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An argument for the origins of heterospory in aquatic environments

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ABSTRACT

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The bifid, grapnel-like processes and apical prominence (acrolamella) found in some heterosporous Middle-Late Devonian spores closely resemble to the bifid processes of acritarchs, dinoflagellates, and some Cretaceous - Recent heterosporous aquatic ferns and the lycopsid *Isoetes*. The spongy wall ultrastructure of *Protobarinophyton pennsylvanicum* and *Barinophyton citrulliforme* shows some similarities to the megaspore wall structure of *Azolla*, *Salvinia*, *Isoetes* and *Marsilea*. The difference between the microspore and megaspore wall structure seen in *B. citrulliforme* and *P. pennsylvanicum* is comparable to the difference found in megaspore and microspore wall structure of *Azolla*, *Salvinia* and *Isoetes*. As the spongy wall structure found in heterosporous aquatic ferns provides buoyancy in an aquatic environment, the same may have been true for *Protobarinophyton* and *Barinophyton* and we suggest they probably were aquatic in the dispersal of their spores. These genera are among the oldest heterosporous megaspores known and we suggest that the earliest line of heterospory evolution may be linked to aquatic dispersal of spores and out crossing in their fertilization during the Middle Devonian. This paper is a review of relevant literature and information. We use these data to support our hypothesis that the reproduction of plants by heterospory has its origins in aquatic environments.

Key-words—Heterospory, Middle-Late Devonian, Pteridophyta, Aquatic plants, Plant evolution.

जलीय पर्यावरण में विषमबीजाणुता के उद्गम पर कुछ विमर्श

रंजीत कुमार कर एवं डेविड एल. डिलचर

सारांश

कुछ विषमबीजाणुविक मध्य-अन्तिम डिवोनियन बीजाणुओं में पाए गए द्विशाखी काँटे की भाँति के प्रवर्ध तथा शिखाग्र उन्नत (एक्रोलैमेला) एक्रीटार्क, घूर्णीकशाओं के द्विशाखी प्रवर्धों तथा कुछ क्रिटेशस-अद्यतन विषमबीजाणुविक जलीय फ़र्न तथा *लाइकॉप्सिड आइसोइटीज़* के समरूप हैं। *प्रोटोबैराइनोफ़ाइटॉन पेन्सिलवेनिकम* तथा *बैराइनोफ़ाइटॉन साइट्रल्लाइफ़ार्मी* की स्पंज की भाँति की भित्ति परासंरचना *एज़ोला, साल्वीनिया, आइसोइटीज़* तथा *मार्सीलिया* की भित्ति संरचना के गुरुबीजाणुओं से कुछ समानता प्रदर्शित करती है। *बी. साइट्रल्लाइफ़ार्मी* तथा *पी. पेन्सिलवेनिकम* में प्रेक्षित सूक्ष्मबीजाणु तथा गुरुबीजाणु भित्ति संरचना में भिन्नता *एज़ोला, साल्वीनिया* तथा *आइसोइटीज़* की गुरुबीजाणु तथा सूक्ष्मबीजाणु में पाई गई भिन्नता से तुलनीय है। चूँकि स्पंज युक्त भित्ति संरचना, जो विषमबीजाणुविक जलीय फ़र्न में पाई गई है, एक जलीय पर्यावरण में प्लवकता प्रदर्शित करती है। अतः यही तथ्य *प्रोटोबैराइनोफ़ाइटॉन* तथा *बैराइनोफ़ाइटॉन* हेतु भी सत्य होना चाहिए। प्रस्तावित किया जाता है कि ये अपने बीजाणुओं के परिक्षेपण में सम्भवतः जलीय थे। ये वंश अभी तक ज्ञात प्राचीनतम विषमबीजाणु गुरुबीजाणुओं में से हैं। अतः यह भी प्रस्तावित किया जाता है कि विषमबीजाणुविक विकास की प्रारंभिकतम

सीमा मध्य डिवोनियन के दौरान बीजाणुओं के जलीय परिक्षेपण तथा उनके निषेचन में बहि:संकरण से सम्बन्धित है। हमने इन आंकड़ों का उपयोग अपनी इस अवधारणा की पुष्टि करने हेतु किया है कि विषमबीजाणुविकता द्वारा पौधों के प्रजनन का उद्गम स्थल जलीय पर्यावरण है।

संकेत शब्द—विषमबीजाणुविकता, मध्य-अन्तिम डिवोनियन, टेरिडोफ़ाइटा, जलीय पादप, पादप विकास.

INTRODUCTION

HETEROSPORY is found today in the Lycopsida in *Selaginella* and *Isoetes*, and the Pteropsida in *Marsilea*, *Salvinia* and *Azolla*, as an effective means of reproduction. Four of these genera are aquatic while *Selaginella* is widely distributed from moist forest floors to seasonally dry habitats (Bateman & DiMichele, 1994). Dilcher *et al.* (1992) proposed

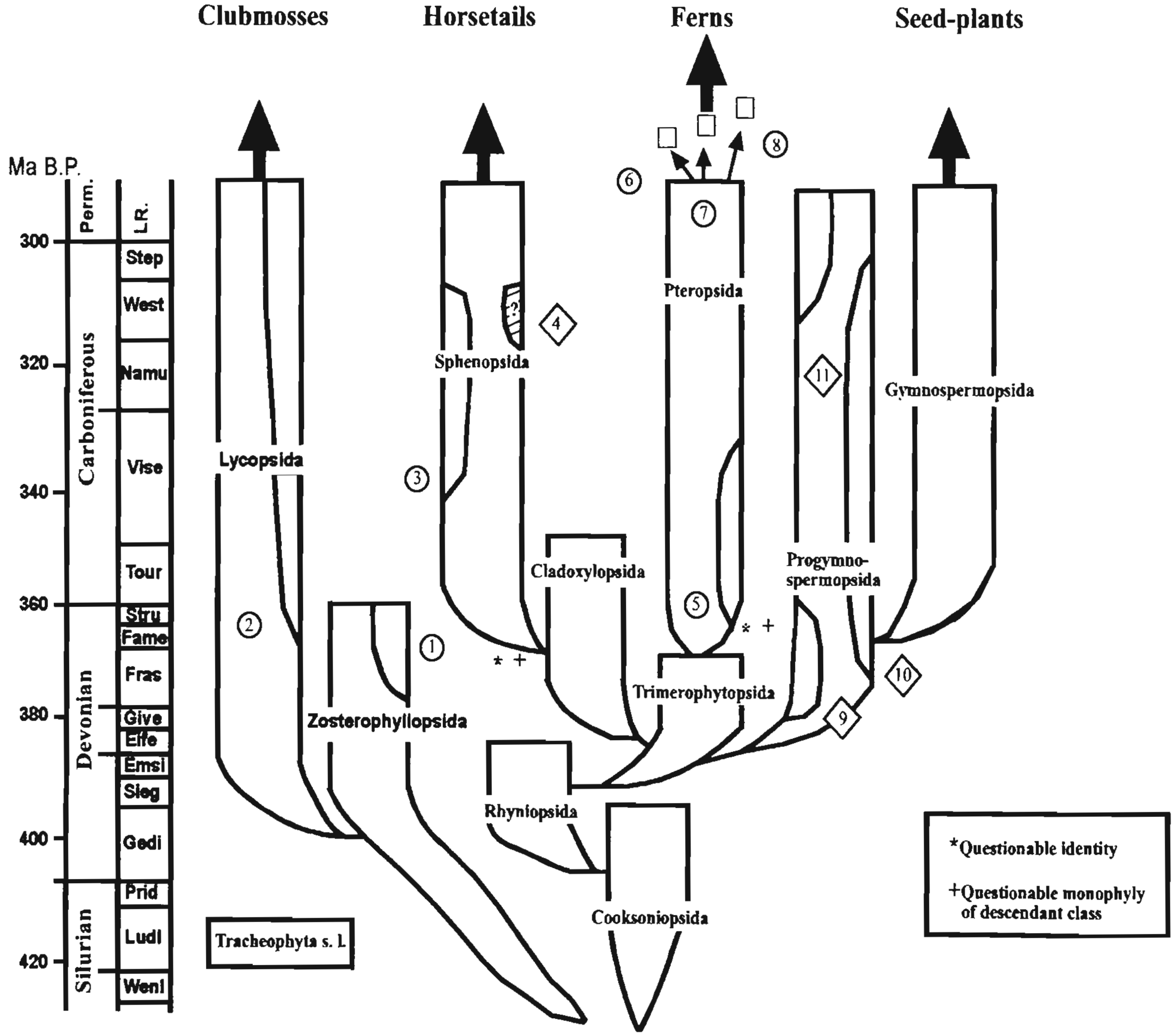

Fig. 1—Tentative non-numerical phylogeny of all tracheophyte classes, showing putative ancestor-descendant relationships and divergence dates: note that the class-level radiation occurred within the Devonian. Stippling indicates the minimum number of potentially independent origins of heterospory: (1) some Barinophytales, (2) all Selaginellales and Rhizomorphales, (3) some Equisetales, (4) some Sphenophyllales (doubtful), (5) some Stauropteridales, (6) all Salviniales, (7) all Marsileales, (8) some Filicales (e.g., *Platyzoma**), (9) some Aneurophytales, (10) some Archaeopteridales, ?all Protopotyales, all Cecropsidales, (11) some Noeggerathiales. Note that the Gymnospermopsida inherit heterospory from their putative progymnospermopsid ancestor. Open circles indicate probable aquatic, open squares indicate possible aquatic (modified from Bateman & DiMichele, 1994).

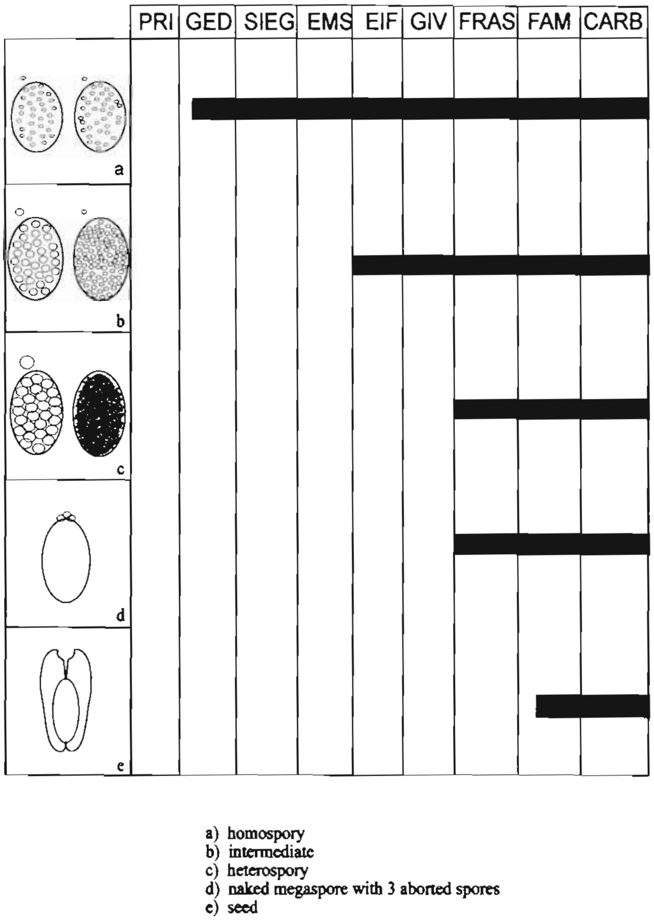

Fig. 2—Diagrammatic record of the time of first appearance of different types of reproductive structures in Devonian fossil plants. **a**. Sporangia with spores of same size (e.g., in *Cooksonia*). **b**. Sporangia with spores of two sizes (e.g., in *Chaleuria*). **c**. Sporangia with mega- and microspores (e.g., in *Archaeopteris*). **d**. Megaspore tetrad: one large, presumed fertile, three small presumed abortive (e.g., in *Cystosporites*). **e**. Radiospermic (*Archaeosperma*) and platyspermic (*Spermolithus*) seeds (modified from Chaloner & Sheerin 1979).

that many megaspores and microspores of the Middle Devonian had morphological features that suggested that they were dispersed in fresh water and demonstrated parallel morphological features with those megaspores and microspores of the aquatic ferns that evolved about 240 million years later during the Lower and Upper Cretaceous. It is obvious from the paleobotanical record presented by Bateman & DiMichele (1994) (Fig. 1) that heterospory has evolved repeatedly in various major groups of plants at various times during the history of land plant evolution.

We suggest that the major stimulus for the initial evolution of heterosporous reproductive systems in plants is to accommodate out-crossing in an aquatic environment. In such an aquatic environment, a two dimensional dispersal system is available in which out-crossing is encouraged. Therefore, it could be considered possible that the potential to capture a new dispersal strategy which increased out-crossing was an important driving force in evolution of heterospory in or near aquatic environments. The megaspores and microspores when released in the water could drift freely mixing microspores and megaspores from diverse populations of the same species and after fertilization further drifting to areas distant from either parent population where the new sporophyte generation would then mature. The data for consideration of such a hypothesis is presented here.

In this paper we are addressing only questions of initial morphological changes that were driven by selection pressures as mentioned by Tiffney (1981). We suggest these selection pressures were directed by the potential for increased out-crossing encouraged by heterospory in aquatic environments. We do not carry this argument further to include modifications of heterospory that might have carried these further to the evolution of the seed habit or seed-like habit (Bateman & DiMichele, 1994) or prepollen so common in the later Paleozoic seed land plants as discussed by Poort *et al.* (1996).

During the Middle Devonian (Givetian), there were many new innovations in land plants (Banks, 1968; Chaloner & Sheerin, 1979; Gensel & Andrews, 1984). By this time, some land plants, such as *Aneurophyton* had attained an arborescent habit that included the production of secondary tissue and major branching systems. Heterosporous taxa were present at this time, some which must have been the precursors of seed plants (Stewart, 1983). The seed habit represented an important innovation in the evolution of plants and became the normal habit of the various groups of vascular plants that were to become the dominant vegetation on the earth (Fig. 2).

Early Devonian spores were simple with a trilete mark, mostly azonate with smooth, apiculate or spinose ornamentation (Traverse, 1988). Early Devonian genera (Figs 3, 4) such as *Retusotriletes*, *Calamospora*, *Lophotriletes*, *Acanthotriletes*, *Punctatisporites*, *Apiculatisporis*, *Leiotriletes* and *Emphanisporites* are examples of these early spores (Banks, 1968). Large spores of 150-200 µm, some pseudosaccate and some zonate, are known from the Middle Devonian Eifelian and Givetian stages (Owens & Richardson, 1972; Richardson, 1974; Turnau, 1986). At that time we also see several spores with bifurcate processes such as *Ancyrospora*, *Hystricosporites*, *Perotriletes*, *Nikitinsporites* and *Dicrospora* while there are some genera that have small bifurcate processes such as *Densosporites devonicus* and *Rhabdosporites langii*. In the Late Devonian (Frasnian) continental and marginal marine facies, there often is dominance of spore genera with grapnel like processes. Pseudosaccate/camerate spores are also found as common elements in these assemblages (Figs 3, 4). Richardson (1969) observed that 50% of the palynological assemblage from the Middle Old Red Sandstone of the Orcadian Basin, Scotland consists of *Ancyrospora* and *Rhabdosporites langii*. Abundance of *Ancyrospora*, *Hystricosporites* and *Rhabdosporites langii*

Series or Stage	Banks, 1980	McGregor, 1977	Richardson, 1974
Post Famennian Tn 1b Tn 1a	?		*V. nitidus*
FAMENNIAN	*Rhacophyton* Assemblage - zone VII		*V. pusillites* *S. lepidophytus*
FRASNIAN	*Archaeopteris* Assemblage - zone VI		*L. cristifer* *optivus - bullatus*
GIVETIAN	*Svalbardia* Assemblage - zone V		*Triangulatus*
EIFELIAN	*Hyenia* Assemblage - zone IV	*devonicus - orcadensis* *velata - langii*	*Densosporites devonicus* *Rhabdosporites langii* *Acinosporites acanthomammillatus*
EMSIAN UPPER	*Psilophyton*	*annulatus - lindlarensis* *Grandispora* *sextantii*	*Calyptosporites biornatus - proteus* *Emphanisporites annulatus*
EMSIAN LOWER	Assemblage- zone III	*caperatus - emsiensis*	
SIEGENIAN			*Dibolisporites cf. gibberosus*
GEDINNIAN	*Zosterophyllum* Assemblage - zone II	*micrornatus - proteus*	*Emphanisporites micrornatus* *Streelispora newportensis*
PRIDOLIAN	*Cooksonia* Assemblage - zone I	*chulus - ? vermiculata*	*Synorisporites tripapillatus*

was also noticed in the Frasnian freshwater deposits of New York State (Richardson, 1969). In the Famennian Stage of the Late Devonian, a progressive decrease of the spores with bifurcate processes, pseudosaccus and zona is observed (Fig. 4).

Dilcher *et al.* (1992) advocated that the bifid, anchor like processes and the apical prominence (acrolamella) found in these heterosporous Middle-Late Devonian spores were produced in order to increase the potential to entangle and hold megaspores and microspore masses in close proximity while the spermatozoa were released (Fig. 5). Also they mentioned there might be some increase in volume ratio which would provide necessary buoyancy in the water. The presence of bifid processes in the Palaeozoic acritarchs (e.g., *Micrhystridium shinetonensis*, *Polygonium gracilis*), Mesozoic, Tertiary (e.g., *Achomosphaera ramulifera*, *Homotryblium tenuispinosum*) and Recent dinoflagellates, Cretaceous (*Arcellites*) and Tertiary aquatic heterosporous hydropterideae as well as the extant Salviniaceae all demonstrate similar functional morphologies. This is probably related to the fact that many of these microspores and megaspores accomplished their fertilization in water. The observation of Taylor *et al.* (1980) of the presence of smaller microspores between the spines, or in the apical prominence (acrolamella) of the megaspore *Nikitinsporites canadensis*, and of Winslow (1962) on the presence of smaller *Archaeoperisaccus* grains associated with *Nikitinsporites*, as in extant *Azolla*, provides additional support for this contention. *Archaeoperisaccus* and *Nikitinsporites* are mostly confined to Frasnian and according to McGregor (1979) are restricted to north of the palaeoequator (Fig. 6). Marshall & Allen (1982) noted the simultaneous occurrence of four larger and smaller species of *Auroraspora* and two species of a similar nature in *Rhabdosporites* from the Devonian sediments of Shetland. Turnau and Karczewska (1987) also observed that nearly all the large spore species described by Fuglewiez and Prejbisz (1981) from the Middle Devonian of Poland are associated with smaller but otherwise similar spores. These genera are *Apiculiretusispora*, *Biharisporites*, *Coronispora*, and *Grandispora*. The spores of the smaller size class are themselves relatively large and their mean ranges from 90-207 µm. Turnau and Karczewska (1987) suggest the reason for the size increase of the isospores was to enhance the nutritional capability for the developing gametophyte. They also postulated that in the course of development of heterospory, endospory preceded size differentiation and presumably sex differentiation (Fig. 7). Similarly, spores of one sporangium of *Faironella* reported by Gerrienne (1996) from the Early Devonian of Belgium have size ranges from 37-210 µm. This according to the author may exhibit the beginning of biometric heterospory.

Chaloner (1967) showed, in a series of histograms, a progressive increase in maximum spore size through the Early and Middle Devonian and then a gradual segregation into small spores and large spores and thus the commencement of heterospory (Fig. 7). The overall picture according to Chaloner (1967) seems to be consistent with a progression from a phase beginning early in the Devonian with a low degree of heterospory and continuing later in the Middle and Late Devonian to a much more pronounced size difference between microspores and megaspores. According to Sussex (1966) the fossil record suggests that there was an early and widespread occurrence of heterospory in almost all the major groups of land plants. By the Late Devonian or Early Carboniferous *Lepidostrobus*, *Sigillariostrobus*, *Pleuromeia*, *Lepidocarpon*, *Mazocarpon* and *Miadesmia* of Lycopsida; *Palaeostachya* and *Calamostachys* of Sphenopsida; *Archaeopteris*, *Lagenostoma* and *Trigonocarpus* of Pteropsida and many other plants as well had attained heterospory.

Cichan *et al.* (1984) considered that the term heterospory has traditionally been used to describe plants that have spores of two different sizes (morphological heterospory). However, because of the consistent correlation in extant plants between a bimodal distribution in spore size and the production of endosporic dioecious gametophytes, this term has also come to denote a particular pattern of reproduction (biological heterospory). To ascertain whether or not a plant is heterosporous (in the biologically heterosporous sense), small and large spores must be germinated and correlations between spore size and archegonial versus antheridial production observed (Cichan *et al.*, 1984; Bateman & DiMichele, 1994). *Platyzoma* (Tryon, 1964) is the first example of a dioecious condition in a heterosporous, terrestrial plant where the spores of two different sizes are found and the small spores bear the antheridia while the larger spores produce archegonia. DiMichele *et al.* (1989), however, think that the gametophytes of *Platyzoma* lack colonizing capabilities and that the life cycle is not comparable to heterosporous species with endosporic gametophytes. The ecological constraints inherent in the life history of *Platyzoma* make it an unlikely candidate for evolutionary intermediate. DiMichele *et al.* (1989) advocated heterochrony to explain the independent evolution of heterospory in most lineages of the lower vascular plants.

Galtier (1964), Brack (1970) and Brack-Hanes (1978) suggest that in fossil plants, where developmental studies are not possible, a biological definition of heterospory can only be applied in cases of morphological heterospory where mature gametophytes bearing either antheridia or archegonia are found preserved within the spore wall. In the cases when micro-

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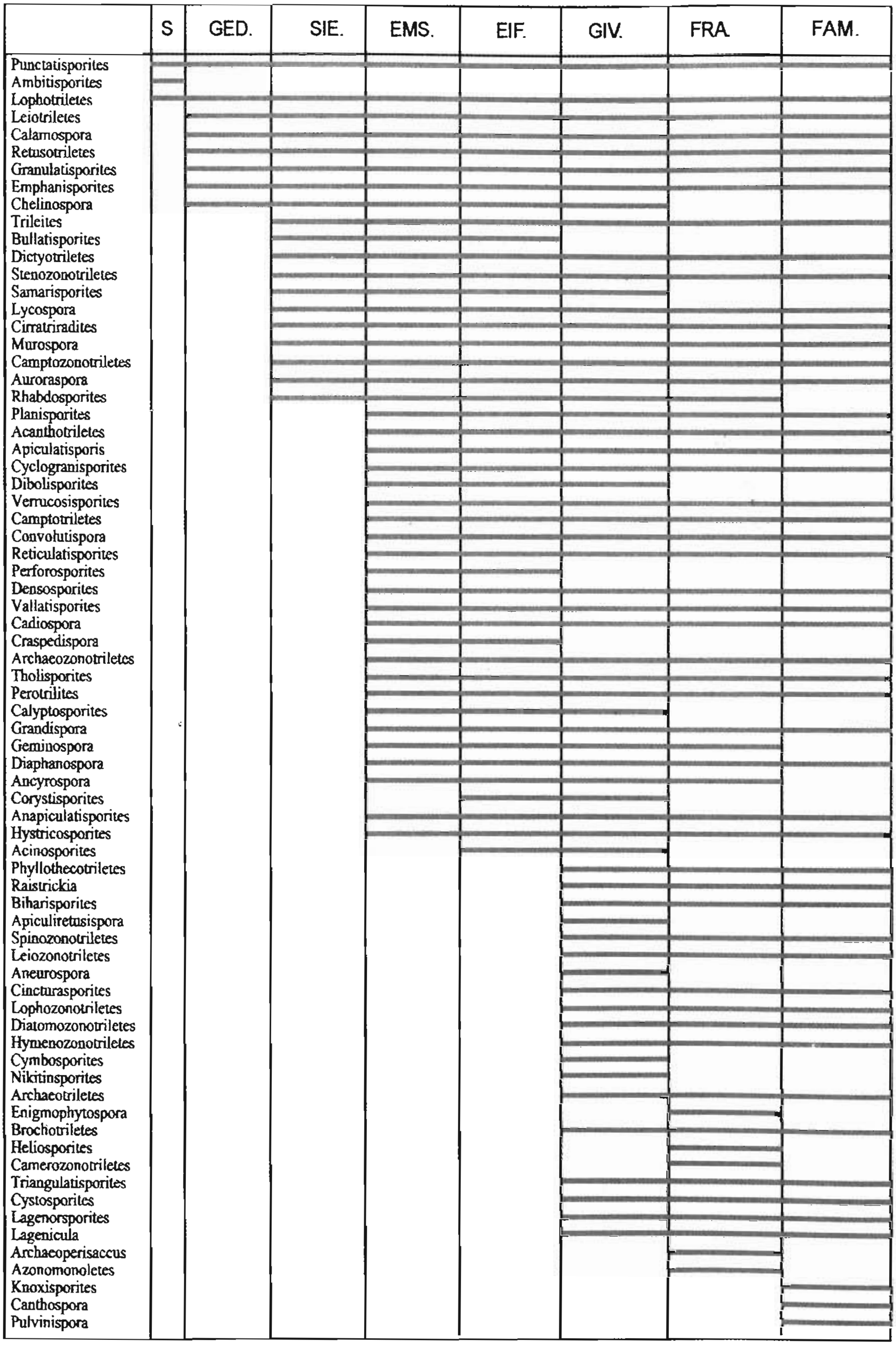
Fig. 3—Showing the comparison of tentative megafossil generic assemblage zones in Devonian with palynological zones suggested by McGregor (1977), Richardson (1974) and Banks (1980) (after Banks, 1980).


S
GED.
SIE.
EMS.
EIF.
GIV.
FRA.
FAM.
Punctatisporites
Ambitisporites
Lophotriletes
Leiotriletes
Calamospora
Retusotriletes
Granulatisporites
Emphanisporites
Chelinospora
Trileites
Bullatisporites
Dictyotriletes
Stenozonotriletes
Samarisporites
Lycospora
Cirratriradites
Murospora
Camptozonotriletes
Auroraspora
Rhabdosporites
Planisporites
Acanthotriletes
Apiculatisporis
Cyclogranisporites
Dibolisporites
Verrucosisporites
Camptotriletes
Convolutispora
Reticulatisporites
Perforosporites
Densosporites
Vallatisporites
Cadiospora
Craspedispora
Archaeozonotriletes
Tholisporites
Perotrilites
Calyptosporites
Grandispora
Geminospora
Diaphanospora
Ancyrospora
Corystisporites
Anapiculatisporites
Hystricosporites
Acinosporites
Phyllothecotriletes
Raistrickia
Biharisporites
Apiculiretusispora
Spinozonotriletes
Leiozonotriletes
Aneurospora
Cincturasporites
Lophozonotriletes
Diatomozonotriletes
Hymenozonotriletes
Cymbosporites
Nikitinsporites
Archaeotriletes
Enigmophytospora
Brochotriletes
Heliosporites
Camerozonotriletes
Triangulatisporites
Cystosporites
Lagenorsporites
Lagenicula
Archaeoperisaccus
Azonomonoletes
Knoxisporites
Canthospora
Pulvinispora

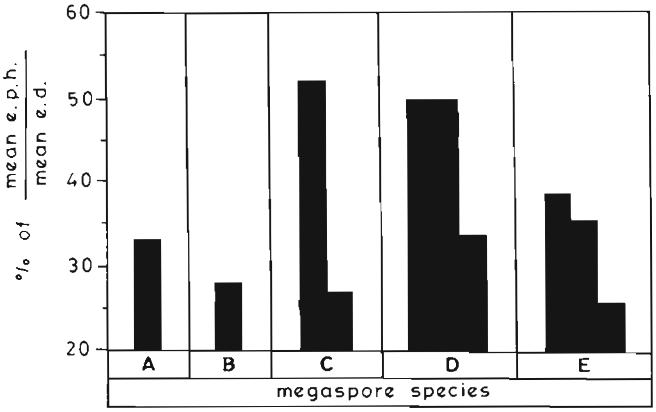


Fig. 5—Givetian and Fransian megaspore species with apical prominence. a.p.h. = apical prominence height, e.d. = equatorial diameter (modified from Allen, 1972).

and megagametophyte development are imperfectly known, they infer that biological heterospory was probably present based upon a correlation with living plants. In cases where the contents of the spores are not preserved, the precise nature of the large and small spores is uncertain because the difference in spore size may merely have been incidental and not significant in a biological sense (Sussex, 1966). Bateman and DiMichele (1994) suggest a spore size of 200 µm is sufficient to designate megaspores as probably containing archegoniate-bearing gametophytes.

Unfortunately, the contents of dispersed spores from the Devonian are not preserved and the parent plants of the Devonian spores with bifurcate processes, and most of the other megaspores, are not known. Balme and Hassell (1962), Potonié (1965), Banks (1968) and Gensel (1980) detailed *in situ* spores of Devonian plants. According to Gensel (1980) spores described from the Devonian sporangia consist of 30 genera and 40 species. She concluded that spore morphology seems to be similar between the various species of some genera e.g., *Psilophyton*, *Pertica* and *Archaeopteris*. Sometimes different genera may have the same type of spores e.g., *Tetraxylopteris* and *Rellimia*. Also, plants of quite different affinities have more or less similar types of spores e.g., *Krithodeophyton*, *Cooksonia*, *Crassipariatalis* and *Psilophyton* producing spores assigned to *Apiculiretusispora*.

Protobarinophyton and *Barinophyton* are exceptions because the *in situ* spores of these two genera are small and large spores (Cichan *et al.*, 1984). Both these genera exhibit intrasporangial heterospory, i.e., the spores within a single sporangium conforms to a bimodal size. According to Cichan *et al.* (1984) microspores of *Protobarinophyton pennsylvanicum* are 30-42 µm and the megaspores are 410-560

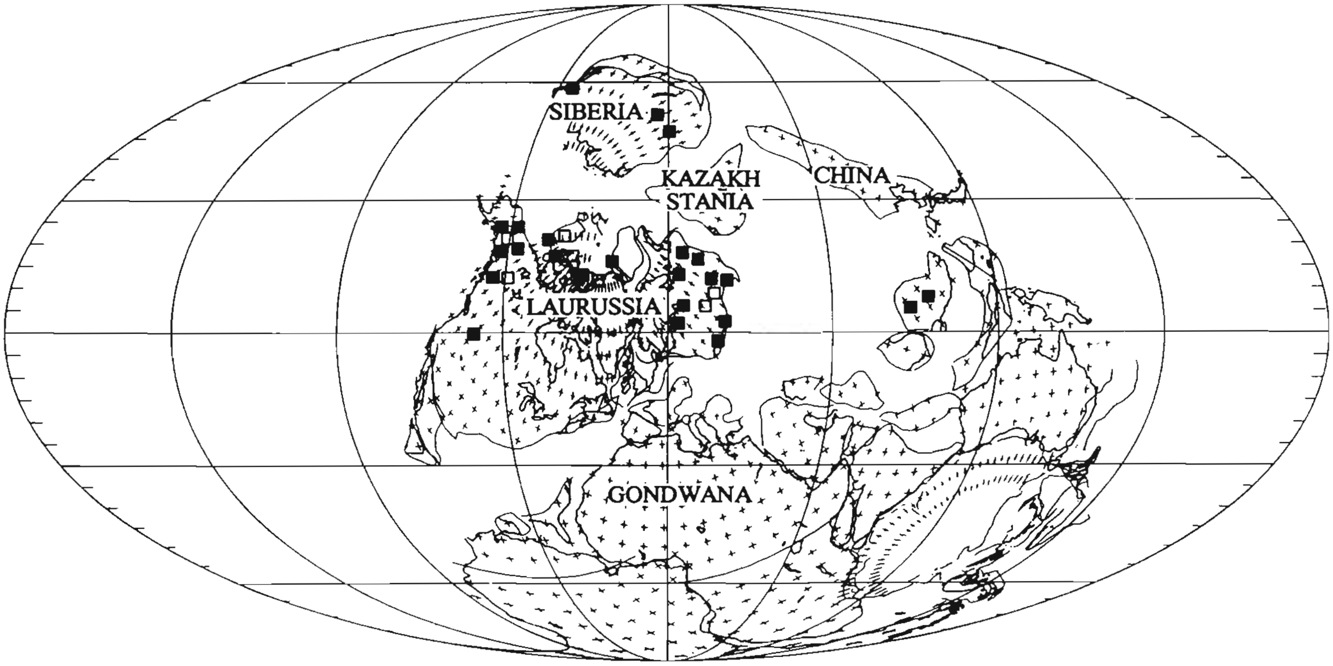


Fig. 6—Geographical distribution of *Archaeoperisaccus* (black squares) and *Nikitinsporites* (white squares) (modified from Streel *et al.*, 1990; map modified from Scotese & McKerrow, 1990).

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Fig. 4—A table showing the first and last appearance of Devonian spore genera (modified from Chaloner, 1967).

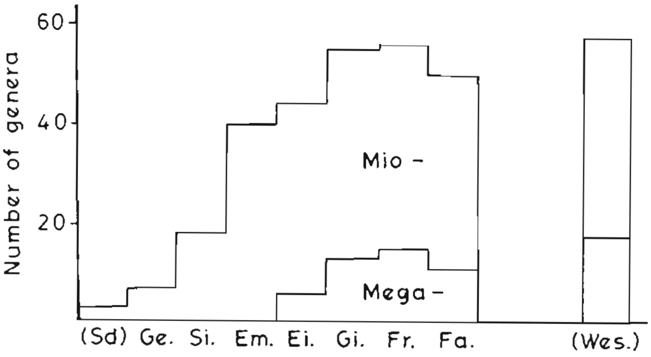

Fig. 7—A histogram showing the numbers of those genera which contain species with a mean size exceeding 200 µm as megaspores (mega) in contradistinction to miospores (mio) (modified from Chaloner, 1967).

µm. The microspores of *Barinophyton citrulliforme* are 30-50 µm and the megaspores are 650-900 µm. The sporangia of *Chaleuria cirrosa* (Andrews *et al.*, 1974) also produce two kinds of spores. The smaller ones are 30-48 µm in size whereas the bigger ones range from 60-156 µm and both types are produced in the different sporangia. The larger spores are subcircular-circular in shape and sculptured with closely packed minute grana. The smaller spores, on the contrary, are triangular in outline and ornamented with baculi, coni, etc. (Gensel & Andrews, 1984). The size range of the megaspores of *Chaleuria cirrosa* falls far below 200 µm, a conventional size often used to mark heterospory in dispersed spores (Pl. 1).

Taylor and Brauer (1983) considered that *Barinophyton citrulliforme* might be regarded as a transitional stage in the evolution of heterospory because the spores already differ in size, wall structure and most importantly sexual expression but are still found in the same sporangium. Cichan *et al.* (1984) considered that in plants with spores distinct in size as well as structure, there is a strong possibility that biological heterospory was also present. They thought that differential sporoderm ultrastructure in conjunction with dimorphic spore size might potentially be a more viable indicator of heterospory than differences in spore size alone. Using such evidence they suggest that *Protobarinophyton pennsylvanicum* and *B. citrulliforme* were biologically heterosporous. In the extant lycopods some species of *Selaginella* have micro- and megaspores in the same sporangium. The same phenomenon was recorded by Goswami and Arya (1970) in *Isoetes pantii* and by Mondal (1978) in *Isoetes coromandelina*.

The most characteristic feature of the megaspore of *Protobarinophyton pennsylvanicum* and *Barinophyton citrulliforme* is the wall structure. Both of them are spongy

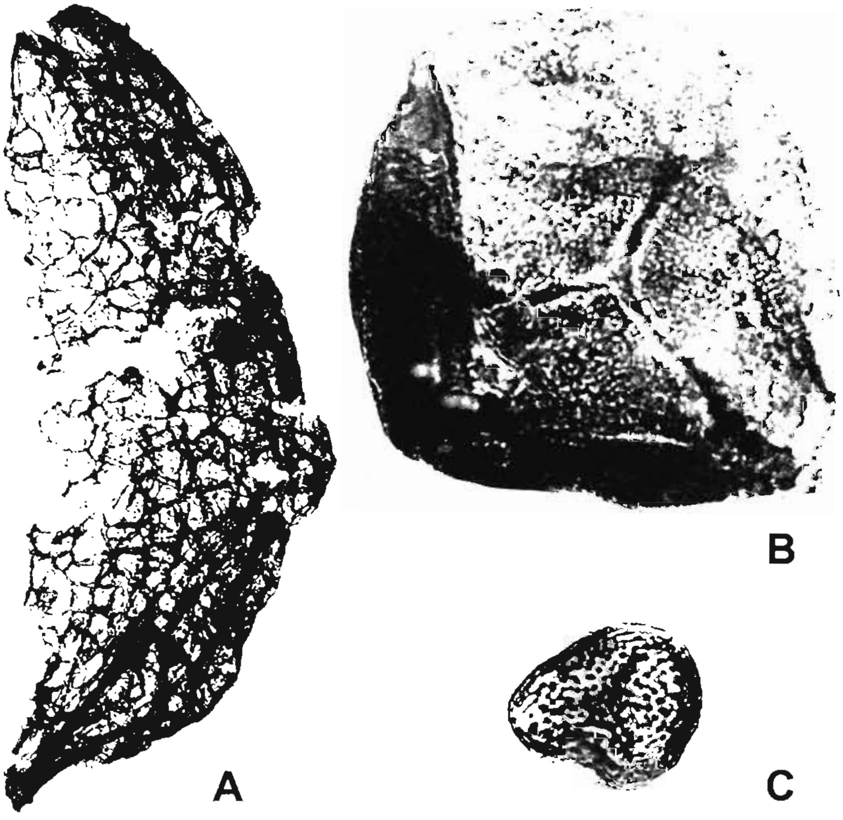

PLATE 1

Chaleuria cirrosa.

A. One single sporangium x 45.
B. A presumed megaspore x 640.
C. A presumed microspore x 640 (after Andrews *et al.*, 1974).

and in *P. pennsylvanicum* SEM study reveals a porous surface layer while the subsurface layer is alveolate and seems to be composed of superposed sheets of wall material with numerous oval/circular lacunae. In *B. citrulliforme*, the sporoderm layer of the megaspore is loosely arranged giving a spongy appearance. The microspore wall of *B. citrulliforme* has a homogeneous sporoderm and the microspore wall of *P. pennsylvanicum* is also different from that of the megaspore (Taylor & Brauer, 1983; Cichan *et al.*, 1984). The spongy megaspore wall structure of *P. pennsylvanicum* and *B. citrulliforme* shows some similarity to the megaspore wall structure of *Azolla*, *Salvinia*, *Isoetes*, *Marsilea*, as well as *Selaginella*. Fitting (1900), Pettitt (1966), Fowler and Stennett-Wilson (1978), Lugardon and Husson (1982) and Zhiyan (1983) observed several layers of spongy sporoderm in the megaspore wall of *Azolla* where the sporopollenin elements forming the ektexine have ramifying rodlets. Pettitt (1966), Lugardon (1973) and Lugardon and Husson (1982) also recorded fairly comparable sponginess in the megaspore wall of *Isoetes* and *Marsilea*. Similar differences between the microspore and megaspore wall structure found in *P. pennsylvanicum* and *B. citrulliforme* were also observed in the microspore and megaspore walls of *Azolla*, *Salvinia*, *Marsilea*, *Isoetes* and *Selaginella* by Pettitt (1966), Stainer (1967), Lugardon (1972) and Lugardon and Husson (1982). An exception to this observation is found in the wall structure of the microspores and megaspores of *Archaeopteris*. Here the wall structure in both microspores and megaspores found in the microsporangia and megasporangia in organic connection have similar wall features. Pettitt (1966) thinks the spores of *Archaeopteris* cf. *jacksonei* was not far advanced from a homosporous stage and the wall structure of the microspores and megaspores had not differentiated much beyond that of the common ancestral isospore type.

The spongy wall structure of the megaspores found in *Protobarinophyton* and *Barinophyton* of the Devonian and extant *Azolla*, *Salvinia*, *Marsilea*, *Isoetes* and *Selaginella* is indeed very striking. Except for *Selaginella*, all are aquatic heterosporous water plants. Dilcher *et al.* (1992) have postulated that the presence of grapnel like processes in extant aquatic *Azolla*, and in aquatic megaspores *Arcellites* and *Ariadnaesporites* from the Late Cretaceous suggests that the heterosporous genera, *Ancyrospora* and *Hystricosporites* from the Middle and Late Devonian, also had an aquatic habit. While the megaspores of *Protobarinophyton* and *Barinophyton* are devoid of bifid processes, the spongy nature of the megaspore wall, which is comparable to the extant megaspore walls of *Azolla*, *Salvinia*, *Isoetes* and *Marsilea* strongly suggests that they had an aquatic habit also. Differences between the microspore and megaspore wall structure of these plants may also suggest such a habit.

Dodd and Stanton (1990) assumed that palaeoenvironmental reconstruction depend upon a comprehensive understanding of the ecological significance of each organism. Such ecological context consists of an understanding of the ways in which present day organisms function within their ecosystems, how their external characters and physiology are adapted to their lives and the way in which their morphology fits the environments. The spongy wall structure of the megaspores of *Azolla*, *Salvinia* and *Marsilea* provide buoyancy in aquatic environments. Thus it may also be postulated that the same character found in *Protobarinophyton* and *Barinophyton* megaspore walls were adapted to the same kind of environment. In the opinion of Dodd and Stanton (1990), the analogy of morphological similarities for individual entities or populations can be regarded as a valid argument for environmental interpretations that are time independent. Lorenz (1974) advocated that whenever we find two kinds of life that are unrelated to each other with a similarity in form it is probably caused by parallel adaptations to similar environmental pressures. When we correlate the megaspore wall structure of *Protobarinophyton pennsylvanicum* and *Barinophyton citrulliforme* with the wall structure of megaspores of living heterosporous aquatic ferns and lycopods, we have to assume that these heterosporous Devonian plants also lived in an aquatic environment. This raises the possibility that heterospory may have originated in aquatic environments. DiMichele *et al.* (1989) reasoned that the heterosporous sexual system is most advantageous in aquatic and semi-aquatic habitats because these exhibit physical conditions more consistently favourable for the release of sperm and eggs. They further suggest that in such environments the heterosporous species may have a distinct advantage over homosporous forms.

Allen and Friend (1968) and Banks (1968, 1975) wrote about the palaeoecology and palaeogeography of the Devonian. According to them, when vascular plants appeared on land all the continents were joined to form a megacontinent and there may have been only about 2% oxygen in the atmosphere. In the uplands there were abundant metamorphic rocks and a predominance of mechanical over chemical weathering. The earliest land plants seem to have occupied chiefly mud flats. However, Banks (1975) assumed that the *Rhynia* chert flora of Emsian age is a good example of an inland intermontane bog (Fig. 6). Dineley (1979) remarked that as much as 85% of the surface of the earth was covered by water during Middle-Late Devonian time in addition to the presence of continental ice in the south polar region. None the less, the volume and the area covered by Devonian sediments are greater than those of other Palaeozoic systems (Raup, 1976). Gregor (1970) calculated that about 1.5 cubic kilometers of sediment accumulated per year during this period, which is more than double that of the Cambrian, Ordovician or Carboniferous periods. According to Dineley (1979) this seems to reflect the vigour of the geological cycle during the Devonian. In North Atlantic, Devonian sedimentation took place widely and rapidly with thick greywackes and associated clastic rocks, cherts and volcanics. In north-west Europe-Russian platform volcanic activity was in full swing during Early-Middle Devonian. In northern Asia, several cratonic blocks collided and fused and stabilization was in progress during the Devonian (Dineley, 1979). This turmoil in a vast area was perhaps responsible for one of the three great Phanerozoic phases of extinction of marine invertebrate life mostly referred to as Frasnian - Famennian mass extinction (McLaren, 1970; Cooper, 1977). Obviously, such palaeogeographical and palaeoecological conditions were not congenial for the plants to thrive in the terrestrial realm. The marginal lacustrine environment where *Ancyrospora*, *Hystricosporites* and *Rhabdosporites langii* are found in abundance could easily harbour and nourish the megaspores at the cradle of their evolution.

SUMMARY

The hypothesis is proposed here that aquatic environments have provided plants with the potential to develop a heterosporous mode of reproduction. Heterospory has occurred independently in several groups (clades) of vascular land plants at different times ranging from the Middle Devonian to the Cretaceous. Many of the extant heterosporous plants, that had their origins in these early times, are still living in aquatic environments. An aquatic environment provides increased potential for out-crossing between microspores and megaspores and provides a safe environment in which to disperse microspores and megaspores. The heterosporous plants that gave rise to seed plants and heterosporous land plants owe their origins to aquatic ancestries.

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Indian Gondwana palynochronology: relationships and chronocalibration

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ABSTRACT

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The concept of Gondwana Sequence on the Indian Peninsula is discussed from the view point of time, geographical extent and environment. It has been ascertained that Talchir deposition began in the late Asselian (Early Permian) and not during the Permo-Carboniferous. The Karharbari succession is a distinct formation. The Barakar Formation should continue to be placed in the Lower Permian of the bipartite division of the Permian System. The Banspitali *Nala* section, in the south of Damodar River, Raniganj Coalfield, West Bengal, India, may be a suitable nonmarine reference section for the Permian-Triassic boundary. To determine the age-ranges of the palynozones through the Gondwana Sequence, there is a need for cross-correlation with sections in the Himalayan region and in other areas of Gondwanaland.

Key-words—Palynology, Gondwana, Palynochronology, Correlation, India.

भारतीय गोण्डवाना परागाणुकालानुक्रमिकी : सम्बन्धन तथा अंशशोधन के कुछ आयाम

रामशंकर तिवारी एवं राजीव कुमार

सारांश

काल, भौगोलिक स्थितियों तथा पर्यावरण को दृष्टिगत रखते हुए भारतीय प्रायद्वीप में गोण्डवाना अनुक्रम की अवधारणा का विस्तृत विवेचन किया गया। यह अभिपुष्ट किया गया कि तालचीर निक्षेप परमो-कार्बोनीफ़ेरस कल्प के दौरान होने प्रारंभ नहीं हुए थे, बल्कि ये अन्तिम एसीलियन (प्रारंभिक परमियन) कल्प के दौरान निक्षेपित हुए थे। करहरबाड़ी अनुक्रम एक सुस्पष्ट शैलसमूह है। बराकर शैलसमूह को परमियन तंत्र के द्विआधारीय प्रभाग के अधोपरमियन कल्प में ही पूर्ववत् रखना चाहिए। भारत के पश्चिम बंगाल के रानीगंज कोयला क्षेत्र अवस्थित दामोदर नदी के दक्षिण का बाँसपीतली नाला परिच्छेद पी.टी.बी. हेतु एक उपयुक्त असमुद्री सन्दर्भ परिच्छेद सिद्ध हो सकता है। गोण्डवाना अनुक्रम के माध्यम से परागाणु मण्डलों की आयु सीमाओं के निर्धारण हेतु हिमालय क्षेत्रों तथा गोण्डवाना भूमि के अन्य क्षेत्रों के परिच्छेदों से इनका संकर सहसम्बन्धन किए जाने की आवश्यकता है।

संकेत शब्द—परागाणुविज्ञान, गोण्डवाना, परागाणुकालानुक्रमिकी, स्थानिक सम्बन्ध, भारत.

INTRODUCTION

GONDWANA was a Supercontinent that assembled during the Neoproterozoic (1000 Ma to the beginning of Cambrian) from fragments of an older continent, Rodinia (Late Mesoproterozoic, *ca* 1 Ga : Unrug, 1996), and existed as an independent supercontinent through the major part of the Palaeozoic Era. But during the middle Carboniferous, the

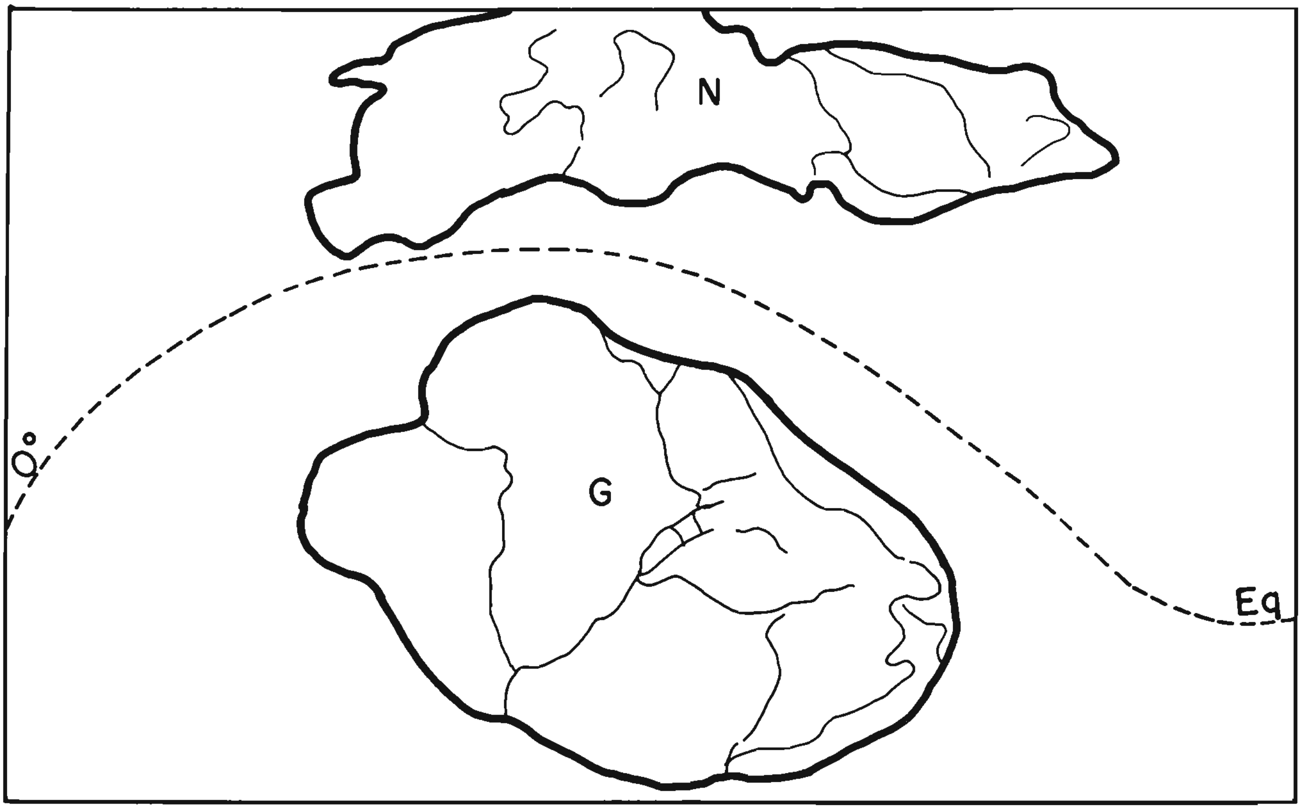


Fig. 1—Isolated Gondwana Supercontinent (G) during Neoproterozoic to middle Carboniferous, existing in the southern hemisphere independent of the northern landmass (N).

northern landmass (Laurasia, Baltica and Siberia) collided with Gondwana to form the supercontinent of Pangaea (Figs 1, 2), which continued to exist in the Mesozoic. Thereafter, its components began to drift apart, ultimately into the configuration of the present continents. Obviously, the Gondwana Supercontinent *sensu stricto* remained as a separate entity only up to the Late Palaeozoic; thereafter it became a part of Pangaea, and lost its identity before the first deposition of Gondwana facies on the southern continents.

However, the northern limits of the original cratons as well as the Neoproterozoic mobile belts of the original Gondwana Supercontinent continued to be well demarcated within Pangaea. Gondwanaland thus comprised the southern portion of Pangaea; and was partly separated from the northern landmass by an equatorial sea, the Tethys (Fig. 2).

The distinctive characteristics of the Gondwana facies are not because of its isolation as Gondwanaland but because of location of most of its land region occupied high latitude in the southern hemisphere thus providing a unique environment (Veevers, 1993). Under the influence of the Gondwanan climate, ecology and land-sea distribution as well as geotectonics, the typical flora and fauna of Gondwana maintained their identities during the Permian and most of the Mesozoic (Tiwari & Vijaya, 1995).

Eastern Gondwana was intact with its component continents even up to the Early Cretaceous (Aptian-Albian). The Gondwana Sequence on the Indian peninsula incorporating similar sediments with characteristic biota spanned through the Permian and most of the Mesozoic. In Australia and Antarctica, this succession continued even beyond the Early Cretaceous as these landmasses remained united up to the early Cenozoic, representing the last phase of existence of Gondwanaland.

The close correlation between floras throughout Gondwanaland during the Permian (*Glossopteris* floral province) and during most of the Mesozoic support the palaeogeographic configuration noted above. Palynofossils are the primary reference group for establishing spatial relationships in the regions of Gondwanaland and for calibration of chronostratigraphy through links with marine successions.

The Gondwana Sequence on peninsular India is basically non marine although evidence for marine episodes occur intermittently. Hence, the dictum that the Gondwana succession comprises only non-marine deposits has to be abandoned (Tiwari *et al.*, 1995; Chandra, 1996; Mukhopadhyay, 1996). Comparable situations exist in other regions of Gondwanaland where mixed marine and continental

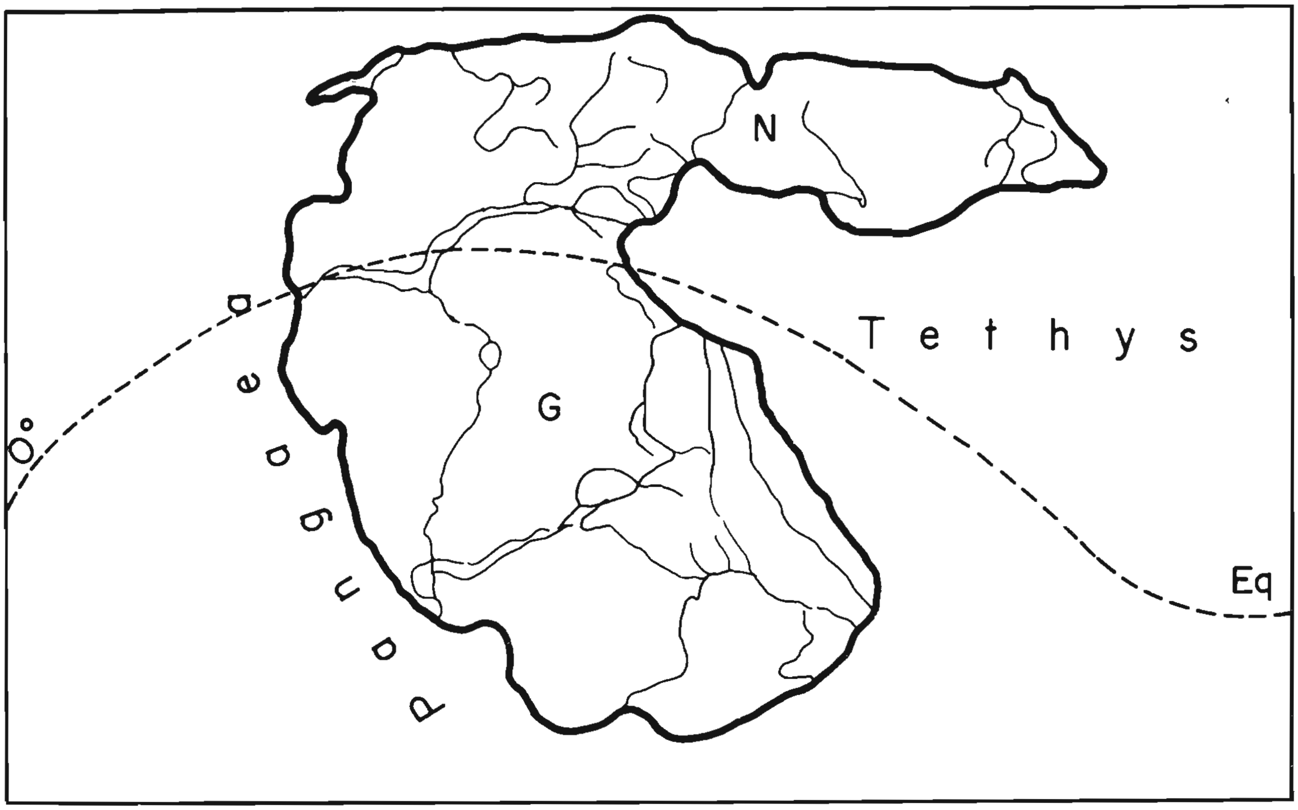


Fig. 2—Pangaea, formed during middle Carboniferous, resulted from collision of Gondwanaland (G) and the northern landmass (N); however, the northern limits of the former remained demarcated, in most of the region, by the Tethys sea.

environments are recorded from Permian to Early Cretaceous (e.g., Madagascar : Rakotosolofo *et al.*, 1998). In these situations, temporal correlations in nonmarine and marine successions need to be refined with reference to palynozones. The nonmarine nature of sediments should not hinder the attempts for global stratigraphic correlation based on multiple parameters.

Efforts continue to be made to fill the gaps in data and resolve the existing problems for achieving palynologically based chronology (i.e., palynochronology) of the Indian Gondwana Sequence; e.g., Tiwari and Tripathi (1992), Lindström (1995, 1996) and Tiwari (1999a, b). The data presented in these and other publications form the basic framework for further refinement of chronology based on palynology.

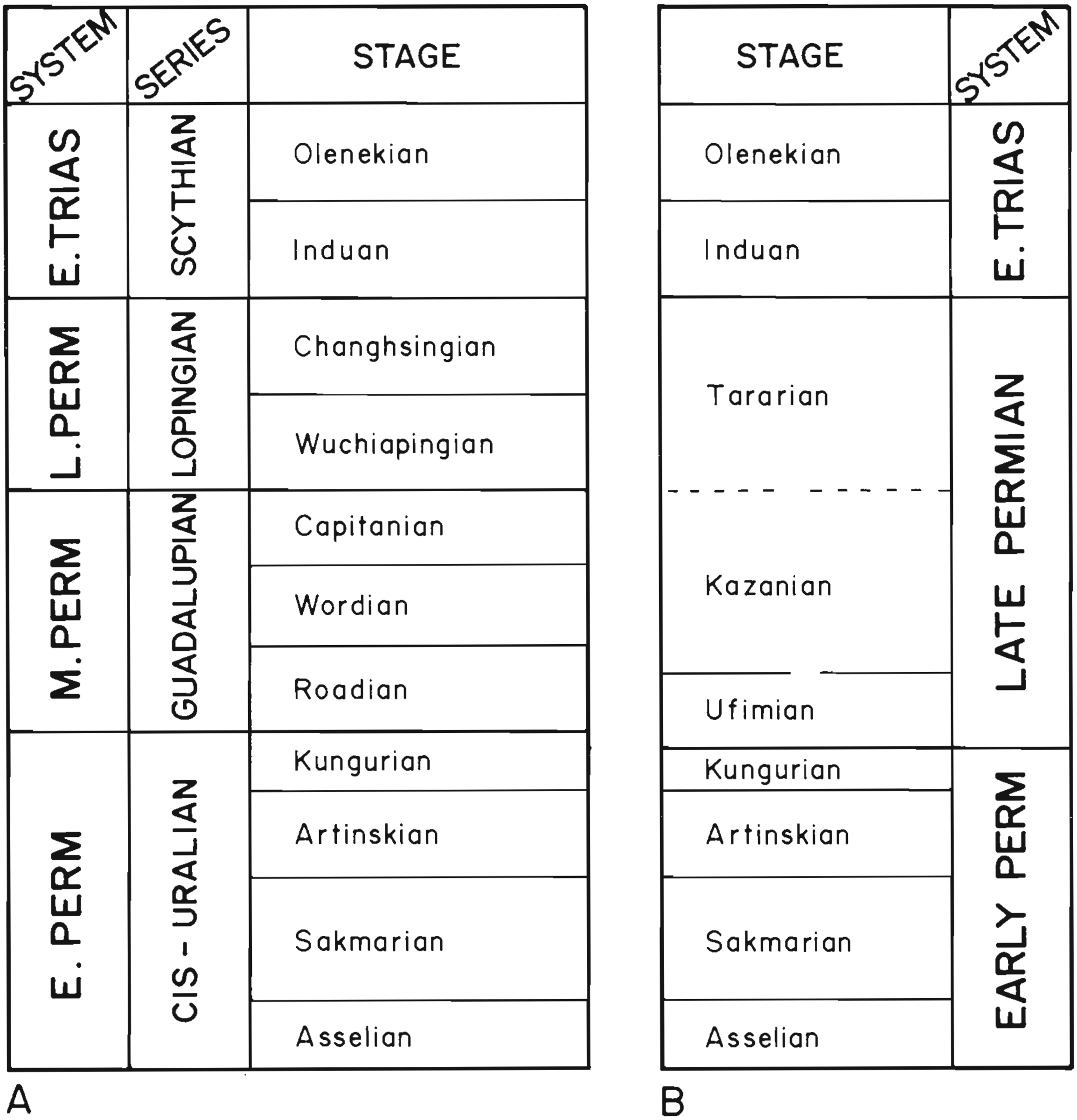
KEY ASPECTS IN PALYNOSTRATIGRAPHY

In the following account, key aspects of certain levels in stratigraphy are discussed :

1. The Talchir Formation : age status as Permo-Carboniferous ?
2. The Karharbari Formation : litho-, bio-, and temporal attributes.
3. Classification of Permian Gondwana and position of the Barakar Formation : Lower, Middle or Upper?
4. Permian-Triassic Boundary (PTB) at outcrop, south of Damodar River, West Bengal : a candidate for nonmarine stratotype?
5. Gondwana palynochronology.

1. The Talchir Formation: age status as Permo-Carboniferous?

On the peninsula of India, the deposition of the Gondwana Sequence commenced with the Talchir Formation, which lies unconformably on uneven Precambrian basement. Talchir sediments, present in all of the basins, are typically of glacial origin with intermittent intercalations of lacustrine and shallow marine tidal-flat deposits through most of the formation (Casshyap & Tewari, 1987). Two distinct levels of marine fossils have been recorded. In the older horizon (i.e., Manendragarh Bed in Madhya Pradesh), a *Eurydesma-Deltopecten* bivalve fauna of an Asselian age, while the younger level (i.e., Umaria Bed in Madhya Pradesh & Daltonganj, Bihar) is characterised by *Stephanonviella,* which implies a Sakmarian age. These two marine marker beds correlate with two transgressive phases



A

SYSTEM	SERIES	STAGE
E.TRIAS	SCYTHIAN	Olenekian
		Induan
L.PERM	LOPINGIAN	Changhsingian
		Wuchiapingian
M.PERM	GUADALUPIAN	Capitanian
		Wordian
		Roadian
E. PERM	CIS - URALIAN	Kungurian
		Artinskian
		Sakmarian
		Asselian

B

STAGE	SYSTEM
Olenekian	E.TRIAS
Induan	
Tararian	LATE PERMIAN
Kazanian	
Ufimian	
Kungurian	EARLY PERM
Artinskian	
Sakmarian	
Asselian	

Fig. 3—Currently accepted (A) and previous (B) chronostratigraphic classifications of System, Series and Stages of the Permian and Early Triassic.

of the Tethys sea. The occurrence of eurydesmids and productids in the Bap Formation of Rajasthan also correlates with the Early Permian of Salt Range on one hand and the Talchir Formation in Central India on the other, both indicating glacio-marine conditions (Rao *et al.*, 1977). In addition, there is evidence of marine signatures in other areas and basins (e.g., varied leiospherids) indicating widespread marine influence over the peninsula during Talchir deposition (Venkatachala & Tiwari, 1987; Tiwari *et al.*, 1995; Ravi Shanker *et al.*, 1996).

Palynologically, three species assemblage zones have been established through the Talchir Formation. From oldest to youngest these are : (1) —*Potonieisporites neglectus*, (2) — *Plicatipollenites gondwanensis*, and (3) —*Parasaccites*

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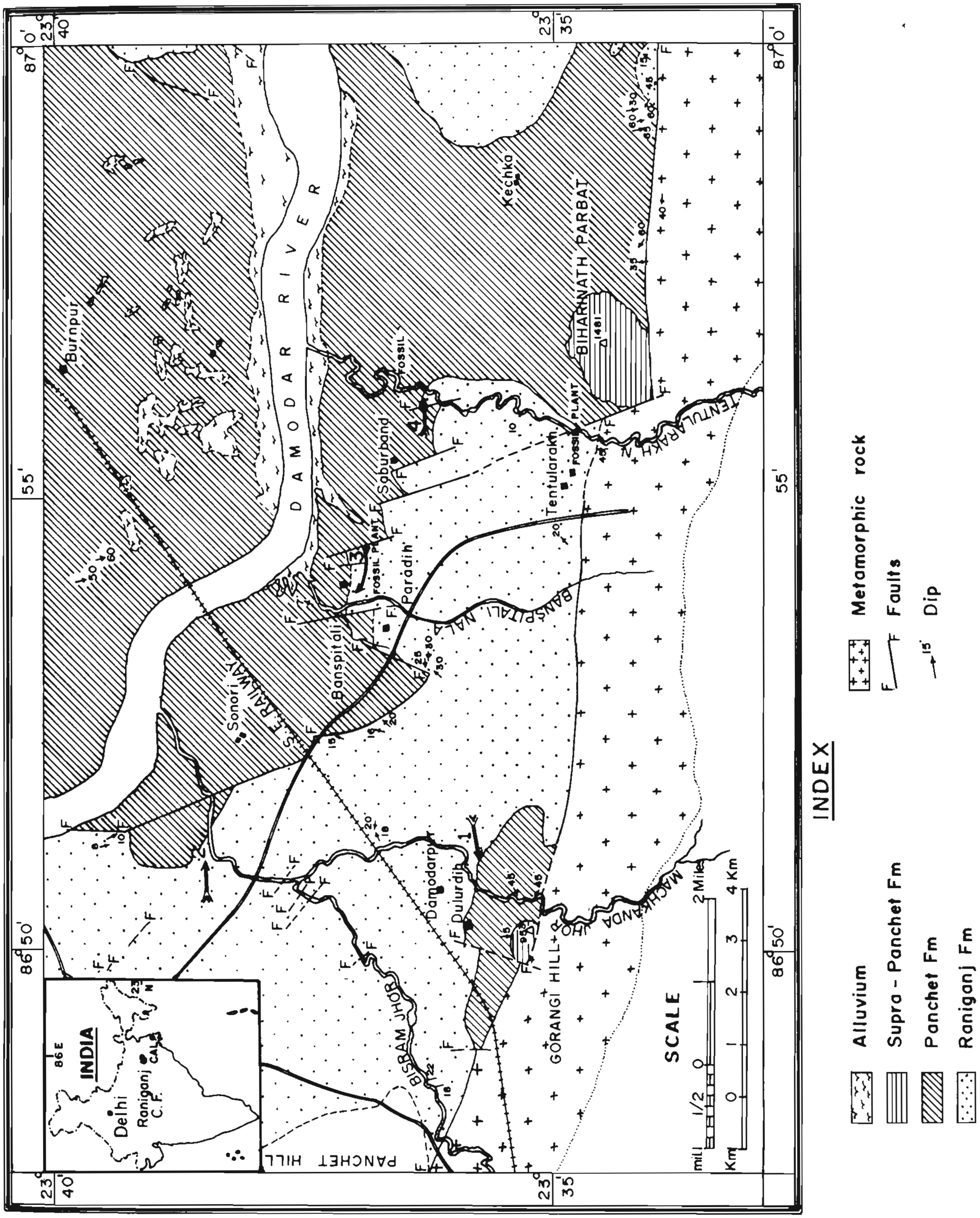
Fig. 4—Geological map of the area south of Damodar River, Raniganj Coalfield, West Bengal, depicting the Raniganj/Panchet Boundary in four sections. Bold arrows indicate the localities whence samples were collected for palynoanalysis : 1 Machhkanda Jhor, near Gorangi Hill; 2. Machhkanda Jhor, near its confluence with the Damodar River; 3. Banspitali Village, Section in Banspitali *Nala*; 4. Tetularakh *Nala*, near its confluence with the Damodar River (see also Fig.7).


INDIA
86E
Delhi
Raniganj C.F.
CAL
23 N
DAMODAR RIVER
S.E. RAILWAY
Burnpur
Sonori
Banspitali
Paradih
Saburband
Kechka
Tentularakh
BIHARINATH PARBAT
BANSPITALI NALA
TENTULARAKH N.
MACHKANDA JHOR
BISRAM JHOR
GORANGI HILL
PANCHET HILL
Damodarpur
Dulurdih
FOSSIL PLANT
FOSSIL
SCALE
mil 1/2 0 1 2 3 2 Mile
Km 0 1 2 3 4 Km
87°0'
86°50'
55'
23° 40'
23° 35'
INDEX
Alluvium
Supra - Panchet Fm
Panchet Fm
Raniganj Fm
Metamorphic rock
Faults
Dip

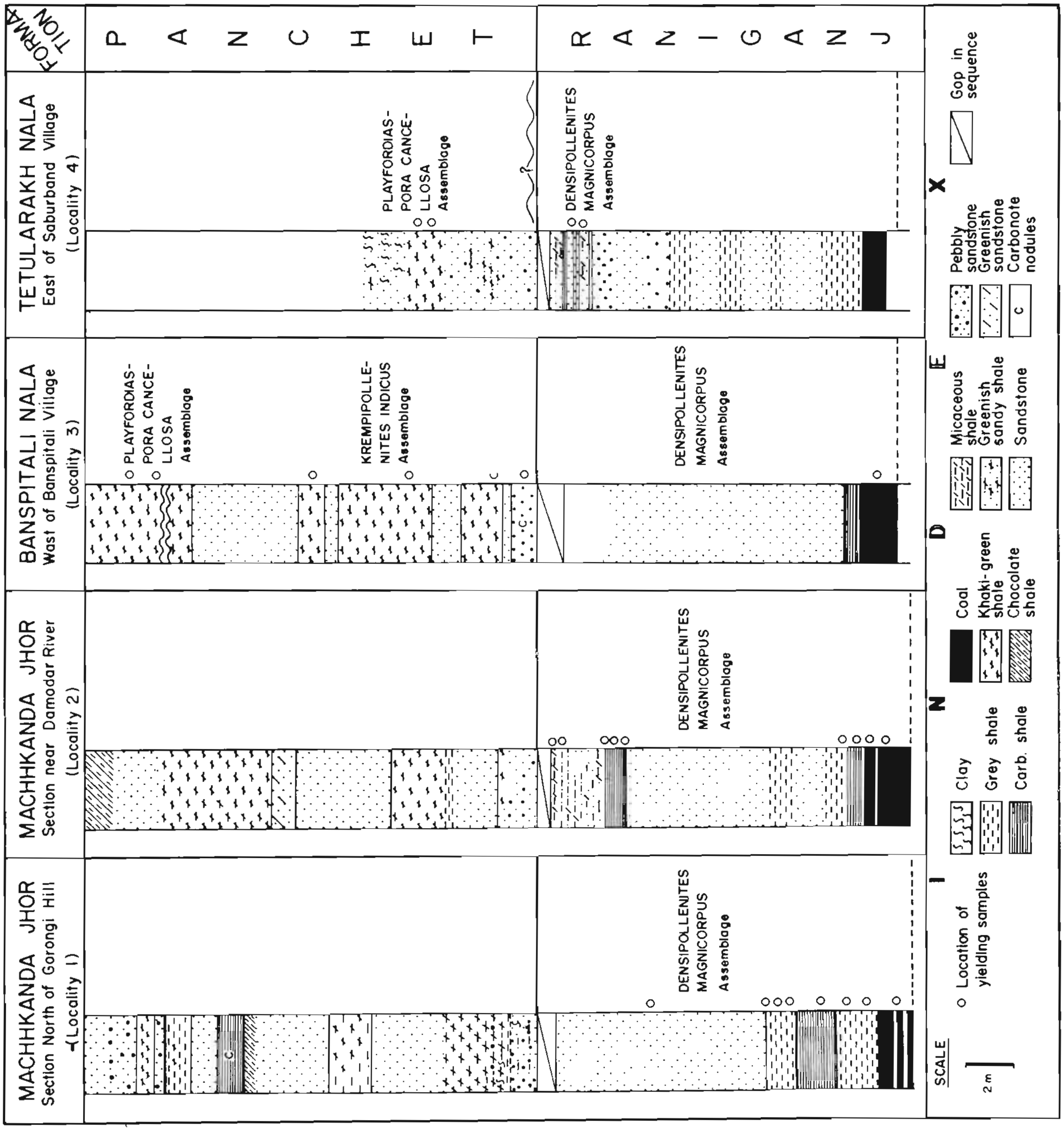


Fig. 5—Generalized sections and palynoassemblages recovered from the four localities depicted in Fig. 4.

korbaensis. For author and date attributions to these palynotaxa and others mentioned in this paper, see Tiwari (1999a).

The structure of these zones does not indicate a Late Carboniferous age for the Talchir palynoflora (Tiwari & Tripathi, 1992; Vijaya, 1996; Tiwari, 1999a, b). These palynozones are dominated by radial or bilateral monosaccate pollen with monolete or trilete germinal mark (species of *Potonieisporites, Parasaccites, Virkkipollenites* and their morphological variants). A progressive incremental innovation of morphologies takes place from the oldest to the youngest zone. Consequently, the First Appearance Datums (FADs) of zonate-cingulate spores (*Jayantisporites* cf. *conatus*), and bilateral (*Parasaccites bilateralis*) and striate pollen (*Crescentipollenites fuscus* and *Faunipollenites perexiguus*) are recorded in Zone II. Further proliferation of forms is

Formation	Assemblage	Spore-pollen species
Panchet Formation	*Playfordiaspora cancellosa* Assemblage (in khaki green shale, sst of upper reaches)	*Arcuatipollenites asansoliensis, Ringosporites fossulatus, Indotriradites mamillatus, Playfordiaspora cancellosa, Verrucosisporites narmianus, Guttatisporites ambiguus, Osmundacidites senectus, Goubinispora morondavensis*
	Krempipollenites indicus Assemblage (in lower shale, sst khaki-green shale suit)	*Alisporites landianus, A. asansoliensis, Callumispora gretensis, Lundbladispora brevicula, Lundbladispora microconata, Verrucosisporites narmianus, Densoisporites playfordii, Densoisporites contactus, Krempipollenites indicus, Arcuatipollenites pellucidus, Arcuatipollenites damudicus, Lahirites triassicus*
Raniganj Formation	*Densipollenites magnicorpus* Assemblage (in uppermost coal-shales-sst suit)	*Densipollenites magnicorpus, D. densus, D. indicus, Gondisporites raniganjensis, Barakarites indicus, Leiotriletes virkkii, Kendosporites striatus, Columinispora* sp., *Laevigatosporites colliensis, Crescentipollenites fuscus, Striatopodocarpites tiwarii, Rhizomaspora triassica, Striatopodocarpites decorus, Lundbladispora* sp., *Verticipollenites secretus, Platysaccus* sp., *Striatites sewardii, Scheuringipollenites maximus, Cedripites priscus, Falcisporites nuthallensis, Arcuatipollenites ovalis, Krempipollenites* sp. *Striatopodocarpites diffusus*

Fig. 6—Occurrence of important spore-pollen species across the Raniganj/Panchet Boundary based on studied sections, emphasising a transformation from Permian to Triassic palynofloras.

evidenced by the cruciform-saccus-bearing monosaccate pollen (*Crucisaccites latisulcatus*), simple bisaccates (*Scheuringipollenites maximus*), and a trilete spore species with well-established stratigraphic index-value in Australia and Antarctica (*Microbaculispora tentula*) commencing in the Zone III.

