Changing patterns of the Permian Gondwana vegetation

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

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

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सारांश

परमी गोंडवाना वनस्पति के बदलते स्वरूप

शैला चन्द्रा

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

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

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

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

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

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

PERMIAN OF PENINSULAR INDIA

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

GLOSSOPTERIS FLORA OF PENINSULAR INDIA

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

Bryophyta

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

Table 1—Lower Gondwana Formations of India in different basins

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

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

Lycophyta

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

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

Arthrophyta

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

Schizoneura Schimper & Mougeot

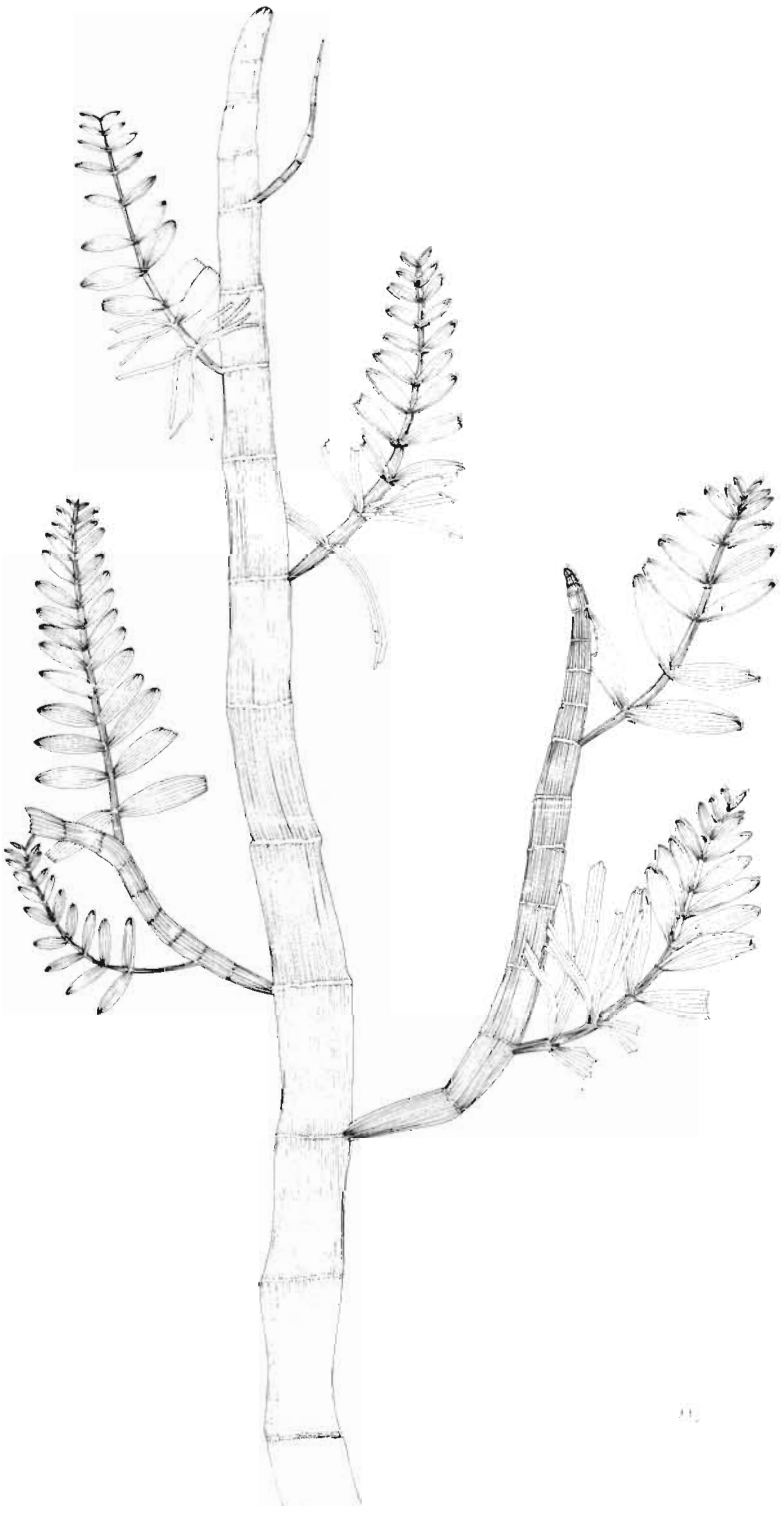
This appears to be a plant of considerable height reaching up to few meters as evidenced by the specimens reported by Feistmantel (1880, 1881) and others. The herbaceous plant had a main stem giving out alternate branches which were also branched sometimes and ultimately possessing opposite leaflets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

