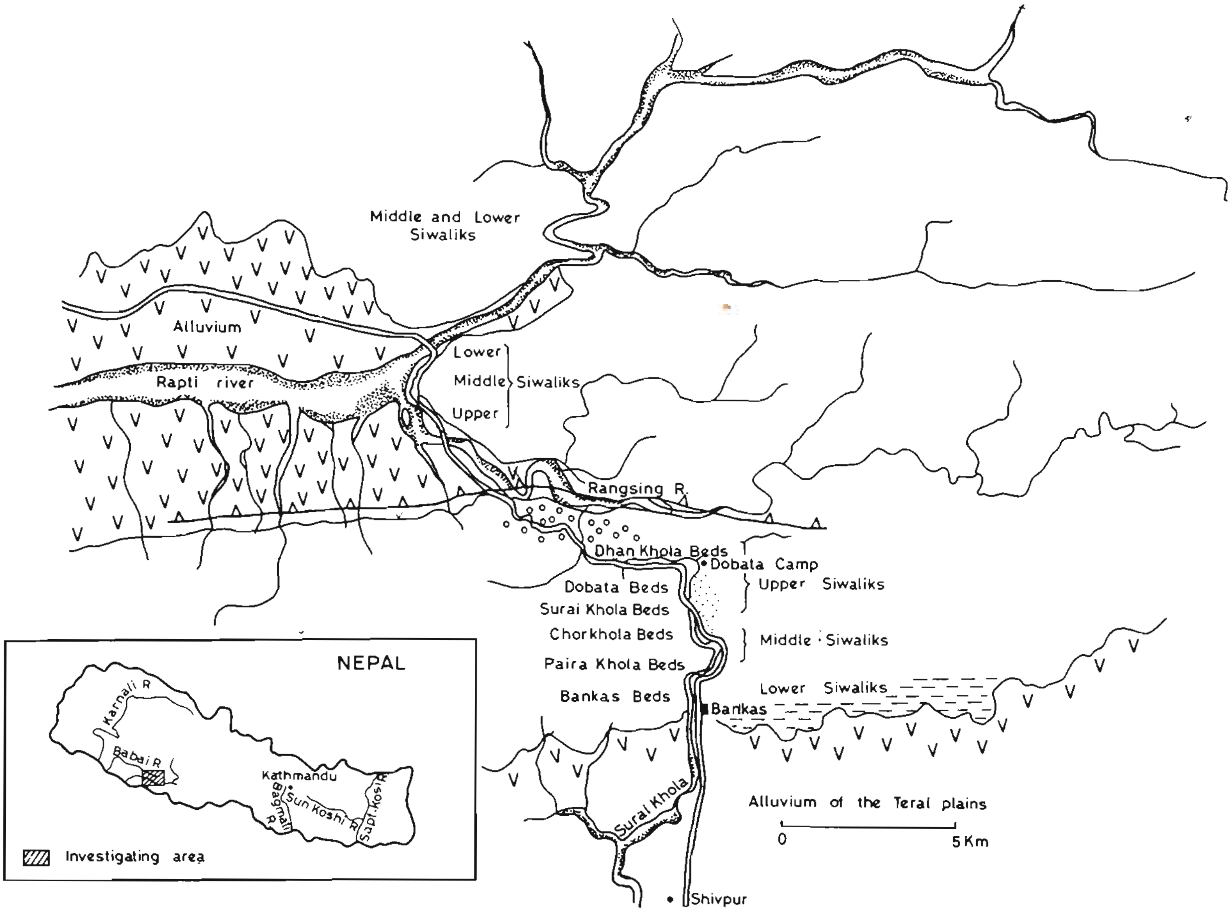
## PREVIOUS WORK

The Siwalik deposits in Nepal have not been studied in detail until recently. The rock successions were only roughly known and there was no clear distinction between rock units and faunal zones. The fossils, which had been recorded (West *et al.*, 1978, 1988; West & Munthe, 1983) have not been described in their stratigraphical context; though they opened first vistas about the fauna of Nepal Siwaliks. No precise ages, therefore, could be ascribed to the various rock units. Recent works on the structural evolution of the eastern Nepal Siwalik have been published by Mascle and Herail (1982) and Herail *et al.* (1986).

A Japanese team has recently carried out detailed mapping and lithostratigraphical studies of another area of the Siwalik, east of Butwal (Tokuoka *et al.*, 1986). Here the magneto-polarity, too, has been recorded, but it is not linked with fossil vertebrate remains. Munthe *et al.* (1983) reported one molar of *Ramapithecus* from near Butwal in Nepal. Unfortunately no other fossil-remain of this elusive hominoid has so far come to light from this area.

## OBSERVATIONS

Two areas were chosen for detailed study: the Surai Khola area in Dang District in west Nepal and the Rato Khola area in Janakpur District in east Nepal, which were found to be fossiliferous. Only the Surai Khola area is described here (Text-fig. 1). The map shows the traverse through the described Siwalik sequence exposed along the Surai Khola from the lower strata at Bankas to the upper strata south of Rangsing Khola. In the Surai Khola area, a road was being built during 1983 and 1984 (Text-fig. 1) which gave the author unique opportunity to study the rock succession which were freshly exposed due to the blasting and cutting, and which greatly helped in the measurement of sections and collection of fossils. The road cuts practically at right angles to the strike of the rocks, which is more or less 60° to 75° to the north. It was found that an uninterrupted and undisturbed sediment body of almost 6,000 m was exposed around the Surai Khola area where an almost entire sequence of Siwalik sediments could be recorded. The vertebrate fossils found in the sediments suggest that the Surai Khola sequence represents the periods from the Chinji faunal zone of the Lower Siwalik at Bankas to the boulder conglomerate of the uppermost Siwalik south of Rangsing Khola. In short, the Surai Khola



**Text-figure 1**

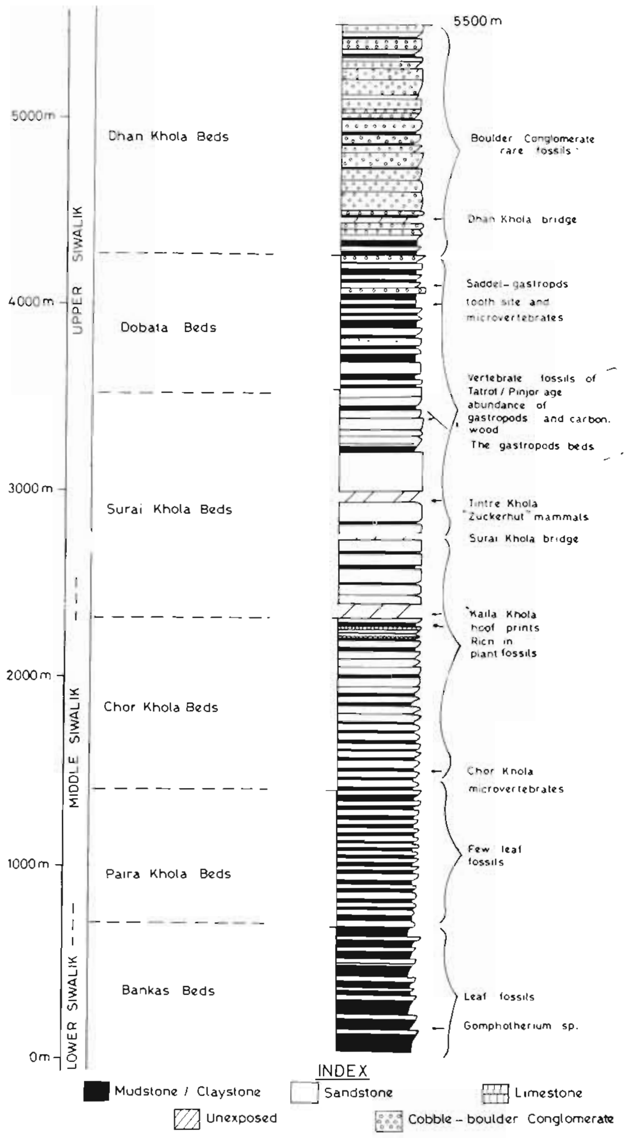
sequence represents almost entire Siwalik succession.

The rock succession (Text-fig. 2) shows a gradual coarsening up from finer clasts of clays and mudstones and shales in the lower part to sandstones and finally to gravel and boulder conglomerates in the uppermost part. The sequence has been divided into six lithological units (Text-fig. 2). All collected and observed data have been recorded and, for the first time, a comprehensive stratigraphical column with *in situ* fossil data has been drawn up.

Great variety of fossils have been recovered from the area. The lowermost part of the succession, the Bankas beds, which is dominated by variegated claystones and mottled mudstones reveal an environment of low-water-regime, with backwaters, pools and swampy areas. The discovery of *Gomphotherium* sp. by its similarity to this fossil group from Pakistan places these beds into the Chinji faunal zone of the Lower Siwalik. In Pakistan, this zone has been magnetostratigraphically dated between 13 to 10 Ma.

Vertebrate fossils are absent, as yet, in the subsequent 1,800 m of the Paira Khola and Chor Khola beds (tentatively equivalent to Middle Siwalik), which mark a change from predominantly colourful clays and mudstones to more pronounced sandstone banks with shales and mudstone and claystone intercalations. The lithology points to an environment of increased fluvial activities, resulting in the deposition of sand bars, but the continued strong component of clays suggests that still-water conditions co-existed. No faunal correlation could be established for these beds as yet. These are, however, extremely rich in plant fossils, especially of leaf-impressions which are particularly prominent and well-preserved in the shaly sediments. In mottled claystones and mudstones also they have been recorded, although poorly preserved. Stratigraphically oriented collections were made from the most important of the recorded 48 plant bearing horizons.

A drastic change in sedimentation marked by thick, micaceous sandstones of the Surai Khola beds suggests a strongly increased fluvial activity. The



**Text-figure 2**—Surai Khola profile.

rivers, emerging from the rising Himalaya deposited thick fans of sandy erosional debris at the margin of the mountain front. The current being strong, the roots of tree and animal bones were embedded in the sand.

The sandstone facies of the Surai Khola beds proved to be the richest in vertebrate fossils of the entire succession, and their identification puts these sandstones equivalent to Tatrot and Pinjor formations of the Upper Siwalik. Most common were the remains of reptiles (Crocodylidae, Trionychidae) indicating an environment of rich water resources. Large mammals of the family Elephantidae, Suidae, Hippopotamidae, Cervidae, Giraffidae and Bovidae were found in the thick fluvial sandstone successions in the Upper part of the sequence, pointing to a forested environment, criss-crossed by wide, sandy meandering streams. Large tree trunks and branches found in the same sandstone which contain vertebrate fossils are equally indicative of thickly forested and heavily flooded environments.

Many clay beds are abundant of molluscs (lamellibranchs and gastropods), sometimes even in the form of lumachelles. The few clay horizons which are intercalated in the sandstone proved to be rich in pollen, but leaf containing horizons are rather rare.

After an interval of a quieter fluvial regime during the period of the Dobata beds which may be equivalent to the Pinjor Formation thick screes of cobble to boulder conglomerates (here called the Dhan Khola beds) were transported down from the rising Himalaya. The boulder conglomerates are devoid of fossils, except a few pollen bearing horizons. A fault running east-west along the Rangsing River thrusts older Siwalik deposits against the conglomerates of the Dhankhola beds.

It is important to note that at the Surai Khola area throughout the entire sequence, most of the clay horizons are surprisingly rich in pollen which is not common in the Indian Siwaliks. The combined data from the palynostratigraphical analysis, complimenting the studies of fossil plants will result in a comprehensive evaluation of the floristic through the sequence which will serve as a model for understanding the changes in plant life and environment during the Siwalik period is one area. This means that we are able to describe an entire Siwalik sequence not only lithologically and faunistically but also climatically and environmentally by establishing the floristic development through megafossils and pollen. Apart from the surveyed Surai Khola succession, the other areas in the Nepal Siwalik too yielded quite abundant vertebrate and plant fossils.

It is apparent that the thick micaceous sandstone facies similar to those of the Surai Khola beds in the Nepal Siwaliks, wherever exposed, are synchronous to the Tatrot and Pinjor faunal zones of the Upper Siwalik. One of the most fossiliferous areas was found to be the Rato Khola in east Nepal, north of Janakpur, where massive micaceous sandstones are exposed. Here, we collected and excavated a large number of vertebrate fossils which are also present in Tatrot and Pinjor sediments. Great stress was laid in collecting the fossils *in situ*. Only those fossils were included in the collection for identification of which the provenance was definite. The remains of crocodile and gavialis as well as a great variety of turtles are always found in abundance. Most of the fossils are of large mammals—particularly of elephantidae (for example, a skull and other remains of *Stegodon ganesa* and teeth and other parts of *Archidiskodon planiforns*) and of hippopotamidae (a whole skull, skull part, post cranial bones, etc of *Hexaprotodon siwalensis*). A well preserved skull of the pig *Hippohyus tatroti*, jaws and teeth of bovids and antelope species are found. One of the most interesting finding is that of an entire skull with part of the tusks belonging to *Archidiskodon planiforns*, described from Pinjor, which was excavated from a sandstone cliff.

One of the most important features of the data from the Surai Khola is the possibility to link up a substantial vertebrate fauna within a stratified, large sediment-body with that of the plant life during the same periods. It will greatly increase our insights into the palaeoenvironment of the Siwalik period by evaluating both plant as well as animal life in their geological setting during the same time and place.

In order to establish a magneto-polarity time scale, palaeo-magnetic sampling has been undertaken this year by W. Roesler and Fassbinder under Dr Appel from the Geophysical Department of the University of Munich. The final results will be a first comprehensive model of a chronostratigraphy of the Nepal Siwaliks and its palaeoenvironmental and climatical interpretations for the last ca 12 million years.

A joint detailed report will soon be forthcoming under the auspices of the Birbal Sahni Institute of Palaeobotany, Lucknow.

## ACKNOWLEDGEMENTS

I am extremely grateful for the collaboration with the Birbal Sahni Institute of Palaeobotany through its Director, Dr Venkatachala to whome I am thankful for his encouragement and assistance. I thank my collegues from this Institute, Drs N. Awasthi, S. Sarkar and M. Prasad for their collaboration. I am grateful to the Research Division under Dr Pradhan and the Geology Department of Tribhuvan University, Kathmandu, and its Director, Dr M. P Sharma for their great assistance I thank the German Research Council for the grant under which this research was made possible. My particular thanks go always to Prof Dr Gisela Freund, Institut fur Urgeschichte, University of Erlangen, Germany for her untiring encouragement and promotion of this research.

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# Siwalik pollen succession from Surai Khola of western Nepal and its reflection on palaeoecology

Samir Sarkar

Sarkar, Samir 1990. Siwalik pollen succession from Surai Khola of western Nepal and its reflection on palaeoecology *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 319-324

A palynological report dealing with the Siwalik Group of sediments from Surai Khola area of western Nepal is presented. The clay samples collected from six different lithological units of Lower, Middle and Upper Siwalik provide data for palaeoecological interpretations. Significant elements of the palynoflora are: *Zygnema, Mougeotia, Botryococcus, Striatriletes, Lycopodiumsporites, Monoporopollenites, Malvacearumpollis* and *Polyadopollenites.* Periodic changes in qualitative and quantitative composition of the palynological spectra show that the vegetational succession reflects changing palaeogeographical conditions. A fresh-water swampy environment is interpreted for the older horizons. Algal remains of *Botryococcus, Pediastrum, Zygnema* and megaspores of *Azolla*, etc., provide cogent evidence for this observation. Gradually swampy conditions seem to have changed to a bottom land habitat which is evidenced by the presence of a number of pteridophytic elements, viz., *Lycopodium, Polypodium, Schizaea*, etc Palynoassociations depict semi-evergreen vegetational pattern during the time of deposition of the Surai Khola Siwalik sequence in West Nepal.

**Key-words**—Palynology, Siwaliks, Palaeoecology, Mio-Pliocene (Nepal).

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## साराँश

### पश्चिमी नेपाल में सुराई खोला से शिवालिक परागकण अनुक्रम तथा पुरापारिस्थितिकी पर इसका प्रभाव

समीर सरकार

पश्चिमी नेपाल में सुराई खोला क्षेत्र से शिवालिक अवसादों से सम्बन्धित एक परागाणविक रिपोर्ट प्रस्तुत की गई है। अधरि, मध्य एवं उपरि शिवालिक की छः विभिन्न शैलिकीय इकाईयों से एकत्र मिट्टी के नमूनों से पुरापारिस्थितिकीय निष्कर्षों हेतु आँकड़े उपलब्ध हुए हैं। **जिग्नीमा, मोगिओटिया, बोट्रिओकोकस, स्ट्रआट्राइलिटीस, लाइकोपोडियमस्पोराइटिस, मोनोपोरोपोलिनाइटिस, माल्वेसियरमपोलिस** एवं **पोलिएडोपोलिनाइटिस** परागाणुवनस्पतिजात के मुख्य अवयव हैं। परागाणविक स्पेक्ट्रम की परिमाणात्मक एवं गुणात्मक संरचना में हुए सामयिक परिवर्तनों से बदलती हुई पुराभौगोलिक परिस्थितियाँ व्यक्त होती हैं। पुराने संस्तरों हेतु स्वच्छ जल वाले दलदली वातावरण का होना सुनिश्चित किया गया है। इस प्रेक्षण के लिए **बोट्रीओकोकस, पैडिआस्ट्रम** व **जिग्नीमा** के शैवालीय अवशेष **तथा ऍजोला** के गुरुबीजाणु विश्वासप्रद प्रमाण जुटाते हैं। धीरे-धीरे दलदली परिस्थितियों से तलीय स्थल परिवर्तित हुआ प्रतीत होता है जो कि **लाइकोपोडियम, पोलिपोडियम, शाइज़िआ** आदि के बीजाणुओं की उपस्थिति से प्रमाणित होता है। परागाणु साहचर्य से पश्चिम नेपाल में सुराई खोला शिवालिक अनुक्रम के निक्षेपण के समय अर्ध-सदाहरित वनस्पति का होना इंगित होता है।

THE Siwalik Group of sediments are well-developed all along the foot-hills of the Nepal Himalaya. The sediments of this group are mainly characterised by clay, sandstones, grits and conglomerates. At some places lignitic nodules and coal bands have also been observed. So far, palynological investigations of this strata from Nepal have been scantily carried out. Mathur (1973) reported a Lower Siwalik palynofloral assemblage from Tharukhola-Chepang area of Nepal. Recently, Mathur (1984) has also recorded palynofossils from the Lower, Middle and Upper Siwalik sediments from the area in the east of Nepalganj. During the last four years, a rich collection of plant megafossils and palynological samples has been made from the Siwalik sediments of Dang region, western Nepal under a collaborative project with Dr G. Corvinus of University of Erlangen, West Germany. Detailed palynological investigations of the Siwalik sediments of Surai Khola and adjoining areas (see Map 1 in Corvinus, p. 295 of this volume) were carried out to build up a palynofloral succession to understand the vegetational history, palaeoecology and phytogeography.

*Location of samples*—The area is situated at about 7 km north-west of Shivpur in the Kapilwastu District of west Nepal. The road section along the Surai Khola stream, between Surai Naka and Rangsing Khola, extends for a distance of 16 km and represents a complete sequence of the Siwalik Group in this region. Sediments of Lower, Middle and Upper Siwaliks are exposed along the road cutting. The basal part is called Bankas Bed. It is seen close to the base of the Surai Naka foot-hill. The top of the Surai Khola sequence is known as the Dhan Khola Bed. Between Bankas and Dhan Khola beds four more beds are present in succession, just south of Rangsing Khola, viz., Paira Khola, Chor Khola, Surai Khola and Dobata (Corvinus, 1988, 1990).

Two field trips were undertaken for collection of material from the Surai Khola sequence. Three hundred and ninety four samples were collected and processed. Samples were mainly taken from the finer clastics. Some coarse grained sandstones from the Surai Khola Bed have also proved to be productive. The slides and negatives of the palynofossil have been deposited in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

## RESULTS

*Palynofloral assemblage*—A rich palynofloral assemblage is recorded from the Surai Khola sequence. Following are the significant constituents of the palynofossils:

a) ALGAL REMAINS
*Botryococcus braunii* Kützing 1849
Zygospores of *Mougeotia*
*Pediastrum* spp.
Zygospores of *Zygnema*

b) FUNGAL REMAINS
*Callimothallus assamicus* Kar, Singh & Sah 1970
*Inapertisporites* spp.
*Notothyrites amorphus* Kar & Saxena 1976
*Phragmothyrites eocaenica* Edwards 1922

c) PTERIDOPHYTIC SPORES
*Azolla* megaspore
*Cyathidites australis* Couper 1953
*Crassoretitriletes vanraadshooveni* Germeraad, Hopping & Muller 1968
*Dictyophyllidites* sp.
*Lycopodiumsporites* spp.
*Lygodiumsporites* spp.
*Polypodiaceaesporites* spp.
*Polypodiisporites ornatus* Sah 1967
*Schizaeoisporites* sp.
*Striatriletes multicostatus* Kar & Saxena 1981
*Striatriletes paucicostatus* Kar 1985
*Striatriletes susannae* (Van der Hammen) Kar 1979

d) GYMNOSPERMOUS POLLEN
*Cycadopites* spp.
*Pinuspollenites* spp.

e) ANGIOSPERMIC POLLEN
*Aglaoreidia* sp.
*Compositoipollenites* sp.
*Liliacidites* sp.

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### PLATE 1

→

(All photomicrographs magnified Ca × 500)

1 *Lycopodiumsporites* sp., Slide no. BSIP 10173, coordinates: 31 × 101.

2. *Lycopodiumsporites* sp., Slide no. BSIP 10172, coordinates: 57.5 × 101

3. *Polypodiisporites ornatus* Sah 1967, Slide no. BSIP 10164, coordinates: 52 × 102.5.

4. *Botryococcus braunii* Kützing, 1849; Slide no. BSIP 10176, coordinates: 44.5 × 107

5. *Striatriletes paucicostatus* Kar 1985, Slide no. BSIP 10167, coordinates: 61 × 93.5.

6. *Lycopodiumsporites globatus* Kar 1985, Slide no. BSIP 10175, coordinates: 45.5 × 96.5.

7 *Cycadopites* sp., Slide no. BSIP 10178, coordinates 49.5 × 103.5.

8. *Dictyophyllidites* sp., Slide no. BSIP 10174, coordinates: 57 × 110.

9,20,21 Zygospores of *Zygnema*, Slide no. BSIP 10177, coordinates: 59 × 100.5; Slide no. BSIP 10173, coordinates: 53 × 79.9; Slide no. BSIP 10171, coordinates: 53 × 96.

10,11,16. *Malvacearumpollis* sp., Slide no. BSIP 10165, coordinates: 42 × 98; Slide no. BSIP 10163, coordinates: 57.5 × 100.5; Slide no. BSIP 10166, coordinates: 59 × 112.

12. *Malvacearumpollis grandis* Sah 1967; Slide no. BSIP 10163, coordinates: 45.5 × 99.

13. *Crassoretitriletes vanraadshooveni* Germaraad, Hopping & Muller 1968; Slide no. BSIP 10159, coordinates: 37 × 95.

14. *Phragmothyrites eocaenica* Edwards 1922,; Slide no. BSIP 10174, coordinates: 62.5 × 109.1.

15. *Striatriletes susannae* (Van der Hammen) Kar 1979; Slide no. BSIP 10169, coordinates: 52.5 × 108.

17. *Polyadopollenites myriosporites* Stover & Patridge 1973; Slide no. BSIP 10163, coordinates: 55 × 103.

18. *Striatriletes multicostatus* Kar & Saxena 1981; Slide no. BSIP 10170, coordinates: 45 × 107

19. *Monosulcites* sp., Slide no. BSIP 10168, coordinates: 56.5 × 109.

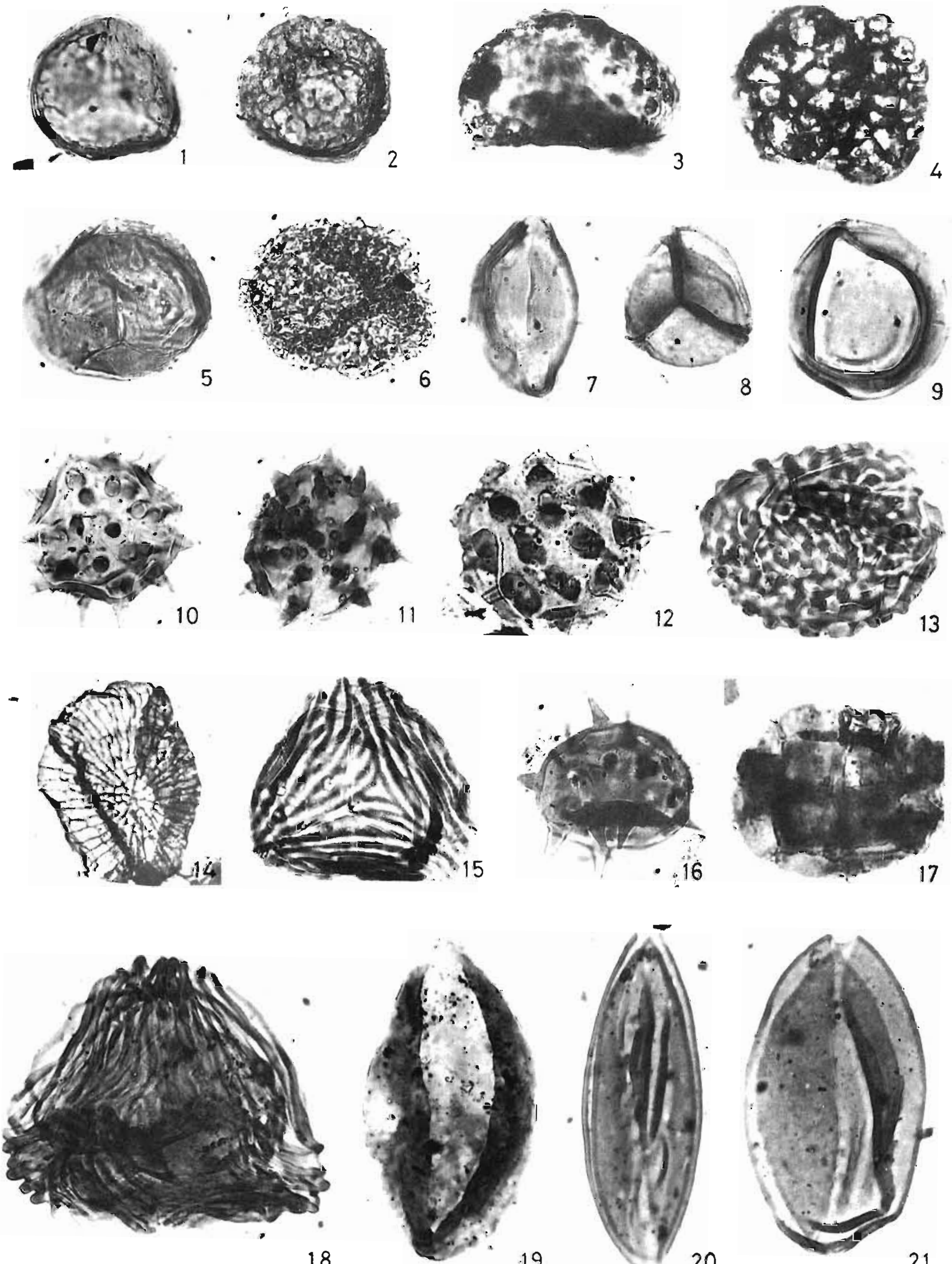

**PLATE 1**

*Malvacearumpollis grandis* Sah 1967
*Malvacearumpollis* sp.
*Monoporopollenites kasauliensis* Singh & Sarkar 1984
*Monosulcites* sp.
*Nympheacidites* sp.
*Palmaepollenites* sp.
*Polyadopollenites myriosporites* Stover & Patridge 1973
*Tricolpites* sp.

Some significant palynofossils have been illustrated in Plate 1

Out of 30 genera a few bryophytic spores have also been recorded. Algal forms are represented throughout the lower part of the Bankas Bed. *Botryococcus, Pediastrum* and *Zygnema* are richly represented. Fungal spores and conidia are poor. Ascostromata of microthyriaceous fungi, viz., *Phragmothyrites* and *Callimothallus*, are common

Pteridophytic spores constitute an important aspect of the assemblage at all levels of the Surai Khola sequence. Ten genera and fifteen species representing seven families, viz., (i) Cyatheaceae, (ii) Schizeaceae, (iii) Parkeriaceae, (iv) Polypodiaceae, (V) Lycopodiaceae, (vi) Matoniaceae, and (vii) Azollaceae, have been recognized, though gymnospermous pollen are qualitatively less, still in some horizons they form a significant group quantitatively Pollen grains of cycadaceous and Pinaceous affinity, viz., *Cycadopites* and *Pinuspollenites* have been recorded respectively.

The angiosperm pollen are represented by nine genera and ten species. The dicotyledonous pollen are assigned to families Compositae, Malvaceae, Cruciferae, Mimosaceae whereas the monocotyledonous pollen grain represent the palmae, Gramineae, Liliaceae, and Typhaceae. A quantitative analysis of the above assemblage reveals the varied representation of pteridophytic spores (35%), gymnospermous pollen (30%), angiospermous pollen (15%), and fungal and algal remains (20%). Among the pteridophytic spores some of the significant forms are *Striatriletes* spp. (33%), *Polypodiaceaesporites* (15%) and *Polypodiisporites* (8%), gymnospermous pollen are represented by *Cycadopites* spp. and *Pinuspollenites* spp. equally. *Malvacearumpollis* spp. (30%) and *Monoporopollenites* spp. (23%) are the most dominant elements among the angiosperm pollen.

## STRATIGRAPHIC DISTRIBUTION

From the distributional pattern of the palynofossils it is evident that the older horizon of Surai Khola succession, i.e., the Bankas Bed is dominated by algal elements, whereas the middle part of the sequence, viz., upper part of Paira Khola and Chor Khola beds, are dominated by

**Table 1—Distribution of significant palynofossils in Surai Khola Siwalik sequence**

| Palynofossils (Genera) | Palynofloral assemblage | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| *Botryococcus* | × | × | 0 | 0 | × | |
| *Pediastrum* | + | – | | | – | |
| *Zygnema* | × | × | | | – | |
| *Phragmothyrites* | – | – | + | + | 0 | 0 |
| *Lygodiumsporites* | | – | × | – | – | 0 |
| *Striatriletes* | | × | × | – | – | |
| *Crassoretitriletes* | | + | + | 0 | | |
| *Lycopodiumsporites* | | + | × | – | – | |
| *Polypodiisporites* | | + | – | + | 0 | |
| *Dictyophyllidites* | | + | | × | | |
| *Cycadopites* | | | | × | × | |
| *Malvacearumpollis* | | | | | + | × |
| *Monoporopollenites* | | | | | | × |
| *Palmaepollenites* | | | | | + | – |
| *Polyadopollenites* | | | | – | – | × |
| *Compositoipollenites* | | | | | + | – |
| *Liliacidites* | | | - | | 0 | |

| | | |
|---|---|---|
| 1. Bankas Bed | × | > 30% |
| 2. Paira khola Bed | + | 15-30% |
| 3. Chor Khola Bed | – | 5-15% |
| 4. Surai Khola Bed | 0 | < 5% |
| 5. Dobata Bed | | |
| 6. Dhan Khola Bed | | |

pteridophytic spores and gymnospermous pollen; the upper part of the sequence is dominated by angiospermic pollen. The emergence of algal elements in the Dobata Bed is a striking feature of the assemblage. Distribution of important palynofossils in the Surai Khola sequence is given in Table 1.

## PALAEOECOLOGICAL INTERPRETATION

Analysis of the palynofloral assemblage provides valuable information regarding the palaeoecological conditions that might have prevailed during the time of deposition of the Siwalik sediments in the Surai Khola area. The lower part of the Surai Khola sequence (Bankas to Chor Khola beds) indicates the presence of fresh water swamps: *Pediastrum, Botryococcus, Zygnema, Mougeotia, Azolla* and *Ceratopteris* are present. It is possible that areas nearby were swampy lowlands which were inhabited by ferns. The most important evidence of fresh water swamp conditions comes from the lowermost sediments of the succession, i.e. the Bankas Bed.

The swampy condition seems to have changed from the upper part of the Chor Khola Bed onwards to a bottomland habitat. This is evidenced by the presence of a large number of pteridophytic elements, like *Lygodium, Lycopodium, Schizaea* and *Polypodium* along with *Cycas, Hibiscus, Acacia*, etc. At the same time, the high incidence of pollen grain of the members of Malvaceae and Mimosaceae indicates a change from semi-evergreen vegetational pattern, typical of the lower part of the sequence, to a moist deciduous vegetation in Dobata Bed. The middle part of the Surai Khola Bed is distinctly marked by the first appearance of bisaccate gymnospermous pollen perhaps of pinaceous affinity, a feature which is largely in conformity with the middle part of Siwalik sequence exposed elsewhere in the Indian subcontinent (Banerjee, 1968; Lukose, 1969; Nandi, 1972, 1975; Saxena & Singh, 1980, 1981, 1982a, 1982b; Saxena *et al.*, 1984; Singh & Saxena, 1980, 1981). This information may be useful to understand the time and spread of modern conifers in the Indian subcontinent. The topmost part of the succession exhibits abundance of graminaceous pollen along with bisaccate pollen which indicate the onset of much drier conditions in the later period.

The palynofloral assemblage recorded by Mathur (1984) from the Tharukhola-Chepang-Chinji area of Nepal does not compare well with the present assemblage; however, the higher representation of grass pollen in the younger horizons as reflected in the Surai Khola palynofloral assemblage seems to be a common feature between the two.

The modern equivalents of Surai Khola

**Table 2—Botanical affinities of Surai Khola palynofossils and their climatic habitats**

| Palynofossils | Modern comparable taxa | Preferable habitat | Climate |
|---|---|---|---|
| *Botryococcus braunii* | *Botryococcus braunii* | Aquatic (Freshwater) | Cosmopolitan |
| *Pediastrum* | *Pediastrum* | Aquatic ,, | Cosmopolitan |
| *Zygnema* | *Zygnema* | Aquatic ,, | Cosmopolitan |
| *Mougeotia* | *Mougeotia* | Aquatic ,, | Cosmopolitan |
| *Phragmothyrites* | Microthyriaceae | Warm, humid | Tropical-Subtropical |
| *Notothyrites* | Microthyriaceae | ,, ,, | Tropical-Subtropical |
| *Callimothallus* | Microthyriaceae | ,, ,, | Tropical-Subtropical |
| *Cyathidites* | Cyatheaceae | Humid shady places | Tropical-Subtropical |
| *Lygodiumsporites* | *Lygodium* | Leaf climber | Tropical-Subtropical |
| *Striatriletes* | *Ceratopteris* | Aquatic (Marshy places) | Tropical-Subtropical |
| *Crassoretitriletes* | Schizaeaceae | Moist and shady places | Tropical-Subtropical |
| *Lycopodiumsporites* | *Lycopodium* | Moist and shady places | Cosmopolitan |
| *Polypodiaceaesporites* | Polypodiaceae | Moist and shady places | Tropical-Subtropical |
| *Schizaeoisporites* | *Schizaea* | Moist and shady places | Tropical-Subtropical |
| *Dictyophyllidites* | Matoniaceae | Warm, humid | Tropical |
| *Azolla* megaspore | *Azolla* | Aquatic | Tropical-Subtropical |
| *Cycadopites* | Cycadaceae | Prefers dry places | Tropical-Subtropical |
| *Pinuspollenites* | Pinaceae | Prefers dry places | Cosmopolitan. |
| *Malvacearumpollis* | *Hibiscus* | | Tropical-Subtropical |
| *Monoporopollenites* | Gramineae | Prefers dry places | Cosmopolitan |
| *Nympheacidites* | *Nymphaea* | Aquatic | Cosmopolitan |
| *Liliacidites* | Liliaceae | | Cosmopolitan |
| *Palmaepollenites* | Palms | | Tropical-Subtropical |
| *Polyadopollenites* | *Acacia* | Dry plains | Tropical-Subtropical |
| *Aglaoreidia* | Typhaceae | Ponds & still water | Cosmopolitan |
| *Compositoipollenites* | Compositae | | Cosmopolitan |

palynofossils denoting their habitats and climates are given in Table 2.

From the above Table it is clear that out of 26 taxa 13 prefer tropical to subtropical climate, the remaining 13 are of cosmopolitan nature. Therefore, it can be inferred that the overall palynofloral contents of the assemblage indicate the prevalence of tropical to subtropical climate during the deposition of Surai Khola sediments.

Data presented in this paper is considered very significant as it throws light on the history of the vegetation through Mio-Pleistocene time and its palaeoecology. Extended investigations are likely to generate a dependable data-base for the reconstruction of the vegetational changes.

## ACKNOWLEDGEMENTS

I am grateful to Drs B. S. Venkatachala, H. P. Singh and N. Awasthi, Birbal Sahni Institute of Palaeobotany, Lucknow for their guidance and fruitful discussion. I am also indebted to Dr G. Corvinus, for her generous help, stimulating discussions and continued interest in the progress of the present work.

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# Siwalik sediments of Arunachal Himalaya: Palynology, palaeoecology and palaeogeography

Trilochan Singh & S. K. M. Tripathi

Singh, Trilochan & Tripathi, S. K. M. 1990. Siwalik sediments of Arunachal Himalaya: Palynology, palaeoecology and palaeogeography. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc Symp. 'Vistas in Indian Palaeobotany'*, *Palaeobotanist* **38** : 325-332.

The palynological assemblages comprising angiospermous pollen, pteridophytic spores, fungal remains, gymnospermous pollen, dinoflagellate cysts, acritarchs and reworked Permian spores and pollen, have been reported from Siwalik sediments exposed in Kameng, Subansiri and Siang districts, Arunachal Pradesh. Palynological comparison with extant plants has been attempted to determine the palaeovegetation, palaeoclimate and environment of deposition. Geological history and palaeogeography of Neogene sediments of Arunachal Himalaya have been discussed.

