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Vagaries of the summer monsoon rains

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ABSTRACT

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Summer monsoonal rains are very important for the agriculture in our country. Fluctuations in monsoonal performance often create wide variations in crop production. In the present paper, the predictability of monsoon rains in the context of Professor Lorenz's recent work has been discussed. Variations in sea-surface temperature and snow cover and their impact on monsoonal rains are also discussed. Recent work on, the ENSO event and monsoons is described. The article covers the statistical methods for long range prediction of rains. The limitations of the current 16 parameter regression equation are mentioned. In conclusion the cost benefits, which can be assessed by methods based on probability are discussed.

Key-words— ENSO, ELNINO, Monsoonal rains, Monsoon prediction, India.

सारांश

ग्रीष्मकालीन मानसूनी वर्षा की उच्छृंखलता

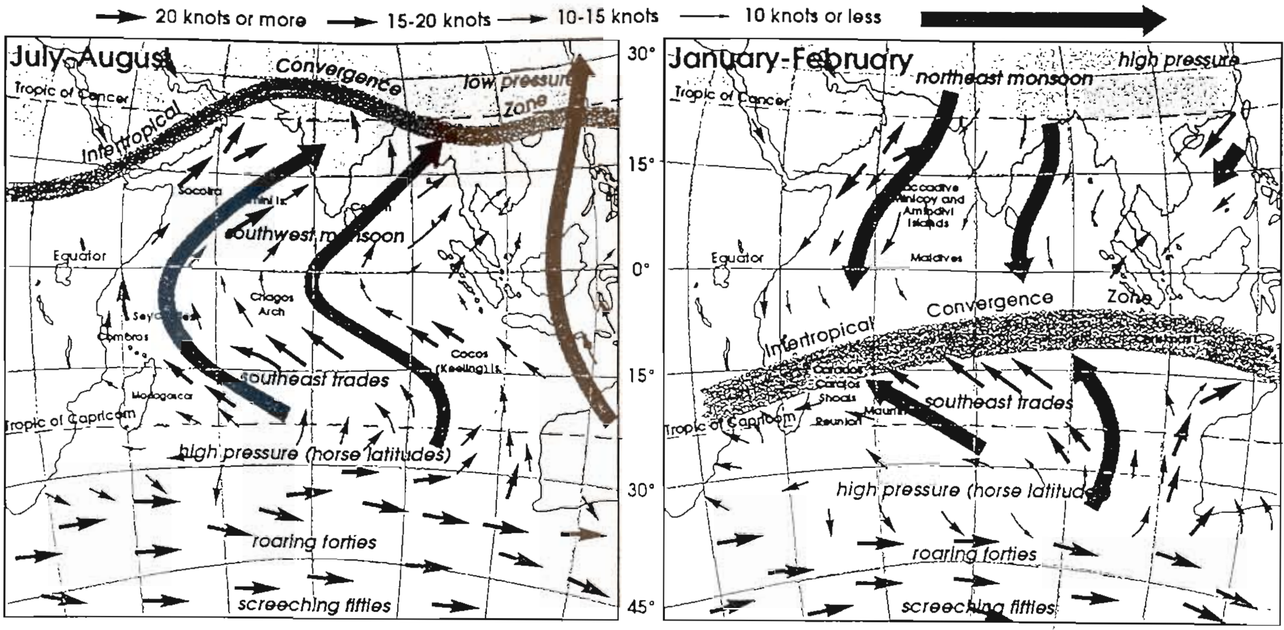
पी.के. दास

ग्रीष्मकालीन मानसूनी वर्षा हमारे देश की कृषि सम्बन्धी आवश्यकताओं के लिए अत्यन्त महत्वपूर्ण है। मानसून की अनियमितता प्रायः फसल उत्पादन में विचलन उत्पन्न कर देती है। प्रस्तुत शोध पत्र में प्रो. लॉरेन्ज़ के अर्वाचीन शोध के संदर्भ में मानसूनी वर्षा के पूर्वानुमान के विषय में चर्चा की गई है तथा समुद्र पृष्ठ के तापमान में विचलन तथा हिमाच्छादन के मानसूनी वर्षा पर पड़ने वाले प्रभाव पर भी प्रकाश डाला गया है। ई.एन.एस.ओ. घटना तथा मानसून के अद्यतन शोध कार्य का वर्णन भी इस शोध पत्र में किया गया है। आलेख में लम्बी परास की वर्षा के पूर्वानुमान के लिए सांख्यिकीय पद्धति का उपयोग किया गया है तथा इस आधार पर वर्तमान 16 प्राचल प्रतिक्रमण समीकरण की सीमाओं पर प्रकाश डाला गया है। निष्कर्ष स्वरूप इस शोध पत्र के अन्त में लागत लाभ की चर्चा की गई है, जिसे प्रायिकता की विधियों के आधार पर निर्धारित किया जा सकता है।

INTRODUCTION

I am grateful to the authorities of the Birbal Sahni Institute of Palaeobotany for inviting me to deliver the Sir Albert Charles Seward Memorial lecture. Sir Charles was an eminent scientist and Professor Birbal Sahni, his beloved student, was a very distinguished scientist of our country whose work helped our country to develop the science of Palaeobotany. I feel greatly honoured to speak on an occasion that is closely associated with the memories of two distinguished scientists.

Monsoonal winds are indistinct print by differences in the response of land and ocean to solar radiation. The land responds much faster than the ocean and, as a consequence, broad currents of air blow towards the land from the ocean around the summer solstice. During the winter solstice this is reversed and the winds flow from the land towards the ocean. The former results in the summer monsoon while the latter is the winter monsoon (Das, 1995). The two monsoons are illustrated in Text-figures 1 and 2 and as shown in these two figures, both the monsoons are extensions of trade winds from (a) the southern hemisphere in summer and (b) the northern hemisphere in winter. The zone separating these two trade winds is referred to as the Inter Tropical Convergence Zone (ITCZ). For us the important question is their prediction. Can we predict, for example, their time of arrival in India, or their



Seasonal surface wind flow in the Indian Ocean. The thickness of the arrows are proportional to the force of the wind. From the *Indian Ocean Atlas*, 1976.

FIG. 1. FIG. 2.

Text-figure 1—Summer Monsoon Surface Winds.

Text-figure 2—Winter Monsoon Surface Winds.

performance in terms of rainfall ? As the summer monsoon is the larger system, we will focus our attention on this system. Unless otherwise stated, the monsoon will hereafter mean the summer monsoon.

PROFESSOR LORENZ'S WORK ON PREDICTABILITY

Over three decades ago, Professor E.N. Lorenz, an eminent meteorologist at the Massachusetts Institute of Technology (MIT), was able to show that the upper limit of predictability for the atmosphere was about two weeks (Lorenz, 1993). In any dissipative system, such as the atmosphere, the solutions of the relevant system of equations can be represented by trajectories in phase space. The phase space is defined by the independent variables, that is, by X, Y and Z in a three dimensional cartesian system. The trajectories often remain confined in space, such as, a circle or an ellipse, which eventually, converges to a point. This is called an "attractor" for the system. Professor Lorenz showed that the equations for weather prediction possessed a set of two attractors and the trajectories in phase space tended to converge towards the first attractor and, later, towards the second attractor. This he defined as a system of "strange attractors" which implied, among other things, great sensitivity to the initial conditions with which we start computing the sequence of weather. Considering these aspects, Professor Lorenz estimated a maximum of about two weeks for short range weather prediction, if the best possible data were available to define the initial state. In reality, the maximum time for meaningful weather prediction today varies from 3 to 5 days.