Palynozone I is highly impoverished, possibly because of adverse climatic conditions or taphonomic factors. So far, no typical Carboniferous palynomorphs (e.g., *Diatomozonotriletes, Lycospora, Cristatisporites*, lycosporoid elements with small cingulate-zonate spore species, *Convolutispora, Pustulatisporites*) have been identified in the Talchir assemblage. Plant megafossils characteristic of a Carboniferous age are also absent from horizons of peninsular Gondwana. *Lepidodendron* forest existed in the southern hemisphere prior to the *Glossopteris* flora; inception of the latter coincides with the base of the Talchir Formation. The genera *Cyclostigma, Archaeosigillaria, Nothorhacopteris* (*Rhacopteris*), *Rhodeopteridium*, which are characteristic elements of the Carboniferous in the southern hemisphere, are absent from the Gondwana Sequence of India.

Accordingly, the Talchir succession cannot be dated as Carboniferous, or even Permo-Carboniferous. A recent reinterpretation by Apak and Backhouse (1998) of the Permo-Carboniferous stratigraphy of the Canning Basin, Western Australia provides further support for this conclusion. The Grant Group of the Canning Basin has been now redefined and divided into (1) Reeves Formation (previously known as Lower Grant Group), and (2) Upper Grant Group. None of the assemblages, or their component taxa, that are typical of the Reeves Formaion representing a Carboniferous palynological complex, is present in the Talchir Formation (for details see Apak & Backhouse, 1998; Backhouse, 1998). With the revised stratigraphic scheme, all sediments included within the younger 'Grant Group' (new delimitation) belong to the *Pseudoreticulatisporites confluens* Zone of Foster and Waterhouse (1988). The palynologically defined Stage 2 of Australia has thus become vague in its limits. The Talchir assemblages are broadly correlated with *P. confluens* Zone (Asselian) of the younger Grant Group.

From an analysis of Early Permian deglaciation in eastern Gondwanaland, Wopfner (1999) suggested that deglaciation extended from the latest Asselian to about the mid Sakmarian. The change from a glacial climate to cool temperate post-glacial conditions is reflected by a change in the mineralogical composition of the sediments (*see* Wopfner, 1999). The massive shales at the top of the Talchir sequence, partly associated with *Eurydesma, Deltopecten* and *Linoproductus*, probably represent this deglaciation event (Wopfner &

Sample No.	Lithology	Thickness of samples (in m)	Remarks	Formation
B-1	Coal	1.5	Lowermost sample: Topmost coal of Raniganj Formation	Raniganj
B-2	Sandstone, massive	20	Roof sandstone (Gorge)	Contact
			Gap (alluvium cover)	
*	Calcarious pebbly bed	5		Panchet
B-3	Khaki-green & Greyish shale	1		
*	Sandstone	0·30	Parting	
B-4	Khaki-green & Grey shale	2		
*	Sandstone	1	Parting	
B-5 to B-8	Khaki-green shale	4		
*	Sandstone	0·50	Parting	
B-9	Khaki-green shale	1	Dip 15° N	
*	Sandstone	4		
B-10 to B-12	Khaki-green shale	3		
*	Sandstone	2·00		
B-13 to B-15	Khaki-green shale }	0·50		
*	Sandstone	0·50		
			Gap	
B-16 to B-26	Khaki-green shale Sequence	Meter wise 11 samples	Bottom Run of a hillock section Top	
		50	Gap	
B-27	Khaki-green shale	1·5	Ahead of confluence of two branches of *nala*	
*	Thick sandstone	30		
B-28	Khaki-green + Red clay	2	Appearance of red-chocolate colour	Upper Panchet
*	Massive sandstone yellow colour			
B-29	Red-chocolate mixed with khaki-green shale	1		
B-30	Red-chocolate mixed with khaki-green shale	1	Topmost	
B-31	Red clay	1	samples	

Fig. 7—Lithological sequence (ascending stratigraphic order) encompassing Raniganj/Panchet Transition and major part of the Panchet Formation in the Banspitali *Nala* section near Banspitali Village.

Casshyap, 1997; Wopfner, 1999). This indicates an Asselian to Sakmarian age for the beds containing invertebrates and the younger deposits of the Talchir Formation.

Waterhouse (1976) opined that the *Eurydesma* fauna is of Kurmanian age (youngest Asselian substage). If accepted, this ties the Manendragarh marine bed of the Talchir Formation in Madhya Pradesh, having this fauna, with the late Asselian. The numerical age-range for the Asselian is from 295 ± 5 Ma (Permo-Carboniferous Boundary) to 287 Ma (Asselian-Sakmarian Boundary) as estimated and synthesised by Ross *et al.* (1994). The beginning of the Talchir Formation coincides with the second half of this period.

Further analysis of the palynological succession through the Carboniferous-Permian sequence in Australia and India reveals that, although the main stocks of radial and bilateral monosaccates and nonstriate bisaccates appear in the

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Fig. 8—Sequence and inferred age of palynozones through the Gondwana Sequence of India (based on Tiwari, 1999a, b with addition of few new palynozones, FADs and Dominance Datums (DOD); Index DOD; in certain cases the dominance datum is not determined by counts but estimated by relative abundance of taxa).

PERIOD	EPOCH	AGE	PALYNOASSEMBLAGE ZONES	PALYN. COMPL	FAD	DOD/INDEX DOD
CRETACEOUS	K_1	ALBIAN	(AI) Appendicisporites distocarinatus	ANGIOSPE-RMIDS	← Murospora truncata	DISTALTRIANGULISPORITES
		APTIAN	(AH-I) Retitriletes eminulus (AH) Coptospora cauveriana (AG-I) Callialasporites reticulatus	CICATRICOSISPORI-TES COPTOSPORA	← Asteropollis vulgoris ← Clavatipollenites hughesii ← Retimonocolpites peroreti-culatus	COPTOSPORA
		BARREMIAN	(AG) Cyclosporites hughesii		← Coptosporo cauveriana	CYCLOSPORITES
	Neocomian	HAUTERIVIAN	(AF) Microcachryidites antorcticus		← Podosporites tripakshi	PODOCARPI ARAUCARIA.
		VALANGIAN	(AE) Foraminisporis wonthaggiensis			
		BERRIASIAN	(AD) Cicatricosisporites australiensis			CICATRICOSISPORITES
JURASSIC	J_3	TITHONIAN	(AC) Callialasporites segmentatus (AB) Callialasporites turbatus/dampieri	CLASSOPOLLIS - CALLIALASPORITES	← Contigni. globulentus	
		KIMMERIDGIAN	(AA) Murospora florida			
		OXFORDIAN				
	J_2	CALLOVIAN	(Z) Callialasporites trilobatus		← Calliala. monoalasporus	CALLIALASPORITES
		BATHONIAN				
		BAJOCIAN				
		AALENIAN				
	J_1	TOARCIAN				
		PLIENSBACHIAN	(Y) Classopollis minor		← Callialasporites dompieri	CLASSOPOLLIS
		SINEMURIAN				
		HETTANGIAN				
TRIASSIC	Tr_3	RHAETIAN	(X) Rhaetipollis germanicus	ARCUATIPOLLENITES 'ALISPORITES'		NONSTRIATE BISACCATE
		NORIAN	(W) Enzonalasporites ignacii (V) Dubrajisporites triassicus (U) Brachysaccus ovalis		← Dictyotriletes aulius ← Stauro. quadrifidus	MINUTOSACCUS DUBRAJISPORITES BRACHYSACCUS
		CARNIAN	(T) Rajmahalispora rugulata			RAJMAHALISPORA
	Tr_2	LADINIAN	(S) Rimaesporites potoniei (R) Dubrajisporites isolatus			STAUROSACCITES PLAYFORDIASPORA
		ANISIAN	(Q) Limatulasporites fossulatus (P) Goubinispora morondavensis		← Lundbladi willmotti	LIMATULASPORITES GOUBINISPORA
	Tr_1	OLENEKIAN	(O) Playfordiaspora cancellasa		← Triplexi. playfordii	ARCUATIPOLLENITES
		INDUAN	(N) Krempipollenites indicus		← Verrucosi. narmianus	KREMPIPOLLENITES
PERMIAN	P_2	TATARIAN	(M) Densipollenites magnicorpus (L) Guttulapollenites gondwanensis	STRIAT. DENSI.	← Densoisporites playfordii	CRESCENTIPOLLENITES/
		KAZANIAN	(K) Gondisporites raniganjensis		← Didecitriletes ericianus	STRIATOPODOCARPITES/
		UFIMIAN	(J) Densipollenites indicus		← Gondi. raniganjensis	DENSIPOLLENITES
	P_1	KUNGURIAN	(I) Faunipollenites varius	SCHEU. FAUNI.	← Guttula. hannonicus	FAUNIPOLLENITES /
		ARTINSKIAN	(H) Scheuringipollenites barakarensis		← Densipollenites indicus	SCHEURINGIPOLLENITES
		SAKMARIAN	(G) Crucisaccites monoletus (F) Virkkipallenites obscurus (E) Rugasaccites obscurus (D) Parasaccites korbaensis	PLICATIPOLLENITES PARASACCITES	← Marsupi. triradiatus ← Microbaculi. tentula	CALLUMISPORA / PARASACCITES /
		ASSELIAN	(C) Plicatipollenites indicus (B) Plicatipollenites gondwanensis (A) Potonieisporites neglectus		← Tuberisaccites tuberculatus	PLICATIPOLLENITES

Spelaeotriletes ybertii Zone (now dated as Namurian : Vijaya & Tiwari, 1992; Apak & Backhouse, 1998), the Talchir palynoflora typically consists of a much more diversified and highly evolved Permian spore-pollen assemblage including *Caheniasaccites decorus, C. densus, C. distinctus, C. ovatus, Crescentipollenites fuscus, Crucisaccites latisulcatus, Faunipollenites perexiguus, F. maximus, Jayantisporites conatus, J. indicus, J. pseudozonatus, Microfoveolatispora foveolata, Parasaccites bilateralis, P. densicorpus, P. korbaensis, Plicatipollenites distinctus, P. indicus, P. trigonalis, Potonieisporites crassus, P. magnus, Rugasaccites obscurus, Scheuringipollenites maximus, Tuberisaccites tuberculatus, T. varius,* and several others; these forms are not recorded from the *S. ybertii* Zone.

The Talchir palynofloras are much more similar to the Lower Permian Karharbari (*Crucisaccites monoletus* Assemblage Zone) and Barakar (*Scheuringipollenites barakarensis* and *Faunipollenites varius* Assemblage Zones) palynofloras than to the Carboniferous Stephanian (*Deusilites tenuistriatus* Assemblage), Westphalian (*Diatomozonotriletes birkheadensis* Assemblage) or Namurian (*Spelaeotriletes ybertii* Assemblage) palynofloras. Clearly, the Talchir Formation must be regarded as Permian in age.

2. The Karharbari Formation: litho-, bio-, and time-attributes

The Indian Gondwana Sequence was initially subdivided into formational units on the lithological characteristics and biota, or exclusively on the latter. Subsequent researches established a close relationship between these parameters in most of the successions which ultimately acquired chronostratigraphical ranks. However, at times, the correlation of lithology and biota are not compatible. The Karharbari Formation, although now defined lithologically in most basins of the peninsula, cannot be delimited in certain sections in spite of its typical plant fossils. Wherever it is distinctly delineated, it is distinguished from the underlying Talchir Formation by the presence of high-grade coal seams, grey, carbonaceous shales, and generally coarse-grained, gritty or pebbly sandstone containing recycled material from khaki-green shales of the Talchir Formation.

The lithologically distinctive characters and mappability of the Karharbari Formation have been strongly supported by Ghosh *et al.* (1964) and Ghosh and Basu (1967) in several basins; however, in a few areas it is not clearly distinguishable from the Barakar Formation unless it contains identifiable plant remains (Sastry *et al.*, 1977). The typical Karharbari flora has been referred to the *Gondwanidium-Buriadia* Assemblage Zone (Shah *et al.*, 1971). Chandra (1992) revealed that the leaf genera *Gangamopteris* and *Noeggerathiopsis*, both lacking midribs, are dominant, whereas *Buriadia, Dolinitia, Euryphyllum, Ginkgophyton, Gondwanidium* and *Palmatophyllites* have their first appearance in this formation. Other plant fossils which may be present are *Arberia, Glossopteris, Neomariopteris, Ottokaria, Phyllotheca* and *Vertebraria*.

Palynology further circumscribes the Karharbari Formation which contains *Crucisaccites* palynozone (Vijaya & Tiwari, 1992). The Talchir palynoflora reaches its climax of diversity at the base of the Karharbari Formation without any extinction of morphotypes. Many new palynomorphs derived from the Talchir stock developed from the monosaccate, nonstriate bisaccate and striate bisaccate groups. In addition, the FADs of *Barakarites gondwanensis, Callumispora barakarensis, Crescentipollenites limpidus, C. rhombicus, Crucisaccites monoletus, Densipollenites indicus, Marsupipollenites triradiatus, Scheuringipollenites barakarensis, Stellapollenites talchirensis, Tiwariasporis gondwanensis, Welwitschiapites magnus,* and a few others, are recorded within the Karharbari succession.

The Karharbari Formation, with coal seams and characteristic plant fossils, conformably overlies the Umaria marine bed (in Madhya Pradesh) of Early Sakmarian age; hence a Sakmarian to Artinskian age has been assigned to the former

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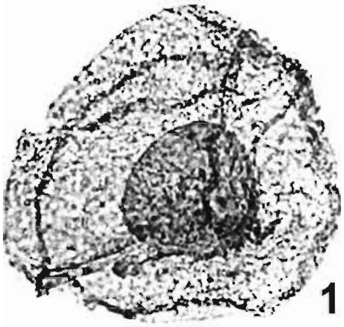
PLATE 1 ⟶

Characteristic spore-pollen taxa of the Raniganj Formation at the transit-sequence in outcrop sections of the south of Damodar River, Raniganj Coalfield, West Bengal. All figures are ca x 500. The slides are deposited at the repository of the Department of Applied Geology, Barkatullah University, Bhopal (DAG BUB). Registered Numbers are given against each figure.

1. *Gondisporites raniganjensis* Bharadwaj 1962, Reg. No.103;
2. *Densipollenites densus* Bharadwaj & Srivastava 1969, Reg. No.104;
3 *Densipollenites magnicorpus* Tiwari & Rana 1981, Reg. No. 104;
4. *Densipollenites indicus* Bharadwaj 1962, Reg. No. 105;
5. *Columinisporites* sp. Reg. No. 105;
6. *Kendosporites striatus* (Salujha) Surange & Chandra 1975, Reg. No.103;
7 *Scheuringipollenites maximus* (Hart) Tiwari 1973, Reg. No. 105;
8. *Striatopodocarpites decorus* Bharadwaj & Salujha 1964, Reg. No.105;
9. *Striatites sewardii* (Virkki) Bharadwaj 1962, Reg. No.106;
10. *Verticipollenites secretus* Bharadwaj 1962, Reg. No.107;
11 *Striatopodocarpites diffusus* Bharadwaj & Salujha 1964, Reg. No. 105;
12. Inner body-like objects in a bisaccate pollen. Reg. No. 108;
13. *Alisporites asansoliensis* Maheshwari & Banerji 1975, Reg. No.109;
14. *Striatites sewardii* (Virkki) Bharadwaj 1962, Reg. No.106;
15. *Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.* 1974. Reg No.105;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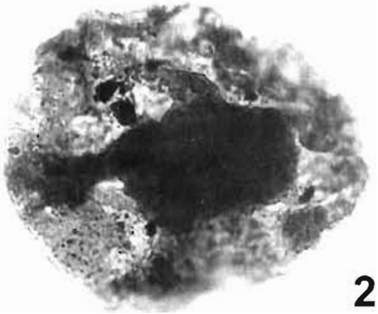
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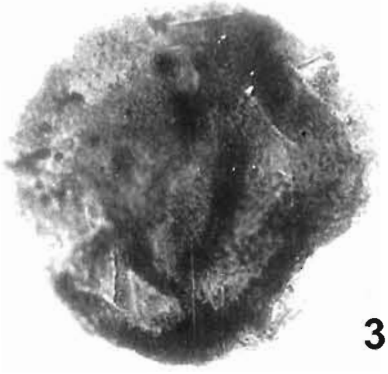
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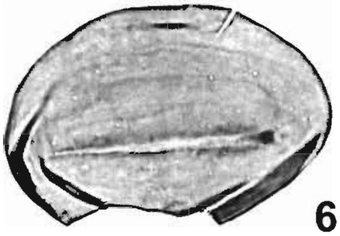
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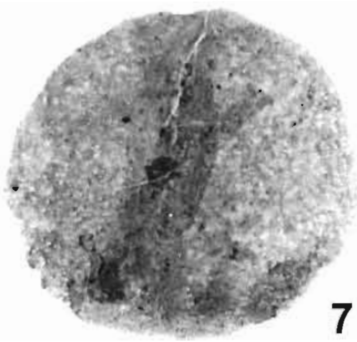
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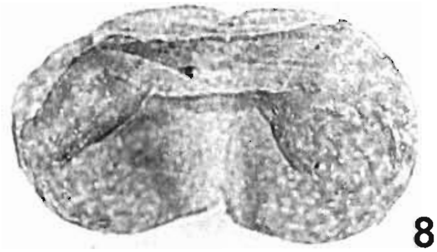
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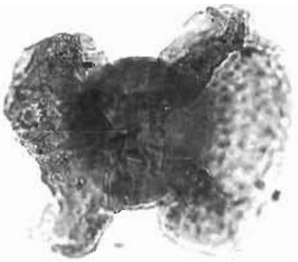
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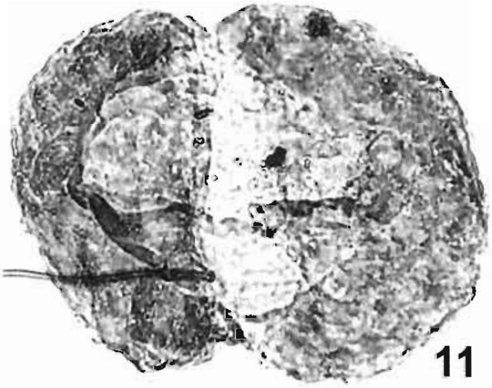
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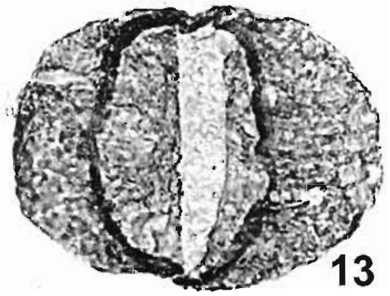
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PLATE 1

(Tiwari, 1999a). The Karharbari plant megaflora is also generally similar to that of the Gangamopteris Bed (*sensu stricto*) of Kashmir which has been dated as late Sakmarian to Artinskian (Ravi Shanker *et al.*, 1996). The marine fauna of the Garu Formation, Arunachal Pradesh, establishes a Sakmarian age for the associated palynoflora which, in turn, is closely, correlated with that in the Karharbari Formation (Singh, 1987). Further, a Sakmarian dating of the Karharbari Formation is reinforced by a recent discovery of a closely similar spore-pollen palynoflora in coal-balls occurring in the Bomte Member of the Garu Formation, west Siang District, Arunachal Pradesh. These coal-balls contain typical marine fauna (e.g., brachiopods *Costatumulus, Cyrtella, Strophlosia, Tivertonia, Tomiopsis, Trigonotreta*) of Sakmarian age (Archbold & Singh, 1993; Srivastava & Bhattacharya, 1998).

In Gondwanaland, a broad-based relationship has been suggested (Tiwari, 1999a, b) between the Karharbari palynoflora and those of the following: Beacon Super Group of Dronning Maud Land and the Mount Glossopteris Formation in Trans-Antarctica (Antarctica); Stage 3 of Australia; and Karoo Zone 3 of the Middle Ecca Series in South Africa.

An analysis of the depositional history of the Karharbari Formation by Casshyap and Tewari (1987) revealed that the basal Karharbari contains conglomerate bodies which are clast-supported, elongated channel-like and massive to cross-bedded. The conglomerate facies merges into pebbly, gritty and coarse to medium sandstones. The succeeding Karharbari Formation is sandy, becoming finer upwards. The coal seams are relatively thin and laterally impersistent. The cycles are asymmetrical in which the lower sandstone member exceeds the upper shale and coal.

The overlying Barakar Formation differs in comprising recurring fining upward, symmetrical cycles of coarse to medium sandstone interbedded with fine sandstone, siltstone, shale and coal. The increased thickness of fine facies usually distinguishes it from the Karharbari Formation, but even where it is not readily differentiated its plant megafossil and palynological content is diagnostic in almost all of the basins. The coal-shale-sandstone sequence of the Karharbari reflects deglaciation, amelioration of climate and proliferation of vegetation.

It is concluded that the Karharbari Formation is a generally recognisable lithological succession that yields plant megafossils and palynomorphs of late Sakmarian-early Artinskian age.

3. Classification of Permian Gondwana and position of Barakar Formation: Lower, Middle or Upper?

The redefinition, new classification and revised names and boundary levels for series and stages of the Permian System, based on marine sections, have been recently approved by the Permian Subcommission of the International Commission for Stratigraphy (ICS; see Fig. 3) despite strong opposition and lack of unanimity amongst the world's stratigraphers. The stratotypes for the Upper Permian units of the Standard Global Chronological Scale (SGCS) outside of the classical Volga-Urals regions are now selected because of the mostly nonmarine nature of sections in this region. The Permian System has now been divided into Cis-Uralian, Guadalupian and Lopingian, corresponding to Lower, Middle and Upper Permian, respectively. The type sections for exclusively marine successions have been selected from the Urals for Cis-Uralian, the USA for Guadalupian, and South China for Lopingian. Hence, the Permian System is now based on a unified and composite sequence with its three subdivisions based on widely separated regions, broadly situated within low palaeolatitudes.

PLATE 2

⟶

Characteristic spore-pollen taxa of the Panchet Formation at the transit-sequence in outcrop sections of the south of Damodar River, Raniganj Coalfield, West Bengal. All figures are ca x 500. The slides are deposited at the repository of the Department of Applied Geology, Barkatullah University, Bhopal (DAG BUB). Registered Numbers are given against each figure.

1 *Cedripites priscus* Balme 1970, Reg. No. 109;
2. *Densoisporites contactus* Bharadwaj & Tiwari 1977, Reg. No.110;
3 *Densoisporites playfordii* (Balme) Dettmann 1963, Reg. No. 106;
4 *Densoisporites contactus* Bharadwaj & Tiwari 1977, Reg. No. 110;
5 *Lundbladispora brevicula* Balme 1963, Reg. No. 106;
6, 7 *Krempipollenites indicus* Tiwari & Vijaya 1995, Reg. No. 111;
8. *Arcuatipollenites ovalis* (Goubin) Tiwari & Vijaya 1995, Reg. No. 105;
9. *Arcuatipollenites damudicus* (Tiwari & Rana) Tiwari & Vijaya 1995, Reg.No. 112;
10. *Callumispora gretensis* (Balme & Hennelly) Bharadwaj & Srivastava 1969, *emend.* Tiwari *et al.* 1989, Reg. No. 113;
11 *Arcuatipollenites pellucidus* (Goubin) Tiwari & Vijaya 1995, Reg. No.106;
12. *Goubinispora morondavensis* Tiwari & Rana 1981, Reg. No. 110;
13. *Verrucosisporites narmianus* Balme 1970, Reg. No.113;
14. *Indotriradites mamillatus* Bharadwaj & Tiwari 1977, Reg. No. 114;
15. *Guttatisporites ambiguus* Tiwari & Rana 1980, Reg. No. 115,
16. *Playfordiaspora cancellosa* (Playford & Dettmann) Maheshwari & Banerji 1975, Reg. No.116;
17. *Osmundacidites senectus* Balme 1963, Reg. No. 115;
18. *Alisporites landianus* Balme 1970, Reg, No.117;


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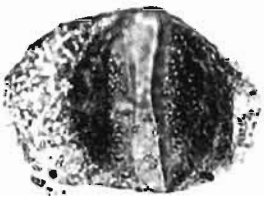
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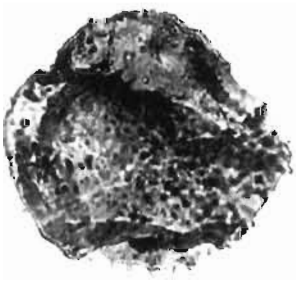
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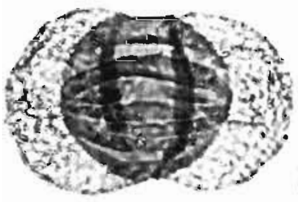
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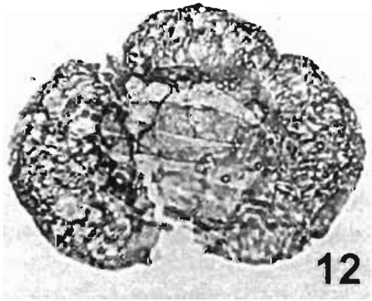
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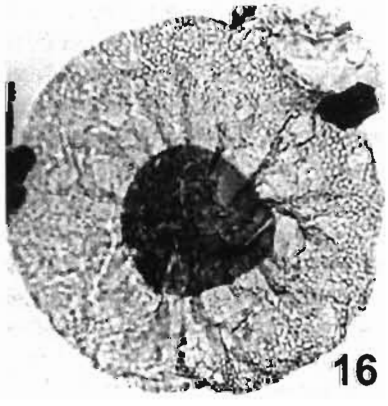
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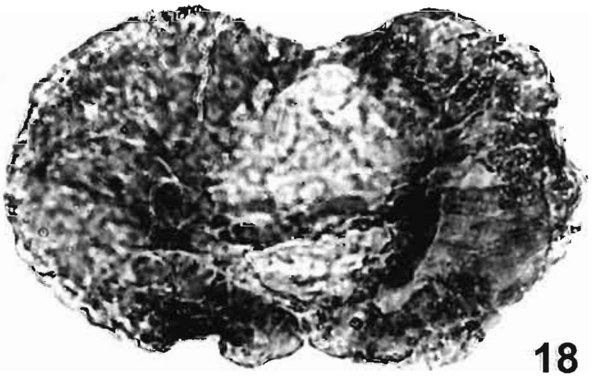
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PLATE 2

It is not intended to discuss here the merits and demerits of this classification because vigorous exchange of ideas has already taken place through the international forum (*see* News Letters of the Subcommission of Permian Stratigraphy; *Permophiles*, 1995-2000). Hence, only brief observations are made below on the adoption of the revised scheme with respect to the Permian Gondwana Sequence, particularly on the Indian peninsula.

World marine faunas are all subject to well-marked provinciality because of varied temperatures, water currents and chemical composition in habitats and latitudinal situations. An ideal correlation based on faunal or floral remains across the globe is not possible. Correlation between marine and nonmarine sequences is impossible unless it is based on shared fossils, such as palynomorphs, and even then it is by no means easy. The correlations between different floral provinces, based on palynomorphs, that have been attempted so far are inadequate because they are based on 'Apparent Form Similarity' in spore-pollen morphology, rather than real similarity. Palynomorphs produced by unrelated types of vegetation may show superficial gross comparable features but differ in intricate details of exine and organisation (Tiwari, 2000). Correlations based on such discrepancies cannot be sustained. The Permian Gondwana in India is basically nonmarine, and even palynology fails to cross-correlate with the northern marine sequences for SGCS because of the marked dissimilarities in the morphologies of palynomorphs from different floral provinces. As a result, no objective basis for determining the three divisions of the Permian in India has been established.

As opined by Archbold and Dickins (1997), the two-fold subdivision, based on the traditional Russian type-sections has proved useful to Gondwana workers. The American and Chinese sections may perhaps be regarded as supplementing this classical scale. The Russian stages have long been established and substantiated in continuous successions in a single large region, a point that is very much in their favour by comparison with the three-fold system which, moreover, is not applicable outside of the palaeo-equatorial belt. It is therefore suggested that use of two-fold division of the Permian on peninsular India and in other regions of Gondwanaland should be continued for the time being.

As already discussed, the Early Permian sequence in Gondwana basins of peninsular India is represented by the stratigraphic continuum of the Talchir, Karharbari and Barakar formations. The lower part of the Barakar Formation consists of braided channel deposits. In the mid Barakar, meandering channel systems are recognised. In places, deltaic/brackish water conditions may also be indicated. In the upper part, marine indicators are more common, suggesting a close proximity to an epicontinental sea. A pronounced hiatus above the Barakar Formation delimits the top of the Lower Permian. Thus, according to the bipartite division of the Permian system, the Barakar Formation is positioned at the upper Lower Permian. Two palynological zones have been identified within the formation : *Scheuringipollenites barakarensis* Assemblage Zone (Lower Barakar), and *Faunipollenites varius* Assemblage Zone (Upper Barakar), dated as Artinskian and Kungurian, respectively.

The Barakar palynoflora is more similar to successively younger palynofloras of the Upper Permian Kulti and Raniganj formations than to that of the underlying Karharbari Formation. Yet an Early Permian character is also evident in the form of a fair representation of radial monosaccate pollen and persistence of *Potonieisporites, Plicatipollenites, Parasaccites* and *Virkkipollenites*, species of which generally terminate at the top of the Barakar Formation. This formation was deposited during a time when vigorous floral diversification was taking place; hence, its transitional content of floras from earlier Early Permian and Late Permian (Tiwari & Tripathi, 1992; Tiwari, 1999a).

4. Permian/Triassic Boundary at outcrop, South of Damodar River: a candidate for nonmarine stratotype?

Ghosh *et al.* (1996) detailed the lithology, palynology, and conchostracans from the Raniganj/Panchet formational boundary interval exposed in three rivulets—Tetularakh *Nala*, Banspitali *Nala* and Machhkanda Jhor, in an area south of the Damodar River, Raniganj Coalfield, Damodar Basin, West Bengal. These authors also measured the sections and synthesised various parameters for locating the Permian-Triassic Boundary (PTB) in the Raniganj Coalfield. This led to the conclusion that the PTB in the area coincides the Raniganj/Panchet lithostratigraphic boundary (*see also* Bharadwaj *et al.*, 1979; Tiwari & Singh, 1983; Vijaya & Tiwari, 1986; Tiwari & Vijaya, 1992; Tiwari, 1999a, b). Of the three sections, Ghosh *et al.* (1996) recommended that the Banspitali *Nala* section be designated as type section for the continental Permian/Triassic Boundary on the basis of estheriid zonation, palynology and plant and animal megafossils.

With a view to further consolidating the data in favour of this proposal, we have undertaken a study of spore-pollen distribution in four sections (Locality Numbers 1-4, arrowed in Fig. 4). The generalised lithological sections, and the palynological assemblages recovered from various levels are illustrated in Fig. 5, and the overall occurrence of important species in successive levels is depicted in Fig. 6. In conformity with the observations of Ghosh *et al.* (1996), it is concluded from the present study, both field observations and palynological analysis, that the Banspitali *Nala*, near Banspitali Village (to its west : 86°54' : 26°37' — Locality 3 in Fig. 4) is the best section and has also yielded four fairly representative assemblages in succession (Pls 1, 2). These assemblages are from the Ranigaj/Panchet Transition, as shown below :

	Playfordiaspora cancellosa Assemblage Zone (in khaki-green shale-sst unit of upper reaches)	OLENEKIAN
PANCHET FORMATION	*Krempipollenites indicus* Assemblage Zone (in lower shale-sst khaki-green shales)	Early Triassic INDUAN
RANIGANJ FORMATION	*Densipollenites magnicorpus* Assemblage Zone (in uppermost unit of coal, shale-sst)	TATARIAN Late Permian

The determination of epoch and age of these assemblage zones has been discussed by Bharadwaj *et al.* (1979), Tiwari and Vijaya (1992), Ghosh *et al.* (1996), Tiwari (1999a, b, c), and others, based upon palynology, plant megafossils, estheriids, nonmarine vertebrate fossils, palynological cross-correlation with the well-dated Tethyan succession of the Himalaya, sequence stratigraphy and inter-regional relationship with comparable levels in Australia, Madagascar and Antarctica.

Notwithstanding such attempts, there remain several important points to be discussed for establishing the section as a stratotype for the nonmarine PTB. The Bansapitali *Nala* section is well exposed, easily accessible and shows a continuous sequence. The marker bed for the uppermost Raniganj, a 1·5 m thick seam, is well exposed. It is overlain by a massive sandstone (about 20 m thick). The Raniganj/Panchet Boundary is indicated by a few metres of alluvial deposits, followed by a calcareous pebbly bed, about 5 m thick, and then a continuous khaki-green shale-sandstone-sequence, typical of the Panchet Formation. The boundary section concerns only this part of the succession (Fig. 7) although the khaki-green shale-sandstone sequence continues upward to expose the entire Lower Panchet Formation until chocolate-coloured facies of the Upper Panchet become prominent (*see also* Ghosh *et al.*, 1996).

The alluvial deposit and calcareous pebble bed at the boundary may indicate a significant break, as in other sections, but it is not a major unconformity; the whole succession has a conformable aspect. Moreover, the palynological components do not indicate a sudden floral break. It is, therefore, inferred that the Raniganj/Panchet contact in the Banspitali *Nala* section records an episode of a subtle, perhaps climatic, change.

Hence, a team of experts in sedimentology, stratigraphy, palaeontology, geochemistry and geophysics should now analyse all aspects (including carbon – isotope and palaeomagnetic reversal studies) of the section, an approach that is necessary prior to allocating the type section of a system boundary. It should be noted that, although the palynological results so far obtained indicate a palynofloral shift across the boundary and the PTB could be located at this level, more closely spaced samples should be analysed because the palynological recovery has been only fair to poor.

Being a nonmarine succession, it cannot be referred directly to the standard marine stage. Hence a stratotype of Global Standard Section and Point (GSSP) is not required, merely a designated reference section. The Banspitali *Nala* section is potentially a good candidate for a PTB reference section in nonmarine deposits.

5. Gondwana Palynochronology

A study of the time significance of palynozones is palynochronology. During the last decade, a palynological zonation for the Gondwana succession on the Indian peninsula has evolved (Tiwari & Tripathi, 1992; Tiwari, 1999a, b). The chronological value of these palynozones is further enhanced by the fact that they can be applied beyond the Indian subcontinent, mainly elsewhere in Gondwanaland (Lindström, 1996; Warrington, 1996). The relevance of the Standard Global Chronological Scale (SGCS), exclusively erected on marine fossils, is obviously limited in case of nonmarine sequences.

In order to delimit the time significance of palynological zones in Indian Gondwana, the scheme given by Tiwari (1999 a, b; also Fig. 8) could form the basis for further discussion and filling in gaps. For such a goal to be achieved, promising areas where marine fossils occur along with abundant palynomorphs should be investigated. The lesser Himalaya and Tethyan sequence on the Indian subcontinent, northwest peninsula and the east coast are most suitable regions for such investigations because of their close floral relationship with the Gondwana basins on the peninsula. The Gondwana succession in Madagascar and Australia have intermittent marine control and can also provide comparative palynological data. To a large extent, the time connotations of the nonmarine fauna and flora of the peninsular India are also well established (*see* Borkar, 1993; Satsangi, 1987; Tiwari, 1996, 1999a, b, d; Bandopadhyay & Roy Chowdhary, 1996; Prasad & Jain, 1994; Prasad *et al.*, 1996; Kutty *et al.*, 1988; Prasad, 1997; Wopfner, 1999; Vijaya, 2000; Vijaya & Roy, 2000; and references therein). Event stratigraphic, radiometric and carbon-isotope studies could provide additional help in refining palynologically determined chronology.

CONCLUSIONS

The Gondwana succession of the Indian subcontinent is traditionally accepted to encompass a time span from the Permo-Carboniferous to Early Cretaceous. Its northern limit is the boundary of the greater Indian Plate in the Himalayas. It is a mainly nonmarine succession but there are some marine intercalations caused by epicontinental sea incursions on the peninsula; the marginal regions are predominantly marine yet they are allied to peninsular Gondwana. Most of the plant fossils have a Gondwana affinity; thus the Gondwana Sequence should not be defined exclusively on the basis of nonmarine deposits.

A Late Asselian (Early Permian) age has been determined for the beginning of Talchir deposition, and not Permo-Carboniferous, as previously thought. The succeeding sediments form a distinctive unit identifiable as the Karharbari Formation.

The practice of placing the Barakar Formation in the Lower Permian of the bipartite division of Permian should be continued until a satisfactory classification of the nonmarine succession has been established. The newly adopted tripartite divisional scheme for the Permian System, based on marine stratotypes from three widely separated regions in the palaeo-equatorial belt, does not seem appropriate for the Gondwana region and needs further assessment.

A continued search for greater precision in the location of PTB on the Indian peninsula has led to an outcrop section of the Raniganj/Panchet formations in the south of the Damodar River, Raniganj Coalfield, West Bengal. The palynology of this section conforms with those in other areas of the Damodar Basin, but if it is to be established as a reference section, a multidisciplinary study including further palynological work will need to be carried out.

Gondwana palynochronology is a challenging target to achieve so that the time significance of various palynozones can be established. Although a zonal framework for the Gondwana Sequence has been erected, several gaps in the record need to be filled. Palynological correlation with marine sections in the Himalayan region of the greater Indian Plate and also in other areas of Gondwanaland is necessary. Marine faunas or palynofossils from marine stratotypes from extra-Gondwana regions of the northern hemisphere have little relevance in erecting the nonmarine Gondwana biochronostratigraphy.

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Reinterpretation of an extinct taxon *Sporangioceros nipanica* Sharma *et al.* from the Rajmahal Hills, India

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ABSTRACT

Sharma BD, Bohra DR & Suthar OP 2002. Reinterpretation of an extinct taxon *Sporangioceros nipanica* Sharma *et al.* from the Rajmahal Hills, India. Palaeobotanist 51 : 31-36.

Morphology of an elongated, cylindrical, oval or ovate, coenocytic plant fossil resembling sporogonium of *Notothylas* is reinterpreted and correlated now with an extant fresh water green alga *Characiosiphon* Iyengar. In extinct material the wall layer is present but non-cellular and is covered over by a thick mucilaginous sheath. The protoplast is divided into discrete units each with a chloroplast and the nucleus. Zoospores ? and zoogametes ? liberated through an apical pore. Aplanospores are also identified. A new name *Characiosiphonites nipanica* has been suggested for *Sporangioceros nipanica* and a reconstruction of the fossil plant is attempted.

Key-words—Mesozoic, Coenocytic, Discrete protoplasts, Green alga.

भारत की राजमहल पर्वतश्रेणियों से प्राप्त सुस्पष्ट वर्गक *स्पोरैंजियोसिरॉस निपानिका* का पुनर्निर्वचन

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सारांश

नोटोथाइलस के स्पोरोगोनियम प्रदर्शित करने वाले एक प्रलम्बित, बेलनाकार, अण्डाकार संकोशिकी पादपाश्म के संरचना विज्ञान का पुनर्निर्वचन किया गया तथा अब इसे एक विद्यमान ताजे जलीय हरित शैवाल *चैरासिओसाइफ़ॉन* आयंगर से सहसम्बन्धित किया गया है। सुस्पष्ट पदार्थ में भित्ति पर्त्त उपस्थित है, किन्तु यह अकोशिकीय है तथा एक स्थूल श्लेष्मीय आच्छद द्वारा आच्छादित है। प्रोटोप्लास्ट को एक-एक क्लोरोप्लास्ट (पर्णहरिम) तथा नाभिक द्वारा प्रत्येक विविक्त इकाई में वर्गीकृत किया गया हैं। अलैंगिक चलबीजाणु? तथा चलयुग्मकों? को एक शिखाग्र रन्ध्र द्वारा विलग किया गया है। अचल बीजाणु भी निर्धारित किए गए हैं। *स्पोरैंजियोसिरॉस निपानिका* हेतु एक नया नाम *चैरासियोसाइफ़ोनाइटीज़ निपानिका* प्रस्तावित किया गया है तथा अश्मित पादप के पुनर्सृजन का प्रयास किया गया है।

संकेत शब्द—मीसोज़ोइक, सीनोसाइटिक, विविक्त प्रोटोप्लास्ट, हरित शैवाल.

INTRODUCTION

RAO (1943) while working on the chert from Nipania in the Rajmahal Hills, Bihar (now Jharkhand) observed isolated sporangia in thin sections and identified as sporangium 1, sporangium 2 and a doubtful (?) sporangium (Rao, 1943; Figs 38-44). The latter two types are similar to the presented here material. Mittre (1958) could also see a number of isolated sporangia in Nipania chert and in 1969 he figured spore mother cells and dividing chromosomes in them. Sharma *et al.* (1984) on the basis of study of a number of sporangia like specimens in thin sections prepared through the Nipania chert, established a new taxon *Sporangioceros nipanica*. It also included 'Sporangium 2' and '(?) Sporangium' of Rao (1943) and similar fertile structures. Sharma and Suthar (1986) figured some more and better preserved specimens of *S. nipanica* and correlated it with *Notothylas* of Anthocerotales (Bryophyta). Since then many more specimens showing different stages of development and sizes are observed in thin sections prepared through the Nipania chert and on this basis the relationship has now been suggested with the fresh water green alga *Characiosiphon rivularis* Iyengar (1936). It grows in groups in shallow water on stones and pebbles. The alga is unicellular with discretely scattered, condensed protoplast units in the thallus. Each protoplast has a large chloroplast (circular or angular), a small nucleus, a pyrenoid body and 2-5 contractile vacuoles. Comparison has also been made with other similar green algae e.g., *Characiochloris, Protosiphon, Codiolum*, etc. (Fritsch, 1935; Bold *et al.*, 1987). In the present paper a new name has been suggested *Characiosiphonites nipanica* for *Sporangioceros nipanica* Sharma *et al.* (1984).

The type slide of *Sporangioceros nipanica* Sharma *et al.* (1984) was deposited at the depository of Birbal Sahni Institute of Palaeobotany, Lucknow (India). The newly prepared slides of this material used in the present paper shall also be deposited at the BSIP, Lucknow.

MATERIAL AND METHODS

Pieces of chert collected from the well known fossiliferous locality Nipania in the Rajmahal Hills, Jharkhand (Srivastava, 1945; Sahni, 1948; Mittre, 1953; Sharma, 1975) were cut into thin slices with the help of a diamond edge wheel and processed for slide preparation by the usual technique of grinding and polishing methods (Darrah, 1960; Sharma, 1996) and mounted in dilute canada balsam. Some of the slides kept unmounted and examined in a water film because in many silicified cherts the fossiliferous material in thin sections becomes transparent by mounting in canada balsam and details disappear. Staining thin sections with aquous safranin increases the contrast between the fossiliferous material and the matrix of the chert (Sharma *et al.*, 1984).

OBSERVATION AND DISCUSSIONS

The earlier descriptions of *Sporangioceros nipanica* were based on the study of only longisections including the Type Specimen No. BDN 500/Raj (Sharma *et al.*, 1984; Sharma & Suthar, 1986). For the present study a large number of specimens of different sizes, shapes and developmental stages, cut in cross, oblique and longisections have been examined. The specimens range 500-2500 x 200-500 mm in size. These are cylindrical (Pl. 1·2; Fig. 1·2), oval or ovate with round to obtuse apices (Figs 1·7, 8). In some of the specimens the apices are seen either ruptured (Fig. 1·3) or have an apical pore (Fig. 1·5) probably for the release of zoospores and zoogametes which are globose bodies. In extant *Characiosiphon* zoospores and zoogametes are biflagellate structures liberated through apical pores. In present material flagellae are not preserved.

Narrow, cylindrical structures (Pl. 1·1) or thalli with small enations (Fig. 1·1) are generally seen associated with the above mentioned ovate, oblong or cylindrical thalli. It has faintly marked discrete but closely placed protoplasts, each bearing a small dark coloured body representing probably the colligated chloroplast and the nucleus (Fig. 1·1). It is believed that these are the horizontal thalli of the extinct plant (alga). The oblong, cylindrical or oval structures (Pl. 1·2-5; Fig 1·2-5) are probably the vertical thalli produced on the horizontal ones. The vertical thalli have distinct walls covered over by a thick mucilaginous sheath ; but the wall is a non-cellular layer (Pl. 1·4, 5). Earlier (Sharma & Suthar, 1986) it was believed to be a 3-4 cells thick layer - which is wrong. The vertical thalli may be stalked or sessile. The stalk is made up of only mucilage layers (Pl. 1·3-5). The protoplast is divided into discrete units. In each a dark coloured circular to a little irregular central body is visible representing probably the colligated chloroplast, pyrenoid and the nucleus (Pl. 1·6, 7; Fig 1·2, 3, 5, 9). In a

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PLATE 1 ⟶

Characiosiphonites nipanica Sharma *et al.*

1 Narrow cylindrical thallus with blunt enations. Poorly differentiated discrete protoplasts. x 60.
2. Cylindrical thallus covered over by a mucilage sheath. Protoplasts hexagonal each with a dark central body (chloroplast). x 120.
3. Oblong thallus with an apical aperture and covered by mucilage sheath. x 80.
4. Same. Fig. 3. enlarged to show discrete protoplasts. x 240.
5 Oblong thalli (young and old) with mucilaginous stalks. Wall distinct but non-cellular. x 240.
6, 7. Enlargement of hexagonal protoplasts from Fig. 2. Dark coloured central chloroplasts are distinctly visible. x 240 (Figs 2-5 from Sharma & Suthar 1986).

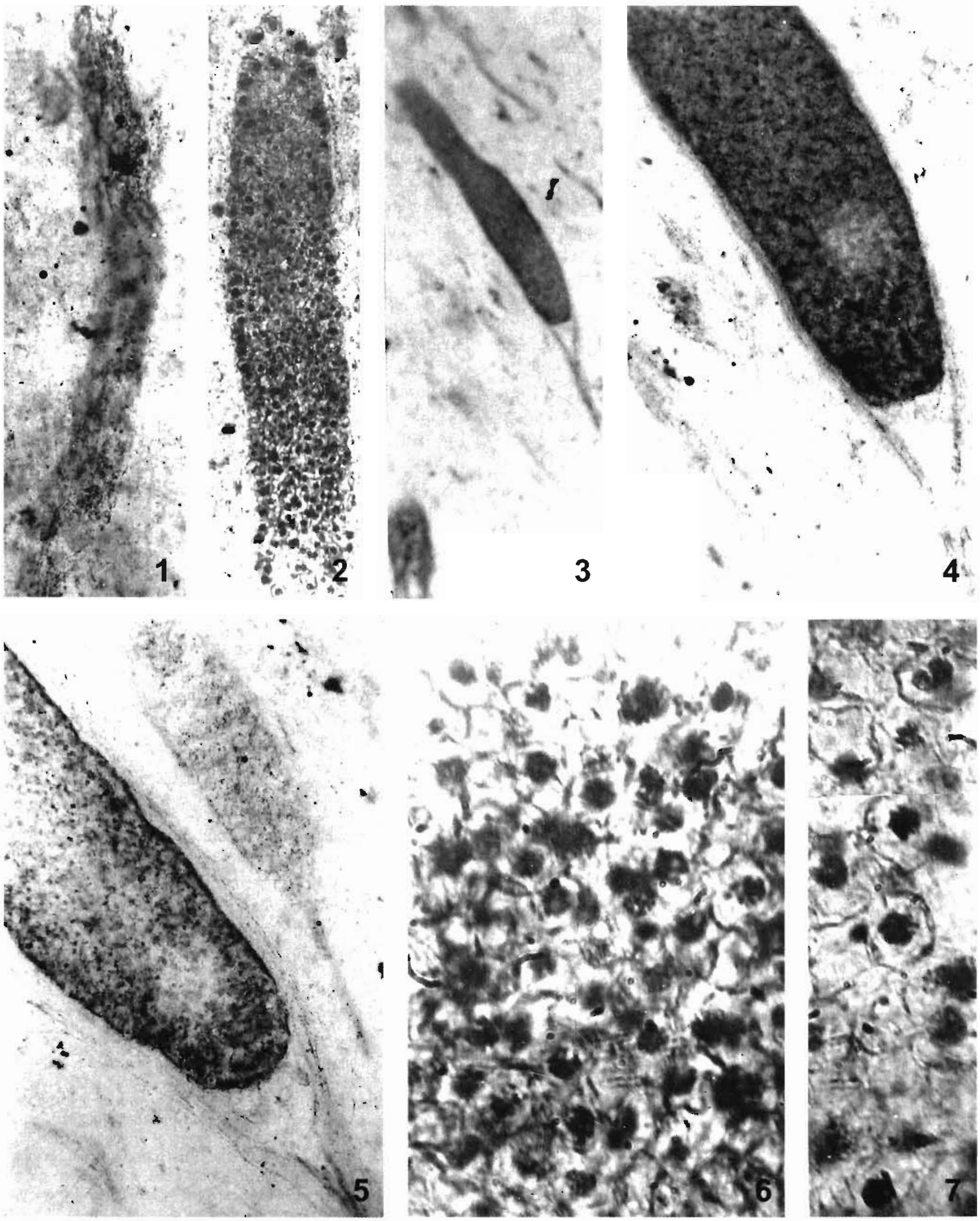

PLATE 1

cylindrical thallus the discrete protoplasts are close hexagonal units each with a dark coloured central body (Fig 1·2, 9 10). A condition quite similar to that of *Characiosiphon* (Iyengar 1936, Fig. 3). The protoplasts become circular when are loose (Fig. 1·14) and may develop protoplasmic connections (Fig 1·6, 11) identical to those seen in the green alga (Iyengar, 1936; Fig. 4).

In some of the specimens with round to obtuse intact apices (Fig 1·7, 8) the discrete protoplasts become distinct and a little or irregular in out line giving a spore like appearance (Fig. 1·12) and resemble Iyengar's description (Iyengar, 1936; Pl. 23; Fig 3 4). These distinct units of protoplasts range 25 to 36 µm in diameter and unlike spores they do not possess any clear exine, there is no distinct pattern of ornamentation on surfaces of these protoplasts. There are seen 1-3 or more cavities per protoplast representing either the contractile vacuoles or mere an artifact of preservation (Fig. 1·12). These dark coloured bodies are considered here as aplanospores or the resting spores which help in survival during adverse conditions.

In archegoniate plants sporogonia (Bryophytes) as well as sporangia (Pteridophytes and Gymnosperms) are characterised by the presence of a distinct sterile cellular walls around spores which may be one cell (*Riccia* leptosporangiate ferns) to several cells in thickness (Anthocerotales, fernallies, eusporangiate ferns and all gymnosperms). Whereas, in majority of thallophyta the wall of sporangium as well as that of the gametangium is non-cellular i.e., there is no sterile cellular wall which surrounds spores, zoospores and zoogametes (Bold *et al.*, 1987). Rao (1943) and Mittre (1958, 1969) considered the structures seen in thin sections prepared through the Nipania chert and which were similar to the present material as an isolated pteridophytic sporangia because of their occurrence in association with leptosporangiate, annuli and spores. While, Sharma *et al.* (1984), and Sharma and Suthar (1986) recognised the material as Bryophyta close to *Notothylas* of Anthocerotales, on the basis of horn-shaped cylindrical oval or ovate morphology of the vertical thalli and because of the presence of a single chloroplast (dark central body) per cell. Sharma and Suthar (1986) in an earlier description considered the narrow horizontal (present view) thalli as gametophytic portions of *Notothylas* like plants. In the present description also it is treated as a vegetative thallus on which probably grew the vertical thalli. The vertical thalli (present view) were earlier thought to be sporogonia bearing spores. It was believed that the body had a wall 2-4 cells thick surrounding many spores, which is incorrect and the wall is non-cellular covered by a thick layer of mucilage. The spores of earlier description are actually descrete condensed protoplasts. In some of the thalli these have distinct shapes and colour and are designated in the paper as aplanospores or resting spores.

The morphology of the material described here resembles *Characiosiphon rivularis*. The vertical thalli having discrete protoplasts, each containing a single chloroplast and an apical liberation of contents (Fig. 1·13) (Iyengar, 1936). In the extinct material similar to the extant one, each protoplast has a large chloroplast (compare fig 1·9, 10) and may develop protoplasmic connections at a later stage of growth (compare fig 1·6, 11). In a mature plant the protoplasts separate out and may become distinct, each giving a spore like appearance (compare fig 1·7, 14). But they do not have the characters of spore of archegoniate plants i.e., neither are regular in size and shape nor have a distinct exine with a definite pattern of ornamentation.

Comparison may also be made with other similar unicellular green algae e.g., *Protosiphon, Characiochloris, Codiolum,* etc. in gross morphology of the plant. But the present material differs in characters like discrete protoplasts each with a single large chloroplast and the nucleus. Apical liberation of contents (may be zoospores and zoogametes) in the present material resemble the unique character of the green alga *Characiosiphon rivularis* Iyengar.

On the basis of the present investigation a new name has been suggested *Characiosiphonites nipanica* Sharma *et al.* for *Sporangioceros nipanica* Sharma *et al.* (1984) with the following diagnosis :-

Thalli narrow, cylindrical with small enations or wide elongated, oval or ovate with a non-cellular wall covered by a thick mucilage sheath; coenocytic, protoplast discrete, close or loose each with a large central colligated chloroplast, pyrenoid body and a nucleus. Protoplasmic connections may be visible; liberation of contents (may be zoospores and zoogametes) through an apical pore. Thalli with no apical

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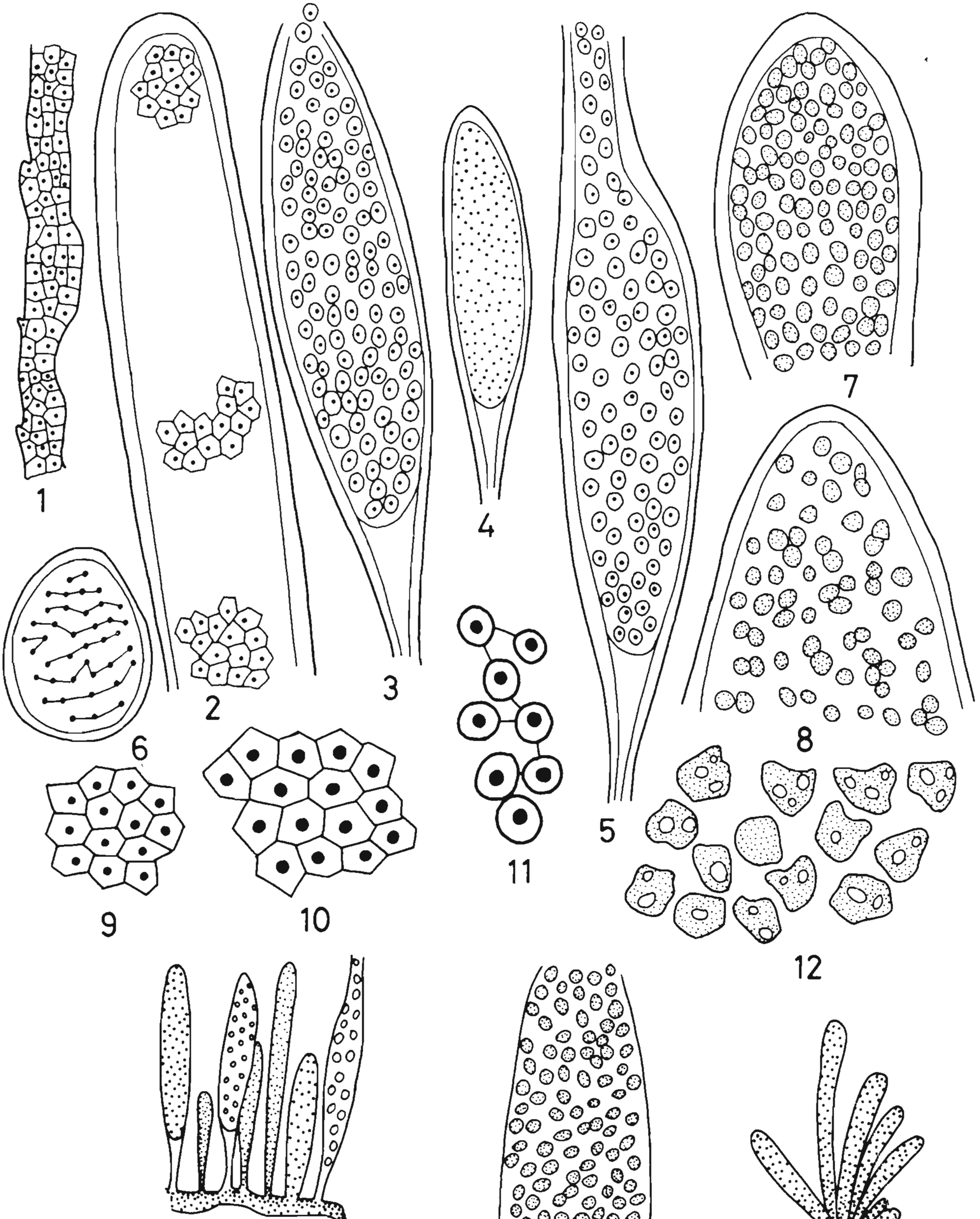
Fig. **1—1-15.**—*Characiosiphonites nipanica* Sharma *et al.* **1**. Narrow cylindrical thallus with blunt enations. Poorly differentiated protoplasts. x 60. **2**. Cylindrical thallus with hexagonal protoplasts, each with a chloroplast. x 240. **3**. Oblong thallus with circular protoplasts (may be zoospores or zoogametes) and an apical rupturing. x 240. **4**. A young coenocytic thallus. x 240. **5**. Thallus with an apical pore for liberation of contents. Mucilagenous stalk is distinctly visible. x 240. **6**. Cross section thallus with interconnected protoplasts. x 240. **7, 8**. Thalli with intect obtuse apices and containing dark protoplasts i.e., aplanospores. x 400. **9**. Hexagonal protoplasts from Fig. 2 enlarged. x 400. **10**. Hexagonal protoplasts of the green alga *Characiosiphon rivularis* Iyengar. x 640. **11**. Interconnected protoplasts in *C. rivularis*. x 640. **12**. Aplanospores enlarged from Fig. 8. Irregular in shape, size and without distinct exine. x 600. **13**. A group of plants of the green alga *C. rivularis* showing habit. x 15. **14**. A portion of thallus of green alga enlarged to show discrete protoplasts (comparable to fig. 7 of the present extinct material). x 300. **15**. Reconstruction of *Characiosiphonites nipanica*. Groups of vertical thalli grow on a horizontal thallus. x 15 (Figs 1-5, 8, 12 from Sharma & Suthar, 1986; Fig. 7 from Sharma *et al.* 1984; Figs. 10, 11, 13, 14 from Iyengar, 1936).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rupturings or pores; have aplanospores, which are irregular in shape and size and without exine.

RECONSTRUCTION

It is presumed that the plant had a horizontal portion made up of a narrow cylindrical thallus with small blunt enations (points of attachment of vertical thalli). Discrete protoplasts were poorly differentiated in it. The vertical thalli were cylindrical, oval or ovate; stalked or sessile, with or without apical rupturings or pores. Wall was distinct but non-cellular and covered over by a thick mucilage sheath. Protoplasts condensed, discrete, close or loose, circular or hexa-angular each with a large central colligated chloroplast, pyrenoid body and the nucleus. Thalli without apical pores i.e., in which apices were intact, obtuse or round, generally had distinct dark coloured discrete condensed protoplasts or aplanospores. They were variable in shape and size and did not have distinct exine of definite ornamentation. The plant had many vertical thalli at a time and of different developmental stages which probably originated from the horizontal thallus more or less in a crowded manner (Fig. 1·15).

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Brachyphyllum liaoningense sp. nov. from the Upper Jurassic of Northeast China

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ABSTRACT

Deng S & Shang P 2002. *Brachyphyllum liaoningense* sp. nov. from the Upper Jurassic of Northeast China. Palaeobotanist 51 : 37-44.

Fossil conifer twigs and foliage referred to *Brachyphyllum liaoningense* sp. nov. were collected from the Tuchengzi Formation of Beipiao Basin, Liaoning Province, Northeast China. The leaves are arranged spirally on twigs, with a basal cushion tapering into a small free part. The length of the free part is little less than the width. Stomata exist on both adaxial and abaxial cuticles, but more on the abaxial side. The stomata are rounded or elliptic in form and arranged in longitudinal files in the abaxial cuticle, the epidermal cells between the stomatal files are elongated rectangular or in strip-form. The guard cells are sunken. The subsidiary cells are monocyclic, 5-7 in number, lack encircling cells. A few stomata are scattered on the adaxial cuticle, which are similar to those of the abaxial cuticle except that they have encircling cells. It is presumed that the subsidiary cells of *Brachyphyllum* show a tendency of increasing in number from Jurassic to the Early Cretaceous.

Key-words—Upper Jurassic, Conifer, Leafy twig, China.

उत्तर-पूर्वी चीन से प्राप्त ऊपरि जुरासिक युगीन *ब्रैकीफ़िल्लम लायनिंगेन्साइ* नवप्रजाति

शेंग हुइ डेंग एवं पिंग शांग

सारांश

उत्तर-पूर्वी चीन के लायनिंग प्रान्त की बेइपियाओ द्रोणी के तुकेंगज़ाइ शैलसमूह से *ब्रैकीफ़िल्लम लायनिंगेन्साइ* नवप्रजाति से सन्दर्भनीय अश्मित शंक्वाकर टहनियाँ तथा पर्णसमूह संग्रहीत किए गए। पत्तियों को एक छोटे स्वतंत्र भाग के अन्दर आधारीय उपधान द्वारा टहनियों पर सर्पिलाकृति में व्यवस्थित किया गया। इस स्वतंत्र भाग की लम्बाई चौड़ाई से किंचित् कम रखी गयी। यद्यपि स्टोमैटा दोनों अभ्यक्ष तथा अपाक्ष उपचर्मों पर विद्यमान है, परन्तु यह अपाक्ष के अधिक निकट है। स्टोमैटा चक्राकार अथवा दीर्घवृत्तीय है तथा यह अपाक्षीय उपचर्म में अनुदैर्ध्य तंतु में व्यवस्थित है। स्टोमैटा की तन्तु के मध्य की अधित्वचीय कोशिकाएँ प्रदीर्घ चतुर्भुजाकार अथवा पट्टिकाओं के रूप में हैं। इसकी द्वार कोशिकाएँ धँसी हुई हैं। 5-7 सहायक कोशिकाएँ एकचक्रीय हैं तथा इनमें परिवेष्टित कोशिकाएँ अनुपस्थित हैं। कुछ स्टोमैटा अभ्यक्ष उपचर्म पर परिक्षिप्त हैं, जो अपाक्ष उपचर्म के निकटस्थ हैं, इनमें एक मात्र अन्तर यह है कि इनमें परिवेष्टित कोशिकाएँ विद्यमान हैं। यह आनुमानित किया जाता है कि *ब्रैकीफ़िल्लम* की सहायक कोशिकाएँ जुरासिक से प्रारंभिक क्रिटेशस के मध्य संख्या में वृद्धि का रुझान प्रदर्शित करती हैं।

संकेत शब्द—उपरि जुरासिक, शंक्वाकार, पर्ण टहनी, चीन.

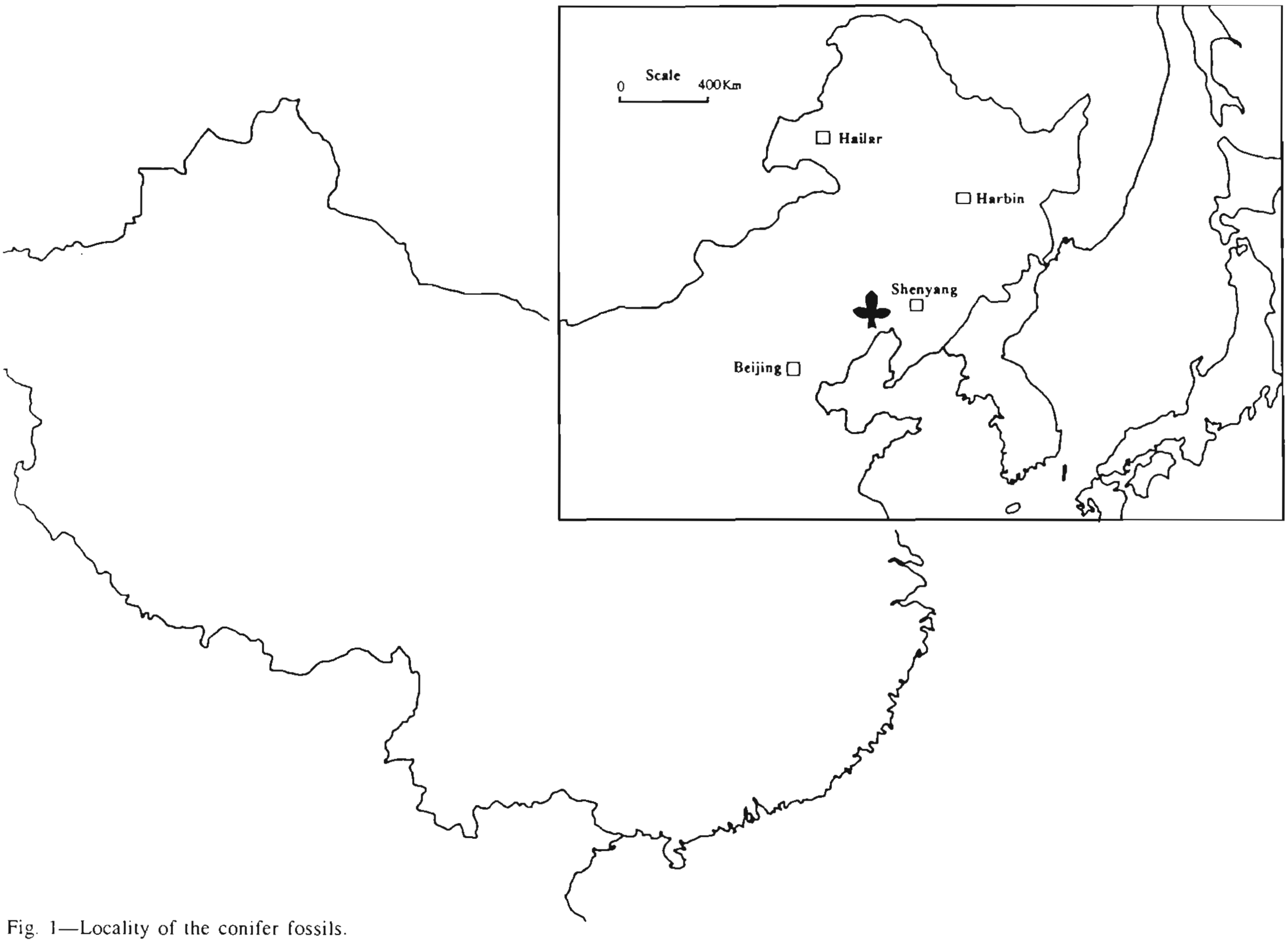

Fig. 1—Locality of the conifer fossils.

INTRODUCTION

DURING the Late Jurassic, the climate in the most parts of China was probably dry. The plant fossils are rare in the Upper Jurassic sediments and as such there are few references in literatures (Wang, 1984). However in recent years, numbers of plant fossils including some angiosperms (Sun *et al.*, 1998; Wu, 1999) have been collected from the Yixian Formation of western Liaoning, NE China, as well as various birds and dinosaurs (Hou *et al.*, 1995, 1999; Chen *et al.*, 1997; Ji *et al.*, 1998). The age of the Yixian Formation is still controversial. It is assigned to the Upper Jurassic based on conchastraca, insects and birds (Chen, 1999; Hou *et al.*,1995), while considered as the Lower Cretaceous on the bases of studies on dinosaurs, spore-pollen, ostracods, gastropods fossils, and this is supported by palaeomagnetic and isotopic dating (Pu & Wu, 1985; Zhang, 1985; Wang *et al.*, 1999; Swisher *et al.*, 1998, 1999). The Tuchengzi Formation, overlain discordantly by the Yixian Formation, is characterized by red coloured sediments, which have rare records of plant fossils (Zheng *et al.*, 2001). Recently, the authors collected many coniferous fossils and a few specimens of *Equisetites* from this formation in Beipiao

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PLATE 1

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(All the specimens described are housed in Research Institute of Petroleum Exploration and Development, Beijing, China)

Brachyphyllum liaoningense sp. nov.

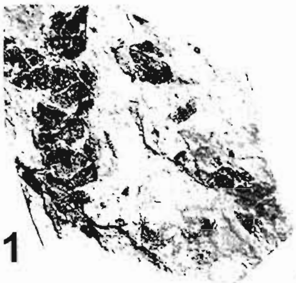
1-7 Twigs. **1**, Holotype, XJG020; **2**, XJG024; **3**, XJG022; **4**, XJG023; **5**, XJG021; **6**, XJG025; **7**, XJG026; 1-3, 5-7, x2; 4, x4.

8-11. leaves. **8-9**, light photographs, showing stomatal furrows, x15; **10**, light photograph, showing the adaxial surface of the leaf, x 20; **11**, SEM photograph, showing the abaxial surface of the leaf, x20.

12-13. Outer surface of the adaxial cuticle (SEM), **12**, x300; **13**, x350.

14. Out surface of the abaxial cuticle (SEM), x350.

15. SEM photograph, showing the inner surface of the adaxial cuticle (left side) and abaxial cuticle (right side), x 220.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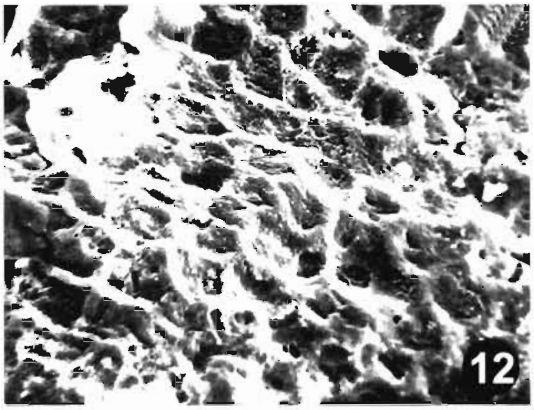
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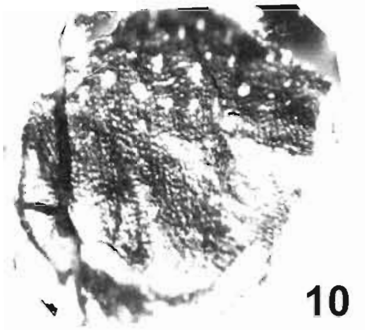
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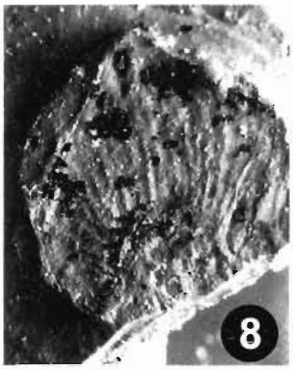
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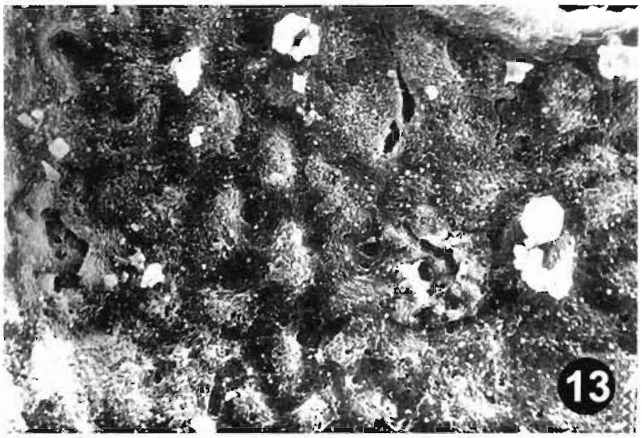
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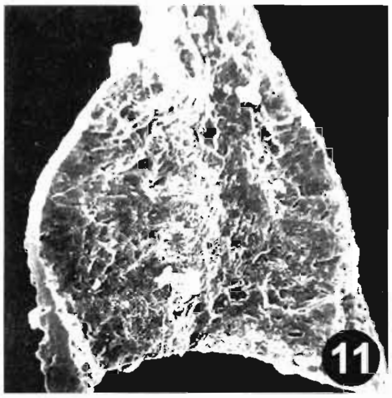
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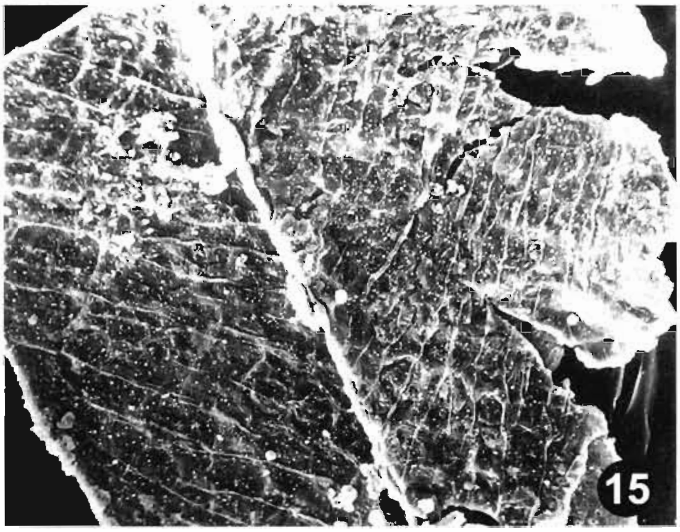
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PLATE 1

Basin, Western Liaoning Province (Fig. 1). The fossils are well preserved in greyish green mudstone. But unfortunately, most of them are broken into small pieces soon after they are exposed to the air.