**Key-words**—Palynology, Palaeoecology, Palaeogeography, Siwalik, Arunachal Himalaya, Miocene (India).

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## सारॉंश

### अरुणाचल हिमालय के शिवालिक अवसाद : परागाणविक अध्ययन, पुरापारिस्थितिकी एवं पुराभौगोलिकी

त्रिलोचन सिंह एवं सूर्यकान्तमणि त्रिपाठी

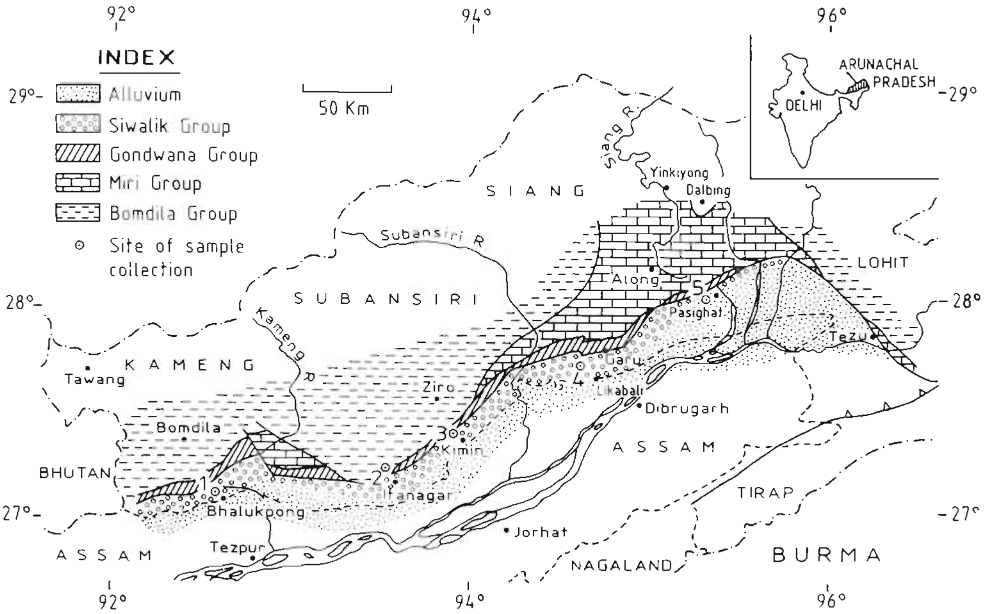
अरुणाचल प्रदेश के कामेंग, सुबनसिरी एवं स्याँग जनपदों में अनावरित शिवालिक अवसादों से उपलब्ध परागार्णविक समुच्चय में आवृतबीजी परागकण, टेरीडोफ़ाइटी बीजाणु, कवकीय अवशेष, अनावृतबीजी परागकण, घूर्णीकशाभ पुटीयाँ, एँक्रीटार्क एवं पुनरीक्षित परमी कालीन परागकण एवं बीजाणु उपलब्ध हुए हैं। पुरावनस्पति, पुराजलवायु एवं निक्षेपण का वातावरण सुनिश्चित करने के लिए वर्तमान पौधों से परागाणविक तुलना करने का प्रयास किया गया है। अरुणाचल हिमालय के पश्चनूतन अवसादों के भूवैज्ञानिक इतिहास एवं पुराभौगोलिकी की विवेचना भी की गई है।

PALYNOLOGICAL study on Siwalik sediments exposed in Kameng, Subansiri and Siang districts, Arunachal Pradesh has been carried out. Taxonomic part of the present palynological work shall be published elsewhere. In the present paper an attempt has been made to apply the obtained data to reconstruct the past vegetation, palaeoecology and environment of deposition.

The Siwalik sediments in Arunachal Himalaya are represented by thick piles of arenaceous and argillaceous sediments which are exposed in a continuous belt all along the Himalayan foot-hills from Kameng District in the west to Siang District in the east (Text-fig. 1). Further eastward in Lohit District, these sediments are covered with alluvium.

The Siwalik sediments mark a change in topography from the plains of Brahmaputra Valley to the Himalayan foot-hills where these rise abruptly and abut against the alluvium. These sediments extend up to 15 to 30 km towards north where they are thrusted against the Gondwana Group of rocks. However, due to overthrusting of the older rocks over the Gondwana rocks, the Siwalik sediments are thrusted directly against the Miri and/or Bomdila groups of rocks.

Palynologically the Tertiary sediments of Arunachal Himalaya are less explored. Dutta and Singh (1980) and Dutta (1980) reported palynological assemblages from these sediments exposed in Kameng District and correlated them with Neogene formations of Upper Assam. The assemblages recovered by them are of mixed type containing elements of Permian, Eocene and Miocene ages.



**Text-figure 1**—Geological map of the area showing localities of sample collection. **1.** Bhalukpong-Sessa Section, Kameng District; **2.** Itanagar-Doimukh-Kheel Section, Subansiri District, **3.** Kimin-Ziro Section, Subansiri District; **4.** Likabali-Garu Section, Siang District; **5.** Pasighat-Koyu Section, Siang District.

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## PLATE 1

(All photomicrographs are magnified, × 500)

1. *Lycopodiumsporites* sp.; Slide no. BSIP 10217, coordinates: 45.5 × 115.9.
2. *Lycopodiacidites* sp.; Slide no. BSIP 10217, coordinates: 48.6 × 112.3.
3. *Lycopodiacidites dextrus* Kar & Kumar; Slide no. BSIP 10198, coordinates: 11.5 × 105.5
4. *Lygodiumsporites eocenicus* Dutta & Sah; Slide no. BSIP 10200, coordinates: 21.1 × 106.6
5. *Pteridacidites* sp.; Slide no. BSIP 10206, coordinates: 12.2 × 115.4.
6. *Lycopodiumsporites palaeocenicus* Dutta & Sah; Slide no. BSIP 10199, coordinates. 14.3 × 112.6.
7. *Couperipollis* sp.; Slide no. BSIP 10216, coordinates: 35.9 × 110.1.
8. *Verrualetes assamicus* Singh & Saxena; Slide no. BSIP 10205, coordinates: 20.2 × 108.9.
9. *Verrualetes* sp.; Slide no. BSIP 10203, coordinates. 34.6 × 105.5.
10. *Assamiapollenites ghoshii* Singh & Saxena; Slide no. BSIP 10203, coordinates: 40.3 × 106.1
11. *Loranthipites* sp.; Slide no. BSIP 10209, coordinates: 41.8 × 105.5.
12. *Palmidites applicatus* Kar & Kumar; Slide no. BSIP 10216, coordinates: 30.7 × 117.6.
13. *Dictyophyllidites* sp.; Slide no. BSIP 10203, coordinates: 25.6 × 95.1.

14,29. *Tricolporopollis rubra* Dutta & Sah; Slide nos. BSIP 10196 and 10207, coordinates: 38.10 × 110.6 and 25.6 × 104.10 respectively.

15,24. *Meliapollis* sp.; Slide nos. BSIP 10194 and 10195, coordinates: 25.5 × 115.7 and 22.1 × 105.6, respectively

16,33. *Striatriletes attenuatus* Singh & Tripathi, Slide nos. BSIP 10214 and 10200, coordinates: 25.7 × 103.1 and 45.7 × 106.5 respectively

17. *Collumosphaera* sp.; Slide no. BSIP 10192, coordinates: 35.2 × 110.3.

18,31 *Lakiapollis assamicus* Tripathi & Singh; Slide nos. BSIP 10194 and 10193, coordinates: 33.4 × 110.5 and 31.6 × 110.8 respectively

19. *Liliacidites* sp. 1; Slide no. BSIP 10203, coordinates: 48.3 × 119.7
20. *Liliacidites* sp. 2; Slide no. BSIP 10203, coordinates: 39.5 × 111.10.
21. *Couperipollis magnus* Kar & Kumar; Slide no. BSIP 10191, coordinates: 46.8 × 117.5.
22. *Intrapunctisporis subtriangularis* Kar & Singh; Slide no. BSIP 10194, coordinates: 60.9 × 111.5.
23. *Palmidites obtusus* Tripathi & Singh; Slide no. BSIP 10189, coordinates: 18.5 × 96.2.
25. *Proxapertites assamicus* (Sah & Dutta) Singh, Slide no. BSIP 10196, coordinates: 32.8 × 111.10.
26. *Palmidites* sp.; Slide no. BSIP 10188, coordinates: 43.10 × 98.2.
27. *Podocarpidites* sp.; Slide no. BSIP 10209, coordinates: 28.2 × 105.7.
28. *Dicolpopollis* sp.; Slide no. BSIP 10213, coordinates: 21.7 × 104.3
30. *Collospermumpollis laevigatus* Tripathi & Singh; Slide no. BSIP 10191, coordinates: 46.10 × 109.9.
32. *Ctenolophonidites costatus* (Van Hoeken-Klinkenberg) Van Hoeken-Klinkenberg; Slide no. BSIP 10211, coordinates: 32.3 × 106.5.

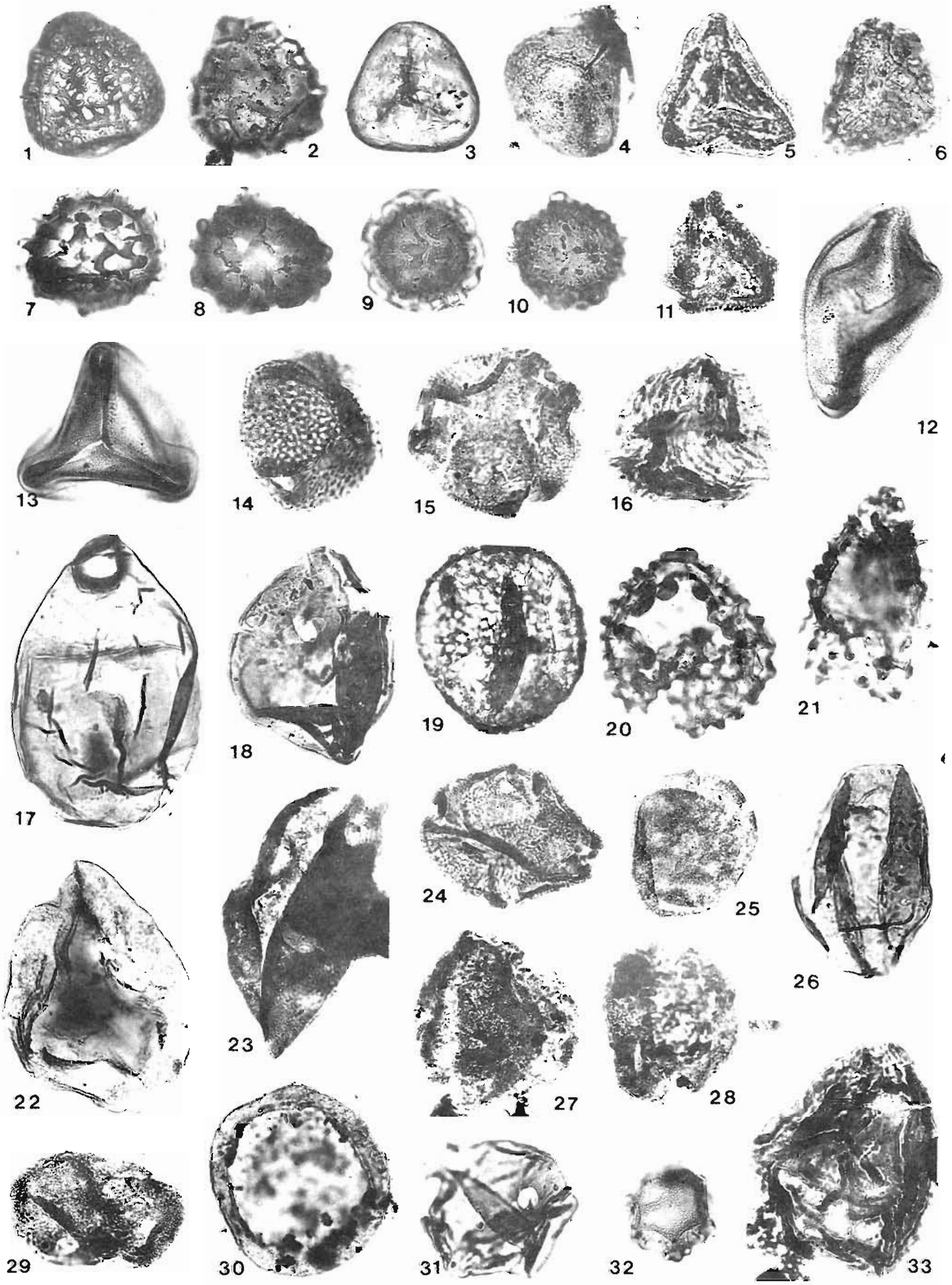
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PLATE 1

Samples for the present palynological study have been collected from the following sections (Text-fig. 1).

1. Bhalukpong—Sessa Section, Kameng District
2. Itanagar-Doimukh-Kheel Section, Subansiri District
3. Kimin-Ziro Section, Subansiri District
4. Likabali-Garu Section, Siang District
5. Pasighat-Koyu Section, Siang District

## LITHOLOGICAL CHARACTERS OF SIWALIK SEDIMENTS

The Siwalik sediments are mainly composed of sandstone, siltstone, clay and pebble beds but lot of lithological variation has been noticed in different sections.

The sandstone, in general, is of salt-and-pepper appearance that weather to pale brown colour. It varies from fine to coarse-grained, sometimes gritty, moderately loose to compact, soft to hard. In Bhalukpong-Sessa section, Kameng District, it is often indurated. Generally the sandstone becomes micaceous and the biotite alignment gives colour-banding. Occasionally it is structureless, but mostly it is laminated showing parallel, cross and ripple cross-lamination. The foreset laminae occasionally consists of carbonaceous shale and clay, mica-flakes and detrital coal grains. Pebbles are also noticed within the sandstone occurring as small pockets or thin layers mostly aligned parallel to the lamination. The pebble and clast percentage is variable. The clasts are generally subrounded to rounded, flat or discoidal. Coarser to gritty gradation in the form of conglomerate is also noted in the sandstone.

The calcareous concretions, mostly aligned along the bedding plane, are commonly found in the sandstone. Their diameter varies from 5 to 40 cm and are spherical to subspherical, ellipsoidal to elongate in shape. Thin lenses and streaks of coal, lumps and lenticles of lignite and sporadic carbonised and silicified wood fragments have also been observed in the sandstone. Grey coloured compact sand-balls and thin pseudobeddings that cut across the bedding plane have also been noted in the loose grey to brownish colour sandstone. These sand-balls and veins have been referred to as 'Sandstone dykes' by Kumar and Singh (1982). Associated with the sandstone are greyish-green clay, siltstone and shale, which often show spheroidal and nodular weathering. Siltstone is splintery and at places becomes sandy in nature.

The conglomerate strata, though not common in Arunachal Pradesh, are observed in Pasighat-Koyu section, Siang District, and Bhairabkund-Kalaktang section, Kameng District. In Likabali-Garu section, Siang District, near Siji, there is a thick sequence of conglomerate sandstone alternation with thin silty clay bands. It is doubtful whether this horizon is a part of Upper Siwalik or it belongs to the Quaternary sediments. No palynofossils have been recovered from this part, hence the age of these sediments could not be determined. The conglomerate beds range in thickness from 3 to 34 m with fragments of pebble to boulder size. The pebbles and boulders generally show orientation parallel to the bedding plane but at some places they do not show any preferred orientation. The pebbles and boulders are predominantly of gneisses, quartzites, schists and limestones. In Pasighat-Koyu section, Siang District, some pebbles of volcanic rocks are also observed. The conglomerates are moderately compact to semi-consolidated.

## STRUCTURE

The abrupt rise of Siwaliks abutting the older alluvium of Brahmaputra plains is marked by a fault. Towards north, the Siwaliks are thrusted against the Gondwana group of rocks. In Pasighat-Koyu section, Siang District the Siwaliks are thrusted against the older Miri and/or Bomdila group of rocks as a result of overthrusting of these older rocks over the Gondwanas.

The regional Siwalik structure is a monocline, dipping at 15°-50° towards north-west. Locally, the dip changes to north-east. However, towards south near the northern thrust contact in Likabalki-Garu section, Siang District these sediments dip at a very high angle (70°-80°). The Siwalik sandstone shows open symmetrical folds in Subansiri District where sometimes folding becomes very tight and the limbs become nearly vertical. The fold axes, at times, become almost horizontal and plunge 10° towards north-west. A few intraformational low-angle faults are also recorded. One such fault is clearly visible at about 23 km stone in Kimin-Ziro section, Subansiri District, where the rocks show high crushing and fault gauge in a shear zone. There also appears to have taken place the post-Tertiary tectonic activity, which is envisaged by the faults effecting both Siwaliks and Gondwana rocks. Such faults are identified in Likabali-Garu-Basar section, Siang District and Bhalukpong Sessa-Jamiri section, Kameng District. The faults strike roughly N-S direction.

Current bedding, channel fill structures are prominent structural features of sandstones and conglomerates. Small scale synsedimentary faulting is also noticed. All these features indicate shallow water torrential deposits. In Itanagar section, Subansiri District, boulders of grey sandstone have been found in the brown, loose sandstone indicating penecontemporaneous erosion of the Siwalik sandstones. The scattered longer axes orientation of clasts at places indicate high energy dispersion and parallel orientation of longer axes of the clasts indicates lower energy and traction currents.

## PALYNOFLORAL COMPOSITION

Palynoassemblages are impoverished and are constituted by dinoflagellate cysts, acritarchs, fungal spores and fungal fruiting bodies, pteridophytic spores and gymnospermous and angiospermous pollen grains. Quantitative representation of individual taxon is very poor. Thus, it has not been possible to apply the palynological data for stratigraphic zonation. However, an attempt has been made to trace the botanical affinity of palynotaxa with a view to reconstruct the past vegetation, palaeoecology and environment of deposition. A list of recovered palynotaxa and their affinity is given below :

| Botanical Group/Family | Present distribution | Palynotaxa | Remarks |
|---|---|---|---|
| PTERIDOPHYTES | | | |
| Lycopodiaceae | Tropical to temperate | *Lycopodiacidites dextrus* Kar & Kumar 1986, *Lycopodiacidites* sp., *Lycopodiumsporites* sp. | Inhabits moist and shady places |
| Polypodiaceae | Cosmopolitan | *Monolites mawkmaensis* Sah & Dutta 1966 | |
| Matoniaceae | Tropical | *Dictyophyllidites* sp. | |
| Schizaeaceae | Tropical to subtropical | *Lycopodiumsporites eocenicus* Dutta & Sah 1970, *Intrapunctisporis subtriangularis* Kar & Singh 1986 | |
| Osmundaceae | Tropical and temperate | *Todisporites major* Couper 1958 | |
| Parkeriaceae | Tropical to subtropical | *Striatriletes susannae* van der Hammen emend. Kar 1979, *S. attenuatus* Singh & Tripathi 1983, *S. pseudocostatus* Singh & Tripathi 1983 | Water fern |
| Pteridaceae | Cosmopoliton | *Pteridacidites* sp. | |
| GYMNOSPERMS | | | |
| Podocarpaceae | Subtropical to temperate | *Podocarpidites meghalayaensis* Rao 1986, *Podocarpidites* sp. | |
| Pinaceae | Temperate | *Pinuspollenites* sp., *Abiespollenites* sp., *Laricoidites* sp. | |
| ANGIOSPERMS | | | |
| Arecaceae | Tropical to subtropical | *Palmidites maximus* Couper 1953, *P. applicatus* Kar & Kumar 1986, *Palmidites* sp., *Couperipollis magnus* (Dutta & Sah) Kar & Kumar 1986, *Couperipollis* sp., *Dicolpopollis* sp., *Longapertites klinkenbergii* Rao & Ramanujam 1978 | |
| Araceae | Tropical and temperate | *Proxapertites assamicus* (Sah & Dutta) Singh 1975 | |

| | | | |
|---|---|---|---|
| Ctenolophonaceae | Cosmopolitan | *Ctenolophonidites costatus* (Van Hoeken-Klinkenberg) Van Hoeken-Klinkenberg 1966 | The plants grow in fresh water swamp forests |
| Bombacaceae | Tropical | *Tricolporopollis rubra* Dutta & Sah 1970,<br>*Lakiapollis assamicus* Tripathi & Singh 1985 | These palynotaxa resemble pollen of *Cullenia* and *Durio* growing in evergreen forests |
| Meliaceae | Tropical to subtropical | *Meliapollis* sp. | |
| Liliaceae | Cosmopolitan | *Liliacidites* sp., *Collospermumpollis laevigatus* Tripathi & Singh 1984 | |
| Loranthaceae | Tropical to subtropical | *Loranthipites* sp. | Plants of this family are parasites on trees and shrubs of diverse forests |
| Malvaceae | Tropical and temperate | *Malvacearumpollis paucibaculatus* Venkatachala & Rawat 1973 | |

In addition, some palynotaxa have also been recovered whose affinity with living plants could not be traced. These are · *Assamiapollenites ghoshii* Singh & Saxena 1984, *Inaperturopollenites* sp. and *Tricolpites* sp.

## QUANTITATIVE ANALYSIS

The present palynological assemblage comprises 29 genera and 38 species of pteridophytic spores, gymnospermous and angiospermous pollen. Apart from these, dinoflagellate cysts, acritarchs, fungal remains and reworked Permian spores and pollen have also been recovered. The assemblage is dominated by angiospermous pollen (43%). Pteridophytic spores (20%) are also richly represented. Fungal remains (10%), gymnospermous pollen (9%), dinoflagellate cysts and acritarchs (2%), reworked Permian palynotaxa (12%) and unidentified taxa (6%) constitute the remaining part of the assemblage. Quantitative representation of individual palynotaxa is poor hence no palynozones could be identified.

## PALYNOLOGICAL COMPARISON

Dutta and Singh (1980) and Dutta (1980) published Upper Tertiary miofloral assemblages from Kameng District, Arunachal Pradesh. *Proxapertites, Palmidites, Lycopodiumsporites* and *Coupertpollis* are common to both the assemblages.

The present palynofloral assemblage is closely comparable to the Miocene palynofloras reported from Bhuban and Bokabil formations of Assam (Saluja *et al.*, 1973; Rao *et al.*, 1985; Rao, 1986; Rao & Singh, 1987; Saxena *et al.*, 1987). Common palynotaxa are: *Lycopodiumsporites, Monolites, Dictyophyllidites, Lygodiumsporites, Striatriletes, Podocarpidites, Pinuspollenites, Abiespollenites, Dicolpopollis, Tricolpites, Couperipollis, Tetracolporites* (*Meliapollis*) and *Proxapertites.*

The present assemblage is also comparable to those recorded from Miocene sediments of Jorajan well-3, Upper Assam (Singh & Saxena, 1984) and Boldamgiri Formation, Garo Hills, Meghalaya (Nandi & Sharma, 1984). *Lygodiumsporites, Striatriletes, Inaperturopollenites, Assamiapollenites, Verrualetes, Tricolopites, Couperipollis* and *Dicolpopollis* are the common elements.

The Miocene palynofloral assemblages recorded from western Himalaya (Banerjee, 1968; Mathur, 1973; Nandi, 1975, 1980; Saxena *et al.*, 1984) and Bengal Basin (Baksi, 1972) are different from the present assemblage.

On the other hand, the Neogene palynoflora of Quilon beds, Kerala (Rao & Ramanujam, 1975, 1978, 1982) compares well with the present assemblage as the following palynotaxa are common to both the assemblages: *Lygodiumsporites, Couperipollis, Longapertites, Dicolpopollis, Retitricolpites* (= *Tricolpites*), *Loranthipites, Ctenolophonidites, Retitricolporites* (= *Tricolporopollis*) and *Meliapollis.*

From the above comparison it is apparent that the present palynoflora resembles those described from the Miocene sediments of Assam Basin (Saluja *et al.*, 1973; Singh & Saxena, 1984; Nandi & Sharma, 1984; Rao *et al.*, 1985; Rao & Singh, 1987; Saxena *et al.*, 1987) and Quilon beds, Kerala (Rao & Ramanujam, 1975, 1978, 1982). Additionally, presence of some Miocene palynotaxa, *Dicolpopollis, Loranthipites, Meliapollis, Assamiapollenites ghoshii, Longapertites klinkenbergii* and *Malvacearumpollis* *paucibaculatus*, in the present assemblage in significant. Keeping in view the resemblance of present palynoflora with other known Miocene assemblages, a Miocene age has been assigned.

## PALAEOCLIMATE

Palynoflora of Miocene sediments of Arunachal foot-hills indicates that the area was inhabited by tropical-subtropical vegetation. Such conclusion has been drawn by rich representation of pteridophytes and angiosperms belonging to the families Parkeriaceae, Schizaeaceae, Pteridaceae, Lycopodiaceae, Matoniaceae, Arecaceae, Araceae and Bombacaceae. Temperate gymnosperm elements referable to the families Podocarpaceae and Pinaceae represented in the assemblage were, however, transported to the site of deposition. Dominance of pteridophytic spores and prodigality of microthyriaceous fungi indicate the prevailing warm and humid conditions.

## ENVIRONMENT OF DEPOSITION

The lithological association of siltstone, sandstone, pebbly sandstone and conglomerate bed indicates that these sediments were largely deposited under fluviatile environment. Based on sedimentological studies Singh *et al.* (1982) indicated that the Siwalik sandstones in Arunachal Himalayas are composed of sands of riverine origin and the material was transported by rolling and suspension to the depocentre. The studies further suggest that these sediments were brought to the river streams by fluvial agencies by rapid erosion from nearby high relief source areas. The current bedding and large thickness of sediments indicate that deposition took place in a rapidly sinking basin. Kumar and Singh (1982), on the basis of sedimentary and microstructural analysis of sandstone dykes in Siwalik sandstone, determined varied conditions of deposition with changing facies from fluvial fan to coastal plain fan-delta.

Dominance of Palm pollen further corroborates the inference that deposition of sediments under study took place in a near-coastal environment. The palynoflora suggests that a stretch of coastal swamp was adjacent to the depositional area and fresh-water elements were also brought to the deposition site by rivarine channels. The high altitude gymnospermic elements, present in the assemblage, indicate an elevated topography in the north of the depositional basin. Thus, the inference of high relief in nearby areas drawn by sedimentological studies (Singh *et al.*, 1982) is supported by palynological studies also.

## GEOLOGICAL HISTORY AND PALAEOGEOGRAPHY

Since the Permian time the area remained a landmass and marine transgression took place during late Early Eocene. The marine regression in the Arunachal foot-hill region took place at the end of Middle Eocene and sedimentation recommenced under the brackish water environment during Middle Miocene in front of the mountain range in a basin which acted as a foredeep area where the Siwalik sediments were deposited in the form of alluvial fan or deltaic deposits, or both. The sandstone dykes formed at the sediment-water interface indicate the fluctuating marine conditions.

The Himalayan orogenic movement accentuated the foredeep and large thickness of Siwalik sediments were deposited mainly under fluviatile conditions. Uplift and strong denudation continued giving rise to the contemporaneous deposition and erosion of these sediments. A thick sequence of such deposit is exposed near Itanagar where Siwalik boulders are seen in the same matrix.

## ACKNOWLEDGEMENTS

This paper forms a part of the collaborative Research Project between the Wadia Institute of Himalayan Geology, Dehradun and the Birbal Sahni Institute of Palaeobotany, Lucknow. The authors are thankful to the Directors of these Institutions for constant encouragement and inspiration. The authors are grateful to Dr H. P. Singh for his initiation to start this project and his able guidance.

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# Vegetational dynamics of Tertiary Himalaya

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Singh, H. P. & Sarkar, Samir 1990. Vegetational dynamics of Tertiary Himalaya. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 333-344.

Selected palaeobotanical and palynological records published from the Tertiary Period of Himalaya have been examined and a generalized vegetational frame work has been reconstructed. The diverse Palaeogene floras of Himalaya are marked by moist deciduous and wet semi-evergreen forest types growing mostly under tropical climate in varying type of environments. The tropical families register a decline in the Early Miocene time. The Middle Miocene Himalayan orogeny coincides with proliferation of Abietineae and by the appearance of several subtropical floral elements. Development and diversity of forest types are controlled by the altitudinal belts. The Pliocene floral diversification is related to climatic changes and increased continentality. The wet tropical forests disappeared from the low altitudes, whereas wet subtropical and temperate forests were transformed into dry or moist vegetational types. The appearance of semi-arid and cold conditions forced several moisture loving plants, either to migrate or perish. The modern composition of the Himalayan flora reveals that it is a partial continuum of Neogene floras which have been progressively enriched by the appearance of several immigrant elements and also by the changes brought in due to evolutionary processes.

**Key-words**—Palynology, Palaeobotany, Tertiary, Himalaya (India).

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## साराँश

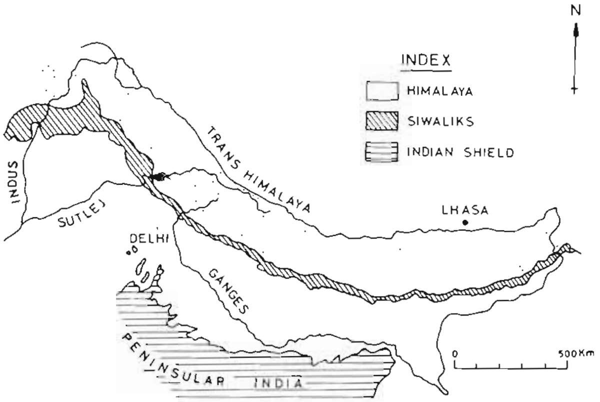
### तृतीयक युगीन हिमालय के वनस्पतिक परिवर्तन

हरिपाल सिंह एवं समीर सरकार

हिमालय के तृतीयक कल्प पर प्रकाशित विशेष पुरावनस्पतिक एवं परागाणविक अभिलेखों का अध्ययन किया गया तथा एक व्यापकृत वनस्पतिक स्वरूप की रचना की गई है। हिमालय के पुरानूतन कालीन वनस्पतिजात से नम पर्णपाती एवं आर्द्र अर्ध-सदाहरित वन प्रस्तावित किये गये हैं जो कि अधिकतर विभिन्न प्रकार के वातावरणों में उष्णकटिबन्धीय जलवायु में पाये जाते हैं। प्रारम्भिक मध्यनूतन काल में उष्णकटिबन्धीय कुलों की संख्या में कमी पाई गई है। मध्य-मध्यनूतन काल में हिमालय की उत्पत्ति के समय ही ऍबीटिनी का अत्याधिक विकास एवं अन्य कई उपोष्ण-कटिबन्धीय वनस्पतिजातीय अवयवों का प्रादुर्भाव हुआ। विभिन्न प्रकार के वनों का विकास एवं उनमें विभिन्नतायें उस स्थान की ऊँचाई में परिवर्तन के साथ-साथ विकसित हुईं। अतिनूतन वनस्पतिजात में प्रेक्षित विभिन्नता जलवायवी परिवर्तनों एवं महाद्वीपों के बढ़ते आकार से सम्बन्धित है। कम ऊँचाई वाले स्थानों से नम उष्णकटिबन्धीय वन विलुप्त हो गये, जबकि उपोष्णकटिबन्धीय एवं शीतोष्ण वन शुष्क अथवा नमी में रहने वाली वनस्पति में परिवर्तित हो गये। अर्ध-मरुस्थली एवं ठंडी परिस्थितियों के कारण नम स्थानों में पाये जाने वाले कई पौधे या तो वहां से दूसरे उपयुक्त स्थानों पर चले गये अथवा समाप्त हो गये। हिमालयी वनस्पतिजात के वर्तमान स्वरूप से व्यक्त होता है कि यह पश्चनूतन कालीन वनस्पतिजातों की आँशिक अविच्छिन्नता है जो कि कई आवासी अवयवों के प्रादुर्भाव से शनैः शनैः और विकसित होते चले गये।

THE present paper focuses attention on the changes in vegetational pattern through the Tertiary Period in Himalaya and its possible impact on the development of modern flora. Published records of Tertiary palyno and megafossils available from Himalaya have been extensively surveyed and analysed with a view to select dependable taxa for the identification of palaeo-associations and generalized vegetational successions in time and lateral extent. The resultant information has brought out several gaps in our knowledge; however, it has been evaluated and synthesized cautiously to build up vegetational models latitudinally and altitudinally, depicting the role of physical barriers and climatic implications in understanding the developmental processes and evolutionary significance of different forest types.

The Himalayan range runs about 2,400 km and stands as the northern rampart in the Indian subcontinent (Text-figure 1). It is the youngest



**Text-figure 1**—Extent of Himalayan range in the Indian subcontinent (after West, 1984).

mountain range in the world which was uplifted about 60-70 million years ago. A generalized account deciphering the emergence, radiation and extinction patterns of the Himalayan flora through the Tertiary Period has been discussed. The accrued evidences throw light on some problems related to endemism, regionalism and floral migration in time and lateral extent.

The palaeobotanical data has been tagged with the important geological events in order to have a peep into the glimpses of Tertiary vegetational history of Himalaya. A brief account of the geological history of Himalaya during the Tertiary Period is given below :

## GEOLOGICAL HISTORY

Geologically, three major sedimentary zones have been identified in the Himalayan orogenic belts. They are known as (i) the southern most sub-Himalayan zone, (ii) the Lesser Himalayan zone, and (iii) the Tethys Himalayan zone.

The sub-Himalayan zone is mainly represented by Neogene and recent deposits accumulated in a foredeep which is known as the Siwalik Group. Its maximum development has been observed in Jammu and Kashmir and Himachal Pradesh. They progressively thin-out towards the eastern flank of the Himalaya.

The Lesser Himalayan zone consists of two distinct subzones. The first subzone is well represented by unmetamorphosed sediments developed in N-W Himalaya which thins-out progressively towards the east, ranging from Palaeocene to Early Miocene in age. The second subzone is mainly represented by metasediments, the age and stratigraphic position of which is uncertain.

The Tethys Himalayan zone is well exposed in Kumaun, Garhwal, Spiti, Kashmir, Zanskar and Ladakh regions ranging in age from Late Pre Cambrian to Late Cretaceous. The Indus Suture zone exposes the sediments which vary in age from Cretaceous to Mio-Pliocene.

## OROGENIC HISTORY

The Himalayan range was uplifted through a series of orogenic pulsations due to the rifting of a large pre-Jurassic Gondwanaland and its subsequent collision with the Eurasiàn Plate. These pulsations continued intermittently till the Pleistocene glaciation started, and uplifted the Himalayan range mostly in Oligocene, Miocene and Pliocene epochs.

The first phase of the Himalayan uplift started during the Late Cretaceous-Early Eocene time due to which the Tethys floor bent at the position of Indus/Tsangpo Suture Zone at Ladakh. This phase of the uplift culminated in the development of a geo anticlinal fold in the basement resulting in the splitting of the Eocene sea into two longitudinal basins. One of these basins developed along the Indus/Tsangpo Zone and the other to the far south which is now known as the lesser and outer Himalaya. The second phase of uplift started towards the end of the Eocene and continued up to the Oligocene. Most of the uplift took place in the Middle Miocene. One of the views is that the third phase of Himalayan orogeny started in the Early Miocene time and continued till to the close of Pleistocene resulting in the rapid sedimentation of Murrees and Siwaliks (Gansser, 1974). The fourth phase started at the end of Pliocene and ended in Pleistocene Epoch and this phase of the uplift caused the development of main boundary thrust which severed the main Himalaya from the newly formed Siwalik mountains. It is believed that the uplift of the Himalaya has been a continuous process even after the Pleistocene time (Sharma, 1984).

The periodic orogeny of the Himalayan range continued to change the climatic, geomorphological and ecological contitions. Thus the rise of Himalaya not only opened several routes for inflow and outflow of floras, particularly from central and west Asia, or even Europe, to east Asia but also dynamically influenced the evolutionary pattern of vegetation in terms of emergence of new taxa and extinction of others. During the course of unstable period of orogeny, the Himalayan range evolved its own characteristic flora which contains tropical, subtropical and temperate constituents, development of which has been controlled by the altitudinal belts. In the beginning, the Himalayan range acted as an important barrier for the temperate climate of the central Asian and European regions which later turned into a favourable ground for the growth of cold-loving plants.

## BOTANICAL PROVINCES

Clarke (1898) and Hooker (1906) recognized two botanical regions in Himalaya—the western and the eastern Himalaya, whereas Chaterjee (1939) and Razi (1955) recognised four regions. The additional two regions fall in the central Himalaya and Assam areas. However, we have segregated palaeobotanical data into two botanical regions, the western Himalaya and the eastern Himalaya, the latter includes the flora of the hilly region of Assam and Meghalaya. Altitudinally, the present Himalayan vegetation can be divided into three broad zones: tropical-subtropical (base to 1,200 m), temperate (1,200 to 3,600 m) and alpine at higher altitudes (up to 4,500 m).

The available palaeobotanical and palynological data-base, though scanty, scattered and fragmentary in nature, has been pieced together from the Tertiary Himalaya and a generalised vegetational frame-work (developed in responses to varying altitudinal and palaeogeographic factors) has been reconstructed all along the Himalayan belt. It has been observed that the composition of plant communities has been changing from time to time in the geological past in response to climatic, edaphic, ecological and topographic factors.

The Palaeocene-Eocene landscape of western Himalaya had a low relief which was periodically subjected to elevation in the subsequent periods. Geographic positions of the palynological and palaeobotanical data discussed in the present paper are shown in the Text-figure 2, whereas the data-sources on stratigraphy and flora are given in Table 1. The general pattern of vegetation through the Tertiary Period is discussed below:

## TERTIARY VEGETATIONAL PATTERNS IN WESTERN HIMALAYA

### Ladakh Himalaya

From the Dras volcanics of Ladakh Himalaya, Palaeocene palynological assemblage (Mathur & Jain, 1980) exhibits the occurrence of a rich coastal type vegetation. Some of the important palynotaxa of the floral composition are : *Nypa, Calamus, Gunnera, Galium, Carya, Carpinus, Fraxinus, Pelliciera, Casuarina*, alongwith the members of the family Ranunculaceae, Fabaceae, Arecaceae, Cycadaceae, etc. A low-salinity assemblage is envisaged by the presence of taxa belonging to the Arecaceae, *Nypa* and *Pelliciera*. Identification of *Rhizophora* pollen does not seem to be authentic. Pollen of *Casuarina, Ephedra* and palms are suggestive of a relatively dry, sandy coastal region. Pollen of Podocarpaceae, *Carpinus, Corylus, Carya* and *Coriara* represent upland vegetation in the assemblage which may be derived from the adjoining higher hills. Floral composition represents tropical and subtropical assemblage of plants.

**Text-figure 2**—Geographic locations of data sources. For explanation, see Table 1

The Pashkyum Eocene palynofloral assemblage from Ladakh Himalaya (Mathur, 1984) also indicates the continuation of similar palaeoecological conditions which were characteristic of Palaeocene. Tropical elements, like *Calamus, Nypa, Gunnera*, alongwith palms and many other pteridophytic elements, confirm this view.