Professor Lorenz was mainly concerned with short range prediction. A little after his work, Professor Jule Charney, another very eminent Professor of Meteorology at MIT put forth a new idea. He felt that there were certain types of weather systems that were driven by slow variations at the earth's surface. Examples of such variations were fluctuations in sea surface temperature (SST), snow cover and soil moisture. Longer range prediction of weather systems, which were dominated by a driving force of this nature was possible, felt Professor Charney. As we shall see this assertion was very relevant for long term prediction of monsoon rains (Charney & Shukla, 1981).

A question that is now of much interest is the possibility of an attractor for climate. The variability of climate, which is often seen in the sequence of ice ages and interglacial periods or in the formation of deserts over land which was once fertile, leads one to question whether an attractor does exist? More specifically, we need to know if we are moving towards a stabler climate in the years to come and the existence of an attractor will help us to answer these questions.

THE EL NINO AND ENSO EVENTS

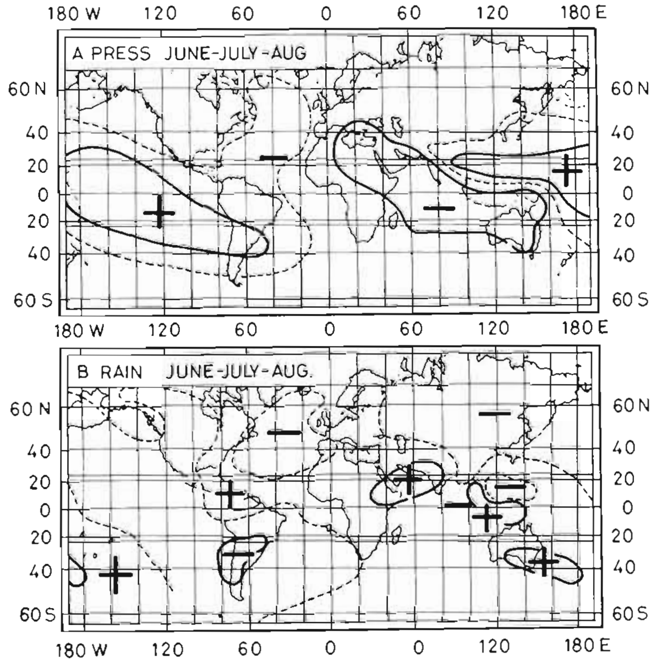
Professor Charney's ideas about climate changes forced by slow changes at the earth's surface have been substantiated by the recent discovery of a sudden change in sea surface temperature (SST). The "El Nino" refers to a sudden increase in SST in the coastal waters off Peru. El Nino is a Spanish word which means 'the male child', while a 'female child' is "La Nina". The abnormally high temperatures have disasterous effects on the Peruvian fisheries. The sudden appearance of warm waters off Peru was first reported in 1891 by Dr Luis Canenza who was the President of the Geographical Society of Peru. In normal or La Nina years, the coastal waters off Peru are cold because of strong upwelling, which brings up the colder waters from the deeper parts of the ocean. The upwelled water also bring up plankton on which the fishes thrive. But, once in a while the trade winds above the sea surface are weak and hence there is no upwelling or plankton for the fish, and warm water appears off the coast. The frequency of an El Nino varies from 2 to 7 years. As the El Nino appears around the time of Christmas, it is often referred to as the "Child Christ".

The sudden appearance of warm waters off Peru is closely linked to another important meteorological event that is referred to as the Southern Oscillation (SO). This was discovered by Sir Gilbert Walker in 1920—an eminent mathematician who noted a see saw pattern of fluctuations in pressure between the Pacific and the Indian Ocean. When the pressure was high over the southern Pacific, it was low over the Indian Ocean. But, once every few years there was a reversal. When this happened, higher pressures prevailed over the Indian Ocean and the pressures were low over the Southern Pacific. Sir Gilbert called this the Southern Oscillation (SO).

Later, Sir Gilbert discovered two more similar oscillations over the North Atlantic and the North Pacific Oceans. The North Atlantic Oscillation (NAO) was marked by periodic reversals in pressure between a centre of high pressure over Azores and a low pressure zone centred over Iceland. This oscillation is often associated with variations in temperature over Europe, especially in winter. The North Pacific Oscillation (NPO), on the other hand, is another see-saw pattern of pressure variations between a high pressure centre over northern Pacific and a low over the Alevtian Islands. It is closely linked to variations in temperature over North America.

Of these three oscillations the one that is important for India is the Southern Oscillation. As the rainfall varies inversely with surface pressure, so a poor or indifferent monsoon could be expected when surface pressures were higher over the Indian Ocean. On the other hand, low pressures over the Indian Ocean presage a good monsoon. A Southern Oscillation Index (SOI) is used for monsoon prediction. This is a measure of the difference in surface pressure between Tahiti, an island in French Polynesia, and Port Darwin in northern Australia. The former represents the Southern Pacific while the latter stands for the Indian Ocean. A negative value of SOI is indicative of a poor monsoon.

In the late fifties, Dr Jacob Bjerknes, who belonged to a family of great Norwegian meteorologists, noticed a coincidence between the Southern Oscillation and the El Nino. This was during the International Geophysical Year (IGY). This discovery made a great impact on meteorologists and oceanographers because it suggested "teleconnections" between meteorological events that were separated by great distances. A combination of the El Nino (EN) and the Southern Oscillation (SO) is now referred to as an ENSO event (Text-figure. 3). The exact mechanisms leading to an ENSO event are still being debated.



Text-figure 3—The Southern Oscillation during June, July and August, (a) pressures and (b) rainfall. Solid lines represent Correlation Co-efficients with the Southern Oscillation Index (SOI) (from Walker & Bliss, 1932).

Unfortunately, observations in India do not indicate a very well defined correspondence between a negative SOI, an ENSO event, and a deficient monsoon. A deficiency in monsoonal rainfall was associated with an ENSO event in only 60% of the cases. Table 1 presents seven cases when a rainfall deficiency was linked with an ENSO event.

Values of the Southern Oscillation Index (SOI) were ob-

Table 1—Deficient monsoons linked with an ENSO event (1901-1960).

S.N.	Year	Monsoon rainfall as % of LPAV	SOI (mb)
1.	1905	83	-5.0
2.	1911	85	-4.0
3.	1918	75	-5.0
4.	1925	97	-5.0
5.	1939	91	-4.9
6.	1941	87	-4.9
7.	1957	98	-2.5
8.	1987	82	-2.0

LPAV : Long period average value (Source : I.Met.D. records).

Table 2—Non-concurrent ENSO and rainfall deficiency.

S.N.	Year	Monsoon rainfall as % of LPAV	SOI (mb)
1.	1951	81	-2.5
2.	1953	110	-2.0
3.	1965	82	-2.0
4.	1972	76	-2.5
5.	1982	85	+2.2
6.	1986	87	-1.0

LPAV : Long period average value for the country as a whole.

tained from graphs provided by Hastenrath (1996). The SOI values shown above are departures from a mean value of -2.8 mb for the period 1951-1980. The interesting feature here is the large negative values of SOI for each ENSO event.

In Table 2 we present six cases of rainfall deficiency, with a negative SOI, that were not associated with an ENSO event.