The fossils are leafy twigs with scale like leaves. The leaves consist of basal cushions and free parts. The width of the free part is greater than the height, a characteristic of the genus *Brachyphyllum*. It is identified as a new species *Brachyphyllum liaoningense* (sp. nov.) on the bases of epidermal features.

STRATIGRAPHY AND MATERIALS

The Upper Jurassic Tuchengzi Formation, Beipiao Basin, Liaoning, NE China, is mainly composed of purple or varicolored clastic rocks, which overlies the Middle Jurassic volcanic rock unit Lanqi Formation and is overlain discordantly by the Yixian Formation that yields a great number of fossils of early birds, dinosaurs and early angiosperms (Sun *et al.*, 1998; Wu, 1999; Hou *et al.*, 1995; Chen *et al.*, 1997; Ji *et al.*, 1998). The Tuchengzi Formation is divided into three portions. The lower part consists of purple coloured sandstone, siltstone and mudstone intercalated with greyish green mudstone and siltstone; the middle part is of conglomerates intercalated with sandstone and shale; and the upper part has greyish green sandstone with great cross beds and intercalated with purple conglomerate and tuff at the top. The mudstone of the lower part is rich in Conchastraca and a few plant fossils. The plant fossils studied in the present paper were collected from greyish green mudstone-siltstone beds, which are intercalated in the upper portion of the lower part. A lot of well preserved compressions of coniferous twigs and shoots are scattered on the surface of the mudstone. Some of the axes are up to 1 cm thick. Being very fragile, the mudstone breaks up when air-dried and consequently most of the specimens were broken into fragments before they were brought to the laboratory from field.

The fossils were first examined and photographed under a stereo microscope. Then a small piece of the rock with leaf material was immersed into hydrofluoric acid for 48 hours. The obtained leaves were macerated with Schulze's solution or sodium hypochlorite for 24 hours followed by treatment with ammonium hydroxide or sodium hydroxide solution. The adaxial and abaxial cuticles were separated with a needle and then the cuticles were examined both under light and scanning electron microscopes.

SYSTEMATICS

CONIFEROPSIDA

BRACHYPHYLLUM Brongniart

BRACHYPHYLLUM LIAONINGENSE sp. nov.

Pl. 1·1-15; Pl. 2·1-6; Fig. 2A-E

Diagnosis—Conifer twigs, pinnately branched in one plane. Axis up to 1 cm thick, length unknown. Leaves sparsely borne on the main axis, spirally and densely arranged on the twigs (Pl. 1·1-7). Twigs 0·4-0·6 cm thick, straight or curved. Leaves scale-like, with cushions and free parts (Pl. 1·8; Fig. 1A-C). Whole leaf 2-3 mm long and 2-3 mm broad; the free parts about 2 mm long and 2·5 mm broad, typically triangular, apices tapering, acute or round. Margin entire. Substance of leaf very thick. The abaxial surface of the leaf without keels, but with longitudinal stomatal furrows radiate (Pl. 1·8-10). The furrow composed of small holes representing the stomata (Pl. 1·9).

Both adaxial and abaxial cuticles thin and fragile, especially the adaxial one. External surface of the adaxial cuticle uneven (Pl. 1·11-12), with obvious papillae (Pl. 1·13) or holes some times in the center of the epidermal cells (Pl. 1·12). The ordinary epidermal cells in the inner area of the adaxial epidermal rectangular or near square, about 20-25 µm long and 18-22 µm wide, walls obviously thickened, about 5-6 µm thick (Pl. 1·15). The corners of the cells thickened. The cells near the margins elongate, about 30-35 µm long, and 10-15 µm wide, walls usually thickened but the corners un-thickened. A few stomata scattered on the adaxial cuticle. Stomata elliptic (Pl. 2·5), about 70 µm long and 50 µm wide. Stomatal pits rounded or elliptic, thinly cutinized, guard cells indistinct, subsidiary cells 5-7, rectangular or elongated polygonal in form, a little larger than that of the ordinary epidermal cells, about 30 µm long and 25 µm broad, surrounding the stomatal pits, with stripes on the surface. With 8-10 encircling cells (Pl. 2·5).

The abaxial cuticle little thicker than the adaxial one. Stomata oriented into lines on the external surface of the cuticle and with a furrow between the stomatal lines, stomata elliptic and longitudinally oriented (Pl. 1·14), placed in single files on the inner surface (Pl. 2·1-2), stomatal files about 50-80 µm wide, expanded in the region of stomatal, with a space of 100-110 µm between the adjacent stomata. Epidermal cells in the stomatal files strongly cutinized, especially near the stomata (Pl. 2·1-3). Stomatal files obviously raised, over the surface of the ordinary

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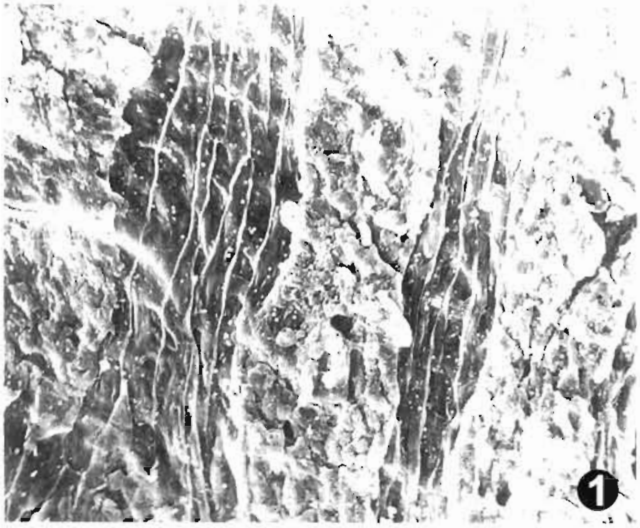
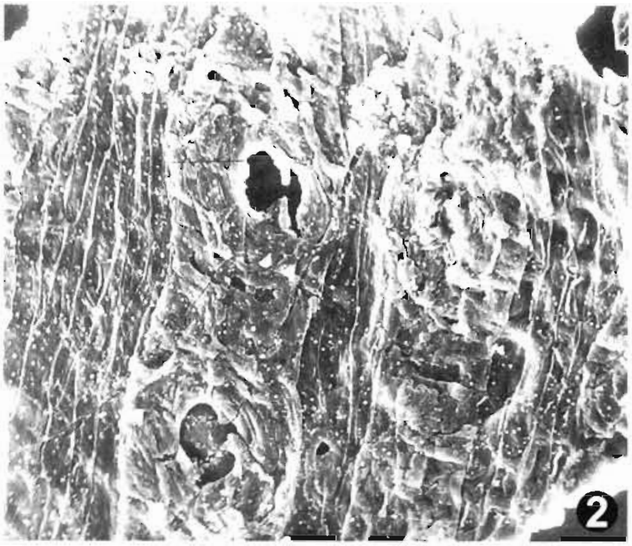
PLATE 2 ⟶

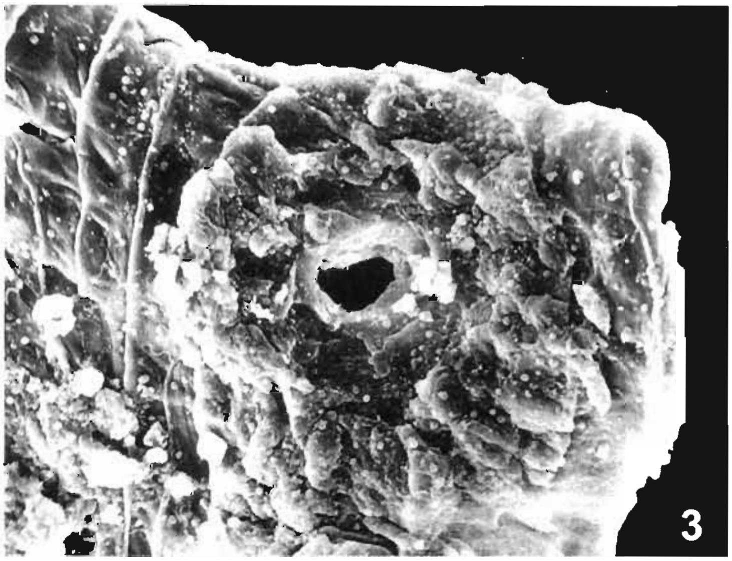
(SEM photographs)

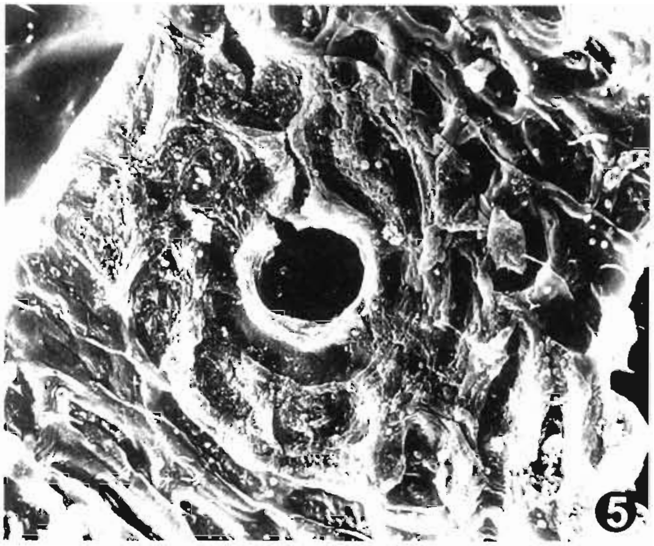
Brachyphyllum liaoningense sp. nov.

1-2. Showing the stomatal files and the strip-like cells between the files in abaxial cuticle. x300.
3. A stoma with strongly cutinized subsidiary cells. x700.
4. A stoma with six subsidiary cells, abaxial cuticle. x700.
5. A stoma on adaxial cuticle. x700.
6. A stoma on abaxial cuticle. x700.









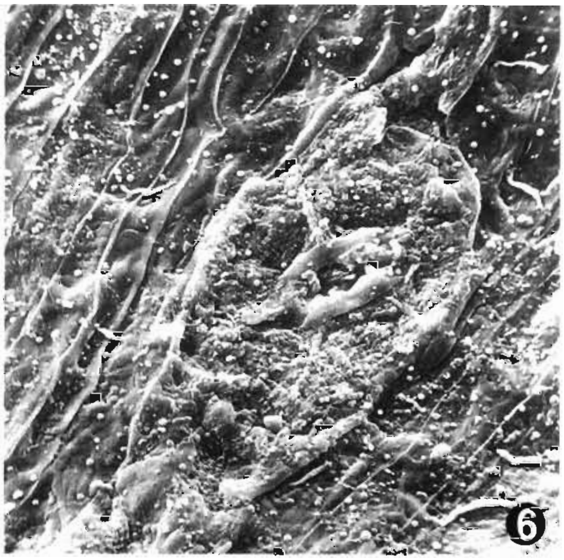


PLATE 2

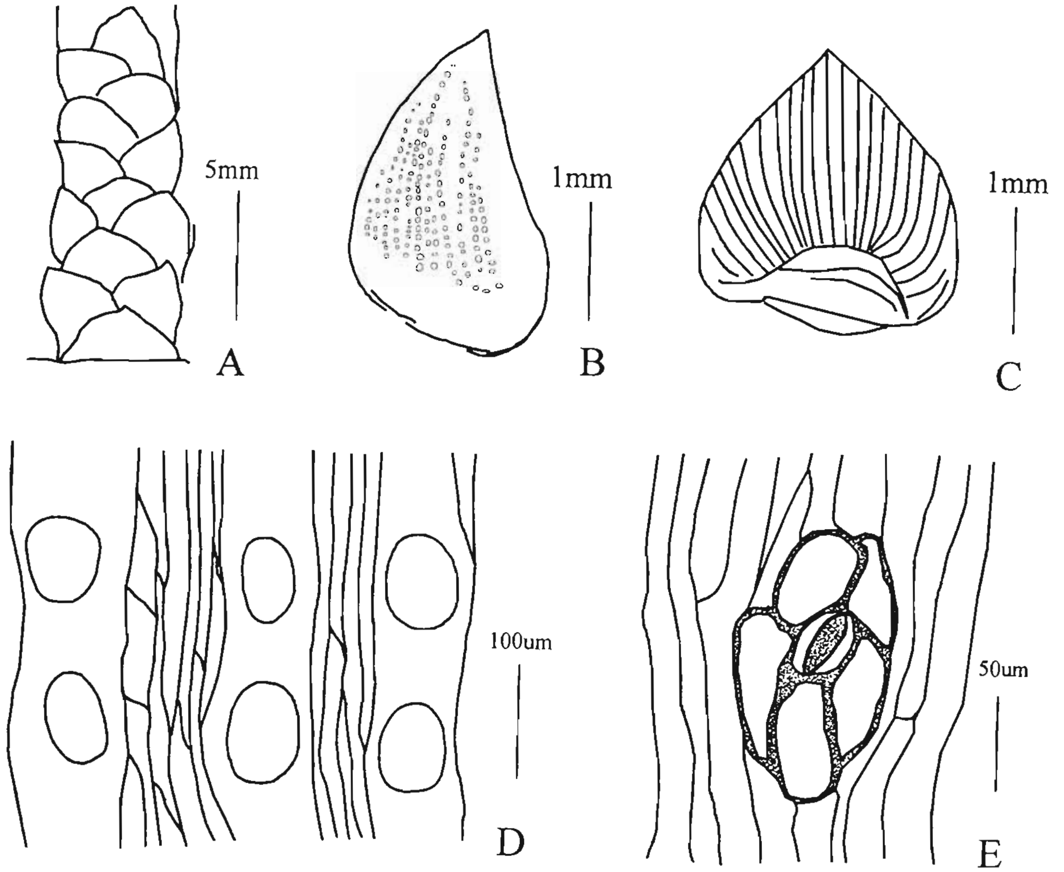


Fig. 2—*Brachyphyllum liaoningense* sp. nov. **A**. Twig (after Pl. 1·4), showing the arrangement of the leaves; **B**. Lateral-view of a leaf (after Pl. 1·9), showing the arrangement of the stomata (abaxial surface); **C**. Showing leaf form (after Pl. 1·8); **D**. Showing the stomatal files and the cells between the files (abaxial surface), **E**. A stoma (after Pl. 2·6).

cells. The structure of the epidermal cells in the stomatal file indistinct (Pl. 2·1-3) or possibly squarish form (Pl. 2·4). The space between the two stomatal files 20-70 µm, consisting of 3-8 lines of cells (Pl. 2·1-2). The epidermal cells longitudinally arranged in irregular rows, elongated, 5-15 µm wide and more than 100 µm long. Transverse walls usually indistinct and the longitudinal ones sinuous (Pl. 2·1-3, 6). Wall is usually unthickened, less than 1µm thick. Stomata elliptical, about 50-70 × 40-50 µm in size. Stomatal pits elliptic, slightly oblique to the stomatal line (Pl. 2·4, 6), 20-30 µm in diameter. In some times, the surface lightly and irregularly thickened (Pl. 2·4). In some relatively slightly thickened stomata, the outlines and the structure of the stomata clear. Guard cells unclear or partly seen (Pl. 2·6), subsidiary cells 6-7 in number. Subsidiary cell wall 2-5 µm. Surface of the subsidiary cells slightly thickened, stomata elevated on the epidermal cells, lack encircling cells.

Locdlity—Beipiao of Liaoning Province, China.

Stratigraphy—Tuchengzi Formation.

Age—Late Jurassic.

Etymology—The species name is after the locality.

Holotype—XJG020 (Pl. 1·1).

Repository—Research Institute of Petroleum Exploration and Development, Beijing, China.

DISCUSSION

The present fossils are similar to the Late Mesozoic scale or awl-like leaf conifers *Pagiophyllum*, *Athrotaxites* and *Brachyphyllum*, but can be undoubtedly assigned to *Brachyphyllum* on the basis of their structure of leaves and attachment.

The difference between *Pagiophyllum* and *Brachyphyllum* is that the free part of the leaf of the former is larger than width, while the free part of the latter is smaller than the breadth. The cuticle of the two genera are similar to each other (Kendall, 1947, 1948; Harris, 1979). In most *Pagiophyllum* species of the Yorkshire Flora, the stomata are chiefly arranged in regular files. But four species from Lower Cretaceous of Zhejiang, Southeast China have scatteredly arranged stomata (Cao, 1991). Recently, Cao (1999) described a new species from the same stratum and locality, which is characterized by the stomata oriented in rows. It is difficult to differentiate these two genera on their epidermal features.

Athrotaxites, an Early Cretaceous conifer, is characterized by spirally borne scale leaves. The free parts of its leaves are larger than broad. *Athrotaxites berryi* Bell, *A. magnifolius* (Chen and Meng) Chen and Deng and *A. orientalis* Deng and Chen have been described on the structure of cuticle (Miller & Lapasha, 1983; Chen & Deng, 1990; Deng, 1995). The stomata of these species are restricted to the middle-upper portion near the two sides of the leaves, and differs from *Brachyphyllum*, in which stomata are distributed on the whole surface of the leaf. The stomata in *Athrotaxites berryi* are oriented in rows, while those of *A. magnifolius* and *A. orientalis* are scattered or concentrated into groups. Sometimes, the adjacent stomata unite and have common subsidiary cells. Thus the stomatal distribution pattern of *Athrotaxites* is different from that of *Brachyphyllum*. Moreover, *Athrotaxites* is a seasonally defoliated swamp tree (Miller & Lapasha, 1983; Chen & Deng, 1990) and are usually preserved in the coal-bearing sediments, while *Brachyphyllum* is usually preserved in grey or multicoloured rocks representing rather dry climates. They have totally different habits. *Athrotaxites* is considered to have affinity with the Taxodiaceae *Athrotaxus* presently grows in Tasmania, Australia, but *Brachyphyllum* probably belongs to various conifer groups based on epidermal features. For examples, *Brachyphyllum crucis* is possibly related to Hirmerellaceae, while many others to the Araucariaceae (Kendall, 1947; Harris, 1979).

Brachyphyllum has spirally borne leaves, in which the free part is short and not exceeds the width of the leaf cushion (Kendall, 1947; Harris, 1979). Cuticles of a number of twigs and associated cones were described by (Kendall, 1947; 1949) and Harris (1979) from the Middle Jurassic of Yorkshire, England. Konijnenburg-V. Cittert J.H.A. van (1971) successfully obtained some pollens *in situ* of this genus, and made a comparison with the dispersed pollens of *Classopollis*. Based on the observation of the cuticle, cones and pollen grains *in situ*, the affinity of this genus was also discussed by Kendall (1947) and Florin (1958) who believed that some species of this genus were related to *Araucaria* of Araucariaceae.

Since *Brachyphyllum* twigs from different ages bear a similar morphology, epidermal features constitute important tools in species identification. Kendall (1947, 1949) and Harris (1979) gave importance to the epidermal features in identification of species of *Brachyphyllum*. In most of the Yorkshire species epidermal cells are squarish and oriented transversely. In the present materials the adaxial epidermal cells are similar to the Yorkshire materials but the abaxial cuticle has strips arranged in longitudinal rows. In Yorkshire species of *Brachyphyllum* stomata are hypostomatic and mostly restricted to margins, subsidiary cells 2-6 and with encircling cells even dicyclic. The present materials are amphistomatic, have 5-7 subsidiary cells and without encircling cells on the abaxial cuticle.

Brachyphyllum praetermissum Wesley from the Upper Lias of Italy has hypostomatic leaves (Wesley, 1956), and is different from the amphistomatic pattern of the present fossils. *Brachyphyllum lorchii* Raab *et al.* from the Upper Jurassic of Israel (Raab *et al.*, 1986) is somewhat similar to the present specimens in the arrangement and structure of stomata but differs in the form of leaves and epidermal cells.

Summarily, the present specimens are characterized by amphistomatic leaves, with a few stomata scattered on the adaxial cuticle and a lot arranged in rather regular single files on the abaxial cuticle. The guard cells are usually indistinct. The subsidiary cells are 5-7 in number, with encircling cells on the abaxial cuticle but without this cell on the adaxial cuticle. Therefore, the present materials are different from the known Jurassic *Brychyphyllum*.

Brachyphyllum castatum Waston *et al.* a species from the English Wealden (Lower Cretaceous) (Watson *et al.*, 1987), which is characterized by circular stomata with 5-12 subsidiary cells and is either monocyclic or dicyclic. In China, *Brachyphyllum* is also frequently found from the Lower Cretaceous, and mostly are in the South Phytogeographical Province of China (Chow & Tsao, 1977; Cao, 1989), e.g., *B. obtusum* Chow & Tsao from Lingbi, Anhui Province, *B. ningshiaensis* Chow & Tsao from Liupanshan Basin, Ningxia (Chow & Tsao, 1977) and *B. elegans* Cao from the Lower Cretaceous Linan, Zhejiang (Cao, 1989). The common features of these species are that the stomata on the abaxial cuticle are arranged in single files separated by several elongate cells. The epidermal cells in the stomatal files are short and markedly thick. The guard cells are usually unclear. These features are also observed in the present materials, in the latter, the stomata are strongly thickened, regularly arranged in single files, and within the files the spaces between the adjacent stomata are rather stable. In the stomata, the number of subsidiary cells are variable, e.g., *B. ningshiaensis* (6-9 in number), *B. elegans* (6-8) and *B. obtusum* (7-11) and are more than that of the present new species (5-7). Furthermore, the leaves of *B. ningshiaensis* and *B. obtusum* are triangular in form, with lower free parts and arc-like margins, while those of the present specimens are triangular with rather higher free parts and quite straight sides. The adaxial cuticle of *B. elegans* is unknown, and there have several regularly arranged oblong cells between the stomatal files on the abaxial cuticle.

Consequently, study of the epidermal features show that the present materials belong to a new species of *Brachyphyllum*.

An increase of number of subsidiary cells and decrease of encircling cells possibly indicate an evolutionary trend in the taxon *Brachyphyllum*. The species from the Middle Jurassic of England have 2-6 subsidiary cells, while those of the Early Cretaceous from China have 6-12. The new species from the Late Jurassic possibly represents a transition type with 5-7 subsidiary cells. Similarly, almost all the Middle Jurassic species from England have encircling cells, while those of the Early Cretaceous including the new species are devoid of encircling cells.

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Some new pteridophytic remains from the Permian strata of Rajmahal Hills, India

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ABSTRACT

Srivastava PC & [†]Pant DD 2002. Some new pteridophytic remains from the Permian strata of Rajmahal Hills, India. Palaeobotanist 51 : 45-55.

The paper describes two new species, one each of *Liknopetalon* (Smithies) Anderson & Anderson and *Lelstotheca* Maheshwari, from the Permian strata of the Rajmahal Hills, Jharkhand, India. The new species are named, respectively, as *Liknopetalon rajmahalensis* and *Lelstotheca harikrishnae*. On the basis of certain similar floristic elements, these strata appear to be floristically equivalent with those of Middle Ecca Series of South Africa and the Permian strata in a ravine section near Mamal Village in Liddar Valley of Kashmir Himalaya.

Key-words—Pteridophytic fossils, Permian, Rajmahal Hills, Jharkhand, India.

भारत की राजमहल पर्वतश्रेणियों के परमियन युगीन स्ट्राटा से प्राप्त कुछ नूतन टेरिडोफाइटी अवशेष

प्रदीप चन्द्र श्रीवास्तव एवं दिव्यदर्शन पंत

सारांश

प्रस्तुत शोध पत्र में भारत के झारखण्ड प्रान्त की राजमहल पर्वतश्रेणियों के परमियन युगीन स्ट्राटा से प्राप्त *लिक्नोपीटेलॉन* (स्मिथाइज़) एण्डरसन एवं एण्डरसन तथा *लेल्सटोथीका* माहेश्वरी की एक-एक प्रजाति का वर्णन किया गया है। नई प्रजातियों के नामकरण *लिक्नोपीटेलॉन राजमहलेन्सिस* तथा *लेल्सटोथीका हरिकृष्णाइ* किए गए हैं। कुछ समरूप वनस्पतिजात तत्त्वों के आधार पर ये स्ट्राटा दक्षिण अफ्रीका के मध्य एक्का श्रेणी से तथा कश्मीर हिमालय की लिड्डर घाटी के मामल ग्राम के समीप कन्दरा परिच्छेद में परमियन युगीन स्ट्राटा से वनस्पतिजातपरक ढंग से समतुल्य प्रतीत होते हैं।

संकेत शब्द—टेरिडोफ़ाइटी पादपाश्म, परमियन, राजमहल पर्वतश्रेणियाँ, झारखण्ड, भारत.

INTRODUCTION

IT was Feistmantel (1880) who reported the first pteridophytic fossils from the Lower Gondwana strata of Rajmahal Hills exposed at Dubrajpur under the name *Phyllotheca robusta* (see also Surange, 1964). After a gap of about eighty two years Surange and Prakash (1962) described similar fossils from Tattitola, a locality in the same area and assigned Feistmantel's *Phyllotheca robusta* along with their new specimens to a new genus, *Stellotheca* as *Stellotheca robusta* comb. nov. After renaming this genus as *Lelstotheca*, Maheshwari (1972) described an additional species, *L. striata*. Subsequently, Singh *et al.* (1987) described two more sphenopsids, *Sphenophyllum gondwanensis* and *Lelstotheca* sp. from the Permian strata exposed at Lalmatia Colliery in Rajmahal Hills area. We also collected some fossils from the

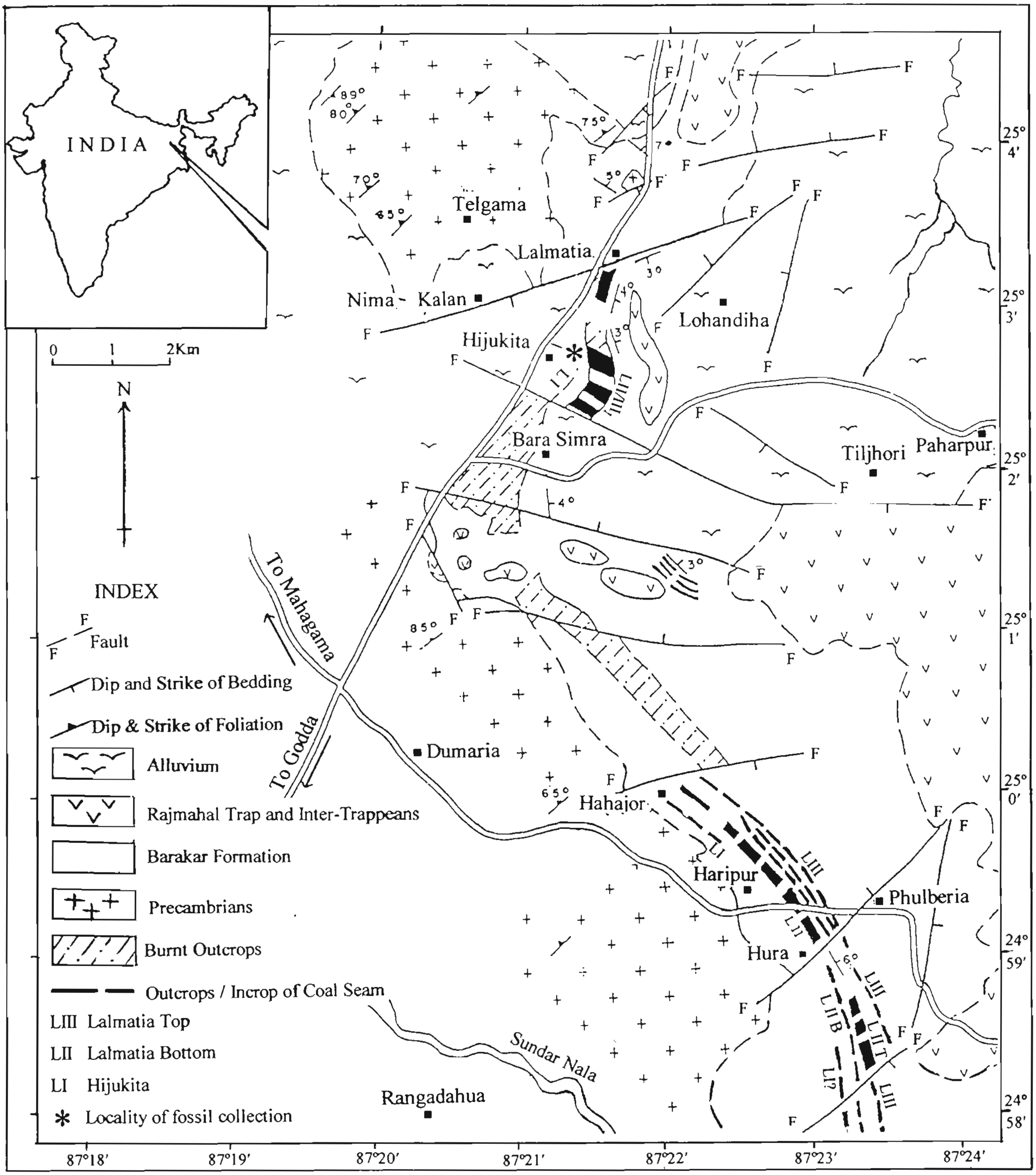

Fig. 1—Geological Map of Lalmatia-Haripur area in Hura tract of Rajmahal Hills (after Raja Rao, 1987).

same locality and published a preliminary report on these (Srivastava & Pant, 1996). A detailed study of some of these fossils has enabled us to recognize one new species of each, *Liknopetalon* (Smithies) Anderson & Anderson and *Lelstotheca* Maheshwari, which are described in the present paper. The new species of the two genera are *Liknopetalon rajmahalensis* sp. nov. and *Lelstotheca harikrishnae* sp. nov.

MATERIAL AND METHODS

The fossils described in this paper were collected from interbedded grey-whitish arenaceous shales of Lalmatia coal seam of Rajmahal Hills, exposed near Lalmatia of Godda District of Jharkhand of India. The Lalmatia coal seam of the Hura tract which attains a thickness of about 78 m in the northern part of the Rajmahal Basin, divides southwardly in three parts (Fig. 1, Raja Rao, 1987) designated as bottom (LI- Hizukita), middle (LII) and top (LIII) seams. The shales between seams LI-LII and LI-LIII are rich in plant fossils and have yielded the investigated fossils, which are in the form of compressions with ill preserved fragmented carbon. The specimens were observed under oblique incident light with stereo-binocular. Cellulose acetate pulls were also made to look for structural details of axes and laminae. The sporangia were extracted by dissolving these pull preparations in amyl acetate and, thereafter, the carbonaceous material was macerated in Schulze's fluid to obtain the spores. The coherent spores of the spore mass were separated by ultrasonic shaking and also manually with needles. These were observed under LM and SEM.

OBSERVATION

Genus—*Liknopetalon* (Smithies) Anderson & Anderson 1985

At the first sight the fossils including the vegetative specimens described in the present paper as *Liknopetalon* seemingly resembled *Vinaykumaria* (Pant & Srivastava, 1991) described from the Permian of Kashmir Himalaya in having small cuneate leaves apparently attached to a slender axis and we were inclined to assign them to a new species of that genus since *Vinaykumaria indica* differs from the Rajmahal specimens assigned here to *Liknopetalon rajmahalensis* sp. nov. in having invariably rounded shoulders of the laminae (the laminae of *Liknopetalon rajmahalensis* sp. nov. have pointed shoulders). On the basis of reinvestigation of *Vinaykumaria indica* we now realize that the leaves could have been opposite as in Text fig. 1A and Pl. 1 fig. 1 of Pant and Srivastava (1991) while it was described as alternate in a loose spiral. However, in the meantime we noticed another genus *Liknopetalon* (Smithies, 1978) Anderson and Anderson (1985) having similar looking fan-shaped but only fertile leaves attached to slender axes described from the Lower Permian strata of Hammanskraal and Vereeniging localities in South Africa (Generitype Specimen No. BP/2/7414, pl. 52·1). Unlike these South African specimens our fossils from the Permian of Rajmahal Hills show only attached vegetative leaves but we were lucky in finding detached fertile leaves like those born on axes of *Liknopetalon* form South Africa. The detached fertile laminae were recovered from the same rock piece, which yielded the attached vegetative leaves. As the form of our vegetative and fertile leaves are closely comparable but specifically different from that of the South African species, we assign our specimens to a new species of the same genus, herein named, *Liknopetalon rajmahalensis* after emending the generic diagnosis.

We suspect that *Vinaykumaria indica* (Pant & Srivastava, 1991) from Kashmir may ultimately prove to be yet another species of *Liknopetalon* but since its single specimen is only a small vegetative fragment and its details are not sufficiently known, we are unable to compare *Vinaykumaria* with *Liknopetalon* further and merge the two genera. Moreover, no attached or detached fertile leaves like those of *Liknopetalon* were found in case of *Vinaykumaria* and, accordingly, it would be best to continue to treat *Vinaykumaria* as a different genus at present (see Fig. 3).

Emended Generic Diagnosis—Unbranched slender axes with small, gracile cuneate or fan-shaped vegetative and fertile simple laminae in apparently opposite and decussate pairs. Laminae nonpetiolate; side margins entire and concave, distal margins convex and entire in vegetative laminae but apparently fluctuate in fertile laminae; veins in both kinds of laminae repeatedly dichotomised and divergent. Sporangia apparently sessile, inserted singly in a submarginal row along the distal margins.

Type species—*Liknopetalon enigmata* (Smithies) Anderson & Anderson, 1985.

LIKNOPETALON RAJMAHALENSIS sp. nov.

(Pl. 1, 2, 3·1-3; Fig. 2A-D)

Diagnosis—Slender twigs bearing cuneate vegetative laminae apparently opposite and decussate in phyllotaxis. Laminae gently tapering towards base with slightly concave entire lateral margins; surface of laminae showing fine striations between divergent forked veins. Distal margins of vegetative laminae entire while in associated fertile laminae seemingly fluctuate with a submarginal row of apparently nonindusiate sessile, exannulate, ovate to obovate sporangia. Sporangial wall showing straight walled parallel rectangular cells; indusium absent. Spores spherical with trilete mark on proximal face and showing reticulate ornamentation both on proximal and distal sides, muri sinuous; luminae with numerous pits on their surface.

Holotype—Specimen no. B/R 150A, B.

Duplicates—Specimen nos. B/R 154, B/R 151, B/R 152, B/R 153 (showing vegetative laminae); B/R 155, & B/R 156 (showing detached fertile laminae) of Divya Darshan Pant Collection, Department of Botany, University of Allahabad.

Locality & Horizon—Lalmatia Colliery, Rajmahal Hills, Barakar Stage (Permian, Lower Gondwana), Jharkhand, India.

Description and Comparison—All the specimens assigned to *Liknopetalon rajmahalensis* sp. nov. were found by splitting a single thick piece of shale. On this basis and on account of the occurrence of the detached fertile segments in close association with axes showing attached vegetative laminae, we believe that the detached cuneate fertile laminae belong to fertile axes of the same type but these lie detached in our material. The fragments of 2·0-3·0 mm wide axis are invariably unbranched and they bear 1·8-2·2 cm long and ca. 0·9 cm wide cuneate vegetative laminae arranged in apparently opposite and decussate phyllotaxis. Attempts were made to pull the carbon from the surface of vegetative laminae and axis but the fragmented carbon failed to yield any cellular details except in one preparation from the axis of the specimen no. B/R 154, in which straight walled vertically elongated cells of epidermis were visible. However, The carbon from fertile laminae yielded almost intact ovate to obovate sporangia ca. 1·0-2·0 mm long x 0·5 mm wide without any stalks. The sporangial surface failed to show an annulus but we could see elongated cell outlines with straight to slightly sinuous walls. We believe that these represent cells of the sporangial wall. However, we could not recognise an annulus. The distal margin of fertile laminae appears to be clearly fluctuate or undulate in one out of our two specimens. The slender axes bearing vegetative laminae show two longitudinal parallel ribs.

The spore out put per sporangium was found to be about 200. The spores are spherical, 30-45 μm in diameter with trilete mark having almost equal arms on their proximal faces. The ornamentation of exine is reticulate with sinuous muri. The surface of luminae surrounded by muri showed a number of minute pits.

Liknopetalon rajmahalensis sp. nov. differs from *L. enigmata* in having only attached vegetative leaves whereas *L. enigmata* shows only attached fertile leaves. The vegetative leaves of *L. enigmata* are unknown. The fertile leaves of *L. rajmahalensis* were only found detached but in close association. The fertile leaves of *L. enigmata* are broader than long while fertile as well as vegetative laminae of *L. rajmahalensis* are longer than broad. The side margins of leaves of *L. enigmata* are deeply concave but those of *L. rajmahalensis* are only slightly concave (Fig. 3).

The specific name of *Liknopetalon rajmahalensis* sp. nov. is based on the Rajmahal Hills, the place of occurrence of the species in Jharkhand of India.

Discussion—At present the affinities of *Liknopetalon* appear to be uncertain even though Anderson & Anderson (1985) believed that *Liknopetalon enigmata* was remotely comparable with *Sphenophyllum* Koenig but at the same time they adjudged it to be different and assigned fern affinity to this taxon. Its opposite and decussate vegetative and fertile laminae with apparently exannulate, submarginal and sessile sporangia along the distal margin are unique. Another possibility about the affinities of the genus would be that it is a fern whose pinnae are attached in opposite and decussate manner on the twigs which may be presumed to be rachis. Even so its affinities would remain enigmatic since we are not aware of any such fern. The fertile laminae could also be compared with those of *Cladoxylon scoparium* Kraüsel & Weyland (1926) if its fertile laminar segments are presumed to have become webbed with each other by their margins. This comparison may, however, appear far-fetched since *Cladoxylon scoparium* is of the Devonian age. Moreover, in this case we have to presume that *Liknopetalon* is a persistent archetype. The opposite and decussate phyllotaxis of leaves in *Liknopetalon* resembles that of the ultimate branches of *Archaeopteris macilenta* (Beck, 1971). However, the shape and venation pattern of the vegetative leaves of *Liknopetalon rajmahalensis* sp. nov. resembles those of *Eddya sullivanensis* Beck (1967), the possible seedling of *Archaeopteris* described from the Upper Devonian of New York.

Liknopetalon is comparable in certain vegetative characters with *Noeggerathia* Sternberg and *Tingia* Halle among the noeggerathiophytes (see in Boureau, 1964; Taylor & Taylor, 1993) but its fertile laminae are quite different. The cuneate shape and dichotomous divergent venation of vegetative laminae of *Liknopetalon rajmahalensis* sp. nov. closely resemble those of *Noeggerathia foliosa* Sternberg while their entire distal margin and opposite decussate phyllotaxis in the former differ from those of latter in which the distal margin is dentate and opposite leaves are arranged in two lateral rows. Further, the arrangement of vegetative laminae of *Liknopetalon* may be somewhat compared with arrangement of anisophyllous vegetative leaves of *Tingia* set in four lateral rows but their shapes are different. The sporophylls of *Noeggerathia* and *Tingia* are condensed to form compact cones and bear sporangia on their adaxial surface whereas in *Liknopetalon* fertile laminae are laxedly arranged with sporangia arranged only along the distal margins with precise mode of their attachment being presently unknown. It is best to assign *Liknopetalon* to *incertae sedis* among pteridophytes till more details are known.

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Fig. 2—**A-D** *Liknopetalon rajmahalensis* sp. nov. **E-G** *Lelstotheca harikrishnae* sp. nov. **A**. An axis bearing cuneate vegetative laminae in opposite and decussate arrangement. Holotype Specimen No. B/R 150A. x 1·8, **B**. Another axis with vegetative laminae. Specimen No. B/R 154. x 1·9, **C**. A fragment of fertile lamina with submarginal row of ovate to obovate sessile sporangia along the distal margin. Specimen No. B/R 155A. x 2·1, **D**. Another fragment of fertile lamina showing the same features. Specimen No. 156. x 4, **E**. An axis with three whorls of lanceolate-linear leaves. Holotype Specimen No. B/R 160. x 1·8, **F**. A fragment of axis with a six-leaved whorl. A prominent mid-vein is present in each leaf. Specimen No. B/R 162. x 1·3, **G**. Fragments of two axes, one with two whorls of leaves and the other with a single whorl. Specimen No. B/R 161. x 1·9.


E
F
A
B
C
D
G

Feature	*Liknopetalon enigmata* (Smithies) Anderson & Anderson	*Liknopetalon rajmahalensis* sp. nov.	*Vinaykumaria indica* Pant & Srivastava
Axis	2-3 mm wide	2-3 mm wide	4 mm wide
Nature of known leaves	Only fertile (attached/ detached)	Vegetative (attached/ detached) and fertile (detached only)	Only vegetative (apparently attached)
Shape of leaves/ laminae	Fan-shaped (broader than long)	Cuneate to fan-shaped (longer than broad)	Cuneate (longer than broad)
Size of leaves	1·5 x 1·8 cm	1·8-2·2 x 0·9 cm	2·0-2·5 x 1·5-2·0 cm
Side margins	Deeply concave	Slightly concave	Slightly concave
Distal margin	Convex	Convex	Convex
Shoulders of the leaves / laminae	Pointed	Pointed	Rounded
Venation	Open furcated, several veins in the basal part	Open furcated, several veins in the basal part	Open furcated, several veins in the basal part
Phyllotaxis	Apparently opposite and decussate, laxed	Apparently opposite and decussate, laxed	Apparently opposite, compact
Sporangia	Obovate, 1·0 x 0·5 mm	Ovate-obovate, 1·0-2·0 x 0·5 mm	Not known
Spores	Not known	Spherical with trilete mark on proximal face and reticulate ornamentation	Not known

Fig. 3—Comparison of two species of *Liknopetalon* (Smithies) Anderson & Anderson and *Vinaykumaria indica* Pant & Srivastava.

Genus—**Lelstotheca** Maheshwari 1972

Maheshwari (1972) renamed *Stellotheca robusta* Surange & Prakash (1962) as *Lelstotheca robusta* since the name *Stellotheca* was adjudged as a homonym in form of merely an orthographic variant of *Stellatheca,* the name applied by Danzé (1956) to a possibly fertile osmundaceous fern frond described from Wesphalian C of Pas-de-Calais, France. Up to date there are two named species of *Lelstotheca,* viz., *L. robusta* (Feistmantel) Maheshwari and *L. striata* Maheshwari & Srivastava. The specimens of *Lelstotheca* collected from the Permian of Rajmahal Hills differ from both the earlier described species and are, therefore, assigned here to a new species.

LELSTOTHECA HARIKRISHNAE sp. nov.

(Pl. 3·4-6; Fig. 2E-G)

Specific Diagnosis—Slender articulated axes with nodes and internodes. Slightly swollen nodes bearing whorls of up to 10 lanceolate to linear sessile, entire margined leaves free up to their bases and with acute apices. Each leaf showing a prominent midvein from base to apex.

Holotype—Specimen No. B/R 160.

Duplicates—Specimen Nos. B/R 161, B/R 162 of Divya Darshan Pant Collection, Department of Botany, University of Allahabad, Allahabad and Specimen No. BSIP 35869 of Birbal Sahni Institute of Palaeobotany, Lucknow.

Locality and Horizon—Lalmatia Colliery, Rajmahal Hills, Barakar Stage (Permian, Lower Gondwana), Jharkhand, India.

Description and Comparison—Of the three specimens in the collection, one specimen (Holotype, Specimen No. B/R 160) shows an articulated axis with three whorls. It appears to be the terminal portion of the axis. The length of the internodes has been measured as 0·8 to 1·0 cm. The upper most whorl has 5 linear-lanceolate leaves with acute apices. The second and third incompletely preserved whorls have four and three leaves in each, respectively. The second specimen (No. B/R161) shows two fragmentary axes, one with two incomplete whorls

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PLATE 1 →

Liknopetalon rajmahalensis sp. nov.

1. A slender axis bearing cuneate vegetative simple laminae in opposite and decussate arrangement. Holotype Specimen No. B/R 150A. x 2.
2. Counterpart of the specimen in Pl. 1.1 showing the same features. Holotype Specimen No. B/R 150B. x 2.

3, 4, 5. Detached fragmentary laminae showing convex distal margins, concave side margins and spreading arched veins. Specimen Nos. B/R 151. x 3, B/R 152 x 3, B/R 153. x 3, respectively.


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PLATE 1

Feature	***Lelstotheca robusta*** **(Feistmantel) Maheshwari**	***Lelstotheca striata*** **Maheshwari & Srivastava**	***Lelstotheca harikrishnae*** **sp. nov.**
Axis	0·3 cm wide	0·2 cm wide	0·3 cm wide
Internodal length	1·0-1·8 cm	1·0 cm	1·0-2·2 cm
Striations in internode	Not known	8-12 fine parallel ribs	Not known
Number of leaves in a whorl	10-15	8-12	3-10
Shape of leaves	Linear (widest near the base, gradually tapering towards the apex)	Linear-lanceolate (widest at middle of length or both margins parallel except at the base and apex)	Linear-lanceolate (widest at middle of length or both margins parallel except at the base and apex)
Size of leaves	Up to 2·0 cm long x 0·4 cm wide	Up to 0·8 cm long x 0·1-0·2 cm wide	Up to 2·0 cm long x 0·4 cm wide
Apex of leaf	Acute	Sharply acute	Acute
Base of leaf	Wide	Sharply constricted	Constricted
Midvein	Single, unstriated	Single, striated	Single unstriated
Striations on leaf surface	Absent	Longitudinal striations common, transverse thickenings occasionally seen	Absent
Leaf margins	Entire	Entire	Entire

Fig. 4—Comparison of three species of *Lelstotheca* Maheshwari.

and the another with only one. In this specimen the length of internode was measured as 2·2 cm. The third specimen (No. B/R162) shows a fragmentary axis with an incomplete six leaved whorl. The specimen described by Singh *et al.* as *Lelstotheca* sp. (1987, Pl. 1, fig. 6) from Lalmatia top (LIII) seam of the same locality has been assigned here to *Lelstotheca harikrishnae* sp. nov. It shows stellate whorls with up to ten linear leaves up to 3·5 cm long and 0·3 cm wide. In our specimens the leaves are lanceolate to linear up to 2·0 cm long and 0·4 cm wide, each with a prominent midvein from the base to apex. At some points the leaves show false union near the point of attachment with axis due to close proximity and overlapping.

Lelstotheca harikrishnae sp. nov. is different from both the previously described species. It differs from *Lelstotheca robusta* (Feistmantel) Maheshwari (1972) in having a small number, three to ten only, of lancelolate to linear leaves in each whorl (*Lelstotheca robusta* has 10-15 leaves which are widest at their bases and gradually taper towards their apices). The leaves of *Lelstotheca harikrishnae* sp. nov. differ from those of *Lelstotheca striata* Maheshwari & Srivastava (1987) in lacking its characteristic longitudinal striations running parallel to the midvein and also the transverse striations on the surface of leaves (see Fig. 4).

The specific name of *Lelstotheca harikrishnae* sp. nov. has been given in honour of Dr Hari Krishna Maheshwari of Birbal Sahni Institute of Palaeobotany, Lucknow, who has described several interesting taxa from the Permian of Rajmahal Hills.

POSSIBLE CORRELATION OF PERMIAN STRATA AT LALMATIA

On the basis of floristic elements and lithology, Barakar affinity has been assigned to the Permian strata exposed at Lalmatia (Singh *et al.*, 1987; Raja Rao, 1987; Maheshwari & Bajpai, 1992). With the finding of heterophyllous

PLATE 2

Liknopetalon rajmahalensis sp. nov.

1. An axis bearing vegetative laminae. Note ribbed nature of the axis. Specimen No. B/R 154. x 1·8.
2. Fragment of a fertile lamina bearing submarginal row of ovate to obovate sporangia along the fluctuate distal margin. Specimen No. B/R 155A. x 2·5.
3. Fragment of a fertile lamina with carbonized sporangia along the distal margin. Specimen No. B/R 156. x 4.

4, 5. Sessile sporangia with obtuse apices showing straight to slightly sinuous walled elongated cells of sporangial walls. **4** Slide No. B/R 156/g & **5** - Slide No. B/R 156/c; both x ca. 80.

6. Three spores isolated from the spore mass of a sporangium under LM. Slide No. 156/h x ca. 550.
7. Single spore showing the trilete mark under LM. Slide No. B/R 156/h x ca. 1000.
8. Two spherical spores isolated from the same sporangium, one large and other small at the same magnification. The smaller one shows the trilete mark. Slide No. B/R 156/h x ca. 770.
9. Elongated straight walled cells of axial epidermis. Slide No. B/R 154/a x ca. 325.


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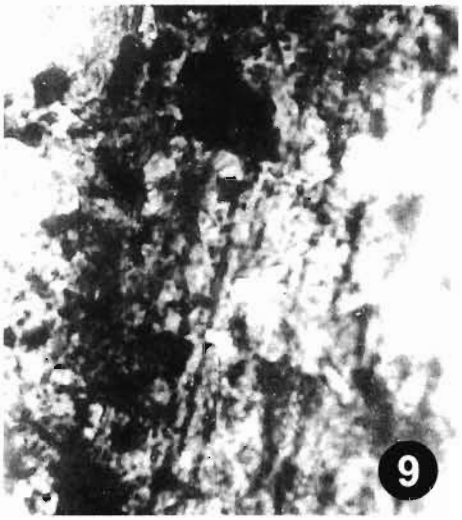
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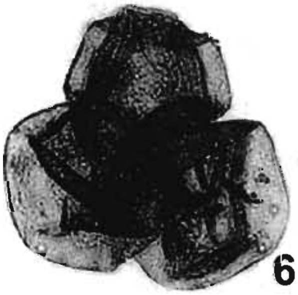
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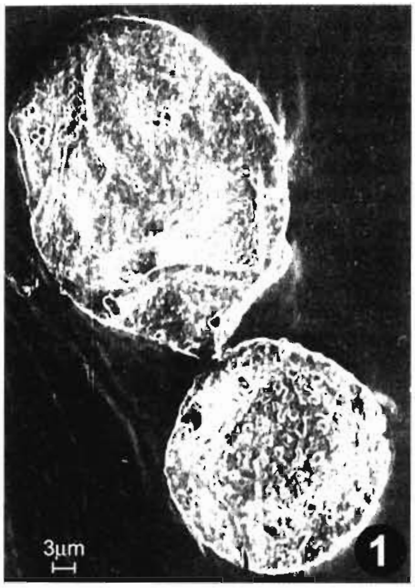
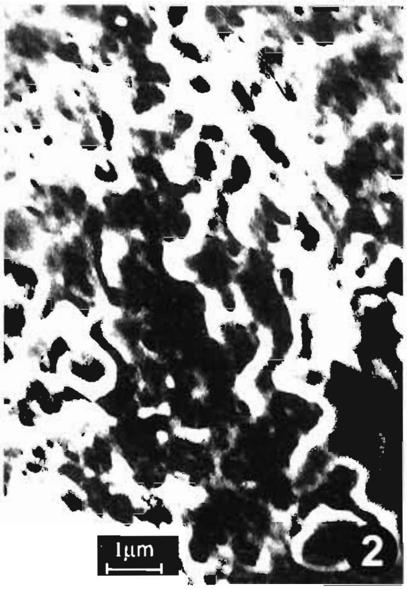
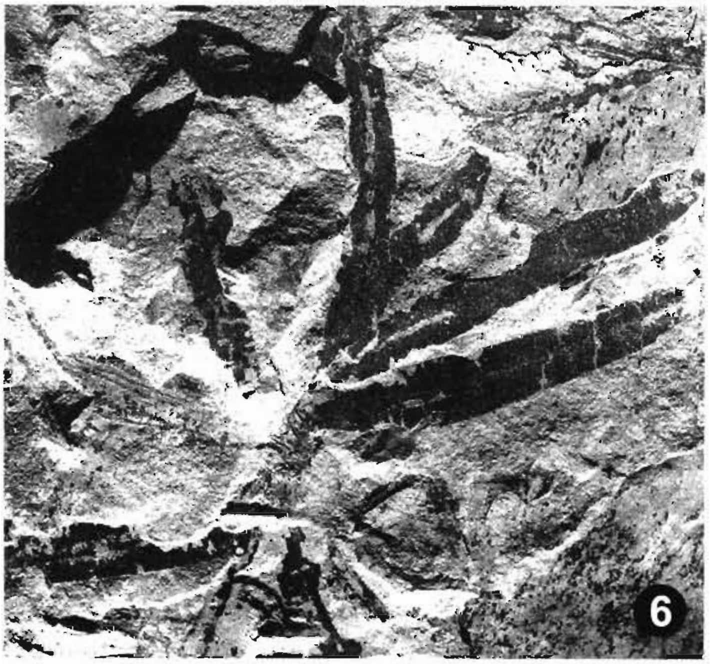
PLATE 2







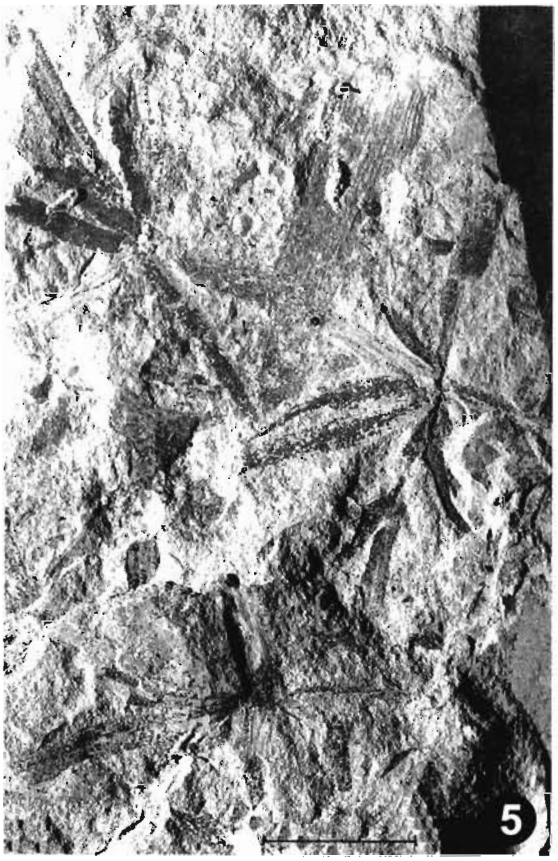


PLATE 3

Sphenophyllum gondwanensis Singh *et al.* (1987) with dentate and crenulate-smooth margined leaves and *Liknopetalon rajmahalensis* described in the present paper, the Permian strata in Rajmahal Basin appear to be floristically equivalent with those of Middle Ecca Series of South Africa wherefrom too a dentate and entire to crenulate leaved forms of *Sphenophyllum*, viz., *S. mesoeccaense* and *S. hammanskraalense* are reported along with *Liknopetalon enigmata* by Anderson & Anderson (1985). These strata also appear to be comparable with those exposed in a ravine section near Mamal Village in Kashmir Himalaya wherefrom dentate and crenulate leaved species of *Sphenophyllum*, viz., *S. thonii* var. *archangelskyii* and *S. thonii var. waltonii* have been described along with *Vinaykumaria indica* (adjudged here as similar to vegetative twigs of *Liknopetalon rajmahalensis*) by Pant *et al.* (1984) and Pant & Srivastava (1991).

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PLATE 3

Liknopetalon rajmahalensis sp. nov.

1. Two spores from the same sporangium under SEM, one large and other small, showing muri of reticulate exine ornamentation. x 1000.
2. Pits on the surface of luminae under SEM. x 75000.
3. A spore showing trilete mark on the proximal face under SEM. x 1300.

Lelstotheca harikrishnae sp. nov.

4. An axis with three whorls of lanceolate-linear leaves, each with a midvein. Holotype Specimen No. B/R 160. x 2·5.
5. Fragments of two axes, one with two incomplete whorls of leaves and the other with a single incomplete whorl. Specimen No. B/R 161. x 2.
6. A fragment of axis with six-leaved whorl. Note the prominent midveins of the lanceolate-linear leaves. Specimen No. B/R 162. x 2·5.

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Plant megafossil remains from Shemshak Formation of Jajarm area, NE Alborz, Iran

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ABSTRACT

Javadi FV & Syooki MG 2002. Plant megafossil remains from Shemshak Formation of Jajarm area, NE Alborz, Iran. Palaeobotanist 51 : 57-72.

The basal part of Shemshak Formation contains abundant well-preserved plant megafossils belonging to 17 taxa of various orders viz., Equisetales, Filicales, Bennettitales, Cycadales and Coniferales. On the basis of present study specially *Dictyophyllum exile, Equisetites arenaceus, Podozamites latissimus* and *Nilssonia polymorpha*, this part of the Shemshak Formation is dated as Rhaetian.

Key-words—Rhaetian Flora, Shemshak Formation, NE Alborz, Iran.

ईरान के उत्तर-पूर्वी अल बोर्ज़ के जाजर्म क्षेत्र के शेमशाक शैलसमूह से प्राप्त पादप गुरुपादपाश्म अवशेष

ऍफ़ वाएज़ जवादी एवं ऍम. गाविदेल स्यूकी

सारांश

शेमशाक शैलसमूह के आधारीय भाग के विभिन्न क्रमों के 17 वर्गकों से सम्बन्धित सुसंरक्षित प्रचुर पादप गुरुपादपाश्म, जैसे—इक्वीसिटेलीज़, फ़ाइलिकेलीज़, बेनीटाइटेलीज़, साइकेडेलीज़ तथा कोनिफ़ेरेलीज़ विद्यमान हैं। वर्तमान में विशेषकर *डिक्ट्योफ़िल्लम एक्ज़ाइली, इक्वीसिटाइटीज़ एरीनेशियस, पोडोज़ैमाइटीज़ लैटिस्सिमस* तथा *निल्ससोनिया पॉलीमॉर्फ़ा* पर किए गए अध्ययन के आधार पर शेमशाक शैलसमूह के इस भाग की आयु रीशियन के रूप में निर्धारित की गयी है।

संकेत शब्द—रीशियन वनस्पतिजात, शेमशाक शैलसमूह, उत्तर-पूर्वी अल बोर्ज़, ईरान.

INTRODUCTION

THE studied area is located at Ozon mountain 56°32' east longitude and 37°2' north latitude, 15 km northeastern of Jajarm. Jajarm is located at northwest of Khorasan Province at a distance of 175 km from Bojnurd city (Fig. 1). The altitude of the study area is about 1000 m above sea level.

The Shemshak Formation is well-exposed at Kuh-e-Ozon (Kuh: means mountain) which is about 800 km away from its type locality at Central Alborz. The Shemshak Formation has a thickness of 2080 m in Kuh-e-Ozon and it consists mainly of sandstones, grey shales intercalating with coal seams and a few limestone beds. The Shemshak Formation was identified in Kuh-e-Ozon by Afshar-Harb (1979) based on ammonite fossils and suggested Middle Toarcian-Lower Aalenian for this rock unit. Likewise, Soheili (1982) prepared a geographical map for this area and mentioned that there are no fossils in the basal part of this rock unit up to 750 m. However, based on ammonite fossils in the upper part of this rock unit, he has suggested Toarcian-Batonian.

It should be mentioned that Afshar-Harb and Soheili (p.c.) have reported only the occurrence of ammonite in some horizon of Shemshak Formation, but they did not report any plant megafossils from this Formation. In order to determine the precise age of Shemshak Formation, the authors studied the Formation and discovered plant megafossils at the basal part of this Formation (Fig. 2).

STRATIGRAPHY

The Shemshak Formation at Jajarm area consists mainly of sandstones, shales, coal seams and conglomerates in the lower part and has ammonites and bivalves limestones in the upper part. The Shemshak Formation lies disconformably on the Elika Formation and the upper contact of this formation is gradational with Bash-Kalateh Formation (Afshar-Harb, 1979). The Shemshak Formation begins with 16 m of alternating median-coarse grained sandstones and is followed by olive-grey shales which contain well-preserved abundant plant megafossils.

SYSTEMATIC DESCRIPTION

Order—EQUISETALES

Family—EQUISETACEAE

Genus—EQUISETITES Sternberg 1820

EQUISETITES ARENACEUS Brongniart 1828

(Pl. 1·1)

- 1964 *Equisetites arenaceus* Boureau; p. 432, figs 391-394.
- 1976 *Equisetites arenaceus* Bragin *et al.*; p. 11.
- 1976 *Equisetites arenaceus* Sadovnikov; p. 74, pl. 1, figs 9, 10.
- 1984 *Equisetites arenaceus* Vassiliev; pl. 2, fig. 1, text-fig. 3.
- 1997 *Equisetites arenaceus* Schweitzer *et al.*; p. 120, pl. 2, fig. 2.
- 1998 *Equisetites arenaceus* Kelber & van Konijnenburg-van Cittert; p. 21, figs 2-5.

Description—The specimen is a cast, 21 cm in length, 14 cm in diameter with several nodes and internodes in between. Internode is 3-4 cm in length with alternating ridges and furrows which are clear specially near the nodes. Ridges or furrows are 2-2·5 mm apart (4-5 per cm).

Comparison & Remarks—*Equisetites beanii* Seward 1894 has also such a large cast but differs in longer internodes (more than 9 cm) and closer furrows (0·3-0·5 mm) than those in *E. arenaceus*. Bragin *et al.* (1976) reported this species from the basal series of the Mesozoic sediments of Tazareh Coal Mine (Iran). Sadovnikov (1976) reported it from Upper Triassic strata of Tazareh. Vassiliev (1984) reported it from Rhaetian strata of Parvadeh Coal Mine (Iran). Schweitzer *et al.* (1997) mentioned this species from Norian of Tazareh.

Order—FILICALES

Family—DICKSONIACEAE

Genus—FERIZIANOPTERIS Fakhr 1977

FERIZIANOPTERIS UNDULATA Fakhr 1977

(Pl. 1·2; Fig. 3·12)

- 1977 *Ferizianopteris undulata* Fakhr ; p. 61, pls 10,11, figs 1a, b, 2 ; fig. 5H-J.

Description—Frond bipinnate, 21 cm long, 6-7 cm broad; rachis distinct, with longitudinal strations, 4-5 mm in width, secondary rachis arising at about right angles, alternate to subopposite, 1-2 mm in width. Pinnules attached at right angles to the secondary rachis by a slightly constricted base, set closely, opposite to alternate, margins undulate or irregulate, apices rounded, 2-3 mm in length, 2-2·5 mm in width. Venation

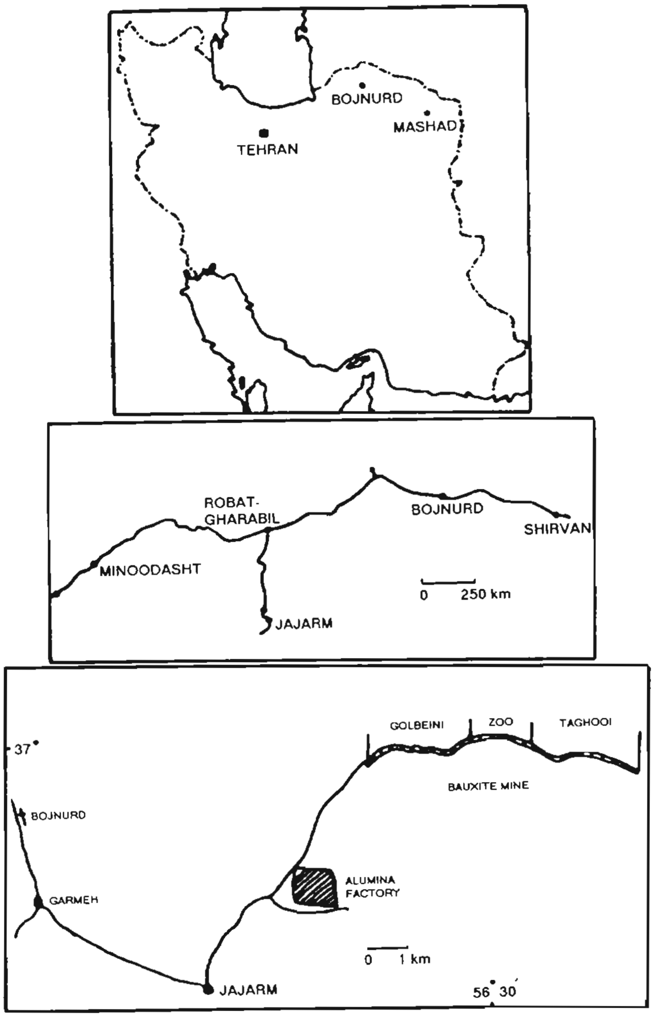

Fig. 1—Location map of study area.

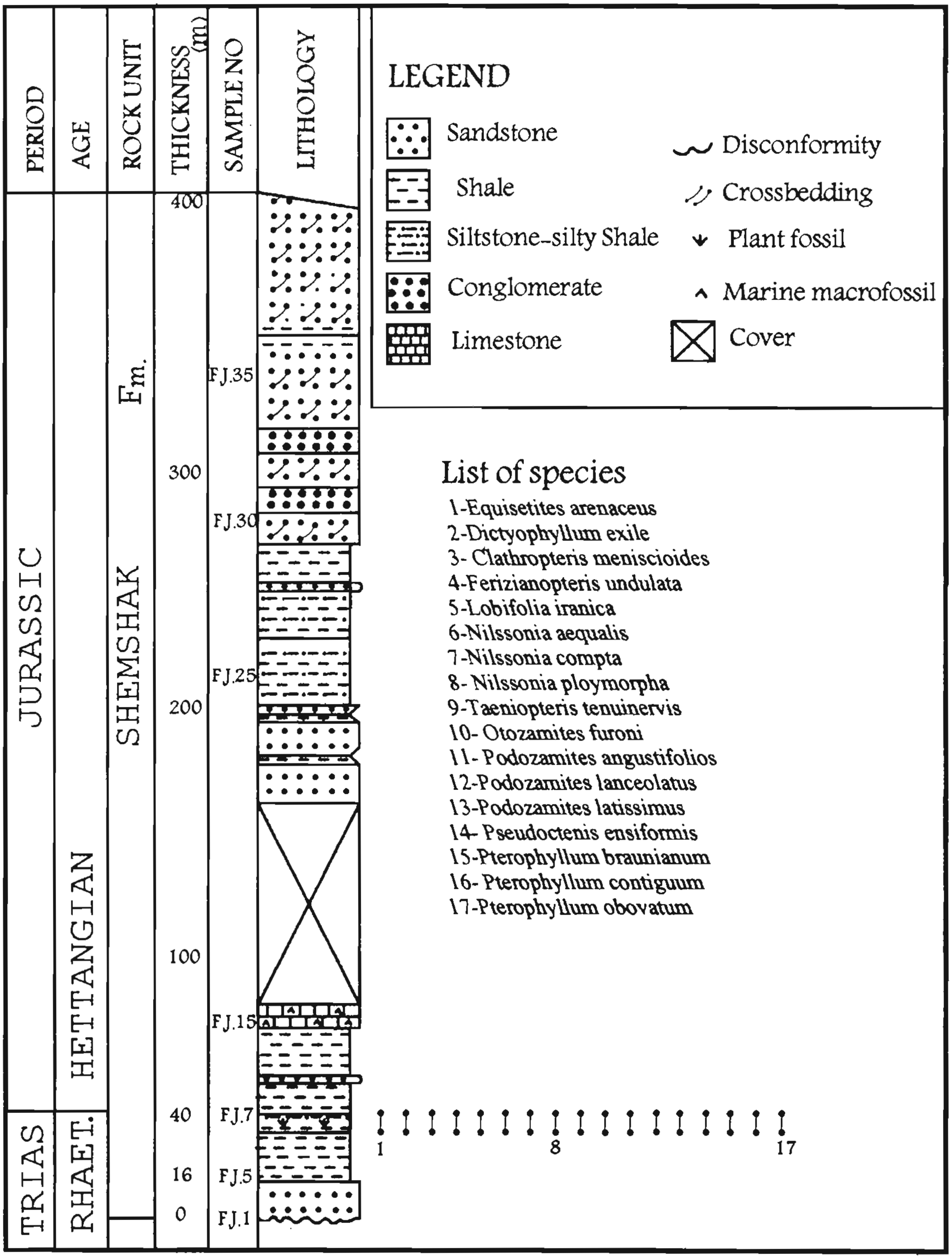

Fig. 2—Stratigraphical column of Shemshak Formation and the plant megafossils bearing horizon in Jajarm.

sphenopteroid, main midrib passes to somewhat one-half of the pinnule length; lateral veins branch dichotomously once or twice.

Comparison & Remarks—This specimen has more closely set pinnules and broader pinnule base than Fakhr's specimen. This specimen *Sphenopteris* spp. In having broader pinnule bases and right angle attaching to rachis. Fakhr (1977) reported this species from Lias-Dogger strata of Ferizi (Iran).

Genus—LOBIFOLIA Rasskazova & Lebedev 1968

LOBIFOLIA IRANICA Fakhr 1977

(Pl. 1·4; Fig. 3·11)

1977 *Lobifolia iranica* Fakhr ; p. 61, pl. 13, figs 1-3.

Description—Frond bipinnate, incomplete; primary rachis straight, 1 cm in width, with longitudinal striations; secondary rachis arising at a right angle, 1-2 mm in width; pinnae alternate; pinnules opposite, attached at about a right angle by a broad base to the secondary rachis, 9-10 mm in length, 7-8 mm in width, margins entire or finely undulate, with rounded apices. Midvein is not visible, lateral veins forked twice or three times.

Comparison & Remarks—*Lobifolia (Eboracia) doruda* (Barnard) Rasskazova & Lebedev 1968 resembles the present species but it can be distinguished from *L. iranica* in having only once forked lateral veins and the pinnules attached at an angle of 50°-60° Fakhr (1977) reported this species from Rhaeto-Lias strata of Ziaran (Iran).

Family—DIPTERIDACEAE

Genus—CLATHROPTERIS Brongniart 1828

CLATHROPTERIS MENISCOIDES (Brongniart 1825) Brongniart 1828

(Pl. 2·2)

1825 *Filicites meniscoides* Brongniart; p. 200; Atlas; pl. 12 (in Harris 1931, p.88).
1847 *Clathropteris meniscoides* Germar; p. 117, pl. 16, figs 1-4.
1911 *Clathropteris meniscoides* Thomas; p. 55, pl. 8, fig. 1.
1931 *Clathropteris menisciοides* Harris; p. 88, pl. 15, fig. 1.
1940 *Clathropteris meniscoides* Ôishi; p. 214, pl. 5, fig. 4.
1949 *Clathropteris meniscoides* Sze; pl. 1, fig. 5; pl. 4, fig. 1.
1950 *Clathropteris meniscoides* Lundblad; p. 27.
1964 *Clathropteris meniscoides* Kilpper; p. 37, figs 15, 16.
1968 *Clathropteris meniscoides* Kon'no; p. 100, pl. 2, figs 2-6; text-fig. 3.
1968 *Clathropteris meniscoides* Assereto *et al.*; p. 11, tab. 1a.
1977 *Clathropteris meniscoides* Fakhr; p. 75, pl. 22, figs 1-3; fig. 8G.
1977 *Clathropteris meniscoides* Corsin & Stampfli; p. 523, pl. 1, fig. 6.

Description—Leaf big in size, petiole not preserved; pinnae elongate-lanceolate, attaining a width about 13-14 cm and a length of ca. 20 cm, lamina contiguous, margins toothed, length of tooth and that of its supporting lateral vein reaching 24 mm and 65 mm respectively. Thus division of pinna-lamina into teeth extending less than one-third of total length of supporting lateral vein; marginal teeth triangular, acutely pointed; rachis of pinna rather slender, 1-2 mm in width; lateral veins about 0·2-0·4 mm across, arising from rachis at angles of 40°-60°, at intervals of 15-20 mm; tertiary veins arising from lateral vein at about a right angle, slightly flexuous, giving off a few quaternary veins, forming quadrate or polygonal reticulation of about 3 to 4 mm in width. First type rectangular mesh of about 6-8 mm broad, 12-14 mm long.

Comparison & Remarks—*Clathropteris platyphylla* Goeppert 1846 resembles this species. *C. platyphylla* as described by Zeiller (1902-03) in further details, appears to differ in arising the lateral veins at angles of 60°-70° instead of 40°-60°. Kon'no (1968) brought *C. platyphylla* under synonymy list of *C. meniscoides*. Vozenin-Serra & De Franceschi (1999) cited these are two different species and noted that the lateral veins in *C. platyphylla* arise at angle of 75° and the proportion of length of tooth to its supporting lateral vein is about 1/8 to 1/13. *C. meniscoides* also differs from *C. elegans* Ôishi 1941 in having more distinct quarternary veins. These meshes are thin and not visible in *C. elegans*. *C. walkeri* as described by Ash (1969, p. 41) does not present a similar distinctive reticulation and pinna apices. This species has a wide geographical distribution. In Iran, it is reported from Zirab (Kilpper, 1964); Qazvin and Nur Valley (Assereto *et al.*, 1968).

CLATHROPTERIS sp.

(Pl. 1.3)

Description—Pinna incomplete; main vein is 2 mm in width; lateral veins arise at a right angle to form rectangular nets with 10 x 11 mm dimension; tertiary veins arise from rectangular or sometimes polygonal meshes 5 x 11 mm in dimension. The surface of specimen is covered completely by collapsed pores.

Genus—DICTYOPHYLLUM Lindley & Hutton 1843

DICTYOPHYLLUM EXILE (Brauns 1862) Nathorst 1878

(Pl. 3·2)

1862 *Camptopteris exilis* Brauns; p. 54, pl. 13, fig. 11.
1878 *Dictyophyllum exile* (Brauns) Nathorst; p. 39, pl. 5, fig. 7.
1926 *Dictyophyllum exile* Harris; p. 64, pl. 1, figs 1, 2.
1931 *Dictyophyllum exile* Harris; p. 80, pl. 18, figs 15, 16.
1950 *Dictyophyllum exile* Lundblad; p. 28, pl. 3, fig. 12.
1970 *Dictyophyllum exile* Boureau; p. 347.
1977 *Dictyophyllum exile* Fakhr; p. 72, pl. 20, figs 2-5; fig. 6E.