Phyllotheca Brongniart

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

Lelstotheca Maheshwari

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



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

***Raniganjia* Rigby**

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

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

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

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

Trizygia Royle

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

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

Filicophyta

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

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

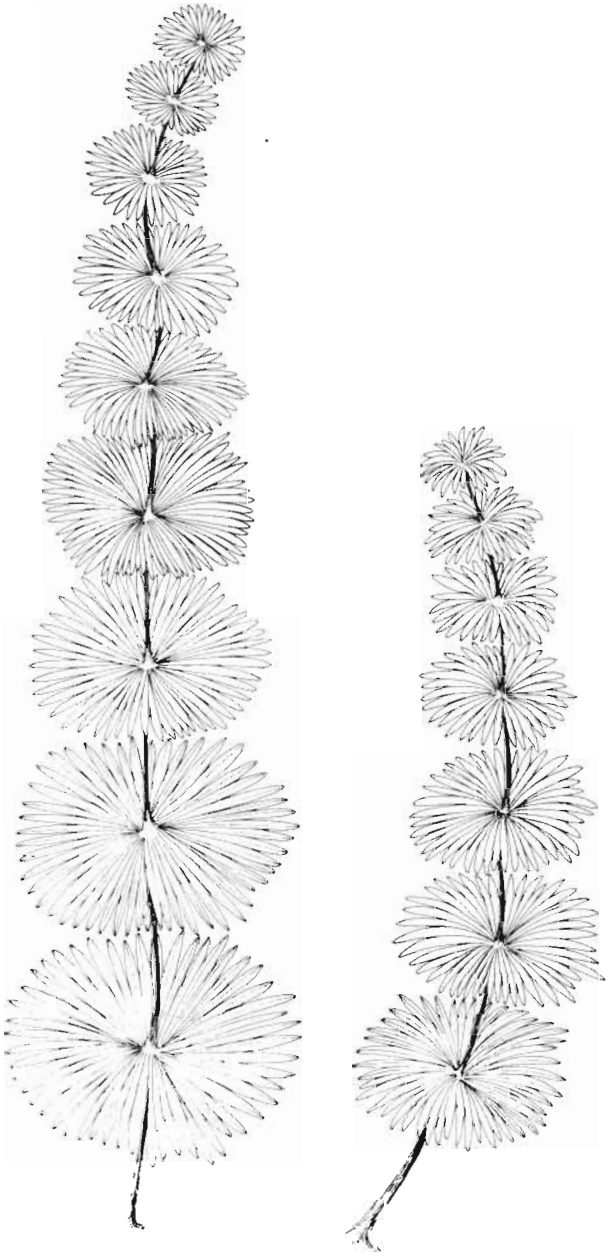
generic names till late. Now several of them have been assigned to new genera and species (Maithy, 1974b, 1975, 1977; Pant & Khare, 1974; Pant & Misra, 1976, 1977, 1983). *Neomariopteris* and *Damudopteris* (former *Sphenopteris*), *Dizeugotheca* (former *Alethopteris*), *Asansolia, Damudosorus, Trithecopteris*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

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

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

Gymnospermophyta

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



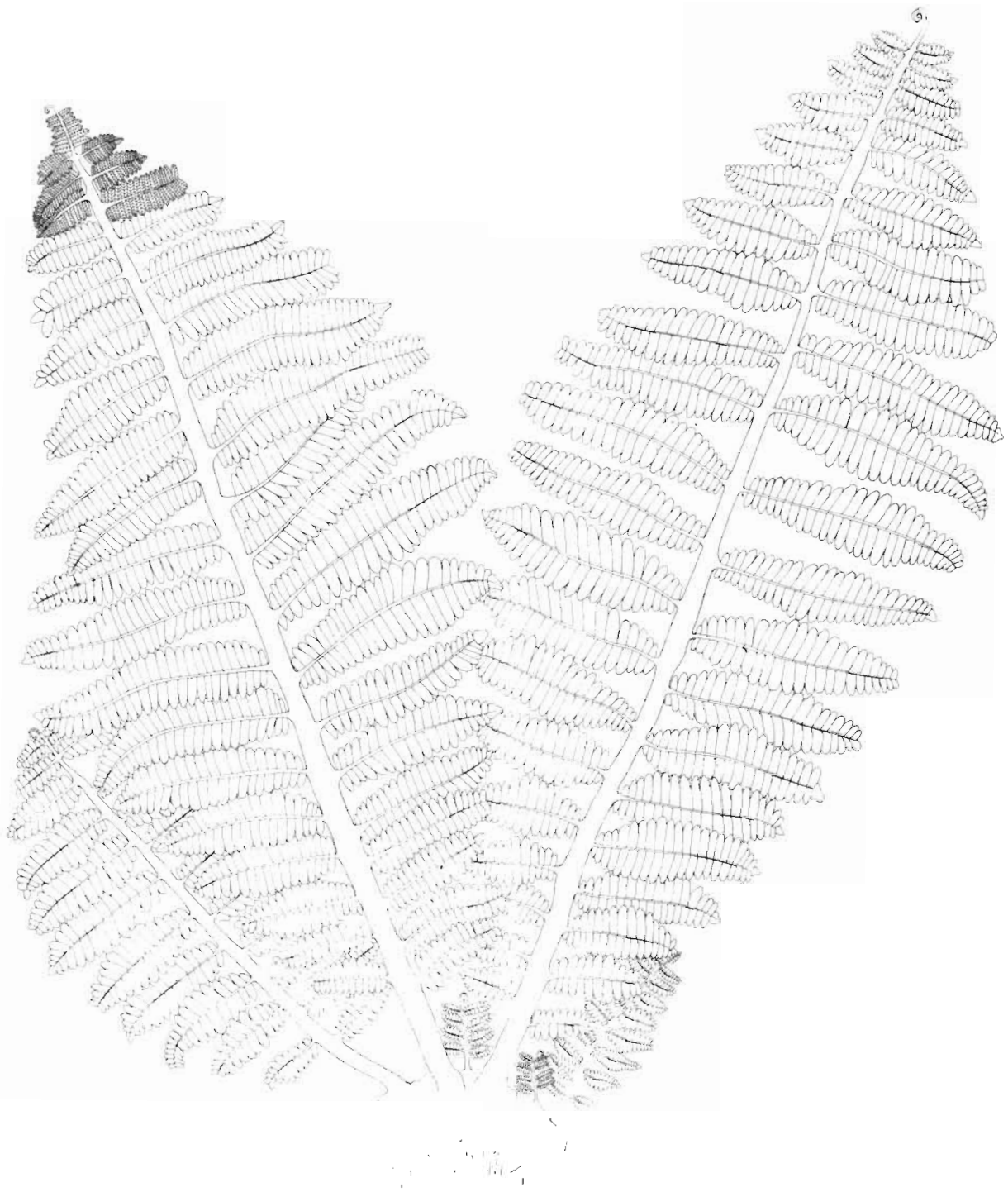
Text-figure 4—Reconstruction of the plant of *Raniganjia bengalensis* (Rigby) Pant & Nautiyal.