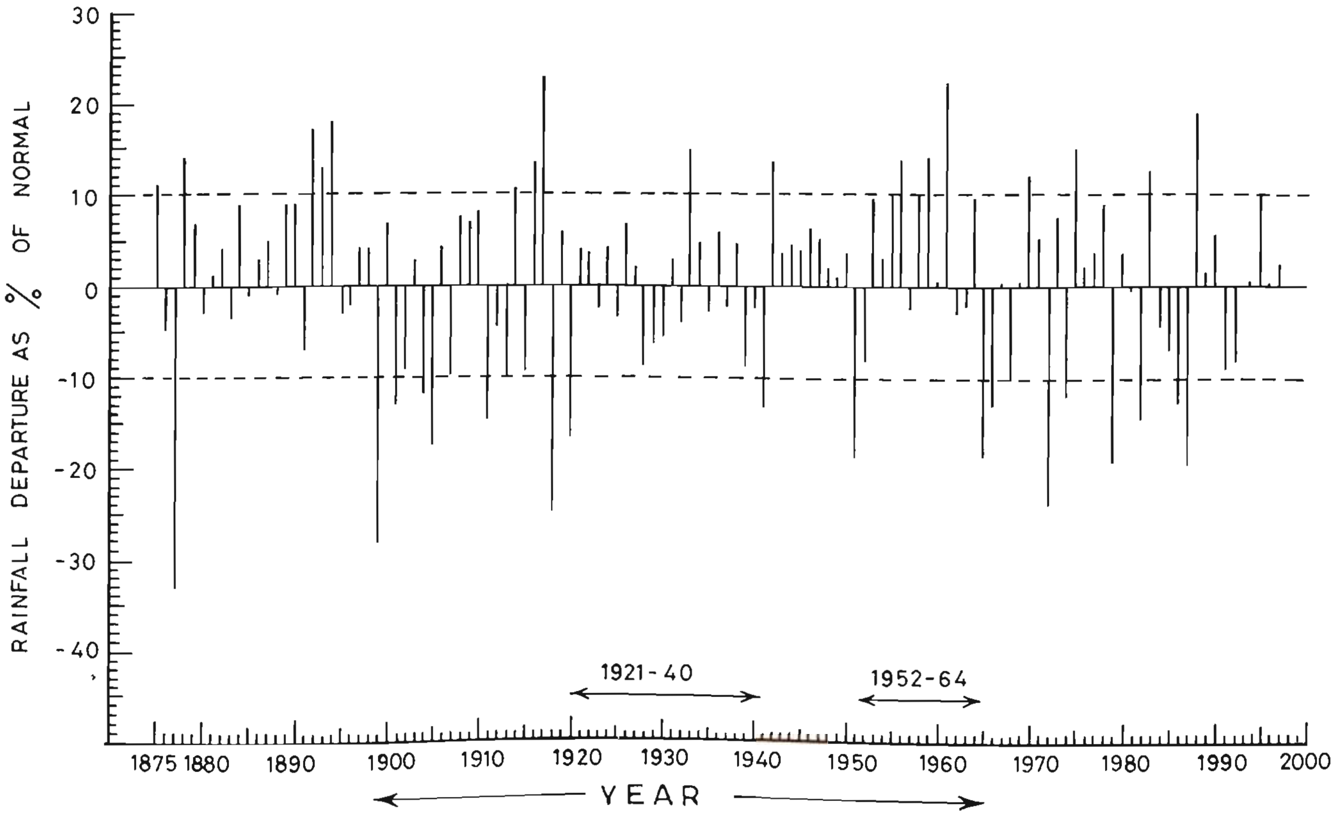
Compared to the values in Table 1, the SOI values in the above table are smaller, but negative SOI values do occur even when there is no ENSO event. Even when the monsoon is normal, as in 1953, a negative SOI can occur. But, as stated earlier, large negative values precede a deficient monsoon in about 60% cases.

How predictable is an ENSO event? With the help of atmosphere-ocean coupled models, it is now possible to predict the arrival of an El Nino several months ahead of the event. But, there is a sudden fall in predictability after 10 months. The reasons for the loss in predictability is not yet well understood (CLIVAR, WMO, 1992).

The irregular periodicity of the El Nino is another problem on which researches are currently in progress. Mathematical models have been able to show that the appearance of warm coastal waters is possible with a periodicity of 5 years over the eastern and central Pacific, but its appearance with a variable frequency is not well understood. We know that the El Nino appears with a weakening of the trade winds leading to the absence of coastal upwelling, but more research is needed to explain why the trade winds should suddenly weaken.

GENERAL CHARACTERISTICS OF MONSOON RAINS

The time series of monsoon rainfall over the country as a whole from 1875 to 1996 is illustrated in Text-figure 4. A few interesting features of this figure are : (a) the period 1921 to



Text-figure 4—Time Series of Monsoon rainfall. Dotted lines indicate deviations of ±10% from mean. Another ±4% is added to account for moddemors.

1940 was one of normal rainfall, if one considers a departure within ±10% to be within the normal range of variability; (b) the years between 1986-1988 saw a period of rapid fluctuation from large deficiency to an excess or abundant rain and (c) the last 10 years, that is, from 1988 to 1998 have again been one of normal rainfall. The point that emerges is that the rainfall time series consists of fairly long periods of normal rainfall, with short periods of rapid fluctuations.

The average rainfall for the country is 851.3 mm, but during 1986, 1987 and 1988 it was 786, 707 and 1018 mm respectively, while 1987 was an El Nino year 1986 was not, but the SOI was negative in both years.

A factor which controls the overall deficiency or excess of rainfall is the timely arrival and withdrawal of the monsoon. In 1986 the monsoon arrival was delayed by 4-5 days over most parts of the country, but its date of withdrawal was normal. In 1987, the northward advance of the monoon was abnormally delayed. Some parts of northwest India received monsoonal rains after a delay of nearly one month. The net result was a rainfall deficiency of 18% for the country, but it was -46% for northwest India. These figures indicate the rapid variations of the monsoonal rains in both space and time. A detailed spectral analysis of these fluctuations has not yet been undertaken, but this could yield results of considerable interest.

HIMALAYAN SNOW COVER AND THE MONSOON

Changes in Himalayan snow cover provide another example of low frequency changes at the earth's surface. It is one of the parameters currently used for long range prediction of summer rains over the country. Recent studies carried out by Groisman *et al.* (1994) suggest the existence of a negative correlation of –0.58 between the extent of snow cover and the Southern Oscillation Index (SOI). The correlation co-efficient is statistically significant. It implies that the snow cover is larger for years of rainfall deficiency. This has been observed for the prominent El Nino years in recent times.

Our data on the variation of snow cover on a time scale is not yet adequate. The impact of an increase in snow cover on the radiative balance of the earth-atmosphere system, especially on the formation of connective clouds over a snow covered region needs more research. The aerosol content of the atmosphere is yet another topic of interest, because clouds and aerosols represent two areas over which there is much uncertainty about their role in climate change.

STATISTICAL METHODS FOR LONG RANGE PREDICTION

Regression equations

Several statistical methods have been employed in the past to anticipate the performance of monsoonal rains, especially in the context of floods and droughts. Mention must be made of the pioneering work of Sir Gilbert Walker in the early part of this century. He developed regression equations with different predictors to compute the rainfall. His predictors were essentially independent of each other, and his forecasts were for (a) the northwestern sector of India and (b) the Indian peninsula. These two sectors were chosen because the variability of rainfall was largest over these two sectors. The variability of rainfall is measured by the ratio of standard deviation to the mean rainfall, which is expressed as a percentage. Of the early Indian scientists, we may mention the work of Professor P.C. Mahalanobis, who used a regression equation to forecast floods in Orissa (Das, 1995).