Description—Sterile leaf shown in Pl. 3·2 bearing 8-9 pinnae; rachis is about 7 cm length, 3 mm width; the web of basal lamina of adjacent pinnae is negligible about 1-2 cm in

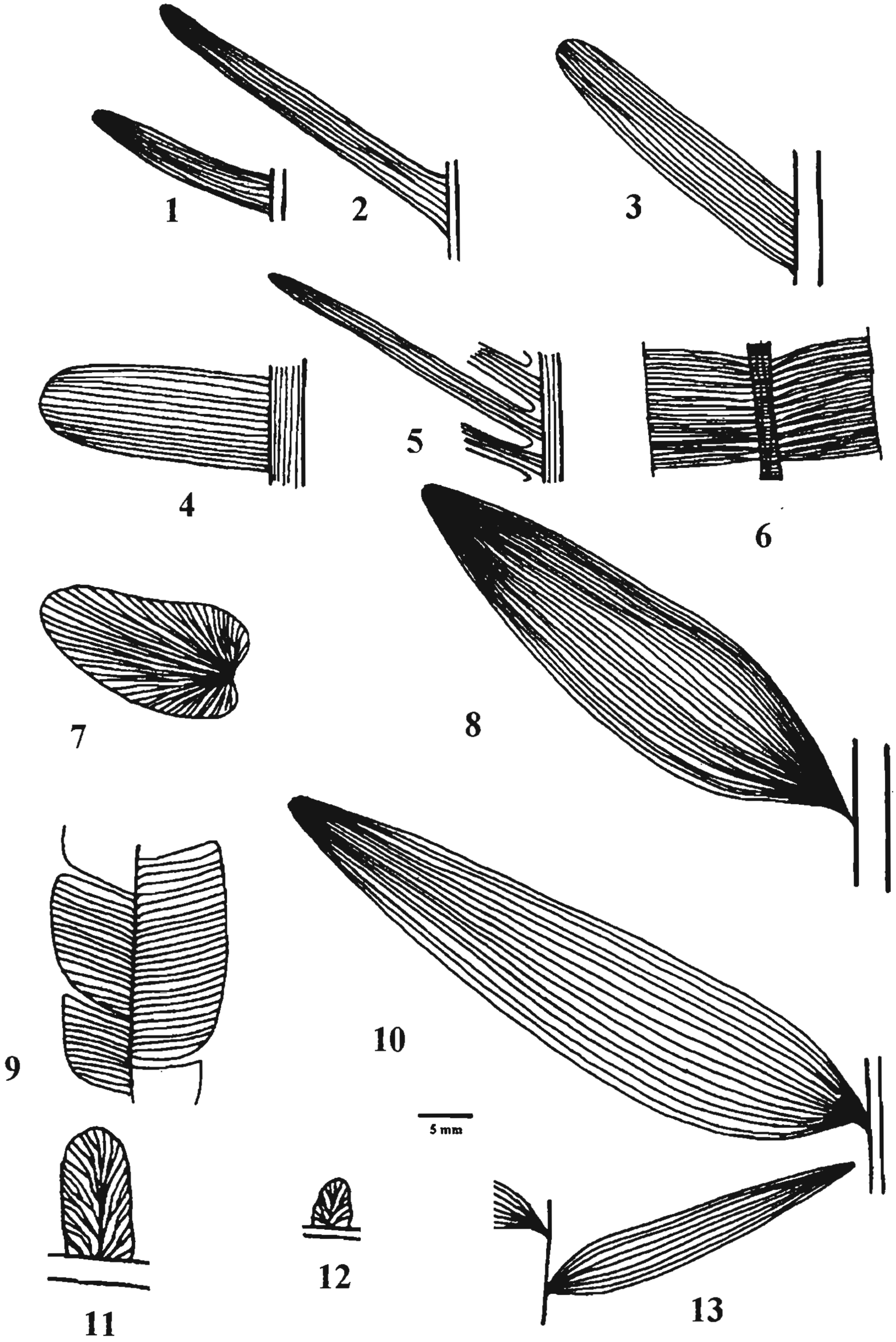

Fig. 3—**1**. *Pterophyllum obovatum*, **2**. *Pterophyllum contiguum*, **3**. *Nilssonia aequalis*, **4**. *Nilssonia compta*, **5**. *Pterophyllum braunianum*, **6**. *Taeniopteris tenuinervis*, **7**. *Otozamites furoni*, **8**. *Podozamites lanceolatus*, **9**. *Nilssonia polymorpha*, **10**. *Podozamites latisimus*, **11**. *Lobifolia iranica*, **12**. *Ferizianopteris undulata*, **13**. *Podozamites angustifolius*.

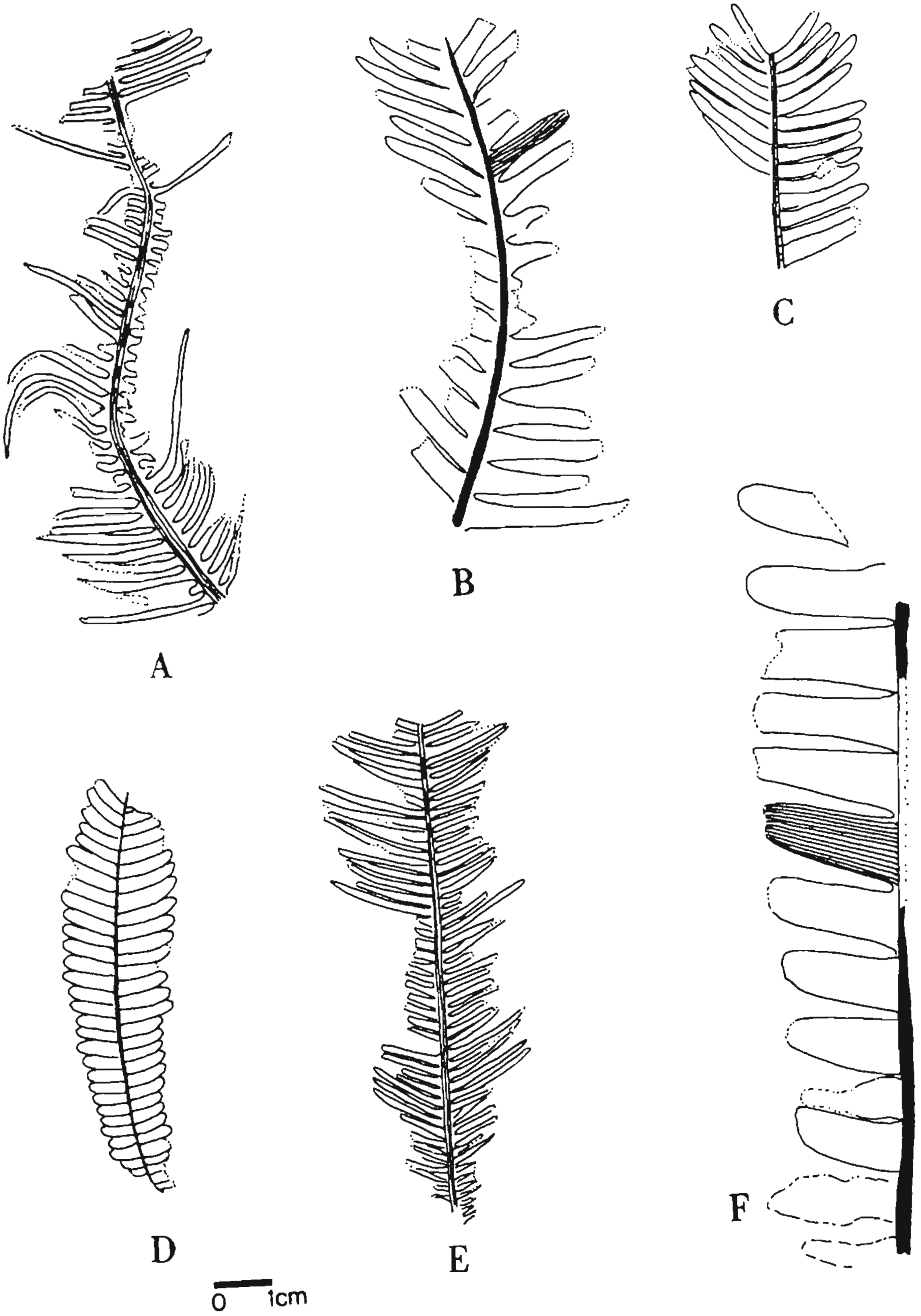

Fig. 4—**A, E**. *Pterophyllum braunianum*, **B**. *Pseudoctenis ensiformis*, **C**. *Pterophyllum contiguum*, **D**. *Pterophyllum obovatum*, **F**. *Nilssonia compta*.

PLATE 1 ⟶

1. *Equisetites arenaceus* Brongniart 1828.
2. *Ferizianopteris undulata* Fakhr 1977.
3. *Clathropteris* sp.
4. *Lobifolia iranica* Fakhr 1977.

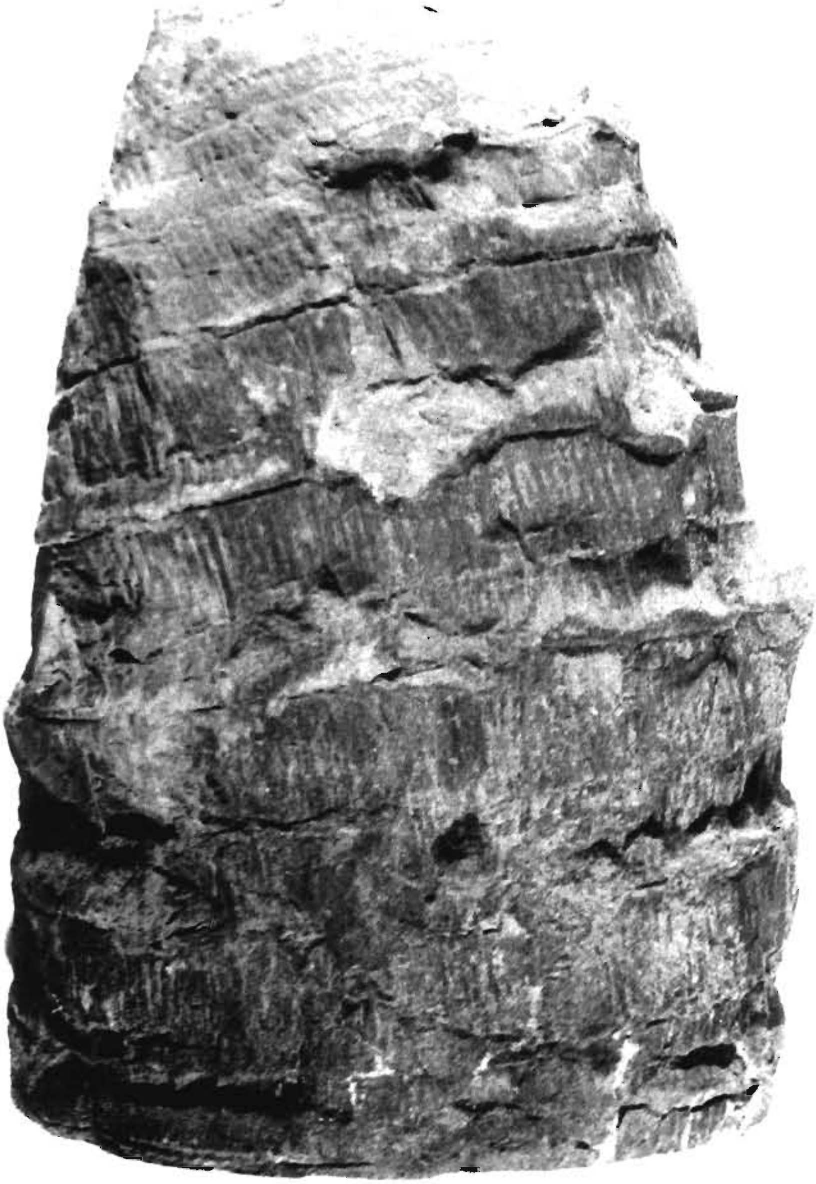
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PLATE 1

width; pinnae narrow, pinnules with acute to obtuse apices; pinna-rachis strong, giving off the midribs of pinnules at angles of 40°-50° at intervals of 8-9 mm. The division of pinna-lamina into teeth extending to one-third or less than of total length of supporting lateral vein. Secondary veins of pinnule from polygonal meshes, with one row of specially large-sized primary meshes on each side of midrib.

Comparison—*Dictyophyllum falcatum* Natio 1968 and *Dictyophyllum nathorsti* Zeiller 1903 are similar to *D. exile*. As Kon'no (1968) described *D. falcatum* was distinguished from *D. exile* by bearing less pinnae (12-13), shorter arms (10-13 mm), having a negligible web of basal lamina as separated from each other completely by narrow gaps or distinct grooves; and narrower, falcate pinnules. *D. nathorsti* in comparison to *D. exile* has a basal lamina web about 5-8 cm width (according to Zeiller, 1903); division of teeth reaches to ½ (1/3-2/3), and shorter pinnae bearing arms (8-12 cm long). The division of teeth in *D. exile* reaches to 1/3. Furthermore, the length of rachis bearing pinnae is about 20 cm (according to Fakhr, 1977), and the main rachis is 1 cm, while it is 6-10 mm (according to Zeiller, 1903) in *D. nathorsti*.

Genus—TAENIOPTERIS Brongniart 1828

TAENIOPTERIS TENUINERVIS Brauns 1862

(Pl. 2·1; Fig. 3·6)

1862 *Taeniopteris tenuinervis* Brauns; p. 50, pl. 13, figs 1-3.
1867 *Taeniopteris tenuinervis* Schenk; pl. 25, figs 3-4.
1985 *Taeniopteris tenuinervis* Vassiliev; p. 75, pl. 37, figs 1, 2.

Description—Leaf linear, 22 cm long and 2 cm wide, midrib clear, tapering gradually towards apex with two fine longitudinal striae. Lateral veins are simple or forked once, 24-25 per cm.

Remarks—This species is reported from Rhaetian of Iran (Schenk, 1867; Vassiliev, 1985)

Class—GYMNOSPERMOPSIDA

Order—BENNETTITALES

Genus—OTOZAMITES Braun 1843

OTOZAMITES FURONI Boureau *et al.* 1950

(Pl. 4·5; Fig. 3·7)

1950 *Otozamites furoni* Boureau *et al.*; p. 229, pl. 7, fig. 39.

Description—Frond pinnate, 3·5 cm long, 2·5 cm broad, pinnules ovate, 12 x 6 mm in size, margins entire, apex rounded, base auriculate, close, alternate and cover proximal face of the rachis at an angle of 80°. Veins divergent, arising from a point at the base of the pinnule, dichotomous three times. The density of veins in the middle part of the pinnule is 18-20.

Comparison & Remarks—*Otozamites eichwaldi* Fakhr 1977 and *Otozamites indosinensis* Zeiller 1903 came closer to *O. furoni*. *O. eichwaldi* differs by its smaller pinnules size (4-6 x 9 mm) and venation with once or twice forked and a density about 13-15 per pinnule. *O. indosinensis* differs by its ovate-linear pinnules (10-13 x 4-5 mm) and veins are once or twice forked veins. *Otozamites kachchhensis* Bose & Banerji 1984 differs in having somewhat rhomboidal or slightly falcate shape and the veins forked once or twice (Bose & Banerji, 1984). This species is reported from Liassic strata of Rudbar, Iran by Boureau *et al.* (1950).

Genus—PTEROPHYLLUM Brongniart 1828

PTEROPHYLLUM BRAUNIANUM (Braun 1843) Goeppert 1843

(Pl. 3·5; Fig. 3·5; Fig. 4A, E)

1843 *Ctenis angusta* Braun; p. 39, pl. 11, figs 1a, b, 3.
1843 *Pterophyllum braunianum* (Braun) Goeppert; p. 134.
1867 *Pterophyllum braunianum* Schenk; p. 164, pl. 38, figs 1-10.
1914 *Pterophyllum angustum* Gothan; p. 134, pl. 26, fig. 3.
1919 *Pterophyllum angustum* Antevs; p. 30, pl. 4, figs 3-7.
1940 *Pterophyllum angustum* Ôishi; p. 340.
1976 *Pterophyllum braunianum* Sadovnikov; p. 93, pl. 4, fig. 5.

Description—Leaf linear-lanceolate as a whole, pinnate, 9 cm in length, 3-3·5 cm in breadth; rachis nearly 1 mm wide, with fine longitudinal striations; pinnae sparsely set, opposite or alternate, attached laterally to the rachis at an angle of about 75°-80°, narrow, gradually tapering at apex, with an even base, 19-21 mm in length, 1·5-2 mm in width. Veins parallel, fine, simple or rarely forked only once, 4-5 per pinna.

Comparison & Remarks—*Pterophyllum bavieri* Zeiller 1903 and *Pterophyllum jaegeri* Brongniart 1828 somewhat resemble *P. braunianum* but *P. bavieri* differs from *P. braunianum* by its closer pinnae than in the present specimen and the proportion of length to width of pinnae is about 10-15 times. Both the earlier pinnae are attached at right angles to rachis. The pinnae in *P. contiguum* Schenk are shorter and wider than in *P. braunianum*. This species is reported from Rhaetian strata of Tazareh by Sadovnikov (1976).

PLATE 2 ⟶

1. *Taeniopteris tenuinervis* Brauns 1862.
2. *Clathropteris meniscioides* (Brongniart 1825) Brongniart 1828.
3. *Pterophyllum obovatum* Fakhr 1977.
4. *Pseudoctenis ensiformis* Halle 1913.

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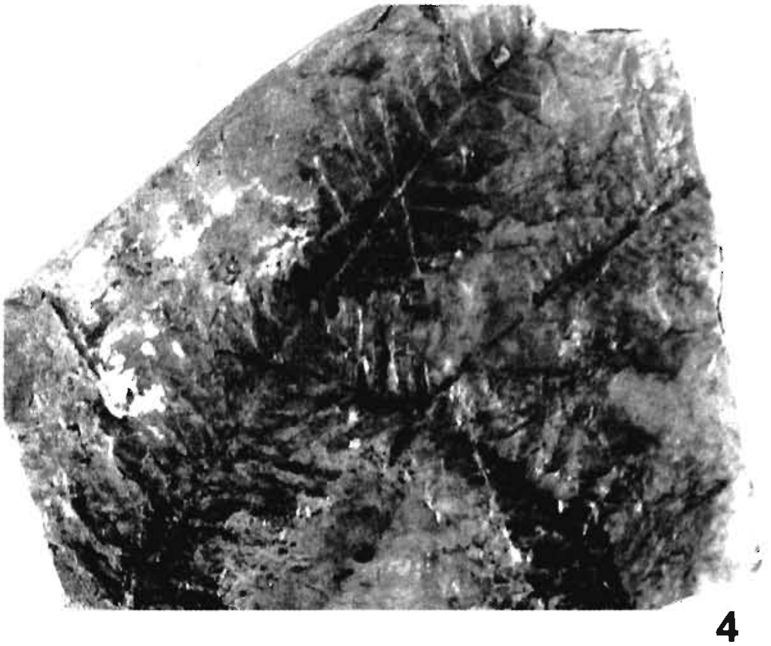

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PLATE 2

PTEROPHYLLUM CONTIGUUM Schenk 1883

(Pl. 4·3; Fig. 3·2; Fig. 4C)

1903 *Pterophyllum contiguum* Zeiller; p. 191, pl. 48, figs 1-4, 6.
1905 *Pterophyllum contiguum* Zeiller; p. 194.
1965 *Pterophyllum contiguum* Vu Khuc *et al.*; p. 42, pl. 13, figs 1-3.
1977 *Pterophyllum contiguum* Fakhr; p. 119, pl. 40, fig. 8; fig. 13E.

Description—Incomplete frond 4 cm in length and 3 cm in breadth, pinnate, lanceolate, tapering towards apex; rachis 0·2-0·4 mm broad; pinnae attached at angles of 40°-50° to the rachis laterally by the entire base, opposite, closely placed, 12-18 mm long, 1·5-3 mm broad, margins parallel, apex obtuse to round; veins parallel, fine, simple or rarely once forked, 6-7 per pinna.

Comparison & Remarks—*Pterophyllum braunianum* Goeppert 1843 resembles this species. It differs in having larger pinnae with more narrow apex than *P. contiguum*. In *P. braunianum*, pinnae are never set closely, and they are expanded at the base. *Pterophyllum bavieri* Zeiller 1903 is distinguished by its much more linear pinnae (long is 12-25 times than width). *Pterophyllum aequale* (Brong.) Nathorst differs from *P. contiguum* by its usually broader pinnae (4-5 mm) and greater number of veins in each pinnae (10-12). Fakhr (1977) reported this species from Rhaeto-Liassic strata of Shemshak area (Iran).

PTEROPHYLLUM OBOVATUM Fakhr 1977

(Pl. 2·3; Fig. 3·1; Fig. 4D)

1977 *Pterophyllum obovatum* Fakhr; p. 115, pl. 40, figs 1, 2; fig. 13H-J.

Description—Leaf obovate-lanceolate as a whole, pinnate, 7 cm in length, up to 2 cm in width; rachis up to 1 mm wide; pinnae attached laterally to the rachis, opposite to alternate, 5-11 mm long, 2-2·5 mm broad; set closely at 80°-85° angles with the whole base, margin parallel, apex rounded; veins parallel, fine, simple or forked only once at its base, 7-8 veins per pinna.

Comparison & Remarks—*Pterophyllum nathorsti* Schenk comes closer to this species. *P. nathorsti* has always fewer veins per pinna (5-7) than *P. obovatum* (7-8). Moreover, the leaf of *P. nathorsti* is a linear-lanceolate in shape while *P. obovatum* has an obovate-lanceolate contour. *Pterophyllum rajmahalense* Morris 1863 differs in having oblanceolate frond and in vein concentration (15-25 per pinna: Bose & Banerji, 1981). This species is reported from Rhaeto-Liassic strata of Shemshak area (Iran) by Fakhr (1977).

Order—CYCADALES

Genus—NILSSONIA Brongniart 1825

NILSSONIA AEQUALIS Brongniart 1825

(Pl. 4·1; Fig. 3·3)

1825 *Nilssonia ?aequalis* Brongniart; p. 219, pl. 12, fig. 6.

Description—An incomplete leaf, 8 cm in length; rachis is covered at places, 2 mm wide, with longitudinal striations on the exposed part. Pinnae attached laterally with entire base at angles of 50°-60°, margin parallel, both the acroscopic and basiscopic margins curved upward and downward; apex rounded; 2·5-3 cm long, 5-8 mm wide, veins strong, simple, parallel, 10-12 per pinna.

Comparison—Our specimen resembles *Pterophyllum aequale* (Bron.) Nathorst 1878. *N. aequalis* in comparison with *P. aequale* has no forked veins but it has more linear pinnae (2-6 cm long, 2·5-5 mm wide) than present specimen and more veins per pinna (18-28). Fakhr (1977, p. 125) described *P. aequale* with pinnae attached to the rachis at angles of 70°-90° and pinnae with truncate apices. Our specimen as a whole resembles *Pterophyllum* cf. *subaequale* Hartz described by Boersma & van Konijnenburg-van Cittert (1991, p. 227) from Aghdarband, Iran. But, venetion is not visible in the present specimen. *Nilssonia aequalis* has thicker and simple veins in comparison with the species of *Pterophyllum*.

NILSSONIA COMPTA (Phillips 1829) Goeppert 1844

(Pl. 4·2; Fig. 4F)

1829 *Cycadites comptus* Phillips; p. 148, pl. 7, fig. 20.
1844 *Nilssonia compta* (Phillips) Goeppert; p. 139.
1864 *Pterophyllum comptum* Leckenby; p. 77, pl. 9, fig. 1.
1875 *Pterophyllum comptum* Phillips; p. 227, pl. 7, fig. 20.
1900 *Nilssonia compta* Seward; p. 223, pl. 4, figs 5, 39, 40.
1905 *Nilssonia compta* Ward; p. 94-95, pl. 17, figs 11-14.
1942 *Nilssonia compta* Harris; p. 578, fig. 5.
1960 *Nilssonia compta* Farshad; p. 95, fig. 81.
1964 *Nilssonia compta* Benda; p. 115, pl. 11, figs 1, 2; fig. 20.
1964 *Nilssonia compta* Harris; p. 50-54, text-figs 22, 23.
1977 *Nilssonia compta* Fakhr; p. 92, pl. 27, figs 6, 7.

Description—Leaf incomplete, 13·5 cm in length, rachis 2-3 mm broad; pinnae rectangular to trapezoid in shape, laterally attached at right angles, 20-25 mm in length, 8-10 mm in width; pinnae are unequal in size; apex truncate with rounded angles,

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PLATE 3 ⟶

1. *Podozamites latissimus* Stanislavski 1971.
2. *Dictyophyllum exile* (Brauns 1862) Nathorst 1878.
3. *Nilssonia polymorpha* Schenk 1867.
4. *Podozamites angustifolius* (Eichwald 1865) Schimper 1870.
5. *Pterophyllum braunianum* (Braun 1843) Goeppert 1843

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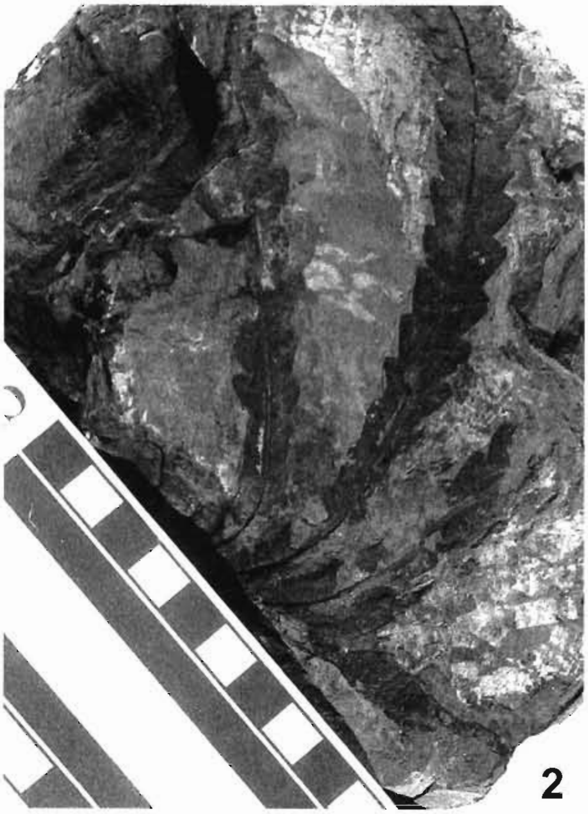

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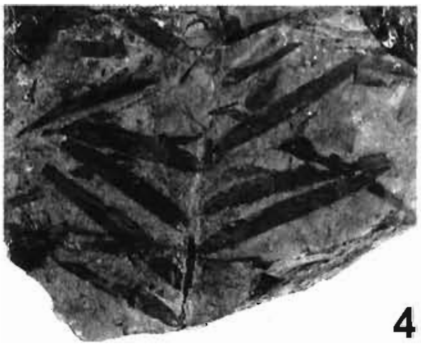

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PLATE 3

pinnae decrease in size towards the apex, so leaf margins slightly convergent. Veins parallel, rough, simple, 12-14 per pinna.

Comparison & Remarks—*Pterophyllum portali* Zeiller 1903 and *Pterophyllum inconstans* (Braun) Goeppert 1844 resemble to the present specimen. *P. portali* differs by its larger pinnae, with rounded apex, and stronger veins. *P. (An.) inconstans* is distinguished by numerous veins (15-28) per segment which forked once or twice. *Pterophyllum muensteri* (Presl) Goeppert has fine veins which forked once or twice. *Nilssonia princeps* Oldham & Morris 1863 differs in having large apical segment, rectangular pinnules and distant bases of pinnules. This species is reported from Rhaeto-Lias strata of Abiek (Iran) by Fakhr (1977).

NILSSONIA POLYMORPHA Schenk 1867

(Pl. 3·3; Fig. 3·9)

1867 *Nilssonia polymorpha* Schenk; p. 127, pl. 29, figs 1-9; pl. 30, fig. 1.
1869 *Nilssonia polymorpha* Schimper; p. 489, pl. 65, fig. 9.
1876 *Nilssonia polymorpha* Nathorst; p. 40, pl. 8, figs. 2-15; pls 8, 9.
1878 *Nilssonia polymorpha* Nathorst; p. 17, pl. 2, figs 6-7.
1879 *Nilssonia polymorpha* Nathorst; p. 72, pl. 15, figs 3-5.
1887 *Nilssonia polymorpha* Schenk; p. 7, pl. 1, fig. 3; pl. 5, fig. 22.
1909 *Nilssonia polymorpha* Nathorst; p. 10, pl. 5, figs 9-13; pl. 6, figs 9-13; pl. 7, fig. 20; pl. 8, figs 12-18.
1940 cf. *Nilssonia polymorpha* Ôishi; p. 210, pl. 26, fig. 6.
2000 *Nilssonia* cf. *polymorpha* Schweitzer *et al.*; p. 20, pl. 3, figs 3-5.

Description—Incomplete leaf 5·6 cm in length and 1·6 cm in width, rachis about 1 mm thick. The segments cover the rachis proximally. The segments attached at right angles to the rachis, with the upper margin nearly straight or slightly concave and the lower margin with a gentle broad curve towards the outer margin. The outer upper margin is obtusely pointed. The veins are parallel, unbranched, and vein concentration 11-21 per segment or 11-12 per cm.

Comparison & Remarks—*Nilssonia schaumbergensis* (Dunker) Nathorst 1881, *N. sarakhs* Barnard & Miller 1976 and *N. serratus* (Prynada) Schweitzer *et al.* 2000 are somewhat similar to *N. polymorpha*. *N. schaumbergensis* can be distinguished by its narrower frond (less than 1 cm broad) and more veins concentrations (30 per cm). *N. sarakhs* has 20 veins per cm and it is reported from Dogger strata of Iran (Barnard & Miller, 1976, p.72). *N. serratus* distinguished by its more triangular-falcate shape of the pinnae and more veins in each pinna (11-34). Moreover, the margins of pinnae are dentate (Schweitzer *et al.*, 2000, p. 48-50). Schenk (1887) and Schweitzer *et al.* (2000) reported this species from Rhaetian of Alborz.

Genus—PSEUDOCTENIS Seward 1911

PSEUDOCTENIS ENSIFORMIS Halle 1913

(Pl. 2·4; Fig. 4B)

1913 *Pseudoctenis ensiformis* Halle; p. 51, pl. 6, fig. 8.
1976 *Pseudoctenis ensiformis* f. *minor* Sadovnikov; p. 100.

Description—Leaf 8·5 cm in length, 3-3·3 cm in width, pinnate; rachis rather slender, 1-2 mm broad; pinnae inserted laterally with the whole of the base at angles of 70°-80°, bases expanded with both the edges of the pinna continuing on the rachis sometimes to the next pinna, thus forming a rounded sinus between two adjacent pinnae. Pinna ensiform with somewhat obtuse to rounded apices, 20-28 mm in length, 4-5 mm in width; veins parallel, strong, simple or rarely once forked, 5-7 veins per pinna.

Comparison—*P. ensiformis* described by Halle (1913, p. 51) is a large leaf (12-14 cm in width). Although our specimen bears morphologically similar pinnae but smaller in size. Fakhr (1977, p. 89, pl. 39, figs 1-3) also described somewhat similar species as *Pseudoctenis ?abiekensis* from Iran. *P. ? abiekensis* differs from *P. ensiformis* by its obtuse to acute apices of pinnae. Furthermore, the density of veins is more in the present than Halle's specimen.

Order—CONIFERALES

Genus—PODOZAMITES Braun 1843

PODOZAMITES ANGUSTIFOLIUS (Eichwald 1865) Schimper 1870

(Pl. 3·4; Fig. 3·13)

1865 *Zamites angustifolius* Eichwald; p. 39, pl. 2, fig. 7.
1870 *Podozamites angustifolius* (Eichwald) Schimper; p. 160.
1941 *? Zamia angustifolia* Furon; p. 250.
1958 *Podozamites angustifolius* Vakhrameev; p. 122, pl. 31, figs 3-5; pl. 32, fig. 5.
1967 *Podozamites angustifolius* Takhtajan; pl. 11, figs 10, 11.
1977 *Podozamites angustifolius* Fakhr; p. 142, pl. 45, fig. 10; fig. 20A.

Description—Shoot incomplete, 7 cm in length, 8 cm in width; leaves lanceolate-linear in shape, typically 5 cm long, 5 mm wide, spirally attached at angles of 70°-80° to the rachis; margins entire, parallel, gradually tapering to apex; base strongly contracted; veins simple or forked once at the base of leaf, parallel, 6-8 in number in the middle part of the leaf, converging towards the apex.

Comparison & Remarks—*Podozamites schenki* Heer 1876 and *Podozamites gramineus* Heer 1876 are two comparable species to *P. angustifolius*. *P. gramineus* can be distinguished from this species by its more linear leaves (up


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PLATE 4

1 *Nilssonia aequalis* Brongniart 1824.
2. *Nilssonia compta* (Phillips 1829) Goeppert 1844.
3 *Pterophyllum contiguum* Schenk 1883.
4. *Podozamites lanceolatus* (Lindley & Hutton 1837) Braun 1843.
5 *Otozamites furoni* Boureau *et al.* 1950.

to 10 cm long) and fewer number of veins (4-5 per leaf). *P. schenki* has shorter and narrower leaves (2·5-4 cm in length and 1·5-2·5 mm in width: Fakhr, 1977, p.143) than *P. angustifolius*. Fakhr (1977) reported it from Rhaeto-Liassic strata of Shemshak area, Iran.

PODOZAMITES LANCEOLATUS (Lindley & Hutton 1837) Braun 1843

(Pl. 4·4; Fig. 3·8)

1837 *Zamites lanceolata* Lindley & Hutton; p. XCIC.
1843 *Podozamites lanceolatus* (L. & H.) Braun; p. 36.
1950 *Podozamites lanceolatus* Boureau *et al.*, p. 227, pl. 7, fig. 36.
1956 *Podozamites lanceolatus* Sze; pl. 52, fig. 1; pl. 53, fig. 1.
1963 *Podozamites lanceolatus* Jongmans; p. 2525.
1976 *Podozamites lanceolatus* Sadovnikov; p. 110, pl. 6, fig. 6.
1977 *Podozamites lanceolatus* Corsin & Stampfli; p. 536, pl. 5, fig. 6.
1977 *Podozamites lanceolatus* Fakhr; p. 141, pl. 48, figs 3, 4, 7-9.
1984 *Podozamites lanceolatus* Vassiliev; pl. 41, fig. 2, pl. 42, fig. 1.

Description—Incomplete specimen bearing lanceolate leaves, rachis 3 mm in width; leaves large, 50 mm in length, 12 mm in width, base strongly contracted; optimum width below the middle, at about 5 mm from the base; veins simple or dichotomous only at the base of the leaf, parallel, 27-29 per leaf at the broadest part, converging towards the apex.

Comparison & Remarks—*Podozamites distans* (Presl) Braun 1843 resembles *P. lanceolatus*. It can be distinguished by lesser concentration of veins (13-22 per leaf : Schweitzer & Kirchner, 1996, p. 89). Boureau *et al.* (1950) reported this species from lower Lias of Haoz-e-Hadj Mehdi (Khorassan) and Shemshak. Sadovnikov (1976), Corsin & Stampfli (1977), Fakhr (1977) and Vassiliev (1984) reported it from Karmozd; Farsian; Shemshak, Abiek, Ferizi, Alasht and Sangrud (Iran) respectively.

PODOZAMITES LATISSIMUS Stanislavski 1971

(Pl. 3·1; 3·10)

1971 *Podozamites latissimus* Stanislavski; in Boersma *et al.*, 1991, p. 226.
1976 *Podozamites latissimus* Sadovnikov; p. 110, pl. 6, fig. 6.

Description—Shoot 9 cm long, 6 cm wide; leaf-blade lanceolate, typically 5-6 cm long, 8-10 mm wide, arranging in a simple helix at variable distance at an angle of 30°; margins entire; base strongly contracted without any distinct petiole, optimum width in the middle, about 2-2·5 cm from the base; apex slightly obtuse; veins simple or forked once at the base of leaf, parallel, 13-14 per leaf at the broadest part, converging towards the apex.

Comparison & Remarks—*Podozamites paucinervis* Boersma & van Konijnenburg-van Cittert JHA, 1991 is comparable to the present species in shape. It can be distinguished by its fewer veins per leaf (10-11) and its optimum width is about 10 mm (Boersma & van Konijnenburg-van Cittert JHA, 1991). *Podozamites distans* (Presl) Braun differs from this species in having more concentration of veins (13-22 per cm: Schweitzer & Kirchner, 1996). It is reported from the Rhaetian flora of Donets Basin by Stanislavski (1971). Sadovnikov (1976) reported this species from Upper Triassic strata of Tazareh, Iran.

CONCLUSION

There are several index species such as *Dictyophyllum exile, Nilssonia polymorpha, Podozamites latissimus* and *Equisetites arenaceus* (only in Iran) which suggest the Rhaetian age for the basal part of Shemshak Formation. Furthermore, abundance of fern genera of Dipteridaceae such as *Clathropteris* and *Dictyophyllum* and greater frequency of large stem of Equisetales indicate the prevalence of a warm and humid climate in this area. The former groups are identified usually as thermophilic and the later one as flourishing in humid places.

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Seeds, fructifications, bracts and calamitalean axes from the Karanpura and Bokaro Group of coalfields

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ABSTRACT

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The paper deals with fructifications of glossopterids (viz. *Gonophylloides* sp., *Scutum* sp., *Ottokaria* sp., & *Bokarospermum* gen. nov.), seeds (*Cordaicarpus*), bracts and calamitalean axes found in a detached condition from the Barakar Formation of the Karanpura and Bokaro Group of coalfields. *Vertebraria* axes were also observed from the Rikba plant bed of North Karanpura Coalfield. These mentioned taxa are only a small part of an extensive and significant flora of Karanpura and Bokaro Group of coalfields.

Key-words—Fructification, *Bokarospermum,* Calamitalean, *Cordaicarpus.*

करनपुरा तथा बोकारो समूह के कोयला क्षेत्रों से प्राप्त बीज, फलन, सहपत्र तथा कैलामाइटेलियन अक्ष

शिवमोहन सिंह

सारांश

प्रस्तुत शोध पत्र में करनपुरा तथा बोकारो समूह के कोयला क्षेत्रों के बराकर शैलसमूह से विलगित अवस्था में प्राप्त ग्लासोप्टेरिडों के फलनों (जैसे—*गॉनोफ़िल्लॉयडीज़* प्रजाति, *स्क्यूटम* प्रजाति, *ऑटोकेरिया* प्रजाति एवं *बोकारोस्पर्मम* नव वंश), बीज *(कॉर्डेकार्पस)*, सहपत्र तथा *कैलामाइटेलियन* अक्षों का विवेचन किया गया है। उत्तरी करनपुरा कोयला क्षेत्रों के रिकबा पादप संस्तर से *वर्टीब्रेरिया* अक्ष भी प्राप्त हुई हैं। ये सूचित वर्गक करनपुरा तथा बोकारो समूह के कोयला क्षेत्रों के सघन एवं महत्त्वपूर्ण वनस्पतिजातों का एक छोटा सा अंश मात्र है।

संकेत शब्द—फलन, *बोकारोस्पर्मम*, कैलामाइटेलियन, *कॉर्डेकार्पस*।

INTRODUCTION

THE term glossopterid is applied to the Lower Gondwana leaf genera *Gangamopteris, Glossopteris, Palaeovittaria,* and similar leaves, which share similar epidermal features and are associated with comparable fructifications. The first glossopterid fructification was described and illustrated by Feistmantel (1881) as *Dictyopteridium sporiferum* who thought it to be a fern. Zeiller (1902-1903) reported *Ottokaria* (*Feistmantelia*) *bengalensis,* now known as an ovuliferous capitulum with a long stock and subtended by a glossopterid leaf, probably *Glossopteris communis* (Banerjee, 1978). Bose re-examined the specimen of Zeiller, i.e., *Ottokaria bengalensis*. From these observations he convinced that the three forms are related to each other. But Bose did not agree with Zeiller's observation because he had found that *O. bengalensis* is definitely attached to the midrib of a *Glossopteris indica* type of leaf (in Plumstead, 1956 on pp. 232-233). White (1908) established the genus *Arberia* for "broadly incised, coriaceous or striate and thick nerved scale leaves whose distant recurvate and truncate lobes appear to owe their abrupt or even slightly ragged terminations to the detachment of some sort of bodies, presumably reproductive in nature". On the basis of association a relationship between *Arberia* and *Gangamopteris* was presumed. Rigby (1972) interpreted *Arberia* as a fructification "that bore large numbers of naked ovules on pinnate branchlets arranged laterally along a forked rachis". Plumstead (1952, 1956, 1958) described and illustrated a large number of fructifications in organic connection with leaves of *Gangamopteris, Glossopteris* and *Palaeovittaria*. Several other fructifications of the glossopterids, were described by Surange and Maheshwari (1970), Banerjee (1969, 1984, 1991), Surange and Chandra (1973a, b, 1975), Kov'acs-Enró'dy (1974), Chandra and Surange (1977a, b, c), Pant and Nautiyal (1984), Anderson and Anderson (1985), and others. The taxonomic position and phylogenetic relationship of different types of glossopterid fructification have been analysed by Maheshwari (1990).

In the present collection only a few fructifications in detached condition, are present. These are referable to the genera *Gonophylloides, Scutum, Ottokaria* and *Bokarospermum* gen. nov.

Feistmantel (1879, 1881, 1882, 1886) reported a number of seeds under the genera *Carpolithes, Samaropsis, Cardiocarpum,* etc. from the Talchir, Karharbari and Raniganj formations. Subsequently, numerous other seeds were described under the genera *Cardiocarpon, Cardiocarpus, Cycadospermum, Cornucarpus, Indocarpus, Nummulospermum, Eucerospermum,* etc.

The dispersed bracts are now accepted as part of some fertile organs of Glossopterids. These are deciduous in nature and occur singly as protective structures of fertile organs. The study of large numbers of such scale leaves has revealed significant characteristic features worthy of generic recognition (Banerjee, 1984). The scale leaves which occur singly have been recognised under the new genus *Gondwanolepis*, by Banerjee (1984). Calamitalean and *Vertebraria* axes were also found in large numbers in these coalfields.

MATERIAL & METHODS

The material is preserved as impressions and compressions on grey carbonaceous shales. Most of the specimens belong to the Barakar Formation of the South Karanpura, North Karanpura and West Bokaro coalfields. One *Vertebraria* cast has also been collected from the Talchir Formation of the North Karanpura Coalfield.

The collected specimens have been cleaned, sorted out, photographed and lodged in the repository section of Birbal Sahni Institute of Palaeobotany, Lucknow, India.

SYSTEMATIC DESCRIPTIONS

Glossopterid Fructifications

Genus—GONOPHYLLOIDES Maheshwari 1968

(=*Cistella* Plumstead 1952)

GONOPHYLLOIDES sp.

Pl. 1.1,2

Specimen No.—BSIP 38816 (2/4578), BSIP 38856 (20/4578).

Locality—Sirka Colliery, South Karanpura Coalfield.

Horizon—Barakar Formation.

Plumstead (1952) instituted the genus *Cistella* for a certain type of fructification found 'attached' to the midrib of *Glossopteris* leaves. Maheshwari (1968) observed that the name *Cistella* was preoccupied and hence he instituted a new name *Gonophylloides* for Plumstead's specimens. Plumstead (1956) interpreted *Cistella* as a female bivalved structure comprising a fertile head and a sterile bract. Many later workers thought it to be of strobiloid nature (Surange & Maheshwari,

PLATE 1 ⟶

1, 2. *Gonophylloides* (= *Cistella*) sp., Specimen No. BSIP 38816 (2/4578), BSIP 38856 (20/4578), Barakar Formation, Sirka Colliery, South Karanpura Coalfield, Bihar. x nat. size.

3. *Scutum* sp., Specimen No. BSIP 38857 (S/4578), Barakar Formation, Shales associated with Naditoli Seam, Sirka Colliery, South Karanpura Coalfield, Bihar. x nat. size.

4, 8. Bracts, Specimen No. BSIP 38858 (J/5007), BSIP 38859 (J$_2$/5004) Barakar Formation, Jharkhand Colliery, West Bokaro Coalfield, Jharkhand. x nat. size.

5, 9. *Cardiocarpus* sp., Specimen No. BSIP 38860 A & B (2/4753), Barakar Formation, Religara Colliery, South Karanpura Coalfield, Bihar. x 3.

7. *Cardiocarpus* sp., Specimen No. BSIP 38861(J/5007), Barakar Formation, Jharkhand Colliery, West Bokaro Coalfield, Jharkhand. x nat. size.

6. *Ottokaria* sp., Specimen No. BSIP 38822-A (J$_2$/5007), Jharkhand Colliery, West Bokaro Coalfield, Jharkhand. x nat. size.

10. *Calamitalean* axis, Specimen No. BSIP 38862 (9/4739), Barakar Formation, Kuju Colliery, West Bokaro Coalfield, Bihar. x nat. size.

11. *Calamitalean* axis, Specimen No. BSIP 38863 (2/5007B), Barakar Formation, Gidi- C Colliery, South Karanpura Coalfield, Bihar. x nat. size.

12. A cast of *Vertebraria* axis, Specimen No. BSIP 38864 (6/4993). Talchir Formation, Chano-Rikba Basin, North Karanpura Coalfield, Bihar. x nat. size.

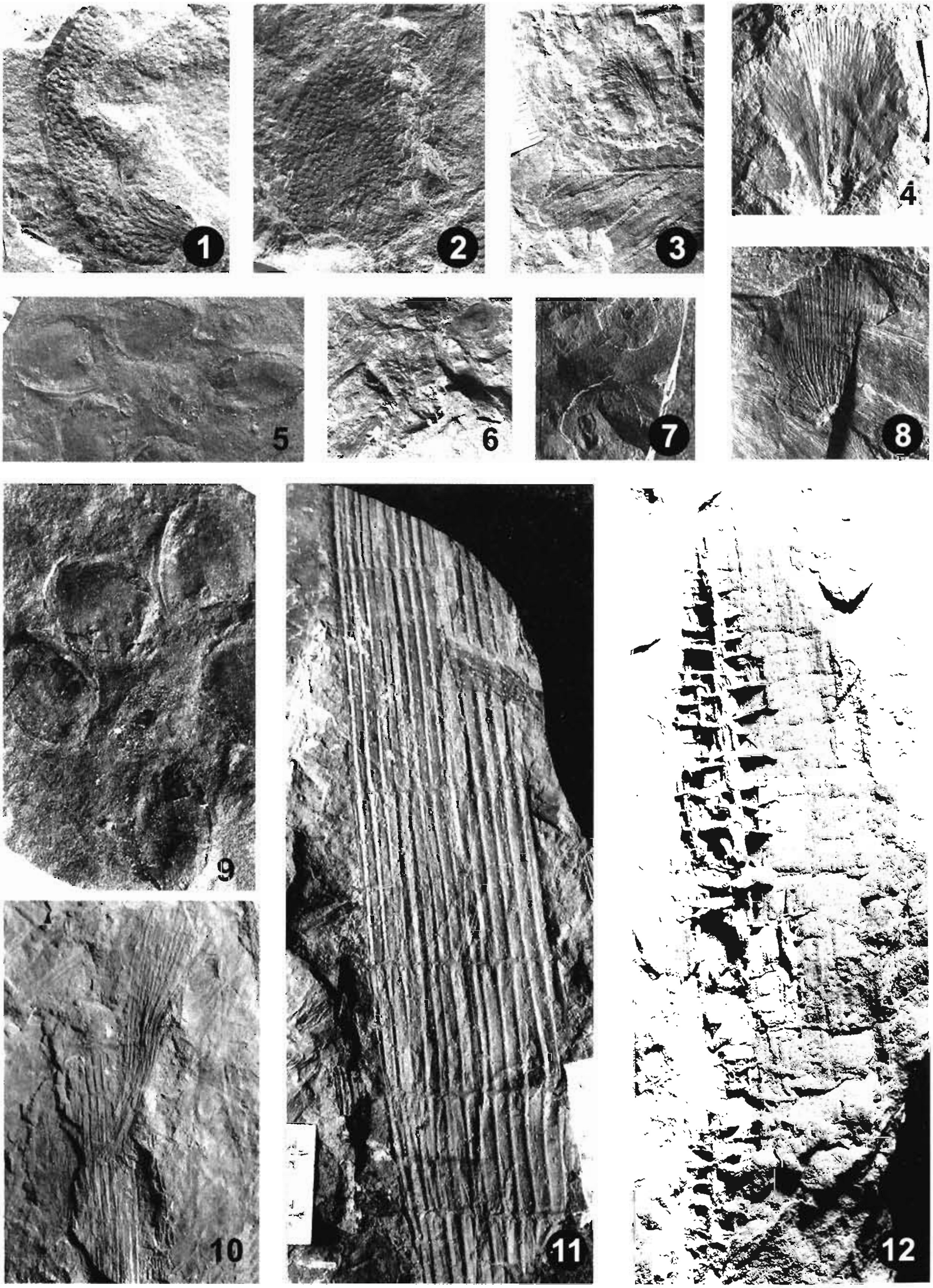

PLATE 1

1970; Surange & Chandra, 1974, and others). Of late opinion is emerging that the female glossopterid fructification may be of foliar nature, bearing ovules on one surface only (Maheshwari, 1965; Gould & Delevoryas, 1977; Maheshwari, 1990). Organisationally there is not much difference between *Dictyopteridium, Scutum* and *Gonophylloides*. The main difference lies in their shape and nature of ovule "bases".

Present specimens are incomplete, measuring 3·5-5 cm in length and 1·3-2 cm in width. At the base is a distinct mark of the stalk. The surface is studded with a large number of overlapping, more or less polygonal-circular, elevated areas which appear to have been arranged in close spirals. These probably represent bases of ovules/seeds.

Genus—SCUTUM Plumstead 1952

SCUTUM sp.

Pl. 1.3

Specimen No.—BSIP 38857 (S/4578).

Locality—Sirka Colliery, South Karanpura Coalfield.

Horizon—Barakar Formation.

This genus was established by Plumstead for a type of reproductive organ found attached to *Glossopteris* leaves or unattached. According to her "*Scutum* is a bilaterally symmetrical, two sided cupule usually borne on its own short pedicel which grows, according to the species, from the midrib or from the top of the petiole of a leaf which in every other respect resembles the vegetative leaves of a species of *Glossopteris*. The fructification is believed to be axillary but the pedicel is adnate for the greater part of its length 2 cm, width 1·5 cm. On the out side each half consists of a central part, or head, which is thick or raised and has fan-shaped venation, and a surrounding wing which is often fluted, striated and has a dentate margin. The adaxial half called the fertile half, bears a number of small oval sacs embedded in the tissue of the central head, whilst in the vast majority of cases the opposite abaxial half is empty and apparently only protective".

Genus—OTTOKARIA Zeiller 1902-1903

OTTOKARIA sp.

Pl. 1·6

Specimen No.—BSIP 38822-A (J_2/5007).

Locality—Jharkhand Colliery, West Bokaro Coalfield.

Horizon—Barakar Formation.

Zeiller (1902-1903) described a fructification consisting of a lobed terminal disc and a slender stalk. Seward and Sahni (1920) observed that it "consists of a stalk attached in a slightly eccentric position to an almost orbicular lamina 2.5 cm in diameter with sub-acute teeth and traversed by numerous radially disposed irregular striations. The lamina is slightly concave and has the form of a shallow cup. The surface features are more like that of a bract than a regular veined leaf". Later Pant and Nautiyal (1966) and Mukherjee *et al*. (1966) commented on the connection of *Ottokaria* to a leaf of *Glossopteris*. Surange and Chandra (1975), Pant and Nautiyal (1984), Maheshwari (1990), and others have also put forth their ideas about *Ottokaria* Zeiller.

BOKAROSPERMUM gen. nov.

Diagnosis—Semicircular concave disc presents at the median part of leaves. Size variable; 0·5-1 cm, 2-3 labium like structures surrounds the concave disc, probably it bears reproductive organs. At the point of fructification the midrib is not clear. There is only one fructification on one leaf.

BOKAROSPERMUM MAHESHWARI sp. nov.

Pl. 2·1-4

Specimen Nos.—BSIP 38864 (30/5004), BSIP 38865 (13/4746), BSIP 38866 (J/5004), BSIP 38867 (16/5004).

Locality—Jharkhand Colliery, West Bokaro Coalfield.

Horizon—Barakar Formation.

Holotype—Specimen No. BSIP 38866.

Description—Fructification .

Diagnosis—As generic diagnosis.

Remarks—Many leaves of *Glossopteris* spp. showing median location of a fructification type not reported previously. In overall features it does not show resemblance with other fructifications. The fructification looks to be sufficiently distinctive and interesting to be named as *Bokarospermum* gen. nov. Various BSIP Staff and John Rigby's recommendation also supported it as new taxon. Thus *Bokarospermum maheshwari* sp. nov. is erected as a new species.

Seeds

Genus—CORDAICARPUS Geinitz 1862

CORDAICARPUS sp.

Pl. 1·5, 7, 9

Specimen No—BSIP 38860 (2/4753), BSIP 38861 (J/5007).

Locality—Religara Colliery, South Karanpura Coalfield, Jharkhand Colliery, West Bokaro Coalfield.

PLATE 2 →

1-4. Leaves of *Glossopteris* spp. Specimen Nos. BSIP 38865 (30/5004), BSIP 38866 (13/4746), BSIP 38867 (J/5004), BSIP 38868 (16/5004), showing location of *Bokarospermum* fructification type not reported so for, Barakar Formation, Jharkhand Colliery, West Bokaro Coalfield, Jharkhand. x nat. size.


1


2


3


4

PLATE 2

Horizon—Barakar Formation.

This type of seed was described by Zeiller (1902-1903) as *Cordaicarpus* sp. Seward and Sahni (1920) described them as *Cordaicarpus* sp. cf *C. cordai* (Geinitz) on the basis of an external morphological resemblance with the northern species. However, the carbonised seed coat of the northern species shows reticulate meshes which are absent in southern forms.

Description—Seeds platyspermic, pear-shaped, base cordate, apex rounded, 0·5-0·9 cm long, 0·2-0·5 cm broad; a narrow border (? sarcotesta), nearly uniform in width, encircles the sclerotesta.

Bracts or Scale leaves

Pl. 1·4, 8

Specimen Nos.—BSIP 38858 (J1/5004), BSIP 38859 (J2/5004).

Locality—Jharkhand Colliery, West Bokaro Coalfield.

Horizon—Barakar Formation.

Description—Shape obovate, length 3·2-3·5 cm, width 2·3-2·6 cm, Apex obtuse, Base truncate, Midrib absent, Margin dented, Veins radiating from base, bifurcating and reaching up to apex.

Calamitalean axes

PARACALAMITES AUSTRALIS Rigby 1966

Pl. 1·10-11

Calamitalean axes are showing ridged and furrows. Nodes and internodes are peculiar features of these elongated cylindrical axes. Length 7·0-14·0 cm, width 5·3-3·2 cm.

Specimen Nos.—BSIP 388662 (9/4739), BSIP 388663 (2/5007B)

Locality—Kuju Colliery, West Bokaro Coalfield, Gidi-C Colliery South Karanpura Coalfield.

Horizon—Barakar Formation.

VERTEBRARIA INDICA Royle 1839 emend. Schopf 1965

Pl. 1·12

Remarks—*Vertebraria indica* was established on the basis of external characters of the axes. Surange and Maheshwari (1962) established two more species, viz., *V. raniganjensis* and *V. myelonis*. Schopf (1965), however, did not consider the difference between anatomy of *V. indica* (Walton & Wilson, 1932) and *V. raniganjensis* to be great enough to separate the two species. He also did not find evidence for the presence of a pith in *Vertebraria* axes and therefore rejected the species *V. myelonis*. He, however, included as a new species, a petrified axis described by Kräusel (1956) from the Karroo Series of South Africa.

Specimen Nos.—BSIP 38864 (6/4993), 3/4995, 10/5003, J1/5007, J2/5007, J3/5007.

Locality—Lurunga *Nala*, Chano-Rikba Basin, North Karanpura Coalfield; Saunda Colliery, South Karanpura Coalfield, South Tapin and Jharkhand Collieries, West Bokaro Coalfield.

Horizon—Talchir and Barakar formations.

Description— Length 5·7-24 cm; width 0·4-3·7 cm.

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Characterisation of organic source material from Tatapani and Ramkola coalfields, Chhattisgarh, India

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ABSTRACT

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Detailed study of the coal microconstituents from Tatapani and Ramkola coalfields has revealed preservation of leaf sections, cork cells, microspores, megaspores, algae, resins, seeds and fruiting bodies. The completely intact leaf sections showing various tissues are reported here for the first time from Early Permian coals. Occurrence of such well preserved plant structures indicates that certain part of Indian Lower Gondwana coals could be partially of autochthonous in origin, while the Gondwana coals are known to have been formed by drifted plant matter, as also confirmed by the presence of distorted material. The palaeodepositional environment and nature of coal forming plant community has also been discussed.

Key-words—Macerals, Autochthonous, Liptinite, Palaeodeposition, Tatapani and Ramkola.

भारत के छत्तीसगढ़ प्रान्त के ततापानी तथा रामकोला कोयला क्षेत्रों से प्राप्त कार्बनिक स्रोत पदार्थ का विवेचन

शिंजिनी सरन

सारांश

ततापानी तथा रामकोला कोयला क्षेत्रों से प्राप्त कोयले के कोयला सूक्ष्मसंघटकों के विस्तृत अध्ययन से पर्ण परिच्छेदों, कॉर्क कोशिकाओं, सूक्ष्मबीजाणुओं, गुरुबीजाणुओं, शैवाल, रेज़िन, बीज, फल कायों का सुसंरक्षण प्रदर्शित हुआ है। पहली बार यहाँ के प्रारंभिक परमियन युगीन कोयलों से विभिन्न ऊतकों को प्रदर्शित करने वाले पूर्णतः अक्षुण्ण पर्ण परिच्छेद अंकित किए गए हैं। इस प्रकार की सुसंरक्षित पादप संरचनाओं की उपस्थिति इंगित करती है कि अधो गोण्डवाना कोयलों का कुछ अंश मूलतः स्वस्थानिक हो सकता है, जबकि गोण्डवाना कोयले विस्थापित पादप पदार्थों द्वारा निर्मित हुए जाने जाते हैं; यह भी विकृत पदार्थों की उपस्थिति से अभिपुष्ट हुआ है। इसके अतिरिक्त इस शोध पत्र में पुरानिक्षेपणीय पर्यावरण तथा कोयला निर्मित करने वाले पादप समुदाय की प्रकृति का भी विवेचन किया गया है।

संकेत शब्द—मैसेरल, स्वस्थानिक, लिप्टीनाइट, पुरानिक्षेपण, ततापानी तथा रामकोला.

INTRODUCTION

THE Tatapani and Ramkola coalfields form the eastern- most extension of Son Valley Basin, lying 25 km west of Hutar Coalfield. Rivers Kanhan and Rehar flank the eastern and western sides and drain into Son River. The location map appears in Fig. 1. The coalfields lie between 23°30' & 23°55' latitudes and 83°00' & 83°40' longitudes, the northern strip of coal-bearing rocks forms the Tatapani Coalfield and the southern strip as the Ramkola Coalfield. This area is located between Rampur fault in the north and Tatapani fault or Southern boundary fault in the south. 'Tatapani' owes its name to the famous hot spring emanating at 98·50°C from the Southern boundary fault.

Tatapani-Ramkola is a classical basin in which Gondwana sediments lie unconformably over the Basement metamorphic rocks. Talchir, Barakar, Barren measures, Raniganj, Panchet and Mahadeva formations comprise Gondwana Sequence in the area (Raja Rao, 1983; Fig. 2). Barakar Formation is represented by white fine to medium grained sandstone, micaceous grey shale, carbonaceous shale, shaly coal and coal seams. Thin coal bands occur in Raniganj Formation also. The seams at Tatapani-Ramkola are mostly lying as subsurface deposits represented by numerous coal bands. The thickness

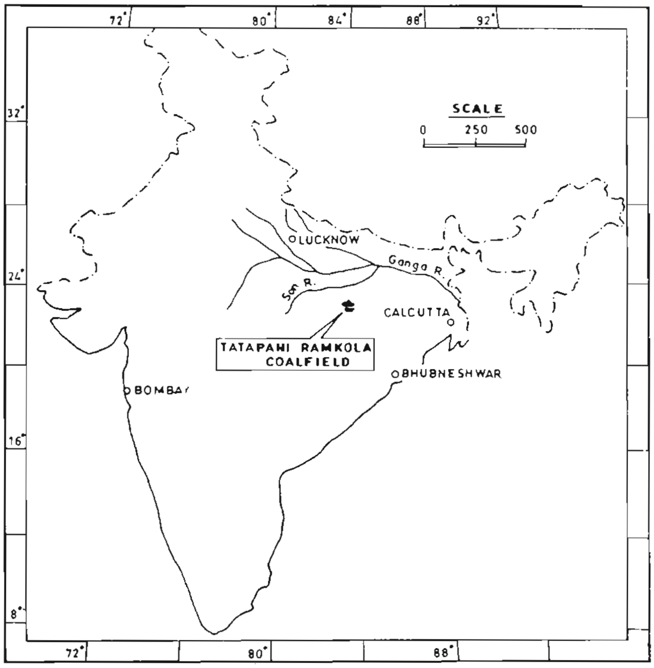


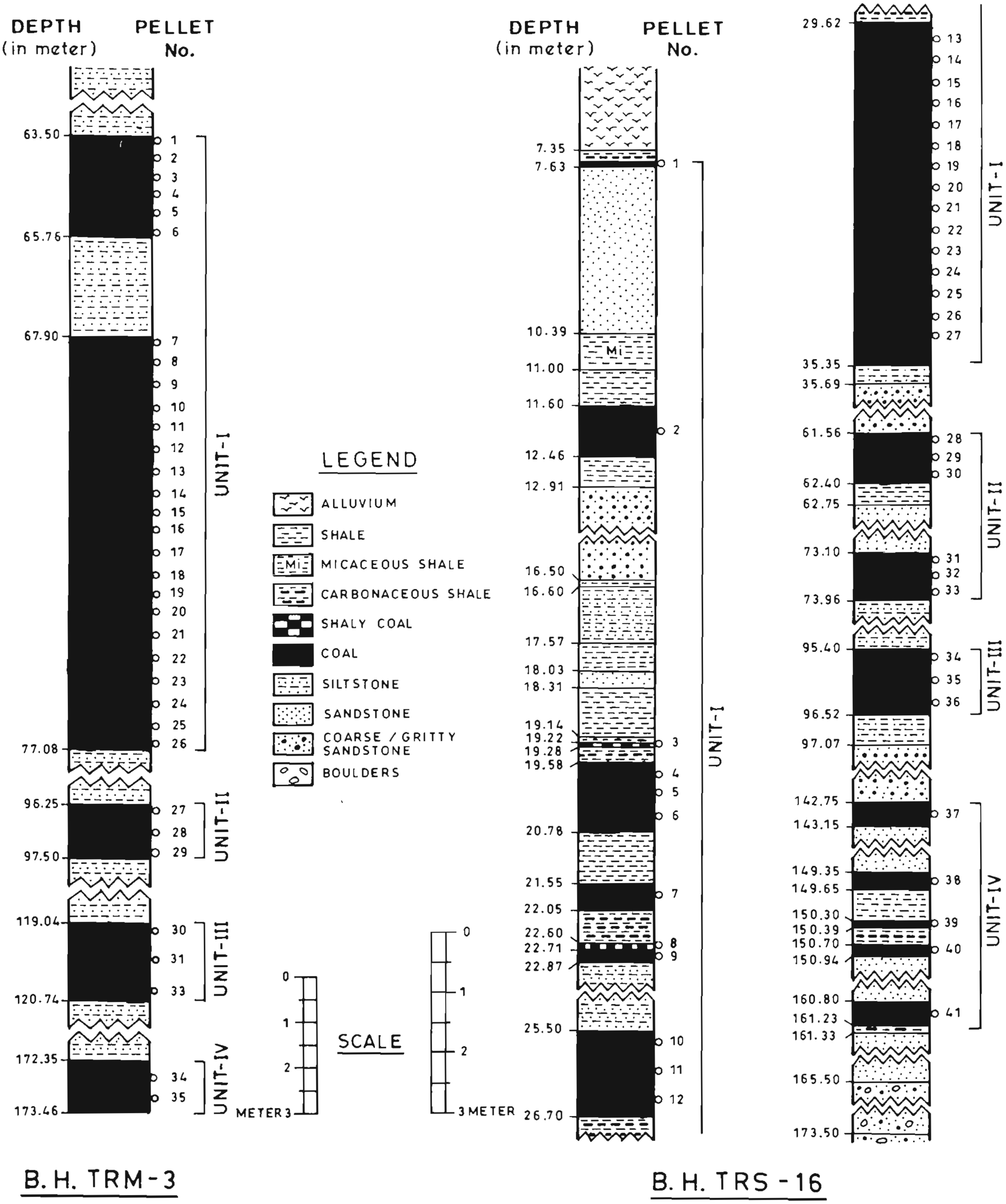
Fig. 1—Map showing the location of Tatapani-Ramkola coalfields in respect to other Gondwana coalfields of India.

AGE	FORMATION	LITHOLOGY
Recent		Alluvium.
Cretaceous?	Basic intrusives	Dolerite dykes.
Upper Triassic	Mahadeva	Thick, cross-bedded, coarse grained ferruginous sandstone.
Lower Triassic	Panchet	Yellowish, fine grained sandstone with alternating red and green siltstones, shales and clays.
Upper Permian	Raniganj	Micaceous fine-grained ripple laminated sandstones, grey and carbonaceous shales and shaly coal bands.
Middle Permian	Barren Measures	Ironstone shales showing box structure, fine grained sandstone, shales and argillaceous sandstone.
Lower Permian	Barakar	Medium to coarse grained pebbly arkosic sandstone, grey and carbonaceous shales and coal seams.
Lower Permian	Talchir	Diamictite, khaki-green needle shales, siltstone fine grained sandstone and varves.
-------------------------------- Unconformity --------------------------------		
Archaean		Granites, gneisses, mica and green schists, phyllites and quartz veins.

Fig. 2—Generalised stratigraphic sequence (after Raja Rao, 1983, modified by the author)

⟶

Fig. 3—Lithologs of Bore-Holes TRS-16 and TRM-3 which has been obtained from the GSI.


DEPTH (in meter)
PELLET No.
63.50
65.76
67.90
77.08
96.25
97.50
119.04
120.74
172.35
173.46
UNIT-I
UNIT-II
UNIT-III
UNIT-IV
LEGEND
ALLUVIUM
SHALE
MICACEOUS SHALE
CARBONACEOUS SHALE
SHALY COAL
COAL
SILTSTONE
SANDSTONE
COARSE / GRITTY SANDSTONE
BOULDERS
SCALE
0
1
2
METER 3
3 METER
Mi
7.35
7.63
10.39
11.00
11.60
12.46
12.91
16.50
16.60
17.57
18.03
18.31
19.14
19.22
19.28
19.58
20.78
21.55
22.05
22.60
22.71
22.87
25.50
26.70
29.62
35.35
35.69
61.56
62.40
62.75
73.10
73.96
95.40
96.52
97.07
142.75
143.15
149.35
149.65
150.30
150.39
150.70
150.94
160.80
161.23
161.33
165.50
173.50
B. H. TRM-3
B. H. TRS-16

	No. of spls		Vitrinite	Liptinite (Normal mode)	Liptinite (Fluoresc. Mode)	Inertinite	Min. matter
B.H.TRS-16							
UNIT-I	27	MEAN (%)	14	10	30	27	49
		RANGE (%)	0-52	1-28	12-49	9-48	19-78
UNIT-II	6	MEAN (%)	29	18	34	28	25
		RANGE (%)	12-50	3-34	1-53	15-46	12-41
UNIT-III	3	MEAN (%)	38	21	25	23	18
		RANGE (%)	19-56	16-26	16-32	18-31	10-24
UNIT-IV	5	MEAN (%)	31	15	22	29	25
		RANGE (%)	3-50	1-38	4-51	11-70	16-36
Total	*41*						
B.H.TRM-3							
UNIT-I	26	MEAN (%)	24	13	23	28	35
		RANGE (%)	0-63	3-34	8-46	10-53	21-67
UNIT-II	3	MEAN (%)	29	18	34	28	25
		RANGE (%)	12-50	3-34	14-53	15-46	12-41
UNIT-III	2	MEAN (%)	38	21	25	23	18
		RANGE (%)	19-56	16-26	16-32	18-31	10-24
UNIT-IV	2	MEAN (%)	31	15	22	29	25
		RANGE (%)	3-50	1-38	4-51	11-70	16-36
Total	*34*						
Grand Total	*75*						

Fig. 4—Distribution of macerals in the units.

of coal bands varies between 16 cm to 9 m and the estimated reserve of coal is 1027·76 million tones.

Bose *et al.* (1975), Srivastava and Kar (1997) and Srivastava *et al.* (1997) were the earlier workers who worked on the palaeobotanical and palynological aspects of Tatapani and Ramkola coals. Detailed petrological studies of coals from Tatapani-Ramkola coals have been undertaken for the first time by the author and the results are incorporated in this paper. The present investigation aims to throw light on the characterisation of organic source material based on the papers by Spackman *et al.* (1976), Teichmuller (1974, 1987, 1989), Teichmuller and Teichmuller (1981) and Teichmuller and Wolf (1977) who were the pioneer workers who named and characterised the source material of coal through fluorescence microscopy. In India the detailed fluorescing macerals studies have been done from Singrauli Coalfield (Misra & Singh, 1990, 1993), Rajmahal Basin (Singh & Singh, 1996) and Tertiary coals (Misra, 1992).

The formation of coal starts with the diagenesis of plant polymers (macromolecules) and ends with the formation of macerals. Certain plant polymers maintain themselves throughout the process of diagenesis, while others get degraded and form geopolymers like humic acid, fulvic acid, etc. (Casagrande, 1987). The plant polymers that maintain

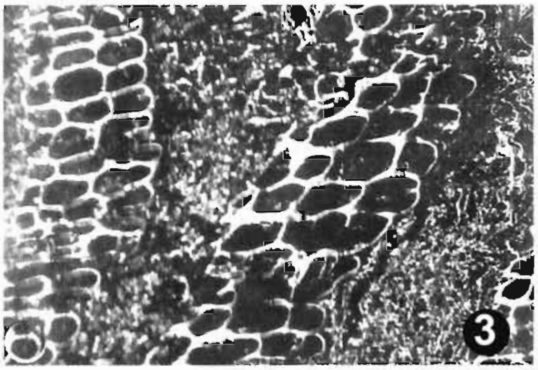
PLATE 1 ⟶

(All the photomicrographs are in normal reflected white light)

1. Telinite with higher reflecting cell walls and spaces partially filled with mineral matter (x 150).
2. Telinite showing cell lumen infilled with gelocollinite (x 150).
3. A large grain of fusinite showing annual growth rings, small celled late wood and large celled early wood (Pl. x 150).
4. Secrinite (x 200).
5. Showing cell lumen transform into spheroidal and elliptical bodies (corpocollinite) in formative stages present between layers of cutinite in desmocollinitic groundmass (x 150).
6. Funginite (x 150).
7. A transitional stage between corpocollinite and macrinite showing oxidation rims (x 150).
8. Secrenite (x 100).

1

2



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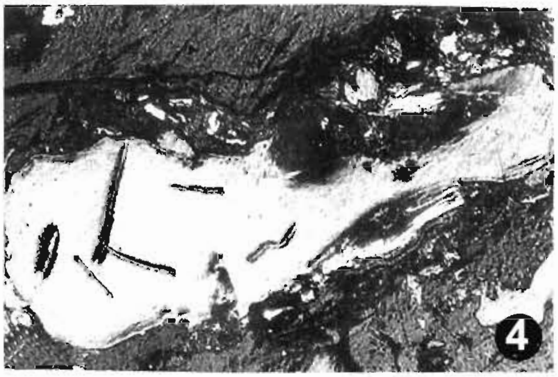

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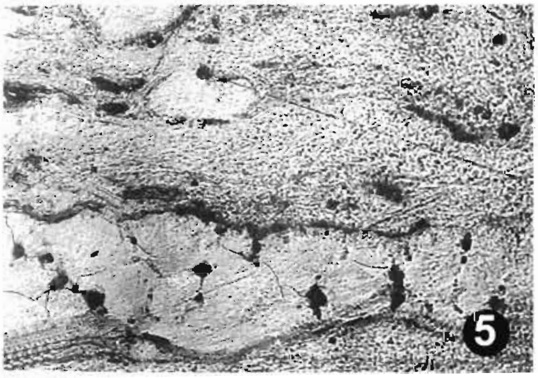

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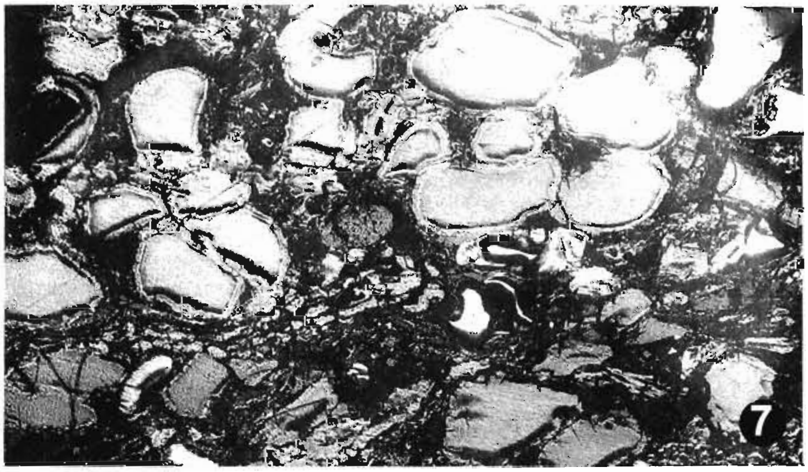

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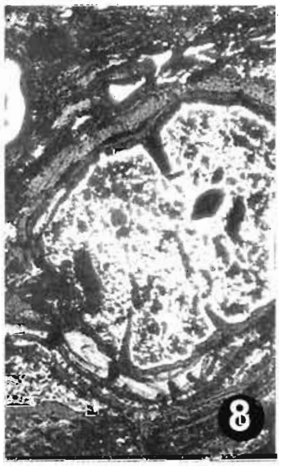

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PLATE 1

themselves are manifested as structured liptinite macerals, e.g., cutinite, sporinite, suberinite, alginite and resinite. Those that could not maintain their original form either undergo the process of humification if oxygen is not available or inertinization in the presence of oxygen. The resultant macerals belong to vitrinite or inertinite maceral group, respectively. In addition well preserved cuticles, spores, cork cells, algae, resins and some unidentifiable fruiting bodies have also been reported in the present communication. These well preserved plant bodies indicate the palaeodepositional conditions.