Bhandari *et al.* (1979) have reported Late Eocene-Miocene assemblage from the Tarums, a ormation of the same area. Some of its important constituents are *Magnastriatriletes, Lycopodiumsporites, Pinuspollenites, Pediastrum, Tricolpites, Caryapollenites, Betulaceoipollenites, Alnipollenites, Juglanspollenites, Polyporina* and *Graminidites*. Composition of the assemblage shows that the Palaeocene coastal semi-evergreen type of vegetation was transformed into moist deciduous type of forests in the Middle Tertiary of Ladaklh Himalaya. The vegetational change denotes the onset of sub-temperate climate. The occurrence of *Prunus* (Kargil Formation) and *Livistonia* (Hemis Conglomerate) has been reported from the Ladakh Himalaya by Guleria *et al.* (1983) and Lakhanpal *et al.* (1983), respectively. Later, Lakhanpal (1988) inferred that *Trachycarpus, Prunus* and possibly

**Table 1—Tertiary stratigraphic sequences of floral data sources. Numbers indicated in parentheses refer to geographic locations as shown in Text-figure 2**

| Chronological Units | Stratigraphic Units | | | |
|---|---|---|---|---|
| | Western Himalaya | | Eastern Himalaya | References |
| | Siwalik Group of Jammu | | Dihing/Dhekiajuli beds. | Sarkar *et al.*, (20) |
| Pliocene | and | Siwalik Group | | Lakhanpal, 1983 (4) |
| | Karewas of Kashmir | | Tipam Sandstone | Lakhanpal, 1988 |
| | | | Formation | Corvinus, 1988 (18) |
| | | | | Du, 1985 (22) |
| to | | | | Mathur, 1984 |
| | | | | Vishnu-Mittre, 1984 (5) |
| | | | | Saxena *et al.*, 1984 (13) |
| | | | | Singh & Sarkar, 1984 (7) |
| | | | | Awasthi, 1982 |
| | | | | Singh & Saxena, 1981 (12) |
| | | | | Saxena & Singh, 1980 (15) |
| | | | | Dutta & Singh, 1980 (30) |
| | | | | Mathur, 1978 |
| | | | | Nandi, 1975 (14) |
| | | | | Prakash, 1972, 1979 (15) |
| Middle Miocene | Kargil (=Liyan) | | Bokabil Formation | Lukose, 1969 (19) |
| | Formation | | | Banerjee, 1964, 68 (15) |
| Lower Miocene | Hemisconglomerate | Kasauli Formation | Bhuban Formation/ | Singh *et al.*, 1987 (26) |
| | Horizon | | Boldamgiri Formation. | Dogra *et al.*, 1975 (11) |
| | Murree Group | | Renji Formation | Nandi & Sharma, 1984 (29) |
| | and | | | Mathur, 1984 (10) |
| | | | Jenam Formation | Singh & Sarkar, 1984 (8) |
| Oligocene | Dharamsala Group | Dagshai | | Guleria *et al.*, 1983 (3) |
| | | Formation | Laisong Formation | Singh & Khanna, 1980 (9) |
| | | | | Mathur & Venkatachala, 1979 |
| | | | | Sahni, 1964 (9) |
| | Tarumsa Formation | Subathu Formation | Kopili Formation | Sarkar & Singh, 1988 (8) |
| | | | Sylhet limestone | Singh & Tripathi, 1987 (28) |
| | | | Formation | Mathur, 1984 (5) |
| | | | | Bhandari *et al.*, 1979 (2) |
| | Nummulitic lime- | | | Khanna, 1978 (6) |
| Eocene | stone of Ladakh, | | | Dutta & Sah, 1970 (21) |
| | Subathu Formation | | | Sah & Dutta, 1968 (23) |
| | of Jammu | | | Mathur, 1963, 1964 (7) |
| | | | | Lakhanpal, 1955 a,b |
| | | | Therria/ | |
| Palaeocene | | | Cherra Formation | Singh & Tripathi, 1987 (28) |
| | Dras Volcanics | | | Kar & Kumar, 1986 (27) |
| | | | Lakadong Formation | Mathur & Jain, 1980 (1) |

also *Populus* immigrated from the mainland of Asia and became a part of the temperate Himalayan flora during the Middle Miocene.

### Himachal Himalaya

From Himachal Himalaya, the Subathu Formation (Palaeocene-Eocene) assemblages have generated a rich information (Mathur, 1963, 1964; Khanna, 1978; Singh & Khanna, 1980; Singh *et al.*, 1978; Singh & Sarkar, 1987; Sarkar & Singh, 1988). Dinoflagellate cysts dominate the palynological assemblage. The terrestrial elements are represented by the taxa belonging to Lycopodiaceae, Schizaeaceae, Matoniaceae, Polypodiaceae, Parkeriaceae, Podocarpaceae, Liliaceae, Nympheaceae, Poaceae, Arecaceae, Oleaceae, Fagaceae, Anacardiaceae, Alangiaceae, etc. Algal elements, viz., *Pediastrum* and *Botryococcus* have also been recorded in abundance. The environment of deposition varies from shallow marine to coastal transition with a tropical climate. The vegetational type conforms to a coastal semi-evergreen type and is comparable to that of Ladakh Himalaya.

A Late Eocene-Oligocene palynological assemblage recorded from the Dagshai Formation (Singh & Khanna, 1980), though not copiously diversified, is easily identified by the absence of marine dinoflagellate cysts and by the presence of palm pollen. Gymnospermous pollen are represented by *Inaperturopollenites* and *Podocarpidites*-complex. The high incidences of *Pediastrum* and the presence of palms indicate a coastal transitional type of vegetation for the Dagshai Formation (Singh & Khanna, 1980).

The Oligocene palynoflora of Himachal Pradesh (Mathur, 1984) is mainly represented by herbaceous elements and tree ferns. Some of the important palynotaxa are *Castanea, Galium, Amaranthus* and *Chenopodium*. Mathur (1984) has also reported the occurrence of taxa belonging to Cyatheaceae, Gleicheniaceae, Osmundaceae, Pinaceae, Arecaceae, Haloragidaceae, Fabaceae, Sapotaceae, Buxaceae, Aquifoliaceae, etc.

An Early Miocene palynological assemblage from the Kasauli Formation (Singh & Sarkar, 1984a) having the representatives of modern families, viz., Cyatheaceae, Schizaeaceae, Lindsaeaceae, Polypodiaceae, Pinaceae, Liliaceae, Arecaceae, Bombacaceae, Oleaceae, etc. is inferred to be subtropical and humid type of vegetation. *Pinus* pollen constitute an important aspect of the assemblage. Their presence denotes the earliest record of occurrence of Pinaceae in the Lower Miocene sediments of western Himalaya. It seems likely that temperate elements had started migrating from the West Asian mainland at that time and later found a favourable climate for proliferation in the western Himalaya even before the Middle Miocene orogeny. It appears that the Kasauli Formation had attained sufficient elevation to support the growth of pines in Himachal Himalaya.

The Dharamsala sediments equivalent of Dagshai and Kasauli sediments contain representatives of the following families, viz., Hymenophyllaceae, Schizaeaceae, Polypodiaceae, Lycopodiaceae, Pinaceae, Arecaceae, Aquifoliaceae, Rutaceae, Tiliaceae, Chenopodiaceae, Caprifoliaceae, Ctenolophonaceae, Oleaceae and Pandanaceae (Mathur & Venkatachala, 1979; Mathur, 1984). Fresh-water alga *Botryococcus* has also been recorded from these sediments. Taxonomic assignments of Dharamsala palynofossils (Dogra *et al.*, 1985) need confirmation.

### Siwalik foot-hills of Himachal Pradesh and Uttar Pradesh

The Miocene vegetational pattern of Himachal Pradesh (Kalka region) and Uttar Pradesh (Dehradun region) based on megafossils (Prakash, 1972, 1979; Awasthi, 1982) shows that some of its important constituents are *Afzelia, Albizzia, Anisoptera, Cassia, Cynometra, Dalbergia, Diospyros, Dipterocarpus, Ficus, Fissistigma, Milletia. Polyalthia* and *Ziziphus*. These assemblages had no representation of gymnosperms. However, the Miocene palynological assemblages from Himachal Pradesh, Punjab and Uttar Pradesh show a wide representation of gymnospermous pollen comparable to *Pinus, Podocarpus, Abies, Cedrus, Picea* and *Tsuga* alongwith other taxa belonging to many families of angiosperms, viz., Arecaceae, Liliaceae, Myricaceae, Juglandaceae, Magnoliaceae, Fabaceae and Moraceae (Banerjee, 1968; Lukose, 1969, 1972; Nandi, 1975; Singh & Saxena, 1981; Saxena & Singh, 1980; Singh & Sarkar, 1984b; Saxena *et al.*, 1984). Lakhanpal (1988) suggested that the temperate pollen occurring in the Siwalik sediments might have been blown in from the surrounding higher hills. Since plant megafossils of temperate climate have not been recovered from these sediments, he has questioned the authenticity of the identification of gymnospermous pollen, particularly of *Pinus, Abies, Cedrus* and *Picea*. The overall palynological evidences from wider regions of Himalaya do indicate that the pines might have been the earliest migrants, pioneering their growth in the Early Miocene times and subsequently attaining a position of dominance after the Middle Miocene orogeny. Gymnospermous megafossils are yet to be recovered from the sediments laid even after the Middle Miocene orogeny.

On the basis of palynological investigations of Mohand Siwaliks (Middle Miocene) Sarkar *et al.* (in press) have identified the occurrence of following families, viz., Arecaceae, Sparganiaceae, Poaceae, Asteraceae, Lentibulariaceae, Malvaceae, Pedaliaceae alongwith gymnospermous pollen, mainly belonging to Pinaceae. The abundance of ferns, together with many angiospermous elements, indicates the existence of a mixed vegetation belonging to moist subtropical climate. Mathur (1984) indicated the prevalence of mangrove swamp and deltaic environment in the Jawalamukhi area of Himachal Pradesh during Middle-Late Miocene Epoch on the basis of occurrence of mangrove swamp trees, like *Sonneratia* and *Rhizophora*. He further observed that the presence of *Crenia, Crudia* and *Phoenix* indicates near-shore conditions whereas *Barringtonia, Sabal*, alongwith dinoflagellate cysts, indicate brackish water condition of environment during Miocene in the Nahan area of Himachal Pradesh. The present authors have extensively worked in these areas and have failed to recover any such elements. Therefore, the identifications of marine or brackish water elements in the Siwalik sediments are not considered authentic. The Siwalik dinoflagellate cysts have been considered to be reworked from the Subathu Formation.

During Pliocene times in the Jammu region, the abundance of palm pollen alongwith grasses representing the palm savana in the Boulder Conglomerate Bed has been observed (Sahni, 1964; Mathur, 1978; Vishnu-Mittre, 1984). Megafossil evidence provided by Lakhanpal and Awasthi (1983) shows the presence of *Ziziphus, Mangifera, Bauhinia, Indigofera, Dalbergia, Litsea, Cinnamomum, Ficus, Gardenia, Toona, Kydia* and members of Fabaceae in the Bhikhnathoree area of west Champaran. Similar evidence has emerged from the Pliocene sediments of Surai Khola area of western Nepal (Corvinus, 1988; Sarkar, in press). The Pliocene palynological assemblages of Siwalik sediments (Singh, 1982) bring out the fact that the cool dry climate had set in, which supported the luxuriant growth of forms, like *Larix, Pinus* and *Pinjoriapollis* (magnoliaceous pollen). Pollen of Poaceae and Arecaceae are also well represented. Some of the important gymnospermous and angiospermous families reported by Saxena and Singh (1980), Singh and Saxena (1981) and Singh and Sarkar (1984b) from the Middle Miocene-Pliocene sediments are Arecaceae, Poaceae, Pinaceae, Fabaceae, Betulaceae, Chenopodiaceae, Euphorbiaceae, Amaranthaceae and Linaceae.

## TERTIARY VEGETATIONAL PATTERN OF EASTERN HIMALAYA

Palaeobotanical and palynological information from the Tertiary Period of eastern Himalaya has been developed mainly by Baksi (1962), Banerjee (1964), Sah and Dutta (1968), Dutta and Sah (1970), Kar and Kumar (1986), Prakash (1972), Lakhanpal (1955a, b), Du (1985), Singh and Tripathi (1987), and Singh *et al.* (1987).

A Palaeocene palynoflora typical of tropical affinity is known from the Lakadong Sandstone of Laitryngew and Mawlong, Sohrarim, Shillong-Cherra road and Mowmluh Hill, Meghalaya (Kar & Kumar, 1986). Important families present in this flora are Lycopodiaceae, Schizaeaceae, Cyatheaceae, Polypodiaceae, Matoniaceae, Adiantaceae, Podocarpaceae, Araucariaceae, Arecaceae, Liliaceae, Brassicaceae, Meliaceae, Fabaceae, Olacaceae, Lamiaceae, Oleaceae, Rhizophoraceae, Lentibulariaceae, Proteaceae, Guttiferae, Anacardiaceae, Myricaceae and Droseraceae. These families mostly inhabit tropical to subtropical regions. Gymnospermous pollen are low in number. The overall vegetational pattern is of coastal swamp type. Leaf-impressions of *Nelumbium, Trema, Neolitsea, Grewia*, some members of Bombacaceae have been described from the Eocene sediments of Garo hills (Lakhanpal, 1955a, b). Sah and Dutta (1968) and Dutta and Sah (1970) have reported palynofossils from Cherra Formation, Assam and assigned them to several monocotyledonous and dicotyledonous families in addition to pteridophytic and gymnospermous elements. Most of the families denote tropical to subtropical affinity.

The palynoflora recorded by Singh and Tripathi (1987) from the Palaeocene-Eocene sediments of Meghalaya supports the existence of rich tropical to subtropical vegetation during early Tertiary times. They have recorded rich assemblage of angiospermous pollen taxa belonging to the families, viz., Arecaceae, Liliaceae, Poaceae, Nympheaceae, Nelumboniaceae, Brassicaceae, Oleaceae, Lamiaceae, Chenopodiaceae, Euphorbiaceae, Myricaceae, Magnoliaceae and Aristolochiaceae, along with many pteridophytic spores and dinoflagellate cysts. These palynofloral assemblages give strong support to the views of Lakhanpal (1970).that a tropical vegetation prevailed during the Palaeogene Period in the Indian subcontinent. A higher representation of epiphyllous fungi indicates the prevalence of warm and humid climate during Palaeocene-Eocene times in Meghalaya. The occurrence of palm pollen, along with dinocysts, indicates coastal environment of deposition during Palaeocene-Eocene times in Meghalaya.

The palynofloral assemblages from the Oligocene and Miocene sediments of the same area have also been studied by Singh *et al.* (1987). The taxa belonging to the families Parkeriaceae, Matoniaceae, Gleicheniaceae, Arecaceae and Fabaceae indicates tropical to subtropical climate. The occurrence of Pinus-type pollen in the Oligocene sediments is sporadic but they attain predominance in the Miocene of eastern Himalaya. The high incidence of pinaceous pollen in Miocene indicates the presence of uplands in close proximity to the depositional area. It appears that the surrounding area was much higher in Oligocene in comparison to the Palaeocene-Eocene times. The vegetation was represented by taxa belonging to Arecaceae, Fabaceae, Oleaceae, Araceae, Bombacaceae, Lamiaceae, Potamogetonaceae, Malvaceae, along with many pteridophytic elements. The close of Oligocene witnessed the development of land connections between India and Burma and Malaya through which several tropical plants migrated to the latter countries so as to avoid the harsh climate. *Ctenolophon* and *Sclerosperma* are the notable examples (Srivastava, 1988). It is likely that representatives of Sapotaceae and Fabaceae migrated from Malaya to India. Simultaneously, *Pinus* seems to have made the pioneering venture to invade the

Indian subcontinent, though megafossil evidences are yet to be found to corroborate this view.

Nandi and Sharma (1984) recorded a rich palynofloral assemblage from the Lower Miocene sediments of Garo hills. The presence of pollen taxa *Palmaepollenites, Couperipollis, Striacolporites* along with *Myricipites, Bombacacidites, Araliaceoipollenites* indicates tropical to subtropical climate. Association of pollen related to *Alnus* (*Alnipollenites*), *Chenopodium* (*Chenopodipollis*) and conifers are indicative of an elevated topography during the Early Miocene in Garo hills.

The Miocene flora of Assam and Meghalaya region, represents 65 per cent of tropical deciduous trees as compared to 35 per cent of tropical evergreen trees (Du, 1984). Besides, there are few species which grow in subtropical condition (*Artocarpus* and *Elaeocarpus*). Palynological evidence also indicates the high incidence of deciduous trees in the Neogene vegetation in the Himalayan region. Some fossil taxa comparable to the modern ones are *Calophyllum, Kayea, Anisoptera, Dipterocarpus, Shorea, Sterculia, Elaeocarpus* and *Bursera*. The Miocene flora of Assam region shows great resemblance with the tropical moist deciduous forests. The common elements are *Sterculia, Gluta, Terminalia, Albizia, Diospyros* and *Artocarpus*. Similar forests are still growing in Assam. The landscape seems to have been beset by a number of rivers, swamps and lakes as is indicated by the presence of *Dipterocarpus, Hopea, Bursera, Pometia, Barringtonia* and *Pongamia*. The Tipam flora in certain regions contains *Schleichera, Vitex* and *Phyllanthus* which may indicate the existence of relatively drier conditions.

The Miocene Tipam flora is distinct by the occurrence of some dense tropical forest elements, especially the moist deciduous ones. The deciduous forests had large to medium-sized angiospermous trees mixed with some medium to small-sized evergreen trees, some shrubs, herbs, and climbers. Members of Clusiaceae, Dipterocarpaceae, Anacardiaceae, Fabaceae, Combretaceae, Lythraceae, etc. were well represented. The xerophytic vegetation is speculated to be inhabiting the top of hills. The presence of littoral elements in the flora indicates that the present day Bay of Bengal might have covered areas far further north to the present Assam during Miocene (Lakhanpal, 1970). This observation is also confirmed by the recent palynological studies (Kar & Kumar, 1986). At present, the littoral forests and sea coasts have disappeared. This is perhaps because of the northward drift of the Indian subcontinent. The Pliocene palynological records from eastern Himalayan region are very scanty and hence have not been included for discussion.

## DISCUSSION

A general floristic pattern characterizing the Tertiary Period of western Himalaya denotes that the Palaeocene-Eocene landscape was dotted with palms and many tropical angiospermous elements, viz., Clusiaceae, Lecythidaceae, Anacardiaceae, Alangiaceae, Sapotaceae, Bombacaceae, Myristicaceae, etc It is a known fact that these taxa and several others inhabit low relief landscapes and tropical climates. Representatives of Parkeriaceae, Alangiaceae, Juglandaceae and Fagaceae, so far known only from the Neogene Period, have been recorded from the Palaeogene sediments as well. Though the gymnospermous records are scanty, they only relate to the families Podocarpaceae and Araucariaceae. The Palaeogene taxa enumerated in Table 2 provide cogent basis for their segregation into four different forest formation types (*Sensu stricto* Singh & Singh, 1987): (1) submontane, broad-leaf ombrophillous forest, (2) submontane, seasonal broad-leaf forest, (3) submontane, broad-leaf summer deciduous forest, and (4) mid-montane, winter deciduous forest.

Later, the Middle Miocene orogeny of Himalaya brought a radical change in the floristic scenario of the area witnessing a decline in the occurrence of tropical families, appearance and proliferation of gymnospermous elements (Abietinae) and rapid increase in the number of subtropical families, viz., Moraceae, Myrtaceae, Euphorbiaceae, Fabaceae, etc. Further, it is apparent that different vegetational patterns of the Miocene Epoch were adapted to different altitudinal belts. Development of tropical, wet semi-evergreen forests, wet subtropical and humid temperate forests certainly indicates the establishment of different altitudinal belts. As at present, it is surmised that the Tertiary tropical forests inhabited the lower slopes whereas subtemperate to temperate forests were confined to the higher slopes. Besides, the Neogene floras of western Himalaya seem to have been enriched by the immigrating elements from Mediterranean, Sino-Japanese and Malayan regions.

The Neogene palaeobotanical data from western Himalaya broadly identifies itself with the following four forest types: (i) low montane, needle-leaf forest with concentrated summer leaf drops, (ii) low montane, sclerophyllous evergreen broad-leaf forests, (iii) mid-montane, broad-leaf ombrophillous forests, and (iv) mid-montane, needle-leaf evergreen

**Table 2—Distribution of plant taxa in the Tertiary of Himalaya**

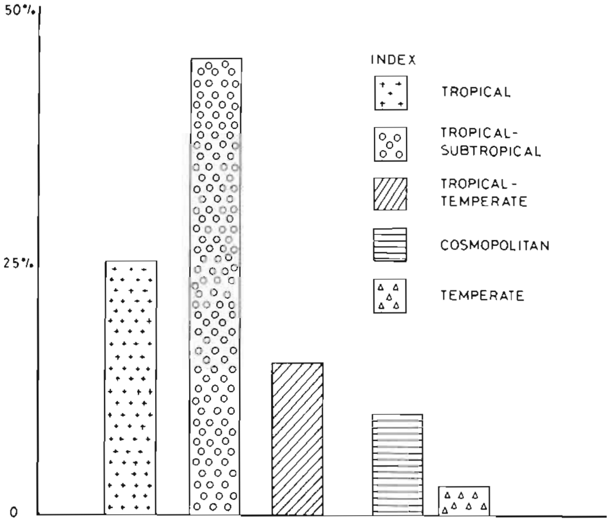
| Families | Palaeocene | | Eocene | | Oligocene | | Miocene | | Pliocene | |
|---|---|---|---|---|---|---|---|---|---|---|
| | W.H. | E.H. | W.H. | E.H. | W.H. | E.H. | W.H. | E.H. | W.H. | E.H. |
| **Pteridophytes** | | | | | | | | | | |
| Adiantaceae | | + | | | | | + | | + | |
| Azollaceae | | | | | | | + | + | + | + |
| Cyatheaceae | | + | + | + | | | | + | + | |
| Dicksoniaceae | | | + | | + | | | | | |
| Gleicheniaceae | | | + | | | | | | | |
| Lycopodiaceae | + | + | + | + | + | | + | + | + | + |
| Matoniaceae | | + | + | + | | + | | | + | |
| Osmundaceae | | + | + | + | | | + | | + | |
| Parkeriaceae | | | + | + | + | + | + | | + | + |
| Polypodiaceae | + | + | + | + | + | | | + | + | + |
| Pteridaceae | | | | | | | + | | + | |
| Schizaeaceae | | + | + | + | + | | + | + | | |
| **Gymnosperms** | | | | | | | | | | |
| Araucariaceae | | + | + | | + | | + | | + | |
| Cycadaceae | + | | + | | | | + | + | + | + |
| Pinaceae | | | | | + | | + | + | + | + |
| Podocarpaceae | + | + | + | + | + | + | + | | + | |
| **Angiosperms** | | | | | | | | | | |
| Aceraceae | | | | + | | | | + | + | |
| Alangiaceae | | | | + | | | | + | | |
| Amaranthaceae | | | | + | + | + | | + | | |
| Anacardiaceae | | | + | + | | | + | + | + | + |
| Annonaceae | | | | | + | | | + | | |
| Apocynaceae | | | | + | | | + | + | | |
| Aquifoliaceae | | | | | | + | + | + | | |
| Araceae | | | | | + | | | + | + | |
| Berberidaceae | | | | | | | | | | |
| Betulaceae | | + | | + | | + | + | + | | + |
| Bombacaceae | | | | + | | | | + | + | |
| Boraginaceae | | | | | | | | + | + | |
| Burseraceae | | | | | | | | + | | |
| Caesalpiniaceae | | + | | + | + | | | | | |
| Caprifoliaceae | | | | | | + | | + | | |
| Casuarinaceae | | + | | | | | | | | |
| Celastraceae | | + | | + | | | + | + | | |
| Chenopodiaceae | | | | + | + | | | + | | |
| Combretaceae | | | | | | | | + | + | + |
| Asteraceae | | | | | | | + | | | |
| Coriariaceae | + | | | | | + | | | | |
| Brassicaceae | | + | | | + | | | | | |
| Ctenolophonaceae | | | + | | | | | | | |
| Dilleniaceae | | | | | | | | + | | |
| Dioscoriaceae | | + | | | | | + | + | | |
| Dipterocarpaceae | | + | | | | + | + | | | |
| Droseraceae | | + | | | | | | | | |
| Ebenaceae | | | | | | + | + | | | |
| Elaeocarpaceae | | | | | | | | + | | |
| Euphorbiaceae | | + | | + | + | | + | + | + | |
| Fabaceae | + | + | | | | | + | + | + | |
| Fagaceae | | | + | | | | | + | + | |
| Flacourtiaceae | | | | + | | + | + | | + | |
| Poaceae | | | + | | | | | + | + | |
| Clusiaceae | | + | | | | | + | | | |
| Haloragidaceae | | | + | | | | | | + | |
| Juglandaceae | + | | + | | + | | + | | | |
| Lamiaceae | | + | + | + | | | + | + | + | + |
| Lauraceae | | | | | | | + | + | + | |
| Lecythidaceae | | + | + | + | | | | | + | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lentibulariaceae | | + | | + | | | + | | | |
| Liliaceae | | + | + | + | | | + | | | |
| Linaceae | | | + | | | | + | | | |
| Lythraceae | | | + | | | | + | + | | |
| Magnoliaceae | | | | | | + | + | + | + | |
| Malvaceae | | | | | | + | + | + | + | |
| Meliaceae | | + | | | | | | + | | |
| Moraceae | | | | | + | + | + | + | + | + |
| Myricaceae | | + | | + | | | | | | |
| Myristicaceae | | + | | | | | | | | |
| Myrtaceae | | + | | + | | | + | | | |
| Nelumboniaceae | | | | | | | | | | |
| Nympheaceae | + | + | | + | | | | | | |
| Nyssaceae | | | + | | | | | | | |
| Olacaceae | | + | + | + | | | | | | |
| Oleaceae | | + | + | + | + | | | | | |
| Onagraceae | | | | + | | | | | | |
| Arecaceae | + | + | + | + | + | | + | | + | |
| Pandanaceae | + | | + | | | | | | | |
| Polygalaceae | | | | | + | | | | | |
| Polygonaceae | | | | | + | | + | | | |
| Potamogetonaceae | | | | | + | | | | | |
| Proteaceae | | | + | + | + | | | | | |
| Ranunculaceae | | + | | | | | | | | + |
| Rhamnaceae | | | | | | | + | + | + | + |
| Rhizophoraceae | | | + | + | + | | | + | | + |
| Rosaceae | | | | | | | | + | | |
| Rubiaceae | | + | | | | | | + | + | + |
| Rutaceae | | | | + | + | + | | | | |
| Santalaceae | | + | | | | | + | | | |
| Sapindaceae | | | | | + | | | + | | |
| Sapotaceae | | + | | + | | | | + | + | |
| Smilacaceae | | | | | | | | + | | |
| Sonneratiaceae | | | | | | | | + | + | |
| Sterculiaceae | | | | | | | | + | + | |
| Symplocaceae | | + | | + | | | | | | |
| Theaceae | | + | | + | | | | | | |
| Tiliaceae | | | | + | | | | + | | |
| Ulmaceae | | | | | | | | + | | |
| Apiaceae | | + | | | + | + | | + | | |
| Urticaceae | | | | | + | | | | | |
| Verbenaceae | | | | | | | | + | | |

forests. During this period the palaeobotanical data makes it crystal clear that the Palaeogene tropical moist, deciduous and wet semi-evergreen forests were transformed into moist semi-evergreen and deciduous forests.

The Pliocene floral diversification is related to climatic changes, increased continentality, semi-arid conditions and further uplift of the Himalayan range. In response to these changes, the wet tropical forests disappeared from the low altitudinal areas whereas subtropical and temperate forests were converted into dry or moist forests. The cold and semi-arid conditions forced moisture-loving plants, like *Dipterocarpus* and several others, to migrate or perish. *Cedrus, Picea, Abies, Pinus, Magnolia* and several other cold-loving plants were the significant components of the Pliocene floras, besides grasses, palms, *Alnus, Machilus, Clematis, Mallotus, Juglans, Quercus, Ficus, Rhamnus*, etc.

The eastern Himalayan Palaeocene-Eocene landscape supported mostly mixed type of coastal swamp vegetation as the present Bay of Bengal is believed to have penetrated far deeper into the north-eastern areas. The Oligocene Epoch witnessed major palaeogeographic changes because of the rise of Himalaya, withdrawal of the sea, regression of the Bay of Bengal and development of several land connections with Burma, Malaya and other adjoining areas facilitating inflow and outflow of plant species. It is believed that *Ctenolophon* and *Sclerosperma* made their entry into Malaya at this time. The Oligocene floral components show the abundance of pteridophytes and angiosperms. Gymnospermous records are poor or lacking.



**Text-figure 3**—Estimated distribution of plants in terms of climatic complexes.

The Miocene floras are chiefly represented by *Calophyllum, Anisoptera, Hopea, Dipterocarpus, Sterculia, Gluta, Albizia, Terminalia, Duabanga, Lagerstroemia,* etc. Composition of these floras mostly conform to tropical to subtropical, moist deciduous vegetational type

These floras have also been enriched by the immigrant species from the Sino-Japanese and Malayan regions, e.g., *Rhododendron, Tsuga, Quercus, Dillenia, Ficus,* etc. Geological, palaeogeographical and climatic events during the Late Tertiary do not seem to have altered overall pattern of vegetational types and far less the ecological conditions. It is surmised that the Middle to Late Miocene climate was warmer and more humid with a relatively higher rainfall than to-day, supporting luxuriant vegetation in which *Podocarpus, Elaeocarpus, Dipterocarpus, Gluta, Diospyros, Sterculia* and *Shorea* remain the significant constituents. The Pliocene floral records are fragmentary and hence have not been discussed. However, the Tertiary Himalayan palaeobotanical data has led to the preparation of an idealized model showing the distribution of plants as related to climatic complexes (Text-fig. 3).

The modern composition of the Himalayan flora reveals that it is a partial continuum of the Neogene floras, which progressively modified due to evolutionary changes and by the appearance of several immigrant elements from the surrounding areas. The modern Himalayan flora exhibits the presence of exotic forms which are believed to be of Euro-Mediterranean, Malayan-Burmese, African and Sino-Japanese origin. Some important immigrants to the western Himalayan flora from the Mediterranean region are *Quercus, Acer, Fraxinus, Alnus* and *Prunus*. The Malesian elements which became part of the Himalayan flora are *Bombax, Syzygium, Terminalia* and *Acacia*. The taxa, viz., *Dalbergia* and *Woodfordia* are the African elements. On the contrary, the eastern Himalayan flora is dominated by the Malayan and Chinese elements, like *Dipterocarpus, Ficus, Dillenia, Cassia, Engelhardtia,* etc. Some Sino-Japanese forms are represented by *Rhododendron, Tsuga, Schima,* etc. The representation of the African elements is very less. However, *Zizyphus mauritiana* is a good example.

The study of migratory pathways and the exact time as to when the immigrant forms became part of the Himalayan flora is a challenge before the palaeobotanists which needs to be met squarely. The present paper, though an initial attempt to build the scenario of Tertiary vegetational dynamics of Himalaya, has identified several intriguing problems which need to be understood precisely by carrying out in-depth studies. Quite often the plant fossil assemblages (micro- and mega) are interpreted without taking into consideration the basic requirements of plants in terms of ecological compatability, range of climatic tolerance, geographic locale and differential altitudinal adaptations. A rethinking on these aspects is likely to avoid several pitfalls which lead to inaccurate conclusions. Conflicting views on the elevation of Siwalik range in the Tertiary Period needs to be resolved. As plants are indicators of climate, the overall palynological data, particularly of gymnospermous affinity, may invoke rethinking in regard to their chronological and spatial invasion during the Tertiary Period in Himalaya. Equally challenging is the problem to understand the differential role of physical barriers which promoted endemism, regionalism, migration and immigration of several plant species during the Tertiary Period of Himalaya.

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# Chemical study of Cenozoic woods from Kashmir, India

Farooq A. Lone, Maqsooda Khan & G. M. Buth

Lone, Farooq A., Khan, Maqsooda & Buth, G. M. 1990. Chemical study of Cenozoic woods from Kashmir, India. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 345-347

Acetylbromide chemical treatment of fossil woods recovered from various Pliocene and Pleistocene strata in the Karewa Formation of Kashmir has been carried out to evaluate their degree of humification.

**Key-words**—Chemistry, Fossil woods, Cenozoic, Kashmir (India).

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## सारॉश

### भारत में काश्मीर से नूतनजीवी काष्ठों का रासायनिक अध्ययन

फ़ारूख ए० लोन, मकसूदा खान एवं जी० ऍम० बट

काश्मीर के करेवा शैल-समूह में अतिनूतन एवं नवनूतन कालीन विभिन्न स्तरों से उपलब्ध अश्मित काष्ठों में ह्यूमसभवन का मान अन्वेषित करने के लिए एसिटाइलब्रोमाइड़ की रासायनिक क्रिया की गई तथा अध्ययन किया गया।

THE valley of Kashmir provides a unique opportunity for Quaternary palaeoclimatic and palaeoenvironmental studies of almost 1,000 m thick Karewa sediments of a primeval lake which later got drained off as a result of the emergence of Jhelum River. Fission-track dating and magnetic-polarity stratigraphy of these sediments has revealed that sedimentation has been in progress for the last four million years or so (Burbank & Johnson, 1982; Agrawal *et al.*, 1985). During the course of field work some fossil woods from various localities in the Karewa Series were collected.

Earlier, the studies on the chemical composition of fossil woods have been carried out by Komatsu and Ueda (1923), Waksman and Stevens (1929), Mitchell and Ritter (1934), Gortner (1938), Jahn and Harlow (1942), Cundy (1946), Skrigam *et al.* (1957a, 1957b), Chowdhury *et al.* (1957), Kohara (1958) Brasch and Jones (1959) and Chowdhury *et al.* (1967). These studies deal with the difference between major components (cellulose, hemicellulose and lignin) of fossil and modern woods. But it has been overlooked that humic substances exist in fossil wood (Kagemori, 1973). Therefore, the present work has been conducted to know the degree of humification in the woods from various Quaternary strata. For this purpose, the methods proposed by Itihara *et al.* (1966), Kagemori and Itihara (1967) and Kagemori (1973) are followed.

## RESULTS

The results of the study are summarized in Table 1 and depicted in Text-figures 1-3. In this study four wood samples from archaeological excavations and two samples from living trees (one each from hard and soft wood) are also included for comparison. To know the decompositional differences between fossil hard and soft woods, their behaviour on chemical treatment is shown in Text-figures 2 and 3, respectively.

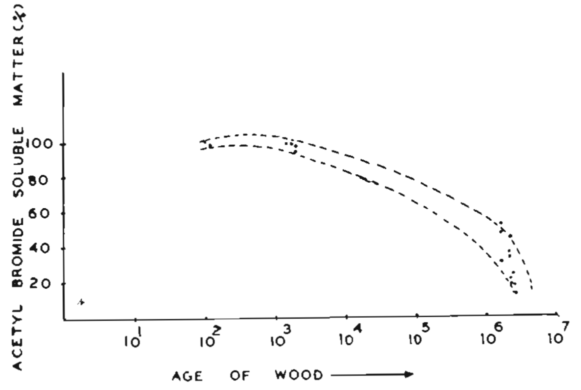
## DISCUSSION

Treatment with acetylbromide proposed by Itihara *et al.* (1966) is a useful method for examining the degree of humification of fossil woods, because the main constituents of wood, i.e., cellulose, hemicellulose and lignin are completely soluble in

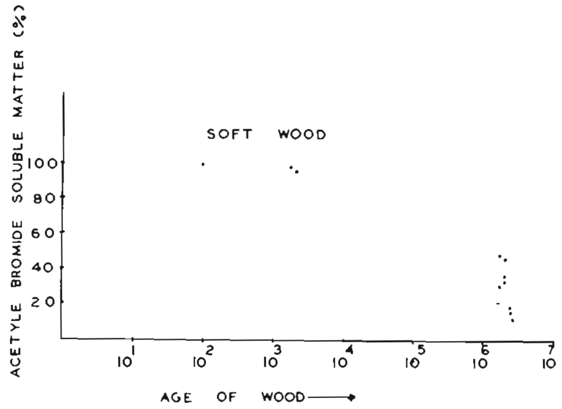
**Table 1**—**Showing horizons, localities of samples analyzed, approximate age of the samples, kind and identity of wood, percentage of acetylbromide soluble matter and humin**

| Sample No. | Horizon | Locality | Assumed average age × $10^4$ years | Kind of wood | Botanical identity | % Cellulose + hemicellulose + lignin = Acetylbromide soluble matter % | % Humin |
|---|---|---|---|---|---|---|---|
| 1 | Fluvio-lacustrine Lower Karewa sediments | Dubjan | 400 | Soft | *Abies pindrow* | 12.22 | 87.78 |
| 2. | Lower Karewa | Dubjan | 400 | Soft | *Pinus* | 16.95 | 83.05 |
| 3 | Lower Karewa | Dubjan | 390 | Hard | *Juglans* | 23.27 | 76.73 |
| 4. | Lower Karewa | Dubjan | 380 | Soft | *Pinus* | 18.31 | 81.69 |
| 5. | Lower Karewa | Dubjan | 380 | Hard | *Juglans* | 21.38 | 78.62 |
| 6. | Lower Karewa | Hirpur Loc. III | 313 (247-380) | Soft | *Pinus* | 46.44 | 53.56 |
| 7 | Lower Karewa | Hirpur Loc III | 313 (247-380) | Soft | *Pinus* | 36.21 | 63.79 |
| 8. | Lower Karewa | Hirpur | 313 (247-380) | Soft | *Pinus* | 33.95 | 66.05 |
| 9. | Lower Karewa | Khaigam | 240 | Soft | *Picea* | 31.08 | 68.92 |
| 10. | Lower Karewa | Khaigam | 240 | Hard | *Populus* | 32.91 | 47.09 |
| 11 | Lower Karewa | Khaigam | 240 | Soft | *Pinus* | 48.41 | 51.59 |
| 12. | Archaeological deposit | Burzahom | 0.43 | Hard | *Betula* | 96.00 | 4.00 |
| 13 | Archaeological deposit | Burzahom | 0.43 | Soft | *Pinus* | 97.50 | 2.50 |
| 14. | Archaeological deposit | Semthan | 0.35 | Hard | *Celtis* | 99.00 | 1.00 |
| 15. | Archaeological deposit | Semthan | 0.35 | Soft | *Cedrus* | 98.5 | 1.50 |
| 16 | Living wood | Srinagar | 0.005 | Hard | *Platanus* | 100.00 | 0.00 |
| 17 | Living wood | Srinagar | 0.003 | Soft | *Pinus* | 100.00 | 0.00 |

acetylbromide (Karrer & Winder, 1921; Karrer & Bodding-Wieger, 1923), whereas humin in fossil wood is insoluble in the reagent (Tokuoka & Matuo, 1942). Hence, the percentage of acetylbromide soluble matter is supposed to correspond to the total contents of cellulose, hemicellulose, lignin, etc. and the acetylbromide insoluble matter to the amount of humin present.

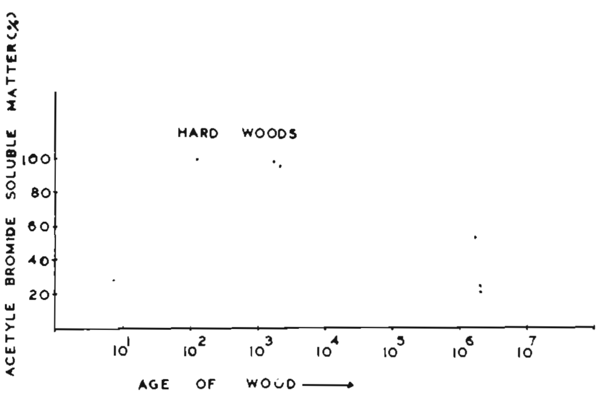


**Text-figure 1**—Percentage of acetylbromide soluble matter of fossil woods and assumed ages of strata bearing them.



**Text-figure 2**—Percentage of acetylbromide soluble matter of soft woods.

The present study reveals that the living woods are totally soluble in acetylbromide indicating that these are entirely made up of cellulose, hemicellulose, lignin, etc. and no humin is present. The percentage of acetylbromide soluble matter of samples decreases depending on the age of the fossil. The wood from the archaeological site are almost soluble in the reagent (96 to 99%). The



**Text-figure 3**—Percentage of acetylbromide soluble matter of hard woods.

woods from Pleistocene deposits show solubility of 31 per cent to 52 per cent and those from Pliocene levels 12 per cent to 46 per cent. Evidently, the fossil wood has been gradually humified in the course of about four million years since it was laid down in the sediments. It could be concluded that during five thousand years of the wood burried in the sediments, zero to 5 per cent of humin is formed within the fossil wood. In about two-and-a half-million years, about 50 per cent of wood is transformed into humin, and by about four million years almost all of the wood (87 per cent) is transformed into humin. It is also deducible that the soft woods are slightly more changeable into humin than hard woods (Text-figs. 2, 3) indicating that the process and degree of humification is dependent on the nature and composition of wood also.

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# Late Holocene environment in Coondapur area, Karnataka: Preliminary palynological results

Colette Tissot

Tissot, Colette 1990. Late Holocene environment in Coondapur area, Karnataka: Preliminary palynological results. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 348-358.