Currently, the prediction of summer monsoon rains (Y) is achieved by the following type of regression equation

$$Y = a_0 + \sum_{1}^{16} a_n (x_n)^{p_n} + R$$

Where p_n is the power to which each predictor (x_n) is raised and R stands for the residual or the unexplained variance of the predictand (Y). The constants a_0 and a_n are chosen in a manner which minimises R.

A wide variety of predictors are used. A detailed list of predictors is available in Das (1995), or in an article by Srivastava and Singh (1993). The predictors are antecedent features of the atmospheric circulation before the monsoon's arrival. They may be grouped under three heads : (a) pressures, (b) winds and temperatures and (c) snow cover and the Southern Oscillation Index (SOI).

According to me there are five reservations with this approach :

(a) The entire country cannot be used as a single unit for rainfall prediction, because the distribution of monsoonal rains is region specific. For example, the droughts over Orissa and parts of Rajasthan in 1998 could not be captured by a regression equation for the whole country. For this reason, Sir Gilbert Walker used regression equations only for northwest India and the peninsula, where the variability of rainfall was largest.

(b) The limits of tolerance are too large. For example, any rainfall deviation within ±10% of the mean value is within normal variation. In addition another ±4% of departures from normal are ignored because that is considered to be due to model errors. Thus, all variations within ±14% of the normal value are ignored. With such large tolerance the rainfall will be treated as normal on 75% of the rainfall time series. As mentioned earlier, the time series shows a prolonged spell of 19 years from 1921 to 1940 when the summer rains were normal (Sen Roy, 1990). This will not be the case if the tolerance limits were lowered.

(c) The predictors, especially pressures and temperatures, are not independent of each other. In developing a regression equation, the independence of the predictors should be ensured.

(d) The number of predictors is too large. Professor Lorenz (1956) had earlier pointed out that a large number of predictors could create difficulties because the influence of one could be off-set by others.

(e) The relative importance of each predictor could be assessed by computing how much of the total variance of Y is explained by each. If this was done, then the total number of predictors could be reduced by combining those which explain the largest variance of the predictand (Y).

Currently, experiments are in progress with other prediction models, especially autoregressive models (ARIMA). The results will be awaited with much interest.

Probability Forecasts

A number of probability forecasts of rainfall are now being devised, but they are still in a research mode.

The methods hinge on the concepts of Principal Components (Preisendorfer, 1988). A vector space X_{ij} is defined by

$$X_{ij} = \sum_{K=1}^{M} a_{kj}\, e_{kj}$$

Where the co-efficients a_{kj} are the Principal Components and e_{kj} are the normalised eigenvectors of the cross covariance matrix of X_{ij}. If the field is a time series of rainfall at different locations, then the Principal Components (PCs) tell us how much of the total variance is explained by each PC.

There are different procedures for finding out how much of the Principal Components consist of a "signal" and how much is "noise" (Steyaert *et al.*, 1977). In general, a PC to be treated as real must explain at least 5 to 10% of the variance of the raw time series. The selected PCs are then used to reconstruct a predicted rainfall pattern. As stated earlier, this along with other techniques are still in research mode, but they do point to the importance of long range prediction of monsoon rainfall in our country.

SUMMARY AND CONCLUSIONS

The main conclusions of the present study may be summarised as follows :

(i) The total monsoon rainfall does show some correlation with the ENSO event. A rainfall deficiency is noted in about 60% of ENSO events.

(ii) There are occasions when a rainfall deficiency is not concurrent with an ENSO event.

(iii) The exact mechanism or mechanisms that lead to an ENSO event are not yet clear.

(iv) Long range predictions of monsoon rainfall with a regression equation, which uses 16 predictors and in which each predictor is raised to a power, has several limitations.

(v) Experiments with an autoregressive model with several leading indicators, or probablistic forecasts with Principal Components is suggested.

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First find of the Early Permian Lower Gondwana plant remains and palynomorphs from the Chhongtash Formation (Upper Shyok valley), eastern Karakoram, India

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ABSTRACT

Upadhyay R, Chandra R, Rai H, Jha N, Chandra S, Kar RK & Sinha Anshu K 1999. First find of the Early Permian Lower Gondwana plant remains and palynomorphs from the Chhongtash Formation (Upper Shyok valley), eastern Karakoram, India. Palaeobotanist 48(1) : 7-18.

A sedimentary sequence mainly consists of black shale, siltstone, calcareous sandstone and dark argillaceous limestone overlying a pillow lava and thinly bedded limestone of the Chhongtash Formation near Chhongtash locality (Upper Shyok valley, eastern Karakoram, India) contains abundant, but poorly preserved plant fossils and palynomorphs probably referable to the Early Permian or Late Asselian (~275 Ma) interval. The plant fossils and associated palynological assemblages of eastern Karakoram show a marked similarity to the marine Lower Gondwana assemblages of the Salt Range and Talchir-Karharbari assemblages of Central India. Based on the present discovery it is suggested that, before the accretion of Cimmerian microplates to the Eurasian continent, the Karakoram microplate in its incipient state was not far from the Salt Range and located along the northern margin of the Indian subcontinent as Peri-Gondwanan microplate.

Key-words—Lower Gondwana, Plant fossils, Early Permian, Chhongtash Formation, India.

सारांश

भारत के छोंगताश शैलसमूह (उपरि श्योक घाटी) की पूर्वी कराकोरम सूक्ष्म प्लेट से प्रथम प्राप्त आरम्भिक परमियन अधोगोंडवानायुगीन पादप अवशेष एवं परागाणुरूप

राजीव उपाध्याय, राकेश चन्द्रा, हकीम राय, नीरजा झा, शैला चन्द्रा, रंजीत कुमार कर एवं अंशु कुमार सिन्हा

छोंगताश संस्थिति के निकट छोंगताश शैलसमूह (उपरि श्योक घाटी, पूर्वी कराकोरम सूक्ष्म प्लेट, भारत) के एक शिरोधान लावे तथा तनु संस्तरित चूना पत्थर पर उपरिशयित एक अवसादी अनुक्रम, जिसमें काला शेल, पांशु प्रस्तर, चूनामय बालुकाश्म तथा गहरे मृण्मय चूना पत्थर समाहित हैं, में प्रचुर किन्तु अत्यल्प मात्र में संरक्षित पादपाश्म एवं परागाणुरूप हैं, जिन्हें सम्भवतः आरंभिक परमियन अथवा अन्तिम एसीलियन (27.5 करोड़ वर्ष पूर्व) अन्तराल से सन्दर्भित किया जा सकता है। पूर्वी कराकोरम के पादपाश्म तथा सहयुक्त परागाणु समुच्चय लवण मालारेखा के समुद्री अधोगोंडवाना

समुच्चय तथा मध्य भारत के तालचीर-करहरबाड़ी समुच्चयों के साथ उल्लेखनीय समरूपता प्रदर्शित करते हैं। वर्तमान खोज के आधार पर प्रस्तावित किया जाता है कि सिमेरियन सूक्ष्म प्लेटों के यूरेशियाई महाद्वीप में सहवर्धन से पूर्व कराकोरम सूक्ष्म प्लेट अपनी प्रारंभिक अवस्था में लवण मालारेखा से अधिक दूर नहीं थी तथा वह परिगोंडवाना सूक्ष्म प्लेट की भाँति भारतीय उपमहाद्वीप के उत्तरी उपांत के पार्श्व में स्थित थी।