MATERIAL AND METHODS

Seventy five samples of coal and carbonaceous shale from two bore-holes TRS-16 and TRM-3 courtesy GSI have been utilized in the present study. Their litholog appear in Fig. 3. Each sample represents 0·50 m of the bore-core section. A term "Unit" has been given to coal bands separated by inorganic partings of greater than 19 m thickness. Each Unit has one or more major coal bands or one or more minor coal bands or both. The 19 m thickness has been taken as the basis for the separation of Units, as it is the minimum width of the parting present in the bore-holes. These Units represent a particular depositional environment in which the sediments were laid down and were identified in the boreholes, named as Unit I, Unit II, Unit III and Unit IV starting from the top (Fig. 3). However, the number of workable coal seams is only three (Raja Rao, 1983). Therefore, seams form a part of the Unit.

The samples were crushed to ±2·0 mm size, mounted in epoxy resin, ground and polished, according to standard procedures (ICCP, 1971, 1975). The maceral and microlithotype studies were done under normal mode on Leitz Orthoplan Microscope fitted with automatic photographic unit (vario orthomat). Up to 500 counts per sample were taken using automatic point counter (James swift model F) for quantitative assessment of fluorescing and non-fluorescing macerals.

The material from which most of the plant entities have been recovered is collected from a 1·25 m thick coal band at 96.25 m depth in Bore-Hole TRM-3 of Tatapani Coalfield and from certain bore-core samples of Ramkola Coalfield (Fig. 3). The study has been carried out on circular (diameter= 3 cm) coal pellets in fluorescence mode under reflected light.

BOTANICAL ENTITIES IN COAL

On the basis of characteristic morphological features observed during petrological study of coal, the source material has been classified and described under the following subheadings:

1. Dominantly wood derived
2. Dominantly foliage derived
3. Dominantly reproductive entities

Dominantly wood derived

Most of the macerals belonging to vitrinite and inertinite groups are derived from gymnospermous wood except phyllovitrinite. However, suberinite of liptinite maceral group derived from cork cells of bark tissues also belong to this category.

Vitrinite Group

Vitrinite maceral group is represented by telinite, telocollinite, desmocollinite, corpocollinite, vitrodetrinite and gelocollinite macerals. Telinite (Pl. 1·1, 2) and corpocollinite (Pl. 1·5, 7) are the only macerals in which the shape of the plant cell remains preserved. The other macerals of the vitrinite group acquire a more or less homogeneous nature through the processes of compaction, dehydration and gelification.

Telinite is characterised by the presence of incipient cell structure. Telinite occurs in two forms. Commonly the cell walls are more highly reflecting than the cell lumen (Pl. 1·1) and rarely the cell walls are gellified (Pl. 1·2).

Desmocollinite forms the groundmass for most of the bimaceral and trimaceral microlithotype. Due to the large quantity of liptinite macerals associated with desmocollinite often they are found to be fluorescing (Pl. 1·5).

Corpocollinite is often represented as infilled material of cell lumen or secretion of certain cells especially in bark tissue. Corpocollinite occurs as isolated bodies or in cluster. Their origin from cell lumen is quite clearly shown in Pl. 1·5. The upper and lower cuticle of phyllovitrinite (vitrinite formed from leaf tissue) is shown to be absolutely intact (Pl. 1·5). On severe oxidation the reflectance of corpocollinite increases to the level

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PLATE 2 ⟶

(All the photomicrographs are in fluorescence mode)

1. A transverse section of leaf showing bright orange-yellow ventral cuticular layer, the yellow upper palisade and spongy parenchyma and feebly fluorescing vascular strand.
2. Yellow resins in fluorescence mode.
3 The transverse section of a complete leaf with dorsal and ventral layers of cuticle and intact cuticular ledges. The ground tissue is of desmocollinite.
4. Resin nodule with sporinite fluorescing bright yellow under fluorescence mode.
5 Suberinite showing rectangular and polygonal cork cells under fluorescence mode. Exsudatinite intruded in a desiccation crack of vitrinite.
6, 7. Alginite-algal colonies of *Botryococcus braunii* showing cups covered by a mucilaginous sheath.
8. A mosaic of smooth walled macrosporinite. Mineral matter and liptodetrinite has replaced the inner body.
9. Unidentified fruiting body.
10. Mosaic of a macrosporinite measuring 1.982 mm.

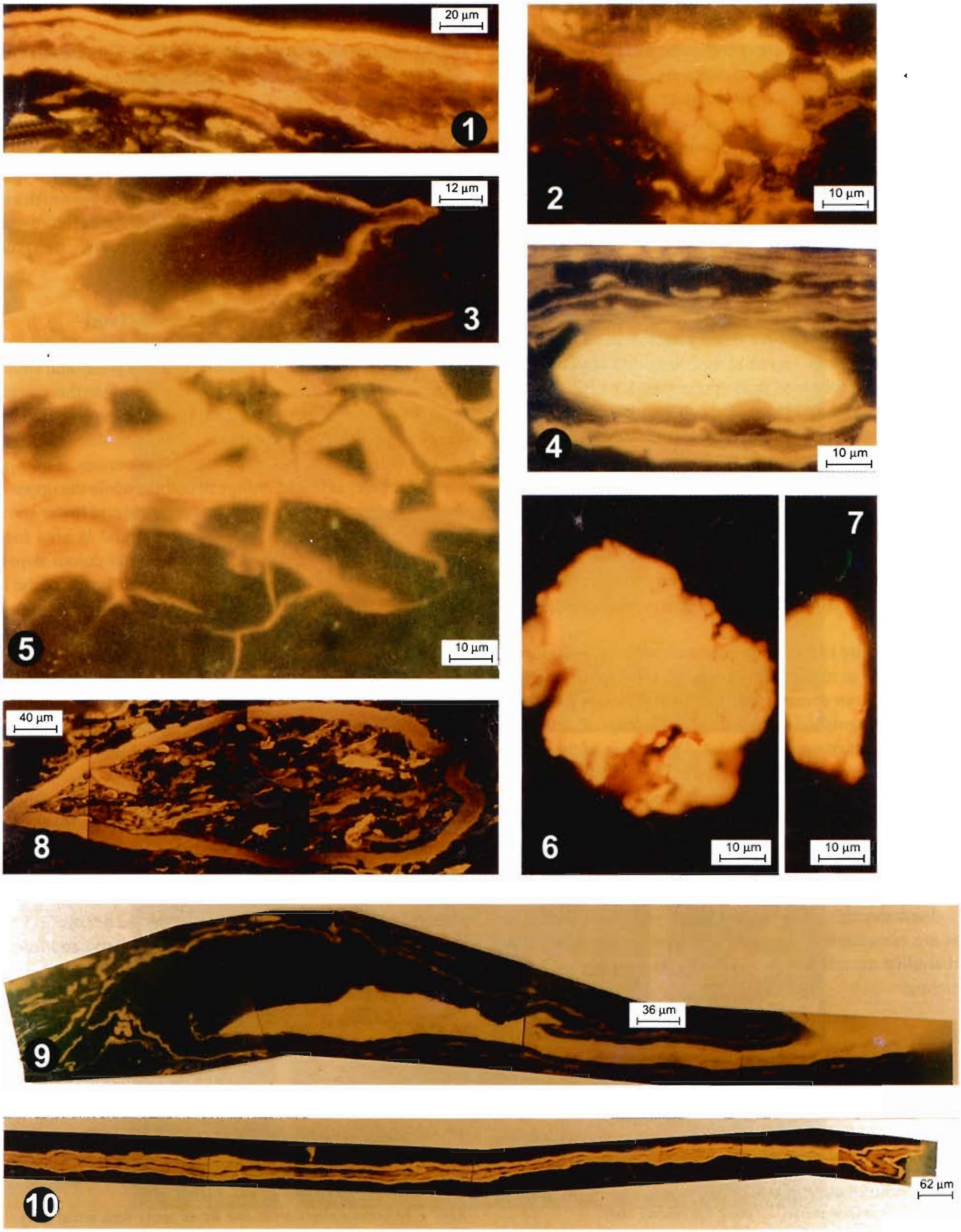

1
20 µm
2
10 µm
3
12 µm
4
10 µm
5
10 µm
6
10 µm
7
10 µm
8
40 µm
9
36 µm
10
62 µm

PLATE 2

of semifusinite and fusinite, sometimes also acquiring similarity to macrinite. Oxidation rims have been developed due to severe oxidation in some of the corpocollinites (Pl. 1·7).

Vitrodetrinite and gelocollinite are not very common in Tatapani-Ramkola coals.·Vitrodetrinite mostly occurs in dull coals in association with durite and carbargillite. Gelocollinite occurs as infillings in cell cavities in association with telinite (Pl. 1.2).

Inertinite Group

Inertinite maceral group comprises fusinite, semifusinite, inertodetrinite, sclerotinite and macrinite (ICCP, 1971, 1975). However, the International Committee for Coal & Organic Petrology (ICCP) replaced the term sclerotinite by the newly recognised macerals secrenite and funginite (Lyons, 2000) which has been followed in the present text.

Fusinite and semifusinite both can be conspicuously recognised on the basis of their higher reflectance and distinct cell structures, the only difference lies in their comparative reflectance. Fusinite is more highly reflecting than semifusinite.

Sclerotinite is the only plant specific maceral of the inertinite group. Sclerotinite has been classified into two categories (Lyons, 2000).

1. Funginite includes macerals with plant structure and is of fungal origin. It encloses fungal spores and mycelium (Pl. 1·6).

2. Secrenite is related to macerals without having plant structures such as macrinite (top right Pl. 1·7). Unlike funginite, it originates from secretory ducts of medullosan seed ferns. They are distinguished by notch and kerfs (curved structures) and resin rodlets or needles (Pl. 1·4, 8). The size of the needle-like bodies in cross section can be used to identify the genera and species of the cycads of Late Palaeozoic and Mesozoic Eras (Lyons, 2000).

In Tatapani-Ramkola Coalfield the percentage of funginite and secrenite is 3%. Pareek recorded them in various Gondwana coals (Pareek, 1966, 1970).

Inertodetrinite represents detrital particles of inertinite that are commonly associated with durite, trimacerite and carbargillite microlithotypes. They may or may not show plant structure.

Liptinite Group

Liptinite group comprises suberinite, cutinite, sporinite, alginite, fluorinite and leptodetrinite of which only suberinite is wood derived.

Cork cells give rise to maceral suberinite. The term is derived from latin word 'suber' meaning cork. In polished sections, it appears as rectangular, brick-like and polygonal four to six sided cellular bodies. Suberinite is brownish black in reflected white light and yellowish orange in fluorescence mode (Pl. 2·5). In Tatapani-Ramkola coals, the overall occurrence of suberinite is rare.

Dominantly foliage derived

Phyllovitrinite of the vitrinite maceral group and cutinite, fluorinite of the liptinite maceral group belong to this category.

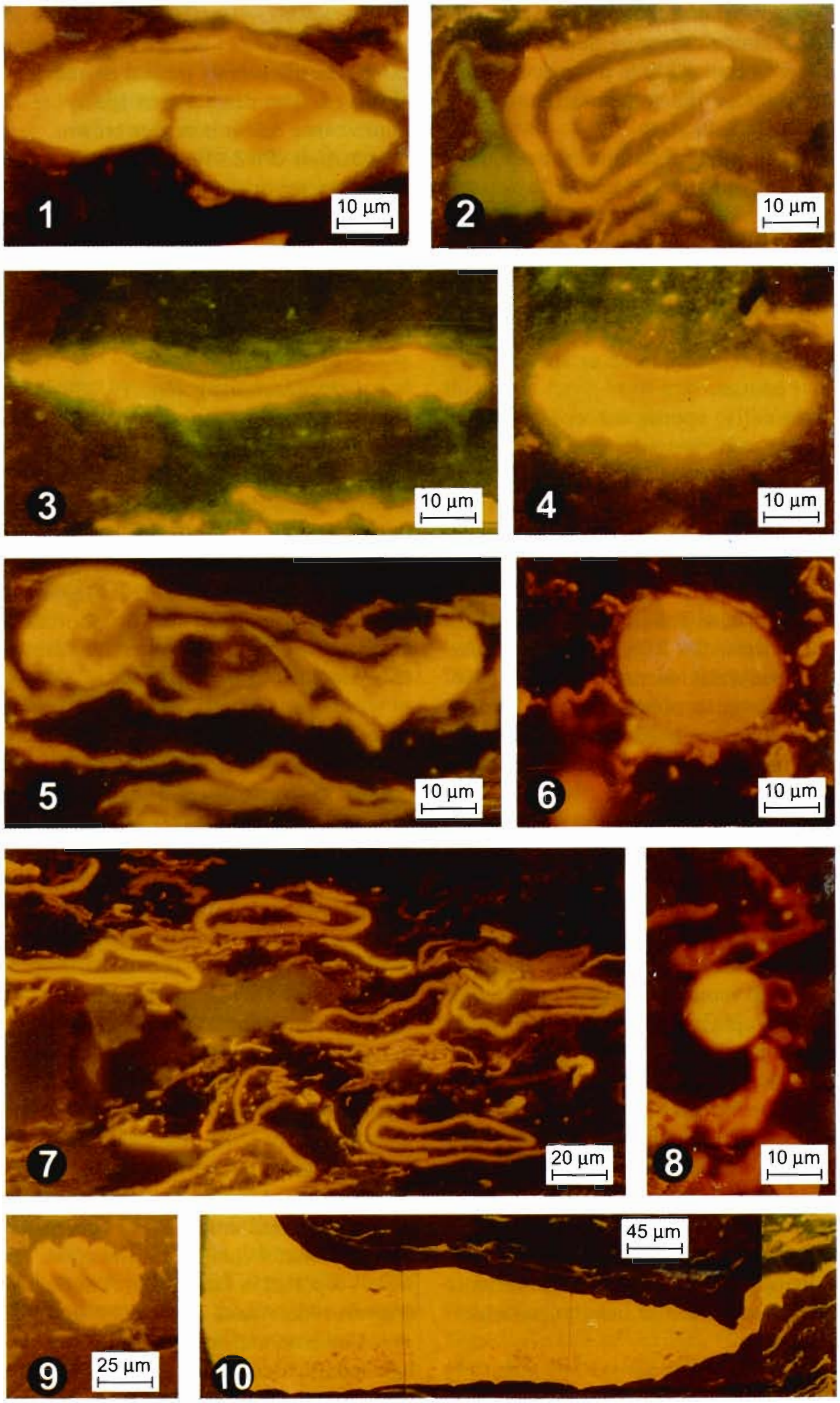
Very well preserved leaf section is being reported from Lower Gondwana coals of India. It has been observed that the whole leaf section has fluorescing properties. The upper cuticular layer is bright orange in colour, while the upper and lower epidermis along with upper palisade and lower spongy parenchyma is yellow. The vascular strand is also feebly fluorescing. The fluorescence intensity and colour depends upon the chemical composition of different layers of the leaf section (Pl. 2·1). Since the cuticle is present only on the upper epidermis, the leaf section seems to be a portion of a hydrophytic plant, a plant that grows in water and marshy or swampy habitats. The presence of cuticle only on the upper epidermis prevents excessive transpiration. The surface in contact with water lacks cuticle so that the cells are capable of absorbing water and nutrients throughout their surface directly rather than by roots alone.

The cuticles separated from leaves form a common feature in certain coal bands of Tatapani and Ramkola Coalfields. They are either thin walled tenuicutinite (Pl. 2·3) or thick walled crassicutinite. The "cutine" of cuticles is similar to "sporine" of spores in chemical composition but are less resistant than "sporine" and more resistant than "suberine". These substances are not accepted as food by bacteria and fungi as they are glycerine esters of fatty acids (Teichmuller, 1982). Cutinite is free from cellulose, the secretion of cutine occurs between the cells of the epidermis which forms the characteristic cuticular ledges (Pl. 2·3).

PLATE 3

⟶

1 Microsporinite showing a bisaccate pollen with saccii attached to the central body.
2. Microsporinite - appears to be a zonate trilete spore.
3. Microsporinite - appears to be a monosaccate pollen showing bright yellow saccus covering the central body.
4. Microsporinite showing a monosaccate pollen with folded saccus.
5. Microsporinite showing a bisaccate pollen with saccii attached to the central body.
6. Microsporinite - appears to be a rounded alete spore.
7. An assemblage of microsporinites.
8. Microsporinite - a circular trilete spore with tetrad mark.
9. Microsporinite - a spore with dull brownish orange fluorescence and slit like mark.
10. Mosaic of a portion of a seed.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25 µm
10
45 µm

PLATE 3

Fluorinite has unusually strong yellow to greenish yellow fluorescence in low rank coals (Teichmüller, 1974). Fluorinite shows striking optical properties and a strong affinity to clarite. It typically occurs in association with cutinite. Schneider traced the genesis of fluorinite way back in 1986 through cuticular analysis of leaves of Myricaceae having aromatic essential oils (*in* Spackman & Thompson, 1964).

In Tatapani-Ramkola Coalfield, fluorinite has been found associated with both corpocollinite and cutinite. Taylor and Teichmuller (1993) have already reported similar associations in German coals.

Dominantly reproductive entities

Spores, sporangia and seeds counted as sporinite are dominantly reproductive entities.

Sporinite—Chemically, spores are composed of sporopollenin, which is an oxidative polymer of carotenoid esters present in the exine. Due to the higher degree of cross-linking, it is the most resistant of all liptinite macerals. Since spores and pollen exines are usually compacted in coal, they appear as small flattened lenses (Pl. 3·7).

Maceral sporinite comprises two submacerals namely microsporinite and macrosporinite. The size of microsporinite varies between 10 to 200 microns (Pl. 3·7). The spores greater than 200 microns are grouped under macrosporinite (Pl. 2·10).

Microsporinite—On the basis of palynological studies, a number of classification schemes have been proposed, but petrologically spores cannot be identified with precision as they get cut along various planes during grinding and polishing of pellets. But features like exine, intine, trilete marks, saccii and folds can be broadly distinguished if the preservation is very good and types could be demarcated on the basis of their morphological characters but genus and species could not be identified on the basis of petrology as could be seen in the present investigation.

Spores are single celled reproductive entities of lower plant groups like fungi, bryophyta and pteridophyta, while pollens belong to higher plant group like gymnosperms. Miospore is a term used when distinction between spore and pollen cannot be made. In normal incident light these miospores look like black or brownish black thread like structures, while in fluorescence mode a variation of colour in sporinite has been observed which is from bright yellow to orangish brown (Pl. 3.7).

Three types of spores have been recorded on the basis of their shape and nature of trilete mark from the lowermost coal band of B.H. TRM-3 from Tatapani-Ramkola Coalfield.

1. Circular trilete
2. Zonate trilete
3. Alete

1. *Circular Trilete* (Pl. 3·8) is a small spore having a diameter of 15 microns with trilete mark at the centre and a non-ornamented thin exine, the fluorescence colour being yellow.

2. *Zonate Trilete* (Pl. 3·2) is represented by a transverse section of the spore having a zone and a thin non-ornamented exine. The trilete mark present on one side of the exine can be observed. The diameter of the spore is 50 microns and fluorescence colour is orange brown.

3. *Alete* (Pl. 3·4) spore is characterised by a linear fold. The diameter of the spore is 27 microns and fluorescence colour is brownish-orange.

Two types of pollen grains, on the basis of their morphological characters have been recorded from the third seam of B.H. TRM-3.

1. Monosaccate
2. Bisaccate

1. *Monosaccate pollen* (Pl. 3·3, 4) is characterised by a saccus attached to the central body, which usually appears brown under fluorescence mode. The diameter of the central body is 47 microns. Saccus covers the whole central body and the maximum diameter of the pollen is 79 microns. The fluorescence colour of the central body is brown and that of saccus is bright yellow.

2. *Bisaccate pollen* (Pl. 3·1, 5) has a central body to which two saccii are attached. The photomicrographs show a transverse section of the pollen. The diameter varies between 65 microns to 75 microns.

Macrosporinite—Megaspores (macrospores) included under this category are single celled reproductive bodies of heterosporous pteridophytes. They are not as frequently occurring as microspores. The size range of megaspores varies from 200 microns to 3000 microns or more (Pl. 2·8, 10). The Lower Gondwana megaspores are mostly smaller than 1000 microns (Bharadwaj & Tiwari, 1970). One rare large sized megaspore is being reported here (Pl. 2·10). It is a very well preserved megaspore measuring 1982.00 microns. It has been recorded from B.H. TRS-16 from Ramkola sub-basin. Like most of the megaspores reported from Lower Gondwana sediments this megaspore also has an inner body appearing light brown in fluorescence mode. The exine is fluorescing bright yellow and appears to be without ornamentation. It has a bifurcated trilete mark of dark brown colour. The mark has many thick projections called trilete laesurae noted in Upper Permian coals (Maheshwari & Bajpai, 1984). The inner body and the exine are not clearly distinguishable. The trilete mark appears like a thin brown thread structure. The occurrence of macrosporinite is significant for coal seam correlation. They have been very widely reported in various forms in Gondwana coals of India (Pareek, 1965; Anand-Prakash, 1970)

Under normal reflected light, macrosporinites appear as light reddish brown to dark grey coloured bodies with granular texture. Whereas, under fluorescence mode they show variation of colours. The colour varies from grey exine and bright yellow intine to bright yellow exine and light brown intine. Very well preserved megaspores with sculptured exine have also been observed. Sometimes detrital mineral matter and liptodetrinite replaces the central body of the megaspore (Pl. 2.8)

Algae

Algal remains are represented by the maceral alginite in coals. This term is derived from Latin word "alga" meaning sea grass. It is similar to clay particles and appears as black globular mass, which is darker than the sporinite in normal reflected light and has a positive relief (ICCP, 1971, 1975).

Alginite can be identified on the basis of strong bright yellow fluorescence, showing positive alteration when excited by short wave radiation. The colonies of algal bodies appear as cups, which are connected by a mucilaginous covering and can be observed under different foci. Although many types of alginite, like *Pila* type, *Reinchia* type, *Caldiscothallus* type have been observed in Lower Gondwana coals, the *Botryococcus braunii* is the most common variety that also occurs in Tatapani-Ramkola coals (Pl. 2·6, 7). The size of the colonies varies widely.

Gymnospermous seed

A portion of the gymnospermous seed has been observed from the third coal seam of B.H. TRM-3 (Pl. 3·10). Such seeds have also been reported from Talchir and Rajmahal coalfields (Anand-Prakash *et al.*, 1996). It is a seed or mature ovule cut in longitudinal section showing a micropylar projection and serrated margin of the stony seed coat. It measures 0·194 x 0·575 mm.

Unidentified fruiting bodies

The structure has an oval body with a stalk- like projection at the base (Pl. 2·9). A similar structure has also been observed from Godavari Coalfield (pers. commun. Dr Sarate), but the difference lies in the size. The one reported from Godavari Coalfield is much bigger in size as compared to the present structure. It might be a germinating seed with a radicle or a sporophyll (mega or micro) detached from the cone showing the stalk and a thorn like projection at the base.

Resin

Maceral resinite can be incorporated in any of the above three categories because it occurs either as resin ducts or secretory cells, in sclereids, in leaves, stems, seeds, rinds of fruits or in dispersed form as lumps (Pl. 2·2), nodules (Pl. 2·4) and rodlets. Resins in coal occur as rounded or subrounded fluorescing bodies of pale yellow to orangish yellow colour which appear reddish brown to blackish or greyish under normal reflected light. However, it is for the first time a bright yellow resin nodule has been observed and reported in Indian Lower Gondwana coals (Pl. 2·4).

DISCUSSION

Tatapani-Ramkola coals like most of the Lower Gondwana coals of India are of low rank and grade that are characterised by the dominance of dull bands with occasional bright bands of variable thickness. These dull coals are dominantly composed of the macerals of fusinite and liptinite and subordinate proportions of vitrinite associated with the variable amount of inorganic mineral matter (Fig. 4). This variation in the coal bands reflects upon the nature of source material and depositional conditions. The dull coals rich in inertinite group of macerals generally pass through the process of fusinization, whereas the vitrinite fraction passes through the process of gelification.

However, occasionally the vitrain bands of variable thickness have been encountered in the bore-holes. The petrological investigations of the coals have revealed that some of the bands contain very high amount of liptinite macerals, particularly well preserved microspores, megaspores, leaf sections, cork cells, algal and resin bodies and other liptinite macerals. Such a characteristic dominance of liptinite macerals in a particular coal band raises a question that under what type of depositional conditions so much of liptinitic material has been accumulated? Further, the preservation of liptinitic macerals is of very high quality. Probably, this has been possible either by the plant matter deposited under autochthonous or hypoautochthonous conditions as suggested by Anand-Prakash *et al.* (1996) for Singrauli and Talchir coalfields or due to the quick burial and compaction of the accumulated fossil peat.

If at all the vegetal matter has been transported it was brought to the basin from very short distances. This appears to be the reason for the exceptionally good preservation of fragile and large sized megaspores, algal remains and leaf sections. Here it has also been suggested that the coal bands rich in cuticles and leaf sections seem to have been contributed by the accumulation of leaves in small shallow niches usually present in the flood plains of a fluvial system. Other evidences in support of the short distance transportation of source material, besides non-damaged leaves and megaspores, is the presence of larger grains of fusinite (Pl. 1·1) and of semifusinite (Beeston, 1987, 1991).

The intact plant entities in high frequency indicate that the wetland at that particular span of time had easy access to high spore yielding herbaceous plants, like sedges and reeds and undergrowths mainly comprising lower plant groups such as bryophytes and pteridophytes. It is also suggested that the particular band of coal rich in megaspores might have been developed at the edge of the wetland where a mixed type of vegetation existed comprising both herbaceous and woody plants.

SUMMARY AND CONCLUSION

In the present investigation macerals have been categorised on the basis of source material into three divisions namely (i) dominantly wood derived; (ii) dominantly foliage derived and (iii) dominantly reproductive entities.

The wood derived macerals are dominantly vitrinitic and inertinitic of which phyllovitrinite, corpocollinite, secrenite and funginite are the only ones that could be traced to a specific plant part. Dominantly reproductive entities mainly comprise spores and pollen that can be broadly distinguished into different types on the basis of morphological character if the preservation is very good. It has also been observed that in Lower Gondwana coals of Tatapani and Ramkola coalfields such well preserved plant parts are confined to specific coal band, emphasizing a unique palaeodepositional condition, related to depth of water in the peat swamp which affected the type of vegetation and also mode of preservation of the petrographic entities.

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Palynodating of subsurface coal measures from Mahadoli area, Wardha Valley Coalfield, Maharashtra, India

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ABSTRACT

Bhattacharyya AP & Sarate OS 2002. Palynodating of subsurface coal measures from Mahadoli area, Wardha Valley Coalfield, Maharashtra, India. Palaeobotanist 51 : 93-98.

Two palynoassemblages have been recorded from the Permian Sequence of Mahadoli area (Borehole WM-14), Wardha Valley Coalfield, Maharashtra. The older palynoassemblage A is *Scheuringipollenites* dominant while the younger palynoassemblage B is characterized by *Parasaccites-Densipollenites* along with striate bisaccates, *Falcisporites* and *Satsangisaccites*. Correlation with palynoassemblages of other coaliferous basins of India and the age of subsurface sediments have been discussed.

Key-words—Palynoassemblage, Barakar, Permian, Wardha Valley Coalfield, India..

भारत के महाराष्ट्र प्रान्त के वर्धा कोयला क्षेत्र के महाडोली में अवस्थित कोयला क्षेत्र से प्राप्त उपपृष्ठीय कोयला संस्तर का परागाणविक आयु निर्धारण

अनन्त प्रसाद भट्टाचार्य एवं ओम प्रकाश शिवदास सराटे

सारांश

महाराष्ट्र के महाडोली क्षेत्र अवस्थित वर्धा घाटी कोयला क्षेत्र (वेध छिद्र डब्ल्यू.एम.-14) के परमियन अनुक्रम से दो परागाणु समुच्चय अंकित किए गए। अपेक्षाकृत प्राचीन परागाणु समुच्चय ए में *श्यूरिंगीपोलेनाइटीज़* की प्रमुखता है, जबकि अपेक्षाकृत नवीन परागाणु समुच्चय बी में स्तरी द्विसकोषियों, *फाल्सिस्पोराइटीज़* तथा *सत्संगीसैक्काइटीज़* के साथ-साथ *पैरासैक्काइटीज़-डेन्सीपोलेनाइटीज़* की प्रचुरता है। भारत की अन्य कोयला धारी द्रोणियों के परागाणु समुच्चयों के साथ इसके सहसम्बन्धन तथा उपपृष्ठीय अवसादों की आयु के विषय में विस्तृत चर्चा की गयी है।

संकेत शब्द—परागाणु समुच्चय, बराकर, परमियन, वर्धा घाटी कोयला क्षेत्र, भारत।

INTRODUCTION

THE Wardha Valley Coalfield has recently emerged as one of the main resource for coal exploration through Open Cast Mining. The main coal centers are localized in Chandrapur and Yeotmal Districts of Maharashtra. The Directorate of Geology and Mining, Government of Maharashtra is presently engaged in coal exploration in Mahadoli area, (longitudes 78°54'15" and 20°21'45" latitudes) for the possibilities of coal reserves in the virgin tracts of the Coalfield through subsurface study. General stratigraphic succession of Wardha Valley Coalfield, Maharashtra is given below [after Raja Rao, 1982 (fig. 1)]

Age	Group/Formation	Lithology
Recent	---------------	Alluvial gravel beds, black cotton soil
? Eocene	Deccan Trap	Basalt
Cretaceous	Lameta Formation	Limestones, cherts and silicified sandstones
		----------Unconformity--------
Upper Triassic	Maleri Formation (only in the south-eastern extremity)	Fine to medium-grained sandstones and red shales
Upper Permian-Lower Triassic	Kamthi Formation	Red, brown and variegated sandstones, reddish siltstones and variegated shales
		---------Unconformity---------
Lower Permian	Barakar Formation	Light grey to white sandstones. Shales and coal seams
? Upper-Carboniferous-Lower Permian	Talchir Formation	Tillites, turbidites, varves, needle shales and sandstones
		---------Unconformity---------
Precambrian	Sullavi Sandstones	White to light brown quartzitic sandstones, conglomerates
		-------------Overlap-----------
	Pakhal Limestones	Grey, bluish or pinkish limestones and cherts
		----------Unconformity--------
Archaean		Quartzites, granite gneises, etc.

Fig. 1—Generalised stratigraphic succession of Wardha Valley Coalfield.

The borehole passes through Deccan Traps, Lameta, Kamthi and Barakar formations. Grey shale, sandstone, clay and carbonaceous shale characterize the Barakar sediments. The present study has been carried out in order to establish palynological succession and its correlation with other Gondwana Basins of India.

The location of the borehole WM-14 is shown in Fig. 3 and the lithological succession present in the borehole is shown in Fig. 2.

Two palynoassemblages have been recorded from borehole WM - 14. The distribution and frequency of spores and pollen of stratigraphic importance have been plotted (see Fig. 4) to show their relative abundance through the entire depth of the borehole. Some important spores and pollen have been illustrated in Pl. 1.

Palynoassemblage—A

Occurrence—Borehole WM -14 (at 106-118 m depth).

Lithology—Grey shale, Carbonaceous shale, Fine-grained sandstone.

Scheuringipollenites (32%-26%) is dominant in this assemblage (see Fig. 4) followed by *Ibisporites* (10%). The taxa *Rhizomaspora* (8%) and *Primuspollenites* (8%-3%) are frequently met within this assemblage. Monosaccate genera are represented by *Parasaccites* with maximum occurrence of 18 per cent along with *Caheniasaccites*, (11%). Other monosaccates are *Virkkipollenites*, *Crucisaccites* and *Potonieisporites*. Trilete spores are represented only by *Verrucosisporites*. *Tiwariasporis* is present up to 118 m depth. Amongst striate bisaccate pollen, *Striatites* and *Striatopodocarpites* are subdominant forms. *Weylandites* and *Ginkgocycadophytus* are found to be 3% each.

The occurrence of spores and pollen at 125 m is meager, hence the percentage frequency could not be estimated. However, on the basis of taxa present, this level is considered to represent a part of the palynoassemblage A.

Palynoassemblage—B

Occurrence—Borehole WM-14 (at 66·25-76·00 m depth).

Lithology—Micaceous sandstone, Carbonaceous shale.

The palynoassemblage is characterized by the dominant presence of *Parasaccites* (21%) along with striate bisaccate genera *Striatopodocarpites* and *Faunipollenites* (15%, each). *Falcisporites* (5%) and *Satsangisaccites* (6%) have also been recorded, along with other nonstriate genera, such as *Alisporites* (2%) and *Platysaccus* (3%). Other monosaccate genera, viz., *Potonieisporites* (3%) and *Densipollenites* (9%) also record their fair occurrence in this assemblage.

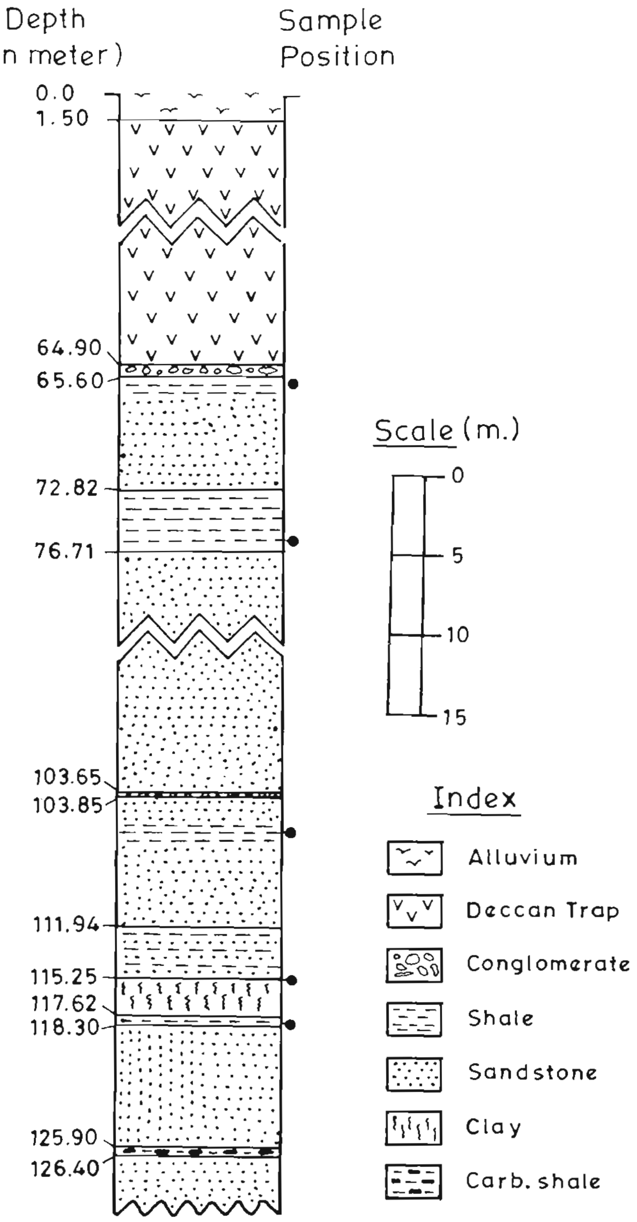

Fig. 2—Showing the levels of yielding samples in the lithological succession

The shale at 76·00 m depth contains lesser frequency of spores and pollen grains but since it contains *D. magnicorpus* (2%), it is preferred to retain it in Palynoassemblage B.

COMPARISON

A *Scheuringipollenites* dominant mioflora has been reported from the lower part of the Barakar Formation in Damodar Basin, Son Mahanadi Basin, Satpura Basin and Godavari Valley coalfields but in the present assemblage it is associated with *Parasaccites* (18%) along with *Caheniasaccites* (11%) and *Primuspollenites*, thus having a close affinity with Lower Barakar mioflora reported from Godavari Valley coalfields by Srivastava and Jha (1989, 1998). *Scheuringipollenites* dominant zone has also been recorded from Pathakhera Coalfield, Satpura Basin, Sarate (1986). Agashe and Chitnis (1972) reported Lower Barakar palynoflora from Hindustan-Lalpet Colliery containing dominance of *Brevitriletes* and *Scheuringipollenites*. Similar palynoflora has been recorded by Agashe and Geetha (1979) from Kamptee Coalfield with dominant *Scheuringipollenites* and striate bisaccate taxa but the present assemblage differs in the presence of monosaccate taxa *Parasaccites* and *Caheniasaccites* in high percentage. The present assemblage is comparable to the palynozone –V of Tiwari and Tripathi (1992).

The Palynoassemblage - B is characterized by the presence of *Striatopodocarpites* and *Faunipollenites* (15% each) along with *Scheuringipollenites* in low percentage. However, *Parasaccites* (21%) and *Densipollenites* (9%), the monosaccate genera are prevalent. The occurrence of *Densipollenites magnicorpus* along with striate bisaccates is well established in Late Permian mioflora of Damodar Basin. However, *Falcisporites* and *Satsangisaccites* suggest younger aspect of the palynoassemblage. The recurrence of *Parasaccites* with striate bisaccate has been reported from Godavari Valley and Supra Barakar Formation in the Son Mahanadi Valley also. The Palynoassemblage – B is closely comparable to Palynozone – 9 of Middle member of Kamthi Formation in Godavari Valley (Srivastava, 1992). Similar palynoassemblages have also been recorded from Jaipuram area (Assemblage in the borehole GJP-1; Srivastava & Jha, 1992), Ramakrishnapuram area (in borehole GJRK- 25), Bhopalpalli area (Palynoassemblage – III, Srivastava & Jha, 1998), Johilla Coalfield, Son Valley (Tiwari & Ram-Awatar 1989), and from Supra Barakar sediments in Son Valley (Assemblage – 5; Tiwari & Ram-Awatar, 1987). The occurrence of

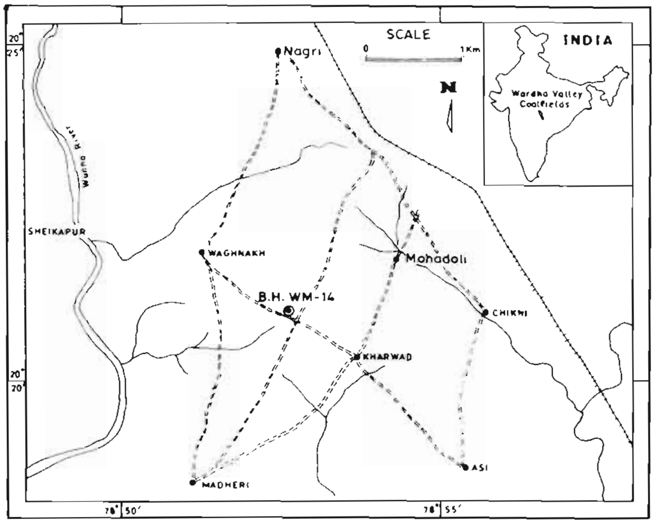

Fig. 3—Showing the location of Borehole WM- 14 (DGM, Nagpur)

Fig. 4—Frequency distribution of important spores and pollen in the Borehole WM – 14, Mahanadi area, Wardha Valley Coalfield, Maharashtra

Parasaccites in high percentage is known from Talchir Formation. Hence, it is possible that Wardha Valley Coalfield experienced a prolonged cooler climate. A cool climate has also been suggested during Upper Permian and Lower Panchet by Tiwari and Tripathi (1988). However, *Callumispora* has not been observed in the present assemblage. A Permo-Triassic plant microfossil assemblage from sediments of glacial origin have also been reported from Sri Lanka (Dahanayaka *et al.*, 1989).

CONCLUSION

In Mahadoli area, two palynoassemblages have been recorded (Palynoassemblage A & B) below the Deccan Traps, which represent Lower Barakar and Lower Panchet palynofloras, respectively. The absence of intervening palynoassemblages of the Upper Permian could be explained envisaging a break in sedimentation after Lower Barakar. The presence of a Boulder Conglomerate bed at 103·65-103·85 m depth substantiates this observation. The presence of Barakar palynoflora is an indication for the occurrence of Lower Gondwana coals in Mahadoli area, Maharashtra.

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PLATE 1

(All magnifications x ca 500, unless otherwise mentioned. All photomicrographs have been taken in DIC).
Coordinates have been stated with respect to England Finder Readings.

1. *Psilalacinites* sp. Slide No. BSIP 12581 (0 43/3).
2. *Anapiculatisporites* sp. Slide No. BSIP 12582 (R 3/1).
3. *Leiotriletes* sp. Slide No. BSIP 12581 (U 24/4).
4. *Scheuringipollenites tentulus* Slide No. BSIP 12581 (P 33/2).
5. *Rhizomaspora indica* Slide No. BSIP 12584 (J 36).
6. *Cuneatisporites majus* Slide No. BSIP 12586 (N 3/32).
7. *Alisporites* sp. Slide No. BSIP 12587 (P 58/3).
8. *Satsangisaccites* sp. Slide No. BSIP 12587 (P 58/3).
9. *Distriatites bilateralis* Slide No. BSIP 12582 (W 41).
10. *Arcuatipollenites* sp. Slide No. BSIP 12584 (J /44).
11. *Illinites disertus* Slide No. BSIP 12583 (J 47/2).
12. *Falcisporites stabilis* Slide No. BSIP 12586 (N /32).
13. *Plicatipollenites indicus* Slide No. BSIP 12583 (K 39/4).
14. *Primuspollenites singrauliensis* Slide No. BSIP 12586 (R /61).
15. *Tiwariasporis flavatus* Slide No. BSIP 12585 (L 53/2).
16. *Brevitriletes unicus* Slide No. BSIP 12583 (U /56).


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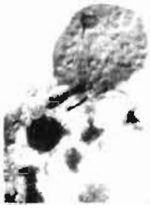
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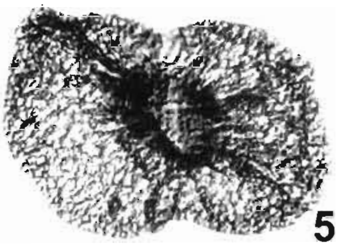
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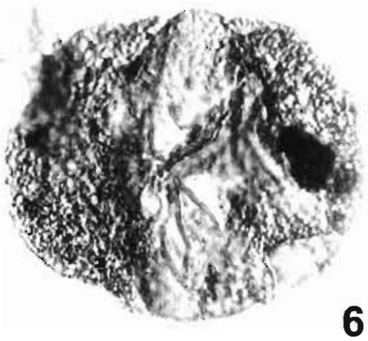
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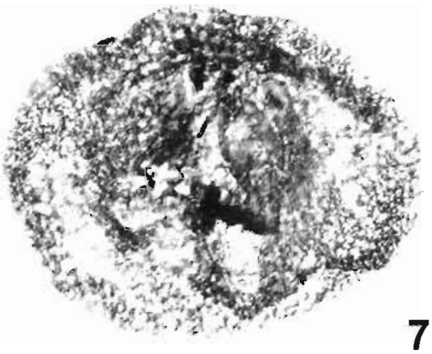
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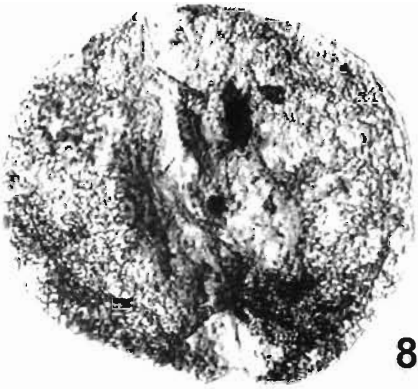
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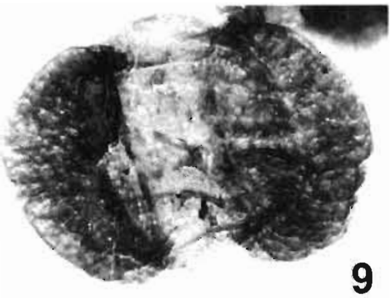
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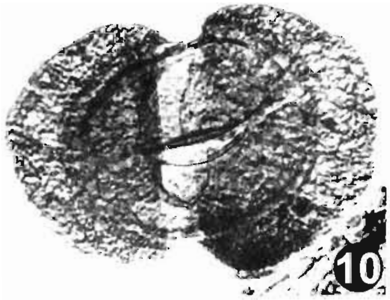
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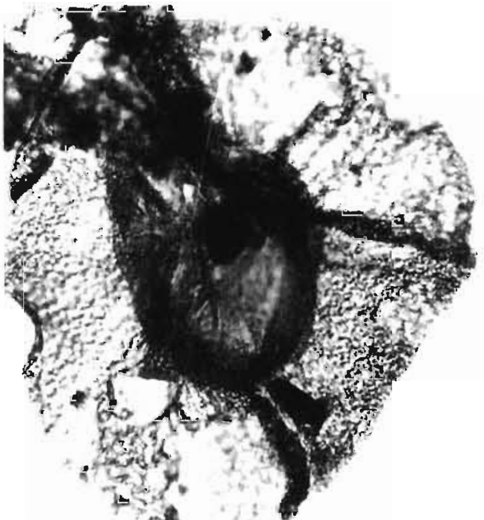
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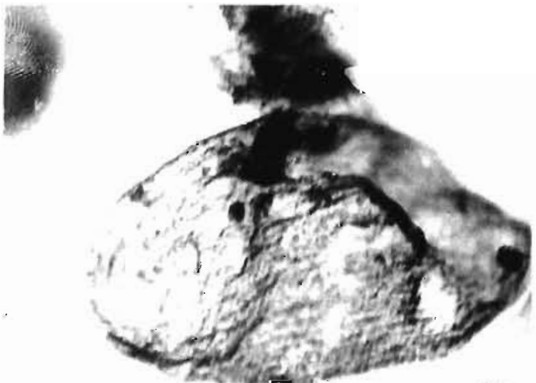
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PLATE 1

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Depositional environment of Bagra Formation (Upper Triassic), Satpura Basin, India : a palynological approach

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ABSTRACT

Kumar P 2002. Depositional environment of Bagra Formation (Upper Triassic), Satpura Basin, India : A palynological approach. Palaeobotanist 51 : 99-106.

Bagra Formation is the youngest lithounit of non-marine Mahadeva Group in Satpura Basin. The recorded palynological assemblage from Bagra Formation contains prominence of fungal and algal remains. Palynomorphs of Denwa Formation such as *Falcisporites, Satsangisaccites, Samaropollenites, Arcuatipollenites, Striatopodocarpites* including *Callialasporites, Cycadopites, Corollina* (=*Classopollis*) *simplex* and *Haradisporites* are also represented in the Bagra Assemblage. The palynological assemblage (as a mixed flora) suggests a lateral continuity of the Denwa Formation with younger Bagra Formation, and the difference could be facies variations. The recovered palynological assemblage suggests a Rhaetian age of Upper Triassic to the Bagra Formation. The palynological associations indicate that Bagra Formation was deposited in lacustrine set up near shore -line under cool-temperate climate with derivation of palynomorphs from heavy rain forest upland areas.

Key-words—Upper Triassic (Rhaetian), Palynomorphs, Depositional environment, Bagra Formation, Satpura Basin, India.

भारत की सतपुड़ा द्रोणी के बागड़ा शैलसमूह (उपरि ट्रायसिक) का निक्षेपणीय पर्यावरण : एक परागाणविक परिप्रेक्ष्य

प्रमोद कुमार

सारांश

बागड़ा शैलसमूह सतपुड़ा द्रोणी के असमुद्री महादेवा समूह की नवीनतम अश्म इकाई है। बागड़ा शैलसमूह से अंकित किए गए परागाणविक समुच्चय में कवकीय एवं शैवालीय अवशेषों की प्रचुरता है। इस समुच्चय में देनवा शैल समूह के परागाणुरूप, जैसे—*फ़ाल्सिस्पोराइटीज़, सत्संगीसैक्काइटीज़, समारोपोलेनाइटीज़, आर्क्युआटीपोलेनाइटीज़, स्ट्रायाटोपोडोकार्पाइटीज़* के साथ-साथ *कैलियालास्पोराइटीज़, साइकेडोपाइटीज़, कोरोलाइना (क्लासोपोलिस) सिम्प्लेक्स* तथा *हरादीस्पोराइटीज़* भी अभिनिर्धारित किए गए हैं। परागाणविक समुच्चय अपेक्षाकृत नवीन बागड़ा शैलसमूह के साथ (एक सम्मिश्र वनस्पतिजात के रूप में) एक पार्श्व सततता प्रस्तावित करता है तथा भिन्नता संलक्षणी वैविध्य के कारण हो सकती है। खोजा गया परागाणविक समुच्चय बागड़ा शैलसमूह हेतु उपरिट्रायसिक कल्प के अन्तर्गत रीटियन आयु प्रस्तावित करता है। परागाणविक समुच्चय संकेत करते हैं कि बागड़ा शैलसमूह प्रचुर वृष्टि वाले उपरिभूमि वन क्षेत्रों से प्राप्त परागाणुरूपों के साथ-शीत-शीतोष्ण जलवायु के अन्तर्गत तटीय रेखा के समीप सरोवरी स्थितियों में निक्षेपित था।

संकेत शब्द—उपरि ट्रायसिक (रीटियन), परागाणुरूप, निक्षेपणीय पर्यावरण, बागड़ा शैलसमूह, सतपुड़ा द्रोणी, भारत.

INTRODUCTION

MEDLICOTT (1873) studied the geology of Mahadeva Group in Satpura Basin, and subdivided it into three lithounits in ascending order: Pachmarhi sandstones, Denwa clays and Bagra conglomerates. Crookshank (1936) also studied the geology of Satpura Basin in detail, and described the Bagra rocks as coarse conglomerates which were deposited along the northern border of the Satpura Basin, and considered them to be contemporaneous with the Denwa beds. Singh and Ghosh (in Sastry *et al.*, 1977) observed the extentions of conglomerate beds further southward, where they become gradually fine grained and ultimately pass into sandstones and clays of the Denwas. Casshyap (1999) stipulated (?) a Late Jurassic age for Bagra Formation based on the paleocurrent studies, i.e., during underlying Denwa Formation shows a reversal of direction of sediments transported from north-northeast to south-southwest during Bagra sedimentation.

Crookshank (1936) recorded two imperfect casts of some gastropod shells from Bagra sediments in a *nala* north of Budhimai, being slitghly younger than the Denwas. It was suggested to be of Late Triassic age and unconformably overlain by the Jabalpur Formation. Raja Rao (1983) considered that Bagra sediments succeeded unconformably Denwa beds and a possible Rhaetic age was suggested. Crookshank (1936), Singh and Ghosh (in Sastry *et al.*, 1977), Krishnan (1982) opined that when followed southwards, the Bagras passes laterally into the Denwas, and considered the formation to be a shoreline deposit of Rhaetic age, partly equivalent to and partly younger than the underlying Denwas.

The palynomorphs and other remains have been recovered from the matrix of Bagra conglomerates (sample-1) exposed in the Jamani *Nala* (Figs 1, 2) near Khatama Caves

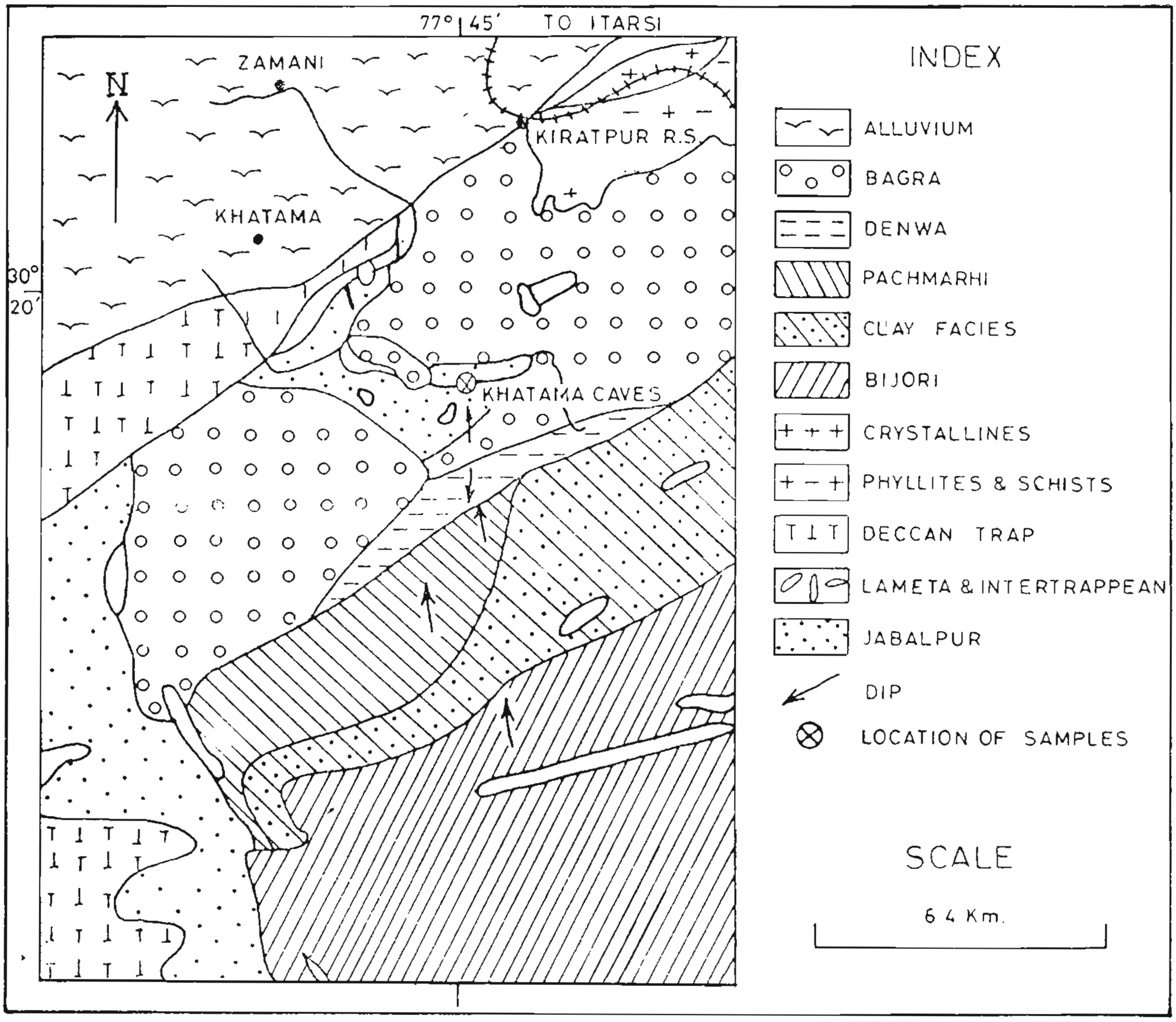

Fig. 1—Geological map of the study area (after Crookshank, 1936).

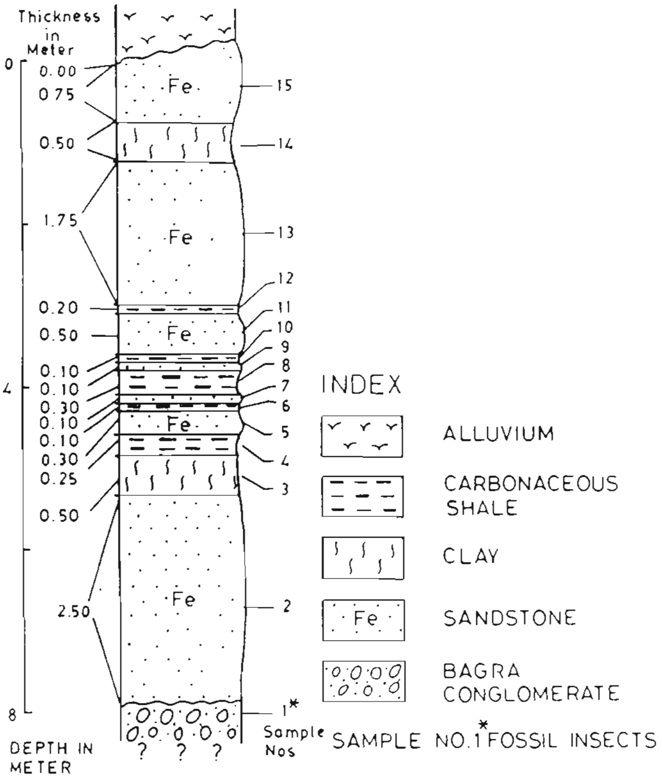

Fig. 2 — Lithostratigraphic succession of the Bagra Formation exposed in Zamani Nala near Khatama caves, Hoshangabad district, M.P., showing stratigraphic positions of studied sample.

(30°10' : 77°45'), Hoshangabad District, Madhya Pradesh. The Bagra conglomerates consist of different kinds of rounded boulders derived from local and distant sources including metamorphic rocks (local), quartzites, banded jaspers, jasperoid conglomerate, etc., loosely cemented by argillaceous matrix (yellowish to reddish sandy clay). The generalised stratigraphic sequence in Satpura Basin as given by Raja Rao (1983) is followed here.

PALYNOLOGY OF BAGRA FORMATION

The palynomorphs (pollen-spores, fungal spores, fungal fruiting bodies, vesicular-arbuscular mycorrhizae (VAM fungi) or algal germinating spores, algal spores, acritarchs, chitinozoa, etc.) have been recovered for the first time from the matrix of the Bagra conglomerates. Kumar and Kumar (1999) recorded mallophagan insect remains from Upper Triassic sediments (Bagra and Denwa Formations) of Satpura Basin. Recently an anopluran insect has also been identified from the same Bagra conglomerates (Kumar & Kumar, 2001).

Palynomorphs

TRILETE SPORES

Haradisporites mineri Singh & Kumar 1972

Biretisporites sp. (Pl. 1.1, size 60 µm)

MONOSUBSACCATE POLLEN

Callialasporites trilobatus (Dev) Bharadwaj & Kumar 1972

MONOSACCATE POLLEN

Scheuringipollenites triassicus (Bharadwaj & Srivastava) Tiwari 1973b

DISACCATE (nontaeniate) POLLEN

Falcisporites nidpurensis (Bharadwaj & Srivastava) Kumaran & Maheshwari 1980

Satsangisaccites triassicus Bharadwaj & Srivastava 1969

Samaropollenites speciosus Goubin 1965

DISACCATE (taeniate) POLLEN

Arcuatipollenites ovatus (Goubin) Tiwari & Vijaya 1995

Guttulapollenites hannonicus Goubin 1965

DISACCATE (striated) POLLEN

Striatopodocarpites dubrajpurensis Tripathi *et al.*, 1990

MONOCOLPATE POLLEN

Cycadopites follicularis Wilson & Webster 1946

OPERCULATE POLLEN

Corollina cf. *simplex* (Maljawkina) Venkatachala & Goczan 1964

Fungal spores: *Brachysporisporites* sp., *Diporicellaesporites* sp.

Fungal hyphae (VAM fungi)

Fungal fruiting bodies: *Phragmothyrites* spp.

Algal spores: *Lecaniella* sp., *Schizosporis* sp., *Oedogonium* sp.

Chitinozoan like-vesicles

Mallophagan (Kumar & Kumar, 1999) and Anopluran insects (Kumar & Kumar, 2001).

Percentage frequencies of palynomorphs in the Bagra Formation, is given below.

Genera		**Frequency in %**
Haradisporites	-	01·00
Biretisporites	-	01·00
Cycadopites	-	02·00
Corollina	-	02·00
Callialasporites	-	02·00
Scheuringipollenites	-	03·00
Falcisporites	-	03·00
Satsangisaccites	-	03·00
Samaropollenites	-	02·00
Arcuatipollenites	-	01·00
Guttulapollenites	-	01·00
Striatopodocarpites	-	03·00
Fungal Spores (Vam)	-	10·00
Fungal Hyphae	-	05·00
Fruiting Bodies	-	10·00
Algal Germinating Spores	-	32·00
Algal Spores	-	05·00
Chitinozoa	-	02·00
Insect Remains	-	02·00
Unidentified	-	10·00

COMPARISON

The palynological assemblage recovered from the cementing matrix of the Bagra conglomerate contains poor representation of pteridophytic/pteridospermic and gymnospermic spores-pollen. It is characterised by the prominence of vesicular arbuscular mycorrhizae (VAM Fungi)/ germinating algal spores, fungal spores, microthyriaceous fungi (fruiting bodies) and algal spores.

The palynological assemblage comprises 12 spore pollen genera and species, of which striated disaccates are present in negligible amount. Three non taeniate disaccates (*Falcisporites, Satsangisaccites* and *Samaropollenites*) are also represented. Two trilete spores, one monocolpate pollen, two taeniate pollen genera and one operculate pollen are also recorded. It is comparable to the Late Triassic Denwa (clays) palynological assemblage of the Satpura Basin (Kumar, 2000) in containing *Falcisporites, Satsangisaccites, Samaropollenites* and *Haradisporites*. However, differs from the latter in the absence of *Brachysaccus, Minutosaccus, Ashmoripollis, Krempipollenites, Staurosaccites* and *Aratrisporites*. The Denwa palynological assemblage has poor representation of fungal/algal remains, whereas these become important (±80%) in the Bagra palynological assemblage. Though both formations possess *Callialasporites, Cycadopites, Haradisporites* and *Corollina* (=*Classopollis*). The presence of *Falcisporites, Satsangisaccites, Samaropollenites* and *Guttulapollenites* indicates a closer association with Denwa palynological assemblage. The similarity in fungal and algal remains in both the assemblages, further emphasises a closer affinity.

Nandi (1996) reported palynological assemblage I from carbonaceous shales at 100 m depth and II at 200 m depth (Late Triassic) in the Anhoni region, which possess the dominance of *Falcisporites* followed by *Satsangisaccites*. Other palynomorphs of the Denwa Assemblage which are absent in the Bagra palynological assemblage are *Brachysaccus, Minutosaccus, Aratrisporites, Staurosaccites,* etc. *Haradisporites, Callialasporites, Corollina,* VAM Fungi, Algal germinating spores, Fruiting bodies and algal spores are lacking in the palynological assemblages-I and -II of the Denwa Formation. Hence, it is younger than the palynological assemblages from Anhoni.

Palynological assemblages described from Nidpur and Gopad River, South Rewa Basin by Bharadwaj and Srivastava 1969 and Tiwari and Ram-Awatar 1990, 1992 were dated as Early to Middle Triassic on the basis of *Satsangisaccites, Nidipollenites* and *Weylandites*. Tiwari and Rana (1980) dated the Nidpur palynological assemblage of Bharadwaj and Srivastava (1969) as Late Triassic (Carnian) in view of the presence of *Praecolpatites, Alisporites* and *Klausipollenites*. The Bagra palynological assemblage is not comparable with the above palynological assemblages because *Weylandites, Praecolpatites* are absent. It is younger (Rhaetian ?) in having *Biretisporites, Haradisporites, Samaropollenites, Callialasporites trilobatus, Cycadopites* and *Corollina* (=*Classopollis*) which are absent in Nidpur palynological assemblages.

Maheshwari and Kumaran (1979) and Kumaran and Maheshwari (1980) studied palynomorphs from the Tiki Formation (Carnian-Norian) argillaceous shales exposed in the Son River and Janar *nala* sections in South Rewa Basin. Palynological assemblage from Tharipathar is dominated by *Samaropollenites* which is poorly known in the Bagra assemblage. The dominant element *Rimaesporites* of the Ghiar section is lacking in the studied assemblage. Hence, it is not comparable with palynological assemblages of South Rewa Basin.

Palynological assemblages A-F from Bore core RJR2, Kazigaon in Rajmahal Basin were described by Tiwari *et al.* (1984). The assemblage - A belonging to Dubrajpur Formation has dominance of *Satsangisaccites* and *Falcisporites* but they are poorly represented in Bagra Assemblage. The characteristic forms *Rajmahalispora, Nidipollenites, Lundbladispora, Playfordiaspora* and *Goubinispora* are absent in the Bagra Assemblage. The palynological assemblages B and C of Rajmahal Basin compare with Bagra Assemblage only in having *Satsangisaccites* and *Samaropollenites*, otherwise it has no comparison with Bagra Assemblage as the former contains *Infernopollenites, Lundbladispora* and *Playfordiaspora* which are absent in the present studied assemblage.

Prasad and Jain (1994) and Prasad (1997) recorded palynological assemblages of Early, Middle and Late Triassic age from the sub-surface Triassic sediments in deep bore cores at Kommugudem-A and Mandapeta - A, C and D wells in the Krishna-Godavari Basin. Prasad (1997) assigned *Rimaesporites*

PLATE 1

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(All photomicrographs are x 500. Co-ordinate of specimens in slides referred to the stage of Labor Lux D Microscope no. 077055)

1 *Biretisporites* sp. Slide No. BSIP 12431 : 43·5 x 104.
2. *Callialasporites trilobatus* Slide No. BSIP 12431 : 25 x 104·5.
3. *Guttulapollenites hannonicus* Slide No. BSIP 12434: 20 x 94.
4. *Corollina* cf. *simplex* Slide No. BSIP 12429: 27 x 95·5.
5. *Cycadopites follicularis* Slide No. BSIP 12433 . 45 x 102.
6. *Phragmothyrites* sp. Slide No. BSIP 12431 : 28 x 108·5.
7 *Phragmothyrites* sp. Slide No. BSIP 12429 : 18 x 107·5.
8. *Corollina* cf. *simplex* Slide No. BSIP 12428: 20 x 102.
9. *Brachysporisporites* sp. Slide No. BSIP 12428 :20.5 x 110·2.
10. *Diporicellaesporites* sp. Slide No. BSIP 12429: 45 x 104.
11. Chitinozoan-vesicle Slide No. BSIP 12432 : 30·5 x 104.
12. *Phragmothyrites* sp. Slide No. BSIP 12429: 26 x 110·5.
13. *Lecaniella* sp. Slide No. BSIP 12431 : 19 x 103.
14. *Schizosporis* sp. Slide No. BSIP 12429 : 16·0 x 95·0.
15. *Lecaniella* sp. (germinating stage) Slide No. BSIP 12350: 23 x 107·5.
16. Vesicular-Arbuscular Mycorrhizae Slide No. BSIP 12428 : 30 x 97·5.
17 *Oedogonium* sp. Slide No. BSIP 12430 : 30 x 102·5.

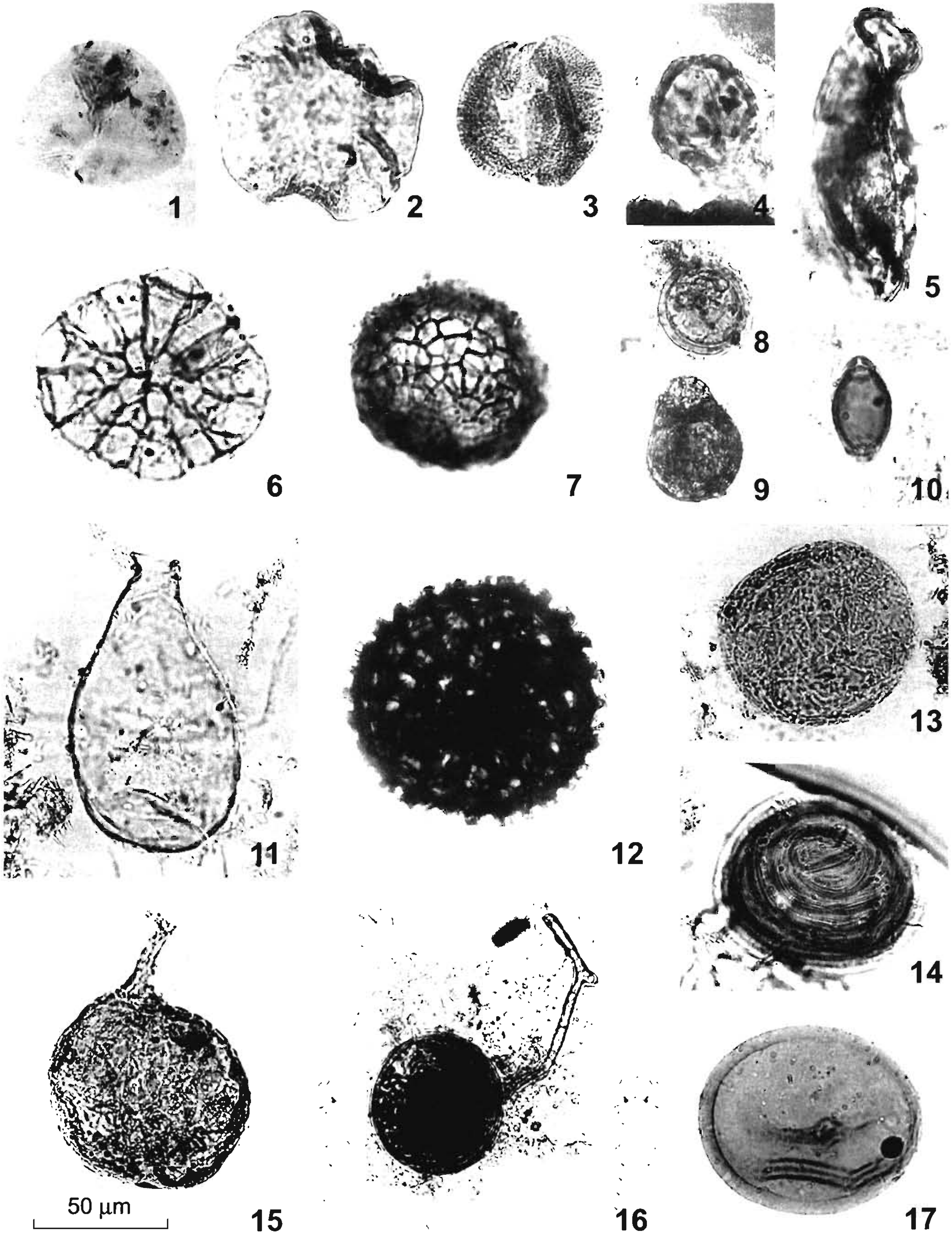

PLATE 1

potoniei - *Samaropollenites speciosus* Assemblage Zone for the Ladinian-Carnian Assemblage of the K-G Basin. The Bagra Assemblage compares with zone II of K-G Basin only in having *Samaropollenites*, otherwise the former differs from the latter in having *Callialasporites, Classopollis* and *Haradisporites*.

Lukose and Misra (1980) recorded a Late Triassic palynofossils in the subsurface sediments drilled in Jaisalmer Basin, Rajasthan. The palynoflora shows some similarities with Bagra palynological assemblage in having *Samaropollenites* in both the assemblages, but differs from the studied assemblage in having *Staurosaccites, Ovalipollis* and *Camerosporites* which are lacking here. The Late Triassic (Rhaeto-Liassic) palynological assemblage recovered from Banni Well No. B in Kutchch Basin possesses dominance of *Gliscopollis* and *Rhaetipollis*, but *Corollina (=Classopollis/ Gliscopollis)* is poorly represented in Bagra Assemblage and shows an equivalent to or younger aspect in having *Callialasporites trilobatus* and *Haradisporites mineri*. The latter two elements are known in the overlying Jabalpur Formation (Jurassic - Lower Cretaceous) in Satpura Basin (Bharadwaj *et al*., 1972; Singh & Kumar, 1972). The presence of these two palynomorphs in Bagra sediments might be the earliest and the First occurrence datum of their occurrences during Rhaetian time.

Helby *et al.* (1987) recorded palynological zones in the Mesozoic sediments of western Australia. They have established several Oppel Zones in *Falcisporites* Super Zone. The Bagra Assemblage compares with Australian Oppel Zones only in having *Falcisporites, Samaropollenites* and *Corollina*. But the former differs in lacking *Enzonalasporites* during Carnian time and *Ashmoripollis, Zebrasporites* (during Rhaetian time). The presence of *Haradisporites, Callialasporites trilobatus* and *Corollina* (= *Gliscopollis/ Classopollis*) in the Bagra Assemblage certainly shows not only a point of difference but shows a younger aspect too.

DEPOSITIONAL ENVIRONMENT

The Upper Triassic Bagra Formation is the youngest lithounit of the Mahadeva Group in Satpura Basin. It consists of conglomerates, variegated clays and limestones. The Bagra conglomerates contain many different kinds of boulders derived from local (metamorphics) and distant sources (red jasper), suggesting varied provenance bringing in sediments with reworked elements.

Singh (1976) opined that Mahadeva Group deposited under rapidly flowing rivers and sub-tropical with pronounced seasonal droughts.

Casshyap (1982) on the basis of palaeocurrent studies, suggested palaeodrainage since Talchir time was from southeast to northwest and shifting towards west northwest near the western margin upto Upper Gondwana (Triassic) time and the sediments supply from highlands of northern side to the southerly Gondwana Basin was occasional and minimal. Later, Casshyap (1999) opined that palaeocurrent during underlying Denwa Formation shows a reversal of direction of sediments transported from north-northeast to south-southwest during Bagra sedimentation.

Palynomorphs recorded from the matrix of Bagra conglomerates exposed near Khatama Caves contains some forms which are described from the underlying Denwa beds by Kumar (2000) such as *Falcisporites, Satsangisaccites, Samaropollenites, Arcuatipollenites, Striatopodocarpites, Guttulapollenites* and forms of the younger age of Jurassic such as *Haradisporites, Biretisporites, Callialasporites* and *Corollina* (=*Gliscopollis/Classopollis*) (Singh & Kumar, 1972; Kumar, 1973) indicate that such palynomorphs were coming from the opposite areas lying northern side of the basin. The pteridospermic/gymnospermic, haploxylonoid disaccates such as *Falcisporites, Satsangisaccites* and *Samaropollenites*) are indicative of upland vegetation brought through the wind and deposited by water channels of the southern side of the basin. Ueno (1958, 1979), Tiwari (1982), Tiwari and Tripathi (1987), Kumar (1996) opined that haploxylonoid sacci bearing pollen grow in the cool temperate and subpolar or sub-alpine zones. Whereas taeniate pollen such as *Arcuatipollenites* and *Guttulapollenites*) and flange bearing sub-saccate pollen *Callialasporites* indicate towards the warmer and dry conditions with seasonal fluctuations at low lying areas.

An operculate non-saccates intrabaculate pollen *Corollina/Classopollis* (Cheirolepidaceae) represents shallow marine near shore areas (Ramanujam, 1993).

Cookson (1947a, b in Elsik, 1978) noted that Microthyriaceae is most abundant in warm temperate to tropical zones especially where high humidity is present. These fungi inhabit either rain forest areas or moist mountain gullies.

Stubblefield *et al.* (1987) reported vesicular arbuscular mycorrhizae (VAM Fungi), septate hypha, terminal swellings comparable to clamydospores from Antarctic roots of Triassic time shows a closer affinity with the Bagra's fungal remains.

The occurrence of chitinozoan like-vesicles indicates a lacustrine environment during the sedimentation of Bagra beds as similar chitinozoans like assemblages are known from elsewhere (Tiwari *et al.*, 1981 from Talchir sediments of Jharia Coalfield, Bihar) and evidently depicted as marine influence.