Palynological studies of sediments cored between the depth of 145 to 425 cm in Coondapur area, on the west coast of India in Karnataka, produced evidence of continuous existence of a well developed mangrove forest during the recent past. The pollen spectrum is mainly constituted by mangrove species; their constant representation (always more than 50%) shows stability of the environmental conditions; beside the dominant mangrove pollen, there are also those of the local vegetation. Prevalence of marine influence has been recorded throughout. Hinterland mountain vegetation is poorly represented. Such a palynological assemblage is indicative of a lagoon environment. The almost total disappearance of mangrove vegetation at this site today may not necessarily be due to a drastic change in ecological and hydrological conditions but it is certainly accelerated because of the anthropic pressure: land reclamation as well as time honoured practice of cutting wood.

**Key-words**—Palynology, Mangrove, Sea level changes, Late Holocene, Karnataka (India).

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## साराँश

### कर्नाटक में कुन्डापुर क्षेत्र में अनंतिम होलोसीन वातावरण : प्रारम्भिक परागाणविक परिणाम

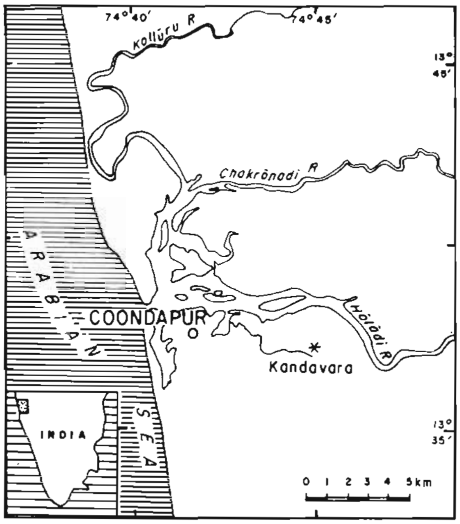
कॉलॅट तिसत

कर्नाटक में भारत के पश्चिम तट पर स्थित कुन्डापुर क्षेत्र में 145-425 सेन्टीमीटर की गहराई के बीच के अवसादीय क्रोड़ों के परागाणविक अध्ययन से इस क्षेत्र में सुविकसित मैंग्रोव वन की उपस्थिति के प्रमाण मिले हैं। परागकण स्पेक्ट्रम में मुख्यतया मैंग्रोव जातियाँ ही हैं; इनकी अविच्छिन्न उपस्थिति (50 प्रतिशत से अधिक) से वातावरणीय परिस्थितियों में स्थायीत्व प्रदर्शित होता है; मैंग्रोव वनस्पति के अतिरिक्त स्थानीय वनस्पति के परागकण भी मिले हैं। समुद्री प्रभाव समस्त क्रोड़ में देखने को मिला है। पश्चभूमि में पर्वतीय वनस्पति की बहुत ही कम संख्या है। इस प्रकार की परागाणविक समुच्चय लैगूनीय वातावरण की द्योतक है। इस स्थान पर अब मैंग्रोव वनस्पति की सम्पूर्ण विलुप्ति जलीय एवं पारिस्थितिकीय परिवर्तनों के कारण नहीं है बल्कि वनों आदि के काटने तथा खेती के लिए अधिक भूमि जुटाने के कारण सम्भवतः ऐसा हुआ है।

SINCE a long time, mangrove forests have been the subject of extensive research in various fields. Being located in the coastal regions, they are all the more interesting because they provide valuable information of sea-level changes and permit the reconstruction of the history of palaeoenvironments. The study of coastal area of Karnataka has been carried out with the purpose of reconstituting the history of forests of the Western Ghats as well as assessing the role of climatic changes and human pressure in this area in the recent past.

The coast of Karnataka is about 320 km long and consists of a narrow strip, about 20 km wide, situated between the Western Ghats and the Arabian Sea. Several rivers flow from the mountains towards the Arabian Sea, spreading out into broad estuaries or lagoons.

Kandavara bore-well has been dug in Coondapur area, at 13°37′ and 74° 45′ E (Text-fig. 1). It is located far away from the main flow, in the southern part of the Gangoli estuarine complex, at about 7 km from the coast. It has been dug near a mud flat, on the bank of a narrow channel which is linked to the Haladi River. This site presents on one hand the advantages of a regular sedimentation devoid of all detritic and coarse material, thereby



**Text-figure 1**—Coondapur area: Location of Kandavara bore-well.

permitting the study of a longer interval of time but its isolation, on the other, may lead to a decrease in the fluvial supplies which can reduce the number of allochthonous pollen carried by water.

## PRESENT VEGETATION

Today, the mangrove vegetation grows mainly in the northern part of Gangoli estuary. Around the bore-well area, only a few remnants of the former mangroves are still seen surviving here and there: small *Rhizophora* and *Acanthus ilicifolius*. Landscap in the neighbourhood is dotted with paddy fields and grasslands. On the hinterland hills, immediately upstream from the bore-well, there spreads a low and discontinuous vegetation with *Sapium*, *Syzygium* and *Ixora*, which is succeeded by a shrubby vegetation alternating sometimes with savanna and which may also grow on the plateau and at the foot hills of the Ghats (Pascal, 1988).

## POLLEN ANALYSES

In order to collect sediments, a hand borer, the "Soviet borer", specially devised to avoid risks of contamination, has been used (Thanikaimoni, 1987). This borer goes down hermetically closed and opens only at the required depth.

Kandavara bore-well registered a depth of 4.25 m, the base being a hard and sandy sediment, bright brown to yellow in colour. The whole core consists of a homogeneous dark coloured silt, containing various small plant debris. A thin layer of coarse sand occurs at a depth of 1.95 m. At the bottom of the core, sediment is more sandy, very compact and without any plant debris.

Because of the regular lithology of the sediment, samples were studied at intervals of 20 or 30 cm, fro 145 cm to the bottom (425 cm). The upper section of the core could not be investigated for pollen analyses because of its very soft and moist sedimentary texture; besides, it was likely to have been disturbed by human activity.

All the samples yielded enough quantity of pollen to enable valuable interpretations, exception being the two lower samples which were either barren, or very poor. In each sample 150 to 250 pollen and spores have been counted, and percentages were established from the total obtained, including the unidentified grains. Marine microplankton was counted separately. The percentage has been established by comparison with the continental microfossil pollen and spores using the ratio: marine microfossils number/continental + marine microfossils total. Same method was used for fresh-water organisms.

## FLORISTIC GROUPS

The taxa have been grouped according to their ecology, geographic distribution, or floristics following the plant associations defined by Gamble (1967), Saldanha (1988) and Pascal (1988). A detailed composition of these groups is given in Table 1. The associations mainly concern mangrove and back-mangrove pollen, hinterland pollen, those of herbaceous taxa belonging to Poaceae and Cyperaceae families, spores of Pteridophyta, allochthonous pollen and the marine organisms. The pollen grouped under "Regional" are those derived from the hinterland vegetation. This term is used in its wide sense and includes the coastal plain as well as the hinterland hills and the western slopes of the Ghats. But most of the pollen identified in our analyses, with the exception of the mangrove and mountains pollen whose origin is very precise, may have been produced by plants growing on the plains as well as in higher zone. The heading "Regional varia" includes the pollen whose ecology is not indicative of specific environment as well as those which could be identified only up to the family level or a little higher.

## POLLEN DIAGRAMS

Pollen diagrams have been established according to the associations defined earlier (Text-fig. 2). Detailed percentages are given in Table 2.

**Table 1—List of taxa constituting the main floristic associations**

| Mangrove | Regional | Regional varia | Upland | Pteridophyta | Marine elements |
|---|---|---|---|---|---|
| *Rhizophora* | *Areca* | *Acacia* sp. | *Artemisia* | Monolete spores | *Leptodinium* |
| Rhizophoraceae | *Arisaema* | Anacardiaceae | *Ephedra* | Trilete spores | *Operculodinium* |
| *Avicennia* | *Arenga wightii* | Arecaceae | *Strobilanthes* | *Ceratopteris* | *Spiniferites* sp. |
| *Sonneratia* | *Borassus* | Asteraceae | | | *S. mirabilis* |
| *Kandelia* | *Calamus* | *Canthium* | | | *Bitectatodinium* sp. |
| | *Caryota* | *Croton* | | | *Tuberculodinium* |
| **Back-mangrove** | *Cocos* | Cyperaceae | | | Foraminifera |
| *Calophyllum* | *Phoenix sylvestris* | *Desmodium* | | | |
| *Excoecaria* | *Pinanga* | Euphorbiaceae | | | **Fresh water** |
| *Sesuvium* | *Aegle* | *Ficus* | | | *Pseudoschizaea* |
| *Heliotropium* | *Artocarpus* | *Hemigraphis* sp. | | | *Botryococcus* |
| | *Bombax malabaricum* | *Justicia* | | | |
| | *Diospyros malabaricum* | Malvaceae | | | |
| | *Dodonaea viscosa* | Melastomataceae | | | |
| | *Elaeocarpus* | *Mimosa* sp. | | | |
| | *Emblica officinalis* | Monocotyledons | | | |
| | *Flacourtia indica* | Myrtaceae | | | |
| | *Garcinia* | Periporate | | | |
| | Poaceae | *Phyllanthus* type | | | |
| | *Holoptelea* | *Randia* type | | | |
| | *Hygrophila* | *Syzygium* | | | |
| | *Lannea* | *Terminalia* | | | |
| | *Mimusops* | Urticaceae | | | |
| | *Olea dioica* | *Ventilago* | | | |
| | *Pandanus* | | | | |
| | Sapotaceae | | | | |
| | *Schleichera* | | | | |
| | *Trema* | | | | |
| | *Ziziphus* | | | | |

## Mangrove

Mangrove is always very well represented from the bottom of the core to the top (145 cm) with percentages rarely below 50; the main pollen grains are those of *Rhizophora* which continues to be the predominant genus in Coondapur area. Some other Rhizophoraceae have been observed, such as *Ceriops, Bruguiera* and some grains of *Kandelia candel*, but their number has always been low. *Avicennia* is poorly represented and only two grains of *Sonneratia*, which, however, is reputed to be a good producer of pollen, have been recorded. The fluctuations which appear on the mangrove diagram are likely to be due to local causes and do not reveal any notable modification of the landscape.

## Regional

The relatively high representation of pollen in this category is regular and no drastic changes appear in the curve representing their percentages. Its contents which are widely varied correspond to the floristic diversity of the hinterland. It is constituted primarily by pollen of Arecaceae with *Calamus, Arenga, Areca catechu, Caryota urens*, etc. Pollen of *Pandanus, Syzygium, Terminalia* and *Elaeocarpus* are also regularly observed.

---

## PLATE 1

→

(All microphotographs are, × 1000)

1. *Rhizophora* sp. (Rhizophoraceae)
2. *Sesuvium portulacastrum* (Aizoaceae)
3. *Calophyllum inophyllum* (Clusiaceae)
4. *Pandanus* sp. (Pandanaceae)
5. *Calamus* type *rotang* (Arecaceae)
6. *Arenga wightii* (Arecaceae)
7. *Aegle marmelos* (Rutaceae)
8. *Caryota urens* (Arecaceae)
9. *Syzygium* sp. (Myrtaceae)
10. Arecaceae
11. *Diospyros* sp. (Ebenaceae)
12. *Elaeocarpus* sp. (Elaeocarpaceae)
13. *Bombax malabaricum* (Bombacaceae)

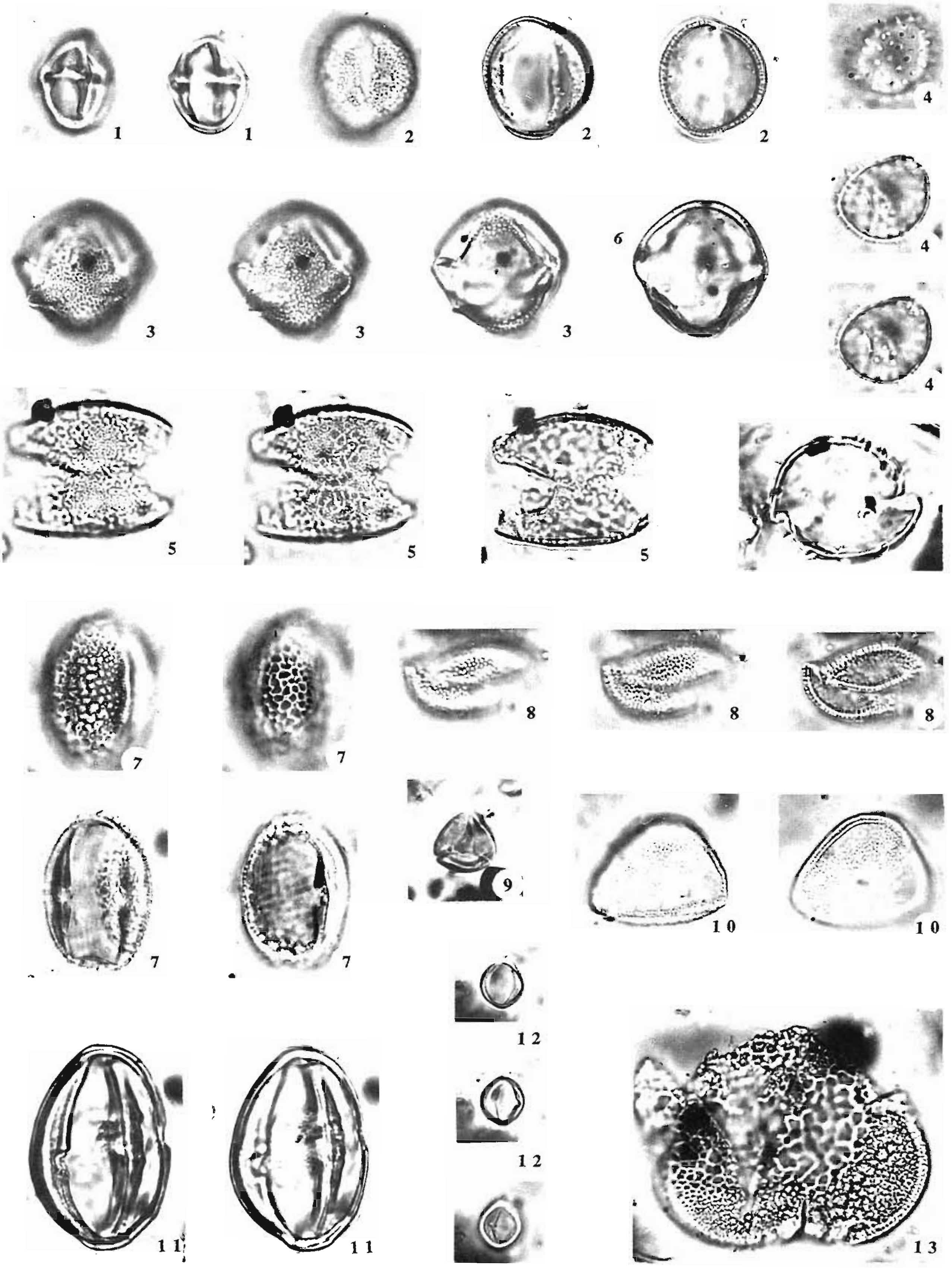
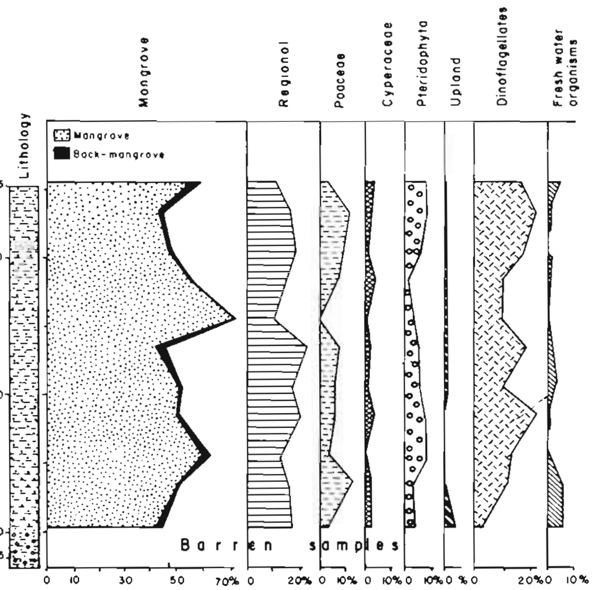


PLATE 1



**Text-figure 2**—Pollen diagram of Kandavara borewell.

Many small pollen, measuring about 10-12$\mu$m, smooth, with 3 colporus and 3 pseudo-colpus are also included in the "Regional" group. Although they could not be identified with certainty, they may belong to Melastomaceae or Boraginaceae, well represented in the region, and which contain several pollen with similar morphology. Their percentage in the samples, though not very high, is regular enough. Similar remarks can be made for certain small sized pollen (12 to 15 $\mu$m), reticulate, tri-aperturate, with endoaperture not well defined, and may belong to Menispermaceae (Thanikaimoni, 1984). Various other taxa, irregularly observed and sometimes with very low percentages are also included in the "Regional" group.

Some taxa whose ecology or floristic requirements correspond to a well-defined environment were used for specifying the main sources of pollen production in the region. The floristic structure to which they belong is given in

**Table 2—Percentages of taxa observed in Kandavara bore-well**

| Level (cm) | 145 | 165 | 195 | 215 | 245 | 265 | 295 | 315 | 345 | 365 | 395 | 425 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mangrove** | **56,6** | **44,2** | **48,1** | **56,1** | **73,9** | **42,9** | **52,2** | **51,2** | **61,7** | **51,9** | **43,5** | **47,4** |
| *Rhizophora* | 53,7 | 41,2 | 43,2 | 56,1 | 68,1 | 35,2 | 46,1 | 43,6 | 53,0 | 46,8 | 41,3 | 42,1 |
| Rhizophoraceae | 2,2 | 2,0 | 3,3 |  | 5,7 | 3,2 | 5,0 | 4,1 | 6,6 | 3.9 | 2,2 | 5,3 |
| *Avicennia* |  |  |  |  | 0,7 |  | 1,1 | 1,2 | 1,1 | 0,6 |  |  |
| *Sonneratia* |  |  |  |  |  |  |  |  | 0,5 | 0,6 |  |  |
| *Kandelia* | 0,7 | 1,0 | 1,6 |  |  | 4,6 |  | 2,3 | 0,5 |  |  |  |
| **Back-mangrove** | **3,7** | **1,5** | **1,1** |  |  | **3,7** | **1,1** | **0,6** | **2,2** | **0,6** | **2,2** |  |
| *Calophyllum* | 3,7 |  | 0,5 |  |  | 0,9 |  |  |  |  | 2,2 |  |
| *Excoecaria* |  |  |  |  |  | 1,8 | 0,6 | 0,6 | 1,6 | 0,6 |  |  |
| *Sesuvium* |  | 1,5 |  |  |  |  |  |  |  |  |  |  |
| *Heliotropium* |  |  | 0,5 |  |  | 0,9 | 0,6 |  | 0,5 |  |  |  |
| **Regional** | **11,8** | **17,1** | **19,1** | **15,4** | **10,6** | **23,3** | **17,8** | **20,9** | **13,1** | **16,2** | **17,4** | **15,8** |
| *Arisaema* |  | 1,5 | 1,1 | 2,4 | 0,7 | 2,7 | 2,2 | 1,2 |  | 3,2 |  |  |
| *Areca* |  |  |  |  | 0,7 | 0,5 |  |  |  |  |  |  |
| *Arenga wightii* |  |  |  |  |  |  | 0,6 |  | 0,5 | 0,6 |  |  |
| *Borassus* |  |  |  |  |  |  |  |  | 0,5 |  |  |  |
| *Calamus* | 1,5 | 4,0 | 2,2 | 1,6 | 1,4 | 2,3 | 3,9 | 0,6 | 1,1 | 0,6 |  |  |
| *Caryota* |  |  |  | 0,8 |  |  |  |  | 0,5 |  |  |  |
| *Cocos* |  |  |  |  |  |  |  |  |  |  |  | 5,3 |
| *Phoenix* |  | 0,5 | 1,1 |  |  |  | 1,1 | 0,6 |  |  |  |  |
| *Pinanga* sp. |  |  |  |  |  | 0,5 |  | 0,6 |  | 0,6 |  |  |
| Arecaceae |  | 1,0 | 1,1 | 1,6 |  | 1,4 | 0,6 | 1,2 | 2,2 | 0,6 |  |  |
| *Acacia polyade* |  |  |  |  |  |  | 0,6 |  |  |  |  |  |
| *Aegle* |  |  |  |  |  | 0,5 |  |  |  |  |  |  |
| Anacardiaceae |  | 0,5 |  |  | 0,7 |  |  | 0,6 |  |  |  |  |
| *Artocarpus* |  | 1,0 |  |  |  |  |  |  |  |  |  |  |
| *Bombax malabaricum* |  |  |  | 0,8 |  |  |  |  |  |  |  |  |
| *Canthium** |  |  | 0,5 |  |  |  |  |  |  |  |  |  |
| Asteraceae | 0,7 | 0,5 |  |  |  |  |  |  |  |  |  |  |
| *Croton* |  |  |  |  |  |  | 0,6 |  |  |  |  |  |
| *Desmodium* |  |  |  |  |  | 0,5 |  |  |  | 0,6 |  |  |
| *Diospyros malabaricum* |  | 0,5 |  |  |  |  |  |  |  |  |  |  |
| *Dodonaea viscosa* |  |  |  |  |  | 0,5 |  |  |  |  |  |  |
| *Elaeocarpus* |  |  | 1,6 |  | 0,7 | 2,7 |  | 1,2 | 0,5 | 1,3 |  |  |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Emblica officinalis* | | | | | | | 0,6 | | | | | |
| Euphorbiaceae | | 0,5 | | | | | | 0,6 | 1,1 | | | |
| *Ficus* | 0,7 | | | 0,8 | 0,7 | | | 0,6 | | 1,3 | | |
| *Flacourtia indica* | | | | | | | 0,6 | | | | | |
| *Garcinia* | | | | | | | | | | 0,6 | | |
| *Hemigraphis* sp. | | | | | | | | | | 0,6 | | |
| *Holoptelea* | | | | | | 0,5 | | | | | | |
| *Hygrophila* type | | | | | | | 0,6 | | | | | |
| *Justicia* | | | 0,5 | | | 0,5 | 0,6 | 0,6 | 0,5 | | | |
| *Lannea* | | | 0,5 | | | | | | | | | 5,3 |
| Malvaceae | | | | | | | | | | | 4,3 | |
| Melastomataceae | 0,7 | | 1,6 | | 1,4 | 1,4 | 0,6 | 0,6 | 0,5 | | 2,2 | |
| *Mimosa* sp. | 0,7 | | | | | | | | | | 2,2 | |
| *Mimusops* | | 0,5 | 1,1 | | | | | 0,6 | 1,6 | | | |
| Monocotyledons | 1,5 | 0,5 | | 0,8 | | 0,9 | 0,6 | 0,6 | 0,5 | | | |
| Myrtaceae | | | | 0,8 | 0,7 | | | | | | | |
| *Olea dioica* type | 0,7 | 0,5 | | | | 0,9 | | 2,3 | | | | |
| *Pandanus* | 0,7 | 1,0 | 1,1 | 0,8 | 1,4 | 0,5 | 1,1 | 1,7 | | 1,3 | 2,2 | |
| Periporate | | 1,5 | 1,1 | 2,4 | | 0,9 | 2,2 | 1,7 | 1,1 | | | |
| *Phyllanthus* type | 1,5 | 0,5 | 0,5 | 0,8 | | 2,7 | | 1,2 | | 0,6 | 2,2 | |
| *Randia* | | | | | | | | 0,6 | | 0,6 | | |
| Sapotaceae | 0,7 | | | | 0,7 | | | 0,6 | | | | |
| *Schleichera* | | | | | | | | | | 0,6 | | |
| *Syzygium* | 0,7 | 0,5 | 1,6 | 1,6 | 0,7 | 2,3 | 0,6 | 1,2 | 1,1 | 1,9 | 2,2 | |
| *Terminalia* | 0,7 | 2,0 | 0,5 | | | | 1,1 | 1,2 | 1,1 | | 2,2 | 5,3 |
| *Trema* | | | | | | 0,5 | | 0,6 | | | | |
| Urticaceae | 0,7 | | 2,7 | | 0,7 | 0,9 | | | | | | |
| *Ventilago* | | | | | | | | | | 0,6 | | |
| *Ziziphus* | | | | | | | | 0,6 | | | | |
| Poaceae | 2,9 | 11,1 | 9,3 | 7,3 | | 7,3 | 5,6 | 5,8 | 3,3 | 12,3 | 4,3 | |
| Cyperaceae | 2,9 | 2,0 | 1,1 | 4,1 | 0,7 | 2,3 | 1,1 | 3,5 | | 2,6 | 2,2 | 5,3 |
| **Upland** | **0,7** | **0,5** | **1,1** | **0,8** | **1,4** | **0,9** | **1,7** | | | | **4,3** | |
| *Strobilanthes* | | | 1,1 | | 0,7 | | 0,6 | | | | 4,3 | |
| *Artemisia* | 0,7 | | | 0,8 | | 0,9 | 1,1 | | | | | |
| *Ephedra* | | 0,5 | | | | | | | | | | |
| **Pteridophyta** | **8,1** | **9,0** | **6,0** | **1,6** | **3,5** | **5,9** | **6,1** | **8,1** | **8,7** | **3,2** | **4,3** | |
| Monolete psilate | 2,9 | 4,0 | 1,6 | 0,8 | 2,8 | 2,3 | 2,2 | 2,9 | 3,3 | 1,3 | 2,2 | |
| Monolete ornamented | 2,2 | 1,0 | 2,2 | 0,8 | | 0,5 | 1,1 | 1,2 | 1,6 | | | |
| Trilete psilate | 1,5 | 1,0 | 1,1 | | | 1,8 | 2,2 | 2,9 | 2,2 | 1,3 | 2,2 | |
| Trilete ornamented | 1,5 | 3,0 | 0,5 | | 0,7 | 1,4 | 0,6 | 1,2 | 1,1 | 0,6 | | |
| *Ceratopteris* | | | 0,5 | | | | | | 0,5 | | | |
| *Varia* | 2,9 | 9,0 | 6,0 | 6,5 | 2,1 | 4,1 | 7,2 | 5,8 | 6,0 | 5,8 | 13,0 | 15,8 |
| Unidentifiable | 10,3 | 5,5 | 8,2 | 8,1 | 7,8 | 9,6 | 7,2 | 4,1 | 4,9 | 7,1 | 8,7 | 15,8 |
| *Total counted* | *136* | *199* | *183* | *123* | *141* | *219* | *180* | *172* | *183* | *154* | *46* | *19* |

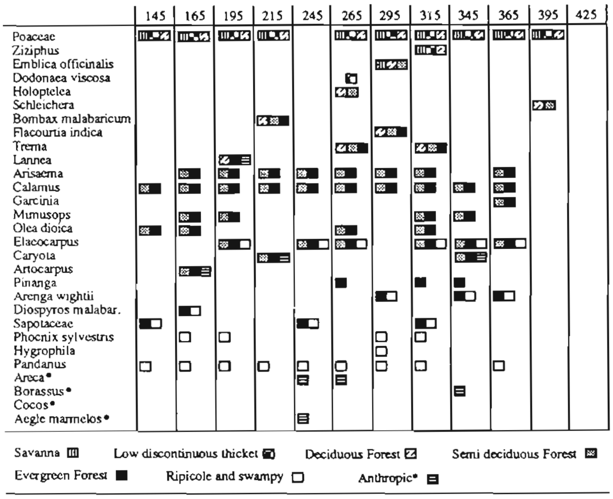
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Marine elements** | **11,7** | **20,7** | **14,1** | **6,8** | **9,6** | **15,4** | **5,8** | **20,7** | **9,0** | **8,9** | | **5,0** |
| *Leptodinium* | | 0,4 | 0,5 | | | 0,4 | | | | 0,6 | | |
| *Operculodinium* | | 0,8 | | | | | | | | | | |
| *Spiniferites* sp. | 10,4 | 18,7 | 10,3 | 6,1 | 8,3 | 14,3 | 5,8 | 16,1 | 8,0 | 7,1 | | 5,0 |
| *S. mirabilis* | | | 0,9 | | | 0,4 | | | | 0,6 | | |
| Incertae sedis | 1,3 | 0,4 | 2,3 | | 1,3 | | | 1,8 | 0,5 | 0,6 | | |
| *Tuberculodinium* | | 0,4 | | 0,8 | | 0,4 | | 0,5 | 0,5 | | | |
| Unidentified | | | | | | | | 2.3 | | | | |
| **Fresh water** | **3,5** | **1,0** | **0,5** | **1,6** | | **2,2** | **3,2** | **0,6** | **1,6** | **4,3** | **6,1** | |
| *Pseudoschizaea* | 0,7 | 1,0 | 0,5 | 1,6 | | 2,2 | 2,2 | 0,6 | 1,6 | 4,3 | 6,1 | |
| *Botryococcus* | 2,8 | | | | | | 1,1 | | | | | |

**Table 3—Classification of the taxa in the different floristic structures of the region (after Pascal, 1988)**

| | Savanna | Low discontinuous thicket | Deciduous forests | Semi-evergreen forests | Evergreen forests | Ripicole and swampy | Anthropic |
|---|---|---|---|---|---|---|---|
| Poaceae | X | (X) | X | | | | |
| *Ziziphus* | X | | | | | | |
| *Emblica officinalis* | X | | X | X | | | |
| *Dodonaea viscosa* | | X | | | | | |
| *Holoptelea* | | | X | X | | | |
| *Schleichera* | | | X | X | | | |
| *Bombax malabaricum* | | | X | X | X | | |
| *Flacourtia indica* | | | X | X | X | | |
| *Trema* | | | X | X | X | | |
| *Lannea* | | | X | X | | | X |
| *Arisaema* | | | | X | X | | |
| *Calamus* | | | | X | X | | |
| *Garcinia* | | | | X | X | | |
| *Mimusops* | | | | X | X | | |
| *Olea dioica* | | | | X | X | | |
| *Elaeocarpus* | | | | X | X | X | |
| *Caryota* | | | | X | X | | X |
| *Artocarpus* | | | | X | X | | X |
| *Pinanga* | | | | | X | | |
| *Arenga wightii* | | | | | X | X | |
| *Diospyros malabaricum* | | | | | X | X | |
| Sapotaceae | | | | | X | X | |
| *Phoenix sylvestris* | | | | | | X | |
| *Hygrophila* | | | | | | X | |
| *Pandanus* | | | | | | X | |
| *Areca* | | | | | | | X |
| *Borassus* | | | | | | | X |
| *Cocos* | | | | | | | X |
| *Aegle marmelos* | | | | | | | X |

Table 3. The distribution of the taxa recorded in the samples coupled with their floristic structure (Table 4) clearly shows that the pollen derived from semi-deciduous and evergreen forests and those of ripicole formations are the most frequent. Savanna, deciduous forest and low discontinuous thicket are only occasionally represented it Poaceae, which can be derived from these three formations, is excluded.

**Table 4**



* *May be native, but widely cultivated at present*

Poaceae, Cyperaceae and Pteridophyta have been shown separately. They have been observed with relatively constant percentages.

### Allochthonous pollen

Among the allochthonous pollen, i.e., the pollen coming from remote areas and which cannot be attributed to any of the previous associations, are those produced by the upland forests, such as *Artemisia, Strobilanthes* and *Ephedra*. These genera are very rarely observed in our sediments where they have most probably been transported by wind.

Mangrove forests constitute a closed environment where allochthonous pollen cannot easily penetrate. This phenomenon has already been observed in other mangrove sediments even where the mountain hinterland was covered by very dense vegetation (Caratini & Tissot, 1987). The poor representation of upland pollen in mangrove sediments is probably due to the high representation of mangrove vegetation which masks that of the hinterland vegetation.

### Marine microplankton

Marine palynomorphs, although generally poorly represented in mangrove sediments, are common here and their percentage varies between

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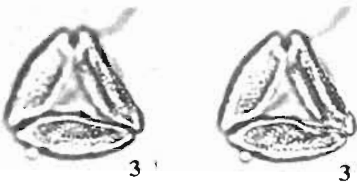
**PLATE 2** →

(All microphotographs are, × 1000, except n° 12)
- 1-3. *Schleichera oleosa* (Sapindaceae)
- 4. *Toddalia asiatica* type (Rutaceae)
- 5. *Artocarpus* sp. (Moraceae)
- 6. *Artemisia* sp. (Compositae)
- 7. *Emblica officinalis* (Euphorbiaceae)
- 8. *Ventilago* sp. (Rhamnaceae)
- 9, 10. Unidentified
- 11. Boraginaceae type
- 12. *Tuberculodinium vancampoe* (× 400)
- 13. Incertae sedis
- 14. *Spiniferites bentori* type


1


2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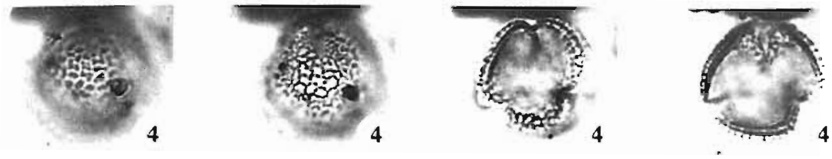
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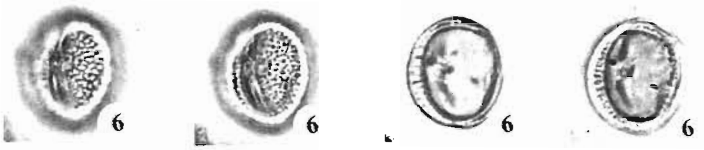
5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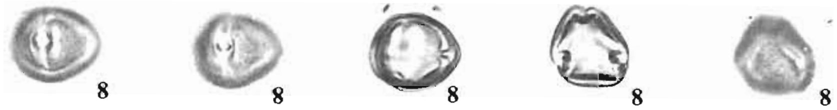
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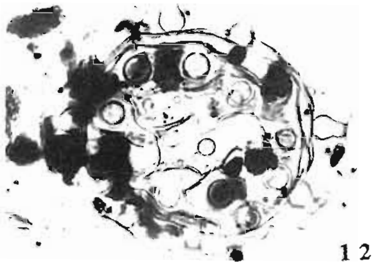
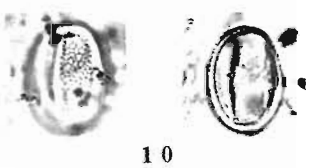

12


9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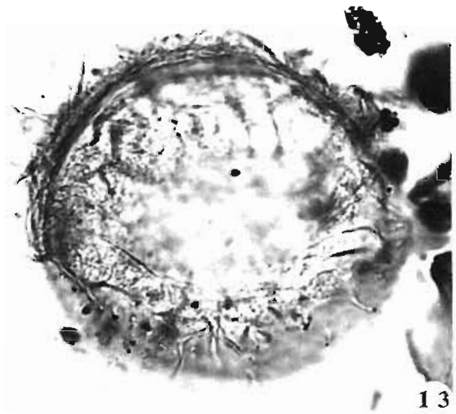
11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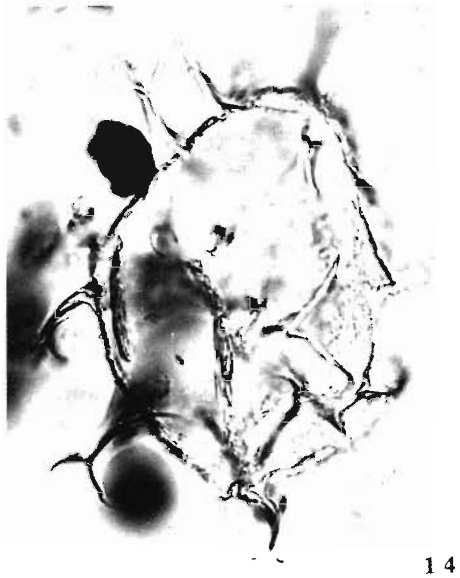
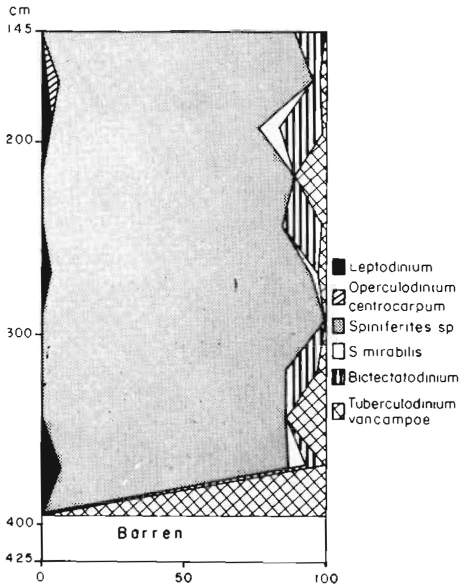

14

**PLATE 2**



**Text-figure 3**—Distribution of marine palynomorphs

10 and 25. They comprise the cysts of dinoflagellates and the tests of foraminifera, the latter representing only a very small part of microplankton Among the cysts of dinoflagellates, the main taxa observed are those generally recorded in deltaic environment, such as *Spiniferites* sp., *S. mirabilis, Operculodinium centrocarpum, Tuberculodinium vancampoe*, and others. Within this group, the predominance of the type *Spiniferites bentori* whose representation always above 75 per cent all along the core (Text-fig. 3) provides evidence of a constant penetration of sea water during the time of deposition Although the other organisms were observed in low percentages, their diversity testifies to an open environment

### Marine/continental ratio

The occurrence of dinoflagellates in a mangrove environment provides evidence of deep and constant penetration of sea water during the time of deposition On the west coast of Karnataka, the freshwater supplies, low or totally lacking during the long period of dry season, alternate with more abundant supplies during monsoon rains. Contrary to what generally takes place in a mangrove environment, here, with the monsoon regime, the deficit of freshwater lasts for 8 to 9 months and the sea water, instead of being pushed off-shore by the strong river currents, can penetrate deeply into the estuary and stay longer in the protected areas, thereby leading to a rise in the population of marine micro-organisms, as observed in our analyses.

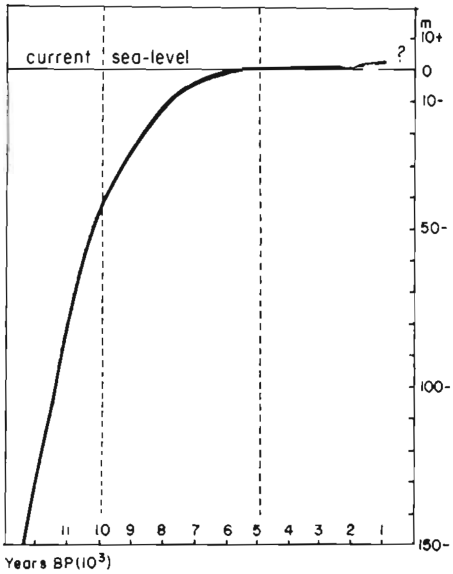
It is clear that a modification in freshwater supplies due to a climatic change liable to affect their regime should have a direct impact on the environment they drain Moreover, the study of evolution of the ratio between continental and marine microfossils can bring valuable data for the reconstruction of the climatic history of the region. In our sediments, the permanence of marine influence testifies to the stability of climatic conditions during the last millenia

### Fresh water organisms

Fresh water influence is mainly represented by *Pseudoshizaea* (= *Concentricystes*) and *Botryococcus*. They are few in number and not regularly distributed in the sediments.