INTRODUCTION

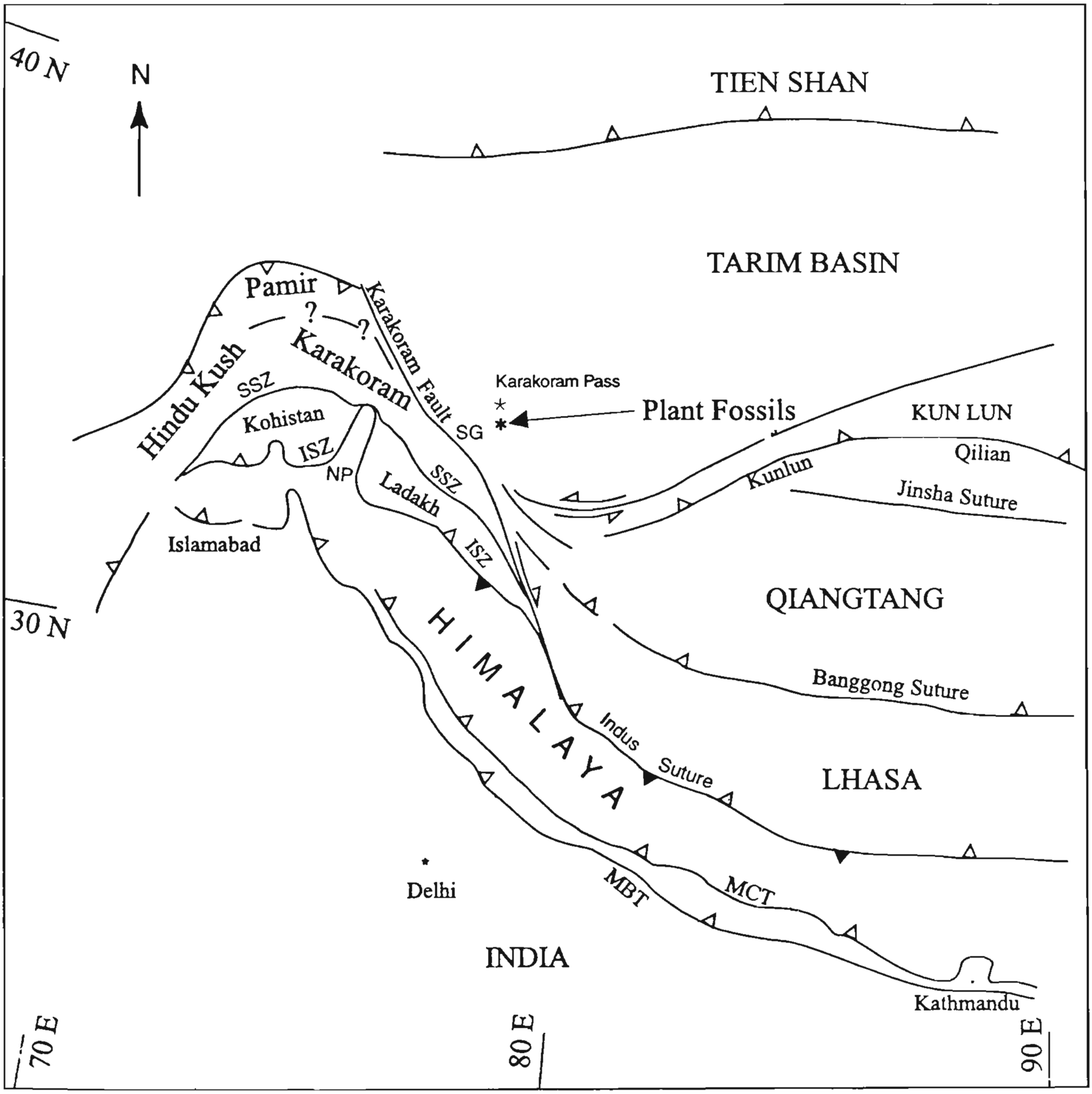
The Karakoram, situated in the very heart of Central Asian highlands is a ~800 km long and ~150 km wide tectonic terrane and occupies an intermediate position between north Pamir and northwestern Tibet (Searle, 1991; Gaetani, 1997; Sinha *et al.*, 1999) (Text-figure 1). The Karakoram terrane also lies along a critical geological juncture immediately to the north of the two major suture zones - the Shyok and Indus sutures, that mark the closing of Tethys ocean and the collision of India with Asia around ~50 Myr ago (Searle, 1991; Upadhyay & Sinha, 1998; Sinha *et al.*, 1999). Since the collision, mountain building processes have been operative and are still ongoing both in the Himalaya to the south and in the Karakoram to the north. All the mountain ranges in the north and east, including the northern Pamirs, the Tien Shan and Kun Lun (Text-figure 1) show evidence of major Palaeozoic orogenies, although they have all been strongly reactivated during India-Asia collision (Dewey *et al.*, 1988, Searle, 1991).

Decades after the initial geological reconnaissance (De Terra, 1932; Dainelli, 1933; Norin, 1946), the eastern Karakoram was visited by Gergan and Pant (1983), Bagati *et al.*, (1994), and Sinha *et al.*, (1999). However, geological information describing different aspects of the eastern Karakoram region is still in an initial stage. There are major gaps in the stratigraphic column and information is needed to explain the structure and tectonics, tectono-sedimentary evolution, localization of economic deposits, prospecting of petroliferous basins and palaeogeographic reconstruction of the Karakoram. Up to date major information to understand the concept of Karakoram have been arrived from the northwestern sector of Karakoram in Pakistan (Desio, 1974; Searle, 1991; Gaetani, 1997). Based on these studies, the Karakoram has been suspected to be one among the most significant Peri-Gondwanan microcontinents. But it has been always left off from the palaeogeographic reconstruction map of Gondwana and Asian microcontinents (Scotese & McKerrow, 1990; Nie *et al.*, 1990; Scotese & Langford, 1995) mainly because of two reasons: (1). Based on limited traverses scanty geological information available from Pamir, Karakoram and western Tibet,(De Terra, 1932; Dainelli, 1933; Norin, 1946; Desio, 1974; Gergan & Pant, 1983; Bagati *et al.*, 1995; Matte *et al.*, 1996; Gaetani *et al.*, 1997; Sinha *et al.*, 1999); and no Early Permian plant remains and palynomorphs were ever reported from the Karakoram Terrane. Early Permian plant remains have for long been considered as a pointer for Peri-Gondwanan origin of most of the Asian microcontinents (Nie *et al.*, 1990), and (2). Owing to the extreme inaccessibility of the Karakoram and also because of the disputed frontiers of Pakistan, India and China, large areas of the region remain unexplored and unstudied.

Recently, during the summer of 1995, three of us (RU, RC & HR) took a traverse in the eastern Karakoram mountain under the leadership of Professor Anshu K. Sinha, to unravel the intricacies and complex geological history of this inaccessible area bounded by the Nubra-Shyok river valleys to the south and the Karakoram Pass point (5575 m, the end of Indian territory) to the north (Text-figures 1, 2). The geographical limits of this inaccessible region are between the upper Yarkand river in the Chinese territory of the Kun-Lun range of Tibet in the north and the Ladakh Himalayan ranges in the south (Text-figures 1, 2). As a significant breakthrough we here report the first find of the Early Permian plant remains and Late Asselian (~270 Ma) palynomorphs from the Chhongtash Formation of the eastern Karakoram Terrane, India. This paper discusses the palaeogeographical significance of the plant remains and palynomorphs preserved in the sedimentary sequence of the Chhongtash Formation of eastern Karakoram.