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

Glossopteris Brongniart

It is the best known, most common member of the group. The leaf remains in India are known from the base to the top of the Permian and also perhaps in the Triassic. The leaves mostly occur in the form of impressions and a few as compressions. To date, there are no reports of petrified leaves from India, though they are known from Australia and Antarctica. The genus has the largest number of species, well

over seventy from the peninsular region. Some species are characteristic of a particular formation and they could be useful for stratigraphic purposes (Chandra & Surange, 1979).

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

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

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

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

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

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

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PLATE 1

Reconstruction of Late Talchir vegetation:

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

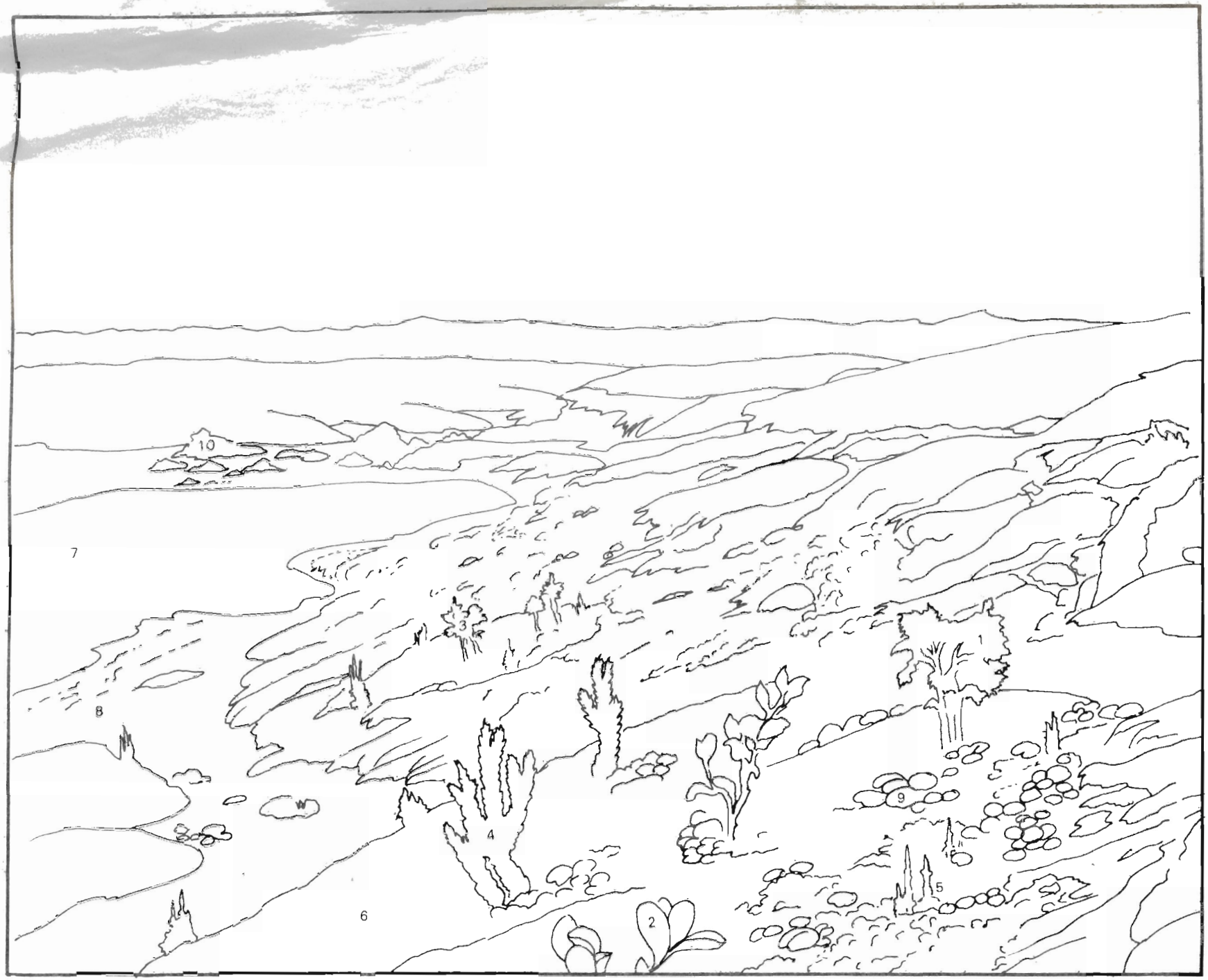
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PLATE 1