### DATING THE EVENTS

Synthetic study of the different interpretations of sea level history in the world during the last 10,000 years (Kidson, 1986) brings out the relative stability of the sea-level from 5,000 years BP; according to this author, the fluctuations of the curves in some areas are due to eustatic regional phenomena. It is well known that during Quaternary, the Indian peninsula has remained relatively stable On the west coast of India and particularly on Kanara coast, no major tectonic activity was reported during the Late Quaternary (Dhoundial, 1987). The curve established for the west coast of India by Kale and Rajaguru (1985) from absolute dates of beach rocks, shelf surface sediments, corals and other materials from shore and coastal zone (Text-fig. 4)



**Text-figure 4**—Sea level curve on the west coast of India, after Kale and Rajaguru (1985) shows that the sea level has become stable at about the current sea level between 6,000 and 5,000 years BP

At present, as no radiocarbon dating has been carried out on our bore-well, the age of the sediments is not known. A synthesis of the various palynological studies carried out in mangrove environments on the Indian coasts (Thanikaimoni, 1987) reveals ages generally younger than 6,000 yrs BP, i.e., after the stabilization of the sea level. However, since the sedimentation rate in deltaic environments is closely related to the local conditions and varies according to the place in the same basin, it is not reliable to establish exact correlations with other palynological studies carried out along the Indian coasts, specially in regions known for their neotectonic activity, such as the Bengal Basin or Saurashtra (Dhoundial, 1987).

From these data we can deduce that in Kandavara the age of the deepest sample cannot be older than 6,000 to 5,000 years BP, this age corresponding to the approximate date when the sea reached the lower level of the deposit. But it could also be considerably younger since the filling up of the channel at the site may have started later, specially if the place selected for the bore-well was not the deepest in the area and therefore does not represent the longer period of time. If a drastic change of sea-level had occurred during the time of the deposition, it would have been necessarily expressed by a discontinuity in the pollen spectra. Thus the regularity of the percentages in all the assemblages, the high and constant representation of the mangrove and the marine influence observed with the same intensity all along the core are proofs of the permanence of the geomorphological, hydrodynamic and ecological conditions in this area.

## COMPARISON WITH PRESENT LANDSCAPE

Mangrove forests grow in fragile environments and their disappearance is often provoked by modifications or breaks in the conditions necessary for their development. The sedimentary filling of the lagoons where they are growing and which is a natural morphological evolution of this ecosystem is often the cause of their disappearance.

It is likely that the disappearance of the mangrove in Kandavara at present is partly due to a natural process as suggested earlier, but if the present landscape is considered, it is obvious that because of the time honoured practice of cutting wood and land reclamation in this part of the estuary (Untawale & Wafar, 1986), this degradation has been hastened by man, as it has been already observed in similar coastal areas (Tissot, 1987).

## CONCLUSIONS

On observing our results, we can assess that:

—the regularity of our spectra testifying to the perenniality of the environment of the site can confirm the view of a stable sea-level allowing the site to develop in similar conditions during a long time,

—the site has always been located within a well-developed mangrove forest mainly constituted by Rhizophoraceae;

—because of the constant occurrence of marine organisms, it was probably situated in a widely open lagoon where the sea water could penetrate deeply, at least during the long dry season;

—the high representation of marine microfossils attests not only to the penetration of the sea water but also to its permanence in the estuary. Such a situation can occur only in the case of a seasonal lack of fresh-water supplies.

—the regularity of the ratio between continental microfossils (pollen and spores) and marine microfossils (Dinoflagellates) observed all along the core goes in favour of the hypothesis that the region has not been affected by an important climatic change during the last millenia.

—the age of the deeper sediments cannot be older than 6,000 and 5,000 years BP, because it was approximately during this period that the area became accessible to the sea.

## ACKNOWLEDGEMENTS

The author wishes to thank Dr J. P Pascal, Director of the French Institute of Pondicherry, and Dr V. M. Meher-Homji for their fruitful comments on the distribution of the regional flora and for their useful suggestions regarding the interpretation of the results.

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# History of mangrove vegetation in Paradip and Jambu islands, Orissa for the past 500 years B.P.: A palynological assessment

H. P. Gupta & R. R. Yadav

Gupta, H. P. & Yadav, R. R. 1990. History of mangrove vegetation in Paradip and Jambu islands, Orissa for the past 500 years B.P.: A palynological report. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 359-369.

Modern surface samples from Paradip and Jambu islands, Orissa have provided clues of modern pollen deposition, reconstruction of palaeovegetation and to interpret with greater precision the pollen data recovered from the sediments. Pollen composition of modern surface samples coheres with the type of vegetation growing today within the area of 10 sq km and facilitates the comparison of past vegetation with the modern analogues. Pollen diagram constructed from Paradip profile has revealed the history of mangrove vegetation for the past 500 years B.P., wherein four zones of vegetational developments have been recorded. The decline of mangrove vegetation at the top of the diagram going back to about 35 years B.P. could be correlated with a record date around early nineteen-hundred-sixties, when the construction of Paradip Port came into existence. This feature suggests the excessive human pressure over the surrounding vegetation resulting into the ruthless damages to the mangrove and the same has been depicted in the pollen diagram. The plantation of *Casuarina* along the coastline in the recent past has also been recorded in pollen diagram.

**Key-words**—Palynology, Mangrove, Paradip and Jambu Islands, Orissa (India).

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## साराँश

### पिछले 500 वर्षों में उड़ीसा में पैरादीप एवं जम्बू द्वीपों की मैंग्रोव वनस्पति का इतिहास : एक परागाणविक मूल्याँकन

हरीपाल गुप्ता एवं राम रतन यादव

उड़ीसा में पैरादीप एवं जम्बू द्वीपों के वर्तमान सतही नमूनों के परागाणविक अध्ययन से परागकण निक्षेपण, पुरावनस्पति की संरचना तथा परागकण विश्लेषण संबंधी ऐसे आँकड़े उपलब्ध हुए हैं जिनसे अच्छे परिणाम उपलब्ध हुए हैं। इन नमूनों से उपलब्ध परागकण इस क्षेत्र में 10 किलोमीटर के क्षेत्रफल में पाई जाने वाली वनस्पति से सामंजस्यता प्रदर्शित करते हैं। पैरादीप परिच्छेदिका के परागकण चित्र से 500 वर्ष पूर्व की मैंग्रोव वनस्पति का इतिहास व्यक्त हुआ है, जिसमें चार वनस्पतिक मंडल अभिलिखित किये गये हैं। परागकण चित्र में ऊपर की ओर मैंग्रोव वनस्पति का ह्रास 1960 के आस-पास के एक अभिलेख से सम्बद्ध किया जा सकता है जिस समय कि पैरादीप बंदरगाह का निर्माण हुआ था। इससे यह प्रस्तावित होता है कि इस क्षेत्र की वनस्पति पर वहाँ आस-पास रहने वाले लोगों का अत्यधिक दबाव पड़ा है और जिसके कारण मैंग्रोव वनों की कटाई हुई है। कुछ वर्षों पूर्व समुद्र तट के साथ-साथ **कैजुएराइना** के लगाये गये पौधों के प्रभाव को भी परागकण चित्र में प्रदर्शित किया गया है।

MAHANADI River in combination with Brahmani, Baitarani, Dharma and Devi rivers forms an extensive delta around Bay of Bengal which stretches from Chilka Lake in the south to Bhadrak in the north covering approximately 170 km long and 60 km wide area (Lat. 20°15′ : 20°55′ N; Long. 86°40′ : 87°E). This deltaic complex constituted the second largest mangal formation and today a major part of the mangal zone is a bare land.

Palynostratigraphical analysis of the sediments from this deltaic complex was undertaken to study on various aspects of mangal developments and causes of its deterioration in time and lateral extent. To begin with, Paradip was chosen and its 3 m deep soil profile was investigated which is dated *ca* 500 year B.P. A combined study of modern surface samples and soil profile has been conducted. The palynological information of the estuaries is mainly from the Gangetic-Sunderban deltaic complex (Das, 1961; Mallik, 1969; Gupta, 1970, 1978, 1981, Chanda & Mukherjee, 1969; Mukherjee, 1972a, b; Vishnu-Mittre & Gupta, 1972; Banerjee & Sen, 1986a, b). Gupta (1981) has investigated one profile each from all the four flanks of the basin and found metachroneity in the development of mangrove vegetation. In addition, several features of interest, such as—submergence and subsidence of forest, nature and extent of peat deposits, have also been worked out in detail. The other pollen analytical studies on the coastal sediments in India are from Bombay (Agrawal & Guzder, 1974; Vishnu-Mittre & Guzder, 1975), Gujarat (Vishnu-Mittre & Sharma, 1975), Pichavaram, Tamil Nadu (Blasco & Caratini, 1973; Caratini *et al.*, 1973; Tissot, 1980); and Brahmani Delta, Orissa (Caratini *et al.*, 1980). A review of the coastal palynology and ecology was made by Thanikaimoni (1987).

## GEOLOGY AND GEOMORPHOLOGY

Mahanadi delta occupies shallow, rigid peninsular shield in largely an erosional basin. The basin roughly coincides with an Early Permian rift valley, but at the head of the delta the Upper Gondwana (Athgarh Sandstone) is found all over to north of Puri and extend up to Cuttack and Athgarh (Ahmad, 1972).

It is a tripple delta where the sediments of Mahanadi, Baitarani and Brahmani join to form a protuberant shore. The extensive alluvial tracts are found from Chilka Lake in the south to Bhadrak in the north. The delta projection (about 60 km) indicates the abundance of sediment-discharge from a large catchment of rugged terrain marked by heavy torrential rains. The various distributaries in deltaic region are characterised by an estuarine inlet of the sea near their mouth.

## CLIMATE

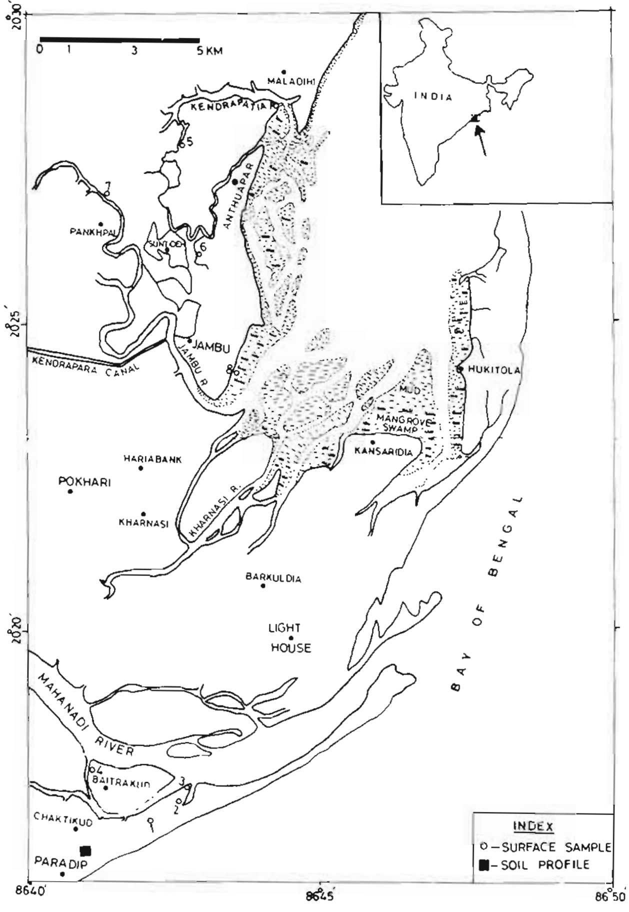
The entire region of Mahanadi delta enjoys oceanic tropical humid climate which is equable throughout the year and humidity recorded is 75 per cent and 82 per cent for the driest and wettest months, respectively. April is the hottest month with 36°C and 21°C maximum and minimum temperatures, respectively. July-August receive torrential rains with 1,585 mm as an annual average. With the onset of monsoon, the wind velocity increases to 40 km/h and reduces to 15-25 km/h during the winter. The weather is disturbed during post monsoon and early part of eastern monsoon when the depression and storms originate in the Bay of Bengal. Some of these depressions intensify and develop violent cyclones and storms with a speed of 180-220 km/h causing heavy damages to the plant and animal life.

## VEGETATION

The vegetation of Mahanadi delta has been investigated alongwith its ecological aspects by Haines (1961), Rao and Mukherjee (1972), Choudhury (1984) and Banerjee and Rao (1985). Banerjee (1987a, b) has recognised three vegetation zones, viz., (a) zone of typical mangrove habitat with the preponderance of Rhizophoraceae members adapted by means of stilt roots and vivipary, e.g., *Rhizophora* spp., *Ceriops* sp., *Bruguiera gymnorrhiza, Kandelia* sp., *Aegiceras* sp., etc.; (b) zone of less pronounced mangrove habitat associated with different groupings of taxa adapted by means of pneumatophores and buttresses, e.g., *Sonneratia* spp., *Heritiera fomes, Avicennia* sp., *Excoecaria* sp., etc.; (c) zone of midland and hinterland mangrove with the mingling of upland flora due to sudden change of habitat, e.g., *Brownlowia tersa, Dalbergia horrida, Pongamia pinnata, Cynometra iripa, Caesalpinia bonducella, Aglaia cucullata, Cerbera manghas, Bruguiera sexangula, Heritiera littoralis, Phoenix paludosa, Crinum asiaticum, Thespesia populnea, Clerodendrum inerme, Syzygium* sp., *Carissa spinarum, Diospyros* spp., etc.

The mangrove vegetation of Mahanadi delta, particularly in and around Paradip, is on decline. The increasing human pressure, unplanned development ignoring long term repercussions, and its problem of deforestation, plantation of cash crops, urbanization and industrialization have taken a heavy toll of the mangrove forest. As a result, forests are reducing fast, ecological balance is disturbed and cyclones are becoming worse. Erosion of top soil is on way maring the chance for regeneration of mangrove. The vegetation around Paradip has been ruthlessly damaged in the recent past with the construction of port. Paradip port has maritime tradition, going back to 16th and 17th century A.D., and since then the mangroves are being exploited.

At present, mangroves could be seen in the creeks and channels along the upper part of the inner estuarine zone with degraded mosaic. Hardly any mangrove taxon is found near Paradip as the topography has been considerably disturbed. A few scattered bushes and stands of *Avicennia alba* and *Excoecaria agallocha*, respectively, are seen. Nevertheless, entire deforested area is succeeded by



**Map 1**—Sites of samples investigated.

*Acanthus ilicifolius* bordering watery places. The reason for its existence is mainly two-fold: (i) these are vegetatively propagated and hence form extensive thickets, and (ii) it is not preferred by browsing animals and are of no economic potential. *Phoenix paludosa* forms pure formations at places in the flood plain area and *Borassus* is found isolated as midland vegetation. The fern commonly occurring in this area is *Acrostichum aureum*.

## MATERIAL AND METHOD

Eight surface samples from different places along various creeks were collected to study the modern pollen/vegetation relationship. A three metre deep profile was also collected from Paradip, near Mahanadi mouth (Map 1). The material for pollen analysis and radiocarbon assay were collected from different borings using Hiller's peat auger. The sediments are composed of soft clayey silt with rich organic matter.

The method employed for extraction of pollen and spores from the matrix is the same as suggested by Erdtman (1943). The relative frequencies for all taxa (Pl. 1, figs 1-29; Pl. 2, figs 1-19) encountered from the sediments have been calculated in terms of total land plants and the pollen spectra have been constructed highlighting ecological groups. The plus sign (+) in the pollen spectra and diagram denotes values below one per cent.

## MODERN POLLEN/VEGETATION RELATIONSHIP

Surface sample nos. 1-3 were collected at the mouth of Mahanadi River and sample no. 4 from Baitrakud in Paradip (Text-fig. 1).

The study of these samples has revealed poor occurrence of mangrove taxa which match with the present day condition of mangrove degradation. Nevertheless, core constituents of mangrove recorded are *Excoecaria* (7%) and *Sonneratia* (3-7%) followed by *Acanthus* and *Avicennia* (1-3% each), *Rhizophora* (up to 4%) and *Ceriops/Bruguiera* (1-2%). The peripheral mangrove taxa recorded are *Sesuvium* and *Phoenix* (1-2% each), *Acrostichum aureum* and *Tamarix* (1% each). The brackish water swamp taxa, such as *Barringtonia* and *Pandanus*, are sporadic. Cyperaceae (6-9%) are dominant amongst fresh-water swamp taxa. The upland arboreal taxa are represented by *Casuarina* (up to 4%), *Carissa, Terminalia, Adina,* Sapotaceae, *Emblica* (1-2% each). Poaceae (34-42%) dominates the herbaceous vegetation; its high values are related to the increasing open-land all around. Ferns, represented by both trilete (7-10%) and monolete (1-3%) spores, are quite high and suggestive of enhanced atmospheric humidity. *Potamogeton*(1-2%) and *Nymphaea* (1%) are the two fresh-water taxa present in this environment.

Reworked bisaccate pollen grains (1-6%) have been found in all the samples; they are more concentrated near the mouth of Mahanadi River indicating a transportation of sediment from the nearby coal-bearing strata of Lower Gondwana.

Surface sample nos. 5-7 were procured from Barpal, Pankhpal an Suntideh in Jambu, respectively. This area, too, is under heavy biotic pressure, as the major forest cover has been cleared for paddy cultivation. The vegetation growing today comprises *Acanthus ilicifolius, Excoecaria agallocha, Dalbergia spinosa, Derris trifoliata, Phoenix paludosa, Tamarix troupii, Cocos nucifera* and *Borassus flabellifer.* Recently, the forest department has introduced the afforestation scheme on waste lands by planting *Casuarina equisetifolia* and *Eucalyptus* sp. Around Pankhpal, *Suaeda maritima* forms dense thickets.

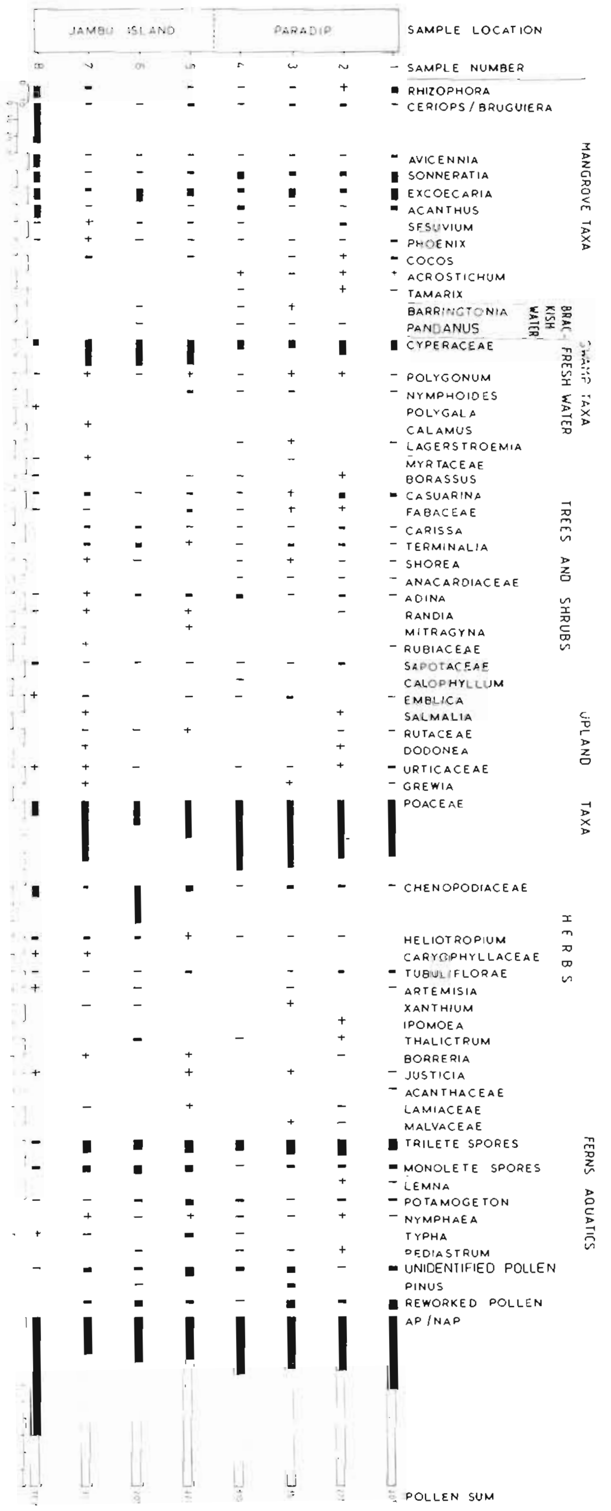
Pollen analysis of the above samples exhibits the dominance of *Excoecaria agallocha* (2-8%). The other mangrove taxa are represented by *Rhizophora* (up to 3%), *Ceriops/Bruguiera* (1-2%), *Sonneratia* (3-5%), *Acanthus* (1-5%), *Avicennia* (1-2%) and *Sesuvium* (1-2%).

Cyperaceae (15-16%) is common. The upland tree taxa, such as *Casuarina*, Fabaceae (1-3%) each, *Carissa*, Sapotaceae (1-2% each), *Terminalia* (up to 3%), *Adina* (up to 2%) and Rutaceae (1%), are present in low frequencies, whereas herbaceous taxa of ubiquitous ecology are represented by Poaceae (15-36%), Chenopodiaceae (2-23%), *Heliotropium* (up to 2%) and Tubuliflorae (1-2%). Fern spores, both triletes (6-8%) and monoletes (4-5%), are present in good values. The fresh-water elements present are *Potamogeton* (1-4%), *Typha* (1-3%), *Nymphaea* (1%) and *Pediastrum* (1%). Bisaccate reworked pollen are common in all the samples.

The pollen spectra is incoherent with the present day vegetation statistics. For example, *Acanthus ilicifolius* and *Excoecaria agallocha* are not adequately represented in the pollen spectra. *Avicennia* and *Rhizophora* pollen seem to be drifted from the adjacent mangrove zone. High pollen frequency of Chenopodiaceae from Pankhpal sample corroborates the common occurrence of *Suaeda maritima* in the area.

Sample no. 8 is collected from near Jambu Village. The biotic pressure is also operational in this area but still there are some patches of undisturbed nature where both core and peripheral mangrove exist in natural ecology. The pollen spectrum is dominated by mangrove taxa, like *Ceriops/Bruguiera* (24%) followed by *Avicennia* and *Acanthus* (8% each), *Rhizophora, Sonneratia* and *Excoecaria* (7% each). *Sesuvium* and *Phoenix* are present in low values.

Fresh water swamp taxa, such as Cyperaceae (4%) *Nymphoides* (1%) and *Polygala* (1%), are relatively low. The upland taxa, including both arboreals and non-arboreals, are either poor or sporadic. Such taxa recorded are *Casuarina, Myrtaceae, Borassus, Adina, Randia,* Fabaceae, Sapotaceae, *Emblica*, Urticaceae, Poaceae,



**Text-figure 1**—Modern pollen spectra from Paradip and Jambu islands in Mahanadi Delta, Cuttack, Orissa.

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## PLATE 1

(All figures, × 1000)

1-3. *Rhizophora* sp., equatorial view.

4-6. *Avicennia* sp., polar view and equatorial view.

7,8. *Heritiera* sp., equatorial view.

9-11. *Aegiceras* sp., equatorial view.

12,13. *Adina* sp., equatorial view.

14-16. *Emblica* sp., polar view and equatorial view.

17-21. *Excoecaria agallocha*, polar view and equatorial view.

22,23. *Sonneratia* sp., equatorial view.

24-26. *Acanthus ilicifolius*, equatorial view.

27. Chenopodiaceae pollen.

28. *Barringtonia* sp., equatorial view.

29. Chenopodiaceae.

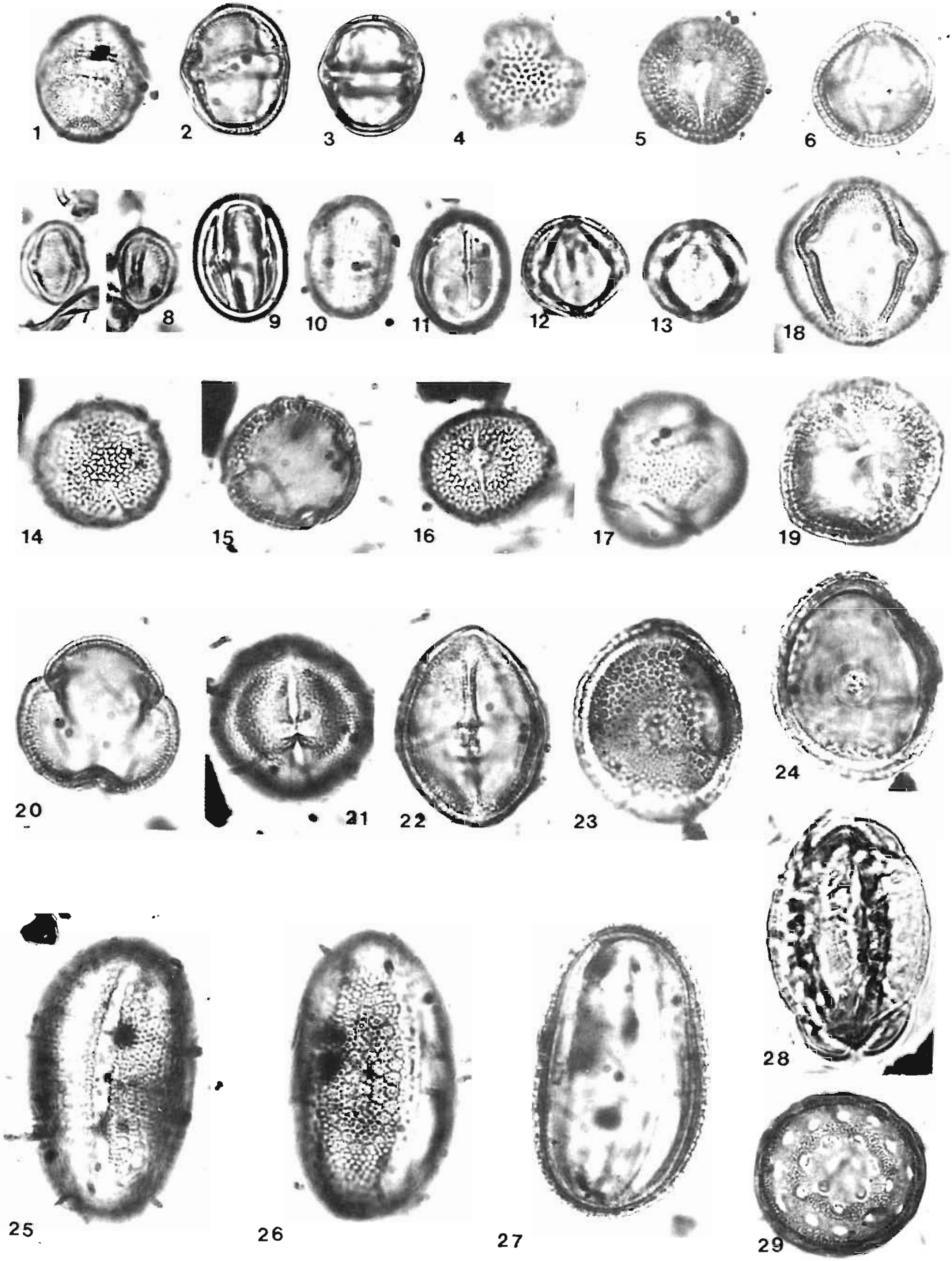


PLATE 1

Chenopodiaceae, *Heliotropium*, Tubuliflorae, Caryophyllaceae, *Artemisia* and *Justicia*. Ferns and aquatic taxa are poorly represented.

The comparison of pollen sums of the taxa recorded in the pollen spectra and their actual frequency in the modern vegetation composition of the area reveals that certain taxa, like—*Rhizophora*, *Ceriops/Bruguiera* and *Sonneratia*, are over-represented while *Avicennia*, *Excoecaria* and *Acanthus* are under-represented in the pollen spectra.

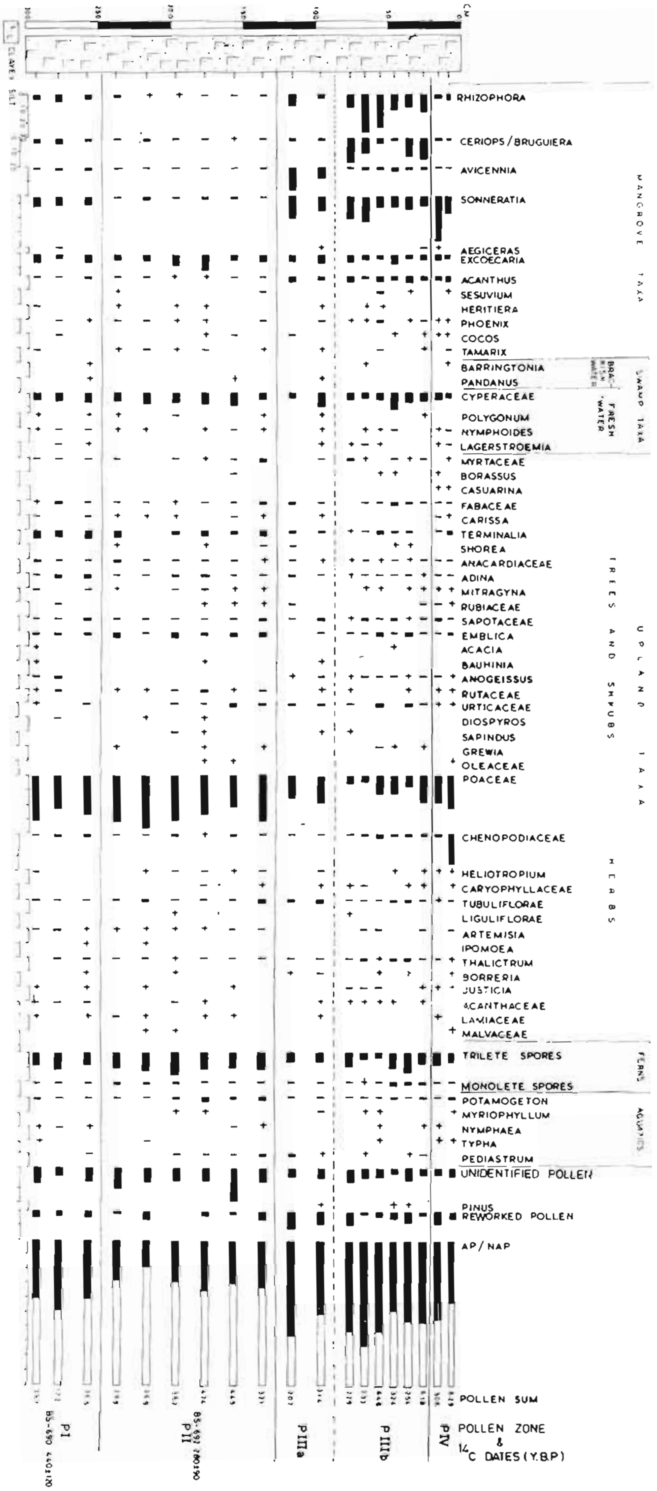
## POLLEN DIAGRAM AND ITS COMPOSITION

The pollen diagram (Text-fig. 2) from Paradip has been graded into four zones in chronological order and prefixed with the site initial, e.g. P-I-IV.

*Zone P-I (3.0-2.5 m)*—This zone is characterised by moderate values of core mangrove taxa, out of which *Sonneratia* and *Excoecaria* attain relatively higher values as compared to *Rhizophora* and *Ceriops/Bruguiera*. *Avicennia* and *Acanthus* are present in consistently low values whereas *Heritiera*, *Phoenix*, *Cocos* and *Tamarix* are sporadically low throughout the zone.

Fresh water swamp taxa are mainly represented by Cyperaceae while *Polygonum*, *Nymphoides*, *Lagerstroemia*, etc., are recorded in low values, not exceeding one per cent. The midland and upland vegetation, however, is dominated by *Terminalia*, *Adina*, Fabaceae, Anacardiaceae, Sapotaceae, *Emblica*, etc. Poaceae is present in high values attaining up to 35 per cent of the total vegetation. This taxon cannot be relied upon for interpretation of the depositional environments since its members grow in marine, brackish water and fresh water environments and also difficult to be differentiated palynologically. Ferns are quite high in frequency in this zone but the fresh water taxa, such as *Potamogeton*, *Nymphaea*, *Typha* and *Pediastrum*, are present in low values. The pollen of unknown affinities as well as the reworked pollen are present in high values. These features indicate a drifting of the reworked pollen and fresh-water aquatic pollen taxa through rivers and rivulets.

AP/NAP ratio indicates little higher values of non-arboreal vegetation as compared to the arboreals. The vegetational picture evolved in zone P-I, after considering the information perceived from the modern pollen vegetation relationship, indicates that *Sonneratia* and *Excoecaria* were the two dominant taxa suggesting the contact point nearer to the fresh-water sources with higher turbidity. The other mangrove taxa, such as *Rhizophora*, *Ceriops/Bruguiera*, etc., relatively lower in values, are derived from the inner estuary line with comparatively deeper parts along the creeks and slopes.



**Text-figure 2**—Pollen diagram from Paradip in Mahanadi Delta, Cuttack, Orissa.

*Zone P-II (2.5-1.20 m)*—This zone denotes open conditions as non-arboreal vegetation dominates over the arboreals. There is an overall depression in the mangrove tree taxa as compared to the preceding zone. The values for *Excoecaria*, however, remained static althrough the zone, whereas other taxa enumerated in the preceding zone continued in exceedingly low values. Fresh water swamp taxa have improved slightly than before. The notable difference in this zone is marked by an overall spurt in the values of midland and upland taxa, particularly the non-arborescent taxa, such as Poaceae, Caryophyllaceae, *Heliotropium*, etc. The ferns and fresh water aquatics, such as Potamogeton and *Pediastrum* improved considerably and so also the reworked pollen. This is indicative of a high magnitude flow in the channels. The vegetational picture obtained in zone P-II depicts recession in the tidal magnitude as a result of which the fresh water discharge increased encouraging the influx of salt-tolerant, fresh water and the upland taxa.

*Zone P-III (1.20-0.20 m)*—This zone, on the basis of marked variations in the mangrove taxa, has been subdivided into two subzones, viz., P-III a and b.

*Subzone P-III a (1.20-0.85 m)*—This subzone records high values of *Avicennia* and *Sonneratia*, followed by *Excoecaria, Acanthus, Rhizophora* and *Ceriops/Bruguiera* indicating most conducive environment for the luxuriant growth of mangrove vegetation. *Avicennia* sp. cf. *A. marina* is adapted to exceedingly high salinity condition as they possess salt glands in their leaves for exuding excess of salts. On the other hand, *Sonneratia* has a preference for lesser saline conditions. This association of the two taxa suggests the depositional environment to be typical of marine nature subject to high turbidity and silt deposition.

The other elements of the mangrove zone with greater salt tolerance, such as *Heritiera, Phoenix, Cocos*, etc., are present in low frequencies. Cyperaceae is present with still higher values at the close of this subzone. There is also a general reduction in the values of upland tree taxa. Poaceae has declined considerably as compared to the preceding zone. There is also a depression in the overall values of ferns and fresh-water aquatics. AP/NAP ratio has revealed improvement in the arboreal vegetation.

*Subzone P-III b (0.85-0.20 m)*—Subzone P-III b is recognised by high values of *Rhizophora, Ceriops/Bruguiera* and *Sonneratia* wherein *Avicennia* experiences a setback and *Excoecaria* continued to be moderate. All other mangrove taxa with a preference of low salinity are present either in extremely low values or are sporadically dispersed. This zone covers a time span of about 150 years and the mangrove vegetation thrived well and established The other taxa recorded in high frequencies are Cyperaceae, Poaceae, Chenopodiaceae, *Heritiera, Sesuvium, Phoenix, Cocos, Tamarix*, etc. Upland tree taxa continue as before, however, with a slight depression. Chenopodiaceae and *Acrostichum aureum* have improved considerably indicating high salinity. The general picture of the Zone P-III has revealed a favourable environment for the luxuriant growth of mangrove vegetation with an increased salinity, giving pace to front-line estuary mangroves to thrive.

*Zone P-IV (0.20—0.00 m)*—In this zone, mangrove taxa declined sharply except for *Sonneratia* which flourished at the cost of suppression in the values of Rhizophoraceae. *Excoecaria* and *Acanthus* remain static. The other mangrove taxa, like *Aegiceras, Sesuvium, Phoenix, Cocos* and *Tamarix* have gained a little. Cyperaceae has reduced considerably whereas other swamp taxa have improved a little than before. The upland tree taxa continue with more or less same values. Nevertheless, Poaceae and Chenopodiaceae have registered marked improvement while other herbaceous elements are present in reduced values than before. Ferns, aquatics, etc., continue in almost same values as before. The picture obtained from this zone has revealed a steep fall in the values of mangrove taxa in general and Rhizophoraceae members in particular. *Sonneratia*, being high pollen producer, increased considerably in the begining but dwindled in the later half of this zone. This decrease in the value of mangrove elements can be assigned to the activity of man as the total time span for this zone is around thirty-five years and could be well correlated with record date around early nineteen hundred sixties when the construction of Paradip Port came into being.

## DISCUSSION AND CONCLUSION

The results permeated from the pollen analytical study of surface samples are variable. At places it has been recorded that the pollen composition of the surface samples is coherent with the existing vegetation of the area. For instance, sample nos. 1-4 collected from near the mouth of Mahanadi River at Paradip have brought about a close relationship between the pollen assemblage and modern vegetation. However, sample nos. 5-7 but for no. 8, collected from Jambu Island, have shown a partial relationship between the pollen assemblage and modern vegetation. The analysis of all the surface samples reveals that some of the taxa are over-represented and a few are under-represented. The members of Rhizophoraceae and *Sonneratia* are over-represented. The members of Rhizophoraceae are high pollen-producers in the mangrove complex and are provided with all contrivances for their transportation and spread. This feature had already been observed by several earlier workers (Muller, 1959; Caratini *et al.*, 1973; Vishnu-Mittre & Gupta, 1972; Ratan & Chandra, 1983, 1984; Grindrod & Rhodes, 1984; Grindrod, 1988). As regards *Sonneratia*, it is also a high pollen producing taxon but generally does not represent its high frequency in the sediments Similar observations have also been made by Caratini *et al.* (1973). Nevertheless, *Sonneratia* pollen may present in low values or even absent in the sediments owing to the fact that bats feed on its pollen (Tomlinson, 1986).

*Acanthus, Avicennia* and *Excoecaria* are under-represented in the pollen assemblage in contrast to its position in the vegetation. This could be well explained due to the entomophily coupled with low pollen production. Nevertheless, in Pichavaram mangroves in Tamil Nadu, *Acanthus ilicifolius* has been recorded to its expected values (Caratini *et al.*, 1973). In Sample no. 8, collected from near Jambu Village where undisturbed patches of mangroves are present, the pollen spectrum recorded the predominance of core mangrove taxa followed by peripheral mangrove taxa. All surface samples contain reworked pollen indicating a high influx of water transportation from far of distances.

The surface sample study has enabled to understand that *Rhizophora, Ceriops/Bruguiera* and *Sonneratia* are over-represented whereas *Avicennia, Excoecaria* and *Acanthus* are under represented in the pollen assemblage as compared to their actual occurrence in the forest.