GEOLOGICAL SETTING

On the basis of field evidence across a 150 km long south-north traverse from Sasoma in the Nubra valley to Karakoram Pass in the eastern Karakoram mountain (Text-figures 2d, e). two major tectonic divisions have been recognized (Sinha *et al.*, 1999; Text-figures 2, 3) : (1) the Karakoram Plutonic-Metamorphic Complex, and (2) the Karakoram Tethyan zone. The granites of the Karakoram plutonic complex are two-mica varieties having large xenoliths of metasedimentary and mafic rocks. The most abundant rock types are weakly deformed and relatively well preserved granites, granodiorites and tonalites having both I-and S-type signatures (Sinha *et al.*, 1999). The Karakoram plutonic complex intruded the Carboniferous-Permian sequence of the Karakoram Tethyan zone (Text-figures 2, 3) to the north. The rocks of the Karakoram Tethyan zone are ranging in age from Carboniferous-Permian to Late Cretaceous (Sinha *et al.*, 1999; Text-figures 3). The geological account of the Karakoram Tethyan zone have been provided and discussed elsewhere (Sinha *et al.*, 1999, Bagati *et al.*, 1995 and Gergan & Pant, 1983).



Text-figure 1—Simplified geological sketch map of Central Asia showing present geotectonic position of western Himalaya, Karakoram, Hindukush, Pamirs, Tien Shan and Kun Lun Mountain ranges: their tectonic subdivisions and location of major sutures, microcontinental fragments (modified after Searle, 1991) and location of present findings of the Early Permian plant remains and palynomorphs. SSZ: Shyok Suture Zone, ISZ: Indus Suture Zone, MCT: Main Central Thrust, MBT: Main Boundary Thrust, NP: Nanga Parbat, SG: Siachen Glacier, KK Pass: Karakoram Pass (5575 M), * Location of the Early Permian plant remains and palynomorphs recorded from the Chhongtash Formation near T-Camp nala section in the Chhongtash locality (~70 km south of the Karakoram Pass and ~50-60 km east of Siachen Glacier and 6-7 km west of Chhongtash Camp towards Morgo Formation), eastern Karakoram India.

PLANT FOSSILS AND PALYNOMORPHS BEARING SEDIMENT INTERVAL IN THE CHHONGTASH FORMATION

Tectono-stratigraphy of the eastern Karakoram reveals that the Chhongtash Formation of Karakoram Tethys is in tectonic contact with the rocks of the Aqtash Formation to the south and overlain by thick carbonate sequence of Morgo Formation (Text-figures 2, 3). Based on the occurrence of *fusulinid* – bearing limestone and siltstone the age of the Chhongtash Formation has been assigned as Permian (Gergan & Pant, 1983), Late Permian (Juyal & Mathur, 1996) and Late Permian to the upper part of the Chhongtash Formation (Sinha *et al.*, 1999). The Chhongtash Formation is a thick (1,500-2,000 m) sedimentary unit consisting mainly of thin to medium bedded black shales, slates, siltstones, dark grey pebbly mudstone and diamictite, calcareous sandstone, dark grey limestone and interbedded pillow lava flow (Text-figure 4). This sedimentary sequence is highly folded and faulted, and is intruded at several places by volcanic sills and dykes (Sinha *et al.*, 1999). The lower and middle parts of the Chhongtash Formation are mostly medium- to fine-grained black shale, siltstone and pebbly mudstone. The interbedded pillow lava in the middle and upper-middle portion of the Chhongtash Formation could be related to the intrabasinal rift volcanism during the Early Permian and may be linked to the Late Carboniferous-Early Permian (~300-250 Myr ago) fragmentation processes of the Pangea and opening of the Tethys ocean. The pillow lava is overlain by a thin succession of thin- to medium-bedded limestone, highly folded and faulted in nature. The middle part of upper portion of the Chhongtash Formation is represented by an important plant fossil bearing horizon (Text-figures 3, 4). The plant fossil bearing outcrop of grey-brown sandstone and shale is located along the T-Camp *nala* upstream section (~6-7 km west of the Chhongtash Camp locality towards Morgo Formation), and is lying few meters above the pillow lava horizon (Text-figures 3, 4) which is followed by a thick succession of grey argillaceous limestone which has yielded Late Permian *fusulinids* (Juyal & Mathur, 1996; Sinha *et al.*, 1999).

The plant megafossils collected from eastern Karakoram are poorly preserved in the form of impressions. The identified impressions are a small leaf of *Noeggerathiopsis* which can not be identified up to specific level, a definite gymnosperm seed probably *Samaropsis* , a portion of *Gangamopteris* leaf, some unidentifiable plants type and a portion of large *Equisetalean* stem (Plate 1). This plant assemblage is similar to the Early Permian Lower Gondwana flora recorded from Talchir assemblages (Feistmantel, 1879, 1882; Surange & Lele, 1956; Lele, 1966) and also from the type locality of the Talchir Coalfield in the Indian subcontinent (Chandra & Singh, 1994). Occurrence of *Equisetalean* – stems and other undentifiable plant types have also been mentioned by Norin (1946) from the Horpatso area (south of the Mawang Kangri mountain in northwestern Tibet). This suggests that the Chhongtash Formation may be a continuation of Horpatso Series of Norin (1946) and extends for a distance of ~ 600 km east-southeast from the Chhongtash locality of eastern Karakoram.

The plant fossil bearing shale was macerated for

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Text-figure 2—Geological traverse map of the eastern Karakoram showing the location of Chhongtash Formation and Chhongtash locality (simplified after Sinha *et al.*, 1999).

PLATE 1

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1. *Noeggerathiopsis* sp. Lower portion of the leaf showing straight, dichotomous veins running parallel to each others X 1.5, B.S.I.P. Specimen No. 35358.
2. Unidentifiable plant type on the left and poorly preserved *Noeggerathiopsis* on the right. X 1.5, B.S.I.P. Specimen No. 35359.
3. Equisetalean stem, poorly preserved ribs. X 1, B.S.I.P. Specimen No. 35360.
4. *Samaropsis* seed, enlarged. X 4, B.S.I.P. Specimen No. 35358.
5. ? *Gangamopteris*, a portion of large leaf. X 1.5, B.S.I.P. Specimen No. 35360.