DISCUSSION

Crookshank (1936) considered narrow conglomeratic strip of Bagra beds is to some extent a shore deposit and its southward extensions are in the nature of fans at the mouths of rivers draining from the mountains which lay north of the Satpura Gondwana Basin. Present studies also suggest that the palynological assemblage of the Bagra conglomerate comprises similar palynomorphs recorded in the Denwa Formation e.g., *Falcisporites, Satsangisaccites,* *Samaropollenites, Guttulapollenites, Arcuatipollenites, Striatopodocarpites* and *Scheuringipollenites*. Some fungal spores and fruiting bodies including *Haradisporites, Cycadopites, Callialasporites, Corollina* (=*Classopollis*), found in Denwa sediments are continued to occur in Bagra Formation. The palynological assemblage depicted as mixed flora which were fluorishing in the mountains of the southern side of the Gondwana Basin and coming through the river channels which were still continued to drain from the southern hillocks and were not completely vanished during the Bagra sedimentation. The present palynofloral studies do not support the Casshyap's view as no northern palynomorphs are identified except chitinozoan vesicles which are absent in Denwa clay's assemblage.

An operculate non-saccate pollen *Corollina/ Classopollis* (Cheirolepidaceae) represents shallow marine near shore areas (Ramanujam, 1993).

CONCLUSION

1. Bagra conglomerates were deposited under a lacustrine set up near shoreline.
2. Palynological assemblage of Bagra Formation contains dominance of fungal/algal spores with non-striated, haploxylonoid disaccates and a few striated and taeniate pollen grains belonging to Late Triassic time could be Rhaetian in age.
3. The presence of polar or subpolar or cool-temperate palynomorphs (disaccates) with warmer/dry low land palynomorphs, and the presence of microthyriaceous fungi, fungal and algal spores, fungal hyphae (as a mixed palynological assemblage) indicates fluctuating warm-humid climate at depositional site.
4. The occurrence of algal spores (Zygnemetaceae), fungal spores, microthyriaceous fungi (fruiting bodies) indicates fresh water lake deposits. On the other hand presence of chitinozoan like-vesicles may also strandline indicate a lacustrine set up for the Bagra sedimentation.
5. Bagra Formation was deposited by rapidly flowing rivers and subtropical with pronounced seasonal droughts.

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Amberiwadiacarpon devgarhensis gen. et sp. nov. from Amberiwadi, Sindhudurg District, Maharashtra, India

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ABSTRACT

Agarwal A & Ambwani K 2002. *Amberiwadiacarpon devgarhensis* gen. et sp. nov. from Amberiwadi, Sindhudurg District, Maharashtra, India. Palaeobotanist 51 : 107-111.

A fossil carbonised angiospermous fruit, *Amberiwadiacarpon devgarhensis* gen. et sp. nov. has been recovered for the first time from the Miocene sediments of Amberiwadi Village (Devgarh Taluk), Sindhudurg District, Maharashtra, India. Based on the morphological characters, the affinities of present fossil fruit have been suggested with the extant pantropical family Rubiaceae and more particularly with the taxa *Randia* Houst. ex Linn. and *Psychotria* Linn. of this family.

Key-words—*Amberiwadiacarpon devgarhensis*, Amberiwadi, Sindhudurg District, Maharashtra, Rubiaceae, Miocene.

भारत के महाराष्ट्र प्रान्त के सिन्धुदुर्ग जिले के अम्बेरीवाड़ी नामक स्थान से प्राप्त *अम्बेरिवाड़ियोकार्पन देवगढ़ेन्सिस* वंश नवप्रजाति

अनिल अग्रवाल एवं कृष्ण अम्बवानी

सारांश

भारत के महाराष्ट्र प्रान्त के सिन्धुदुर्ग जिले के अम्बेरीवाड़ी ग्राम (देवगढ़ तालुक) के मायोसीन अवसादों से पहली बार एक अश्मित कार्बनीकृत आवृतबीजी फल *अम्बेरीवाड़ियोकार्पन देवगढ़ेन्सिस* वंश नवप्रजाति प्राप्त किया गया है। संरचनात्मक अभिलक्षणों के आधार पर वर्तमान अश्मित फल की विद्यमान सार्वउष्णकटिबन्धीय रूबिएसी कुल तथा इस कुल के विशेष रूप से *रैण्डिया* एवं *साइकोट्राया* वर्गकों के साथ बन्धुता प्रस्तावित की जाती है।

संकेत शब्द—*अम्बेरीवाड़ियोकार्पन देवगढ़ेन्सिस*, अम्बेरीवाड़ी, सिन्धुदुर्ग जिला, महाराष्ट्र, रूबिएसी, मायोसीन.

INTRODUCTION

AMBERIWADIACARPON DEVGARHENSIS gen. et sp. nov. forms the first record of fossil fruit from the lignitic beds exposed at Amberiwadi Village near Tirlot Village (Latitude 16°30'20" N: longitude 73°23'20" E) (Fig. 1) in Sindhudurg District, Maharashtra. However, the report of fossil fruit, *Canariocarpon ratnagiriensis* from Kalviwadi, Sindhudurg District has been published by Agarwal and Ambwani (2000) showing affinities with the modern taxon *Canarium* of the family Burseraceae. So far a very little information regarding the plant megafossils from the lignite of Maharashtra is known.

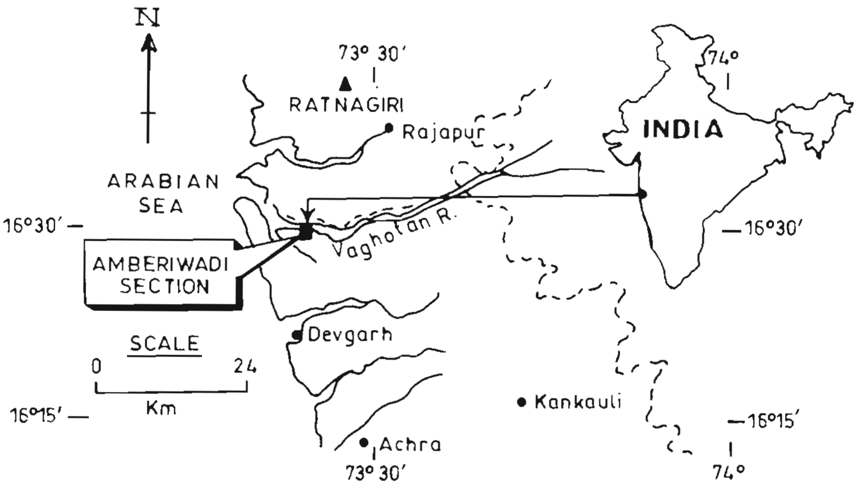

Fig. 1—Map of Sindhudurg District, Maharashtra, India showing Amberiwadi location from where the lignite fruits were collected (after Ramesh *et al.*, 1992)

Reports of pollen, spores and cuticles from Ratnagiri lignites have been published by Dalvi and Kulkarni (1982), Kulkarni and Phadtare (1980, 1983), Kulkarni *et al.* (1985), Phadtare and Kulkarni (1980a, b, 1984a, b), Saxena and Misra (1990), Saxena *et al.* (1992) and Saxena (1995) published the microfossils from Ratnagiri beds of Sindhudurg District. Saxena *et al.* (1992) tentatively reported fossil fruits from the lignite beds of Ratnagiri, Maharashtra without assigning their affinities. Occurrence of *Bouea rediensis* and *Shoreoxylon vayganiensis* of the families Anacardiaceae and Dipterocarpaceae respectively have been recorded by Srivastava and Saxena (1998) from the same beds.

Prasad and Awasthi (1996) described the fossil leaf of *Randia* Houst. ex Linn. in the Siwalik flora of Western Nepal, while other rubiaceous fossil leaves known from Miocene sediments of India are reported by Agarwal (1990) and Prasad (1994a, 1995). However, *Canthiumoxylon neyveliensis* constitutes the only record of rubiaceous wood from the Miocene sediments of India Agarwal (1992).

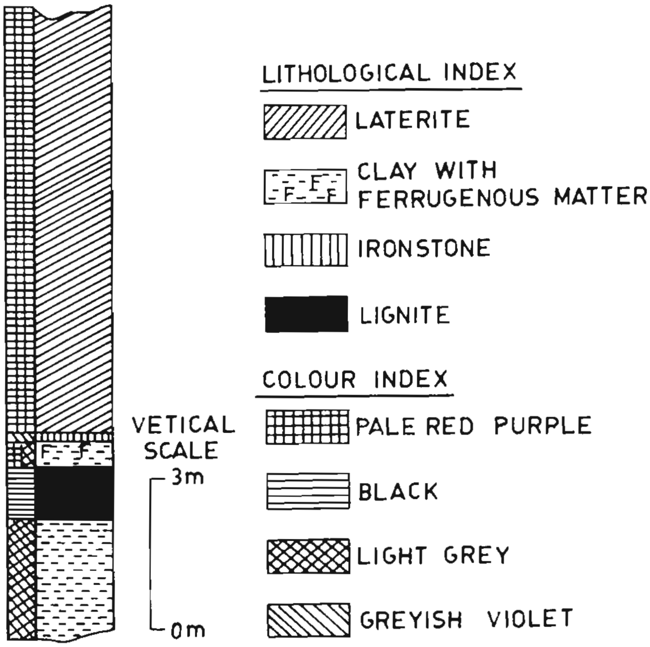

Fig. 2—Lithology of Amberiwadi Section showing sequence of various strata of Ratnagiri Beds, Maharashtra, India (after Ramesh *et al.*, 1992).

MATERIAL AND METHODS

The fossil fruit recovered from an exposed section at Amberiwadi shows basal grey clay which is overlain by compact lignitic layer, hard grey clay mixed with ferrugenous matter, ironstone and laterite (Fig. 2). The lignite bearing part

PLATE 1

1. Fossil fruit, *Amberiwadiacarpon devgarhensis* gen. et sp. nov. showing prominent rf- ridges and furrows, a- apical, b- basal. Museum Specimen No. 38809.
2. Lateral view of the fruit showing ridges and furrows. Museum Specimen No. 38809.
3. Fruit showing broken area with prominent ridges and furrows. Museum Specimen No. 38809.
4. Cellular details between two ridges showing st- stomata dispersed in the outer wall SEM. x 900.
5. Cross section of the outer wall showing meshwork of fibrous cells below the ridge area SEM. x 200.
6. Inner layer of the fruit showing longitudinal and oblique running fibrous cells SEM. x 110.
7. A single fibre cells enlarged to show fibre pits on its wall SEM. x 3200.
8. Cross-section showing the inner surface of the fruit wall SEM. x 800.
9. Branched fibres and fibre tracheids SEM. x 1200.

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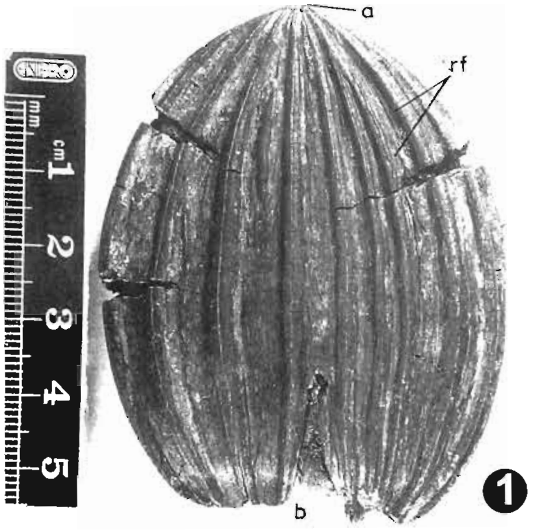

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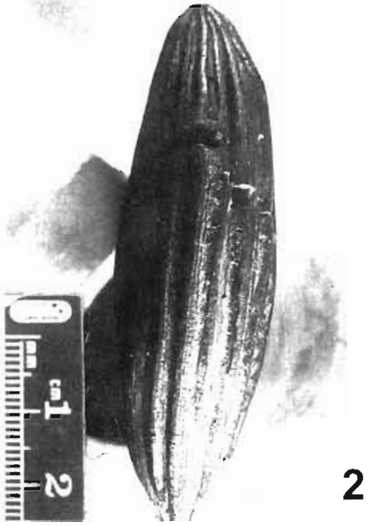

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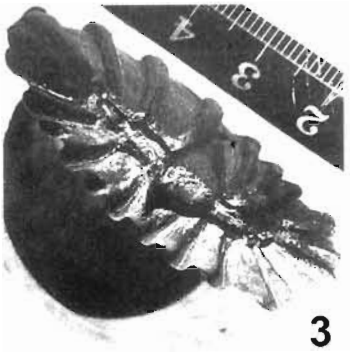

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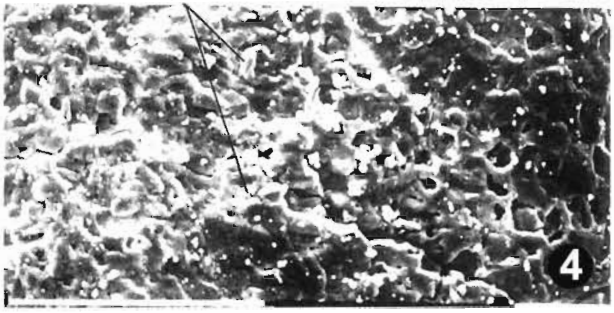

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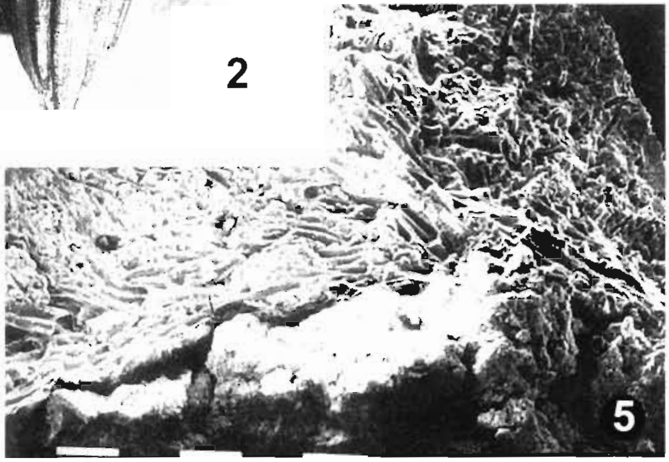

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PLATE 1

is mixed with soft clay. Some fragmentary wood pieces partly carbonised were also present associated with the matrix. The fossil fruit was found loosely embedded in the upper part of the lignite associated with brownish red ferrugenous sediments in the section. Only single carbonised fruit was recovered from this section.

SYSTEMATIC DESCRIPTION

Family—RUBIACEAE

Genus—AMBERIWADIACARPON gen. nov.

AMBERIWADIACARPON DEVGARHENSIS gen. et sp. nov.

(Pl. 1·1-9)

The systematic description is based only on single carbonised fruit measuring 7·5 cm in length, 5·5 cm in breadth and 2 mm thick (Pl. 1·1-3). The fruit is dark brown to blackish in colour; brittle, bilaterally compressed probably due to over burden of the sediments, oval (broadly ellipsoidal) in shape, apically dehiscent, apex ruptured, sessile. The fruit appears to be a capsular in nature and highly ribbed at the outer surface due to ridges and furrows; these ribs numbering 20 are very prominent and run from base to apex of the fruit. The thickness of the ridges varies from 1 to 3 mm and they are 4 to 5 mm apart. They converge from base to apex of the fruit. The fruit wall consists of two layers, the outer and inner, it is highly fibrous in nature, the fibres anastomose on the exterior of the fruit wall and run more or less straight in the inner surface (Pl. 1·5). The area between the ridges shows some cellular details and the stomata dispersed are in these areas (Pl. 1·4). The fibres bear pits on their walls (Pl. 1·7). The inner surface of the fruit wall is thin and contains some interwoven fine fibres and tracheids (Pl. 1·8-9). Overall the cellular details were meagerly preserved probably due to high temperature during the fossilisation The cellular details indicate that the middle lamella of these cells seems to have been severely effected showing its absence thereby indicating the action of high temperature on the cell wall. The fruit was cut in cross-section to know the nature of ovary; however, it was found that the fossil fruit comprised only outer shell indicating that it must have been a capsule which led to shed off the seeds after it was mature and fallen down before fossilisation.

Generic Diagnosis—Fruit capsule, dark brown to blackish in colour, internally hollow, filled with sediments, measuring 7.5 cm long; 5.5 cm broad, 2 mm in thickness. Fruit wall divisible in two layers, the outer and inner, highly fibrous, ridges and furrows prominent, 20 in number, vary from 1 to 3 mm thick and 4 to 5 mm apart running from base to apex, convergent, base broken; stomata present between ridges; inner surface of fruit wall fibrous forming fine mesh work.

Specific Diagnosis—Fossil fruit probably capsule, dark brown to black in colour, size of the fruit is 7·5 cm in length, 5·5 cm in breadth and 2 mm in thickness, ribbed, ridges and furrows prominent on the outer surface; 20 in number, some of the ridges do not reach to the full length of the fruit. They are 1-3 mm thick and 4 to 5 mm apart, stomata present between the ribs, ribs extend from base to apex, convergent, basal part broken. The fruit wall distinguishable in 2 layers; the outer highly fibrous, and the inner thin containing fine fibres which run obliquely. The fruit is internally hollow filled with sediments.

Holotype—Pl. 1·1, Museum Specimen No. BSIP 38809.

Horizon—Tertiary.

Age—Miocene.

Type locality—Amberiwadi, Sindhudurg District, Maharashtra, India.

COMPARISON

As far as the authors are aware fossil fruits similar to the present specimen bearing ridges and furrows have so far not been reported from the Tertiary sediments of India and abroad. However, after critically going through the available literature it has been assigned to a new fossil genus *Amberiwadiacarpon*. The generic name has been derived from the locality Amberiwadi from where it has been recovered while the specific name denotes to Devgarh Taluk. Fruits with similar morphological features are known to occur in the extant family Rubiaceae (e.g., *Randia* Houst. ex Linn. and *Psychotria* Linn.). Generally the fruits of this family are smaller in size than the fossil, they are as large as 3 cm wide in *Randia exaltata* Griff. Corner (1952) whereas 3·7 cm long in *Randia maculata* DC. Backer & Brink (1965). The fruits in *Psychotria* Linn. vary from 1·25-1·5 cm long bearing 10-12 ribs which run from base to apex (Backer & Brink, 1965). They are generally capsular in nature. This justifies the nature of the fossil fruit which seems to have shed off its seeds after its maturity. Due to non availability of more anatomical characters in the fossil, it could not be compared in detail with any extant fruits.

The family Rubiaceae growing in tropical to temperate regions of the world consists of 500 genera and as many as 6000 species comprised of trees, shrubs and herbs (Backer & Brink, 1965; Willis, 1973). The members of this family are distributed mainly in the tropical and sub-tropical regions of the world, but a few also occur in temperate and arctic regions. *Randia* Houst. ex. Linn. is a large genus comprising 200-300 species of shrubs and trees which are distributed in the tropical regions of the world. This genus includes 16 species while *Psychotria* has about 40 species, growing in the forests of Martaban, Tenasserim, Sylhet, Assam and Khasi Hills, eastern Bengal, Chittagong, Western Ghats, Konkan, Sri Lanka as well as evergreen forests of Andaman and swampy forest of Pegu etc. Gamble (1972). *Randia exaltata* grows in mangrove swamps of Tenasserim and Andaman Island while the species of *Psychotria* Linn. occur in all tropical and subtropical habitats of the world (Hooker, 1882). As the members of the family Rubiaceae grows in various ecological conditions so it is difficult to infer about the palaeoecological condition by this fruit alone.

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An interpretation of the palynology and palaeoecology of the Early Miocene Dulte Formation, Mizoram, India

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ABSTRACT

Mandaokar BD 2002. An interpretation of the palynology and palaeoecology of the Early Miocene Dulte Formation, Mizoram, India. Palaeobotanist 51 : 113-121.

A palynological study of the Early Miocene sediments of the Aizawl Basin, Mizoram is presented. The Aizawl Basin is part of the North-East India Dulte Formation (Surma Group: Bhuban Subgroup). The significant elements of the palynoassemblage are: *Pteridacidites, Striatriletes, Polypodiisporites* and *Schizaeoisporites* (pteridophytes), *Compositoipollenites, Malvacearumpollis, Spinizonocolpites, Bombacacidites, Ctenolophonidites, Polyporina, Polyadopollenites, Graminidites* (angiosperms), *Cucurbitariaceites, Dicellaesporites* and *Phragmothyrites* (fungi).

The shale contains abundant plant remains and white gastropod shells. The alternation of shale-siltstone, sandstone-claystone and the palynoflora suggest an Early Miocene age for studied sequence. Palaeoecological interpretation based upon recent botanical affinities of the fossil spores and pollen highlights the presence of mangrove, fresh water, swamp and water edge ecological groups. The presence of fungal remains indicates warm and humid climate. The composition of palynological assemblage suggests that Dulte Formation was deposited in deltaic conditions rich in terrigeneous detritus where the fungal elements thrived.

Key-words—Palaeopalynology, Palaeoecology, Palynoflora, Dulte Formation, Early Miocene, Deltaic, Aizawl Basin, Mizoram, India.

भारत के मिजोरम प्रान्त के प्रारंभिक मायोसीन युगीन दुल्ती शैल समूह के परागाणु विज्ञान तथा पुरापारिस्थितिकी का निर्वचन

भगवानदास दोमाजी मण्डावकर

सारांश

प्रस्तुत शोध पत्र में मिजोरम की आइज़ॉल द्रोणी के प्रारंभिक मायोसीन अवसादों का परागाणविक अध्ययन प्रस्तुत किया गया है। आइज़ॉल द्रोणी पूर्वोत्तर भारत के दुल्ती शैलसमूह (सूरमा समूहः भुवन महासमूह) का एक भाग है। परागाणु समुच्चय के महत्त्वपूर्ण तत्व हैं : *टेरिडासाइडाइटीज़, स्ट्रायाट्रायलिटीज़, पॉलीपोडाइस्पोराइटीज़* तथा *शीज़िओइस्पोराइटीज़* (टेरिडोफाइट्स), *कम्पोज़िटॉयपोलेनाइटीज़, माल्वेसीरम्पोलिस, स्पीनोज़ोनोकॉल्पाइटीज़, बॉम्बेकेसाइडाइटीज़, टीनोलोफ़ोनाइडाइटीज़, पॉलीपोराइना, पॉलीएडोपोलेनाइटीज़, ग्रेमाइनाइडाइटीज़* (आवृतबीजी), *क्यूकरबाइटेरायासाइटीज़, डाइसेल्लीस्पोराइटीज़* एवं *फ्रैग्मोथाइराइटीज़* (कवक)।

शेल में प्रचुर मात्रा में पादप अवशेष तथा श्वेत गैस्ट्रोपोड कवच विद्यमान हैं। शैल-सिल्टस्टोन, सैण्डस्टोन- क्लेस्टोन, तथा परागाणुवनस्पतिजात से प्रस्तावित होता है कि अध्ययन किए गए अनुक्रम की आयु प्रारंभिक मायोसीन युगीन हो सकती

है। अश्मित बीजाणुओं तथा परागकणों की अद्यतन प्राप्त वानस्पतिक बन्धुता के आधार पर निकाले गए पुरापारिस्थितिकीय निष्कर्ष मैंग्रोव, ताजे जल, अनूप तथा अतिनत जल पारिस्थितिकीय समूहों की उपस्थिति दर्शाते हैं। कवकीय अवशेषों की उपस्थिति आर्द्र तथा नम जलवायु का संकेत करती है। परागाणविक समुच्चय का संघटन प्रस्तावित करता है कि दुल्ती शैलसमूह स्थलजात अपरद में प्रचुर डेल्टीय स्थितियों में वहाँ निक्षेपित थे, जहाँ कवकीय अवशेष फल-फूल रहे थे।

संकेत शब्द—पुरापरागाणुविज्ञान, पुरापारिस्थितिकी, परागाणुवनस्पतिजात, दुल्ती शैलसमूह, प्रारंभिक मायोसीन, डेल्टीय, आइजॉल द्रोणी, मिजोरम, भारत.

INTRODUCTION

GEOLOGICALLY the eastern part of Mizoram has remained, until recently, terra-incognita, on account of its inaccessibility and lack of economic mineral content. The only available references to the area are the records of the Assam Oil Company and the Burma Oil Company. The State of Mizoram (Fig. 1) occupies narrow, north-south trending longitudinal ridges, separated by broader valleys. Several of the mountain peak exceed 1800 m in height, the highest being the Blue Mountains (Phawngpui) in the southeastern part of Mizoram. The general ground elevation increases towards the east, from 50 m in the extreme west of the State.

Palynological information from the Tertiary sediments of Mizoram was published by Hait and Banerjee (1994), is based on two lignite samples. Fifty richly diverse taxa were recorded. Mandaokar (2000) studied the palynofloral sequence from the western flank of Aizawl Town, Ramrikawn, near Chandmari, Mizoram. A detailed palynological study of the Tertiary sequence from the Mizoram Basin has not so far been published. The present study reports the results obtained from a collection of palynological rock samples from the Bhuban subgroup in the Dulte area of the Eastern Mizo hills. The objectives were to collate and analyse the total spore and pollen compliments extracted from the Tertiary strata of the Aizawl, Mizoram Basin, and to high light the relevance of the palaeoecological in reconstruction of the area. The present investigation is mainly concerned with the eastern flank of the Aizawl hills. The Dulte Formation lies about 120 km NNE of Aizawl Town (Fig. 1). The area is covered by unconsolidated sandstone alluvium.

GEOLOGY OF AREA

Hayman (1937) reconnoited the Lushai hills in Mizoram State and included a map of the traverses in his report. In 1948 Franklin mapped the Mizo hills from aerial photographs. Das Gupta (1948) reviewed the geology of Mizoram. He considered that the thick succession of Surma Group could referred to be Bhuban and the Bokabil subgroups which is folded into several meridional structures. Since the mid seventies, important contributions have been made to the geological structure of the region (Ganguly, 1975; Ganju, 1975; Nandy, 1980, 1982; Jokhan Ram & Venkataraman, 1983, 1984). A generalised stratigraphic succession of the Tertiary sequence in Mizoram is provided in the Geological Survey of India (1974). A monotonous sequence (7165 m) of arenaceous and argillaceous suites of sedimentary clastics is exposed in Eastern Mizoram. The Bhuban subgroup has been subdivided, on the basis of lithology (sand shale ratio), into two formations: the Dulte

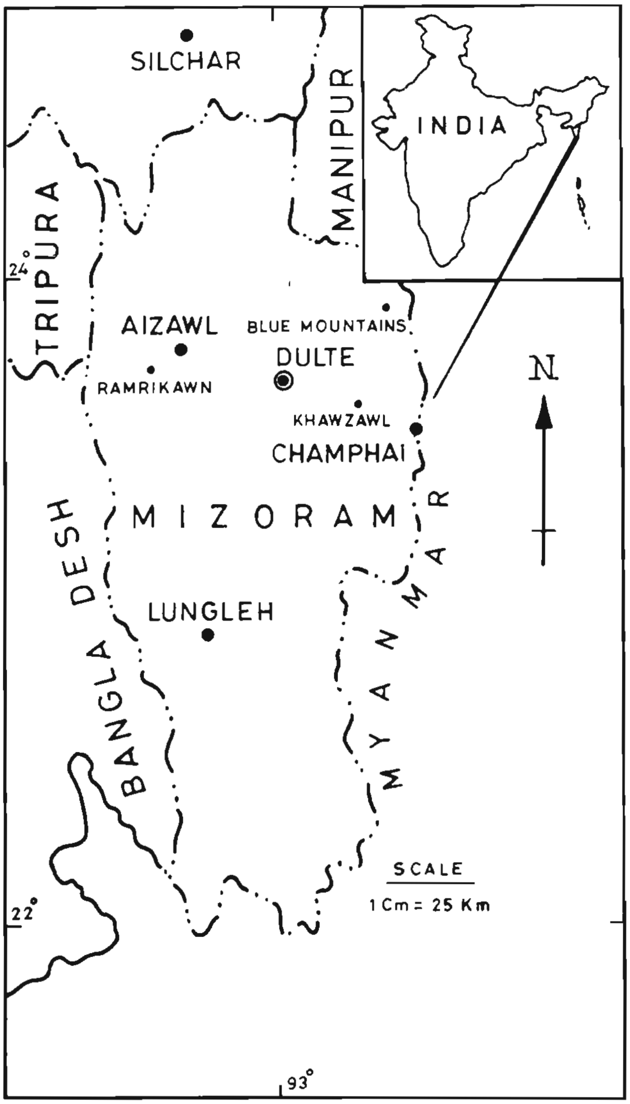

Fig. 1—Showing location map of Mizoram.

and the Keifang formations (Shrivastava *et al.*, 1979). These have not, however, been correlated to the subdivisions of the lower, middle and upper Bhuban Formation in western Mizoram. Therefore, the stratigraphic equivalence of the subdivisions of eastern Mizoram with those of western Mizoram remain to be established. The generalised stratigraphic succession of the area is given in Fig. 2 (after Shrivastava *et al.*, 1979).

Dulte Formation—The Dulte Formation sediments are informally named after Dulte Village. The type section of this formation extends from Dulte to Khawzawl (Fig. 1). It is the development of highly undulatory deeply incised valleys, formed by erosion of the major claystone constituents, leaves major sandstone units standing out as prominent hillocks. The formation consists predominantly of massive to thinly bedded claystone, subordinate sandstone and sandstone-claystone alternations. The claystone is greenish grey, moderately hard, ? micaceous (like), non-calcareous and occasionally silty. Towards the base it becomes more arenaceous, exhibiting micro-cross laminations. The sandstone is thick to thinly bedded, very hard, dark grey to grey, weathering to yellowish brown, fine grained and micaceous ?-like. Calcareous encrustations on the sandstone are also observed. The Dulte Formation consists of 5275 m thick sequence of shale-siltstone and sandstone-claystone alternations, showing the features of turbidites (Shrivastava *et al.*, 1979). The cross lamination of sandstone and interference ripple with tadpol nest structure indicate marine to deltaic environment of deposition.

MATERIAL AND METHODS

The material for the present palynological investigation was collected from the Dulte Formation exposed in 2 km from Dulte Village, along the Dulte-Keifang Road in Aizawl District, Mizoram. Altogether, 25 samples were collected from greyish shale and siltstone bands within the sandstones. Of these, fourteen samples yielded palynofossils. The stratigraphic position of the samples is shown. For recovery of palynofossils, samples were treated with HCL followed by HF and HNO_3. After acid treatment, the samples were thoroughly washed with water and then treated with 10% KOH solution for 5-10 minutes, followed by repeated washing with water through 400 mesh sieve to remove all traces. Macerated preparations were mounted in 2 cm coverslips using polyvinyl alcohol. Pollen-spore from the slides prepared as above were identified and counted using a BH-2 microscope. A total of 58 species and 52 genera were identified in the 25 samples studied. Of these, 24 species in 24 genera are spores (Algae, fungi or pteridophytes) and 34 species and 28 genera are pollen. By counting a hundred individuals in each of the samples, the relative abundance of the determined species and genera were ascertained. Selected examples of the spores and pollen were then included in a palynological diagram (Fig. 4.) More than 15% as abundant, 10-15% is common, 6-9% is less common and 3-5% is uncommon and less than 1-2% is rare.

PALYNOASSEMBLAGE

The geological section from the Dulte Formation is a mixture of shale-siltstone, clay, siltstone-sandstone alternation, includes organic matter. The palynoassemblage extracted from the section encompasses 58 identifiable species in 52 genera. The palynoflora recorded from the Dulte is dominated by pteridophyte spores and angiosperm pollen. Gymnosperm pollen and fungal spores are also present. The dinoflagellate cysts are also present in lower part of sediments which progressively decrease in the middle and upper parts. They are important constituent of Surma Group, Bhuban Subgroup, Dulte Formation, Aizawl Basin, Mizoram. A check list of the different spore and pollen species which represent algae, fungi, pteridophytes, gymnosperms and angiosperms, as well as

Group	Sub-Group	Formation (informal)	Lithology	Thickness in ft (m)
SURMA	BHUBAN	DULTE	Predominantly argillaceous, comprising massive to thinly bedded claystone and subordinate sandstone and sandstone-claystone alternation.	17,300 ft (5275 m)
			Claystone: Massive to thinly bedded, greenish grey to grey, moderately hard, micaceous occasionally, silty and with micro-cross laminations.	
			Sandstone: Thick to thinly bedded, dark grey to grey, weathering to yellow brown, fine grained occasionally silty and micaceous.	

Base not exposed

Fig. 2—Generalised stratigraphic succession of the Surma Group (after Shrivastava *et al.*, 1979).

Algal spores
Achomosphaera ramulifera (Deflandre) Evitt, 1966
Oligosphaeridium complex Davey & Williams, 1966
Operculodinium centrocarpum Wall, 1966
Thalassiphora pelagica (Eisenack) Eisenack & Gocht, 1960

Fungal spores
Cucurbitariaceites bellus Kar *et al.*, 1972
Dicellaesporites minutus Kar & Saxena, 1976
Diporisporites curvatus Ramanujam & Rao, 1978
Dyadosporonites constrictus Kar, 1979
Fusiformisporites crabbii Rouse, 1962
Inapertisporites kedvesii Elsik, 1968
Lacrimasporonites longus Kar, 1979
Phragmothyrites eocaenicus Kar & Saxena, 1976

Pteridophyte spores
Crassoretitriletes vanraadshovenii Germeraad *et al.*, 1968
Cyathidites australis Couper, 1953
Dangripites tuberculatus Mandaokar, 1997
Gleicheniidites senonicus Ross, 1949
Intrapunctisporis intrapunctis Krutzsch, 1959
Lycopodiumsporites umstewensis Dutta & Sah, 1970
Lygodiumsporites lakiensis Sah & Kar, 1969
Polypodiaceaesporites levis Sah, 1967
Polypodiisporites mawkmaensis Dutta & Sah, 1970
Pteridacidites africanus Sah, 1967
Schizaeoisporites phaseolus Delcourt & Sprumont, 1955
Striatriletes susannae Van der Hammen, 1956

Gymnosperm pollen
Pinuspollenites crestus Kar, 1985
Podocarpidites ellipticus Cookson, 1947
Podocarpidites khasiensis Dutta & Sah, 1970

Angiosperm pollen
Araliaceoipollenites psilatus Dutta & Sah, 1970
Bombacacidites bombaxoides Couper, 1960
Chenopodipollis miocenica Kar & Jain, 1981
Compositoipollenites sentis Sah, 1967
Ctenolophonidites costatus Van Hoeken Klinkenberg, 1966
Cupuliferoipollenites ovatus Venkatachala & Kar, 1969
Engelhardtioidites minutiformis Ramanujam & Reddy, 1984
Favitricolporites retiformis Sah, 1967
Graminidites granulatus Kar, 1985
Malvacearumpollis bakonyensis Nagy, 1962
Monoporopollenites gramineoides Meyer, 1956
Paleorubiaceaepites psychotria Biswas, 1962
Paleosantalaceaepites ellipticus Sah & Kar, 1970
Palmaepollenites plicatus Sah & Kar, 1970
Palmaepollenites ovatus Sah & Kar, 1970
Pellicieroipollis langenheimii Sah & Kar, 1970
Polyadopollenites miocenicus Ramanujam, 1966
Polyporina globosa Sah, 1967
Retipilonapites cenozoicus Sah, 1967
Retitrescolpites crassimurus Sah, 1967
Retitrescolpites bellus Sah, 1967
Retitrescolpites oblongus Sah, 1967
Rhoipites bradleyi Wodehouse, 1933

Rhoipites kutchensis Venkatachala & Kar, 1969
Sapotaceoidaepollenites obscurus Sah, 1967
Sparganiceaepollenites polygonalis Thiergart, 1937
Spinizonocolpites echinatus Muller, 1968
Tricolpites crassireticulatus Dutta & Sah, 1970
Tricolpites reticulatus Kar, 1979
Trisyncolpites ramanujamii Kar, 1979
Umbelliferoipollenites constrictus Venkatachala & Kar, 1969

Incertae sedis
Leaf tissue
Woody tissue
Fibrous tissue
Amorphous organic matter

Fig. 3—Palynoassemblage from Dulte Formation, Mizoram.

fibrous tissue, leaf tissue, woody tissue and amorphous organic matter are listed in the Fig. 3.

RESULTS

Palynofloral Composition and Age

From the analysis we can deduce that pollen of angiosperm shrubs and trees forms a major component of the pollen and spore assemblage. In the present study only a few herbaceous pollen taxa were found, for example. *Graminidites* (Poaceae) and *Chenopodipollis* (Chenopodiaceae). Relative abundance of these two taxa in the Early Miocene is extraordinarily low (2-4%). and the gymnosperm species determined in the study (2 %), are of coniferous pollen (Fig. 4). The relationship between the relative abundance of gymnospermous type pollen in the Early Miocene continues into younger strata with increasing dominance of *Pinuspollenites* and *Podocarpidites*.

The alternation of the shale-siltstone and shale-sandstone ratio in the Eastern Mizo hills has been identified as Miocene in age (Shrivastava *et al.*, 1979). The ostracod and mollusc content in the Dulte Formation is considered to be Middle Miocene in age (Tiwari & Kumar, 1996). Early Miocene age was inferred by the presence of *Crassoretitriletes, Trisyncolpites* and *Bombacacidites* (Mandaokar, 1990) to Maibong Assam. A recent palynological study of Ramrikawn quarry, Aizawl District, Mizoram (Mandaokar, 2000) provides evidence that, over a another wider area, the palynoflora varies from Oligocene to Early Miocene in age. Germeraad *et al.* (1968) critically studied the occurrence pattern of *Crassoretitriletes* in pantropical areas and suggested that genus generally occurs in the lower Oligocene and extends up to the Miocene. *Pteridacidites, Malvacearumpollis, Compositoipollenites* and *Chenopodipollis* are significant among the genera recovered from Dulte Formation and indicative of an Early Miocene age. These four genera are also dominant elements in the Khari Nadi Formation of Kachchh in Kar (1985), the Surma Group Meghalaya, and in Cachar, Assam (Rao *et al.*, 1985). It is interesting to note that *Pteridacidites* and *Compositoipollenites* have also been recorded from Miocene sediments in the Rusizi Valley, Burundi (Sah, 1967). Thus the presence of *Pteridacidites, Malvacearumpollis, Compositoipollenites*, and the presence of other elements such as *Striatriletes* and *Crassoretitriletes* may be useful indicators of Early Miocene age.

Depositional Environment

Total counts of the palynoflora, as well as counts of the taxa indicating different habitats, have been made. The palynoflora have been grouped together under Montane, fresh water, low land, swamp and water edge, Back mangrove, mangrove, sandy beach and algal based on the general habitat of present day representatives as indicated in Fig. 5.

Palynofossils can be a valuable indicator of past climate, especially where they can be related to extant taxa. The distribution pattern of the fossil taxa recorded (Fig. 3) are indicative of a tropical to subtropical climate. The Dulte Formation palynoflora have affinities with 21 extant families. Of these, nine families are restricted to tropical or subtropical climates, six families are cosmopolitan, four families are restricted to the tropics and two families have temperate associations (Fig. 5). The presence of spores or pollen of Schizaeaceae, Parkeriaceae, Polypodiaceae, Caesalpiniaceae. Ctenolophonaceae, Oleaceae and Rubiaceae in the assemblage indicates that a tropical climate prevailed at the time of deposition. Fern spores and the occurrence of tropical rain forest elements (Ctenolophonaceae, Oleaceae) provide supporting evidence of a climate with a high rainfall. Most of the fossil taxa attributed to pollen and spore can be pollen and spores of extant plants that have a tropical or subtropical distribution and are present in moist evergreen rain forests.

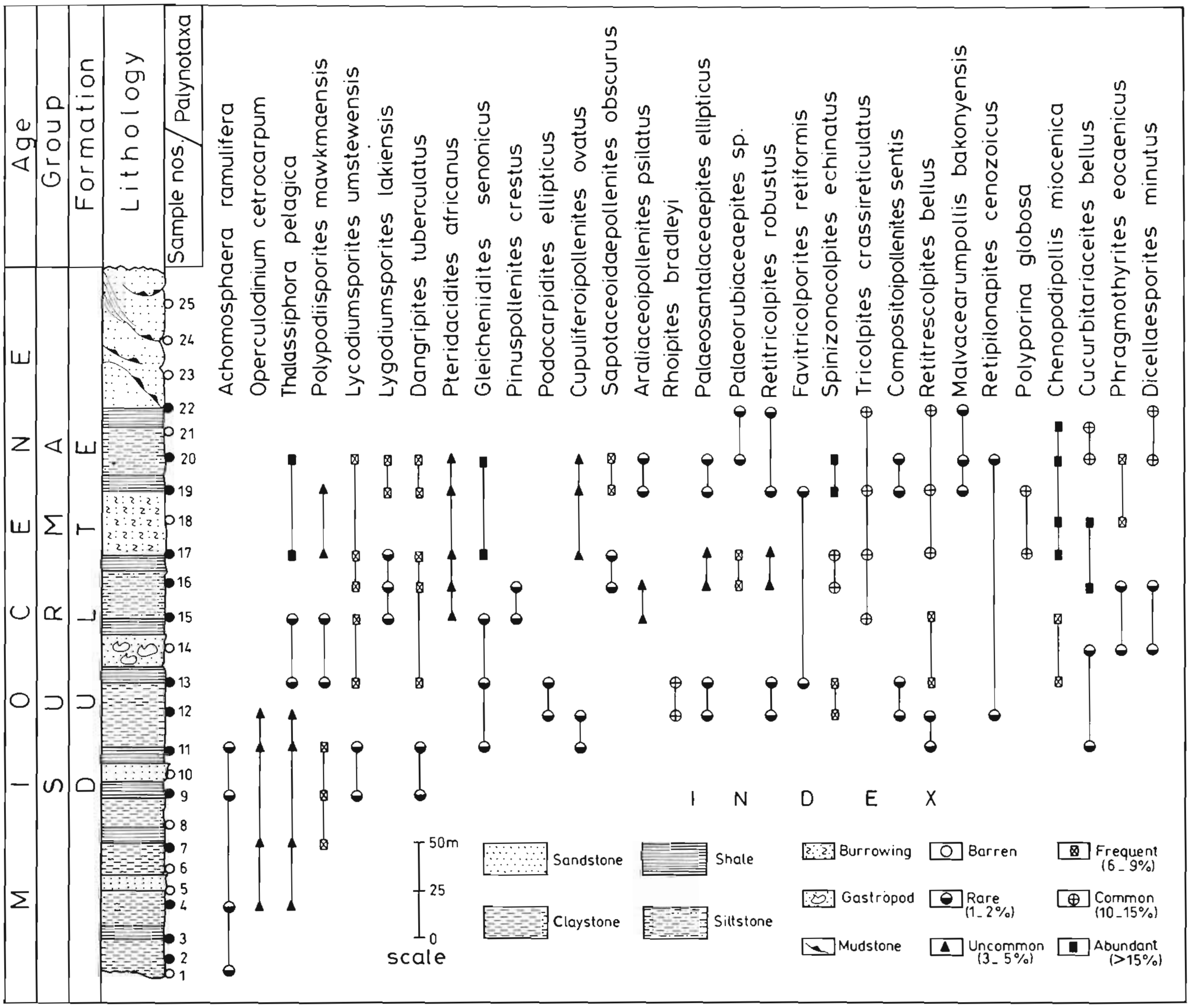

Fig. 4—Diagram showing relative frequency of palynotaxa from the Dulte Formation (Aizawl Basin), Mizoram.

PALAEOGEOGRAPHY AND PALAEOCLIMATE

Fossil spores and pollen are valuable in palaeoecological analysis, and in interpreting the palaeogeography prevailing palaeoclimatic conditions at the time of deposition. The palaeoecological interpretation, in particular, depends on the comparison of the fossil palynomorphs with their nearest living relatives. The percentage of the different spore and pollen taxa present in the assemblage is also to be taken into account in deciphering palaeoecological condition of deposition. Besides, the productivity of the pollen of the producing plant should also be considered to find out the percentage in the assemblages. The fossil pollen and spore forms recorded in this study are not from their extant relatives. Therefore, it has been possible to make the significant inferences: (1) During the deposition of the Dulte Formation subtropical to tropical climatic conditions developed; (2) The existence of *Pinuspollenites, Podocarpidites* indicative that there were highlands around the sedimentation region; (3) Woody plant cover consisting of *Engelhardtia* (Juglandaceae); *Bombacacidites* (Bombacaceae); *Polyadopollenites* (Caesalpiniaceae); Arecaceae probably covered the slopes and lowlands. Shrub forms Myricaceae, *Cupuliferoipollenites* (Fagaceae) constituted the underforest community; (4) The presence of angiosperms such as *Favitricolporites* (Nyssaceae), and *Engelhardtioidites* (Juglandaceae), *Retitrescolpites* (Oleaceae) suggest that there were lowland forests interrupted by lakes with extensive surrounding wetlands. Palynomorphs of forest vegetation covering the

Fossil palynotaxa	Affinities with modern Taxa
Montane	
Pinuspollenites crestus	Pinaceae
Podocarpidites khasiensis	Podocarpaceae
Podocarpidites ellipticus	Podocarpaceae
Cupuliferoipollenites	Fagaceae (Castanea)
Engelhardtioidites	Juglandaceae (Engelhardtia)
Umbelliferoipollenites	Umbelliferae
Lowland	
Bombacacidites	Bombacaceae (Bombax)
Faviotricolporites	Nyssaceae
Lygodiumsporites lakiensis	Schizaeaceae (Lygodium)
Polyadopollenites ramanujamii	Caesalpiniaceae
Retitrecolpites bellus	Oleaceae
Fresh water swamp and water edge	
Compositoipollenites	Asteraceae
Crassoretitriletes vanraadshovenii	Schizaeaceae (Lygodium)
Ctenolophonidites	Ctenolophonaceae (Ctenolophon)
Graminidites	Poaceae
Malvacearumpollis	Malvaceae (Thespesia)
Retipilonapites	Potamogetonaceae (Potamogeton)
Schizaeoisporites	Schizaeaceae (Schizaea)
Sparganiaceaepollenites	Sparganiaceae (Sparganium)
Striatriletes	Parkeriaceae
Trisyncolpites	Caesalpiniaceae (Poinciana)
Back Mangrove	
Araliaceoipollenites	Araliaceae
Rhoipites	Anacardiaceae (Melanorrhoea)
Mangrove	
Spinizonocolpites echinatus	Arecaceae
Malvacearumpollis bakonyensis	Malvaceae
Sandy Beach	
Palmaepollenites	Arecaceae
Polyporina	Chenopodiaceae (Chenopodium)
Algal	
Achomosphaera ramulifera	
Oligosphaeridium complex	
Operculodinium centrocarpum	
Thalassiphora pelagica	

Fig. 5—Distribution of modern pteridophyte, gymnosperm and angiosperm with spores or pollen taxa comparable to the fossil palynotaxa.

slopes and high lands surrounding the lake were carried by rivers and winds into wetlands; (5) The presence of non arborescent angiosperm pollen, for example, Poaceae and Chenopodiaceae is rare in Dulte Formation and suggests that open areas of land that were not swampy were possibly restricted in the depositional environment.

DISCUSSION

The palynoflora recorded from the Dulte Formation dominated by pteridophyte spores and angiosperm pollen. Gymnosperm pollen and fungal spores are also present. They are important constituent of the Middle Bhuban ? subgroup. Interpretation of the depositional environment is based on available lithological and palynological information obtained from the Aizawl Basin.

The presence of *Striatriletes, Polypodiisporites, Crassoretitriletes, Pteridacidites, Intrapunctisporis* and *Glecheniidites* is indicative of fresh water swamp or pond conditions near the site of deposition. Of the modern fern families represented by fossil spores in the Aizawl Basin. Schizaeaceae and Polypodiaceae are predominant. The pteridophyte families Schizaeaceae, Polypodiaceae and Pteridaceae have an extensive distribution, predominantly in the tropics and contribute to the undergrowth of dense moist forest (Kubitzki, 1990). The majority of fossil angiosperm pollen recorded from the site represents land plants. Pollen comparable with that of extant Arecaceae represents both mangrove (*Spinizonocolpites*) and more inland conditions (*Palmaepollenites*). The clay horizon shows a high percentage of pollen referable to *Retitrescolpites, Sapotaceoidae pollenites, Cupuliferoipollenites, Araliaceoipollenites* and *Malvacearumpollis.* The presence of spicules and pyrite granules in the clay are indicative of deposition under mangrove conditions. The presence of a diversity epiphytic microthyriaceous fungi spores is also indicative of high precipitation. These elements suggest that the area of deposition was probably near a shore line. The proximity of shallow marine conditions are indicated by the occurrence of dinoflagellate cysts. It is proposed that the palaeoenvironment might have been similar to the present day environment of the Aizawl area. *Cupuliferoipollenites, Umbelliferoipollenites, Engelhardtioidites* are taxa associated with drier and more temperate environment. *Pinuspollenites* occurs in the topmost surface soil at the northern end of the site. It is possible that the pollen was transported by air currents from a northern pine forest, high altitudinal gymnospermous pollen could probably have reached the site of deposition in large numbers. *Pinuspollenites, Piceapollenites* and *Podocarpidites* were also recorded from the Miocene sediments around Maibong, Assam (Mandaokar, 1990).

The fragments of leaf and wood tissue, amorphous and pyritized woody particles associated with the spores and pollen in the sediments, show a gradual and alternating recurrence of reducing environments. These tissues, however, are well preserved but not definitely identifiable to the genus level. The tissue preservation could be attributed to local flooding of the swamp. This interpretation is consistent with the sedimentological characteristics of the associated strata. The fragments of these tissue indicate the occurrence of forest fire during the deposition of the sediments. It is significant to infer a fluviomarine condition and the surrounding area sustained thick vegetation

CONCLUSION

On the basis of palynological study evidence, the Aizawl Basin was mainly inhabited by tropical to subtropical moist evergreen rainforests. The abundance of fungal remains, palm pollen and pteridophytic spores also indicates warm and humid climate. The alternation of shale-siltstone, sandstone-claystone and palynoflora present indicate an Early Miocene age. The terrestrial angiosperm pollen are comparatively more abundant in the lower part of the section, while the mangrove pollen are less present throughout the assemblage. The composition of the palyno-assemblage suggest that the Dulte Formation was deposited in deltaic conditions, rich in terrigenous detritus where fungal taxa thrived.

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Wood of *Dipterocarpus* from a new locality of the Champanagar Formation of Tripura, India

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ABSTRACT

Mehrotra RC & Bhattacharyya A 2002. Wood of *Dipterocarpus* from a new locality of the Champanagar Formation of Tripura, India. Palaeobotanist 51 : 123-127.

A fossil wood, *Dipterocarpoxylon bolpurense* Ghosh & Roy is described from a new locality, Bisalgarh, situated near Agartala, Tripura. It shows affinities with *Dipterocarpus* of Dipterocarpaceae and its presence indicates the occurrence of tropical evergreen forest in the vicinity.

Key-words—Fossil wood, *Dipterocarpoxylon*, Tipam Group, Bisalgarh, Upper Miocene, Tropical evergreen forest.

भारत के त्रिपुरा राज्य के चम्पानगर शैलसमूह की एक नयी संस्थिति से प्राप्त *डिप्टेरोकार्पस* के काष्ठ का विवेचन

राकेश चन्द्र मेहरोत्रा एवं अमलव भट्टाचार्य

सारांश

त्रिपुरा के अगरतला नामक स्थान के समीप अवस्थित एक नवीनतम संस्थिति बीसालगढ़ से *डिप्टेरोकार्पोज़ाइलॉन बोलपुरेन्से* घोष एवं राय नामक एक अश्मित काष्ठ का विवेचन प्रस्तुत शोध पत्र में किया गया है। यह डिप्टेरोकार्पेसी के *डिप्टेरोकार्पस* के साथ बन्धुता प्रदर्शित करता है तथा इसकी उपस्थिति सन्निकट में ऊष्णकटिबन्धीय सदाबहारी वनों की उपस्थिति को इंगित करती है।

संकेत शब्द—अश्मित काष्ठ, *डिप्टेरोकार्पोज़ाइलॉन,* टीपम समूह, बीसालगढ़, उपरि मायोसीन, उष्णकटिबन्धीय सदाबहारी वन.

INTRODUCTION

GEOGRAPHICALLY the Tripura lies in the north eastern part of India and has a link with rest of the country through the adjoining Cachar District of Assam. Palaeobotanically it is still unexplored as only five fossils in the form of woods have so far been described from near Khowai bridge Teliamura and Dumbur water falls near Amarpur. These are *Glutoxylon burmense* (Holden) Chowdhury of Anacardiaceae (Ghosh & Taneja, 1961), *Pahudioxylon sahnii* Ghosh & Kazmi (1961), *Cassinium tripuranum* Acharya & Roy, *Millettioxylon bengalensis* Ghosh & Roy (Acharya & Roy, 1986) and *Cynometroxylon holdenii* (Gupta) Prakash & Bande of Fabaceae (Awasthi *et al*., 1994).

The fossil wood being described here was collected from a new locality, Bisalgarh, situated at a distance of about 20 km south west of Agartala, Tripura (Fig. 1) where petrified woods occur scattered about in loose sand.

The fossil woods found in Tripura belong to the Champanagar Formation of the Tipam Group which is considered as Upper Miocene in age. The generalised geological succession of Tripura proposed by Karunakaran (1974) is presented in the form of a table (Fig. 2).

MATERIAL AND METHODS

The study is based on a solitary specimen measuring 6 cm in length and 3 cm in width. The wood is silicified and its structural details are fairly preserved. The wood was sectioned in three different planes and its ground thin sections were prepared by grinding on the disc using carborundum powder. Then these sections were mounted on the slides and polished. After polishing they were studied under the high power microscope.

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

SYSTEMATICS

Family—DIPTEROCARPACEAE Bentham and Hooker f.

Genus—DIPTEROCARPOXYLON Holden emend. Den Berger, 1927

Species—DIPTEROCARPOXYLON BOLPURENSE Ghosh & Roy, 1979

Pl. 1·1-7

Description—Wood diffuse porous. *Growth rings* absent. *Vessels* medium to large, t.d. 100-250 µm, r.d. 150-330 µm, almost exclusively solitary, very rarely in pairs, circular to oval, sometimes deformed due to compression, evenly distributed, 5-11/ sq mm, tylosed; vessel members 180-440 µm in height with oblique to horizontal ends; perforations simple; intervessel pits rarely preserved due to exclusively solitary vessels and presence of tyloses, circular to oval, bordered, alternate, about 10 µm in diameter with lenticular apertures. *Tracheids* vasicentric, intermixed with parenchymatous cells and forming a thin sheath around the vessels. *Parenchyma* both paratracheal and apotracheal; paratracheal scanty to vasicentric, forming a thin sheath around the vessels; apotracheal diffuse and in the form of short, broken tangential bands enclosing gum canals; cells 22-45 µm in width and 30-110 µm in length. *Xylem rays* 1-4 seriate, 4-6/mm, ray tissue heterogeneous, uniseriate rays made up of both procumbent and upright cells, 30-35 µm in width and 3-6 cells and 100-165 µm in height; multiseriate rays made up of procumbent cells in the central portion and a few upright cells at the margins, 80-110 µm in width and 15-20 cells and 500-1100 µm in height; sheath cells occasionally present on the flanks of multiseriate

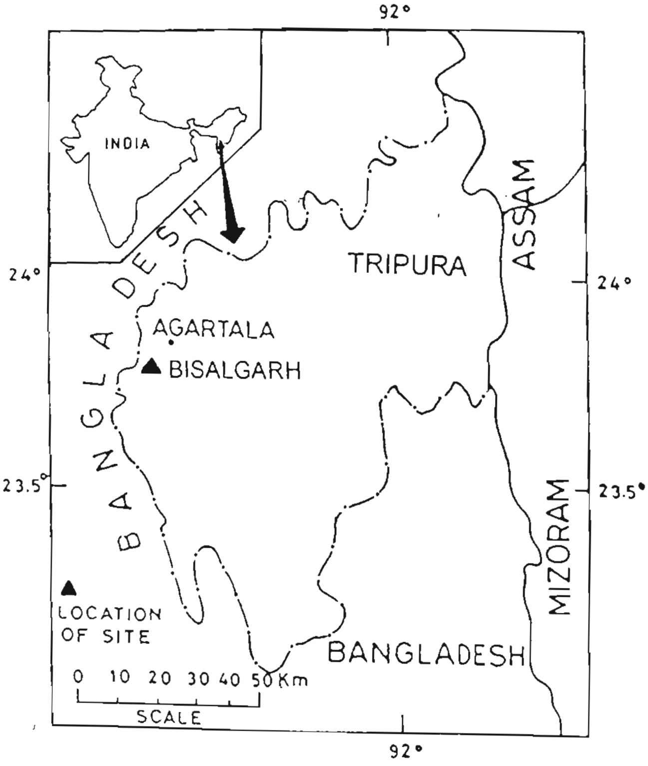

Fig. 1—A map of Northeast India showing the fossiliferous locality of Bisalgarh near Agartala, Tripura.

PLATE 1

→

Dipterocarpoxylon bolpurense Ghosh & Roy

1. Cross section of the fossil wood in low power showing distribution of vessels and gum canals (marked with arrows). x 40; Slide No. BSIP 38885-I.
2. Cross section of the fossil wood in high power showing shape and size of the vessels and parenchyma pattern. x 100; Slide No. BSIP 38885-I .
3. Radial longitudinal section of the fossil wood showing heterogeneous ray tissue. x 100; Slide No. BSIP 38885-III.
4. Tangential longitudinal section of the fossil wood in low power showing distribution of the xylem rays. x 40; Slide No. BSIP 38885-II.
5. Tangential longitudinal section of the fossil wood in high power showing structure of the xylem rays and fibres. x 100; Slide No. BSIP 38885-II.
6. Intervessel pits magnified. x 400; Slide No. BSIP 38885-II.
7. Tangential longitudinal section of the fossil wood in high power showing vasicentric tracheids. x 200; Slide No. BSIP 38885-II.

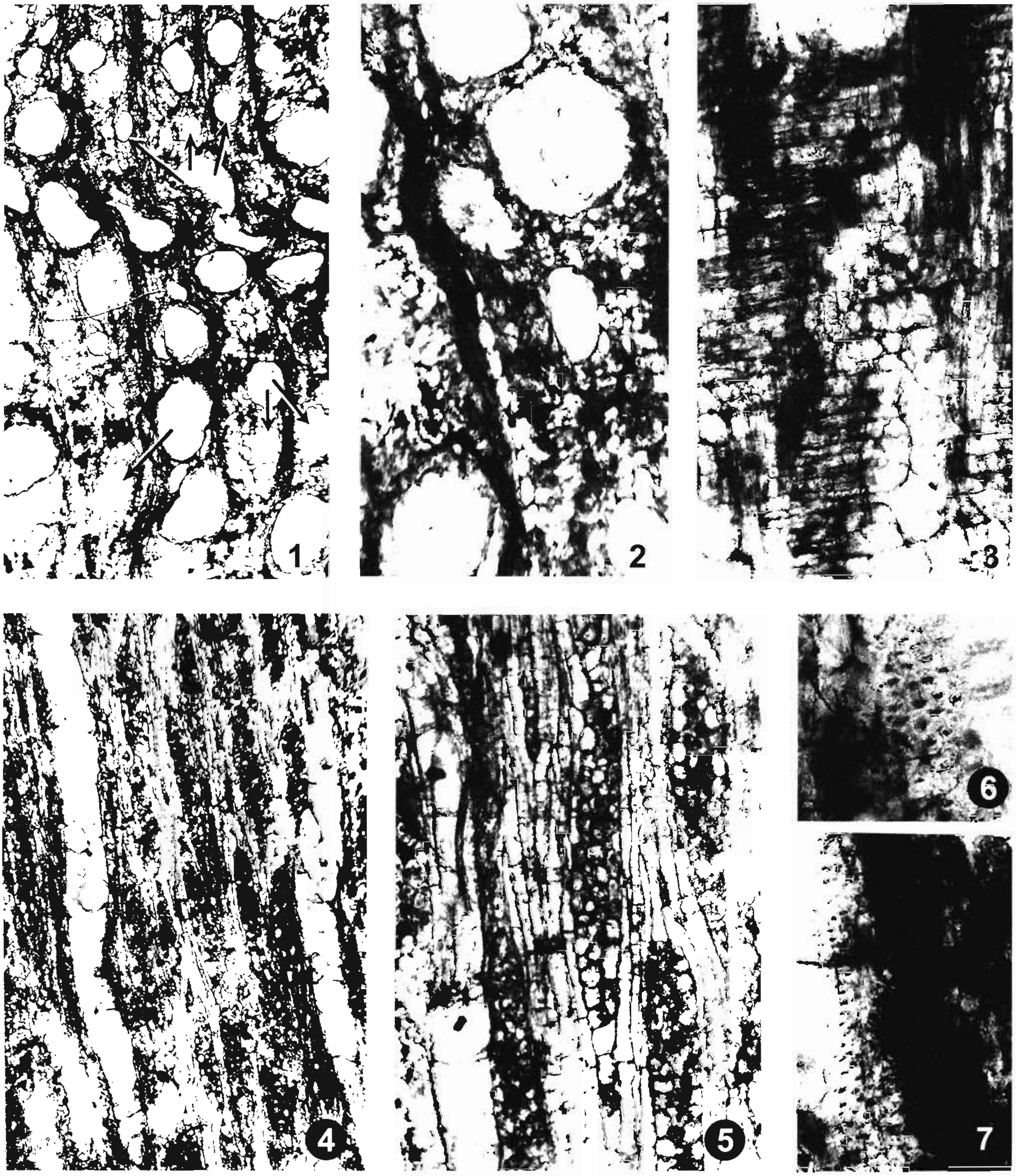

PLATE 1

Group	Subgroup	Formation	Lithology
Recent	--	Recent	Alluvium with decomposed vegetable matter
Unconformity			
Dupi Tila	--	Dupi Tila	Earthy brown to brown buff sandy clays with coarse to gritty ferruginous sandstone
Unconformity			
Tipam	Tipam Sandstone	Champanagar	Medium to coarse, friable, sub arkosic sandstone, with abundant lumps of silicified fossil wood
			Contact gradational
		Manu Bazar	Fine to medium, sub arkosic sandstone, including sandy shale, siltstone and sandy mudstone
Contact transitional			
Surma	Bokabil	--	Thinly bedded, repetition of sandstone, siltstone/ shale alternations, shales, mudstone and ferruginous sandstone
			Contact gradational to transitional
	Bhuban	--	Hard, compact, both massive and well bedded sandstone, sandy shale and siltstone repeatedly occurring in space
	Base not seen		

Fig. 2—Generalised geological succession of Tripura (after Karunakaran, 1974).

rays; ray to ray fusion observed; procumbent cells 50-60 μm in radial length and 20-45 μm in tangential height; upright cells about 25-30 μm in radial length and 30-45 μm in tangential height. *Fibres* moderately thick walled, polygonal in cross section, non septate, 12-18 μm in diameter. *Gum canals* normal, vertical scattered and in groups of 2-4, usually smaller than vessels, enclosed in parenchyma bands, t.d. 80-110 μm and r.d. 100-110 μm.

Specimen—Museum No. BSIP 38885.

Occurrence—Champanagar Formation; Bisalgarh, near Agartala, Tripura; Upper Miocene.

DISCUSSION

Presence of vertical gum canals is the most important character of the fossil. In the absence of epithelial lining these canals look like vessels, but a careful examination distinguishes them from the other vessels. In the present fossil wood vessels have generally scanty paratracheal to vasicentric parenchyma whereas gum canals are mostly smaller than the vessels and enclosed by apotracheal bands of parenchyma. The diagnostic features of the fossil, viz., exclusively solitary vessels, vertical gum canals solitary or in short tangential rows, vasicentric tracheids, vasicentric to diffuse to short broken tangential bands of parenchyma, 1-4 seriate heterocellular xylem rays along with a few sheath cells and non septate fibres, indicate its affinities with the woods of *Dipterocarpus* Gaertn. of Dipterocarpaceae (Pearson & Brown, 1932; Metcalfe & Chalk, 1950; Kribs, 1959; Miles, 1978; Ilic, 1991).

Den Berger (1927) instituted the genus *Dipterocarpoxylon* for those fossil woods which show resemblance with the woods of the extant *Dipterocarpus* of Dipterocarpaceae. Prakash (1973) and Awasthi (1974, 1980) listed various species of the fossil genus described from various parts of the world. Since then a large number of species of *Dipterocarpus* have been described from many Neogene localities of India (Ghosh & Roy, 1979; Trivedi & Ahuja, 1980; Prakash, 1981; Guleria, 1983, 1996; Yadav, 1989; Awasthi & Mehrotra, 1993, 1997; Antal *et al.*, 1999). After a detailed comparison with all these species it was found that our fossil is closely comparable with *Dipterocarpoxylon bolpurense* Ghosh & Roy (1979). This species is already known from the Neogene of Birbhum District, West Bengal (Ghosh & Roy, 1979) and Deomali, Arunachal Pradesh (Awasthi & Mehrotra, 1993). Its presence in Tripura indicates that the species was widespread in Northeast India during the Neogene.

The genus *Dipterocarpus* (Hindi name *Gurjun*) includes about 80 species found mainly in the Indo-Malayan region. The range of its distribution is from South India and Sri Lanka in the west to the Philippines in the east. About 13 of its species grow in the Indian Zone (Andamans, Myanmar, Sri Lanka, India and Pakistan). All of them are large to very large trees found in tropical evergreen forests having good amount of moisture and humidity (Ghosh, 1958).

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Dinoflagellate cyst evidence for the age of Kulakkalnattam Sandstone Member, Garudamangalam Formation, Cauvery Basin, southern India

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ABSTRACT

Khowaja-Ateequzzaman & Rahul Garg 2002. Dinoflagellate cyst evidence for the age of Kulakkalnattam Sandstone Member, Garudamangalam Formation, Cauvery Basin, southern India. Palaeobotanist 51 : 129-143.

Rich and diversified dinoflagellate cyst assemblages comprising 42 genera and 68 species have been recovered from the Kulakkalnattam Sandstone Member of the Garudamangalam Formation exposed in and around Ariyalur, Cauvery Basin, and southern India. First and last appearances of dinoflagellate cyst taxa present in the assemblage, including *Callaiosphaeridium asymmetricum, Circulodiniumn distinctum, Cribroperidinium aceras, C. edwardsii, C. cooksoniae, Conosphaeridium striatoconus, Cyclonephelium compactum, Florentinia cooksoniae, F. mantellii, Heterosphaeridium difficile, Litosphaeridium siphoniphorum* and *Palaeoperidinium pyrophorum*, suggest that the age of the member ranges from Middle to Late Turonian.

Key-words—Dinoflagellate cysts, Middle-Late Turonian, Kulakkalnattam Sandstone Member, Garudamangalam Formation, Cauvery Basin, India.

दक्षिण भारत की कावेरी द्रोणी के गरुड़मंगलम् शैलसमूह के कुलक्कलनट्टम् बालुकाश्म सदस्य के आयु निर्धारण हेतु घूर्णीकशाय पुटी प्रमाण

ख्वाजा अतीकुज़्ज़माँ एवं राहुल गर्ग

सारांश

दक्षिण भारत के अरियालूर, कावेरी द्रोणी में तथा इसके आस-पास अनावरित गरुड़मंगलम् शैलसमूह के कुलक्कलनट्टम् बालुकाश्म सदस्य से 42 वंशों तथा 68 प्रजातियों से युक्त सम्पन्न तथा वैविध्यमय घूर्णीकशाभ पुटी समुच्चय अंकित किए गए। समुच्चय में उपस्थित घूर्णीकशाभ पुटी वर्गकों की प्रथम तथा अन्तिम प्राप्ति में *कैलेइयोस्फ़ेयरीडियम एसाइमीट्रिकम, सर्क्युलोडाइनियम डिस्टिंक्टम, क्राइब्रोपेरिडाइनियम एसीरस, सी. एडवर्ड्साइ, सी. कुकसोनियाइ, कोनोस्फ़ेयरीडियम स्ट्रायाटोकोनस, साइक्लोनीफ़ीलियम कॉमपैक्टम, फ़्लोरेण्टीनिया कुकसोनियाइ, एफ़ मैण्टेलाइ, हेटीरोस्फ़ेयरीडियम डिफ़िसाइली, लिटोस्फ़ेयरीडियम साइफ़ोनीफ़ोरम* तथा *पेलियोपेरिडाइनियम* की उपस्थिति से प्रस्तावित होता है कि सदस्य की आयु मध्य से अन्तिम ट्यूरोनियन के मध्य है।

संकेत शब्द—घूर्णीकशाभ पुटी, मध्य-अन्तिम ट्यूरोनियन, कुलक्कलनट्टम बालुकाश्म सदस्य, गरुड़मंगलम शैलसमूह, कावेरी द्रोणी, भारत.

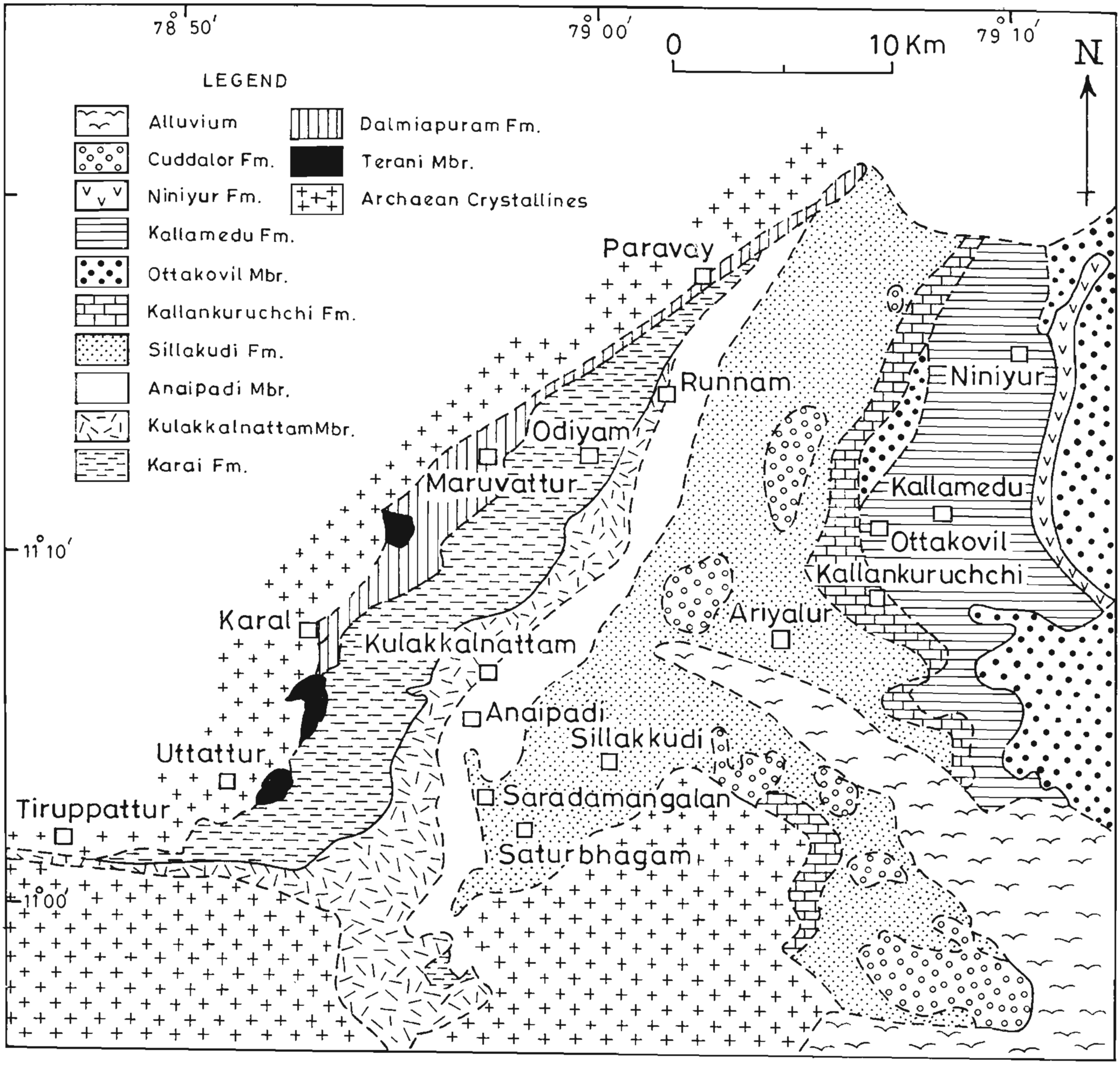

Fig. 1—Geological map of the Ariyalur area (after Blanford, 1864; Sundaram & Rao, 1986).

INTRODUCTION

THE Cauvery Basin is the southernmost basin of the East Coast of India, covering an area of approximately 25,000 sq km, extending from Tuticorin in the south to Pondicherry in the north. The basin shows the development of almost the entire Cretaceous succession, outcrops of which are quite widespread around the town of Ariyalur (Fig. 1), with a low southeasterly dip (Blanford, 1865; Ramanathan, 1968; Sastri *et al.*, 1981).

Biozonation and age determination of the Cretaceous succession of the Ariyalur area has been done mainly on ammonites (Sastry *et al.*, 1968; Chiplonkar & Phansalkar, 1976, 1978; Ayyasami & Rao, 1981; Ayyasami, 1990). Among planktonic microfossils, foraminifera (Banerji, 1973; Narayanan, 1977; Ramasamy & Banerji, 1991; Govindan *et al.*, 1996) and nannofossils (Kale & Phansalkar, 1992) have also been used. Most of the microfossil records are confined to the Uttatur (Albian-Lower Turonian) and Ariyalur (Santonian-Maastrichtian) groups of rocks. The Garudamangalam Formation, dated as Middle Turonian-Coniacian on ammonite

Tewari *et al.* (1996)			**Sundram & Rao (1986)**		**Banerji (1982); Ramasamy & Banerji (1991)**	
Ariyalur Group	Silakudi Formation		Ariyalur Group	Silakudi Formation	Ariyalur Formation	
Uttatur Group	Garudamangalam Formation	Anaipadi Sandstone Member	Trichinopoly Group	Anaipadi Formation	Garudamangalam Formation	Break in sedimentation not recognised
						Kulattur Member
		Kulakkalnattam Sandstone Member		Kulakkalnattam Formation		Anaipadi Member
						Kottarai Member
	Karai Formation		Uttatur Group	Karai Formation	Uttatur Formation	

Fig. 2—Correlation of lithostratigraphic classification for the Cauvery Basin (after Tewari *et al.*, 1996).

evidence, has so far yielded only a meagre assemblage of foraminifera (Phansalkar & Kurien, 1980). Recently, its lower range has been extended to Upper Turonian on stratigraphic criteria (Hart *et al.*, 1996; Tewari *et al.*, 1996). A major hiatus within the Upper Turonian has been interpreted based on subsurface data (Govindan *et al.*, 1996). In the present paper, precisely datable Middle-Late Turonian dinoflagellate cysts are documented from the lower part of Garudamangalam Formation (Kulakkalnattam Sandstone Member), highlighting their significance in age determination and their correspondence with ammonite evidence.