The pollen diagram constructed from Paradip profile has been phased into four zones in chronological order In Zone I, which covered a time span of less than 100 years, the core mangrove taxa except for *Sonneratia* and *Excoecaria* were poorly developed whereas midland and upland vegetation was dominated by *Terminalia, Adina*, Fabaceae, Anacardiaceae, Sapotaceae, *Emblica*, etc. This zone indicates that mangrove vegetation, which perhaps thrived earlier, has been damaged due to either climatic or biotic influence. But the high values of *Sonneratia* and *Excoecaria* do not exclusively support the biotic factor; instead these two taxa have liking for the increased fresh water conditions and colonize the contact point near the fresh water discharge with greater turbidity. Thus, the fresh water discharge with greater magnitude in the delatic complex can not be ruled out. Zone II, which lasted for about 200 years, has recorded further depression in almost all the mangrove taxa whereas the fresh-water swamp taxa including aquatics have risen successively. The overall values of Zone II depicts recession in the tidal magnitude and more fresh water discharge from the rivers and rivulets. In addition, the biotic factor remained operational and the open conditions developed.

Zone III, in general, is a period for luxuriant growth of mangrove vegetation. However, the vegetation composition in the lower and upper parts is incoherent and hence it has been subdivided into two for the convenience of describing the biostratigraphic units in terms of vegetation. Zone IIIa lasted for about 50 years and is marked by high values of *Avicennia* and *Sonneratia*. The core mangrove taxa, particularly Rhizophoraceae members, are lowly present. *Avicennia* is adapted to exceedingly high salinity conditions, whereas *Sonneratia* has liking for lesser salinity. This association of two heterogeneous taxa is suggestive of typical marine condition with high turbidity and salt deposition. Zone IIIb lasted for about 150 years. It is marked by the establishment of core mangroves, such as *Rhizophora, Ceriops/Bruguiera* and *Sonneratia*; all other taxa with a preference of low salinity and those with fresh water inclination have declined considerably. Chenopodiaceae and *Acrostichum aureum* have improved significantly.

The results obtained from this zone have

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**PLATE 2** →

(All figures unless otherwise stated are, × 1000)

1 *Byttneria herbacea*, polar view.

2,3. Unidentified 3-porate, equatorial view

4. *Brownlowia* sp., polar view.

5-7. Unidentified 4-parasyncolpate pollen.

8. *Polygala* sp., equatorial view.

9,10. *Gardenia* sp. pollen tetrad

11,12. *Xylocarpus* sp., polar view and equatorial view.

13. *Acacia* sp.

14. *Ceratopteris thalictroides*, × 500.

15. Monolete spore, × 500.

16-19 Reworked Permian pollen, × 500; 16. *Plicatipollenites* sp., 17 *Crescentipollenites* sp., 18. *Labirites* sp., 19. *Verticipollenites* sp.


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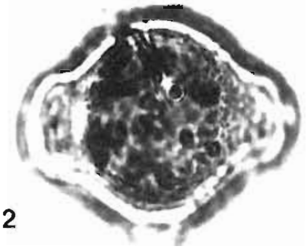
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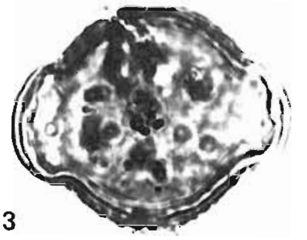
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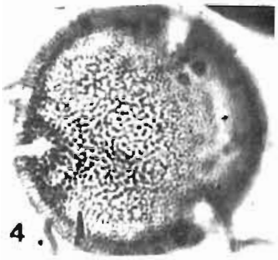
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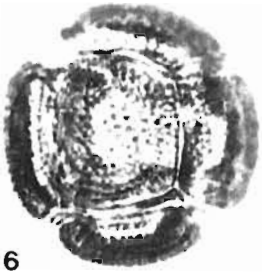
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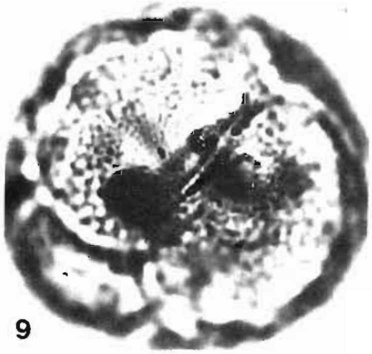
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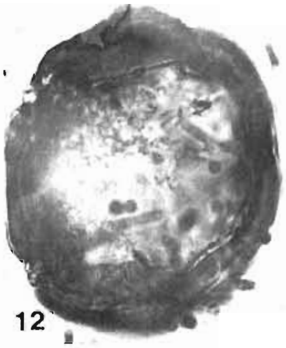
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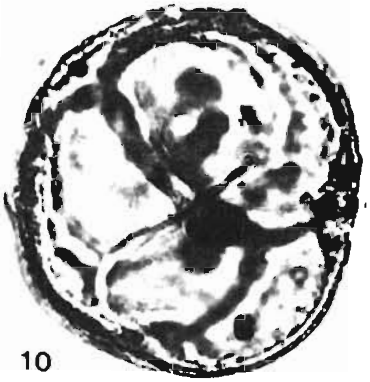
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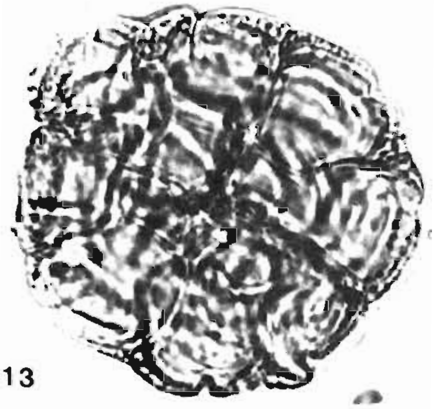
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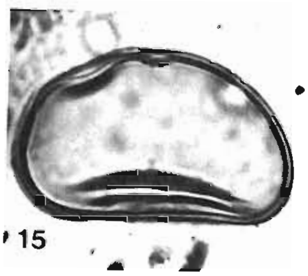
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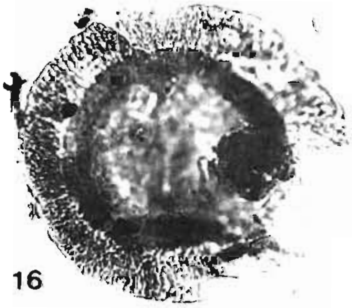
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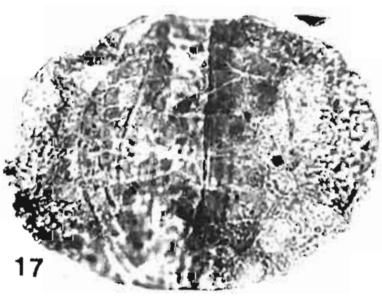
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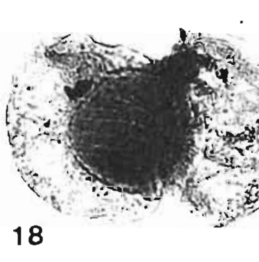
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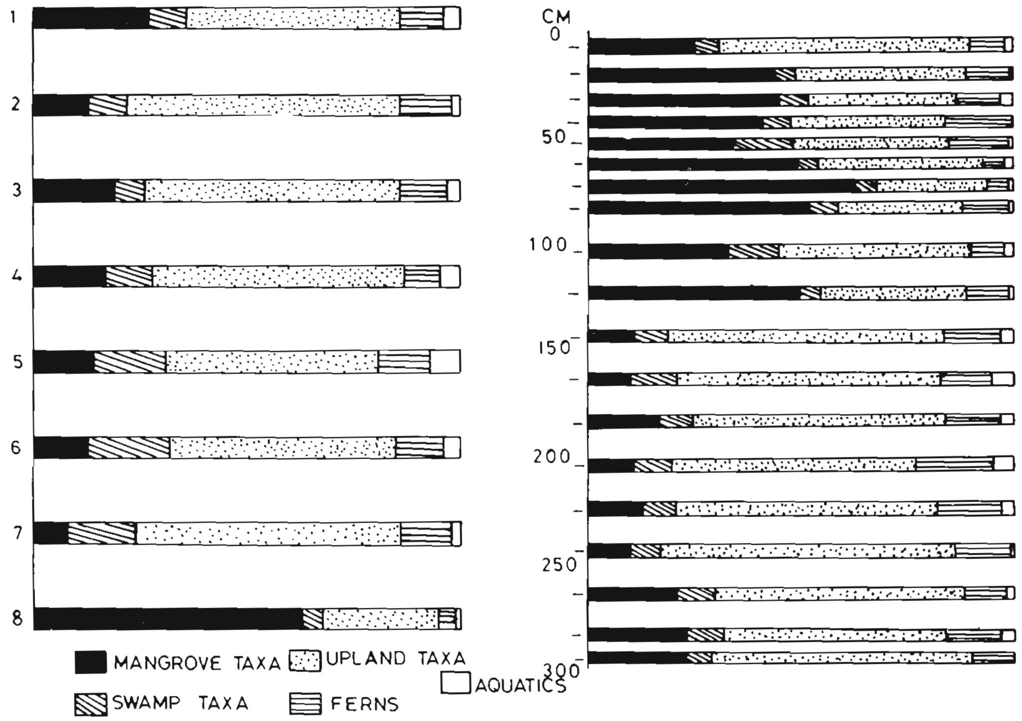
PLATE 2



**Text-figure 3**—Summary diagram showing collective relative frequencies of various ecologically grouped plant taxa based on Text-figures 1 and 2.

revealed a favourable environment for about 200 years for the successive growth of mangrove vegetation with an increased salinity giving pace to front-line estuary mangroves to flourish. The colonisation of the mangrove system is also indicative of undisturbed conditions and hence it could also be assumed that during this phase the biotic pressure ceased for some time; it may be because of the unfavourable natural condition which perhaps precluded the man's entry into the forest.

During the Zone IV , which has short time-span (not exceeding 35 years), all the mangrove taxa declined sharply, except for *Sonneratia.* This setback in the overall mangrove taxa, particularly members of Rhizophoraceae, could be abused in the hands of man; this loss to the mangrove vegetation could be correlated with record date around 35 years when the construction of Paradip Port came into being and a vast area was deforested.

The reworked Permian pollen have been encountered invariably in all the profile samples, in low values in the bottom samples but their frequencies increased in the top samples. The sediments containing these pollen grains after erosion have been incorporated into the Mahanadi and transported up to its mouth or even farther and deposited along with recent sediments.

The summary diagram (Text-fig. 3) gives a comparative picture of mangrove taxa, swamp taxa, upland taxa, ferns and fresh water aquatics. This also provides at a glance correlation between the vegetation of surface samples and profile samples. In broader perspective, the mangrove taxa remain lower than the upland taxa in the lower half of the profile and, thereafter, the former improved and the latter declined. It has also been observed that the surface-sample vegetation statistics has helped greatly in the correct interpretation of pollen diagram.

## ACKNOWLEDGEMENT

Authors express their gratitude to Dr Suresh C. Srivastava for rendering help in the identification of Permian pollen.

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# Palaeomangroves of Kanara coast, Karnataka, India and their implications on Late Pleistocene sea-level changes

C. Caratini, G. Delibrias & G. Rajagopalan

Caratini, C., Delibrias, G. & Rajagopalan, G. 1990. Palaeomangroves of Kanara coast, Karnataka, India and their implications on Late Pleistocene sea-level changes. *In*: Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 370-378.

Along the Kanara coast, some wells show an organic clay layer, 1.5 to 7 m thick, between a layer of 2 to 6 m of coarse yellow sand above and white sand and pebbles below. The altitude of this intermediate organic clay formation is more or less at the present mean sea-level. Palynological analyses reveal that this sediment had been deposited within a mangrove environment, *i.e.*, at sea-level, while the $^{14}C$ datings give ages older than 40,000 years B.P. No proof of vertical movements after the deposit of the intermediate organic clay formation has been put forward up to now. Therefore it can be accepted that the present elevation of this formation is more or less the same as its original altitude, *i.e.*, the present sea-level. Comparison of this altitude with the curves of global sea-level changes indicates that the period of deposition of these organic sediments should be around 125,000 years B.P., during the last Interglacial (Eemian) when the sea-level was ± the same that it is today. The main characteristics of "Eemian" flora were the same as the present. The climatic regime may have been slightly different with less contrasting seasons.

**Key-words**—Palynology, Mangrove, Sea-level changes, Upper Pleistocene, Karnataka (India).

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## साराँश

### कर्नाटक (भारत) में कनारा तट के पुरामैंग्रोव तथा अनंतिम अतिनूतन काल में समुद्र-तल परिवर्तनों पर उनका प्रभाव

सी० केरातिनी, जी० डेलिब्रियास एवं गोविन्दराजा राजगोपालन

कनारा तट के संग-संग कुछ कुओं में ऊपर 2 से 6 मीटर की मोटी पीली बालु तथा नीचे गुटिकाओं युक्त सफेद बालु के बीच में 1.5 से 7 मीटर मोटी एक कार्बनिक मृत्तिका की तह विद्यमान है। इस माध्यमिक कार्बनिक मृत्तिका का तल वर्तमान समुद्र तल से लगभग मिलता-जुलता है। परागकण विश्लेषण से व्यक्त होता है कि ये अवसाद मैंग्रोव वातावरण में समुद्र-तल पर निक्षेपित हुए थे जबकि कार्बन$^{14}$ कालनिर्धारण के आँकड़े 40,000 वर्ष पूर्व की आयु प्रस्तावित करते हैं। इस माध्यमिक कार्बनिक मृत्तिका के निक्षेपण के बाद इसके उर्ध्वाधर स्थिति में स्थापित होने का अभी तक कोई प्रमाण नहीं मिल पाया है। अतएव यह माना जा सकता है कि इस कार्बनिक तह का वर्तमान तल उस समय के समुद्र तल के लगभग बराबर है। भूमण्डलीय समुद्र-तल परिवर्तनों से इस तह की ऊंचाई की तुलना से इंगित होता है कि इन कार्बनिक अवसादों के निक्षेपण का समय पिछले अन्तरहिमानी (ऐमियन) के समय लगभग 1,25,000 वर्ष पूर्व रहा होगा जबकि समुद्र-तल लगभग आज जैसा ही होगा। 'ऐमियन' वनस्पतिजात के मुख्य लक्षण वर्तमान से मिलते-जुलते थे और जलवायु सम्भवतया थोड़ा भिन्न प्रकार की लेकिन कम मौसम वाली रही होगी।

THE question of high sea-levels during the Late Pleistocene is yet to be solved despite the vast data dealing with this "puzzling problem" (Giresse & Davis, 1980). This awkward situation is mainly due to the difficulty, and generally even the impossibility, of obtaining satisfactory answers to the following two questions:

—determination of the altitude of littoral sediments at the time of their deposition; this uncertainty is mostly due to the difficulty in estimating the effects of possible neotectonics;

—estimation of the absolute age of these sediments; the reliability of $^{14}C$ datings becomes low for values near or older than 30,000 yrs B.P. with a physical limit of around 40,000 years B.P.; for earlier periods it is often difficult or even impossible to carry out other isotopic methods, such as $^{230}Th/^{234}U$ or $^{231}Pa/^{235}U$.

On the west coast of India, some organic clay layers recorded in several parts along coastal Kanara (Karnataka) are investigated in this paper. As they are older than 40,000 years B.P. they are not exceptions to this rule of incertitude. Nevertheless, our study will lead towards a better understanding of the age and conditions of their deposition as well as on the regional evolution of Late Pleistocene.

## GEOGRAPHICAL AND GEOLOGICAL BACKGROUND

Kanara, in coastal Karnataka, extends from the shoreline to the great escarpment of the Ghats. Its geology and geomorphology are complex as already emphasized by W. T. Blanford as early as 1869. The most distinctive features are the numerous lateritic terraces with some sporadic emergences of the crystalline substratum. In the absence of true fossils, the age of the detrital sediments as well as their tectonic movements have never been precisely known (for bibliography see Chatterjee, 1961; Mehr, 1987). These lateritic terraces which are dissected by a large number of rivers running from the Ghats slope gently towards the sea where they often end as cliffs. Estuaries are numerous and hence the coast is irregular in both plan and elevation with a characteristic pit-and-lagoon shoreline. The estuaries sometimes penetrate deep inland and these embayments, filled by younger deposits, have a definite ria aspect. In most cases the paleoreliers surrounding the lowest terraces comprise low and smooth mounds only a few metres high and this does not help in elucidating the relationship between the lowest terraces and the surrounding paleoreliefs.

These low terraces seem to constitute a geomorphologic and lithologic unit, but actually there are at least two generations of deposits which are merged and hence not easily distinguishable. It is only from the study of wells that it becomes possible to recognize an older generation of sediments with the following layers.

From the surface downwards:

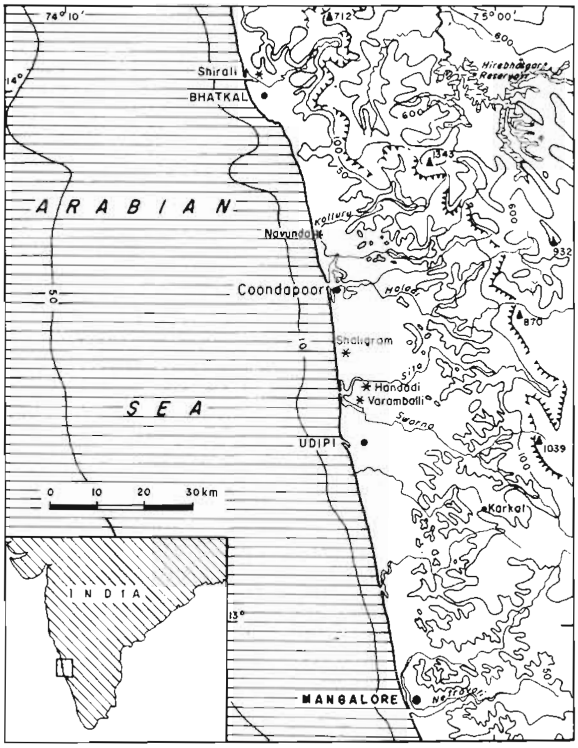
—coarse red mottled sand partly cemented by ferruginous concretions;

—black organic clay with vegetal fragments;

—white sand with pebbles: aquifer.

Each layer is only a few meters thick.

Such a stratigraphy of great petrological uniformity can be found all along the Kanara coast despite the discontinuities between the estuaries. This paper reports studies on this particular sedimentological feature with palynologic and geomorphologic investigations as well as $^{14}C$ ages.



**Text-figure 1**—Coastal Kanara: Location of the investigated wells.

## STUDY OF WELLS

In the low terrace of the Sita and Swarna estuary, two wells were investigated at Handadi and Varambali. Another well was studied a few kilometers away, at Shaligram. Two wells in Navunda and one well near Bhatkal, about 70 km north, also present the same characteristics (Text-fig. 1).

### Handadi Village

*Lithology of the well* (Text-fig. 2)

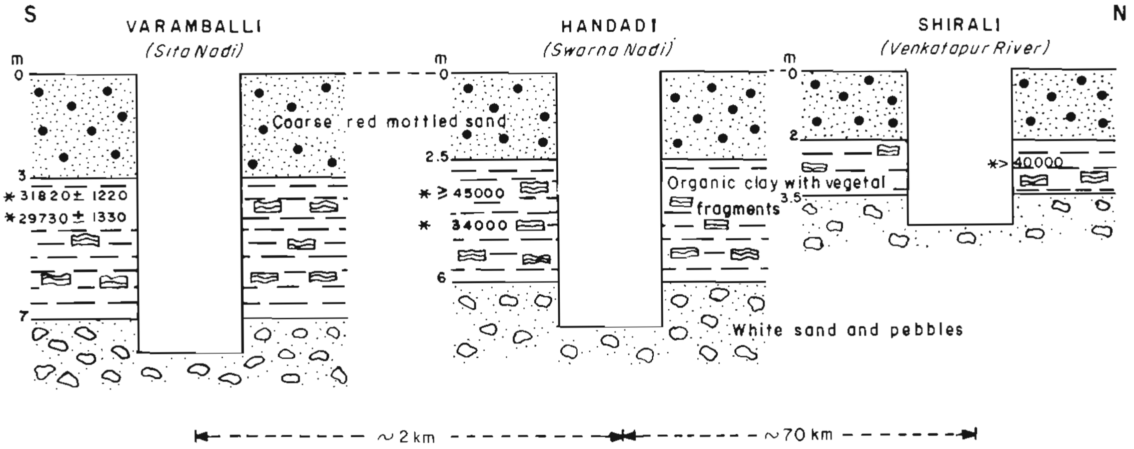
—Surface to 2.5 m (the elevation of the surface of this terrace is approximately 4 m): irregular coarse sand, red mottled and slightly cemented;

—2.5 to 6 m: black organic clay with numerous vegetal fragments of various sizes, some of them measuring several decimeters. The line of contact with the layer above is distinct;

—6 m to bottom, 7 m: aquifer; white, coarse sand with pebbles.

*Palynological data* (Text-fig. 3; Table 1)

Two samples collected at depths of 3.5 and 4.5 m have been studied. Both were deposited within a mangrove environment, their palynological assemblages being dominated by Rhizophoraceae (mostly *Rhizophora* and some *Ceriops, Bruguiera*) with some rare *Avicennia* and *Aegiceras.* In both the samples, *Pandanus* which normally grows along



**Text-figure 2**—Section of three wells in the coastal plain of Kanara.

**Table 1—Intermediate organic clay formation: Palynological assemblages (% calculated from the total pollen + spores)**

| | Varambali 3.5 m | Handadi 4.5 m | | Shaligram I* | Shaligram II* | Shirali |
|---|---|---|---|---|---|---|
| **Mangrove** | | | | | | |
| Rhizophoraceae | 67.2 | 51.2 | 68.7 | 81.9 | 90.9 | 67.6 |
| *Avicennia* | 0 6 | 0.5 | 0.4 | 1.9 | 0.7 | |
| *Aegiceras* | | 1.5 | | 1.0 | 0.7 | 0.3 |
| Total mangrove | 67.8 | 53.2 | 69.1 | 84.8 | 92.3 | 68.0 |
| **Back mangrove** | | | | | | |
| *Acanthus ilicifolius* | | | 0.4 | 1.9 | | |
| *Calophyllum* | | | 0.4 | | | 1.0 |
| *Excoecaria* | | | 1.1 | | | |
| *Heliotropium* | | | 0.4 | | | |
| **Miscellaneous** | | | | | | |
| *Arisaema* | 4.5 | 6.0 | 9 0 | | | 3.0 |
| Asteraceae | | 0.5 | | | | |
| *Calamus* | | 0.5 | | | | 0.3 |
| *Caryota* | | | | 1.0 | 0.7 | |
| *Cyclea peltata* | 0.3 | | | | | |
| Elaeocarpaceae | 0.3 | 3.5 | 3.6 | | | 0.3 |
| *Flacourtia indica* | | | 0.4 | | | |
| *Gardenia* type | 0.3 | | | | | |
| *Melastoma* | 0.3 | | 0.4 | | | |
| Myrtaceae 15μ | 1.3 | 0.5 | | | | |
| *Nauclea* | 0.3 | | | | | 1.0 |
| *Oldenlandia* | | | 0.4 | | | |
| *Pandanus* | 0.6 | 0.5 | 0.7 | | | 0.5 |
| *Phoenix* | 0.3 | 0.5 | 0.4 | | | |
| *Phyllanthus* | | 0.5 | 0.4 | 0.5 | 0.5 | 0.5 |
| Sapotaceae | 0.3 | | | | | |
| *Strobilanthes* | 0.3 | 0.5 | | | | |
| *Syzygium* | 0.3 | 2.0 | 0.7 | 1.9 | | 1.6 |
| *Terminalia* type | 0.3 | 0.5 | | 4.8 | | 1.6 |
| Urticaceae | 0.6 | 0.5 | 0.7 | | | 1.9 |
| *Ventilago* | 0.3 | | | | | |
| *Xylia* | 0.3 | | | | | 0.3 |
| *Xylocarpus* | | | 0.4 | | | |
| Poaceae | 0.3 | 0.6 | | 2.8 | 1.4 | 3.9 |
| Cyperaceae | 1.6 | 1.0 | | 1.0 | | 1.3 |
| *Varia* | 15.5 | 18.9 | 5.8 | 2.9 | 5.6 | 9.7 |
| Unidentifiable | 2.8 | 5.0 | 4.3 | | | 2.9 |
| **Ferns** | | | | | | |
| Spore Ilete psilate | 0.6 | 2.5 | 1.1 | | | |
| Spore Ilete ornam. | 0.6 | 2.0 | 0.4 | | | 0.3 |
| Spore 3lete psilate | 0.3 | 0.5 | 0.4 | 1.0 | | |
| Spore 3lete ornam. | | | | | | 0.3 |
| *Total spores* | 1.6 | 5.0 | 1.9 | 1.0 | | 0.6 |
| *Total P × Sp.* | 317 | 201 | 278 | 107 | 143 | 309 |
| Foraminifera | 2.3 | 8.5 | 4.0 | 2.9 | | 8.4 |
| *Pseudoschizaea* | | 0.5 | | | | |

*analyses: G. Thanikaimoni

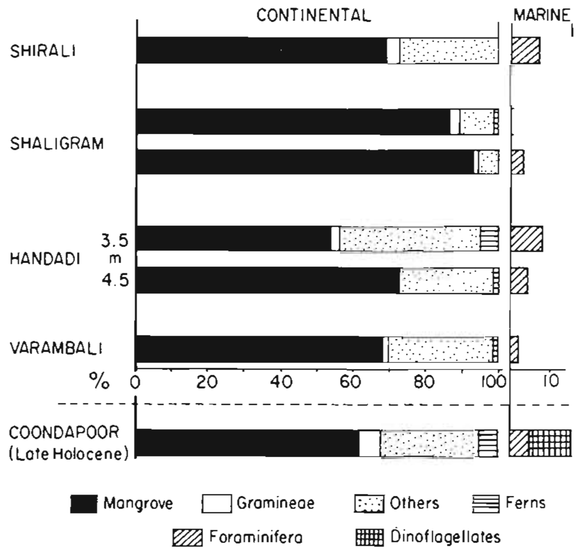
river banks is well represented; the marine influence is marked only by the presence of organic tests of Foraminifera. During the deposition of this organic sequence, the paleoenvironmental conditions were subjected to the usual and characteristic changes, well-known in mangrove sedimentation (Thanikaimoni, 1987). From 4.5 to 3.5 m, the environment became more open, i.e., subjected to influences external to the mangrove ecosystem, as attested by a greater pollen diversity, the occurrence of some herbaceous plant pollen, such as Poaceae and Cyperaceae, as well as a large number of fern spores and more marine microfossils.

*Chronological data*—Two dates were obtained from this well:

—3.5 m: ⩾ 45,000 years BP (GIF 7249)

—4.5 m: 34,000 ± 1500 years BP (GIF 7251).

The 3.5 m deep sample is estimated to be very old, beyond $^{14}C$ age range. The other sample is 1 m deeper to the first one. Hence the result of 34,000 years to this sample constitutes an obvious anomaly which can be explained by contamination with younger material such as humic acids which were not properly eliminated during chemical pretreatment. Since an older date of the upper sample cannot be envisaged, it may be concluded that the age of the entire organic layer is older than 45,000 years B.P.



**Text-figure 3**—Simplified palynological diagram of some intermediate organic clay formation samples and comparison with the mean values from Late Holocene of Coondapur (Tissot, 1990).

### Varambali

A 6 m deep well near the All India Radio tower, less than 2 km from Handadi well (Text-fig. 1), is closely comparable. Located in the same terrace, it has the same lithology (Text-fig. 2), the correlating layers being a little thicker and deeper. The palynological content (Text-fig. 3 and Table 1) is also similar with a strong dominance of Rhizophoraceae.

Two dates were obtained:

—from an organic clay sample: 31,820 ± 1220 years B.P. (BS 681)

—from a wood fragment: 29,730 ± 1310 years B.P. (BS 680).

The exact depths of these two samples are not known because the well was already walled and the samples were collected from the earth recently dug out from the well. However, because of the regularity of the arrangement of the sediments out of the well, it can be assessed that the wood fragment was deeper than the organic clay sample. Here again such results are not compatible and as in the case of Handadi, a rejuvenation of these two samples must be suspected. Hence, the same age, i.e., older than 45,000 years B.P., may be retained.

### Shaligram

A little northwards, near 42° 42′ : 13° 29′ (Text-fig. 1), in the coastal plain, a comparable black organic clay layer is found below coarse sands in a 6 m deep well. Palynological analyses were carried out on two samples from this layer (data from Late Dr G. Thanikaimoni). Prof. B. G. L. Swamy has identified some wood fragments as *Calophyllum* and given a dating of "barely 40,000 years B.P.".

The two samples investigated for palynology (Text-fig. 3 and Table 1) are dominated by pollen of *Rhizophora*. Hence, they were also deposited within a mangrove ecosystem. One of the two samples is marked by marine influence since it contains organic tests of microforaminifera.

### Navunda

Similar black organic clay was observed in two wells located (74° 35′.7 : 13° 45′) in Navunda (Text-fig. 1). The thickness of the layers is more than in the previous wells: 7 to 8 m of coarse mottled sand; 5 to 6 m of black organic clay. Palynological analyses show that this clay was sedimented in a mangrove environment. Two samples from this layer were dated (Murthy, 1977) and were found to be about 40,000 years B.P. These values are at the limit of the feasibility of the $^{14}C$ method and hence cannot be retained without reservations.

### Shirali

North of Bhatkal (Text-fig. 1), near a channel of Venkatapur River in the low plain (74° 31 : 14° 03), an equivalent organic clay layer is seen in well excavations. Despite the distance between this site and those from Udipi Taluk, more than 70 km away, the lithology is similar; only the thickness of the upper two layers, coarse yellowish sand and black organic clay, is slightly less.

Vegetal fragments are numerous in this clay. Among them, a leaf of *Calophyllum* has been identified.

Palynological analyses once again reveal a mangrove environment (Text-fig. 3; Table 1) still dominated by *Rhizophora*. The assemblage resembles those obtained in the southern wells. However, the Shirali assemblage may be distinguished from the others by the little higher percentage of Gramineae: 3.9% *versus* 0.3 to 2.8 per cent. The age of a sample collected in the middle part of the organic layer has been determined as >40,000 years B.P. (BS 805).

## Uniformity of the organic clay layers

In spite of the wide geographical distribution of the investigated wells and the discontinuity between the wells, the organic clay layers belong to the same generation because of their similarities in stratigraphy, lithology, palynology, $^{14}C$ datings and also their location at the same altitude. The deposits investigated here are roughly at about 0 m now, i.e., the present mean sea-level.

Hence they can be considered to belong to the same lithologic formation which will be named "intermediate organic clay formation" because it is always within the same sequence of coarse yellowish sands above and while sands and pebbles below. The intermediate organic clay formation should not be confused with the more recent organic black clay found in most of the recent lagoons. The sedimentation of this younger black clay started during the Late Holocene transgression and is still continuing.

### Organic clay formation in Kanara: Data from literature

Some comparable sediments lying more or less near the present sea-level, rich in organic fragments and dated older than 40,000 years B.P., have been reported in Kanara. Lack of sufficient data makes it difficult to include them in our study. They are cited here only to show the large number of these organic deposits which, despite their overall similarity, can hardly be correlated with the organic layers described above without a reappraisal and further investigation.

*"Kulur submerged forest"* (Agarwal & Gudzer, 1974)

At Kulur, near Mangalore, the authors have mentioned a "submerged forest" without indicating the precise location (a village named Kulur lies about 5 km north of Mangalore) or altitude. The age of this formation (TF 966) is "beyond the dating range of radiocarbon"

*Netravati River* (Murthy, 1977)

During the construction of the road-bridge over Netravati River, "lignitised wood with clay" was discovered in the foundation wells. This layer was found in several bore-holes at depths ranging —25 m to 30 m. Since the level of the 0-mark above mean sea-level was not specified, the exact elevation of this layer cannot be estimated. No isotopic age was given. Due to the lack of any precise data on the elevation, age and also lithology, this very interesting occurrence cannot be considered in detail.

## ESTIMATED AGE OF THE INTERMEDIATE ORGANIC CLAY FORMATION

From the above it can be stated that (1) the discontinuous layers of the intermediate organic clay formation belong to the same generation of sediments, (2) these sediments have been deposited ± at sea-level, (3) the period of deposition is older than 45,000 years B.P. as ascertained by $^{14}C$ data. It is possible to obtain, at least approximately, an indication on the age of the deposition of this coastal formation by plotting its original altitude against those of the curves of sea-level changes defined for periods older than 45,000 years B.P.

It is, therefore, necessary to specify the original altitude of the intermediate organic clay formation by reconstituting the epeirogenic activity during Late Quaternary and to estimate the possible vertical shift in the altitude of the land.

Another point to be considered while determining the original altitude of the deposits is the rate of compaction which in this type of clayey sediment is always high. It has been suggested that clayey muds can gradually be reduced to 10-25 per cent of their original thickness (Greensmith & Tucker, 1986). Because of the small thickness of these layers which after compaction is only a few meters, this process needs not to be taken into account to assess the original altitude of deposition.

### Neotectonics in coastal Kanara and neighbouring areas

Peninsular India is an old craton, devoid of any tectonic activity. This notion which has long been accepted (Vredenburg, 1903) was again demonstrated through the new magnetic maps obtained from satellites (Acache *et al.*, 1988). However, this method of investigation cannot identify the occurrence of faint regional isostatic adjustments. These movements are precisely those which have to be considered for the interpretation of our results in Kanara.

Kanara has formed the subject of numerous and detailed geological studies but only a few have been published on neotectonics in coastal Kanara (Joshi *et al.*, 1973). The feeble interest shown by researchers on this topic is mainly due to lack of data and also because of the absence of any evident neotectonic effects in this area.

In fact, further support can be found to prove the relative stability of Kanara during the Quaternary. A perusal of the recent *"Neotectonic map of India"* (Dhoundial, 1987) confirms this stability since it shows no distinct active process in this part of the western coast, particularly the low heat flow and seismicity contrasting with the higher values of these data north of 16°N, in coastal Maharashtra. It is significant that investigations on neotectonics and eustasy are more frequent in Maharashtra (Agarwal & Guzder, 1974; Vaidyanadhan, 1987) than in the southern regions where very little attention has been given to this subject.

Still in Maharashtra, at about 150 km north of Kanara, another raised beach a few meters above the present sea-level is mentioned near Vengurla, Sindhudurg District (Sukhtankar *et al.*, 1986). This feature is hardly due to a higher relative sea-level stand occurring during the Late Holocene but could be rather a characteristic of neotectonic activity which affects the northern part of the west coast.

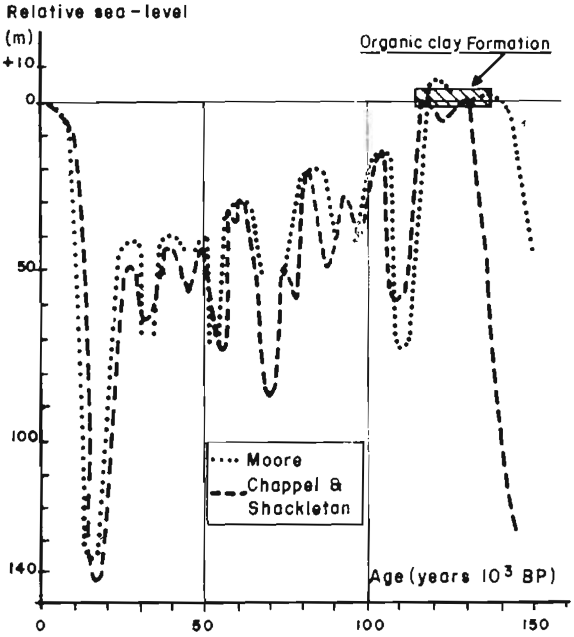
Raised beaches have been described all along the southern part of the west coast but they do not involve recent epeirogenic activity. For example, as early as 1883, R. B. Foote observed beach deposits containing marine shells 5 m above the present sea-level near Cape Comorin. He considered this as clear evidence of either a rise of the coast or a fall in the sea-level. Much later, radiometric date of this same coral was reported to be about 32,000 years B.P. (Rajagopalan *et al.*, 1982; Kale & Rajaguru, 1985), a date which cannot be retained without reservation as with all $^{14}$C age data of carbonates deposits (BS 132, BS 133).

"Monastirien" raised beaches have been cited (Foote, 1883) near Udipi which is within our study area, but we have not come across such outcrops up to now. Moreover the regular sedimentation observed during Late Holocene in the Coondapoor lagoon nearby (Tissot, 1990) constitutes another argument against any recent marked change of the relative sea-level which would have disturbed the sedimentation process and affected the palynological results.

From the brief outline above, it can be admitted with a reasonable degree of accuracy that the original altitude of the intermediate organic clay formation was roughly that of the present sea-level.

## Comparison between the altitude of the intermediate organic clay formation and sea-level curves

Based on various isotope studies, several sea-level curves have been reconstructed for Late Quaternary. Those of Moore (1982) and Chappel and Shackleton (1986) which are very similar, have been considered here (Text-fig. 4). Some authors (Newman *et al.*, 1980; Giresse, 1987) draw attention to the fact that the changes in the sea-level cannot be summarized by a unique global curve because of local or regional events which could produce large distortions, preventing the use of a theoretical global sea-level curve as a correlating tool. However, this method can be validly applied for our study because of the uniformity of the two curves retained here which constitutes good presumption of their accuracy on the one hand and the tectonic stability of the investigated area during the Late Quaternary on the other.



**Text-figure 4**—Late Quaternary sea-level curves from Moore (1982) and Chappel and Shackleton (1986). The Kanara intermediate clay formation is tentatively plotted on this diagram.

During the Interglacial Riss-Wurm corresponding to Eem, the well-known European terminology for the last major Interglacial at about 125,000 years B.P., the sea-level was at an elevation close to that of the present level. There is a general agreement on this world-wide sea-level stand. Hence the conjunction in both the altitudes, i.e., sea-level and deposits, permit us to accept this date of about 125,000 years B.P. as the age of the deposition of the intermediate organic clay formation. There is no reliable alternative to this proposal. In particular, it is not feasible to accommodate the younger high sea-level stands occurring during the Wurm interstades because such a choice implies an upheaval of the continent younger than the deposition. In fact, this hypothesis cannot be fully excluded since the shifting would be small, only a few tens of meters for some interstades.

## PALEOFLORISTICS

A comparison of the palynological assemblages from this intermediate organic clay formation with those from the Late Holocene mangrove deposits (Tissot, 1990) in the same area, near Coondapoor (Text-fig. 1), shows that in spite of overall similarities, some differences exist in the details (Text-fig. 4):

*Sonneratia*—At present, *Sonneratia* is found in the mangrove communities of Karnataka where it is common but not abundant (Untawale & Wafar, 1986). It is represented by a few pollen grains in the Late Holocene of Coondapoor but its pollen has never been observed in our samples.

*Poaceae*—The percentages of Poaceae (0.3 to 3.9; average: 1.5) are always smaller in the intermediate organic clay formation than in Coondapoor (2.9 to 12.3, average: 6.5); Poaceae are found preferentially in the savannas or deciduous forests but also in low deciduous thickets (Pascal, 1984). Hence, it is not reliable to draw climatic or paleogeographic clues from such an ubiquitous family, specially when the differences in the palynological results are not sufficiently pronounced.

*Cyperaceae*—The percentages of Cyperaceae are slightly lower in our samples ranging from 1 to 1.6 (average: 1.2) as against 0.7 to 3.5 (average: 2); Cyperaceae is often considered as a marker of humid conditions.