PLATE 2

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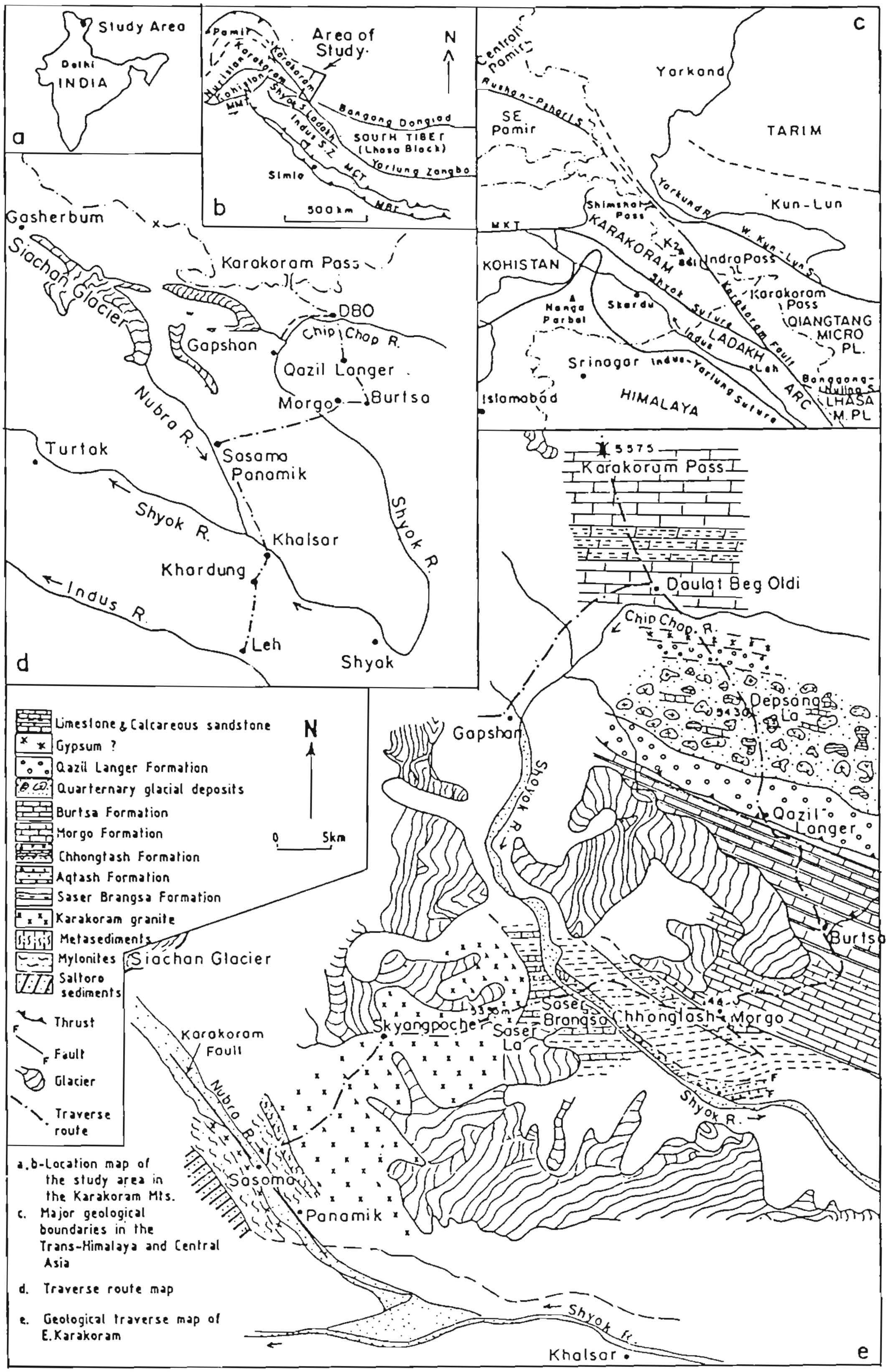
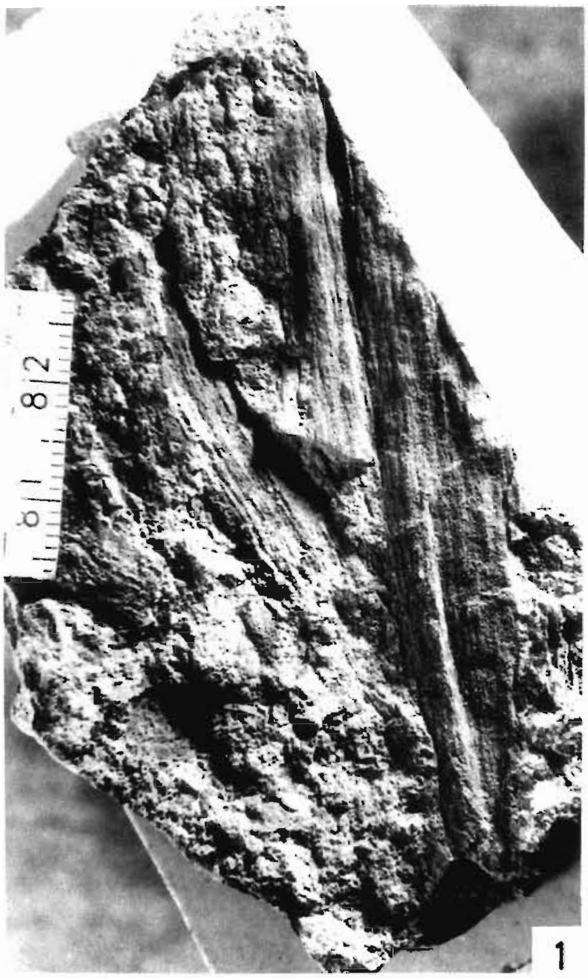
(All magnifications X 500)

1. *Plicatipollenites indicus*. B.S.I.P. Slide No. 12391, T44/1
2. *Parasaccites* sp. , B.S.I.P. Slide No. 12392, G27/4.
3. Unidentified, B.S.I.P. Slide No. 12393, E31/3.
4. *Striasulcites tectus*, B.S.I.P. Slide No. 12391, E38.
5. *Callumispora*, B.S.I.P. Slide No. 12396, S21/4.
6. *Caheniasaccites* sp., B.S.I.P. Slide No. 12393, N29/2.
7 *Lunatisporites* sp., B.S.I.P. Slide No. 12391, T18/4.
8. *Parasaccites* sp., B.S.I.P. Slide No. 12395, P57/1
9. *P. diffusus*, B.S.I.P. Slide No. 12391, T45/4.
10. *Virkkipollenites* sp., B.S.I.P. Slide No. 12393, D46/3.
11 *Verticipollenites debilis*, B.S.I.P. Slide No. 12393, V56/4.
12. *Lunatisporites*, B.S.I.P. Slide No. 12392, O54/4.
13. Acritarch, B.S.I.P. Slide No. 12394, N58/1
14. *Lunatisporites* sp. B.S.I.P. Slide No. 12392, G53/3.
15. Microplankton, B.S.I.P. Slide No. 12395, H59/4.
16. *Crescentipollenites*, B.S.I.P. Slide No. 12393, J25/2.
17. *Parasaccites diffusus*, B.S.I.P. Slide No. 12393, M20/4.



Text-figure 2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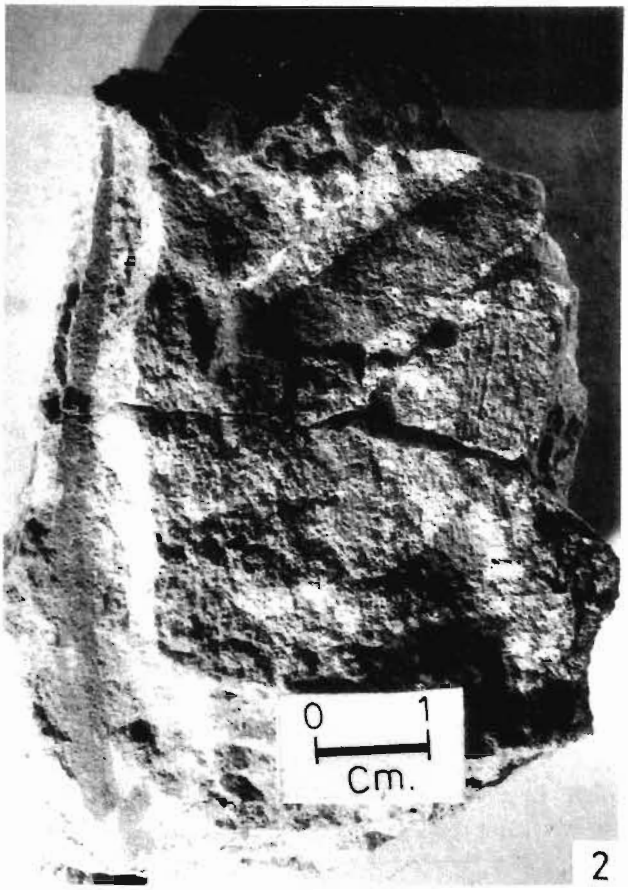