The stratigraphic ranges of dinoflagellate cyst taxa described earlier from Kulakkalnattam Sandstone Member, Garudamangalam Formation (Trichinopoly Formation) by Khowaja-Ateequzzaman and Jain (1990), Khowaja-Ateequzzaman *et al.* (1991) and Khowaja-Ateequzzaman and Garg (1995) are revised herein.

STRATIGRAPHY

The Cretaceous succession of the Cauvery Basin has been the subject of intensive research due to its highly fossiliferous nature since the pioneering studies of Blanford (1865). Several modifications to the lithostratigraphic classification of Blanford have been proposed from time to time with use made of renamed or new lithostratigraphic units (Ramanathan, 1968; Banerji, 1973; Sundaram & Rao, 1979, 1986; Sastri *et al.*, 1981; Ramasamy & Banerji, 1991; Tewari *et al.*, 1996). The generalised lithostratigraphical classification of the Cretaceous rocks in the Cauvery Basin proposed by Sundaram and Rao (1986) and Tewari *et al.* (1996) has been followed here (Fig. 2).

The Garudamangalam Formation consists of a coarse sandy to gritty, shaly succession interbedded with highly fossiliferous gritty to conglomeratic calcareous sandstones and shelly calcareous sandstones. It is subdivided into a lower Kulakkalnattam Sandstone Member and an upper Anaipadi Member (Sundaram & Rao, 1979; Tewari *et al.*, 1996). It overlaps the underlying Karai Formation in the southernmost and northernmost parts. The junction between Garudamangalam Formation and Karai Formation (Uttatur Group) is marked by a fossiliferous pebbly calcareous sandstone, occurring as medium to large concretions, observed from the vicinity of Tappy in the south to Kunnam and Odiyam in the north. Between Varagur-Paravay, and Vayalpadi further north the lower beds of the Garudamangalam Formation can be seen to overlap the sandier succession of the Karai Formation. The basal fossiliferous concretionary calcareous sandstone of the Garudamangalam Formation is characterised by the occurrence of pebbles and cobbles of quartz, older Archaean rocks, and lenses of underlying Karai Shale Formation (see Pascoe, 1959; p. 1235). The basal beds of Garudamangalam Formation are well exposed west of Kunnam towards Odium, Mungilpadi and towards Kunnam reserve forest. The basal conglomeratic shelly calcareous sandstone gradually changes upwards into hard fossiliferous calcareous sandstone that is more or less gritty and weathers out in medium to large concretions. These concretions have sandy outer layers that are often rich in large bivalve shells whereas their interiors are fine-grained, more calcareous and contain layers

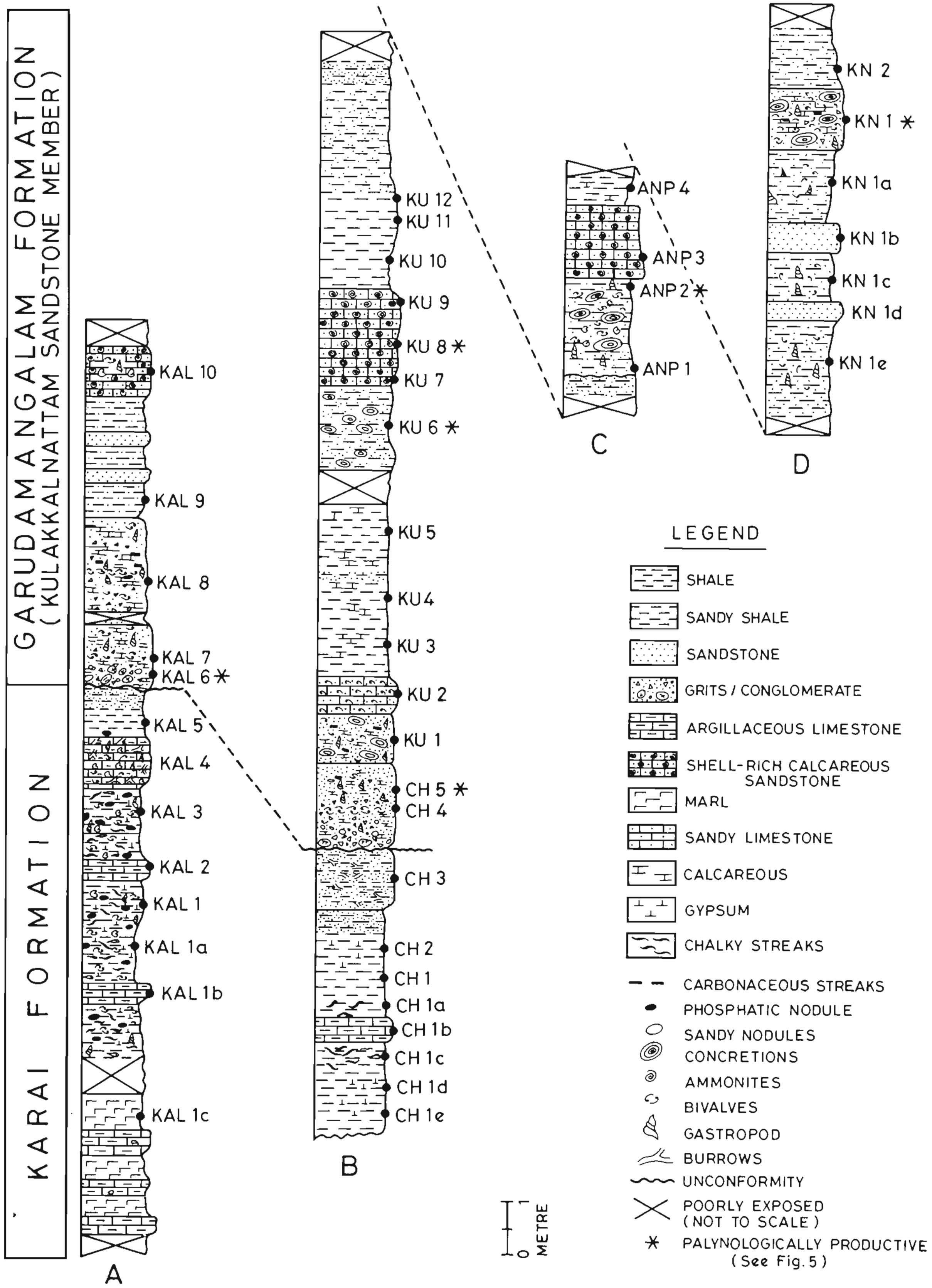

Fig. 3—Lithostratigraphic column of the sections studied. **A**, Kallakudi-Tappy area. **B**, Chittali-Kunnam area. **C**, near Anaipadi. **D**, near Kulakkalnattam.

S. No.	List of dinoflagellate cyst taxa	Plate & Figure reference of illustrated taxa
1.	*Achomosphaera ramulifera* (Deflandre) Evitt, 1963	
2.	*Achomosphaera* sp.	
3.	*Aiora fenestrata* (Deflandre & Courteville) Cookson & Eisenack, 1960	(pl. 3, fig. 15)
4.	*Alterbidinium acutulum* (Wilson) Lentin & Williams 1985 emend. Khowaja-Ateequzzaman *et al.*, 1991	
5.	*A. minus* (Alberti) Lentin &Williams, 1966	(pl. 3, figs 5, 12)
6.	*A. papillatum* Khowaja-Ateequzzaman *et al.*, 1990	(pl. 3, fig. 1)
7.	*Callaiosphaeridium asymmetricum* (Deflandre & Cookson) Davey & Williams *in* Davey *et al.*, 1966	(pl. 1, figs 17-18)
8.	*Cassiculosphaeridia reticulata* Davey, 1969	(pl. 1, fig. 15)
9.	*Cassiculosphaeridia* sp.	
10.	*Cauveridinium indicum* Khowaja-Ateequzzaman & Jain, 1990	(pl. 2, fig. 6)
11.	*C. intermedium* Khowaja-Ateequzzaman & Jain, 1990	(pl. 1, fig. 10)
12.	*C. longispinosum* Khowaja-Ateequzzaman & Jain, 1990	
13.	*Chatangiella* sp. A	(pl. 1, fig. 14)
14.	*Chatangiella* sp. B	(pl. 2, fig. 7)
15.	*Circulodinium distinctum* (Deflandre & Cookson) Jansonius, 1986	(pl. 3, figs 7-8)
16.	*Cleistosphaeridium huguoniotii* (Valensi) Davey, 1969	(pl. 2, fig. 4)
17.	*Conosphaeridium striatoconus* (Deflandre & Cookson) Cookson & Eisenack, 1969	(pl. 1, fig. 4)
18.	*Coronifera oceanica* Cookson & Eisenack emend. May, 1980	(pl. 2, fig. 14)
19.	*C. tubulosa* Cookson & Eisenack, 1974	(pl. 2, fig. 9)
20.	*Cribroperidinium aceras* (Eisenack) emend. Sarjeant,1985	(pl. 3, fig. 19)
21.	*C. cooksoniae* Norvick,1976	
22.	*C. edwardsii* (Cookson & Eisenack) Davey, 1969	(pl. 3, fig. 17)
23.	*Cribroperidinium* sp.	(pl. 3, fig. 4)
24.	*Cyclonephelium chabaca* Below, 1981	(pl. 1, fig. 11)
25.	*C. compactum* Deflandre & Cookson, 1955	
26.	*C. paucimarginatum* Cookson & Eisenack, 1962	(pl. 1, fig. 8)
27.	*C. vannophorum* Davey, 1969	(pl. 1, fig. 12; pl. 2, figs 13, 19)
28.	*Diconodinium multispinosum* (Deflandre & Cookson) Eisenack & Cookson, 1960	
29.	*Dioxya armata* Cookson & Eisenack, 1958	(pl. 1, fig. 1)
30.	*Exochosphaeridium phragmites* Davey *et al.*, 1966	(pl. 1, fig. 9)
31.	*Florentinia buspina* (Davey & Verdier) Duxbury, 1980	(pl. 3, fig. 14)
32.	*F. cooksoniae* (Singh) Duxbury, 1980	
33.	*F. deanei* (Davey & Williams) Davey & Verdier, 1980	(pl. 1, fig. 19)
34.	*F. mantellii* (Davey & Williams) Davey & Verdier, 1973	
35.	*Florentinia* sp.	(pl. 3, fig. 18)
36.	*Hapsocysta peridictya* (Eisenack & Cookson) Davey, 1979	(pl. 2, fig. 20)
37.	*Heterosphaeridium difficile* (Manum & Cookson) Ioannides, 1986	(pl. 3, fig. 11)
38.	*H. heteracanthum* (Deflandre & Cookson) Eisenack & Kjellstrom, 1971	
39.	*Hystrichodinium pulchrum* Deflandre, 1935	
40.	*Hystrichosphaeridium duplum* (White) Downie & Sarjeant, 1965	(pl. 1, fig. 7)
41.	*H. recurvatum* (White) Lejeune-Carpentier, 1940	
42.	*H. tubiferum* (Ehrenberg) Deflandre 1937 emend. Davey & Williams *in* Davey *et al.*,1966	
43.	*Isabelidinium acuminatum* (Cookson & Eisenack) Stover & Evitt, 1978	
44.	*Jainiella breviornata* Khowaja-Ateequzzaman & Garg,1995	
45.	*Kiokansium polyps* (Cookson & Eisenack) Below, 1982	(pl. 2, fig. 10)
46.	*Litosphaeridium siphoniphorum* (Cookson & Eisenack) Davey & Williams *in* Davey *et al.*,1966 emend. Lucas-Clark, 1984	(pl. 2, fig. 15)
47.	*Meiourogonyaulax bulloidea* (Cookson & Eisenack) Sarjeant, 1969	(pl. 2, fig. 5)
48.	*Odontochitina operculata* (Wetzel) Deflandre & Cookson, 1955	
49.	*Oligosphaeridium complex* (White) Davey & Williams *in* Davey *et al.*, 1966	
50.	*O. complex* sub sp. *brevispinum* Jain, 1977	
51.	*O. pulcherrimum* (Deflandre Cookson) Davey & Williams, 1966	(pl. 1, fig. 16)
52.	*Palaeohystrichophora infusorioides* Deflandre, 1935	(pl. 2, fig. 1)

53. *Palaeoperidinium cretaceum* Pocock 1962 emend. Davey, 1970	(pl. 3, fig. 3)
54. *P. pyrophorum* (Ehrenberg) Sarjeant, 1967	(pl. 3, figs 2,13,16)
55. *Pervosphaeridium pseudhystrichodinium* (Deflandre) Yun, 1981	(pl. 2, fig. 11)
56. *Psaligonyaulax deflandrei* Sarjeant *in* Davey *et al.* 1966 emend. Sarjeant, 1982	
57. *Pterodinium aliferum* Eisenack 1958 emend. Sarjeant, 1985	(pl. 1, figs 5-6; pl. 3, figs 9-10)
58. *Sepispinula huguoniotii* (Valensi) Islam, 1993	
59. *Spiniferites porosus* (Manum & Cookson) Harland, 1973	(pl. 1, fig. 3)
60. *S. ramosus* subsp. *gracilis* (Davey & Williams) Lentin & Williams, 1973	(pl. 2, fig. 8)
61. *S. ramosus* subsp. *ramosus* (Ehrenberg) Davey & Williams, 1966	(pl. 1, fig. 13)
62. *Subtilisphaera habibii* Masure, 1980	(pl. 2, fig. 3; pl. 3, fig. 6)
63. *Tanyosphaeridium* sp.	
64. *Tenua hystrix* Eisenack, 1958	(pl. 2, fig. 16)
65. *Trichodinium castanea* (Deflandre) Clarke & Verdier, 1967	(pl. 2, fig. 2)
66. *Valensiella griphus* Norvick, 1976	(pl. 1, fig. 2)
67. *Xenascus ceratioides* (Deflandre) Lentin & Williams, 1973	(pl. 2, figs 17-18)
68. *Xiphophoridium alatum* (Cookson & Eisenack) Sarjeant *in* Davey *et al.*, 1966	(pl. 2, fig. 12)

Fig. 4—List of dinoflagellate cyst taxa recovered from the Kulakkalnattam Sandstone Member of the Garudamangalam Formation, listed alphabetically by genera, followed by plate and figure references of illustrated taxa.

of small, broken fragments of bivalves. Current bedding is often prominent. This "conglomerate", considered by most of workers to indicate an unconformable relationship between the two formations, has recently been interpreted as having formed during a transgressive event, indicative of a sequence boundary caused by forced regression at the top of the underlying deeper water Karai Shale.

The succeeding beds consist of a succession of soft silty calcareous shales, which are variegated in colour and poorly fossiliferous. In the upper part the shales contain hard, sandy to calcareous concretions. This shaly succession is overlain by a compact, richly fossiliferous, grey, shell-rich calcareous sandstone, 1-2 m thick ("Shell Limestone" in Pascoe, 1959), typical of the Garudamangalam Formation. These shell-rich calcareous sandstones can be traced almost along the entire strike from Garudamangalam in the south to Kunnam in the north. However, there are significant lateral facies changes from south to north. The younger beds of Garudamangalam Formation (Anaipadi Sandstone Member) are exposed intermittently eastwards of Kulakkalnattam, Anaipadi, Garudamangalam and Kunnam. Better exposures of sandy to silty shales with interbedded medium to coarse sandstones and sandy to gritty fossiliferous calcareous sandstones can be seen between Kunnam, Karambium and Mel Mattur in the north and between Kulakkalnattam-Kullatur,

PLATE 1

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(All photomicrographs in Nomarski Interference Contrast; magnified x 500)

1. *Dioxya armata* Cookson & Eisenack 1958, Slide No. BSIP 11501, coordinates 21·6 x 139·6.
2. *Valensiella griphus* Norvick 1976, Slide No. BSIP 10262; co-ordinates 21·8 x 138·5.
3. *Spiniferites porosus* (Manum & Cookson) Harland 1973, Slide No. BSIP 10263; coordinates 13·5 x 130·0.
4. *Conosphaeridium striatoconus* (Deflandre & Cookson) Cookson & Eisenack 1969, Slide No. BSIP 11499; coordinates 15·2 x 164·3.

5-6. *Pterodinium aliferum* Eisenack 1958 emend. Sarjeant 1985, Slide No. BSIP 11522; coordinates (5) 20·0 x 139·2 (6) 28·2 x 113·9.

7. *Hystrichosphaeridium dupulum* (White) Downie & Sarjeant 1965, Slide No. BSIP 11509; coordinates 11·6 x 138·2.
8. *Cyclonephelium paucimarginatum* Cookson & Eisenack 1962, Slide No. BSIP 11517; coordinates 15·0 x 161·9.
9. *Exochosphaeridium phragmites* Davey *et al.*, 1966, Slide No. BSIP 11511; coordinates 14·0 x 155·8.
10. *Cauveridinium intermedium* Khowaja-Ateequzzaman & Jain 1990, Slide No. BSIP 11509; coordinates 9·5 x 167·8.
11. *Cyclonephelium chabaca* Below 1981, Slide No. BSIP 10262; coordinates 16·3 x 154·1.
12. *C. vannophorum* Davey 1969, Slide No. BSIP 11499; coordinates 8·2 x 155.
13. *Spiniferites ramosus* sub sp. *ramosus* (Ehrenberg) Loeblich & Loeblich 1966, Slide No. BSIP 11502; coordinates 19·5 x 140·9.
14. *Chatangiella* sp. A, Slide No. BSIP 11505; coordinates 7·3 x 129·0.
15. *Cassiculosphaeridia reticulata* Davey 1969, Slide No. BSIP 10264; coordinates 8·0 x 151·0.
16. *Oligosphaeridium pulcherrimum* (Deflandre & Cookson) Davey & Williams 1966, Slide No. BSIP 11509; coordinates 13·5 x 163·7.

17-18. *Callaiosphaeridium asymmetricum* (Deflandre & Courteville) Davey & Williams *in* Davey *et al.* 1966, Slide No. BSIP 11509; coordinates 15·5 x 153·5.

19. *Florentinia deanei* (Davey & Williams) Davey & Verdier 1980, Slide No. BSIP 11516; coordinates 8·0 x 144·0.

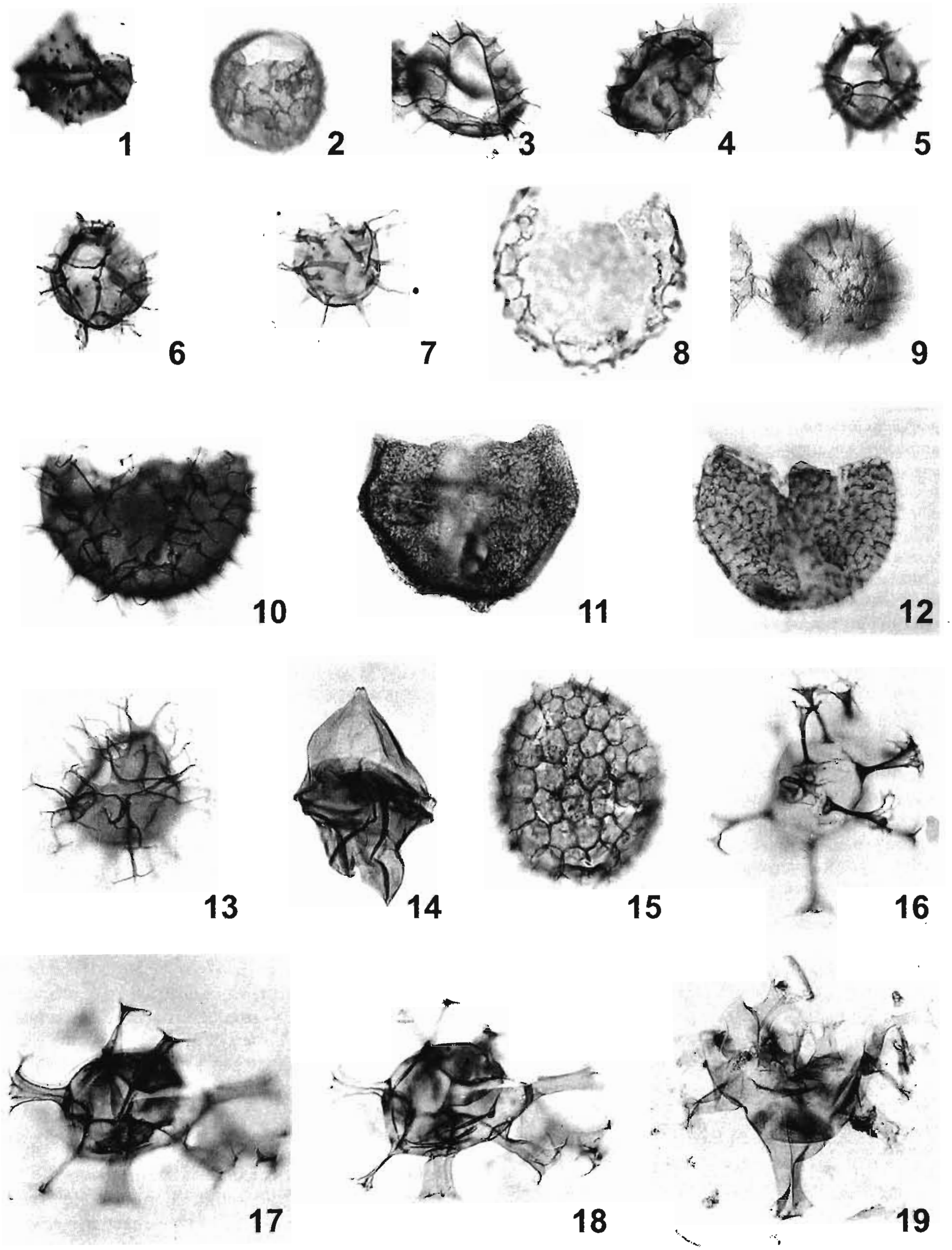

PLATE 1

	Sample					
Dinoflagellate cyst Taxa	**KAL 6**	**CH 5**	**KU 6**	**KU 8**	**ANP 2**	**KN 1**
Spiniferites ramosus sub sp. *ramosus*	■	■	■	■	■	■
Achomosphaera sp.	■		■	■		■
Tenua hystrix	■					■
Cyclonephelium vannophorum	■	■	■	■	■	
Oligosphaeridium complex	■	■	■	■	■	
Cauveridinium indicum	■	■	■	■		
Circulodinium distinctum	■	■	■	■		
Xenascus ceratioides	■	■	■	■		
Cribroperidinium cooksoniae	■	■		■		
Cauveridinium intermedium	■			■		
Alterbidinium minus	■	■	■			
Exochosphaeridium phragmites	■	■	■			
Chatangiella sp. A	■	■				
Criborperidinum edwardsii	■	■				
Cyclonephelium chabaca	■	■				
Kiokansium polyps	■	■				
Psaligonyaulax deflandrei	■	■				
Callaiosphaeridium asymmetricum	■					
Chatangiella sp. B	■					
Cleistosphaeridium huguoniotii	■					
Florentinia cooksoniae	■					
Hystrichosphaeridium duplum	■					
H. recurvatum	■					
Isabelidinium acuminatum	■					
Litosphaeridium siphoniphorum	■					
Oligosphaeridium pulcherrimum	■					
Palaeohystrichophora infusorioides	■					
Pervosphaeridium pseudhystrichodinium	■					
Sepispinula huguoniotii	■					
Spiniferites ramosus gracilis	■					
Trichodinium castanea	■					
Cyclonephelium compactum		■	■	■		
Spiniferites porosus		■	■	■		
Conosphaeridium striatoconus		■		■		
Hystrichodinium pulchrum		■		■		
Dioxya armata		■	■			
F. mantellii		■	■			
Heterosphaeridium difficile		■	■			
Coronifera tubulosa		■				
Diconodinium multispinosum		■				
Hapsocysta peridictya		■				
Meiourogonyaulax bulloidea		■				
Subtilisphaera ? habibii		■				
Achomosphaera ramulifera			■	■	■	■
Coronifera oceanica			■	■		■
Cribroperidinium sp.			■	■		
Florentinia deanei			■	■		
Palaeoperidinium cretaceum			■	■		
Aiora fenestrata			■			
Alterbidinium acutulum			■			
A. papillatum			■			
Cassiculosphaeridia sp.			■			
Cassiculosphaeridia reticulata			■			
Cribroperidinium aceras			■			
Florentinia buspina			■			

Florentinia sp.	■	
Jainiella breviornata	■	
Pterodinium aliferum	■	
Cauveridinium longispinosum		■
Cyclonephelium paucimarginatum		■
Heterosphaeridium heteracanthum		■
Hystrichosphaeridium tubiferum		■
Odontochitina operculata		■
Oligosphaeridium complex brevispinum		■
Palaeoperidinium pyrophorum		■
Tanyosphaeridium sp.		■
Valensiella griphus		■
Xiphophoridium alatum		■

Fig. 5—Stratigraphic distribution of dinoflagellate cyst taxa; see Fig. 3 for sample locations.

Anaipadi-Sattambadi and Garudamangalam-Sardamangalam in the south.

MATERIAL AND METHODS

In order to cover the entire succession as well as to document the lithological variations and nature of contacts, the following traverses were undertaken along and across the strike : Kallakudi – Arogyapuram – Tappy – Siruvayalur; Karai – Kulakkalnattam – Aynapuram – Anaipadi – Garudamangalam; Chittali – Odiyam – Kunnam; Kunnam – Odiyam – Mungalpari; Kalpadi – Kunnam – Varagur – Paravay – Vayalpadi.

More than 200 samples for palynological studies were systematically collected from several sections exposed along *nala* cuttings, hillocks, road cuttings, ponds and dug-wells. A composite lithological log indicating the positions of the productive samples is given in Fig. 3.

Standard palynological techniques were used to recover the dinoflagellate cysts. Samples were treated with HCL and HF and the organic matter recovered oxidised using 40% HNO_3. A 20 μm sieve has been used for washing purposes. The residue was stained with safranine and the permanent slides were prepared using polyvenyl alcohol and Canada balsam. Specimens were photographed using an Olympus BH2 microscope. The slides have been registered and deposited in the repository of the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow, U.P., India.

AGE OF KULAKKALNATTAM SANDSTONE MEMBER, GARUDAMANGALAM FORMATION

The age of the Garudamangalam Formation (*ex* Trichinopoly Group, Trichinopoly Stage, Trichinopoly Formation) has been a matter of controversy since the time of Blanford (1865), despite its fossiliferous nature. The formation is rich in molluscs, including ammonites, which form the main basis for most of the evidence of age determination. There is not much microfossil evidence from surface deposits. A lack of datable plankton and ammonites in the basalmost part of the formation (comprising conglomerate or concretionary calcareous sandstone) has further compounded the situation. Our study is, however, based on precisely datable dinoflagellate cyst assemblages recovered from the lower part of the Garudamangalam Formation.

Different workers have assigned different ages to the Garudamangalam Formation from time to time. A Middle Turonian – Early Senonian age-range was first determined on the ammonite evidence (Kossmat, 1895, 1898 *in* Sastry *et al.*,1968; Pascoe, 1959). Pascoe (1959, p. 1223, 1240) pointed out that the lower part of the Trichinopoly Stage (Garudamangalam Substage) is characterised by the ammonite *Pachydiscus peramplus* and occupies the bulk of Turonian, "representing all but the lower portion of Turonian". This conclusion was also derived from the fact that the uppermost beds of the underlying Uttatur Stage (now Karai Shale) were dated as Early Turonian on ammonite (*Mammites conciliatum*) and inoceramid (*Inoceramus labiatus*) evidence (see Pascoe, 1959; p. 1233). An Ammonite biozonation of the formation was subsequently proposed by Sastry *et al.* (1968); this comprised, in ascending order, *Lewesiceras raju* (Middle – Upper Turonian), *Kossmaticeras theobaldianum* (upper most Turonian-Coniacian) and *Placenticeras tamulicum* zones (Santonian). According to Chiplonkar and Ghare (1979) *Kossmaticeras theobaldianum* Zone does not appear to be a distinct zone including it in the *Proplacenticeras* (*Placenticeras*) *tamulicum* Zone suggesting a Late Turonian – Coniacian age. It is pertinent to note here that Chiplonkar and Phansalkar (1976) and Phansalkar and Kumar (1983) reported the ammonites *Romaniceras ornatissimum* and *R. deverianum* from the lower part of the formation. These can be correlated with the uppermost Middle Turonian – basal Upper Turonian ammonite *Ornatissimum* and *Deverianum* zones of the Type Turonian of France (see Robazynski *et al.*, 1982; p. 136, fig. 7; Haq *et al.*, 1988). All of the above suggest that the Garudamangalam Formation is Middle Turonian – Coniacian in age as favoured by Acharyya and Lahiri (1991, p. 6) on ammonite and inoceramid evidence. Chiplonkar & Tapaswi (1979), however, assigned Late Turonian – Santonian age, based on inoceramids. More recently Hart *et al.* (1996) and Tewari *et al.* (1996) have suggested a Late Turonian – Coniacian age-range for the formation. They reported a planktonic foraminiferal assemblage containing *Whiteinella archaeocretacea* and *Praeglobotruncana helvetica* from the underlying Karai Shale and dated it as early Middle Turonian. Similar assemblages were reported by Govindan *et al.* (1996) also from surface and subsurface sections. Hart *et al.* (1996) interpreted a major regression event towards the top of Karai Shale as a sudden replacement of the planktonic foraminiferal fauna by a dominantly agglutinated microfauna was considered to be indicative of rapid shallowing. They further concluded that the nodular/concretionary calcareous sandstone beds at the base of Garudamangalam Formation formed during a Late Turonian transgressive event that is recognisable over much of the globe. It was thus interpreted as a succession of Late Turonian – Coniacian age with its base constituting a sequence boundary caused by forced regression.

Ramanathan (1968) and Sastry *et al.* (1981) indicated that rocks of Garudamangalam Formation are difficult to recognise in the subsurface. Based on planktonic foraminiferal studies of subsurface sections, a major hiatus within the Upper Turonian has recently been identified (Govindan *et al.*, 1996; Raju & Ramesh, 1998). Although, Govindan *et al.* (1996, p. 168) suggested that the unfossiliferous deposits above the *Praeglobotruncana helvetica* Zone (Early – Middle Turonian) may represent the Upper Turonian sediments in the outcrop area, they still favoured a Coniacian – Santonian age for the Trichinopoly Group (see Govindan *et al.*, 1996, figs 4, 11). The occurrence of distinctive Middle – Late Turonian ammonite assemblages, noted above, have probably not been given due consideration. Against this background information, recovery of Middle – Late Turonian dinoflagellate cysts from out crop succession is highly significant.

Palynological assemblages recovered from the Kulakkalnattam Sandstone Member are rich and well preserved. They are dominated by dinoflagellate cysts, spores and pollen grains, and terrestrial organic matter. Dinoflagellate cysts are represented by 68 species (see Fig. 4) and show remarkable changes in their vertical distribution, with distinctive assemblages occurring at different stratigraphic levels (Fig. 5). A comparison of the assemblage overall with that of the type region of the Turonian of France (Robaszynski *et al.*, 1982) shows close resemblance with taxa. The following taxa are common to both regions thus supporting Turonian age for Kulakkalnattam Sandstone Member : *Callaiosphaeridium asymmetricum, Cassiculosphaeridia* spp., *Circulodinium distinctum, Coronifera oceanica, Cyclonephelium vannophorum, Exochosphaeridium phragmites, E. pseudhystrichodinium* (*Pervosphaeridium pseudhystrichodinium*), *Florentinia deanei, F. mantellii, Heterosphaeridium difficile, H. heteracanthum, Kiokansium polyps, Litosphaeridium siphoniphorum, Odontochitina operculata, Oligosphaeridium complex, O. pulcherrimum, Palaeohystrichophora infusorioides, Psaligonyaulax deflandrei, Spiniferites ramosus gracilis, S. ramosus ramosus, Trichodinium castanea* and *Xenascus ceratioides. Conosphaeridium striatoconus, Heterosphaeridium difficile* (First appearance datum for both FAD) at the base of Middle

PLATE 2

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(All photomicrographs in DIC x 500)

1. *Palaeohystrichophora infusorioides* Deflandre 1935, Slide No. BSIP 10262; coordinates 19·3 x 152·9.
2. *Trichodinium castanea* (Deflandre) Clarke & Verdier 1967, Slide No. BSIP 11502; coordinates 17·6 x 131·0.
3. *Subtilisphaera habibii* Masure 1988, Slide No. BSIP 10263; coordinates 11·6 x 124·2.
4. *Cleistosphaeridium huguoniotii* (Valensi) Davey 1969, Slide No. BSIP 11502; coordinates 17·0 x 139·4.
5. *Miourogonyaulax bulloidea* (Cookson & Eisenack) Sarjeant 1969, Slide No. BSIP 11494; coordinates 15·4 x 120·9.
6. *Cauveridinium indicum* Khowaja-Ateequzzaman & Jain 1990, Slide No. BSIP 10273; coordinates 3·0 x 146·9.
7. *Chatangiella* sp. B. Slide No. BSIP 11507; coordinates 9·6 x 166·1.
8. *Spiniferites ramosus* sub sp. *gracilis* (Davey & Williams) Lentin & Williams 1973, Slide No. BSIP 11509; coordinates 11·6 x 138·0.
9. *Coronifera tubulosa* Cookson & Eisenack 1974, Slide No. BSIP 11503; coordinates 18·3 x 140·0.
10. *Kiokansium polyps* (Cookson & Eisenack) Below 1982, Slide No. BSIP 11500; coordinates 16·6 x 163.
11. *Pervosphaeridium pseudhystrichodinium* (Deflandre) Yun 1981, Slide No. BSIP 11510; coordinates 16·6 x 142·0.
12. *Xiphophoridium alatum* (Cookson & Eisenack) Sarjeant 1966, Slide No. BSIP 11504; coordinates 5·5 x 137·4.
13. *Cyclonephelium vannophorum* Davey 1969, Slide No. BSIP 11498; coordinates 11·0 x 148·2.
14. *Coronifera oceanica* Cookson & Eisenack 1958 emend. May 1980, Slide No. BSIP 11513; coordinates 11·7 x 156·8.
15. *Litosphaeridium siphoniphorum* (Cookson & Eisenack) Davey & Williams 1966 emend. Lucas-Clark 1984, Slide No. BSIP 11506; coordinates 7·4 x 156·7.
16. *Tenua hystrix* Eisenack 1958, Slide No. BSIP 11503; coordinates 13·6 x 128·4.

17-18. *Xenascus ceratioides* (Deflandre) Lentin & Williams 1973; (17) Slide No. BSIP 11515; coordinates 20 x 144·2; (18) Slide No. BSIP 11513; coordinates 12·5 x 127·4.

19. *Cyclonephelium vannophorum* Davey 1969, Slide No. BSIP 11496; coordinates 17·4 x 161·5.
20. *Hapsocysta peridictya* (Eisenack & Cookson) Davey 1979. Slide No. BSIP 11516; coordinates 17·4 x 161·5.

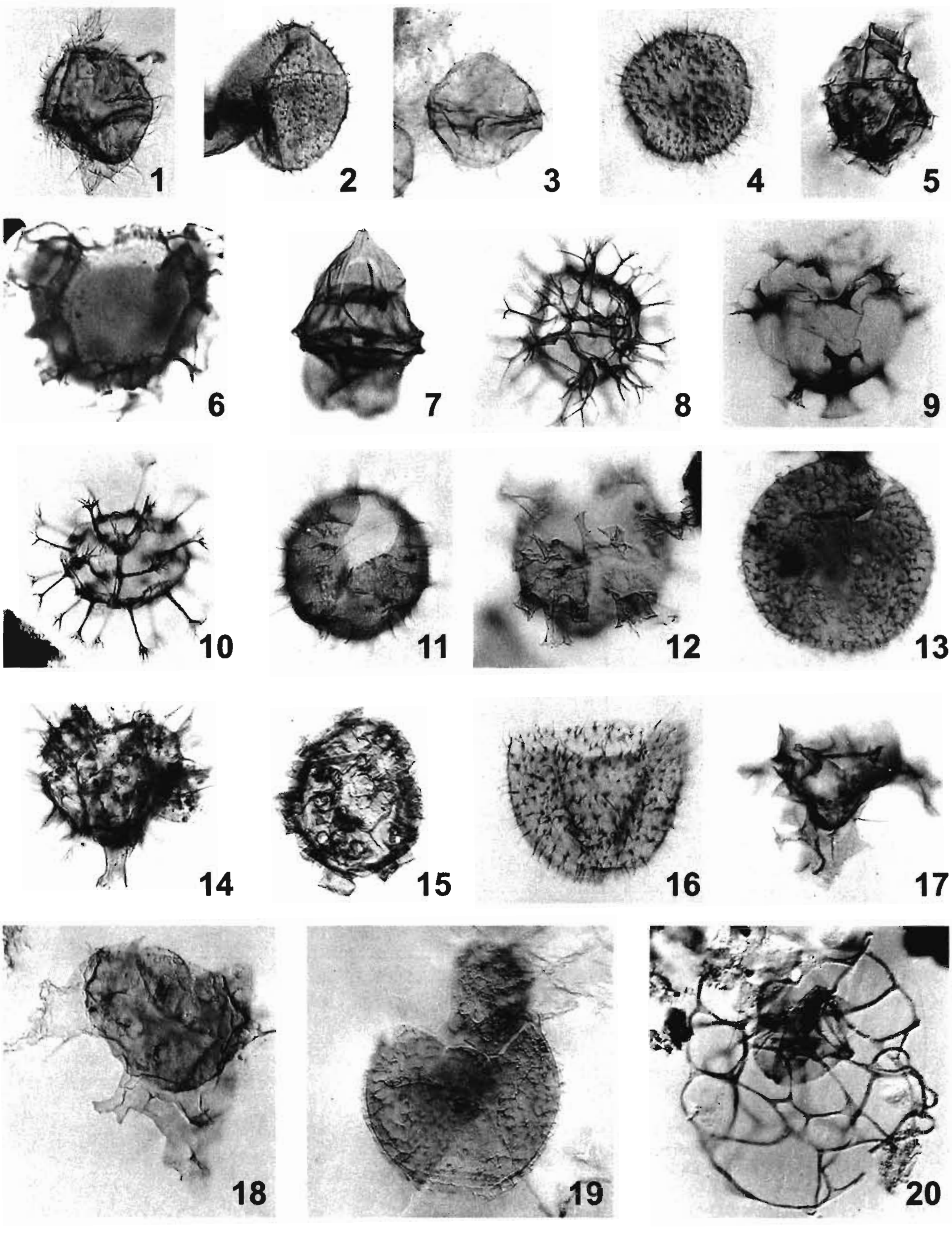

PLATE 2

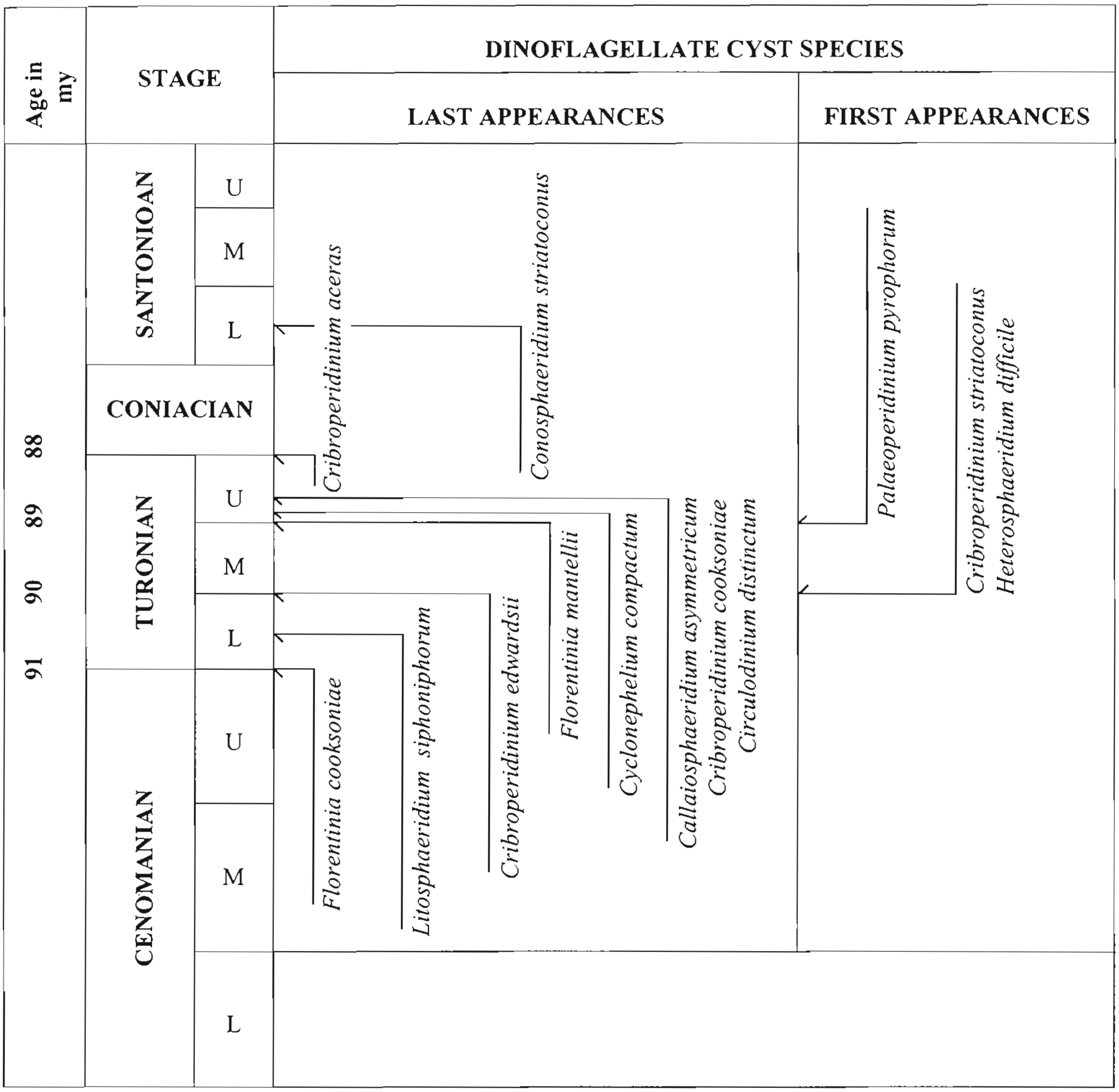

Fig. 6—First and last appearance (FAD & LAD) of significant dinoflagellate cyst taxa (Ranges after : Powell, 1992; Prossl, 1990; Stover *et al.*, 1996; Williams *et al.*, 1993).

PLATE 3

(All photomicrographs in DIC x 500)

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1. *Alterbidinium papillatum* Khowaja-Ateequzzaman *et al.* 1990, Slide No. BSIP 10263; coordinates 7·6 x 128·2.

2,13,16. *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant 1967, Slide No. BSIP 11521; coordinates (2) 13·4 x 146·5 (16) 16·3 x 127·2 (13) Slide No. BSIP 11519; coordinates 9·0 x 154·2.

3. *Palaeoperidinium cretaceum* Pocock 1962 emend. Davey 1970, Slide No. BSIP 11517; coordinates 9·7 x 149·7.

4. *Cribroperidinium* sp., Slide No. BSIP 11503; coordinates 11·5 x, 167·8.

5,12. *Alterbidinium minus* (Alberti) Lentin & Williams 1985, Slide No. BSIP 10263; coordinates (5) 11·5 x 167·8, (12) 5·4 x 143·6.

6. *Subtilisphaera habibii* Masure 1988, Slide No. BSIP 10263; coordinates 14·6 x 131·6.

7-8. *Circulosphaeridium distinctum* (Deflandre & Cookson) Jansonius 1986; (7) Slide No. BSIP 11503; coordinates 15·3 x 133·4, (8) Slide No. BSIP 11508; coordinates 10·2 x 133·7

9-10. *Pterodinium aliferum* Eisenack 1958 emend. Sarjeant 1985, (9) Slide No. BSIP 11495; coordinates 22·8 x 155·0, (10) Slide No. BSIP 11501, coordinates 12·5 x 128·2.

11. *Heterosphaeridium difficile* (Manum & Cookson) Ioannides 1986, Slide No. BSIP 11512; coordinates 9·6 x 155·3.

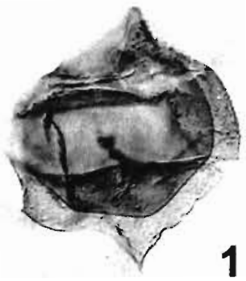
14. *Florentinia buspina* (Davey & Verdier) Duxbury 1980, Slide No. 11520; coordinates 22·2 x 163·3.

15. *Aiora fenestrata* ((Deflandre & Cookson) Cookson & Eisenack 1960, Slide No. BSIP 11494; coordinates 14·6 x 130·7.

16. *Cribroperidinium edwardsii* (Cookson & Eisenack) Davey 1969, Slide No. BSIP 10263; coordinates 9·7 x 123·2.

18. *Florentinia* sp., Slide No. BSIP 11514; coordinates 5·8 x 142·5.

19. *Cribroperidinium aceras* (Eisenack) emend. Sarjeant 1985, Slide No. BSIP 11506; coordinates 22·8 x 124·1.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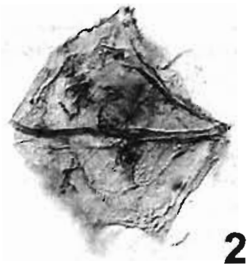
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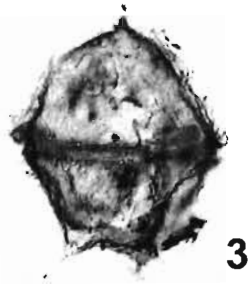
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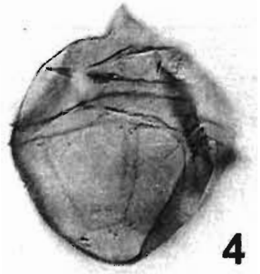
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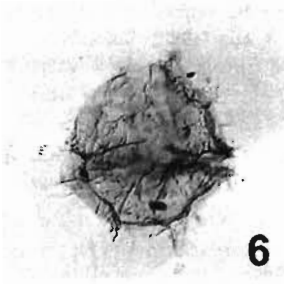
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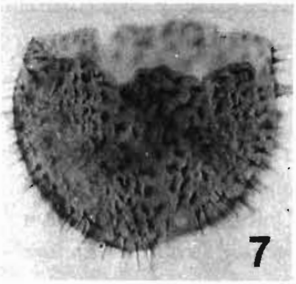
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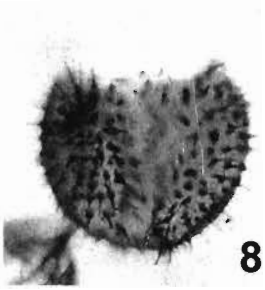
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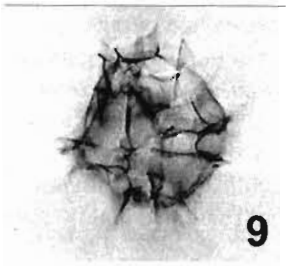
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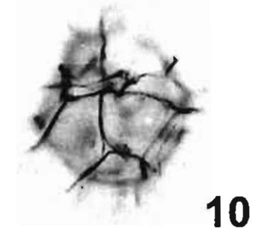
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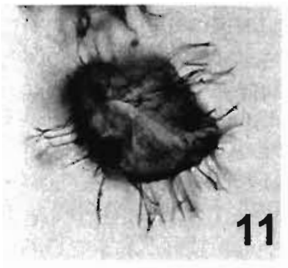
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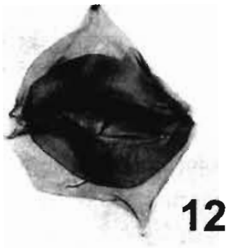
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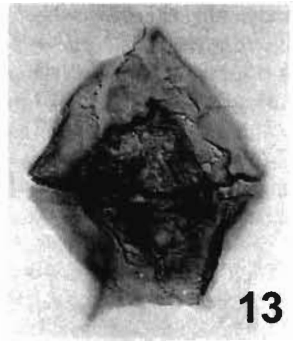
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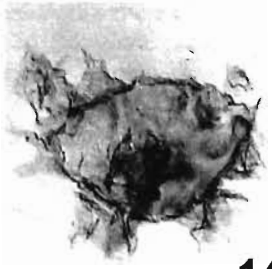
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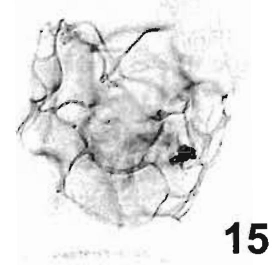
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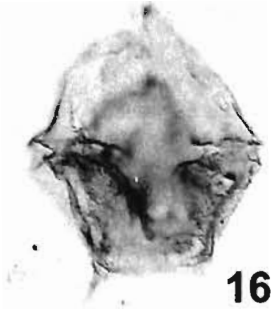
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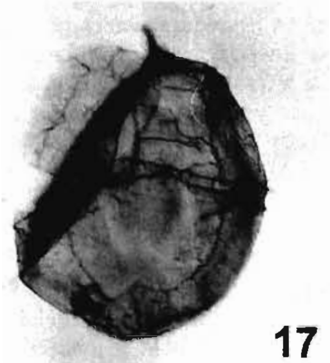
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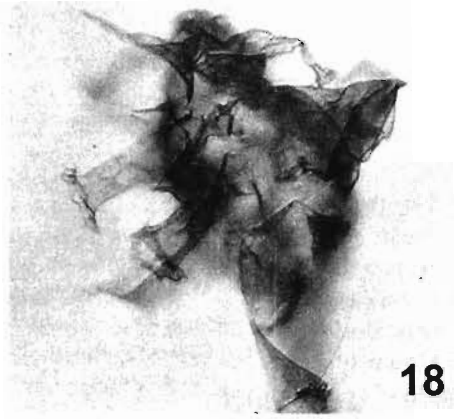
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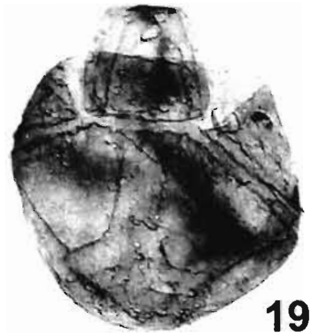
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PLATE 3

Taxa	Occurrence (sample no.)	Previous age determination	Revised age
Cauveridinium indicum	KAL6, CH5, KU6, KU8	Turonian-Santonian	E. to M. Turonian
C. intermedium	KAL6, KU8	Turonian-Santonian	E. to M. Turonian
C. longispinosum	KU8	Turonian-Santonian	Late Turonian
Alterbidinium papillatum	KU6	Turonian-Santonian	Middle Turonian
A. acutulum	KU6	Turonian-Santonian	Middle Turonian
A. minus	KU6, CH5, KL6	Turonian-Santonian	E. to M. Turonian
Jainiella breviornata	KAL6, CH5, KU6	Late Cretaceous	Middle Turonian

Fig. 7—Revised ages for the taxa earlier described by Khowaja-Ateequzzaman & Jain (1990), Khowaja-Ateequzzaman *et al.* (1991) and Khowaja-Ateequzzaman & Garg (1995), from Kulakkalnattam Sandstone Member of the Garudamangalam Formation.

Turonian, *Florentinia mantellii* (Last appearance datum LAD) at top of Middle Turonian; *Palaeoperidinium pyrophorum* (FAD at the base of Late Turonian), and *Callaiosphaeridium asymmetricum, Circulodinium distinctum, Cribroperidinium aceras, C. cooksoniae* and *Cyclonephelium compactum* (LADs within or at the top of Late Turonian) clearly suggest a Middle – Late Turonian age-range for dinoflagellate cyst assemblage, except for the lowermost assemblage recovered from sample KAL 6 (Figs 5, 6). Dinoflagellate cyst assemblage recovered from this particular sample indicates a latest Cenomanian – Early Turonian age due to the presence of *Cribroperidinium edwardsii, Florentinia cooksoniae* and *Litosphaeridium siphoniphorum* having LADs at the base, within or at the top of Lower Turonian (Figs 5, 6). This calcareous shale samples represents reworking of the underlying Karai Shale in the basal conglomeratic or concretionary sandstone beds of the Garudamangalam Formation. Several samples collected from the Karai Shale, however, proved unproductive of dinoflagellate cysts, possibly due to preservation factors.

Kale and Phansalkar (1992) assigned the youngest nannofossil assemblage from the Karai Shale to the *Quadrum gartneri* Zone (CC11), based on the first occurrence of the nominate taxon. They pointed out, however, that the top of the zone is not observed in the Uttatur Group and dated the basal part of the Garudamangalam Formation as late Middle Turonian (Kale & Phansalkar, 1992, figs 3-4). It is pertinent to note that the FAD of *Quadrum gartneri* predates the FAD of ammonite *Romaniceras ornatissimum,* which lies within the upper Middle Turonian (Robazynski *et al.*, 1982; Haq *et al.*, 1987). The occurrence of typical Middle Turonian dinoflagellate cyst assemblages from the lower part of the Kulakkalnattam Sandstone Member (samples CH5, KU6) underlying the typical shell-rich calcareous sandstone ("Shell Limestone") is, therefore, quite significant in this context. It agrees well with the ammonite evidence and indicates that the hiatus between deposition of the Karai Shale Formation and the Garudamangalam Formation may have been of extremely short duration. Furthermore, the Late Turonian transgressive event at the base of the Garudamangalam Formation may actually be slightly older, i.e., late Middle Turonian. Dinoflagellate cysts also provide convincing evidence for the presence of Upper Turonian sediments in the outcrop succession.

Khowaja-Ateequzzaman and Jain (1990), Khowaja-Ateequzzaman *et al.* (1991) and Khowaja-Ateequzzaman and Garg (1995) described some dinoflagellate cyst taxa from Kulakkalnattam Sandstone Member of the Garudamangalam Formation viz., *Alterbidinium acutulum, A. minus, A. papillatum, Cauveridinium indicum, C. intermedium, C. longispinosum,* and *Jainiella breviornata.*

The ages assigned in these publications are revised in Fig. 7 in the light of the observations presented in this paper.

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Some biodeteriorating air-borne fungi in and around Lucknow, India

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ABSTRACT

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The paper presents the result of qualitative and quantitative analyses of mycoflora in the air of Lucknow city and adjoining areas. Burkard slide sampler and Andersen two-stage volumetric samplers were employed for air sampling at forty places of Lucknow at different times of the year from January 1997 to February 1998. As many as thirty-five types of fungal spores and twenty-nine types of fungal colonies were registered.

It has been envisaged that certain fungi such as *Alternaria, Aspergillus, Chaetomium, Cladosporium, Curvularia, Diplodia, Epicoccum, Fusarium, Nigrospora, Penicillium, Rhizopus, Torula, Trichoderma, Trichothecium,*etc., prevalent in the air are associated with the biodeterioration of cultural properties.

Key-words—Air-borne fungi, Biodeterioration, Cultural properties, Lucknow.

भारत अवस्थित लखनऊ तथा इसके आस-पास उपस्थित कुछ जैवअवनतिकारक वायुजात कवक

आशा खण्डेलवाल, रश्मि तिवारी, लिली मिश्र एवं रश्मि सक्सेना

सारांश

प्रस्तुत शोध पत्र में लखनऊ शहर तथा इससे जुड़े क्षेत्रों के वायुमण्डल में उपस्थित कवक वनस्पतिजात के गुणात्मक तथा मात्रात्मक विश्लेषण के परिणामों की विवेचना की गयी है। इस हेतु जनवरी 1997 से फरवरी 1998 के मध्य के भिन्न-भिन्न कालों में लखनऊ के चालीस स्थानों के वायु नमूने लेने के उद्देश्य से बरकार्ड स्लाइड प्रतिलिपित्र तथा एण्डरसन के दो चरणों वाले आयतनी प्रतिलिपित्र लगाए गए। कवकीय बीजाणुओं के लगभग पैंतीस रूप तथा कवकीय उपनिवेशों के उन्तीस रूप अंकित किए गए।

यह प्रस्तावित किया जाता है कि वायुमण्डल में व्यापक रूप से उपस्थित कुछ कवक जैसे—*आल्टरनेरिया, एस्पर्जिलस, कीटोमियम, क्लैडोस्पोरियम, कर्व्यूलेरिया, डाइप्लोडिया, एपिकोकम, फ़्यूजेरियम, नाइग्रोस्पोरा, पेनिसिलियम, राइज़ोपस, टोर्यूला, ट्राइकोडर्मा, ट्राइकोथीशियम,* इत्यादि सांस्कृतिक सम्पत्तियों के जैवअवनतिकरण से सम्बद्ध हैं।

संकेत शब्द—वायुजात कवक, जैवअवनतिकरण, सांस्कृतिक सम्पत्तियाँ, लखनऊ।

INTRODUCTION

THE district of Lucknow (26°30'-27°10' N and 80°30'-81° 13'E) is an irregular, quadrilateral area located in the Gangetic plain of Uttar Pradesh. The climate is characteristically periodic with three well-marked seasons and sub-tropical monsoon type of climate. The flora of this district has changed dramatically over the recent years.

The valuable articles such as manuscripts, books, wall hangings, wood articles, paper crafts and various types of paintings of museums, archives, libraries, etc. get deteriorated due to the attack of different kinds of micro-organisms. This problem is more deterimental in tropical humid climate like India and can be solved to a large extent by estimating the qualitative and quantitative measures of causal organisms in the ambient air followed by suitable control measures. The present study was aimed to determine the correlation of air-borne fungal spores present in different parts of Lucknow and their impact on the properties of cultural heritage.

MATERIAL AND METHODS

The sampling was carried out by two internationally recognised air samplers provided under MEF sponsored project entitled "Aeroallergens and human health: aerobiological studies". These volumetric air samplers are usually employed for aerobiological studies where both qualitative and quantitative estimates of aeromycoflora are required and precise identifications are the prerequisites.

The air samples were collected from forty different places of Lucknow city and suburbs at different times of the year from January 1997 to February 1998 employing both the samplers simultaneously. The slides smeared with safranin-stained glycerine jelly were exposed for 10 min in Burkard slide sampler for identification and estimation of dispersed air-borne fungal spores. It is battery/power operated volumetric sampler, which sucks air at the rate of 10 litres/min. The rectangular cover slips (22 x 50 mm) were used and data was calculated in terms of fungal spores/sq cm of the slide surface.

The petridishes with sabourand's nutrient agar medium were exposed for 10 min time in Andersen two-stage sampler simultaneously with a visual identification method for specific identification of culturable fungi. After recording the data, the average colony concentration was converted into per metric cube of air by using recommended conversion factor. The data generated on these samplers provide specific number and frequency of fungal spores/colonies in a given volume of air, thus increasing the importance of data to be readily used as a prerequisite for aeropalynological studies in general and indoor aeromycological studies in particular.

RESULTS

The qualitative and quantitative analyses of aeromycoflora of forty different places of Lucknow are quite variable. The petridishes exposed in Andersen air sampler recorded the highest colony counts from Kanpur Road followed by Chinhat, Sitapur Road, Lucknow University, Sarojini Nagar, Talkatora Road, Charbagh, Hardoi Road, Bani, River Bank Colony, etc (Fig. 1). Amongst the twenty-nine types of fungal colonies recorded from all the sites, *Cladosporium cladosporioides* was dominant and *Alternaria alternata* was subdominant. It was followed by *Mucor hiemalis, Fusarium oxysporum, Penicillium funiculosum, Aspergillus niger, Curvularia lunata, Helminthosporium* sp., *Penicillium citrinum, Aspergillus flavus, A. nidulans*, etc.

The composition of dispersed fungal spore obtained on the slides by Burkard sampler was quite different. The site of maximum occurrence of fungal spores was different from that of fungal colonies. The maximum fungal spores were recorded from Sitapur Road followed by Hardoi Road, Sugarcane Research Institute, Residency, Charbagh, Malihabad, CIMAP, Jankipuram, Sardar Patel Marg, etc. (Fig. 2). The spores of *Cladosporium* were dominant as was the case in registration of fungal colonies. The small round spores ranked second followed by *Alternaria, Curvularia, Epicoccum, Helminthosporium, Drechslera, Periconia, Torula, Chaetomium*, etc.

DISCUSSION AND CONCLUSIONS

Fungi are ubiquitous and have wide range of genera and species. The earlier aeromycological studies carried out in Lucknow either in Birbal Sahni Institute of Palaeobotany or elsewhere in Lucknow only provided the qualitative estimates of aerobiota. But in the present study both qualitative and quantitative data was obtained by employing the technologically advanced air-samplers.

The botanical specimens, manuscripts, books, wall hangings, wood/paper crafts and various other material of cultural heritage provide an ideal substrates for the growth and proliferation of several fungi and probably in most of the cases they get liberated in the ambient air. In enclosed spaces, the bindery glues, old paper dust, binding fabrics and humidity due to coolers deteriorate the situation manifold. Several species of *Aspergillus, Fusarium, Penicillium, Alternaria, Trichoderma, Cladosporium*, etc. are found growing on herbarium and other dry preserved materials of National Museum of Natural History, New Delhi (Nair, 1971).

The aerobiological studies in the indoor air of library was conducted by Tilak and Vishwe (1976) recording the presence of air-borne spores of *Aspergillus, Cladosporium, Torula, Penicillium, Trichoderma* and *Chaetomium*. Many cellulose decomposing fungi such as *Alternaria, Monilia, Fusarium,Chaetomium, Myrothecium, Torula, Stachybotrys, Cladosporium, Paecilomyces, Rhizopus* and *Epicoccum* were also reported from a library of Aurangabad (Tilak & Saibaba, 1984). The high prevalence of *Cladosporium, Penicillium* and *Alternaria* inside libraries are also reported by Tripathi (1987), Tilak and Pillai (1988) and Singh *et al.*, (1990). Species of *Aspergillus, Penicillium* and *Cladosporium* were in great abundance in the indoor air of library of Madras University (Nadimuthu & Vittal, 1995). The agitation of books causes marked increase in the concentration of fungal spores (Burge *et al.*, 1978; Singh *et al.*, 1990; Vittal & Glory, 1985).

Alternaria alternata, Aspergillus sydowii, A. niger, Cladosporium cladosporioides, Penicillium citrinum were found occurring on different cellulosic materials such as manuscript and books, wood craft, paintings, wall hangings, etc. in Gorakhpur (Lakshmikant & Mathur, 1989). *Aspergillus flavus, A. nidulans, A. niger, A. sydowii, A. terreus, A. ustus, A. versicolor, Alternaria, Chaetomium, Cladosporium, Diplodia, Epicoccum, Fusarium, Paecilomyces varioti, Penicillium citrinum, Rhizopus, Torula, Trichoderma, Trichothecium,* etc. recorded in the present study, have been identified for the considerable damage of miniature paper paintings and lithographs by Dhawan and Agarwal (1986). Most of the fungi encountered in the present survey are generally similar to those found in indoor environment. The outdoor fungal spores get easy access in indoor air through open doors and windows and on getting optimum environmental conditions and proper substrates they start growing and proliferating. The air-monitoring inside the Ajanta and Ellora caves (Tilak *et al.*, 1972) and in Aurangabad (Tilak & Kulkarni, 1972) has established a correlation between air borne micro-organisms and environmental conditions that led to the biodeterioration of wall paintings of Ajanta and sculptures of Ellora. Thus, from the study of aerial survey it may be concluded that fungal spores suspended in the air must be traced back to their sources to which much attention has not been paid by the scientist so far. Hence, studies on biodeterioration aspects of conservation of cultural properties need to be expanded and strengthened in order to save the cultural heritage. The role of micro-organisms in causation of allergic rhinitis and bronchial asthma from library dust is well documented and should also be properly assessed in indoor environments.

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S.N.	Locality Date of collection Name of fungal spores	Rae Bareli Rd. (10 km) 3·1·97	Aisbbagh 22·1·97	Residency 24·1·97	River Bank Colony 4·2·97	Kanpur Rd. (15 km) 18·2·97	Charbagh 21·2·97	Nirala Nagar 4·3·97	Hardoi Rd. (15 km) 6·3·97	Art's College 21·3·97	Musabagh 4·4·97	River Bank Colony 15·4·97	Sardar Patel Marg 22·4·97	CIMAP 9·5·97	Ring Road 9·5·97	Janki -puram 14·5·97	Sitapur Rd. (10 km) 13·6·97	Rail Nagar 16·6·97	SGPGI 23·6·97	Sarojini Nagar 9·7·97	Mohanlal Ganj 11·7·97
1	*Aspergillus candidus*				1	1		2	2	2	1	2	1								
2	*A. flavus*	1	1			1	2	2			1		1	5	4	1	8	1	2	1	2
3	*A. nidulans*	2	2			3	1	3		1	2		2	3	14		2		1		
4	*A. niger*			1	2	1	1	2	2	2	1	2	1	2	3	4	5	1	2	2	2
5	*A. carneus*																				
6	*A. fumigatus*					2		2			2		2		1	1					
7	*A. sydowii*																				
8	*A. terreus*					2		2	2	2	1		1	4	2	3	5	1	1		
9	*A. versicolor*								1			7									
10	*A. sulphureus*						2		8												
11	*A. tamarii*				1			1			2		2	2	3		1		1		
12	*Alternaria alternata*	2	2	2	3	2	3	1	6	3	3		3	10	2	4	9	4	7	5	3
13	*Curvularia lunata*	12	1	1	3	2	7	2			5		5		1	2		2		2	2
14	*C. tetramera*	5	4	3		16	1										2		2		
15	*Chaetomium globosum*																				
16	*Cladosporium cladosporioides*	4	3	5	5	10	11	6	2	4	3	5	3	5	2	5	5	2	5	10	6
17	*Emericella nidulans*																		2		
18	*Fusarium roseum*				2	2	2		4	2	2	6	2				4			1	2
19	*F. oxysporum*	3	1	3	5		4	6	3	6	4	3	4	3			1	1	2	2	2
20	*Helminthosporium sp.*	1	2	3	12	4	1				2		2		5	1	3	1	1	1	6
21	*Monilia sitophila*																				
22	*Mucor hiemalis*		2	1	7	5	2	4	5	5	4	3	4		2	1				6	1
23	*Penicillium funiculosum*				2	9	1	4	4	3	3	8	3		1	1	2	1	3	3	1
24	*P. citrinum*				1	4	2	2	6	2	2	6	2					2		2	2
25	*Rhizoctonia sp.*																				
26	*Rhizopus stolonifer*																			10	5
27	*Trichoderma lignorum*	1			1	2	5	2							1	2	2		1		
29	*Trichothecium roseum*																			3	3
30	*Unidentified fungal colonies*							1	1												
	Total	31	18	19	45	66	45	42	46	32	38	42	38	34	41	25	49	16	30	48	37

Continued...

	Locality	Jail Road	HAL Colony Rd.	Kanpur Rd. (15 km)	Chinhat Rd.	Barabanki (15 km)	Jhande Wala Park	Malihabad	Bani	Lucknow University	Talkatora Road	Sitapur Rd (10 km)	Kanpur Rd. (12 km)	Hardoi Rd (15 km)	Mohaan Marg	Sugarcane Institute	Cariappa Road	Ashiana Colony	Hardoi Rd. (15 km)	Rae Bareli Rd. (14 km)	Sitapur Rd (13 km)	
	Date of collection	25·7·97	1·8·97	19·8·97	19·8·97	1·9·97	3·9·97	4·9·97	6·10·97	16·10·97	20·10·97	4·11·97	12·11·97	13·11·97	15·12·97	17·12·97	19·12·97	9·1·98	20·1·98	6·2·98	9·2·98	**Total**
S.N.	Name of fungal spores																					
1	*Aspergillus candidus*		2	2	6		1	3	2	5	3		5	2		1				1	2	**47**
2	*A. flavus*	1	4	1	2	7	2	2	3			1	3	2			2				1	**64**
3	*A. nidulans*		1	2	1	6	2	2		1	2							1	2		2	**58**
4	*A. niger*	1	3	5	3	3	6	10	2	7	6	1	3	2		2			1	1		**92**
5	*A. carneus*	2																				**2**
6	*A. fumigatus*		2	1	2	3			4	3	2									1		**28**
7	*A. sydowii*							1			1											**2**
8	*A. terreus*	1	1		1		2	2	2	2	3		4							2		**46**
9	*A. versicolor*									1												**9**
10	*A. sulphureus*									1			1									**12**
11	*A. tamarii*	2	2	4			1						2	3								**27**
12	*Alternaria alternata*	5	3	4	2	2	3	4	3	6		2			1	2	1		1	2	2	**117**
13	*Curvularia lunata*	3	3	4	3		2	3	2	2		3	1	5	1	2	3	1	1	1	2	**89**
14	*C. tetramera*					1	5	2			2	1			1	2	2	1	1	2	1	**54**
15	*Chaetomium globosum*											2	2				2					**6**
16	*Cladosporium cladosporioides*	2		6	8				3	6	5	1	2		1	2	2		1			**140**
17	*Emericella nidulans*		2		1																	**5**
18	*Fusarium roseum*	5			2		2	3	1	1		1	3		1			1				**49**
19	*F. oxysporum*	2	3	1	2	4	6	3	4	3	3	2	2		1	2	4		2	1	1	**99**
20	*Helminthosporium sp.*	1		2	9				1	1	3	4	1			2	1	3		1	3	**77**
21	*Monilia sitophila*						1															**1**
22	*Mucor hiemalis*	1	6	3	5	4			4	4	3	2	5	3	2	1	3				1	**99**
23	*Penicillium funiculosum*	2	2	2		10	2	3	7	3	4	1	4		1		2		1		1	**94**
24	*P. citrinum*	2			2			2	2	2	6	1	2	9	2			1	1	1	2	**68**
25	*Rhizoctonia sp.*	1		1																		**2**
26	*Rhizopus stolonifer*	2	5	1	3								1			1						**28**
27	*Trichoderma lignorum*					2		3	4								1					**27**
29	*Trichothecium roseum*	2					1			1	3					1						**14**
30	*Unidentified fungal colonies*				1	1	1			1		1		1								**8**
	Total	**35**	**39**	**39**	**53**	**43**	**37**	**43**	**44**	**50**	**46**	**23**	**41**	**27**	**11**	**18**	**23**	**8**	**11**	**13**	**18**	**1364**

Fig. 1—Number of fungal species (CFU/m^{1}) during sampling period (Andersen two-shape sampler).

	Locality	Rae Bareli Rd. (10 km)	Aishbagh	Residency	River Bank Colony	Kanpur Rd. (15 km)	Charbagh	Nirala Nagar	Hardoi Rd (15 km)	Art's College	Musabagh	River Bank Colony	Sardar Patel Marg	CIMAP	Ring Road	Janki -puram	Sitapur Rd. (10 km)	Rail Nagar	SGPGI	Sarojini Nagar	Mohanlal Ganj
	Date of collection	3·1·97	22·1·97	24·1·97	4·2·97	18·2·97	21·2·97	4·3·97	6·3·97	21·3·97	4·4·97	15·4·97	22·4·97	9·5 97	9·5·97	14 5·97	13·6·97	16·6·97	23·6·97	9 7·97	11·7·97
S.N.	Name of fungal spores																				
1	*Alternaria* sp.	1	2	7	5	3	13	2	6	5	6	7	8	15	7	7	50	10	14	8	3
2	*Bispora* sp.	1	3	2	2	2	6	1	1	2	2	1	3	2	2						1
3	*Beltrania* sp.		2	1	1																
4	*Cercospora* sp.																7	8	4		1
5	*Chaetomium* sp.					2·	3	2	2			2	2	1		3	6				1
6	*Cladosporium* sp.	6	13	17	14	13	14	8	15	7	10	10	10	20	20	27	3	4	8	10	7
7	*Curvularia* sp.	4	2	6	2	1	4	1		1	2	3	5	7	4	8	4	1		7	
8	*Dictyosporium* sp.								2												
9	*Didymosphaeria* sp.																				
10	*Drechslera* sp.	2		3	1	3	1	6	4	1	2	1	2	2	1	3	2	2			1
11	*Epicoccum* sp.	1	2	27	7	2	11	2		4	2	2	7	9		4		1	4		
12	*Exosporium* sp.								1		1	2		1							1
13	*Fusariella* sp.																				
14	*Fusarium* sp.	4	1	3		4	10				2		2								1
15	*Ganoderma* sp.																				
16	*Helminthosporium* sp.	2	2	3	3	4	9	4	4	4		4	3	10	3	3	5	1	6		2
17	*Heterosporium* sp.				2	2				2											
18	*Leptosphaeria* sp.						2		2			2	2	2	2						
19	*Lophiostoma* sp.																				
20	*Myrothecium* sp.								4							2					
21	*Nigrospora* sp.	1					2	2	3	1		1	1	3	1		2	1			1
22	*Periconia* sp.	2	2	12	3	1	6	1	9	1		1	2								
23	*Pithomyces* sp.	2																			
24	*Pleospora* sp.	1		2			1	1					8		2		3				1
25	*Sordaria* sp.																				
26	*Spegazzinia* sp.															2					
27	*Sporidesmium* sp.	1		7		2	2	4	4	2	1	1	1	2							
28	*Teichospora* sp.				1							2		1							
29	*Tetraploa* sp.																				
30	*Torula* sp.	3	2		1	3	1	2	2			2									
31	*Trichothecium* sp.							4													
32	2-4 celled spores										3					5	12				
33	Round spores									14	3	4	7	6	6	8	15	6	7	2	5
34	Uredo. of *Puccinia*	2	2	7	4		2	1	1	1	1	1	2								
35	Smut spores																				
36	Unidentified spores	8	9	1	9	14	4	13										1	1		
	TOTAL	**41**	**42**	**98**	**55**	**56**	**91**	**54**	**60**	**45**	**35**	**46**	**65**	**81**	**48**	**72**	**109**	**35**	**44**	**27**	**25**

Continued...