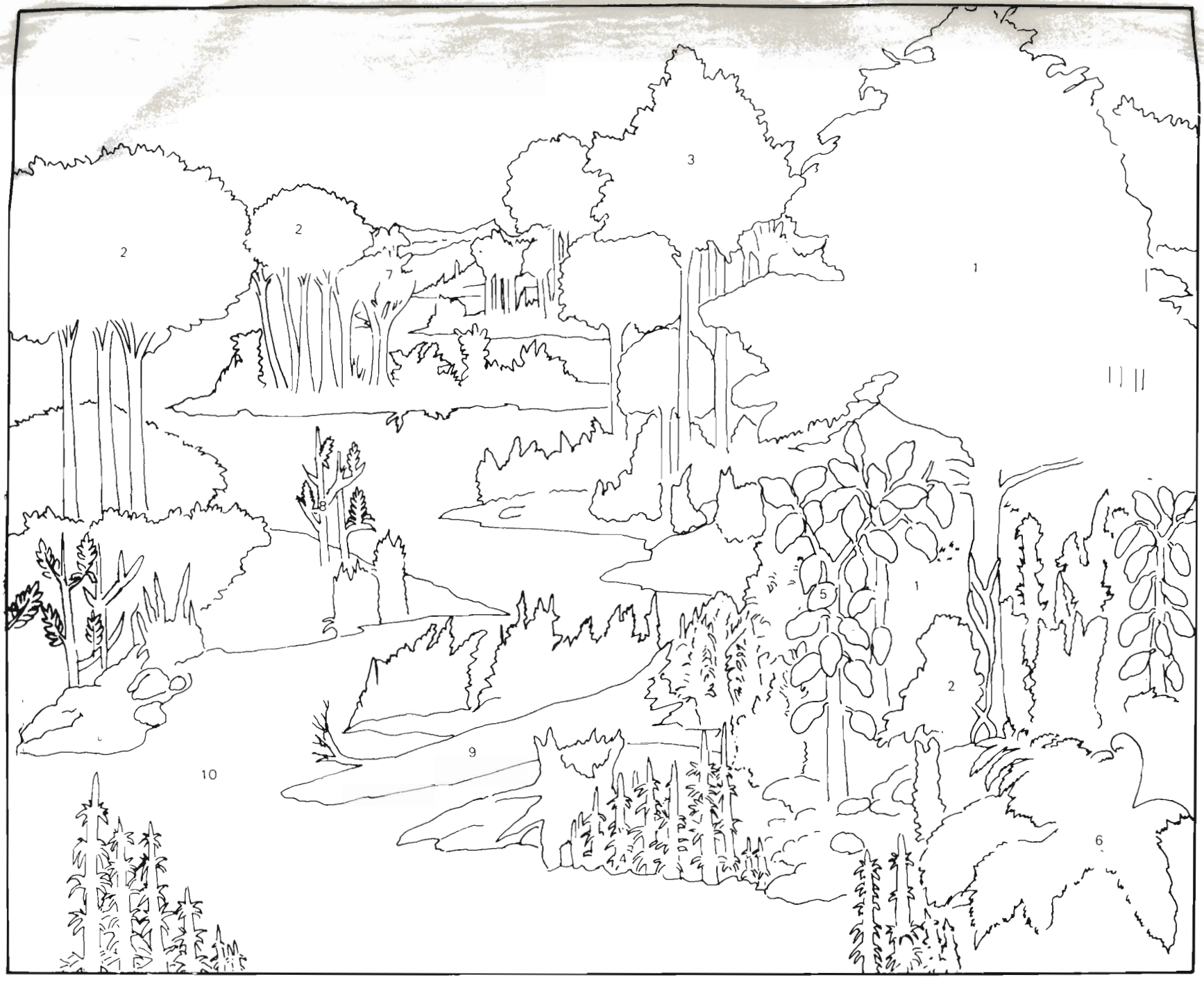
Text-figure 7—Reconstructions of plant of *Glossopteris* as suggested by various authors. **A** and **C**—by Rigby, **B**—by Seward, **D**—by Pant, and **E**—by Pant and Singh.