*Fern spores*—The fern spores also have smaller representation in "Eemian" (0.6 to 5%; average: 1.7%) than in Holocene samples (1.6 to 9%; average: 6%). It is an accepted fact that the number of fern spores increases with a more humid climate.

*Fresh water algae*—Practically absent in the intermediate clay formation, *Pseudoschizea* and *Botryococcus* have been consistently recorded in the Late Holocene of Coondapoor but with low values (0.5 to 4.3% of the total pollen + spores).

*Hinterland vegetation*—It is well known (Thanikaimoni, 1987) that the pollen released by the hinterland vegetation never have a fair representation in mangrove sediments. The mangrove forest itself being a high producer of pollen, the allochthonous pollen are relatively too few and the remote vegetation does not appear clearly in the pollen assemblages. In our study, from the taxa grouped under "miscellaneous" records (Table 1), no significant difference can be seen between the past and the present hinterland floras.

## PALEOCLIMATE

In the absence of concrete evidence, it is difficult to accurately reconstruct the paleoclimate. However, some reliable indications and clues can be obtained from our palynological results.

### Palynological assemblages

The overall resemblances between "Eemian" and Late Holocene palynological assemblages makes it possible to postulate that during these periods the general climatic features were not very different. This conclusion agrees well with the climatic pattern of Quaternary which is closely related to global sea-level changes: lowstand sea-levels occur during cold stades when the climate became drier, whereas highstand sea-levels correspond to warm and more humid stades, a scheme which has been confirmed by the study of oceanic cores in the Arabian Sea (Caratini *et al.*, 1981; Van Campo E., 1986). The intermediate organic clay formation having been deposited during a highstand sea-level, the climate prevailing at that time would have been basically warm and humid, comparable to the present.

### Marine microplankton

The occurrence of dinoflagellates in Late Holocene mangrove deposits is variable along the west coast; in Coondapoor (Tissot, 1990), Dinoflagellate cysts are numerous (5 to 20.7% of the total palynomorphs; average: 12.3%) and are also common in Vembanad Lake, Kerala (work in progress). Yet dinoflagellate cysts have rarely been recorded in "Eemian" samples. Only some rare cysts of *Operculodinium* are present in Navunda samples. Hence, it seems necessary to take a climatic factor into account, viz., the rainfall regime, to explain the occurrence of dinoflagellates cysts in mangrove sediments.

The current monsoon regime with its alternation of a long dry season and a shorter rainy season enables the sea water to penetrate into the lagoons, permitting the growth of dinoflagellates. Thus the quasi-total absence of dinoflagellate cysts in "Eemian" sediments could be the consequence of a wetter climate with a greater supply of fresh water in the lagoon where the sea water-fresh water limit is pushed seawards. However, as seen above, we have no proof of such a wet climate. The low occurrence of marine microfossils could be explained by a more regular rainfall distribution during the course of the year and a less contrasted regime; in this case the lagoons may have been flooded with fresh or brackish water for a longer period than at present.

### The oceanic core OSIRIS 77202

Lack of sufficient data on the last Interglacial in and around India (Williams, 1985) makes it difficult to place our results in a more general frame. A marine core taken off shore Oman, in the Indian Ocean (19° 13′ 3 N : 60° 40′ 9 E; 2427 m) was studied by means of the oxygen isotope ($^{18}O/^{16}O$) and palynology (E. Van Campo, 1983). From this the regional climatic evolution is known from about 150,000 years B.P. It has been emphasized that the climatic conditions of the Late Pleistocene were the wettest during the last Interglacial, centred around 125,000 years B.P. This period is marked by high values of the $^{18}O/^{16}O$ ratio and among palynological characteristics, by the dominance of humid pollen taxa, such as Cyperaceae, as well as a few *Rhizophora* resulting from the development of mangroves on the shorelines nearby; in this core, mangrove pollen were observed only twice; during this Interglacial and at about 10,000 years B.P. Such results are probably the consequence of a slightly wetter climate than to-day.

In the "Eemian" of Kanara, it is hard to state a wetter climate than at present from our palynological observations because Cyperaceae pollen, pteridophytic spores and fresh water algae, all considered as markers of humid conditions, are slightly more abundant during Late Holocene than during "Eemian".

The difference in the climate could be rather linked to the rainfall regime, the alternating seasons being less pronounced at that time.

## CONCLUSION

No irrefutable argument can be advanced to state that the intermediate organic clay formation along the Kanara Coast was deposited at about 125,000 years B.P. However, the combination of facts assembled here, even with their hypothetical aspects, provides a result which may not be considered as accurate reference mark but constitutes an useful chronological guide for a period where hardly any information is available in this part of India. The comparison between "Eemian" and Late Holocene spectra in Kanara leads to remark that: (1) the floristic differences between the two periods are few; (2) regarding the general concept of humidity the "Eemian" climate was not quite distinct from Late Holocene conditions but it could present a difference in the regime with less pronounced alternating seasons.

## ACKNOWLEDGEMENTS

In 1976, Mr K. S. Shivaram Karanth from Shaligram, deeply interested in the history of the black clay with numerous plant fragments extracted from his well, had given some samples to Professor B. G. L. Swamy. Dr G. Thanikaimoni, at the request of his previous teacher Professor Swamy, carried out a palynological study of this organic clay and recognized it as deposited in a mangrove environment. The age of this sediment being specified as older than 40,000 years B.P., the questions posed by this problematic layer resulted in this study which is dedicated to its two promoters, Professor B. G. L. Swamy and Dr G. Thanikaimoni.

We wish to thank Mr G. Bourgeon (Pedologist, French Institute, Pondicherry) who pointed out some exposures of the intermediate clay formation in Kanara to us and Mr E. Subraya, for his hospitality at his estate of Navunda.

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# Sholas in south Indian montane: Past, present and future

H. P. Gupta

Gupta, H. P. 1990. Sholas in south Indian montane: Past, present and future. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 394-403.

The forest, short to medium-boled attaining a height between 15 to 20 m, constitutes the only tropical montane forest in pockets in the montane region of Nilgiris, Anamalai, Palni and Silent Valley, southern India. Palynological studies have revealed that these shola forest communities had been wide spread in the past. They originated through gradual invasion of shrubs and under trees into the grassland, about 35,000 years BP, corresponding in time to the last glaciation in the north and were established about 24,000 years BP. The progressive recession of sholas had started around 7,000 years BP. Both biotic and climatic factors have not only reduced the sholas to its present day minimal size but have also created conditions under which the community has almost completely stopped regeneration outside the sholas.

Degeneration and fast receding trend in the shola communities and expanding grasslands and massive plantation of exotic trees reduced the soil as well as above surface moisture which is not conducive for the sholas. If preventive measures are not taken the sholas in near future would ultimately perish.

**Key-words**—Palynology, Shola forest, south Indian Montane.

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## साराँश

### दक्षिण भारतीय पर्वतीय शोला वन : अतीत, वर्तमान एवं भविष्य

हरीपाल गुप्ता

दक्षिण भारत में नीलगिरी, अनामलाई, पलनी एवं शान्त घाटी के पर्वतीय क्षेत्र के कुछ सीमित उपक्षेत्रों में 15 से 20 मीटर की औसतन ऊंचाई वाले उष्णकटिबन्धीय पर्वतीय वन विद्यमान हैं। परागाणविक अध्ययन से व्यक्त होता है कि ये शोला वन अतीत में दूर-दूर तक विस्तृत थे। ये वन उत्तर में अन्तिम हिमनदन के समय लगभग 35,000 वर्ष पूर्व घासभूमि में झाड़ियों एवं अधोवृक्षों के शनैः शनैः अतिक्रमण से विकसित हुए तथा लगभग 24,000 वर्ष पूर्व स्थापित हो पाये। लगभग 7,000 वर्ष पूर्व शोला वनों का ह्रास हुआ। केवल जलवायवी एवं जैविक कारक इनके ह्रास का कारण ही नहीं हैं अपितु इनके और प्रसार एवं विकास के लिए इन कारकों ने प्रतिकूल परिस्थितियाँ उत्पन्न कर दी।

शोला वनों के तेजी से होते ह्रास तथा बढ़ते घास के मैदानों एवं विदेशज वृक्षों के लगाने के कारण मिट्टी एवं उपसतह की नमी काफी कम हो गई है जो कि शोला वनों की अच्छी वृद्धि के लिए सर्वथा अनुपयुक्त है। अगर उचित उपाय न किये गये तो निकट भविष्य में शोला वन समाप्त हो जायेंगे।

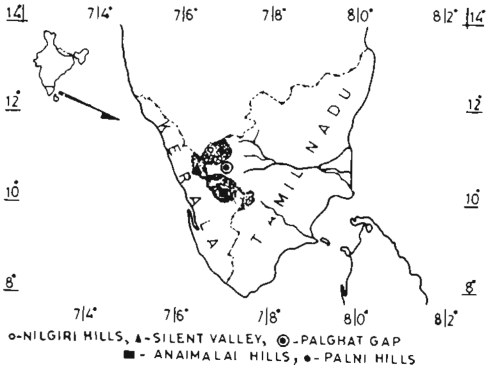
## PRESENT

CLOSED evergreen woods occurring above 1,500 m on high hills in the Nilgiris, Anamalai, Palni and Silent Valley in southern India are known as sholas (Text-fig. 1). This community is composed of both tropical and temperate species which are generally found in the isolated patches in protected valleys, often associated with streams. Trees are characteristically short-boled, rarely exceeding 15 m in height, well branched, attaining considerable girth and supporting numerous epiphytes. The crowns are dense and leaves coriaceous. These patches of shola grow under the equable climate with varying annual rainfall from 130 to 650 mm. The vegetation of south Indian montane region is ecologically important because two distinct plant communities, viz., evergreen shola and grassland, co-exist in juxtaposition and apparent equilibrium (Ranganathan, 1938).

Considering the status of shola and grassland, the following main points have been discussed:

1. Role played by man in grassland formation
2. Recent afforestation in the grassland
3. Future grassland—shola ecology

Besides the effect of high-speed winds, the



**Text-figure 1**—Showing shola localities in south Indian montanes.

effect of fire and grazing is very pronounced. A record, dated 1117 AD, refers to Todas—a pastoralist tribe who fired grasses annually in order to promote the growth of young tender grass more edible for livestock (Noble, 1967). If the practice of fire continues, the ever expanding grassland shall develop and the shola will be diminished in areal extent. During fire, flames reach shola edges and damage the trees too. The damaged trees are prone to diseases and insects. Slowly, shola trees perish and grasses spread.

Interestingly, phytogeographical affinities provide a link with western and eastern Himalaya. The wet forests of south Indian hills could be compared with the northern temperate oak-conifer forest of western Himalaya. The oaks and conifers, except for *Podocarpus* sp., are absent from south Indian hill forests, the members of Ternstroemiaceae and Lauraceae are common to both.

*Rhododendron arboreum*—a conspicuously common plant in north-west Himalaya is represented by its variety *nilgiricum* in south Indian hill tops. Likewise *Gaultheria fragrantissima* is found on south Indian montanes while at the same elevation *Lyonia ovalifolia* occurs as a chief associate of oak-woods in north-west Himalaya.

The common plants that occur in eastern and western Himalaya and in south Indian hills are : *Indigofera pulchella, Hamiltonia suaveolens, Viola patrinii, Peperomia reflexa* and *Reinwardia trigyna* (Mukherjee, 1935).

Hills of Bihar and Orissa served as a route of migration and played a vital role in the migration from southwest to northeast, or *vice versa* according to Hooker and Thompson (1855). Razi (1954) suggested that there is a trend prevailing in the plant migration from south to northeast.

The statement of Fyson (1915-21) that 17 per cent of the species of south Indian hill tops occur on Khasi hills, 12 per cent in the temperate parts of Himalaya and none in the intervening regions even along the Western Ghats, does not hold good since the species common to the Western Ghats, Bihar and Orissa have been recorded.

Regarding the occurrence of south Indian plants on the Bailadilla range in Baster, Madhya Pradesh, Mooney (1942) states "It does not call for great powers of imagination to visualize how species having their origin in Nilgiris, Palni and other hills of Mysore and Travancore, etc. may have travelled along the line of Eastern Ghats until they reached their extremity in Kashipur plateau of Kalahandi state and the agency tracts of Ganjam and Vishakhapatnam districts with their humid climate". He further presented evidence of the south-north migration of plants in the light of the occurrence of thirty-two species of southern India in Bailadilla range. However, at the same time, he found it difficult to explain the occurrence of 36 north eastern species in the latter.

Hora (1949) took recourse of his "Satpura hypothesis" and explained that although the present day topography and climatic set up do not permit the plants to migrate, the conditions that prevailed during the Pio-Pleistocene times were favourable for such migrations. It was once thought that freezing of climate was responsible for migration of plants and animals (Medicott & Blandford, 1870).

Meher-Homji (1975) opined that migration of species was possible, firstly climate was cooler in the past with lower rate of evapo-transpiration enabling species of tropical deciduous forest to thrive in the plains and the montane forest to descend below 1,500 m. The montane species, being finicky, disappeared quickly from altitude below 1,500 m when warmer climate set in during the post-glacial period, and secondly climate remained unchanged but diaspores of deciduous forest species reached the altitude of 800-1,300 m, and montane species above 1,500 m. Recently, Meher-Homji (1984, 1987-88) has provided further details of biogeographic and ecological diversity in Nilgiri District.

The commonly held view about the distribution of Himalayan species on south Indian hills is that the Pleistocene refrigeration was responsible for pushing some Himalayan plants southward (Burkill, 1924). Blasco (1970, 1971 a, b) emphasized that long distance dispersal through birds or winds is the main possibility for migration of plants, but Meher-Homji (1975) pointed out certain problems with the long distance dispersal and proposed three hypotheses, viz., (i) parallel evolution, (ii) long distance dispersal, and (iii) direct land-connection in the distant past.

It has been the subject of ecological discussions since long as to which of the two plant communities be designated as climatic climax. Champion (1936) did not consider grasslands as climaxes anywhere since he accounted for their origin from the destruction of sholas. Bor (1938) realised that sholas alone are the true climaxes whereas grassland is only a biotic climax. Ranganathan (1938) opined that both sholas and grasslands formed co-climaxes. Shankaranarayanan (1958) accepted the views of Champion and Bor that grasslands are, in real sense, not the true climax. He further suggested that grassland is a subclimax governed by a set of biotic factors which did not admit easy passage towards the final climax.

The precise information of vegetation of shola forest could be obtained by grouping taxa in an order, to meet the ecological requirements, differential pollen production, dispersal, and preservation. Such groupings of the characteristic taxa are as follows (Meher-Homji, 1965)·

### A. Core shola trees

Aquifoliaceae
    *Ilex denticulata, I. wightiana*
Araliaceae
    *Schefflera racemosa*
Celastraceae
    *Euonymus crenulatus, Microtropis ramiflora, Celastrum paniculata*
Elaeocarpaceae
    *Elaeocarpus ferrugineus*
Ericaceae
    *Rhododendron nilagiricum*
Euphorbiaceae
    *Glochidion neilgherense, G. fagifolium, Macranga indica*
Flacourtiaceae
    *Hydnocarpus alpina*
Icacinaceae
    *Mappia tomentosa, M. foetida, M. ovata*
Lauraceae
    *Cinnamomum wightii, C. perottettii, Actinodaphne bourneae, Litsea wightiana, Phoebe wightii.*
Magnoliaceae
    *Michelia nilagirica*
Myrtaceae
    *Syzygium arnottianum*
Oleaceae
    *Olea glandulifera*
Rosaceae
    *Pygeum gardneri, Photinia lindleyana*
Rubiaceae
    *Ixora notoniana*
Sabiaceae
    *Meliosma wightii, M. arnottina*
Sapotaceae
    *Sideroxylon tomentosum*
Staphyleaceae
    *Turipina nepalensis*
Symplocaceae
    *Symplocos foliosa, S. obtusa, S. pendula*
Ternstroemiaceae
    *Ternstroemia japonica*
Theaceae
    *Gordonia obtusa*

### B. Marginal shola trees

Icacinaceae
    *Gomphandra coriacea*
Euphorbiaceae
    *Daphniphyllum glaucescens*
Rosaceae
    *Photonia notoniana*
Melastomataceae
    *Osbeckia reticulata*
Caprifoliaceae
    *Viburnum coraceum, V hebanthum*

### C. Core shola shrubs

Berberidaceae
    *Berberis tinctoria*
Theaceae
    *Eurya japonica*
Rutaceae
    *Melicope indica*
Rhamnaceae
    *Rhamnus wightii*
Rubiaceae
    *Oldenlandia stylosa, Chomelia asiatica, Pavetta breviflora, Stylocoryne lucens, Psychotria elongata, Lasianthus coffeoides*
Myrsinaceae
    *Maesa perrottetiana*
Acanthaceae
    *Strobilanthes foliosus, S. pulneyensis, S. papillosus, S. urceolaris, S. micranthus, Barleria involucrata*
Thymelaceae
    *Lasisiphon eriocephalus*
Elaeagnaceae
    *Elaeagnus kologa*
Santalaceae
    *Osyris arborea*
Loranthaceae
    *Elytranthe loniceroides*
Urticaceae
    *Pouzolzia bennethina*

### D. Marginal shola shrubs

Berberidaceae
    *Mahonia leschenaultii*
Sapindaceae
    *Dodonaea viscosa*
Caprifoliaceae
    *Lonicera leschenaultii*
Ericaceae
    *Gaultheria fragrantissima*
Oleaceae
    *Jasminum brevilobum, J. bignoniaceum, Ligustrum perottetii*

### E. Core shola herbs

Ranunculaceae
    *Ranunculus muricatus*
Brassicaceae
    *Cardamine africana*
Violaceae
    *Viola serpens*
Caryophyllaceae
    *Cerastium indicum, Stellaria paniculata, S. media*
Balsaminaceae
    *Impatiens orchioides, I. neo-barnesii, I. rufescens*
Apiaceae
    *Sanicula europaea, Heracleum sprengelianum*
Rubiaceae
    *Anotis longiflora, A. monosperma, Ophiorrhiza brunonis, O. roxburghiana*
Asteraceae
    *Senecio walkeri*
Lamiaceae
    *Leucas lamifolia*
Amaranthaceae
    *Achyranthes bidentata*
Dipsacaceae
    *Dipsacus leschenaultii*
Piperaceae
    *Peperomia reflexa*
Moraceae
    *Dorstenia indica*
Urticaceae
    *Laportea terminalis*
Liliaceae
    *Disporum leschenautianum*
Poaceae
    *Ishchne punthiana*

### F. Marginal shola herbs

Ranunculaceae
    *Clematis wightiana*
Pittosporaceae
    *Pittosporum tetraspermum*
Malvaceae
    *Hibiscus angulosa*
Geraniaceae
    *Geranium nepalense*
Balsaminaceae
    *Impatiens floribunda*
Melastomataceae
    *Osbeckia cupularis, O. leschenaultiana*
Gentianaceae
    *Halenia perrottetii*
Lamiaceae
    *Pogostemon speciosus, Scutellaria violacea, S. rivularis, Leucas lancaefolia*
Euphorbiaceae
    *Euphorbia rothiana*

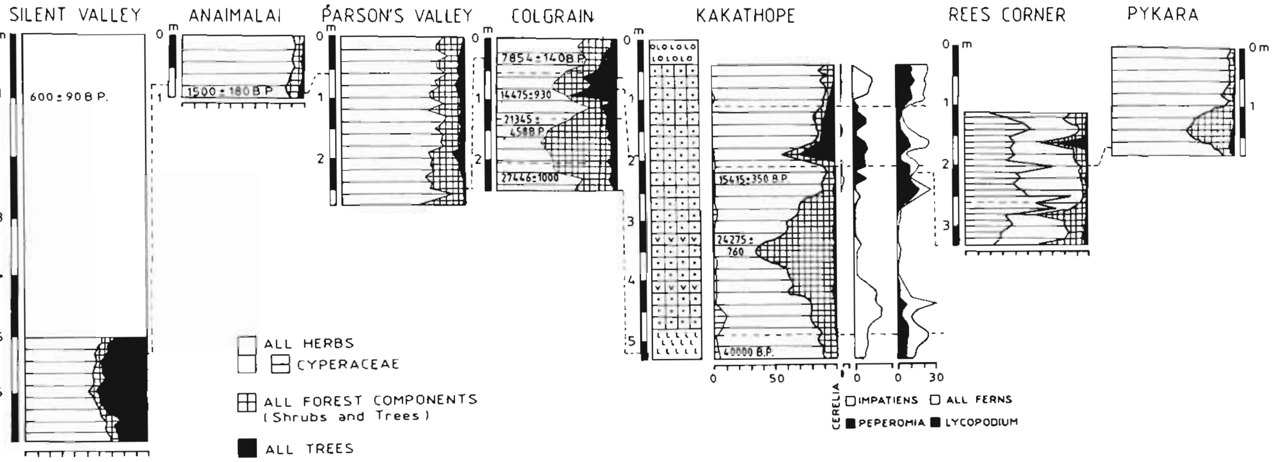
### G. Shola climbers

Menispermaceae
    *Diploclisia glaucescens*
Rutaceae
    *Xanthoxylum tetraspermum, Toddalia asiatica*
Vitaceae
    *Parthenocissus neilgherriensis*
Papilionatae
    *Perochetus communis, Dumasia villosa*
Rosaceae
    *Rosa leschenaultiana*
Passifloraceae
    *Passiflora leschenaultii*
Loganiaceae
    *Gardneria ovata*

## PAST

An effort has been made to work out the history of shola, step by step, since the time of last glaciation. Fine resolution palynostratigraphy, correlation of Quaternary sedimentary sequences from Nilgiris, Palni, Anamalai in Tamil Nadu and Silent Valley in Karala, have been used to reconstruct vegetation characteristics and land-use by man for pastoral and arable systems, which made it possible to translate all finer details of vegetation dynamics for the past 35,000-40,000 years BP.

For tracing the history and development of vegetation in time and lateral extent, the general practice is to work out changes in the relative abundance of pollen assemblages. These changes in the relative values of arboreal and nonarboreal vegetation pattern are considered to be brought about by climatic, biotic and edaphic factors or cummulative effect of all the three factors. However, in southern India, it is not possible to follow the conventional method to evaluate and reconstruct palaeofloristic models. Because of stenopalyny,



**Text-figure 2**—Palaeofloristic reconstruction in south Indian montanes.

differential production, dispersion and preservation of pollen and entomophily, generally tree taxa of shola are either unrepresented or are under represented in pollen assemblage. Hence, the face value evaluation of pollen diagram does not exhibit arborescent vegetation. To overcome this problem, modern surface samples have been investigated to correlate the distribution pattern of arborescent and non-arborescent taxa. Through these studies it has been proved that tree taxa are not represented in the pollen rain to the extent they are actually present in the forest composition. In view of these technical vagaries, certain herbaceous taxa which are associated with shola forest and are abundantly present in the pollen rain have been taken into consideration for highlighting the existence of forest (Gupta & Prasad, 1985). Thus, a forest type may be represented even when herbaceous taxa are found in abundance (Guinet, 1966).

In order to have precise information of palaeovegetation, different areas investigated so far are discussed separately and, thereafter, a synthesis has been made to present the regional picture of south Indian hills (Text-fig. 2).

## PALAEOFLORISTICS OF NILGIRIS

Four soil profiles, one each from Kakathope, Rees-Croner, Colgrain, Pykara and Sandynallah have been palynologically investigated. In addition, a number of surface samples from Colgrain have been analysed. Kakathope, the reclaimed swamp area now transformed into the State Potato Seed Farm, situated about 6 km northwest of Udhagamandalam (Ootacamund) city, at an altitude of 2,500 m a.s.l. (lat. 11°36′ N, long. 76°52′ E). Kakathope swamp comprises an area of about 25 acres in a flat, undulating valley following the contours of the valley between round-topped hills which are totally bare except for recent plantations of eucalyptii and acacias. The indigenous vegetation is lacking and the area is under extensive biotic pressure.

A 5.30 m deep soil-profile has been investigated palynologically (Gupta, 1971). Lithostratigraphy of the area has revealed that the deposits, largely composed of humified and compressed organic mud with abundant plant debris, were laid under lacustrine conditions. However, 30 cm top and bottom sediments with clay and pebbles indicate fluvial environment. The rate of deposition of organic mud was slow and estimated to be 1 cm per 83 years. The biomass potential since 35,000 years BP till 3,000-4,000 years BP was very high as compared to the present day biomass accumulation.

While analysing the signatures of past vegetation from 40,000 years old deposits, it was observed that vegetation was not static, instead, several vegetation shifts, small and big, had occurred. Following the concept that these shifts in vegetation was brought about by climate followed by biotic and edaphic factors, the pollen diagram plotted from Kakathope has been phased under four heads, as given below:

### Phase I (between 40,000-35,000 years BP)

During this phase, the vegetation chiefly consisted of herbaceous elements with shrubs as co-dominant and a few scattered trees indicating an open shrub savanna. The taxa characteristic of this phase are as follows:

| | |
|---|---|
| Dominant (Herbs) | — Poaceae, Cyperaceae, Chenopodiaceae, Caryophyllaceae, Urticaceae, Liliaceae, |

*Justicia, Campanula, Geranium* etc.
Co-dominant (Shrubs) — Malvaceae, Rutaceae, Fabaceae, Oleaceae, *Berberis, Strobilanthes,* etc.
Sporadic (Trees) — *Rhododendron* and *Ilex*
High — Ferns
Low — Aquatics

### Phase II (between 35,000-15,000 years BP)

This phase is characterized by a shift in vegetation through gradual invasion of shrubs into the open land, marking an initiation of a thicket with dominance of shrubs alongwith sporadic herbs. Nevertheless, tree taxa continued to be isolated. The species composition of this phase is as follows:

Dominant (Shrubs) — Oleaceae, Rutaceae, Fabaceae, Rosaceae, *Lonicera, Berberis, Strobilanthes, Dipsacus, Sarcococca* etc.
Isolated (Trees) —*Rhododendron* and *Ilex*
Sporadic (Herbs) — Poaceae, Apiaceae, Urticaceae Liliaceae, Chenopodiaceae, Caryophyllaceae, Asteraceae, *Artemisia, Justicia, Portulaca, Impatiens,* etc.
High — Aquatics
Low — Ferns

### Phase III (between 15,000-7,000 years BP)

In this phase, arboreal vegetation was established indicating the formation of closed evergreen forest. Most of the shrubby taxa which were prevalent in the preceding phase declined significantly. Some shrubs of savanna, such as *Berberis* and *Sarcococca*, became rare with the onset of forest formation. Amongst herbs, the forest associates, like *Peperomia, Impatiens, Senecio*, etc. improved proportionately. A few herbaceous elements of open land have also been recorded. The floristic composition of this phase is as follows:

Dominant (Trees) — *Gordonia, Elaeocarpus, Euonymus, Ilex, Rhododendron,* etc.
(Forest Associated herbs) — *Peperomia, Impatiens, Senecio* etc.
Co-dominant (Shrubs) — Rosaceae, Rutaceae, Fabaceae, *Lonicera, Strobilanthes, Dipsacus, Sarcococca, Berberis,* etc.
Sporadic (Herbs) — Asteraceae, Liliaceae, Urticaceae, Caryophyllaceae, Apiaceae, Chenopodiaceae, Poaceae, *Gentiana, Portulaca, Justicia, Campanula, Plantago, Artemisia,* etc.
High — Ferns
Low — Aquatics

### Phase IV (between 7,000 years BP-till date)

This phase has witnessed a decline in tree taxa. All those tree taxa alongwith shrubs constituting the closed evergreen forest in the preceding phase have slowly and gradually declined ceding place to the heathland condition. This shift in vegetation is not wholly and directly brought about by climate. During this phase, man had entered the landscape at Kakathope and exploited the forest wealth. In recent past, man has so ruthlessly damaged the forest elements that a major part of the hill tops has become bare and many of the forest associated herbaceous taxa, left after forest clearance, have also been damaged by frost and speedy chilly winds which otherwise would not have affected these ground cover herbs under the forest canopy.

Rees-corner, located about five km south-west of Udhagamandalam, is smaller as compared to Kakathope swamp. It is almost dry and inhabited by sedges, grasses, *Drosera* and *Equisetum*; along its margins, thick patches of shola could be seen. The swamp is regularly fed by sub-soil water from a nearby water-course flowing along its slope. It is also being regularly cleaned by the Soil Conservation Department and dykes have been constructed through the swamp for the purpose of drainage system.

One 3.30 m deep profile has been collected for investigation (Gupta, 1971). The top 0.30 m sediment is lateritic soil mixed with sand and pebbles and, thereafter, up to 0.90 m laminated gritty clay is present with no biomass accumulation. Between 0.90 to 2.80 m, sediments comprise clayey organic mud. The bottom sediments between 2.80 to 3.00 m are composed of clay, mixed with sand and pebbles with no biomass.

The palynological sequence from Rees-corner is comparable with upper part of Kakathope profile where the establishment of closed forest came into being. Therefore, on the basis of comparison, the total palynological sequence could be dated to about 15,000 years BP. In view of the total similarities in two pollen sequences, almost the same picture of vegetation development has emerged from Rees-Corner.

Colgrain, located about 15 km south of Udhagamandalam and 5 km south of Nanjanad on

Avlanche Road, at an altitude of about 2,450 m a.s.l. lies within the Kundah range in Nilgiris. This area is quite protected and the swamp is surrounded by patches of shola forest. The biotic pressure is mild and not yet fatal to the shola plant community.

A 2.50 m deep profile has been collected dating back to a period of about 30,000 years BP (Gupta & Prasad, 1985). In addition, surface samples procured from within the shola and open land have been investigated in order to work out the modern pollen vegetation relationship. The field examination of sediments reveals that degree of decomposition varies greatly: a sharp demarcation in the lithostratigraphy is seen at 1.30 m depth The top 1.30 m sediments comprise clayey, organic mud which is largely mouldered; it contains high biomass potential. The bottom 1.20 m sediments are pale-yellow-coloured clay with fine to coarse sand and the biomass potential is almost negligible. The rate of sedimentation for the top and bottom sediments is estimated 1 mm per 16 years and 1 mm per seven and-a-half years, respectively.

Within the framework of pollen analysis of modern sediments, a surface sample procured from beneath *Eurya* complex within the shola yielded pollen of *Eurya* to the extent of 72 per cent of the total assemblage In the successive samples procured on way to open land, *Eurya* pollen frequency began to fall considerably and ultimately the pollen disappeared from sample collected in the open land, near shola. Thus, surface sample study has added to our knowledge that pollen of tree taxa generally do not uniformly disperse throughout, and hence information so perceived could be utilized *Sensu stricto* for the reconstruction of palaeofloristics and its interpretation.

The palaeovegetation reconstructed from Colgrain is broadly similar to Kakathope. However, some minor differences and shift in time boundaries observed could be assigned to the local factors operating independently. For instance, the shrub savanna phase has been recorded between 30,000-25,000 years BP at Colgrain which was between 40,000-35,000 years BP at Kakathope. Similarly, Phase II, between 35,000-15,000 years BP at Kakathope recording the establishment of shrubby vegetation could be equated to Colgrain Phase II, between 25,000-12,000 years BP. The Phase III at Kakathope, between 15,000-7,000 years BP, marking the establişhment of closed evergreen forest, corresponds to the Phase III of Colgrain, between 12,000-2,000 years BP. The decline in shola at Colgrain has been recorded only 2,000 years BP unlike Kakathope where decline of forest took place much earlier around 7,000 years BP. These variations observed in two different localities are largely due to local anthropic factor; the exploitation of forest at Kakathope had begun for the last 7,000 years BP whereas human activity started at Colgrain only recently and not very intensively. Another reason for this phenological variation is that Kakathope abounds with the hill tribes such as Badagas, Kotas, Kurambhas, Irulas, Todas, etc.

Pykara, located about 19 km north of Udhagamandalam city on Mysore road, lies near the Pykara hydro-electric station. A 1.75 m deep profile has been investigated palynologically (Menon, 1968). As neither listhostratigraphy nor chronostratigraphy have been provided, nothing could be inferred about the nature and antiquity of the deposits. The palynological study reflects predominance of grasses throughout the pollen diagram attaining 85 per cent of total vegetation in upper half of the pollen diagram whereas lower half of the diagram is dominated by Poaceae and pteridophytes. Other taxa encountered in the assemblage are herbaceous, such as Brassicaceae, Balsaminaceae, Apiaceae, Asteraceae, Scrophulariaceae, Chenopodiaceae, Xyridaceae and Cyperaceae. Anacardiaceae and Caprifoliaceae in this assemblage belong to trees and shrubs, respectively.

On comparison, Pykara pollen diagram could be correlated with the top most part of Kakathope pollen diagram which has an estimated date of about 5,000 years BP. This period of Kakathope has been identified as the phase of anthropogenic activities and rapid savannization, this is true of Pykara as well.

Sandynallah, another reclaimed swamp area of about 422 hectare land now transformed into the sheep-breeding station, is situated (11°26′ 12″ N, 76°38′2″ E; 2,200 m a.s.l.) on right side of the Pykara road about 70 km NW from Udhagamandalam. The indigenous vegetation is almost lacking in and around the area, except for recently introduced frost tolerant trees, viz., *Pinus patula, Acacia melanoxylon, A. decurrens, Grevillea robusta,* etc.

One 2.30 m deep soil profile was pollen analysed and dated to 30,000 ± 1,500 years BP (Vasanthy, 1988); however, anomaly is observed in Text-figure 4 where only 2 m depth has been shown. The cause of paucity of palynomorphs between 80 to 90 cm could have easily been determined if lithostratigraphic column was provided along the pollen diagram. The written version under the material and methods does not provide clarity as there are two contradictory statements, "a section of black argillaceous to silty peat was sampled to a depth of 230 cm' and "from 205 to 230 cm somewhat more arenaceous core was collected"

(Vasanthy, 1988). The summary pollen diagram from Sandynallah reveals overall predominance of Poaceae, followed by Asteraceae and other herbs except they declined at 55 cm depth coinciding with the spurt in swamp flora. Arborescent taxa are absent till the depth of 50 cm and, thereafter, they are recorded in reduced values. The face value interpretation of pollen diagram (Vasanthy, 1988) could have been altered if attempted to understand differential pollen dispersal and preservation through the study of modern surface samples. It has been established that the arborescent in the sediments from south Indian montanes are not represented to the tune they are actually present in the forest (Guinet, 1966; Gupta & Prasad, 1985).

The palaeofloristic picture at Sandynallah is more or less similar to Kakathope and coincides with phase 'b' and 'c' where the shrubs colonized and shola established, respectively

## PALAEOFLORISTICS OF PALNI

A 2.80 m deep profile from Parson's Valley has been analysed (Blasco & Thanikaimoni, 1974). This profile, too, does not record litho-chronostratigraphical details, hence it is difficult to assess the nature and time span taken for the deposits to be laid in. However, palynological details obtained with very high values of herbaceous elements, Poaceae being the most dominant point to open conditions. The tree/shrub savanna and forest elements are present in highly reduced values and do not exceed more than 6 per cent and 4 per cent, respectively. On comparison, Parson's Valley pollen diagram corresponds to upper part of the Kakathope pollen diagram which goes back to about 5,000-7,000 years BP envisaging a savanna type of landscape.

## PALAEOFLORISTICS OF ANAMALAI

A number of surface samples and three soil profiles, one each from Arumparai, Kalikamati and Schichali, have been investigated. Most of the surface samples have revealed predominance of herbaceous group of vegetation. The arboreal vegetation is meagerly represented by taxa, like *Elaeocarpus, Meliosma, Symplocos, Glochidion*, etc.

All the three profiles investigated are not more than one meter in depth and lithology is clay with pebbles in plenty. The substratum is very stiff and does not permit the boring. The radiometric dates obtained are 1,500 years BP at 1 m depth in Kalikamati profile; Arumparai profile is dated to 710 years BP at the depth of 0.8 m and Schichali to 220 years BP at 0.60 m indicating the Late Holocene Period. The investigations have revealed that most of the profiles are palynologically barren and only sporadic pollen of some of the herbaceous taxa have been observed which are insufficient for percentage calculation The most prevalent factors which inhibit the pollen preservation are: (i) excessive occurrence of saprophytic fungi which might have led to the pollen destruction, and (ii) that they have alkaline pH which is not favourable for pollen preservation.

## PALAEOFLORISTICS OF SILENT VALLEY

Silent Valley is a reserved forest area and the shola is well protected. Due to difficult and remote nature of the terrain, a profile could not be collected Byson swamp, which is deep into the forest, may provide ideal soil profile for palynological purpose.

Palynological analysis of several surface samples has revealed quantitative and qualitative richness. The pollen assemblage thus obtained matches with the modern vegetation to a greater extent and records arborescent taxa in good frequency The important taxa encountered are *Elaeocarpus, Euonymus, Melastoma, Palaquium, Ilex, Michelia*, Meliaceae, etc

Along the road-cutting, about six meter scarpment profile was collected and has been dated to about 600 years BP at 0.6 m level. The sediments are reddish-brown clay with plenty of sand and pebbles. The palynological investigation of the samples has revealed a good pollen assemblage mainly consisting of nonarboreal taxa. The arboreal taxa are poorly represented. This anomaly between the surface and profile samples' pollen assemblage as to why the profile samples lack arboreal vegetation, is yet to be worked out

## DISCUSSION

The palynostratigraphic study has brought out that vegetation cover on south Indian hill tops had witnessed considerable changes during the past 40,000 years BP. These changes were largely controlled by climatic factor, except for the last phase encompassing a few thousand years when the biotic factor coupled with climatic and edaphic factors played a vital role in transforming the forest cover into open land and in bringing about savannization

The total vegetion development for the past 40,000 years BP could be segregated into four phases. Phase I is the period when only herbaceous group of plants predominated with sprinkling of a few shrubs and under trees with cold and dry climate. The lithology, being yellowish green clay with abundance of sand and pebbles, further supports the view that cold climate with higher aridity prevailed at that time. This phase spanned for five thousand years, between 40,000-35,000 years BP.

In the succeeding Phase II, a shift in the vegetation through gradual invasion of shrubs into the open land took place—a step towards initiation of forest. The lithology of this phase is largely composed of organic mud with high biomass accumulation and less clay and sand. This shift in the palaeofloristics is believed to have been brought about by amelioration in temperature, increase in precipitation and humidity, as compared to the preceding phase. This phase lasted between 35,000-15,000 years BP. Phase III is quite important as it was a period for the establishment of closed, evergreen forest. In addition, all the forest associated herbs were present in their maxima and this phase continued for about 8,000 years indicating the period of maximum warmth with much higher precipitation and humidity than the preceding phase.

Phase IV has different time spans at different places, ranging from 7,000 years BP at Kakathope, 5 7,000 years BP at Pykara and Parson's Valley, and 2,000 years BP at Colgrain. This phase marks the decline of closed evergreen shola, its confinement to the protected moist depressions, loss of power of colonising open areas and in ultimate case the total savannization of the land. This phase is largely governed by consistent efforts and magnitude of man's activities to meet the hunger of pasture-land and farm-land. The recurrence of fire to obtain new tender grass for livestock, has forced the shola plant community to restrict to its present position. The uninterrupted biotic pressure over the forest has changed the climatic conditions as well. As a result, the speedy chilling winds coupled with frost have become effective in not providing the conditions conducive to the spread of shola.