	Locality	Jail Road	HAL Colony Rd	Kanpur (15 km)	Chinhat Rd.	Barabanki (15 km)	Jhande Wala Park	Malihabad	Bani	Lucknow University	Talkatora Road	Sitapur Rd (10 km)	Kanpur Rd. (12 km)	Hardoi Rd. (15 km)	Mohaan Marg	Sugarcane Institute	Cariappa Road	Ashiana Colony	Hardoi Rd. (15 km)	Rae Bareli Rd (14 km)	Sitapur Rd. (13 km)	
	Date of collection	25·7·97	1·8·97	19·8·97	19·8·97	1 9·97	3·9·97	4·9·97	6·10·97	16 10·97	20·10·97	4·11·97	12·11·97	13·11·97	15·12·97	17·12·97	19·12·97	9·1·98	20·1·98	6·2·98	9·2·98	**Total**
S.N.	Name of fungal spores																					
1	*Alternaria* sp.		2	2	6	3	10	26	1	1	6	2	1	13	1	2	3	4	1	1	9	**273**
2	*Bispora* sp.			2	1		1		4	1	2		1	3	1	2	8	2			1	**60**
3	*Beltrania* sp.																					**4**
4	*Cercospora* sp.	2			2	4	3	5	1	5	6	6	2	2	2		1	2	2			**65**
5	*Chaetomium* sp.		2	3	2	2	1	2	3	2	7	3	2	3	2	3	2	1	1		2	**67**
6	*Cladosporium* sp.	3	4	8	6	8	2	6	2	2	6	8	7	18	6	8	4	9	19	6	17	**385**
7	*Curvularia* sp.		6	1	1	1	10	10	2	3	3	1	1	4	2	7	1	1		2	3	**121**
8	*Dictyosporium* sp.																					**2**
9	*Didymosphaeria* sp.								4													**4**
10	*Drechslera* sp.		2	2		1	1	4	1	2	4	2	3	5		14			2	1	3	**84**
11	*Epicoccum* sp.	2	1							4		2	1	3			3	1	2	3	4	**111**
12	*Exosporium* sp.											1										**7**
13	*Fusariella* sp.			2																		**2**
14	*Fusarium* sp.					3			3	2		1	2	6	2	8				2	2	**58**
15	*Ganoderma* sp.			2			2		1			1										**6**
16	*Helminthosporium* sp.			2	7	2	7	10		1			2	2				2		1	2	**110**
17	*Heterosporium* sp.							2														**8**
18	*Leptosphaeria* sp.					1		2	2			2					1					**20**
19	*Lophiostoma* sp.								1													**1**
20	*Myrothecium* sp.															7						**13**
21	*Nigrospora* sp.		1	1		2	1	2	1	3	2	4	3	2		3	2	1	1	3	1	**52**
22	*Periconia* sp.			1		2	2	1		2	1	3	2	8	2	4	3	1	1	1	4	**78**
23	*Pithomyces* sp.									1	1		1	1		3		1				**10**
24	*Pleospora* sp.															4						**23**
25	*Sordaria* sp.								2							2	1					**5**
26	*Spegazzinia* sp.																					**2**
27	*Sporidesmium* sp.			2		1	1	2		2							1				7	**43**
28	*Teichospora* sp.																					**4**
29	*Tetraploa* sp.							2											1	1		**4**
30	*Torula* sp.						1	2	2	1	3		2	7	1	5	7	1	21	1		**70**
31	*Trichothecium* sp.														1	3						**8**
32	2-4 celled spores	5	1			4		4														**34**
33	Round spores	4	4	11	4	8	2		6	14	13	12	8	26	14	16	9	12	11	11	15	**283**
34	Uredo. of *Puccinia*		1					1	2	1				2		11			1	2	2	**47**
35	Smut spores				6																	**6**
36	Unidentified spores	1	1			2		2			1									2	1	**70**
	TOTAL	**17**	**25**	**39**	**35**	**44**	**44**	**83**	**38**	**47**	**55**	**48**	**38**	**105**	**34**	**102**	**46**	**38**	**63**	**37**	**73**	**2140**

Fig. 2—Number of fungal spores (No./m³) during sampling period (Burkard Slide Sampler).

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Long term monitoring of air-borne pollen and fungal spores and their allergenic significance

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ABSTRACT

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The qualitative and quantitative analyses of aerospora at Birbal Sahni Institute of Palaeobotany are assessed for the biogenic pollutants of Lucknow atmosphere. The Impaction method was employed for preparing annual pollen and spore calendars over six years (1969-1970, 1970-1971, 1971-1972, 1983-84, 1984-1985, 1985-1986). As many as 61 types of pollen grains and 27 types of fungal spores have been encountered. The maximum number of pollen grains were recorded in the year 1985-86 (24383) and minimum in the year 1969-70 (13005), whilst the maximum number of fungal spores encountered were in 1971-72 (22604) and minimum in the year 1969-70 (12771).

It has been visualized that long term pollen/spore monitoring at a particular site provides a strong base for the prediction of aeroallergens as a warning towards the allergenic disorders. The well recognised allergenic pollen and spore of Lucknow area include *Argemone mexicana, Amaranthus spinosus, Cannabis sativa, Chenopodium album, Prosopis juliflora, Cyperus rotundus, Ricinus communis, Xanthium strumarium* and many species of *Aspergillus*.

Key-words—Allergy, Pollen and fungal spore monitoring, India.

वायुजात परागकणों तथा कवकीय बीजाणुओं का दीर्घावधिक पर्यवेक्षण तथा इनका प्रत्यूर्जता की दृष्टि से महत्व

आशा खण्डेलवाल

सारांश

लखनऊ के वातावरण में जैवजनित प्रदूषकों के मूल्यांकन हेतु बीरबल साहनी पुरावनस्पतिविज्ञान संस्थान के वायु बीजाणुओं का गुणात्मक एवं मात्रात्मक विश्लेषण किया गया। लगभग 6 वर्षों (1969-70, 1970-71, 1971-72, 1983-84, 1984-85, 1985-86) के वार्षिक परागकण एवं बीजाणु कैलेण्डर निर्मित करने हेतु इम्पैक्शन प्रविधि का प्रयोग किया गया। 61 प्रकार के परागकण तथा 27 प्रकार के कवकीय बीजाणु समागमित किए गए हैं। वर्ष 1985-86 में सर्वाधिक परागकण (24383) प्राप्त हुए, जबकि वर्ष 1969-70 में न्यूनतम परागकण (13005) प्राप्त हुए। इसी प्रकार वर्ष 1971-72 में अधिकतम बीजाणु (22601) प्राप्त हुए, जबकि वर्ष 1969-70 में न्यूनतम बीजाणुओं की संख्या 12771 थी।

यह प्रेक्षित किया गया है कि एक विशिष्ट संस्थिति के परागकणों/बीजाणुओं का दीर्घावधि तक प्रेक्षण करने से प्रत्यूर्जता सम्बन्धी गड़बड़ियों के संकेतक के रूप में वायु प्रत्यूर्जकों का अनुमान अधिक सहजता से लगाया जा सकता है। लखनऊ क्षेत्र के सुनिर्धारित वायु प्रत्यूर्जक परागकणों तथा बीजाणुओं में *आर्जीमोन मेक्सिकाना, एमेरैन्थस स्पाइनोसस, कैनेबिस*

सैटाइवा, चीनोपोडियम एल्बम, प्रॉसोपिस जूलीफ़्लोरा, साइपर्सस रोडण्डस, राइसिनस कम्यूनिस, ज़ैन्थियम स्ट्रूमैरियम तथा *एस्पर्जिलस* की अनेक प्रजातियाँ विद्यमान हैं।

संकेत शब्द—लखनऊ, परागकण तथा कवकीय बीजाणु पर्यवेक्षण, प्रत्यूर्जता.

INTRODUCTION

THE paper presents the long term monitoring of air-borne pollen grains and fungal spores on the premises of Birbal Sahni Institute of Palaeobotany, Lucknow. The pollen and fungal spore calendars of three consecutive years were prepared during 1969 and again in 1983. The aim of continuing similar type of investigation for longer duration was to have comparative accounts of aerospora on a yearly basis and to know the changing pattern of pollination periods of different plant taxa at different seasons of the year. The survey of atmospheric pollen grains at B.S.I.P, Lucknow, was earlier carried out by Lakhanpal and Nair (1958). In the year 1969, the analysis of aeromycoflora was incorporated along with pollen studies in order to complete the picture of the aerobiota (Vishnu Mittre & Khandelwal, 1973). During the year 1976-77, the survey of air-borne fungal flora of Lucknow University area was conducted in relation to plant and surface mycoflora (Wadhwani, 1979). A two-year (1980-81) survey of air-borne pollen alone was carried out in the National Botanical Research Institute, Lucknow (Chaturvedi *et al.*, 1987-88). The standard record of aerospora of Lucknow assembled in the present paper could be utilised as a 'Ready reckoner' for periodic biopollutant predictions required for the treatment of various allergic disorders caused by air-borne pollen grains and fungal spores. However, aerobiological data generated over a period of four years (Anonymous, 1994-1998) in All India Coordinated Project entitled "Aeroallergens and Human Health: Aerobiological studies" employing three internationally recognised samplers viz., Burkard, Rotorod and Andersen could not be compared with earlier records due to changed methodology and sampling sites. The aerobiological monitoring over an 11-years period in Italy have been utilised for building forecasting models of various species (Bricchi *et al.*, 1995).

MATERIAL AND METHODS

The district of Lucknow (26°30'-27°10' N and 80°30'-81°13' E) is an irregular quadrilateral area covering length and breadth of 72·5 km and 40·3 km respectively. The area is level plain, 117·8 m a.s.l. with old gangetic alluvial soil. The climate like that of entire north India consists of three well-marked seasons viz., the rainy, the cold and the hot.

The Lucknow flora comprises 927 plant species of which Gramineae (grasses) form the dominant group and next, in order, are Leguminosae, Compositae, Cyperaceae, Euphorbiaceae, Acanthaceae, Convolvulaceae, Scrophulariaceae, Amaranthaceae, Labiatae, Malvaceae and Polygonaceae (Kapoor, 1962). As an aid to the atmospheric pollen and spore survey, the Lucknow area was thoroughly botanised. The anemophilous and entomophilous species have been listed and observation was gathered on their flowering periods and distribution in Lucknow.

The apparatus used throughout the investigation, was first used by Lakhanpal and Nair (1958) which is placed in the group classified by Gregory (1961) under Impaction using wind movement by vertical and inclined microscopic slide. The slides were exposed on the terrace of B.S.I.P at a height of about 7·5 m above ground level. The Safranin stained glycerine jelly was smeared on the slide and exposed for 24 hrs. Rectangular cover slips (22 x 50 mm) were used and data were calculated in terms of pollen or fungal spores/sq cm of slide surface.

The petridish method was also adopted for one year during the period of April 1970-March 1971 simultaneously with a visual identification method for specific identification of Fungi (Khandelwal, 1992). The experiment was conducted for one year (March 1971-February 1972) by exposing slides on the ground and terrace level in order to ascertain the differences in qualitative and quantitative abundance of pollen grains and fungal spores, the time of first appearance, monthly maxima and period of settlement of aerobiota at two dissimilar heights (Khandelwal, 1988).

RESULT AND DISCUSSIONS

The pollen and spore monitoring over six years have shown marked variation in number and frequency of aerobiota each year (Figs 1 & 2). The qualitative and quantitative abundance of pollen grains and fungal spores over different years were as follows:

Years	Pollen grains	Fungal spores	
1954-55	23274 (29 types)	-	(Lakhanpal & Nair 1958)
1969-70	13005 (48 types)	12771 (18 types)	
1970-71	16726 (41 types)	19979 (22 types)	
1971-72	19521 (47 types)	22604 (21 types)	
1983-84	20485 (55 types)	18988 (23 types)	
1984-85	21326 (61 types)	15901 (27 types)	
1985-86	24383 (61 types)	17191 (25 types)	

On the basis of annual distribution of atmospheric pollen grains, three periods in relation to the seasons have been recognised viz., Spring and early summer (February to May),

	POLLEN GRAINS	1969-70	1970-71	1971-72	1983-84	1984-85	1985-86
1	Gramineae (Poaceae)	4510(34·6)	3197(19·1)	2962(15·1)	3425 (16·7)	6619 (31·0)	8642 (35·4)
2	*Holoptelea integrifolia*	1701(13·0)	6009(35·9)	7746(39·7)	5501(26·85)	3765(17·66)	3463(14·20)
3	*Syzygium cumini*	1648(12·7)	246(1·4)	259(1·3)	635(3·09)	20(0·09)	462(1·89)
4	Amaranth-Chenopod type	1125(8·6)	1130(6·75)	2138(10·9)	2573(12·56)	2292(10·74)	2634(10·8)
5	*Azadirachta indica*	468(3·6)	482(2·8)	654(3·3)	378(1·84)	167(0·78)	246(1·00)
6	*Ailanthus excelsa*	322(2·4)	1902(11·3)	745(3·8)	1125(5·49)	939(4·40)	1034(4·24)
7	*Casuarina equisetifolia*	319(2·45)	168(1·0)	649(3·3)	941(4·59)	1100(5·15)	1420(5·82)
8	*Ricinus communis*	297(2·2)	405(2·4)	617(3·1)	1463(7·14)	2018(9·46)	2108(8·64)
9	Leguminosae (Caesalpinoidae, Papilionoidae)	251(1·9)	11(0·065)	3(0·01)	4 (0·019)	2(0·009)	23 (0·094)
10	*Emblica officinalis*	248(1·9)	114(0·68)	173(0·88)	328(1·60)	114(0.53)	112(0·45)
11	Cyperaceae	243(1·9)	98(0·58)	353(1·8)	314(1·53)	316(1·48)	312(1·27)
12	*Xanthium strumarium*	208(1·6)	143(0·8)	1108(5·6)	259(1·26)	609(2·85)	483(1·98)
13	Cruciferae (Brassicaceae)	203(1·5)	144(0·85)	142(0·72)	300 (1·4)	336 (1·5)	342 (1·4)
14	*Putranjiva roxburghii*	179(1·4)	353(2·1)	197(1·0)	765(3·73)	156(0·73)	236(0·96)
15	*Artemisia vulgaris*	123(0·94)	78(0·46)	33(0·16)	105(0·51)	91(0·42)	124(0·508)
16	*Morus alba*	122(0·93)	153(0·91)	117(0·59)	343(1·67)	599(2·8)	621(2·54)
17	*Cannabis sativa*	118(0·9)	59(0·35)	38(0·19)	103(0·50)	179(0·83)	310(1·27)
18	*Polyalthia longifolia*	95(0·73)	82(0·49)	124(0·63)	70(0·34)	41(0·19)	14(0·05)
19	*Pinus roxburghii*	73(0·56)	80(0·48)	166(0·85)	89(0·43)	317(1·48)	302(1·23)
20	Compositae (Asteraceae)	64(0·49)	42(0·25)	45(0·23)	103 (0·5)	148 (0·6)	94 (0·38)
21	Urticaceae	39(0·3)	13(0·07)	3(0·01)	2(0·009)	16(0·07)	32(0·13)
22	*Eucalyptus citriodora*	35(0·26)	541(3·2)	326(1·6)	223(1·08)	158(0·74)	211(0·86)
23	*Dodonaea viscosa*	28(0·22)	265(1·5)	97(0·49)	-	-	21 (0·08)
24	*Cedrela toona*	25(0·19)	6(0·03)	22(0·11)	-	-	3(0·012)
25	*Argemone mexicana*	22(0·16)	45(0·26)	30(0·15)	120(0·58)	57(0·26)	34(0·13)
26	*Justicia sp.*	22(0·16)	-	13(0·06)	50(0·24)	12(0·05)	14(0·05)
27	*Prosopis juliflora*	20(0·15)	79(0·47)	37(0·18)	17(0·08)	21(0·09)	26(0·10)
28	*Heliotropium* sp.	19(0·14)	24(0·14)	43(0·21)	25(0·12)	58(0·27)	18(0·07)
29	*Rumex dentatus*	16(0·12)	3(0·01)	-	-	-	-
30	*Pithecolobium dulce*	16(0·12)	161(0·96)	12(0·06)	67(0·32)	16(0·07)	14(0·05)
31	*Terminalia arjuna*	16(0·12)	166(0·99)	16(0·08)	9(0·04)	15(0·07)	4(0·016)
32	*Coriandrum sativum*	13(0·09)	37(0·22)	86(0·44)	121(0·59)	47(0·22)	36(0·14)
33	*Grevillea robusta*	12(0·09)	1(0·005)	32(0·16)	-	-	-
34	*Anagallis arvensis*	11(0·08)	-	9(0·04)	44(0·21)	37(0·17)	16(0·06
35	*Acacia arabica*	11(0·08)	9(0·05)	14(0·07)	10(0·04)	24(0·11)	10(0·04)
36	*Alnus* sp.	11(0·08)	22(0·13)	68(0·34)	69(0·33)	39(0·18)	12(0·04)
37	*Salmalia malabarica*	10(0·07)	6(0·03)	13(0·06)	195(0·95)	236(1·10)	243(0·99)
38	*Anethum graveolens*	10(0·07)	6(0·03)	-	63(0·30)	19(0·08)	14(0·05)
39	*Citrus* sp.	6(0·04)	-	-	-	9(0·04)	3(0·012)
40	*Carica papaya*	3(0·02)	-	-	3(0·01)	23(0·10)	4(0·016)
41	Malvaceae	2(0·015)	-	13(0·06)	47(0·22)	97(0·45)	34(0·13)

42	*Ephedra* sp.	2(0·014)	10(0·05)	6(0·03)	20(0·09)	16(0·07)	3(0·012)
43	*Tamarindus inidca*	2(0·014)	-	1(0·005)	4(0·01)	6(0·02)	-
44	*Tribulus terrestris*	1(0·007)	-	72(0·36)	18(0·08)	56(0·26)	5(0·02)
45	*Cleome viscosa*	1(0·007)	-	-	-	2 (0·009)	4 (0·016)
46	*Jatropha pendurifolia*	1(0·007)	-	-	29(0·14)	46(0·21)	32(0·13)
47	*Pyrostegia venusta*	1(0·007)	-	-	17(0·08)	19(0·08)	10(0·04)
48	*Santalum album*	1(0·007)	-	5(0·02)	-	-	-
49	*Aegle marmelos*	-	411(2·45)	44(0·22)	121(0·59)	28(0·13)	46(0·18)
50	*Melia azedarch*	-	-	41(0·21)	-	-	-
51	*Jasminum* sp.	-	5(0·03)	19(0·09)	-	-	-
52	*Albizia lebbek*	-	5(0·03)	-	7(0·03)	3(0·01)	4(0·016)
53	*Chrozophora rottleri*	-	1(0·005)	-	2 (0·009)	-	2 (0·008)
54	*Cycas circinalis*	-	-	130 (0·6)	14(0·06)	7(0·03)	4(0·016)
55	*Bauhinia* sp.	-	-	10(0·05)	-	7(0·03)	3(0·012)
56	*Typha* sp.	-	-	4(0·02)	10(0·04)	72(0·33)	6(0·024)
57	*Parthenium hysterophorus*	-	-	-	82(0·40)	131(0·61)	342(1·40)
58	*Polygonum* sp.	-	-	-	25(0·12)	4(0·01)	4(0·016)
59	*Alternanthera* sp.	-	-	-	11(0·05)	4(0·01)	12(0·04)
60	*Croton bonplandianum*	-	-	-	11(0·05)	3(0·01)	4(0·016)
61	Lamiaceae (Labiatae)	-	-	-	11(0·05)	1(0·004)	6(0·024)
62	Acanthaceae	-	-	-	-	3(0·01)	1(0·004)
63	Apiaceae (Umbelliferae)	-	-	-	-	4(0·01)	2(0·008)
64	*Galphimia gracilis*	-	-	-	-	5(0·023)	7(0·02)
65	*Impatiens balsamina*	-	-	-	-	2(0·009)	4(0·016)
66	Myrtaceae	-	-	-	-	9(0·04)	32(0·13)
67	*Betula* sp.	-	-	-	5 (0·02)	17 (0·07)	-
69	*Ligustrum* sp.	-	-	-	81 (0·39)	27 (0·12)	-
70	*Dendrophthoe falcata*	-	-	-	8 (0·03)	-	3 (0·12)
71	*Madhuca indica*	-	-	-	4 (0·01)	-	-
72	*Rauwolfia serpentina*	-	-	-	-	2 (0·009)	-
73	Trilete spores	-	-	-	17(0·08)	3(0·01)	1(0·004)
74	Unidentified and damaged	332(2·55)	14(0·08)	86(0·44)	99(0·48)	137(0·6)	115(0·47)
Total		**13005**	**16726**	**19521**	**20485**	**21326**	**24383**

Fig. 1—Number and percentage of pollen grains caught during different years of investigation (percentages are calculated in terms of total annual pollen catch)

	FUNGAL SPORES	1969-70	1970-71	1971-72	1983-84	1984-85	1985-86
1	*Alternaria*	4583 (35·8)	6563 (32·8)	9170 (40·5)	7149 (37·65)	4463 (28·06)	4462 (25·95)
2	*Helminthosporium*	1644 (12·8)	2806 (14·0)	3332 (14·7)	2460 (12·95)	2944 (18·51)	3126 (18·18)
3	Uredospore of Puccinia	1552 (12·1)	3726 (18·64)	2532 (11·22)	2902 (15·28)	1261 (7·93)	2432 (14·14)
4	2-4 celled spores	1358 (10·6)	461 (2·3)	460 (2·03)	216 (1·13)	266 (1·67)	343 (1·99)
5	*Aspergillus, Penicillium, Mucor* type spores	865 (6·7)	1547 (7·74)	1404 (6·21)	1214 (6·39)	675 (4·24)	484 (2·81)
6	*Cladosporium*	643 (5·0)	866 (4·33)	701 (3·10)	864 (4·55)	865 (5·43)	782 (4.54)
7	*Nigrospora*	638 (4·9)	644 (3·22)	651 (2·87)	340 (1·79)	506 (3·18)	643 (3·74)
8	*Cercospora*	434 (3·4)	566 (2·83)	904 (3·99)	239 (1·25)	776 (4·88)	748 (4·35)
9	Smut spores	176 (1·4)	402 (2·01)	382 (1·68)	142 (0·74)	107 (0·67)	312 (1·81)
10	*Chaetomium*	133 (1·04)	193 (0·96)	312 (1·38)	28 (0·14)	69 (0·43)	40 (0·23)
11	*Curvularia*	121 (0·9)	459 (2·29)	539 (2·38)	583 (3·07)	1105 (6·94)	1423 (8·27)
12	*Epicoccum*	114 (0·89)	1288 (6·44)	1406 (6·22)	1242 (6·54)	1049 (6·59)	1124 (6·530
13	*Fusarium*	102 (0·8)	109 (0·54)	253 (1·11)	182 (0·95)	259 (1·62)	131 (0·76)
14	*Diplodia*	58 (0·45)	24 (0·12)	56 (0·24)	175 (0·92)	193 (1·2)	41 (0·23)
15	*Acrothecium*	51 (0·4)	73 (0·36)	104 (0·46)	482 (2·53)	283 (1·77)	312 (1·81)
16	*Tetraploa*	25 (0·2)	57 (0·28)	299 (1·32)	322 (1·69)	361 (2·27)	156 (0·90)
17	*Tilletia*	11 (0·08)	13 (0·06)	20 (0·08)	327 (1·72)	376 (2·36)	321 (1·86)
18	Teleutospores of *Puccinia*	7 (0·05)	87 (0·43)	15 (0·06)	14 (0·07)	53 (0·33)	14 (0·08)
19	*Torula*	-	17 (0·08)	13 (0·05)	22 (0·11)	31 (0·19)	44 (0·25)
20	*Zygodesmus*	-	5 (0·02)	-	-	-	8 (0·04)
21	*Beltrania*	-	4 (0·02)	-	-	4 (0·02)	-
22	*Botryodiplodia*	-	3 (0·01)	10 (0·04)	-	2(0·012)	-
23	*Spegazzinia*	-	-	2 (0·008)	4 (0·02)	9 (0·056)	4 (0·02)
24	*Cornespora*	-	-	-	2 (0·01)	9 (0·056)	11 (0·06)
25	*Pleospora*	-	-	-	9 (0·04)	30 (0·18)	44 (0·25)
26	*Sporedesmium*	-	-	-	18 (0·09)	133 (0·83)	142 (0·82)
27	*Trichoconis*	-	-	-	-	9 (0·056)	4 (0·02)
28	*Endophragmia*	-	-	-	-	2 (0·012)	-
29	Unidentified fungal spores	256 (2·0)	66 (0·33)	39 (0·17)	52 (0·27)	61 (0·38)	40 (0·23)
Total		**12771**	**19979**	**22604**	**18988**	**15901**	**17191**

Fig. 2—Number and percentage of fungal spores caught during different years of investigations (percentages are calculated in terms of total annual spore catch)

Late summer and rainy season (June to September) and Late rainy season and winter (October to January). In spring and early summer arboreal pollen grains dominated; in late summer and the rainy season, pollen grains of grasses and weeds were recorded, while in the late rainy season and winter, pollen of grasses and cultivated plants were found. However, there was some pollen, which occurred throughout the year in small or sporadic numbers. The graphic representation of important pollen grains and fungal spores of year 1969-70, 1970-71 and 1983-86 have been published elsewhere for ready assessment of daily fluctuations in their frequencies (Vishnu Mittre & Khandelwal, 1973; Khandelwal, 1988, 1991, 1992). The continuous air monitoring of pollen grains and fungal spores for the year 1997 was done in Vikas Nagar on Kursi Road by employing Rotorod sampler (Khandelwal, 2001)

Unlike the seasonal distribution of pollen grains observed in the pollen calendars, the fungal spore calendars do not exhibit such seasonal distribution; however, two periods, one from February to June and another from July to December have been recognised. Most of the fungal spores are present throughout the year showing high fluctuation in some part of the year.

Allergenic significance of pollen grains and fungal spores

Clinical investigation carried out at King George Medical College, Lucknow have proved the allergenicity of many fungal spores and pollen grains present in the air of Lucknow (Agnihotri & Singh, 1971; Khandelwal, 1974; Khandelwal *et al.*, 1996; Jamil *et al.*, 1981, 1986; Wadhwani *et al.*, 1986). The significant aeroallergens are *Alstonia scholaris, Amaranthus spinosus, Azadirachta indica, Chenopodium album, Cynodon dactylon, Cyperus rotundus, Holoptelea integrifolia, Prosopis juliflora, Putranjiva roxburghii, Ricinus communis, Alternaria alternata, Aspergillus flavus, A. fumigatus, A. nidulans, A. niger, A. terreus, Cladosporium cladosporioides, Curvularia lunata, Fusarium oxysporum, Helminthosporium spiciferum, Monilia* sp., *Penicillium citrinum, Phoma* sp., *Rhizopus* sp., *Trichoderma virde*, etc. Besides the cutaneous reactivity of these allergens, the preponderance of *Alternaria, Aspergillus, Candida, Curvularia, Helminthosporium, Mucor, Paecilomyces, Penicillium* and *Trichoderma lignorum* have also been reported in the respiratory tract of many allergic patients (Singh *et al.*, 1981).

CONCLUSIONS

The pollen spore calendars are useful in identifying allergies against particular airborne pollen and fungal spore types. Comparison of the time of sensitivity with the pollen/spore calendar can lead to diagnosis and preventive measures against the pollen and spore allergies. However, the limitation of pollen calendar is the occurrence of year-to-year variation in both number and time of appearance of each type of pollen grains and fungal spores. This kind of variation most probably be sought in both climatological/meteorological and plant physiological factors affecting various plant species.

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Short Communication

Palmoxylon kamalam Rode from Wardha District, Maharashtra

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(Received 8 January 2002; Revised version accepted 20 August 2002)

INTRODUCTION

DECCAN Intertrappean beds of Wardha District, Maharashtra are well known. Nawargaon-Maragsur localities (21°1' N : 78°35' E) are rich in microfossils and megafossils, however angiospermic fossils are predominating. A small hillock present in Maragsur is rich in palm stumps.

Recently, authors have collected plant fossils from this area, one of the specimens showing interesting features is described below.

SYSTEMATICS

Genus—PALMOXYLON

PALMOXYLON KAMALAM Rode, 1933

(Fig. 1·19, Pl. 1·1-12)

The fossil specimen is a piece of a palm stem measuring 11 cm in radial extent and 15 cm in length. It is reddish brown externally as well as internally. Its external surface is eroded and it has no periderm, cortex or leaf scars. The present description is based on account of subdermal and central zone of the specimen. A number of transverse and longitudinal sections passing through the stem were prepared in order to study the internal structure.

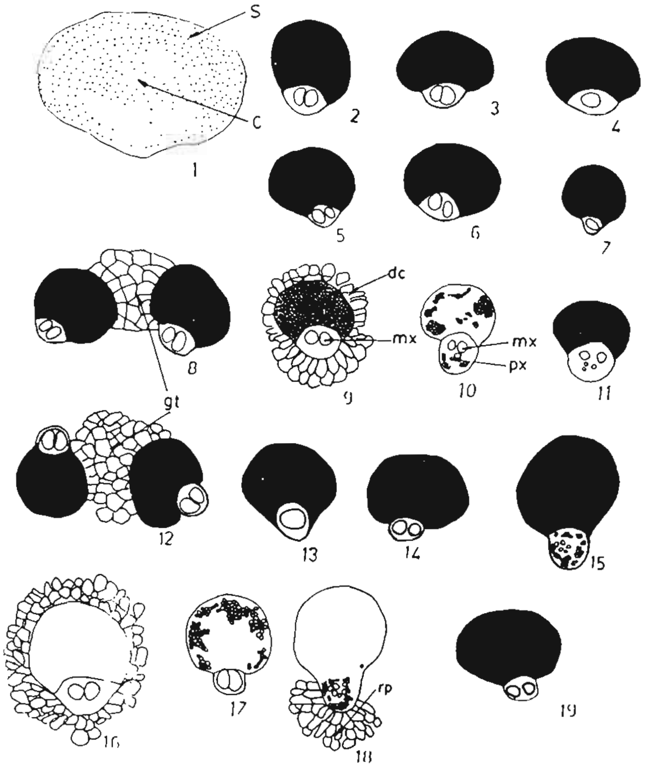

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Fig. 1—*Palmoxylon kamalam* Rode (1-19). **1.** T.S. of stem showing subdermal and central zone. x 7.5. **8.** T.S. of subdermal zone showing two slightly irregularly oriented fibrovascular bundles and ground tissue – gt. x 25. **12.** T.S. of central zone showing two irregularly oriented fibrovascular bundles. Note the complanate dorsal cap. x 25. **4, 7.** A typical fibrovascular bundle from the subdermal zone with complanate dorsal cap and vascular part extruded with single metaxylem element. x 25. **2, 3, 5, 6.** Fibrovascular bundles from the subdermal zone with two metaxylem elements. x 25. **9.** A typical fibrovascular bundle from subdermal zone with complanate dorsal cap- dc and vascular part extruded with two metaxylem elements – mx. Note the petaloid arrangement of intercellular spaces around the fibrovascular bundle. x 25. **10, 11.** A leaf trace bundle from the subdermal zone with complanate dorsal cap and vascular part extruded with two metaxylem elements – mx and 2-3 protoxylem elements – px. x 25. **13.** Fibrovascular bundle in the central zone with one metaxylem element. x 25. **14, 16, 17, 19.** Fibrovascular bundles in the central zone with complanate dorsal cap and two metaxylem elements. x 25. **15.** A leaf trace bundle from the central zone. x 25. **18.** A leaf trace bundle from the central zone. Note the radiating parenchyma-rp around the vascular part. x 25.

The important diagnostic features exhibited by the present fossil are :

1) The fibrovascular bundle with complanate dorsal cap (Fig. 1·2-7; Pl. 1·3, 4, 8) , two metaxylem elements without ventral cap and protoxylem elements, distribution 39-42 sq cm in subdermal zone (Fig. 1·8; Pl. 1·1) and 19-24 sq cm in central zone (Fig. 1·12; Pl. 1·7).
2) Leaf trace bundles are present in subdermal and central vascular zone, those of subdermal zone (Fig. 1·10; Pl. 1·5, 6) are smaller in size than the normal bundles but more common than the central zone, those of central zone are larger than normal vascular bundles but lesser in number than those of subdermal zone. (Fig. 1·15, 18; Pl. 1·9).
3) Ground parenchyma highly lacunar loose and mesh like (Pl. 1·12).
4) The trabaculae in between the intercellular spaces are 1-2 cells thick (Pl. 1·12).
5) The intercellular spaces around the fibro vascular bundle are so arranged that they make the appearance of petaloid arrangement of lotus flower (Fig. 1·9, 18; Pl. 1·6, 10, 11).
6) Fibre bundles are absent.

COMPARISON

The diagnostic features enumerated above closely agree with *Palmoxylon kamalam* Rode. Rode (1933) described *P. kamalam* from Deccan Intertrappean beds of Mohgaonkalan. The account was based on peripheral region. Shukla (1939) described a piece of central region from the same locality. Later on Sahni (1964) described a piece from the subdermal zone. Further details of this palm were described by Kulkarni and Mahabale (1971) on the basis of new specimen collected from Kondhali in Nagpur District. Their account was based on transitional zone between dermal and subdermal zone, the subdermal zone and central zone, and they have discussed all the structural details of this palm. All the structural details shown by the present specimen closely resemble with the *P. kamalam*. Present description is based only on the central and subdermal zone, but it is from new locality Maragsur in Wardha District. This is the third report of occurrence of *P. kamalam* from Deccan Intertrappean series. So it adds more data to the distribution ranging from Mohgaonkalan to Maragsur, Wardha District.

Among the living palms, *P. kamalam* shows considerable resemblance with the genus *Roystonea* in its ground tissue and fibrovascular bundle. The genus *Roystonea* is South American in origin and has four species in Cuba, Puerto Rico. They grow in the low ground and swamps in Florida and South America. The present description indicates the existence of *Roystonea* in the Deccan Intertrappean flora of India. The present specimen *P. kamalam* Rode is reported here from a new locality Maragsur – belonging to Wardha District of Maharashtra.

Isotype—Department of Botany, Smt. K.W. College, Sangli.

Museum No.—FWM 372.

Locality—Maragsur, Wardha District, Maharashtra.

Horizon—Deccan Intertrappean beds.

Age—Early Tertiary (probably Eocene).

Acknowledgements—*The authors wish to express their sincere thanks to Professor AR Kulkarni for going through the slides of the fossil stem and for useful suggestions and valuable comments.*

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PLATE 1

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Palmoxylon kamalam Rode

1. Transverse section of the stem showing subdermal zone. Note the distribution of fibrovascular bundles. x 2·6.
2. The two fibrovascular bundles from the subdermal zone and surrounding intercellular spaces. x 85.
3. A fibrovascular bundle from the subdermal zone with complanate dorsal cap and extruded vascular part with one metaxylem element and surrounding ground tissue. x 85.
4. A fibrovascular bundle from the subdermal zone with complanate dorsal cap and extruded vascular part with two metaxylem elements. x 85.
5. A leaf trace bundle from the subdermal zone. Note the dorsal cap and vascular part. x 85.
6. A leaf trace bundle from the subdermal zone note the dorsal cap, vascular part and intercellular spaces arranged in a petaloid manner. x 85.
7. Transverse section of the stem showing central zone. Note the distribution of fibrovascular bundles. x 3.
8. A fibrovascular bundle from the central zone with complanate dorsal cap and extruded vascular part with two metaxylem elements. x 85.
9. A leaf trace bundle from the central zone, with dorsal cap and extruded vascular part. x 85.
10. A fibrovascular bundle from the central zone with extruded vascular part with two metaxylem elements and lacunar ground tissue. x 85. Note the intercellular spaces arranged in a petaloid manner of lotus flower around the fibrovascular bundle.
11. A leaf trace bundle from the central zone, showing the vascular part. x 85. Note the intercellular spaces arranged in a petaloid manner of lotus flower around the fibrovascular bundle.
12. Transverse section of central zone showing ground tissue with large intercellular spaces. x 85.

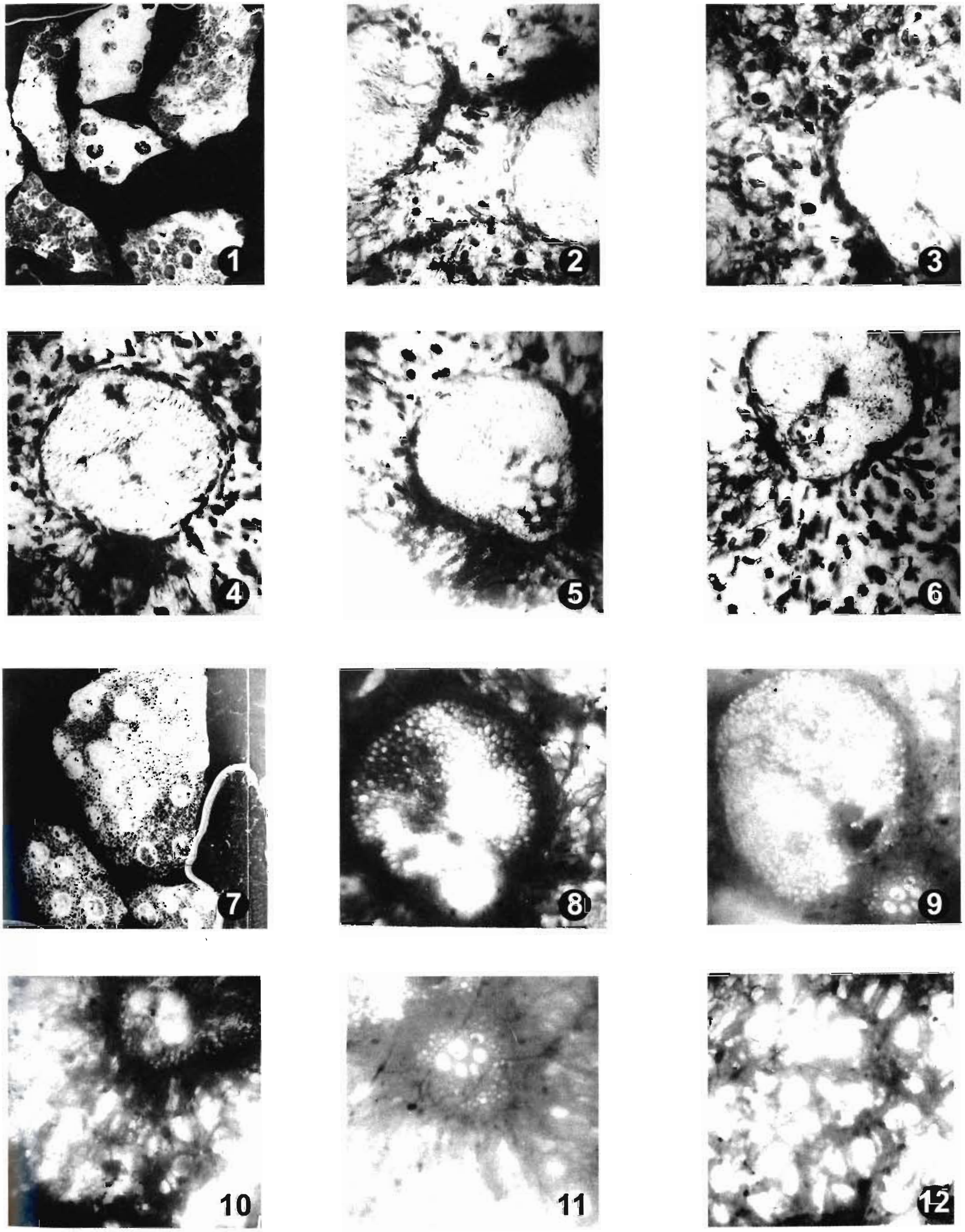

PLATE 1

Rode KP 1933. Petrified palms from the Deccan Intertrappean beds, I. Quarterly Journal of Geology, Mining & Metallurgical Society of India 5 : 75-83.

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Short
Communication

Ocimum pollen grains from the Subathu Formation (Late Ypresian) of Shimla Hills, Himachal Pradesh, India

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INTRODUCTION

WELL-PRESERVED pollen grains of *Ocimum* belonging to the family Lamiaceae have been recovered from the Subathu Formation, exposed in the Koshalia *Nala* section, near Koti, Sirmaur District, Himachal Pradesh (Fig. 1). The palynological information of fossil lamiaceous pollen is very meagre. Embolden (1964) reported fossil *Salvia* pollen from the Late Miocene of Alaska for the first time. Later, Von Campo (1976) and Menke (1976) reported some lamiaceous pollen from Late Miocene of Spain and Pliocene of Germany respectively. Boltenhagen (1976a, b) recorded hexacolpate pollen grains from Coniacean of Gabon which resembles *Salvia* pollen. Kar (1996) reported *Ocimumpollenites indicus* from Palana Formation (Eocene) of Rajasthan. As far as the authors are aware, this is the only record of fossil lamiaceous pollen from Indian Tertiary rocks. *Ocimumpollenites* resembles extant *Ocimum* pollen by having thick exine, pluricollumellate, broad reticulation and presence of collumella in the lumina. *Ocimum* is an important genus of the family Lamiaceae (Labiatae) because of its restricted species distribution in tropics. The objective of this communication is to describe *Ocimum* pollen recorded from the Subathu Formation of Lesser Himalayas as

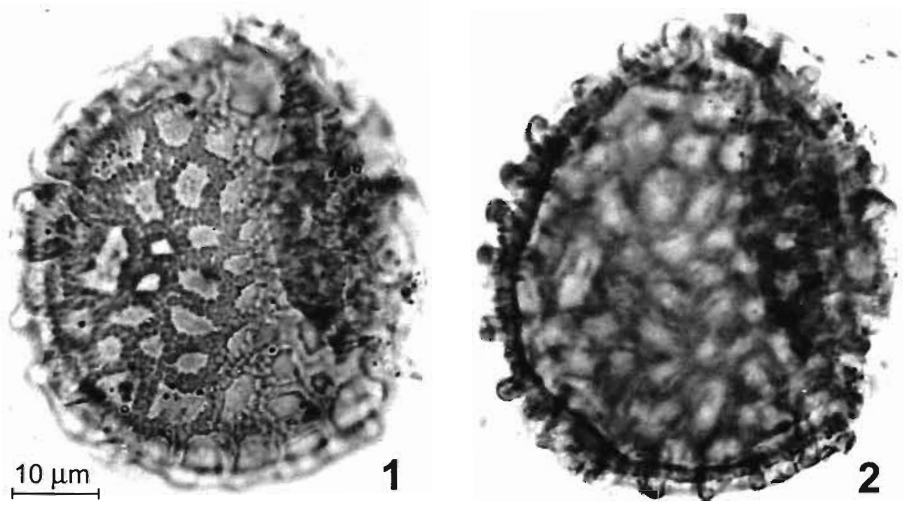

PLATE 1

1 *Ocimumpollenites indicus* Kar, 1996 (ca x1000); BSIP Slide No. 12021, coordinates: 22 x 96·5.

2. Same specimen in different focus showing distinct collumellate condition (ca x 1000).

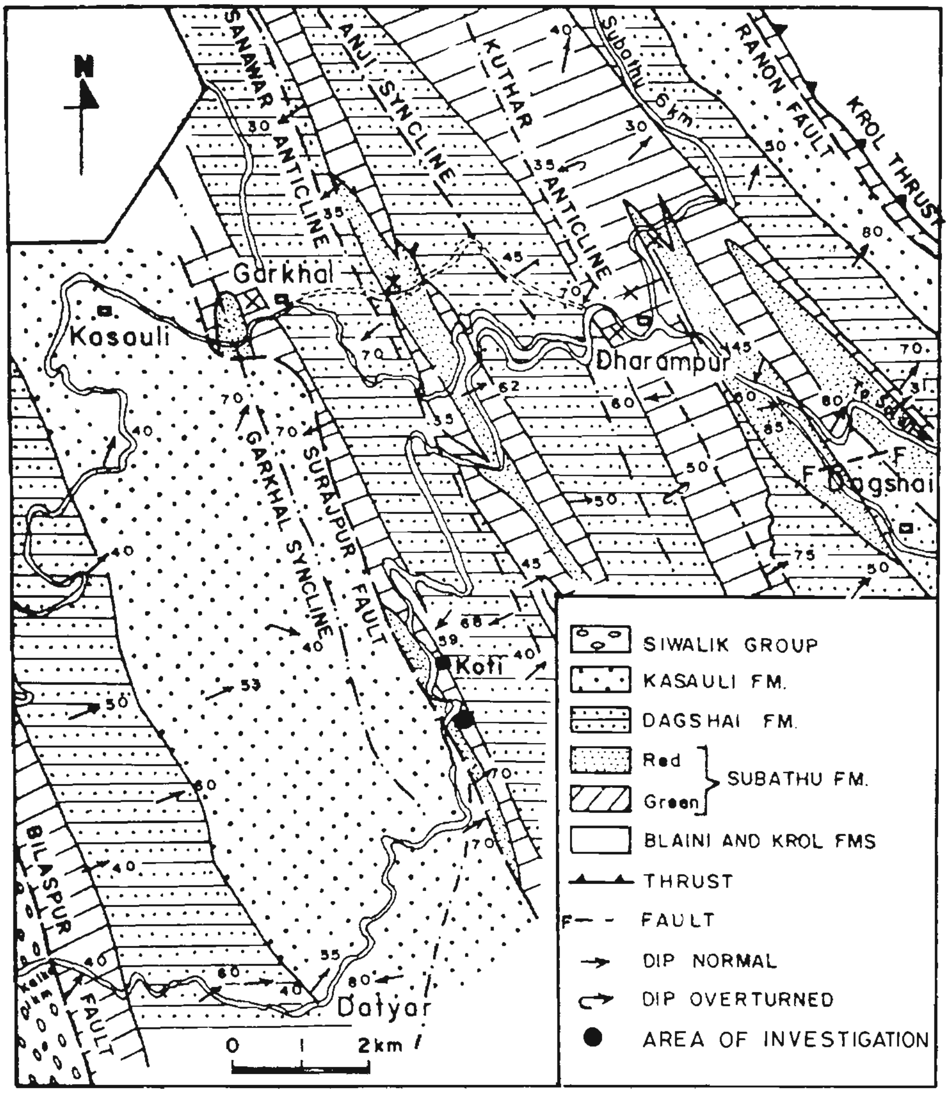

Fig. 1—Geological map of the area showing the locality (after Mathur & Juyal, 2000).

well as to throw light on its distribution in India during the Tertiary Period.

OBSERVATION

The recorded pollen grains are found mostly in polar view (Pl. 1). Size range 50-60 μm in diameter, hexacolpate, brevicolpate, colpi slit funnel-shaped in polar view, exine 3·5 μm thick, tectate, collumellate, reticulate, reticulation pentagonal or hexagonal and of different shapes and sizes, muri pluricollumellate. The recorded pollen grains are very much similar to those recorded by Kar (1996) from a bore core (No. K-12) at Kuchaur-Benia area, about 30 km south west of Bikaner, Rajasthan. The pluricollumellate condition and prominent reticulation patterns are considered to be important characters for the identification of *Ocimum* pollen in fossil state. Nine species of *Ocimum* are found in India. Among them, the widely distributed species are *O. basillicum*, *O. sanctum*, *O. americanum* and *O. killimundscharicum*. It is difficult to assign recorded fossil *Ocimum* pollen to any particular extant species. However, the present specimens closely resemble pollen grains of extant *Ocimum* sp. (BSIP Slide No. 9705, Birbal Sahni Institute of Palaeobotany, Lucknow).

REMARKS

The present record of *Ocimum* pollen grains from the Lesser Himalayan sediments indicates that the genus *Ocimum* was widespread during Late Ypresian than hitherto known. On the basis of the restricted distribution and undoubted fossil record of *Ocimumpollenites indicus* in the Early Eocene sediments of India. Kar (1996) postulated that different species of *Ocimum* except *O. killimundscharicum* might have originated in India and then migrated towards east and west. The Subathu Formation horizon from which *Ocimum* pollen grains have been described has been dated Late Ypresian on the basis of Larger Foraminifera (Bhatia & Singh, 1991; Bagi, 1992), nannofossils (Jafar & Singh, 1992) and dinoflagellates (Sarkar & Prasad, 2000). The close similarities between the recorded *Ocimum* pollen grains from widely separated areas viz., Rajasthan and Himachal Pradesh in Eocene times strongly indicates that during Early Eocene the Genus *Ocimum* was well established in the north-western part of India.

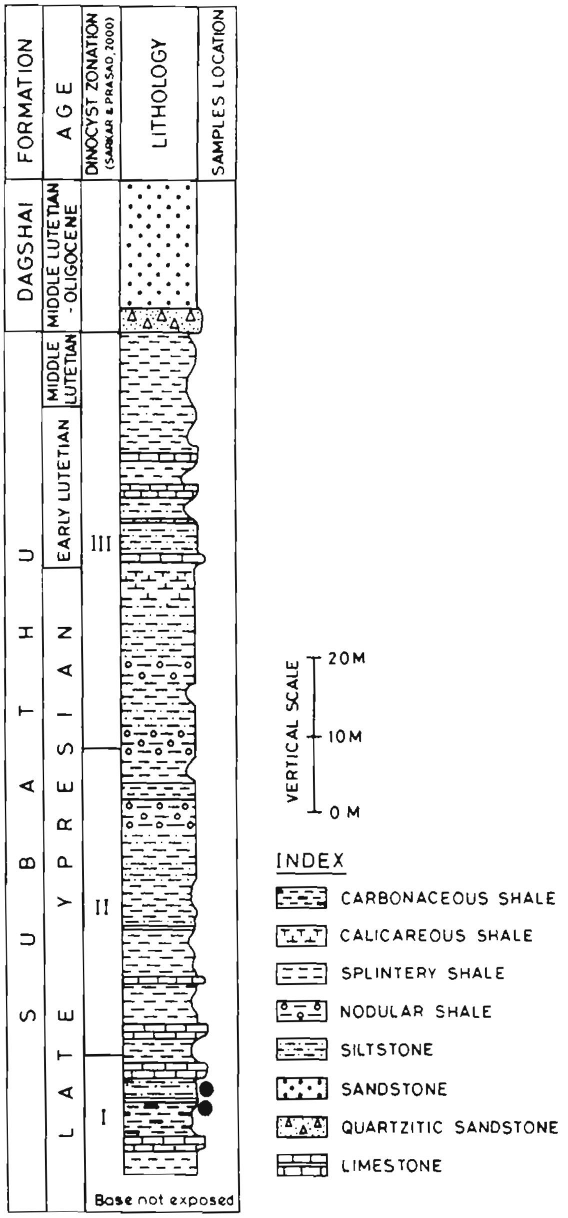

Fig. 2—Litholog (modified after Bhatia & Singh, 1991) showing the location of samples.

Acknowledgements—*We are grateful to Professor Anshu Kumar Sinha, Director, Birbal Sahni Institute of Palaeobotany, Lucknow, for allowing us to publish this paper and for constant encouragement throughout the study. We are thankful to Professor SB Bhatia (Retd.) Centre of Advance Studies, Geology Department, Chandigarh for his invaluable help in making the necessary collections from the river section.*

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Obituaries

PROFESSOR DIVYA DARSHAN PANT

October 18th 1919 - May 8th 2001.

Professor Divya Darshan Pant, a world-renowned plant morphologist and palaeobotanist, breathed his last on 8th May 2001 at Allahabad. In his death the palaeobotanical world has lost an expert par-excellence on Gondwana flora. A prolific writer, visionary and interpreter with perfect blend of living and fossil botany was active till his last. His leadership established a flourishing school of Palaeobotany and Morphology at Allahabad University, which he headed for 16 long years and was also Dean of the Science Faculty known for his researches in Palaeobotany and Morphology. Professor Pant was inspiring perceptor for generations of students and researchers. He was champion for the cause and upliftment of basic researches.

Professor Pant was born on 18th October 1919 at Ranikhet a picturesque place in Kumaon Himalaya. He had his early education in Ranikhet and Nainital from there he moved to Lucknow for University Education, where he was initiated by Professor Birbal Sahni, FRS in Botany research. Later he received British Council Grant – 1954 and was associated in research with Professor T.M. Harris, FRS of Reading University, Regius, Professor John Walton at Glassgow University and Professor R. Kraüsel of Senkenberg Institute, Frankfurt.

He is well known for his equal facility in living and fossil plants and started work on Cyacadales half a century ago publishing his first paper on cycads in 1953. His first comprehensive account of cycads appeared in 1963 in *Senkenbergiana biologica* and first edition of his book '*Cycas*' in 1962 which was later revised and enlarged, appeared in 1973. He has ever since continued his researches on living and fossil cycads that have resulted in altogether a new book "An introduction to Gymnosperms, *Cycas* and Cyacadales" which is being released with this volume.

His significant contributions include the work on morphology and anatomy of the root and shoot systems of living plants, their air pores, stomatal ontogeny and structure, nodal anatomy and the study of fossils mainly of the Glossopteris flora. His well-known contributions on the gametophytic nature of *Rhynia guyne–vaughanii*, which provided a widely quoted new concept about the life cycles of early vascular plants and their gametophytic generations. This led others like Remy and Remy (1980) and Remy *et al.* (1980) to work on Rhynie Chert where they discovered more gametophytes with archegonia & antheridia in the Rhynie Chert.

In order to have comparative idea about comparable gametophytes of living plants he worked on the gametophytes of the Ophioglossaceae and published a monograph on gametophytes of Ophiglossaceae (Pant *et al.*, 1984). His morphological and anatomical studies of diverse pteridophytes and Gymnosperms led to modification of Bower's concept about the phyletic slide of annulus in fern (Pant & Khare, Trans. Roy. Soc. London, 1974) and led to establish a new family—Damudopteridaceae from the Lower Gondwanas of India. His work on *Buriadia* (Pant & Nautiyal, Phil. Trans. Roy. Soc. London, 1967) and *Birsinghia* (Pant *et al.*, 1995) are of fundamental importance in formulating concepts about the evolution of early conifers as emphasised by Rothwell (1988) and Clement-Westershof (1988). His major contribution is in the understanding of the plant of *Glossopteris*. Besides, working on the cuticles and other structural features of diverse glossopterids, he reconstructed the plant of *Glossopteris* (Pant, 1977). He explained the occurrence of two kinds of leaves arranged in a decussate manner in *Diphyllopteris* as those of a seedling of *Glossopteris* (Rev. Palaeobot. Palynol.–Harris Comm. Vol. 1987). Lately additional evidence favoured his view on the plant of *Glossopteris* and suggested that *Glossopteris* and other glossopterids were large deciduous trees in Lower Gondwana forests (Pant, 1999). He had also made important contributions on Triassic plants. He demonstrated the spiral insertions of cupules in *Pteruchus*. His papers on classification of fossil spores and pollen (Bot. Rev. 1954) and the concept of primitive mode are classic. His studies on the carbonaceous pulls of compressions of the *Trizygia gondwanensis* suggested that in all likelihood these fossils belong to Sphenophylls and he also found diverse *Sphenophyllum* in the *Glossopteris* flora. He elucidated the structural features of two genera *Phyllotheca indica* and also those of *Raniganjia bengalensis* which indicated that they were different from northern *Umbellaphyllites* and are assignable to two families Damudopteridaceae and Asterothecaceae. Besides he reported *Chiguites mamalensis*, a modern *Chigua*-like leaf impression and *Cycadites meyenii* from the Permo-Carboniferous strata of Kashmir.

He had contributed more than 300 original research papers, reviews and monographs published in reputed international journals. Present volume of the *The Palaeobotanist* carries one of his contributed papers submitted by his student after his death. During his last days he was engaged in giving shape to a monograph on "*Pinus* and Pinales".

He was fellow and member of several leading Academic societies of the world namely, Linnean Society (London), International Society of Plant Morphologists, International Association of Plant Taxonomy, Society of Plant Taxonomists, International Organisation of Palaeobotany, Indian National Science Academy, Indian Academy of Science and National Academy of Sciences of India. He was Honorary Foreign Life Member of the Cycad Society of South Africa, and Palm and Cycad Society of Australia and also Member, Cycad Group IUCN – International Union for Conservation of Nature and Natural Resources.

His academician wife Radha, an accomplished son, two daughters and host of students initiated by him to Palaeobotany, survives him.

Mukund Sharma
Birbal Sahni Institute of Palaeobotany
53 University Road, Lucknow
INDIA

PUBLICATIONS OF PROFESSOR D.D. PANT

1941

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1943

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1949

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1950

Microfossils from a micaceous shale from the Talchir coalfield, Palaeobotany in India. *Jour. Indian bot. Soc.*, **29**: 15.

1953

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1954

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1955

On two new disaccate spores from the Bacchus Marsh Tillite, Victoria (Australia). *Ann. Mag. Nat. Hist.* London, **8** (12): 757-764, 1 Pl. 1 Text-fig.

1956

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1957

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1958

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1960

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1961

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Occurrence of intracortical roots in *Bambusa*. *Curr. Sci.*, **30**: 308, 1 Fig (with Bharati Mehra).

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1962

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Seed cuticles in some modern cycads. *Curr. Sci.*, **31**: 75-76, 4 Figs (with D.D. Nautiyal).

Path of bundles in the stem of *Bougainvillea*. *Curr. Sci.*, **31**. 295-296, 1 Fig (with Bharati Mehra).

Stem anatomy of some *Nyctaginaceae*. *Curr. Sci.*, **31**: 199-201, 2 Figs (with Bharati Mehra).

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1963

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PROFESSOR T.S. SADASIVAN

May 22nd 1913 - August 18th 2001

The demise of Professor T.S. Sadasivan on 18th August 2001 must have come as a message of mourning to scores of students of Botany who had obtained their degrees in that subject from the Madras University during the 40s, 50s, 60s and 70s of 20th Century. Even those who passed out in the 80s would known his name as he was the first director of the Centre of Advanced Studies in Botany (CAS) at the University of Madras. He was a renowned Plant Pathologist and an excellent teacher.

After graduation from the Madras Presidency College in 1934, he had a long academic pursuit at England. He was awarded Ph.D. in Plant Virology and Soil Microbiology from the University of London.

My acquaintance with Professor Sadasivan goes back to 1959-61, He used to engage us then in intercollegiate lectures at the Old Botany Lab in the university compound. Subsequently (1962) onwards, our interactions grew through practical demonstration together.

During the years 1976-1980 when he was the Chairman, Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow, I was a research scholar under UGC's Faculty Improvement Program (FIP). With his persistent encouragement, I could successfully complete my Ph.D. program. Professor Sadasivan was the first occupant of the Chair of Birbal Sahni erected in 1978 at BSIP. He occupied it as Professor Emeritus between 1978-1980 and was engaged in writing a monograph on 'The Diseased Plant'.

Professor Sadasivan was prompt to reply all letters written to him and was meticulously punctual in his responses to greetings sent on festive occasions. He evinced special interest inquiring not only about academic progress but also about the welfare of family members. His wife, Mrs Radha Sadasivan, is the sister of Mrs Chandrasekaran, spouse of Dr Chandrasekaran of 'Black-Hole' fame. Students who had the opportunity of studying under his leadership and had benefitted academically and spiritually miss this inspired teacher.

He was awarded Padma Bhushan in 1974 and was a fellow of the Indian Academy of Sciences, Indian National Academy and many other national and international scientific bodies.

He was survived by his wife and three daughters.

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Selaiyur P.O., Chennai 600 073.

PROFESSOR HENRY N. ANDREWS

June 15th 1910 - March 03rd 2002

Palaeobotanical World has lost one of the greatest Palaeobotanist, a thorough gentlemen and a perfect human being on 3rd March 2002 at the ripe age of 91 at Concord Hospital in Concord, New Hampshire, USA.

Personally it was a great loss to me as he was my mentor, inspiring teacher, guide and philosopher.

He was born on 15th June 1910 in Melrose, Massachusetts. He received his Bachelor's Degree in Food Technology from MIT in 1934. From Food Technology to Palaeobotany was a big jump in which he received Master's Degree in 1937 and Ph.D. in 1939 from Washington University, St. Louis, Missouri, USA. He carried out research in Palaeobotany under the supervision of Professor Hamshaw Thomas in the famous Palaeobotanical Laboratory at Cambridge University, Cambridge, England.

Professor Andrews was most loyal to his *alma mater*, i.e., Department of Botany, Washington University, St. Louis. He was a graduate student in this University where he worked later as a Tutor, Assistant Professor, Professor, Chairman and Dean of Science.

I was privileged to be his last Ph.D. student in Washington University, which he left in 1964 to join as Professor and Chairman, Department of Botany, Connecticut University, Storrs, Connecticut. He retired from this position in 1985. He settled down at his ancestral farmhouse in Sanbornton, Laconia, New Hampshire. He continued his writings from this place. His professional life was very rich with outstanding accomplishments. He published 79 original research papers and 7 books. His textbook "Studies in Palaeobotany" published by John Wiley & Sons, New York, 1961 was most popular among the graduate and research students and teachers of Botany and Geology throughout the world.

He served as a Palaeobotanist and Assistant to the Director at Missouri Botanical Garden in St. Louis and as a staff member of the US Geological Survey.

He was very simple, jovial person and had better understanding of India and Indian science since he spent almost one year with his family at Poona in 1961 as a Visiting Fulbright Scholar in the Department of Botany, University of Poona. He and his family — wife, two sons and daughter travelled widely in India. He spent most enjoyable and memorable days hiking in the foothills of Himalayas near Simla. His palaeobotanical exploration took him to many countries, most outstanding and productive one was to Ellesmere Island in Canadian Arctic. He published his monumental work on Devonian *Archaeopteris* based on this expedition jointly with T.L. Phillips and N.W. Radforth in 1965.

He wrote an excellent book on history of Palaeobotany entitled "Fossil Hunters: In search of ancient plants" published in 1984. This book makes a very interesting reading as it is full of historical information, anecdotes, his personal experience with outstanding Palaeobotanists world over. He devoted a full chapter in it on Indian Palaeobotanical work and Birbal Sahni Institute of Palaeobotany at Lucknow. He had great admiration for Professor Birbal Sahni who had visited his laboratory in Washington University, St. Louis. Professor Andrews also appreciated quality of work carried out by Palaeobotanists at the Birbal Sahni Institute of Palaeobotany at Lucknow. He also admired the quality of journal Palaeobotanist in which he published a paper on Coenopterid fructification from American coal balls jointly with me in 1962.

Though earlier he worked mostly on Upper Carboniferous Coal Ball flora later he shifted his attention to Devonian plants of Eastern USA and published a monograph on Devonian plants jointly with his student Patricia Gensel.

A few of the outstanding books published by him are listed below.

- Ancient plants and the world they lived (1947). Cornell University Press, Ithaca p. 279.
- Studies in Palaeobotany (1961). John Wiley & Sons, New York p. 487.
- The Fossil Hunters : In search of ancient plants (1984). Cornell University Press, Ithaca. p. 421.
- Plant life in the Devonian (with Patricia G. Gensel) 1984. Praeger Publishers. p. 380.
- Index of generic names of Fossil plants: 1820-1965. 1970. U.S. Geological Survey Bull. 1300. p 354.

Professor Andrews will be always remembered for his following attributes:

- Simplicity in thinking, dressing and behaviour.
- Excellent skill in writing and photography.
- Compassionate understanding of his colleagues and students.
- Hospitality to one and all.
- Total dedication to teaching and research in Palaeobotany.
- Keen interest in his students' work and welfare. Incidentally he had only one Ph.D. student at a time and hence he was always available to his research student for guidance and discussion.

May his soul rest in peace and give courage to his innumerable admirers to emulate some of his good qualities.

Shripad N. Agashe
Professor Emeritus
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Bangalore University
Bangalore 560056, India

PROFESSOR RAMESH CHANDRA MISRA

January 8th 1913 - June 6th 2002

Professor Misra was born at Muktesar, a small town northeast of Nainital in the Kumaun Himalaya on January 8, 1913, the youngest of five children – four sons and a daughter. His father Kaiser-I-Hind Captain Ayodhya Prasad Misra was an Army Doctor. Born in a family of army men, scientists, doctors and academicians, Professor Misra as a child soon found himself in an ideal geological surrounding at Muktesar, whose picturesque mountain landscape filled in him an inherent and abounding love of nature.

He was a brilliant, hardworking and devoted student. In 1929, he passed the High School from Christ Church College, Kanpur, the *alma mater* of his personality but also left a deep impact on his young and receptive mind by way of self-discipline, dedication and diligence. He passed the Intermediate and B.Sc. Examination in 1931 and 1933, respectively, from Banaras Hindu University. With the background of physics and mathematics as his subjects of study, he very much wanted to be an engineer. Had it been so, geology would have been deprived of a versatile person – a teacher, explorer, researcher, scholar, administrator, writer, and above all a naturalist. But it was not to be. An inborn love for nature, mountains and rocks lured him to geology. He obtained M.Sc. degree in 1935 from the Geology Department of Banaras Hindu University.

While in Banaras Hindu University, Professor Misra was greatly influenced by geological stalwarts of those days like Professor K.K. Mathur, Professor V.S. Dubey, Professor K.P. Rode, Professor D.K. Chakravarti and others. He worked as Lecturer in Geology Department of Banaras Hindu University till 1943. During those days, particularly in the early thirties and forties, geological field work used to be very hazardous with gripping fears of epidemics like plague, malaria and of wild animals, local tribes, etc. Ignoring all difficulties and banishing fear, he worked in Jammu and Kashmir, Kumaun, Mirzapur, Bundelkhand, Chhota Nagpur, Maihar, Satna, Kodarma mica belt and in some areas in Tamil Nadu. In 1943, he joined Lucknow University as Lecturer in Geology. He obtained his Ph.D. degree in 1944.

In Lucknow he had a very fruitful association with Professor Birbal Sahni, F.R.S., the then Head of the Department of Botany and Geology, Lucknow University. He accompanied Professor Sahni to the Salt Range in October 1943. Professor Sahni and Professor Misra worked very hard for the development of the Department since its inception in 1943. They realised the need for a separate building and their efforts soon resulted in the construction and opening of the new building of the Geology Department in July 1951.

Gifted with a remarkable memory, Professor Misra was a very knowledgeable person and his interests encompassed the entire gamut of earth sciences. Whenever he was approached for a reference on any branch of geology, he used to reel out from his memory, reference of the important contributions.

His field of study ranges from deep bore holes as a part of groundwater investigations to the mighty Himalaya. Professor Misra was in proud possession of a chip of 'Everest Limestone' from the summit of the Everest, which was presented to him by the legendary hero, the late Sonam Gyastso.

Professor Misra's pioneering work on Bundelkhand rocks, discovery of minerals pyrophyllite and diaspore, Vindhyan sedimentation and Himalayan geology are well known, which has led to extensive work of very high order by his students in these fields.

His inherent interest in the Himalaya and his association with the late Professor D.N. Wadia, F.R.S., the then Geological Adviser to Government of India, led to the founding of Wadia Institute of Himalayan Geology, now at Dehradun.

Professor Misra's interactions with overseas geologists like Martin F. Glaessner of Australia, Mme. Raaben of Russia, Late Professor Aurthur Holmes and Late Professor H.H. Read of England, Professor A.T. Cross, Late Professor Aurthur Buddington, Professor J.M. Schopf, Professor B.F. Howell, Professor Preston Cloud – all of U.S.A., Professor K.H. Wedepohl of West Germany and host of others have kept him abreast of the latest developments in the various fields of geological sciences.

Professor Misra successfully guided twelve students for Ph.D. degree in Lucknow University; He has over ninety research papers to his credit.

During his long association with Lucknow University extending over thirty-two years, he held many eminent positions. He became Dean, Faculty of Science in 1972, but resigned after a year because of interference and hindrance in teaching and research work. He was Dean of Students Welfare, Chief Provost, President of the Lucknow University Teachers' Association and Member Administrative Committee of Lucknow University.

His sphere of activities has not been confined to Geology alone. He was a great lover of nature. He had a very good collection of roses. A true sportsman, he had been a good hockey player in his college days and continued to take very active interest in sports and other activities in the University and was associated with the Canning College Athletic Association – the sports body of Lucknow University – for a very long time, patronizing, nurturing and encouraging young sportsmen.

Professor Misra was very kind and generous. He would open his doors and purse for the needy students. He never failed to spot out hidden talents. He was a connoisseur of good things, good clothes and good food. He was a visionary, a perfectionist, an optimist, an idealist and above all a nationalist to the core. Physically very active and mentally extremely alert, Professor Misra was leading a peaceful, quite and regulated life after retirement in January 1975. Both he and his wife, Dr (Mrs) Savitri Misra, Lecturer in Sanskrit in Lucknow, lived happily in their house "Rasavgunthan' on Ram Krishna Marg, Lucknow.

Professor Misra wrote many papers, edited books and made other academic contributions. He was a fellow of Indian National Science Academy and joined on various boards and committees of several institutes. He headed the Indian Committee on Geology under ICSU. He had been President of the Palaeobotanical Society and also of several other prestigious organisations.

In his demise on 6th June 2002, after a prolonged illness, we have lost a great teacher, scientist, academician, science-manager, a great human being and also a great friend of the Institute.

We pay our respects to him and offer our condolences to his bereaved family members.

Anshu Kumar Sinha

(Text adopted and modified after Girjesh Chandra, Lucknow University, published in Goelogy of Vindhyãnchal, Eds Valdiya KS, Bhatia SB and Gaur VK 1982, Hindustan Publishing Corporation Press, New Delhi 3-8.)

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AN HISTORICAL OUTLINE OF INDIAN PALAEOBOTANY

RAJENDRA N. LAKHANPAL

Birbal Sahni Institute of Palaeobotany, Lucknow

Early History

The history of Indian Palaeobotany can be traced as far as back as 1828 when Adolphe Brongniart described a few fossil plants from this country in his well known *Prodrome* and the encyclopaedic *Histoire des végétaux fossiles*. The next available record is the figures of some fossils included by J.F.Royle in his *Illustrations of the Botany and Other Branches of Natural History of the Himalaya Mountains*. These fossils were later re-examined by E. A. N. Arber (1901) who also described some Lower Gondwana plants from India in his monograph on the *Glossopteris* flora published in 1905. Numerous references to fossil plants are contained in the earlier volumes of the *Journal of the Asiatic Society of Bengal*, while some also occur in European journals like the *Quarterly Journal of the Geological Society of London* and the *Geological Magazine*. However, most of our knowledge of the earlier history of Indian Palaeobotany is derived from the publications of the Geological Survey of India which was founded in the middle of the nineteenth century.

So much material of the Gondwana Flora had been collected in the early days that by 1886 four volumes of a monumental work entitled the *Fossil flora of the Gondwana System* were published (OLDHAM & MORRIS, 1863; FEISTMANTEL, 1876-86), mainly due to the untiring labours of Ottokar Feistmantel. The collections that formed the basis of this work were made by the Geological Survey in different parts of peninsular India. Subsequently, additions to these collections were made not only from the peninsular but also from the extra-peninsular India. Noetling in 1902 found a Lower Gondwana locality near Srinagar, Kashmir, from where important collections were made by Hayden and Middlemiss. Middlemiss also discovered a number of other localities in Kashmir containing plants of the Palaeozoic age.

With the increase in the knowledge of the fossil plants and the many additions to the Gondwana material after the completion of Feistmantel's work, it was realised that his descriptions and interpretations needed revision. This was done in Europe chiefly by Professor Zeiller at Paris (ZEILLER, 1902) and by Professor Seward at Cambridge, who, in collaboration with Professor Sahni, published a revision of the more important Indian Gondwana plants (SEWARD & SAHNI, 1920).

REVIVAL AND ORGANISATION OF INDIAN PALAEOBOTANY IN THE PRESENT CENTURY

After the retirement of Feistmantel in 1885, palaeobotanical research in India came to an end, and plant fossils collected by the Geological Survey were sent to Europe for investigation. The revival of the science took place on the return of Professor B. Sahni from Cambridge in 1919. Inspired by his teacher, Sir Albert Seward, he took up palaeobotanical research in India with great enthusiasm. In fact, the progress of Palaeobotany in India in the present century is entirely due to him.

The Palaeobotanical Society and the Birbal Sahni Institute of Palaeobotany—As early as 1929 Professor Sahni wanted to place palaeobotanical research in India on an organised basis, and to establish a museum of fossil plants at a suitable centre. He approached the Government of India for financial aid but without success. Ultimately he decided to start this project with his own private resources. On 19th May 1946 with seven other members of the Committee of Indian Palaeobotanist he founded a Palaeobotanical Society. On 3rd June a trust bearing that name was created to which Professor and Mrs Sahni donated their private funds and immovable property, a reference library and fossil collections. The trust was charged with the foundation of a research institute having a broad international outlook for carrying on original research in fossil botany. By a resolution passed on 10th September 1946 the Governing Body of the Society established an Institute of Palaeobotany with Professor Sahni as its Honorary Director.

The Palaeobotanist—One of Professor Sahni's aims in founding the Institute was publication of a journal of palaeobotany. Unfortunately he could not live to see it done. After his death the Institute started publishing a journal called *The Palaeobotanist* of which the first issue appeared in 1952 in the form of Sahni Memorial Volume.

RECENT STUDIES

Morphological Aspects—From the phytomorphological viewpoint, palaeobotanical research in India at present embraces several horizons from the Carboniferous to the Pleistocene. In the Palaeozoic and Mesozoic, the fossils studied are from the Gondwanas. Until recently there was not much information available about the Lower Gondwana *Glossopteris* flora of India. As a result of intensive search numerous impressions and compressions of leaves and fructifications have been collected and are being studied at Birbal Sahni Institute of Palaeobotany. One of the best-known floras of India is the Jurassic of Rajmahal Hills.

Plant Microfossils—In 1937, under Professor Sahni's guidance, Miss C. Virkki (now Mrs K. Jacob) examined the microfossils in some lower Gondwana rocks of India and Australia. This resulted in important observations and may be regarded as the beginning of micropalaeobotanical studies in India.

Palaeobotany of Coal—In 1932, Banerji published the results of a detailed examination of some Gondwana and Tertiary coals from India. Besides examining thin microscopic sections he also macerated the specimens and studied their microfossil contents. The importance of microfossil examination in the correlation of coal seams in India was indicated by Professor Sahni in 1940.

Palynology—In India, palynology is in its nascent stage. Although the importance of this study in India was pointed out by Professor Sahni in 1948, it has been possible to start systematic work on Indian pollen only since June 1953. It is being carried on at the Institute under a scheme financed by the Council of Scientific and Industrial Research.

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