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

PLATE 2 →

Reconstruction of Karharbari vegetation:

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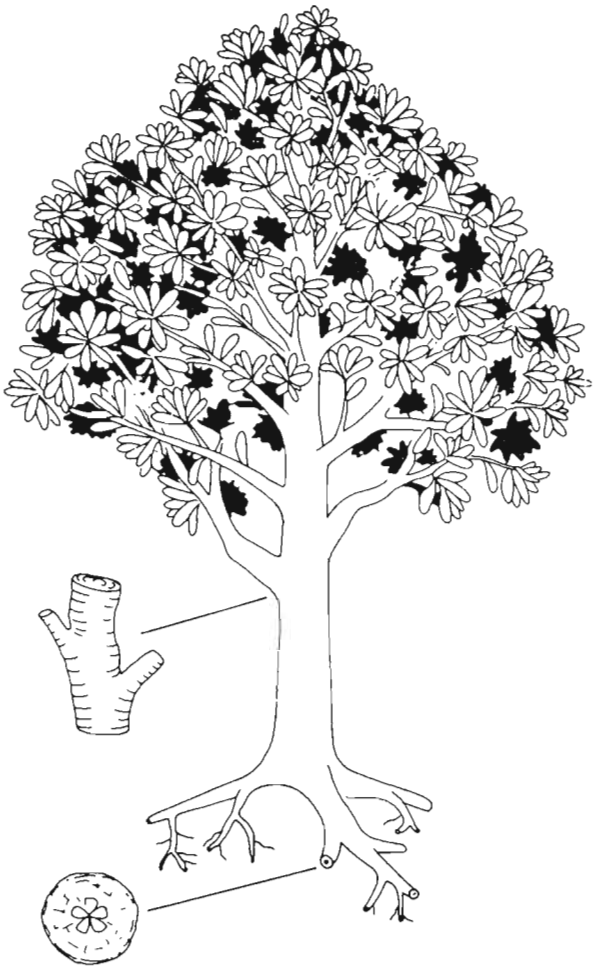


Text-figure 8—Reconstruction of the plant of *Glossopteris* as suggested by Gould & Delevoryas.

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

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

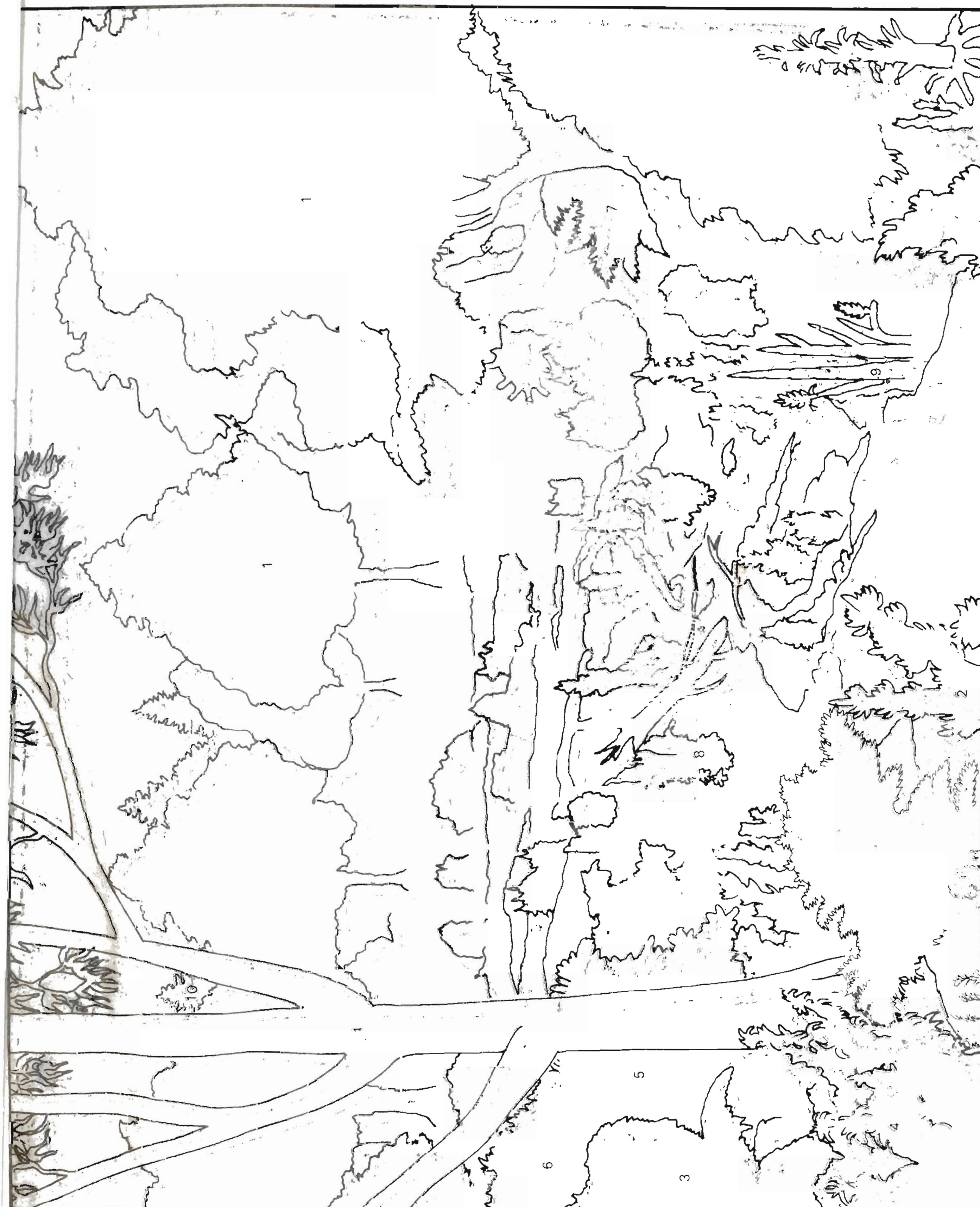
Pant and Singh (1974) on the study of Indian fossils thought that the *Glossopteris* plant had terminally or laterally attached leaves which belonged to two kinds of shoots (Text-figure 7D, E). Those which had short shoots with short internodes and those whose short shoots had long internodes. Alternatively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