As to the current burning problem regarding the status of shola *vis-a-vis* grassland, we now have enough data base to say that shrub savanna was the pioneer plant community on south Indian hills under the cold and dry climatic regime. With the amelioration in temperature and increase in precipitation, shola constituents invaded the grassland and established around 15,000 years BP. In the last phase, with increasing human needs, the closed evergreen forest came under heavy pressure and most of the landscape was transformed into the shrub savanna again. Under this type of vegetation cycle, in which open conditions are the ultimate result, it may be suggested that the shrub savanna be designated as climatic climax plant community and the shola as a sub-climax.

## FUTURE

From the foregoing account, it has been observed that how the vegetational development during last 40,000 years BP took place under various controlling factors. It has also been worked out that at times shola was established and thereafter declined in the areal extent; the biotic factor has been identified as the main reason for destruction of shola forest ceding place to savannization in the near past.

There are two main factors operating concurrently in the south Indian hill tops: (i) destruction of shola, clearing the land by way of felling the trees and repeated fires, and (ii) afforestation of the bare land with exotic plants, such as eucalyptii, acacias, teak, cinchona, coffee, etc. These factors are effectively operating and are chiefly controlled by man.

The pernicious practice of felling trees and fire promote the formation of shrub savanna. It has also been revealed by palynological investigation that forest got transformed into the shrub savanna with the advent of man into the landscape around 7,000 years BP. If the process of felling of trees and fire are intensified then shrub savanna gets converted into the herbland. Coupled with plantation of exotic trees, they exhaust the surface soil-moisture because of excessive evapo-transpiration. It is believed that the *Eucalyptus* tree absorbs large amount of sub-soil water, several times higher than indigenous trees, though experiments on the water uptake of *Eucalyptus* spp. are still in progress. Reduction of soil moisture, making the soil dry and winds to blow at a fast rate, help the erosion of top soil. Thereafter, degradation of rocks takes place making them denuded preventing the vegetation to colonize. These conditions play a havoc in extermination of shola from their homeland, disbalancing the ecosystem.

Palynology has been instrumental in unfolding the facts that shola species are not regenerating under adverse conditions and therefore, a phenomenal reduction in their areal extent is recorded. In view of the past and present features of the evolution of vegetation it had been suggested that the shola be considered as a living fossil plant community which, in due course of time may vanish and become extinct (Vishnu-Mittre & Gupta, 1968, 1971).

Keeping in view of wide spread herbland, one ought to think about future of the shola ecology as to how shola woods could spread into herb land and overcome acacias and eucalyptii. The continued exotic plantation and fast expanding grassland clubbed with the hunger for pastoral and arable lands will tend further shola destruction.

For the restoration of shola ecology and proper management of the montane environment, the first step to be taken is to reduce the biotic pressure and put a check over unplanned development. Ways and means have to be found to regenerate shola species in the areas now covered by herbs, grasses and plantation. The slow but continuous process of plant succession has to pave the way for a thorough restitution of shola community which under the existing conditions is on its way to extinction like the Dodo or the Dinosaur.

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# Correlation between pollen spectra and vegetation of Chhota Shigri Glacier in Himachal Pradesh, India

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Bera, S. K. & Gupta, H. P. 1990. Correlation between pollen spectra and vegetation of Chhota Shigri Glacier in Himachal Pradesh, India. *In*: Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38**: 404-410.

Pollen analysis of modern surface samples and glacial deposits, collected from Chhota Shigri Glacier at different altitudes, ranging between 3,750 to 5,010 m, has been carried out to understand the pollen/vegetation relationship. The study reflects predominance of extra-regional arboreals over local non-arboreal taxa.

**Key-words**—Palynology, Vegetation, Chhota Shigri Glacier, Himachal Pradesh (India).

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## साराँश

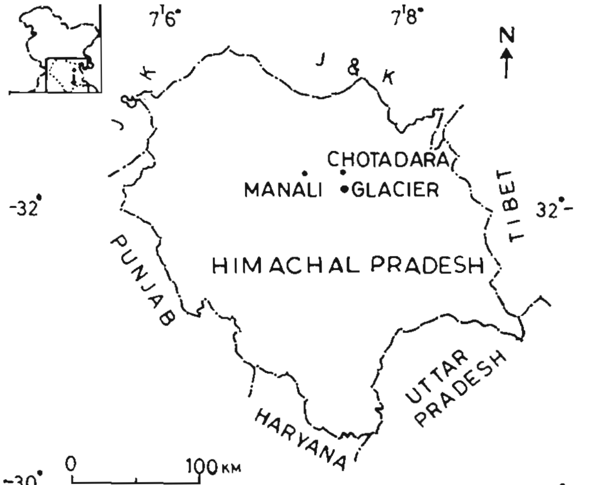
### हिमाचल प्रदेश (भारत) में छोटा शिगरी हिमनद की वनस्पति एवं परागकण स्पेक्ट्रम में सहसम्बन्ध

समीर कुमार बेरा एवं हरीपाल गुप्ता

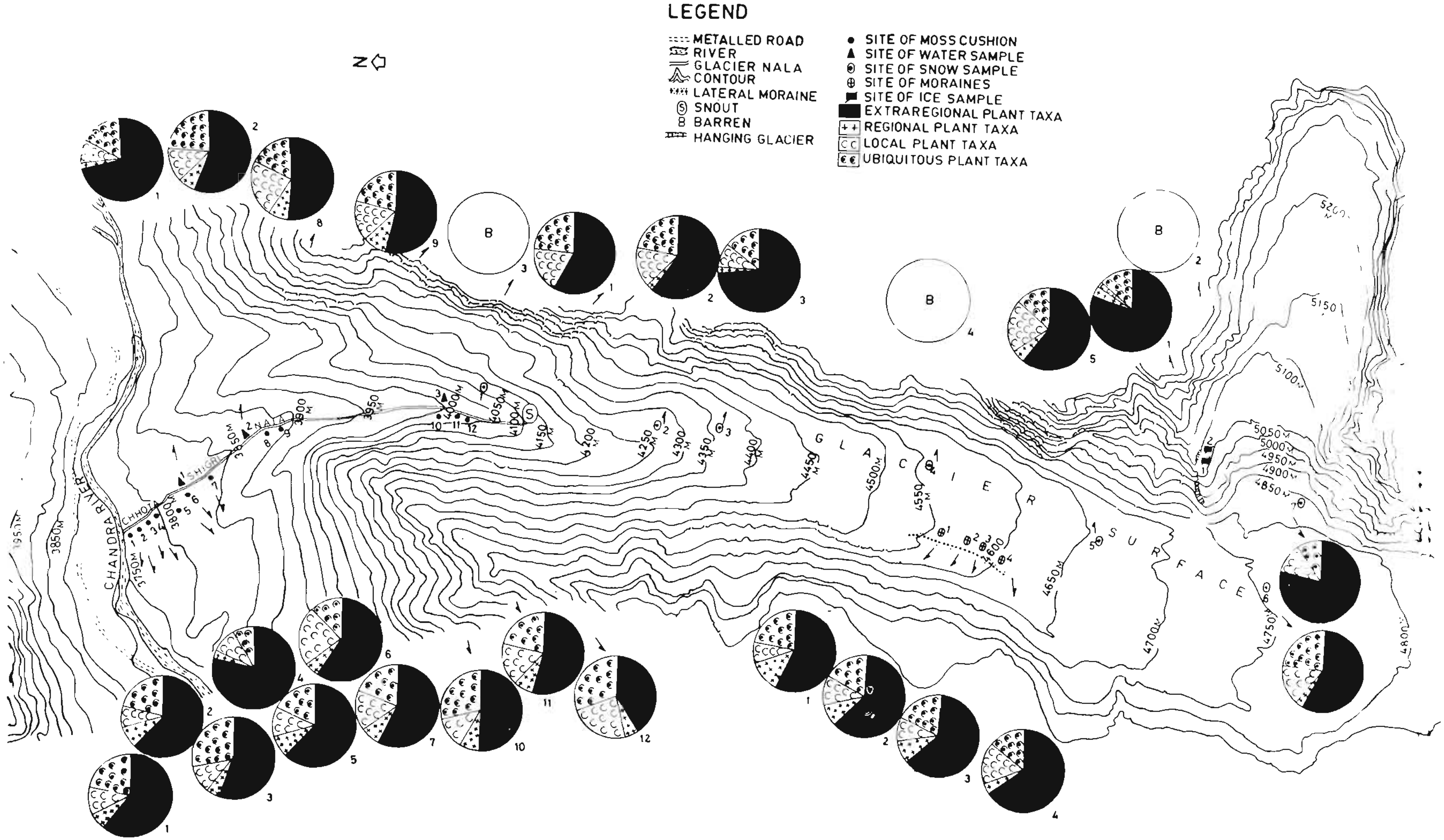
लगभग 3,750 से 5,010 मीटर की ऊंचाई के मध्य छोटा शिगरी हिमनद से एकत्र वर्तमान सतही नमूने एवं हिमानी निक्षेपों का परागकण-विश्लेषण किया गया। प्रस्तुत अध्ययन स्थानीय अवृक्षीय वर्गकों से बाह्य-क्षेत्रीय वृक्षीय अवयवों की अधिकता प्रदर्शित करता है।

NO PALYNOLOGICAL work has been done so far on Chhota Shigri Glacier. Nevertheless, a preliminary attempt has been made to study seismotectonics and geomorphology of the area by WIHG, Dehradun during the years 1984-86 (Personal Communication). Recently a multidisciplinary research project on Chhota Shigri Glacier has been sponsored by the Department of Science and Technology, New Delhi wherein 15 various research organisations in India have participated. Consequently, an expedition to Chhota Shigri Glacier was organised from June August, 1987, and one of us (SKB) participated in it. In the first phase, palynology of the modern surface samples has been undertaken. The study of glacier dust and Quaternary sediments are to be taken up in the subsequent phases.

The area covered in this study is situated at about 2.5 km south of Chhotadara Rest House along the old Manali-Kaza road and 98 km away from Manali (Lat. 32°13.5′ to 32°16.5′, Long. 77°31′ to 77°32′) in the Lahul and Spiti districts, Himachal Pradesh (Map 1). The area lies above the tree-line zone comprising diversified ground vegetation only. The floristic clusters are mainly confined along



**Text-figure 1**—Location map of Chhota Shigri Glacier, Himachal Pradesh.



**Text-figure 2**—Pollen deposition model at Chhota Shigri Glacier, Himachal Pradesh.

glacier streams, river terraces, moraines and rockscrees. As a rule, glacier surfaces are generally devoid of any biota.

During the expedition it was observed that the plants are colonized either in the open flats near the river terraces or on moraines/rockscrees. A systematic collection of the following season's plants was also made:

*Open flats near river terraces*—The characteristic herbaceous plants of this habitat comprise *Potentilla rigida, P. fulgans, Rubus nutans* (Rosaceae); *Anemone rivularis, Delphinium brunonianum, D. denudatum* (Ranunculaceae); *Corydalis cornuta* (Papaveraceae); *Primula reidii, Androsace lanuginosa* (Primulaceae); *Geranium wallichiana* (Geraniaceae); *Impatiens gigantea* (Balsaminaceae); *Trifolium repens* (Fabaceae); *Saxifraga diversifolia* (Saxifragaceae); *Bupleurum himalayensis* (Apiaceae); *Saussurea gossypiphora, Solidago virga-aurea* (Asteraceae); *Pedicularis hoffmeisteri* (Scrophulariaceae); *Polygonum nepalense* (Polygonaceae); *Juncus himalensis* (Juncaceae); Grasses are dominated by *Agrostis munroona, A. nervosa, Deschampsia caespitosa, Phleum alpinum, Trisetum scitulum.* Sedges are represented by *Carex alpina, C. cruciata, C. setigera*, etc.

*Moraines and rockscrees*—The plant taxa growing in this habitat are *Anemone rivularis* (Ranunculaceae); *Draba* sp. (Brassicaceae); *Saxifraga* sp., *Swertia* sp. (Gentianaceae); *Meconopsis aculeata* (Papaveraceae); *Astragalus* sp. (Fabaceae); *Primula reidii* (Primulaceae); *Anaphalis triplinerus; Erigeron alpinus* (Asteraceae); *Allium sp* (Liliaceae), etc.

## MATERIAL AND METHOD

In all, 12 moss cushions were collected from the vicinity of glacier at an interval of about 100 m each in a traverse ranging between 3,750 to 4,020 m elevation approaching glacier snout. Three water samples from glacier nala, seven snow samples from glacier bed starting from 4,050 m a.s.l. (near snout) to 4,850 m a.s.l. near accumulation zone, four samples from lateral moraine deposits at 4,550, 4,570 and 4,650 m elevation, two ice samples from a well stratified hanging glacier with two distinct zones at 5,010 m near accumulation zone, been collected for pollen analysis. All the surface samples were chemically processed following the standard technique for extraction of palynofossils (Erdtman, 1943).

A sum of 150-300 arboreal and non-arboreal pollen were counted in each sample. Percentages were calculated in terms of total land plants pollen. Relative frequencies for pollen and spores were plotted separately. Because of the insufficient carbon contents in the moraine samples, the absolute dating could not be feasible

## POLLEN SPECTRA

The results obtained from all the surface samples, viz., moss cushions, glacier nala water, snow and moraines, have been plotted separately in order to present a collective and comparative picture of the data (Text-fig. 3).

*Moss cushion*—Pollen spectra of moss cushions reveal an overall dominance of arboreal pollen except for sample no. 12 located near glacier snout

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## PLATE 1

(All figures, × 500)

1. *Cedrus deodara*
2. *Pinus wallichiana*
3. *Picea smithiana*
4. *Abies pindrow*
5. *Polygonum plebejum*
6. *Juglans regia*
7. *Betula utilis*
8. Polygonaceae
9. Ranunculaceae
10. *Alnus* sp.
11. Poaceae
12. Caryophyllaceae
13. Brassicaceae
14. Cyperaceae
15. Rosaceae
16. Asteraceae
17. *Ephedra* sp.
18. Trilete spore
19. Trilete spore
20. Monolete spore

21, 28. *Alternaria* sp.

22. Fungal spore, Type-1
23. Fungal spore, Type-2
24. Fungal spore, Type-3
25. *Curvularia* sp.

26, 29. *Tetraploa* sp.

27. *Helminthosporium* sp.

30, 31. *Melosira* sp.

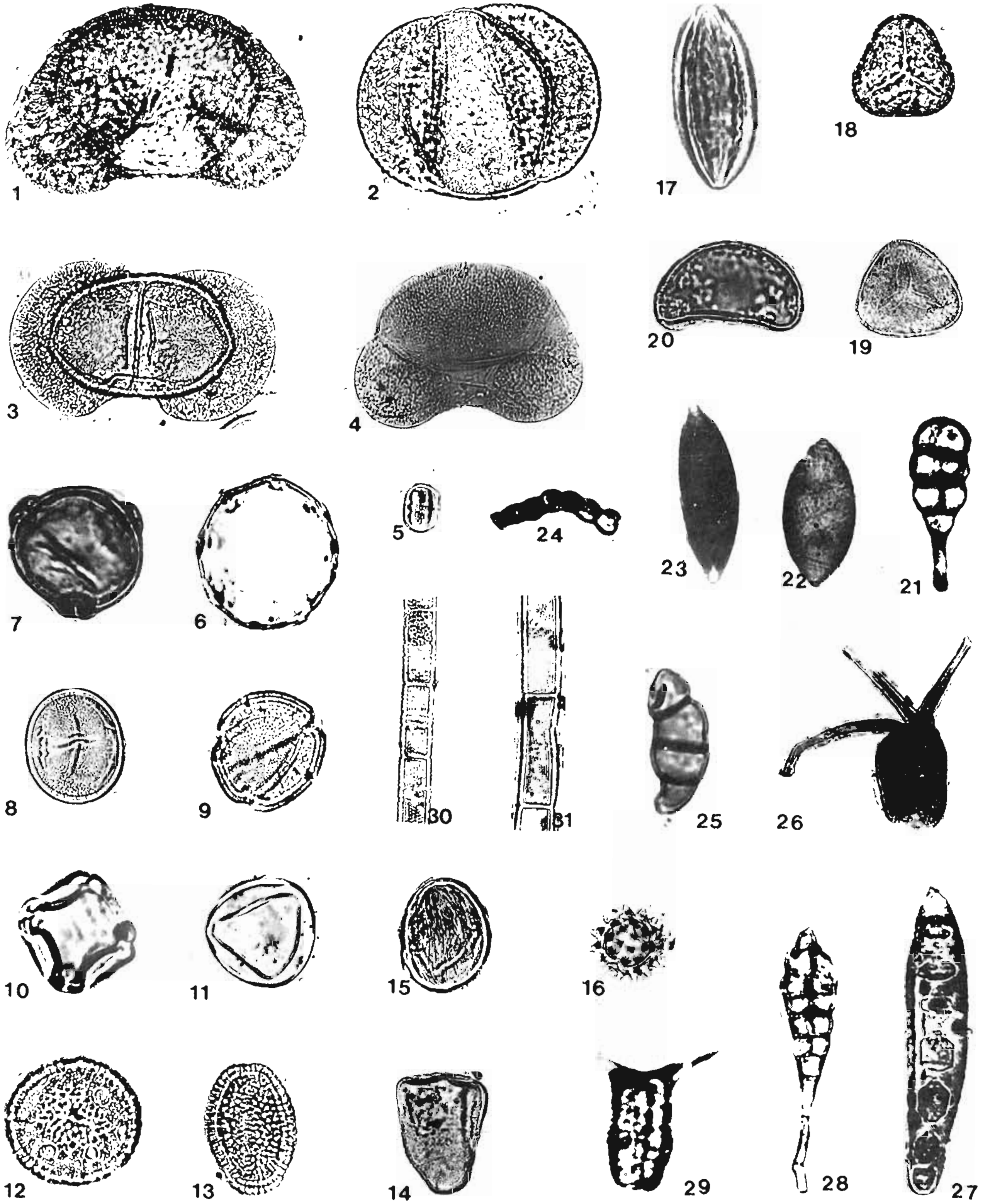
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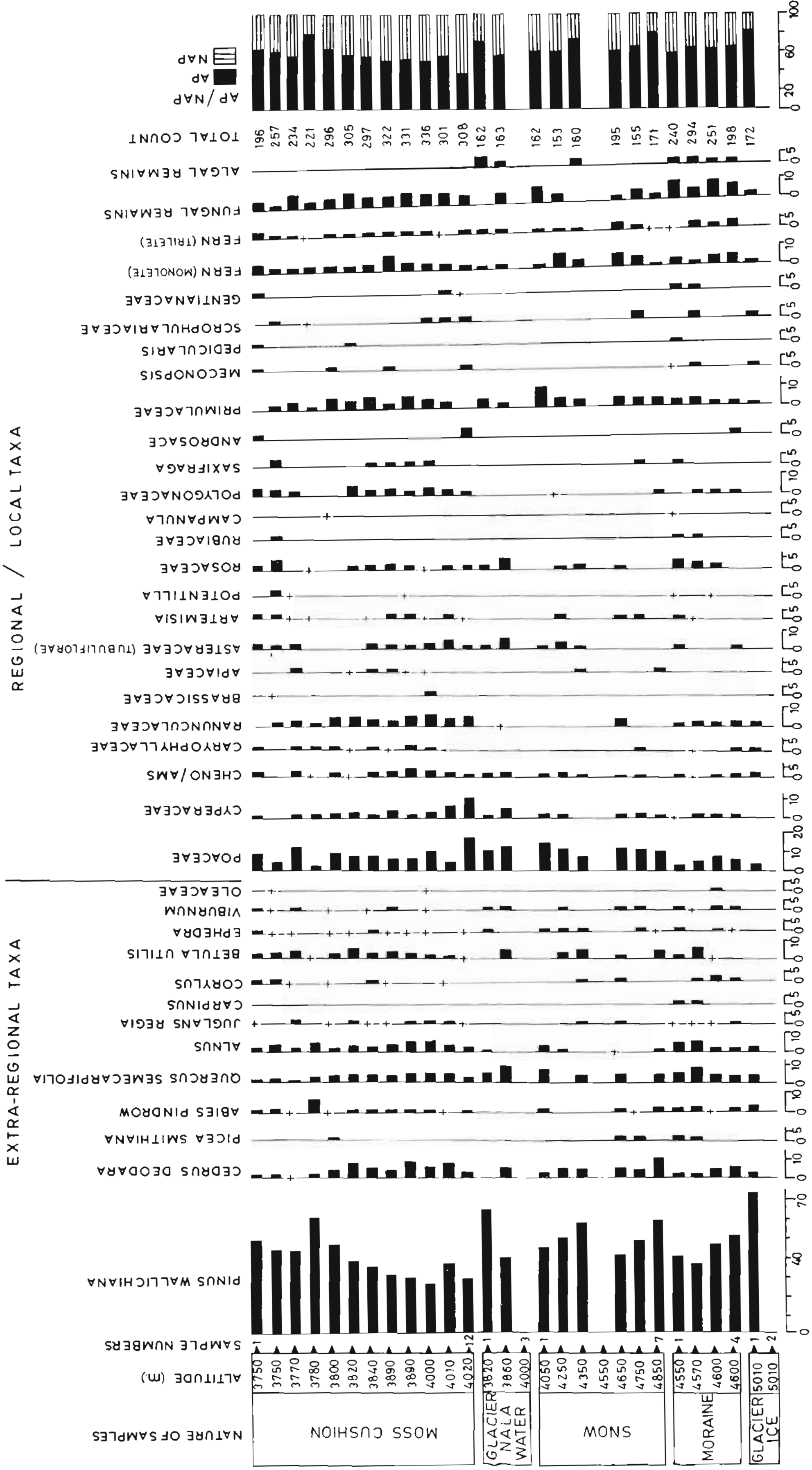
PLATE 1



**Text-figure 3**—Modern pollen spectra from Chhota Shigri Glacier, Himachal Pradesh.

which depicts higher values for non-arboreals. The arboreals are present to the tune of 85 per cent of the total vegetation. Amongst arboreals *Pinus wallichiana* records highest value (62%), whereas other taxa, such as *Cedrus* (7.6%), *Abies* (8.7%), *Quercus* (6%), *Betula* (5%), are present in moderately good values. The other associates, like *Carpinus, Corylus, Juglans, Ephedra* and *Viburnum* are either poor or sporadic.

The ground vegetation is meagre as compared to the arborescent vegetation. Poaceae has the highest value (17%) followed by Cyperaceae (10%), Rosaceae, Primulaceae (6% each) and Cheno/Ams. (3%). Other taxa present sporadically are Caryophyllaceae, *Artemisia, Saxifraga, Meconopsis,* Scrophulariaceae and Gentianaceae.

Monolete and trilete fern spores are also present in good frequencies maintaining 8 per cent and 4 per cent, respectively. Fungal spores are also recorded which maintain 8 per cent of the total value.

*Glacier nala water*—The pollen spectrum obtained from glacier nala water samples reflects an overall dominance of arboreal pollen. The pine pollen, amongst arboreals, attain a summit (64%) followed by *Cedrus* (5%), *Quercus* (8%), *Juglans, Alnus, Betula, Ephedra* which are either sporadic or absent. The ground vegetation is much lowly represented than the arborescent vegetation. The highest value is attained by Poaceae (12%), followed by Cyperaceae and Rosaceae (5% each). Other elements, such as Asteraceae, Cheno/Ams., Primulaceae, are present under 4.5 per cent each; Ranunculaceae has stray occurrence. Monolete and trilete spores are also present in low values (3% each). Fungal spores maintain 4 per cent of the total values and a few algal filaments have also been recorded.

*Snow surface*—The pollen spectra obtained from snow surface samples depict an overall dominance of arboreal pollen over non-arboreals. Amongst arboreals, *Pinus wallichiana* predominates attaining a summit of 57 per cent of the total values, whereas other taxa such as *Cedrus deodara* (10%), *Quercus* (7%), *Alnus* (6%), *Betula* (5%), *Abies pindrow* (2%), and *Ephedra* (2%) are present in moderately good values.

The ground vegetation is represented by low value of Poaceae (14%) followed by Asteraceae, Primulaceae, Cyperaceae, *Artemisia,* Rosaceae Cheno/Ams. and Ranunculaceae. Among fern spores, monoletes maintain 8 per cent and triletes 4 per cent. Fungal spores are recovered in higher frequency and algal remains have stray occurrence.

*Moraine samples*—Pollen spectra obtained from moraine samples reveal the dominance of arboreals over non-arboreals. Amongst arboreals, *Pinus wallichiana* records highest value at 49.5 per cent, whereas other taxa such as *Cedrus* (9%), *Alnus* (6%), *Betula* (5%), *Quercus* (3%), *Picea, Abies* and *Ephedra* (2% each), are present in moderate values. Other associates, like *Juglans* and *Viburnum,* have stray occurrence. The ground vegetation is poor as compared to the tree taxa. Amongst non-arboreals, Poaceae attains the highest value (7%) followed by Primulaceae and Scrophulariaceae (4% each), Ranunculaceae, Rosaceae (3% each), Polygonaceae, *Saxifraga,* Cheno Ams. (under 2% each). Other associates like Caryophyllaceae, Asteraceae, *Meconopsis* and Gentianaceae have stray occurrence. Among fern spores, monoletes and triletes maintain 6 per cent and 3 per cent values, respectively. Fungal spores are present in moderately good values. Algal remains are also recovered from the samples.

*Glacier ice sample*—The pollen spectra obtained from glacier ice reveal the dominance of arboreals attaining 83 per cent of the total vegetation. Amongst arboreals, *Pinus wallichiana* records highest value (71%), whereas other taxa such as *Quercus* (4%), *Alnus* (3%), *Cedrus* (2%) and *Abies* (3%), are present in moderate values. The herbage is considerably reduced as compared to the arboreals. Amongst non-arboreals, Poaceae (3%), Cheno/Ams. (2%), Ranunculaceae and Scrophulariaceae (under 2% each) are present in low values. The other associates like Caryophyllaceae, Primulaceae and ferns, are sporadically present. Fungal spores are higher than in other samples.

## DISCUSSION AND CONCLUSION

The evaluation of all the pollen spectra individually and collectively has deduced an overall dominance of arboreal taxa. The picture thus obtained from the pollen spectra does not portray the true regional or local vegetation rather abounds with extra-regional vegetation. The conifer woods predominated by *Pinus wallichiana, Picea, Abies* and *Cedrus* in the spectra, do not grow in and around the glacier; instead they are mostly confined to the subalpine/apline belt of climatic zone. Nevertheless, the Rohtang Range, far off from Chhota Shigri Glacier, is inhabited with coniferous forest

Well represented *Pinus wallichiana* pollen (25-71%) in all surface samples (maximum in ice sample at 5,010 m) appear to have been derived from the temperate and subalpine regions alongwith *Cedrus deodara, Abies pindrow, Picea smithiana, Quercus, Corylus, Alnus* and *Betula* through upthermic winds. However, presence of *Quercus* pollen in low value in all the samples needs to be reinvestigated in view of its relatively low pollen production and deficient buoyancy.

Moderately high values of Poaceae together with overall dominance of arboreals are suggestive to have derived from the local flora with vast stretches of open land. On the contrary, the conifers are derived from extra-regional zones.

Other non-arboreals, like Ranunculaceae, Primulaceae, Asteraceae, Rosaceae, Poaceae and Caryophyllaceae, are considered to be either local, regional or ubiquitous. The fluctuations in the values of non-arboreals could be taken as reference to decipher the microclimatic changes, whereas the arboreals have been considered for macroclimatic interpretation.

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# Growth and climate relationship in *Cedrus deodara* from Joshimath, Uttar Pradesh

A. Bhattacharyya & R. R. Yadav

Bhattacharyya, A. & Yadav, R. R. 1990. Growth and climate relationship in *Cedrus deodara* from Joshimath, Uttar Pradesh. *In* : Jain, K. P. & Tiwari, R. S. (eds)—*Proc. Symp. 'Vistas in Indian Palaeobotany', Palaeobotanist* **38** : 411 414.

Tree-ring analysis of 12 cores of *Cedrus deodara* collected from Joshimath, Uttar Pradesh has shown clear annual rings with year to year high variability. The statistics of tree ring data exhibits mean sensitivity 0.317, standard deviation 0.33 and first order auto-correlation 0.312 indicating suitability for climatic analysis. Response function analysis reveals that the growth of this tree is inversely related to the maximum temperature of previous summer (July, August and September) and the current summer, but directly related with precipitation of March, April, July and August of the current year.

**Key-words**—Dendrochronology, Dendroclimatology, *Cedrus deodara*, Himalaya (India).

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## सारॉंश

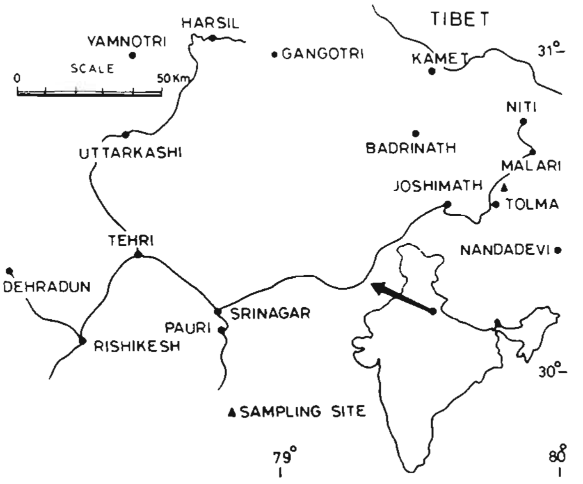
### उत्तर प्रदेश में जोशीमठ से सिड्रस देवदारा की वृद्धि एवं जलवायु में अन्तरबन्धुता

आमलव भट्टाचार्य एवं रामरतन यादव

उत्तर प्रदेश में जोशीमठ से एकत्र 12 क्रोड़ों के वृक्ष-वलयों में प्रत्येक वर्ष की स्पष्ट वार्षिक वलय प्रेक्षित की गई हैं। वृक्ष-वलय आँकड़ों अर्थात् 0.317 औसतन संवेदनशीलता, 0.33 मानक विचलन तथा 0.312 प्रथम स्वः सहसम्बन्धन से जलवायवी विश्लेषण के लिए उपयुक्तता प्रदर्शित होती है। अनुक्रिया कार्य विश्लेषण से व्यक्त होता है कि इस वृक्ष की वृद्धि पिछली गर्मी की ऋतु तथा इस गर्मी की ऋतु के तापक्रम के व्युत्क्रमानुपाती है परन्तु इस वर्ष मार्च, अप्रैल, जुलाई एवं अगस्त की वर्षा से इसकी वृद्धि का सीधा सम्बन्ध इंगित होता है।

IN India, besides the temperate trees, about 25 per cent of the tropical trees are also known to produce growth rings, though these are formed annually or not is uncertain (Chowdhury, 1964). The formation of an annual ring is controlled by various environmental factors during and prior to the growing season. With the rapid advancement of tree ring science it is now possible to understand which climatic variables are significantly involved in tree growth through a type of multivariate statistical analysis known as Response Function (Fritts, 1976). Here we have discussed the climate relationship with the growth of *Cedrus deodara* considering the available data on phenology and environmental variables regulating physiological activity. Phenology of this tree has been studied in detail by Troup (1921) and Maheshwari and Biswas (1970) but their publications hardly provide information on the effect of various environmental variables on various physiological activities of this tree.

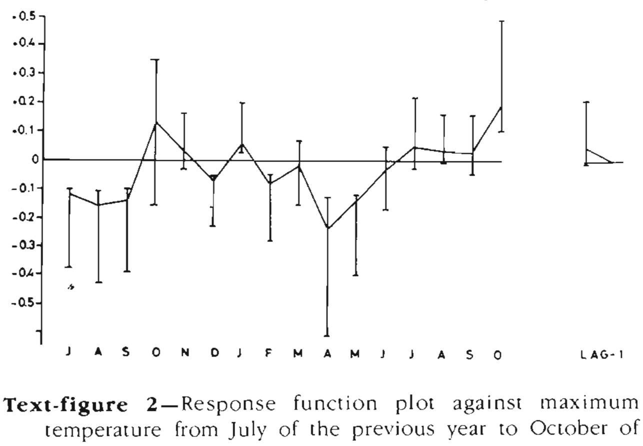
The utility of tree ring study in India has so far been to determine the productivity of a tree and a site. Science of dendrochronology has recently been introduced in India. Recent researches emphasize the selection of suitable sites and conifer species for climatic reconstruction (Pant & Borgaonkar, 1984; Ramesh *et al.*, 1985; Hughes & Davies, 1987; Bhattacharyya *et al.*, 1988). In contrast to conifers, the broad leaved taxa are less explored. They constitute a major part of the Indian forest but their potentiality in dendroclimatic analyses are yet to be established. Many of these trees producing growth rings have large number of false, missing and anastomosing rings which make them difficult or



**Text-figure 1**—Map showing the site of samples collection.

impossible to date (Yadav & Bhattacharyya, 1988). So far, only *Tectona grandis* has been found to have the potential for the reconstruction of precipitation from Thane, Maharashtra (Pant & Borgaonkar, 1983; Ramesh *et al.*, 1989).

The cores of *Cedrus deodara* have been collected from the village Tolma (30° 31′ N : 79° 45′ E) in Dhauli Valley near Joshimath (Text-fig. 1) at elevation ranging from 1,800 to 2,400 m. It remains covered with dry temperate conifer mixed broad leaved taxa with *Cedrus deodara* as its dominant constituent. Other associated taxa are *Juniperus macropoda* and *Quercus ilex* at its lower level and *Pinus wallichiana* at the higher level. Cores were taken at about breast height of trees through increment corer of 40 cm in length. Generally two increment cores per tree in opposite directions were collected except in a few cases only one core from one side of the trunk was taken where the other side was difficult to approach due to steep slope.



**Text-figure 2**—Response function plot against maximum temperature from July of the previous year to October of the current year.

**Table 1—Sample and chronology statistics of Deodar, Joshimath, U.P.**

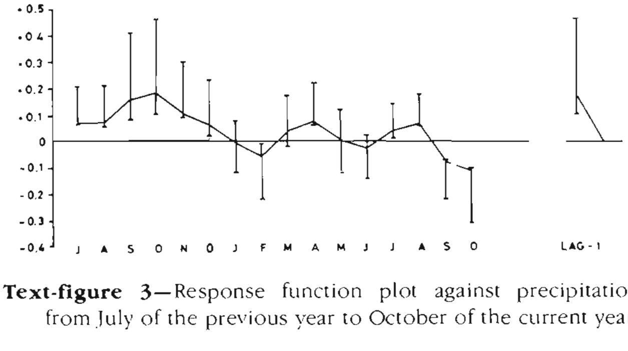
| | |
|---|---|
| Number of tree cores | 12 |
| Time span of analysis | 1917-1985 |
| Mean ring width | 1.466 |
| Analysis of variance | |
| Common variance % Y | 51.63% |
| Cross correlation | |
| Mean correlation between trees | .519 |
| Chronology statistics | |
| Time range | 1806-1987 |
| First order autocorrelation | 0.312 |
| Standard deviation | 0.330 |
| Mean sensitivity | 0.317 |

The samples were processed and growth rings were dated to the calendar year of their formation using skeleton plot method (Stokes & Smiley, 1968). Most of the samples are dated between 1806-1987 except few which go back to around 1287 A.D. The ring widths of dated samples were measured by using Bannister tree ring measuring machine. The data analysis has been done only on 12 cores for the period of 1917-1985 which have common time range.

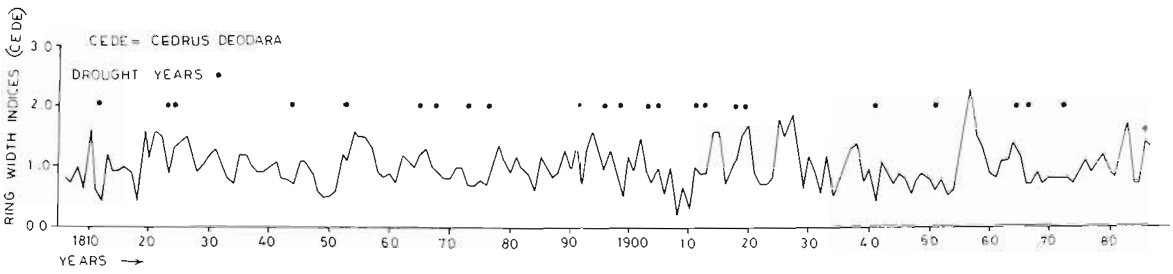
The chronology considered suitable for climatic analysis should have low first order auto-correlation, high standard deviation and high mean sensitivity (Fritts & Shatz, 1975). The studied chronology of *Cedrus deodara* exhibits first order auto-correlation 0.312, standard deviation 0.330 and mean sensitivity 0.317. The analysis of variance of the standarized data for the period 1917-1985 indicates a common variance of 51.63 and mean correlation between trees 0.519 (Table 1). These features clearly indicate the suitability of it for climatic analyses.

## RESPONSE FUNCTION ANALYSIS

Response function analysis was computed for *C. deodara* utilizing the computer programme



**Text-figure 3**—Response function plot against precipitation from July of the previous year to October of the current year.



**Text-figure 4**—Chronology of Deodar showing matching with drought years and low ring width indices.

'Respons' of Tree Ring Research Laboratory, Tucson, USA. Climatic data of monthly mean maximum temperature and total average monthly precipitation extending from 1920 to 1976 A.D. are used from Joshimath which is the nearest meteorological station from the sampling site. Sixteen values each of temperature and precipitation beginning from July to December of prior year and January to October of current year along with ring width indices for one year prior to current ring year were used as variables. Later has been used to measure the effect of previous growth on current growth. The response function plot for both maximum temperature and average monthly precipitation has been shown in Text-figures 2 and 3.

A positive correlation has been observed between ring width (growth) and maximum temperature during October-November of prior year and October of the current year but a inverse relationship exists during summer, both prior and current years (July, August and September of prior year and April, May and June of current year). This positive relationship might be due to continued higher photosynthetic activity during the later part of the growing period with the increasing temperature. The inverse relationship during summer is perhaps the result of enhanced evapo-transpiration causing water stress at higher temperature.

With precipitation, high growth has been observed during September, October and November of the prior year and also with March, April, July and August of current year. The existence of enough soil moisture due to high precipitation during the end of the growing season of the prior year and the beginning of the growing season of the current year promotes photosynthetic activity. This increased photosynthate enhances initiation of the cambial activity during March and April. The precipitation during summer reduces evapo-transpiration resulting an increase in the photosynthetic activity. However, inverse relationship during September and October might be due to low temperature associated with increased precipitation. The low temperature may also reduce the ability of roots to absorb water and nutrients from the soil.

## CONCLUSION

The response function of *C. deodara* growing near Joshimath in Uttar Pradesh Himalaya indicates that growth exhibits an inverse relationship with summer temperature but a positive relationship exists with precipitation during both summer and winter. These climatic variables seem to be potentially reconstructable by tree ring analysis. A cross matching observed between most of the recorded drought years and low ring width indices (Text-fig. 4) suggests that the tree ring chronology seems to have great potential in the reconstruction of drought from the western Himalayan region. Some trees of *C. deodara* have been dated over 700 years old from this region, which indicate the possibility of a long term climatic reconstruction.

## ACKNOWLEDGEMENTS

Authors express their sincere gratitude to Dr B. S. Venkatachala, Director, BSIP, Lucknow, for his constant encouragement during the course of this study. Thanks are also due to Drs G. B. Pant and K. Rupa Kumar, I.I.T.M., Pune for providing the meteorological data and running the computer programme. We are grateful to Mr H. C. Raizada, Chief Conservator of Forests, Uttar Pradesh for his kind help during the collection of samples.

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