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

PLATE 3 →

Reconstruction of Barakar vegetation:

1. *Glossopteris*
2. *Phyllotheca*
3. Usual fern plant
4. *Lelstotheca*
5. *Macrotaeniopteris*
6. *Rhabdotaenia*
7. *Pseudoctenis*
8. Log of *Glossopteris* plant
9. *Schizoneura*
10. *Walkomiella*



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

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

Gangamopteris McCoy

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

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

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

Palaeovittaria Feistmantel

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

Petrified woods and their affinities

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

ANCESTORS AND ORIGIN OF GLOSSOPTERIS FLORA

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

PRE-PERMIAN VEGETATION OF INDIA

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

PERMIAN VEGETATION OF INDIA

Talchir Formation, vegetation and forest type

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

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

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

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

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

Talchir plant community, climate and landscape

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

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

In the early phase of Talchir deposition the Indian Peninsula was presumably a land surface of high elevation ice covered and nearly barren of vegetation (Lele, 1976; Chandra & Chandra, 1987). The Early Talchir basins were embryonic without any diastrophic control (Ghosh & Mitra, 1975). The

glacial sedimentation in several basins indicate a cyclic pattern governed by advancing and retreating ice fronts. Records of fossils are poor everywhere in the Lower Talchir. Towards the end of the Talchir the flora shows definite improvement. The plants continued to occupy the land as more and more space became available by melting of ice. The climatic situation seems to have improved considerably with the increased sunlight and temperature and improved size of the leaves (Surange, 1966; Lele, 1976; Chandra & Chandra, 1987). It seems appropriate that the *Glossopteris* flora had already come into existence before the land was ice free (Sahni, 1939). This also indicates that some of the hardy plants could survive even under an ice cover.

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

Karharbari Formation, vegetation, forest type

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

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

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

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

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

Karharbari plant community, climate and landscape

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

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

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

Barakar Formation: vegetation and forest type

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

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

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

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

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

Barakar plant community, climate, landscape

The vegetation during the Barakar time was lush green dominated by arborescent *Glossopteris* plant community with secondary wood. The forests were very dense swampy in low lying river valleys as shown in the landscape (Plate 3). The climatic conditions during Barakar were warm temperate, in general, with appreciable amount of humidity. Intermittent spells of hot and cold seasons were also recorded with abundant rainfall. The Barakar is an important period exhibiting maximum development of coal of our country. The most important prerequisite for the formation of coal swamps is dense vegetation and abundant rainfall which should exceed potential evaporation. The quality and the characteristics of Lower Barakar coals indicate that the vegetal matter must have been deposited in somewhat deeper waters. The conditions of sedimentation were such that the mineral matter is found intergrown with the coals (Basu, 1964).

It is further observed that during Middle Barakar, the vegetal matter might have possibly been deposited in deeper waters where considerable degree of sorting of vegetal and mineral matters have occurred. The Upper Barakar coals contain good to medium quality coals and variable phosphorous content. The depositional conditions of Upper Barakar coals appear to be same as that of Middle Barakar.

Kulti Formation, vegetation, forest type

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

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

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

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

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

Kulti plant community, climate, landscape

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

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

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

Raniganj Formation, vegetation and forest type

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

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

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

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

Gymnosperms are represented by a high

PLATE 4 →

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

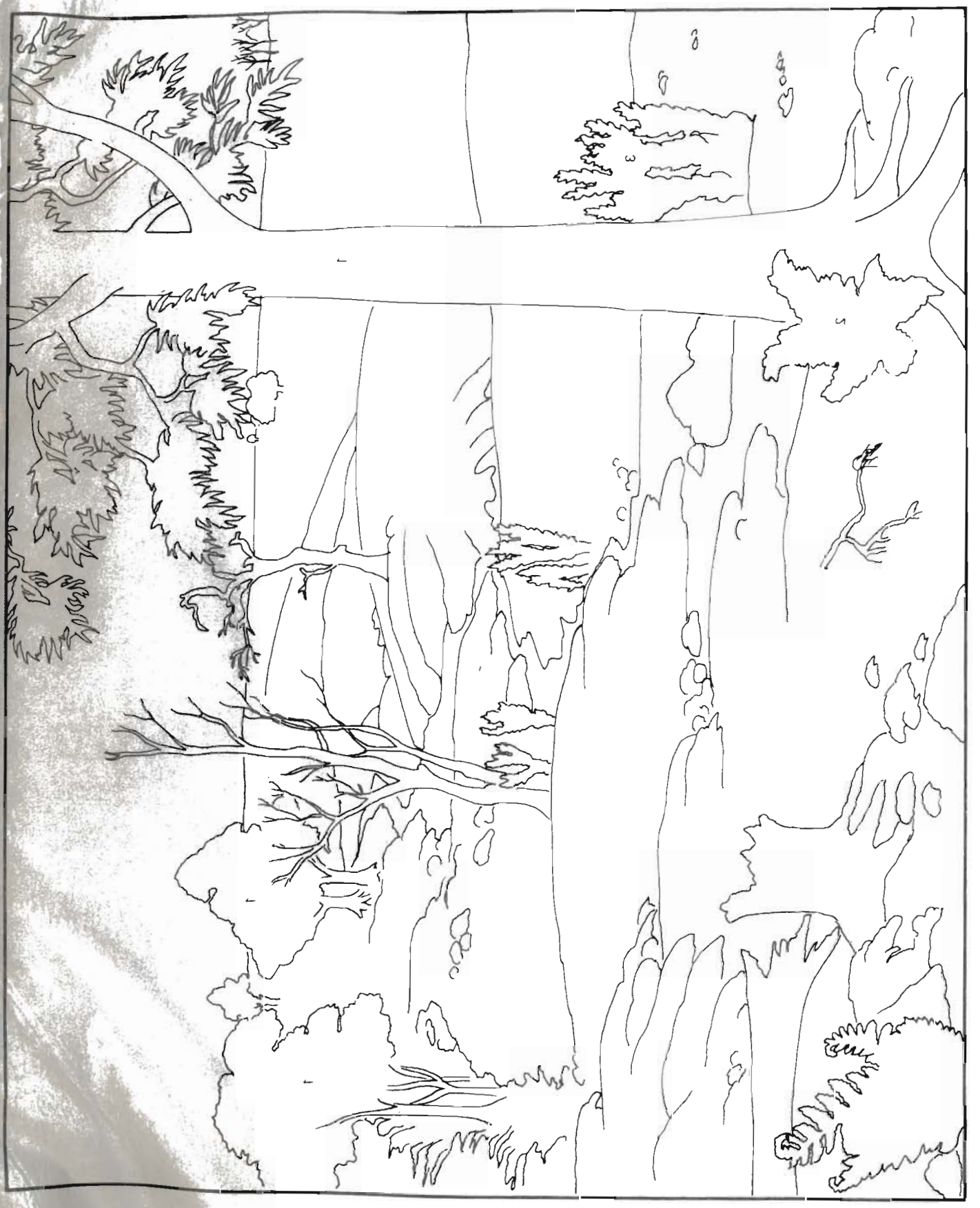


PLATE 4

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

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

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

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

Raniganj plant community, climate and landscape

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

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

Kamthi Formation, vegetation and forest type

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

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

PLATE 5

Reconstruction of Raniganj vegetation:

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

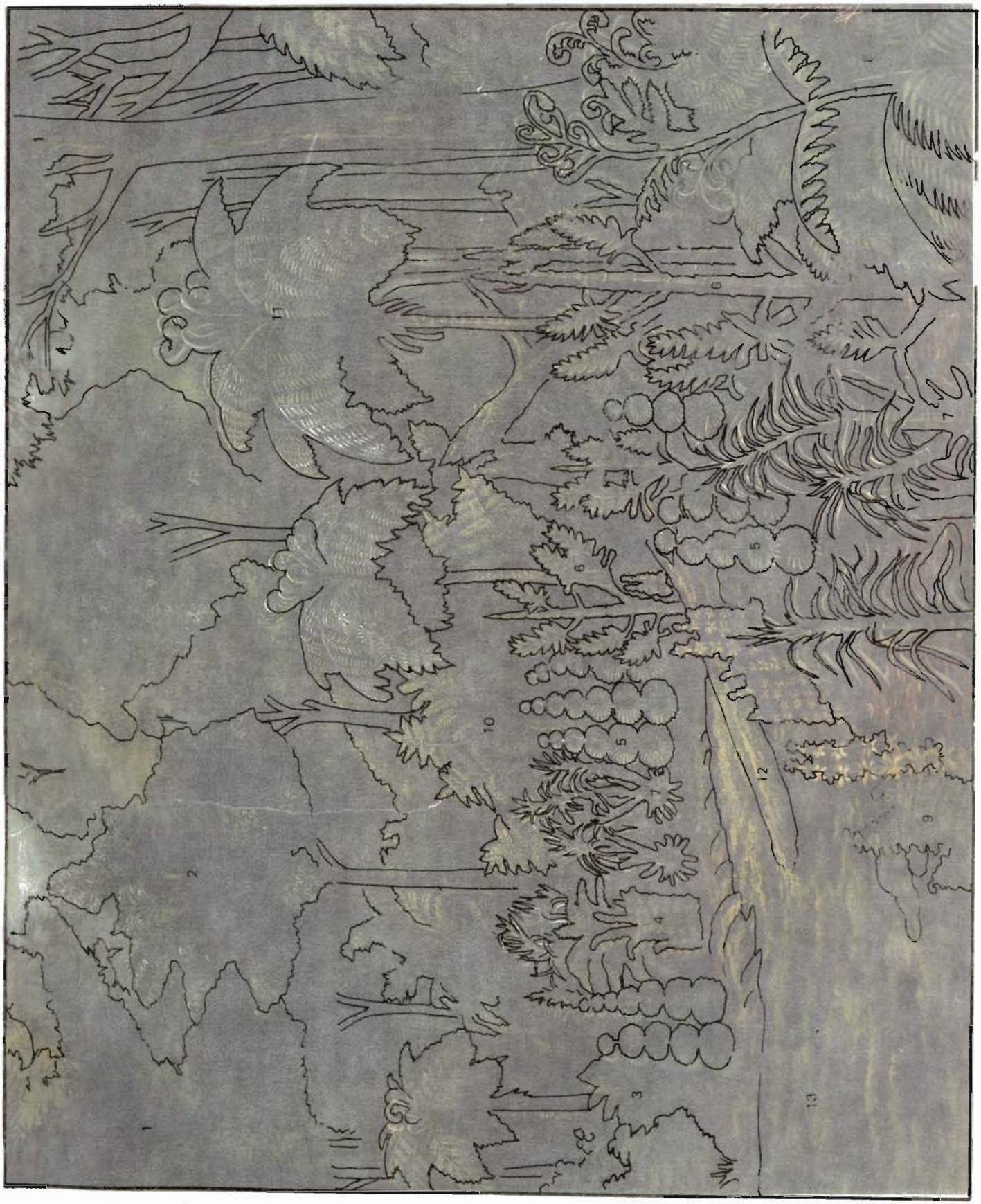


PLATE 6

PLATE 5

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

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

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

Kamthi plant community, climate and landscape

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

CONCLUDING REMARKS

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

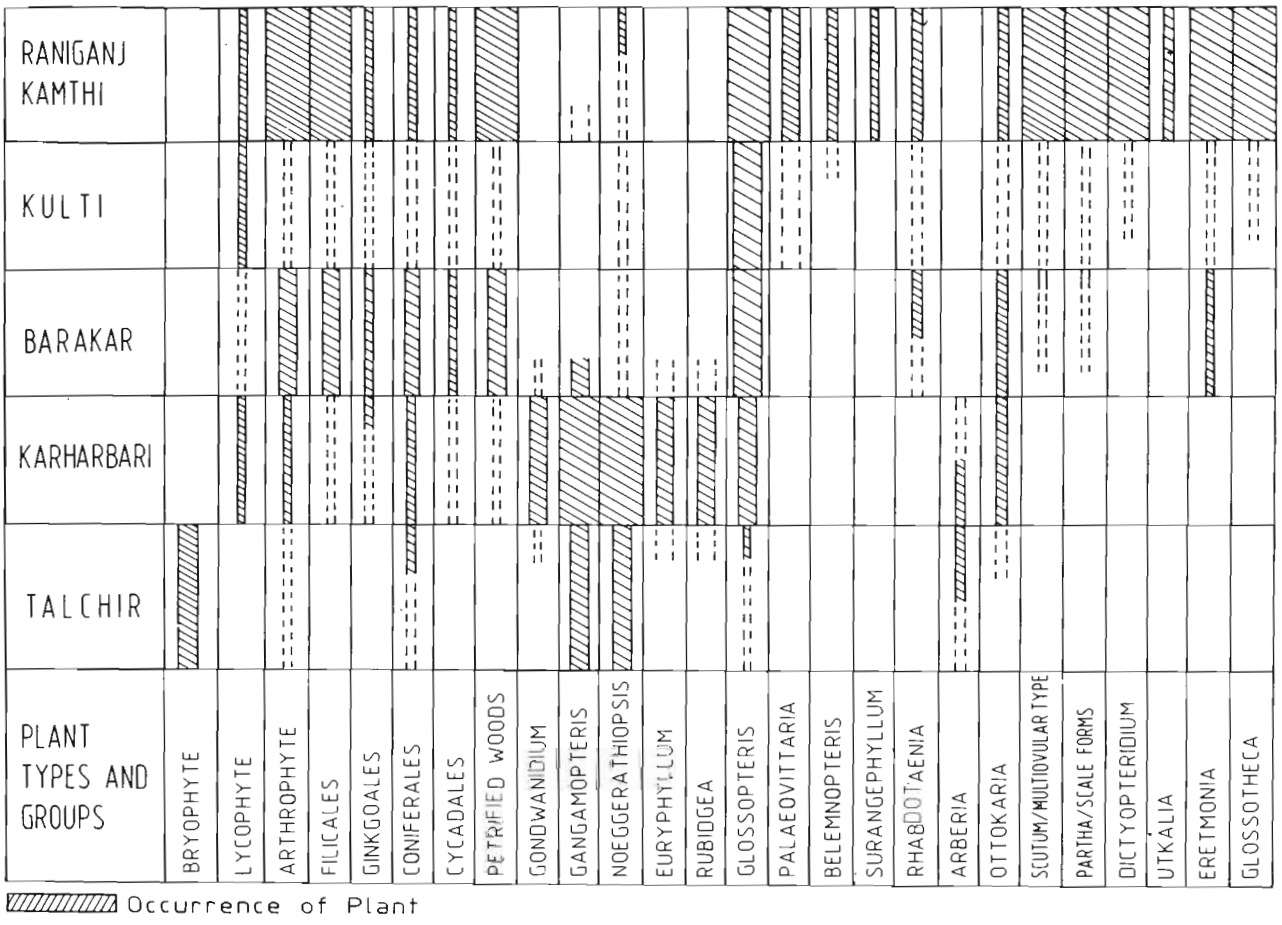
Lacustrine system—This is generally the site for sediment and biomass deposition. Most data concerning fauna could be obtained here. Algae, bacteria and some arthrophytes compose this system.

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

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

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

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



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

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

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

climate represented the Kamthi forest. The general patterns of change in the plant ecology were controlled in parts by broad climatic changes.

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

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

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