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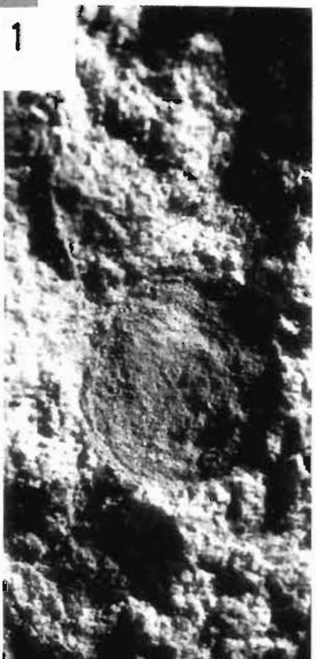
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PLATE 1


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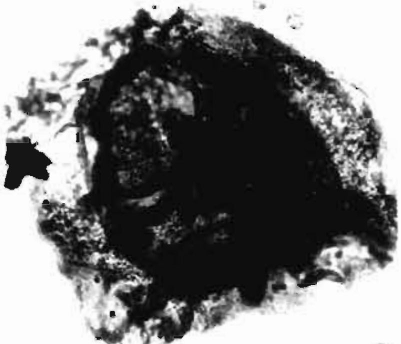
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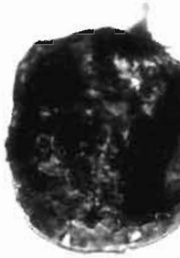
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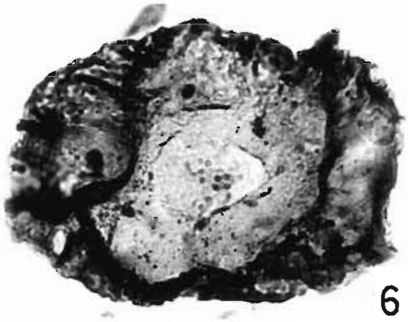
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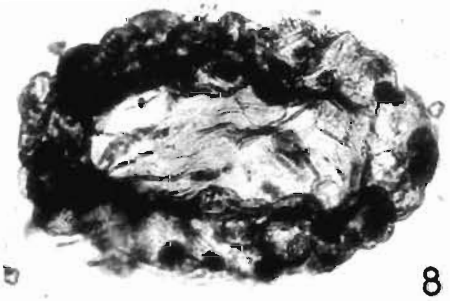
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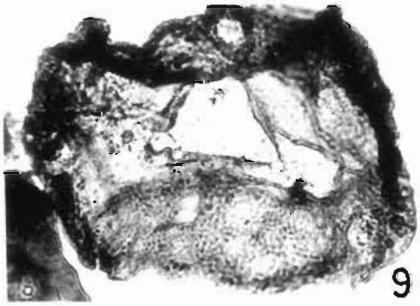
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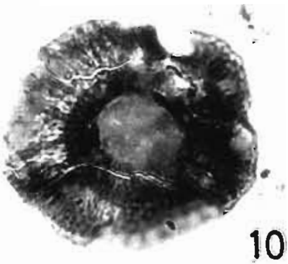
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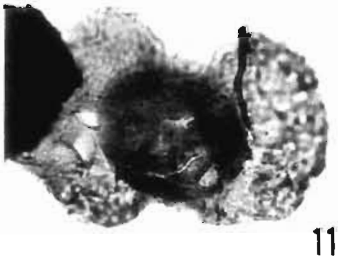
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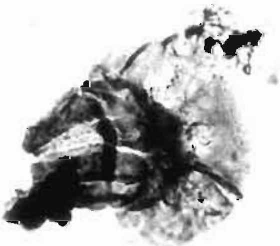
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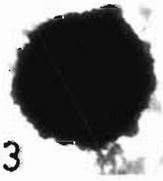
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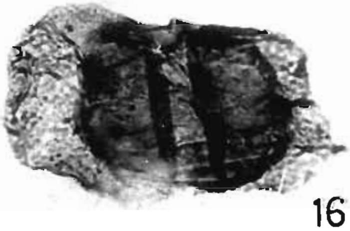
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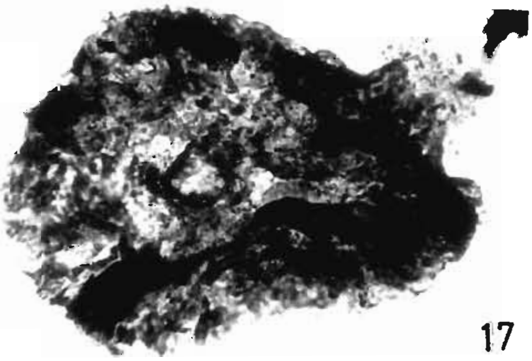
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PLATE 2

palynological study and the following 25 genera and 28 species were recorded (Plate 2): *Leiotriletes* sp., *Punctatisporites* sp., *Cyclogranisporites gondwanensis* Bharadwaj & Salujha, 1964, *Cyclobaculisporites minutus* Bharadwaj & Salujha, 1964, *Indotriradites* sp., *Plicatipollenites indicus* Lele, 1964, *Virkkipollenites obscurus* Lele, Bose & Maheshwari, 1968, *Elilasaccites elilaensis* Bose & Kar, 1966, *Elilasaccites ovatus* Bose & Kar 1966, *Parasaccites korbaensis* Bharadwaj & Tiwari, 1964, *Parasaccites diffusus* Tiwari, 1965, *Parasaccites bilateralis* Tiwari, 1965, *Caheniasaccites flavatus* Bose & Kar, 1966, *Caheniasaccites ovatus* Bose & Kar, 1966, *Caheniasaccites elongatus* Bose & Kar, 1966, *Crucisaccites* sp., *Divarisaccus lelei* Venkatachala & Kar, 1966, *Platysaccus papilionis* Potonie & Klaus, 1954, *Cuneatisporites radialis* Leschik, 1955, *Cuneatisporites flavatus* Bose & Kar, 1966, *Scheuringipollenites* sp., *Valiasaccites validus* Bose & Kar, 1966, *Striatites sewardi* (Virkki) Pant, 1954, *Striatopodocarpites antiquus* Leschik, Potonie, 1958, *Striatopodocarpites venustus* Bharadwaj & Salujha, 1965, *Verticipollenites debilis* Venkatachala & Kar, 1968, *Faunipollenites varius* Bharadwaj, 1962, *Rhizomaspora costa* Venkatachala & Kar, 1968, *Trisaccites* sp., *Vittatina subsaccata* Samoilovich, 1953 and *Striasulcites tectus* Venkatachala & Kar, 1968.

The palynological assemblage is dominated by monosaccates (54%) and followed by bisaccates (42%). Amongst the bisaccates the nonstriate (22%) and striate (20%) are more or less equally represented. The triletes are found only in 3% and the monocolpate is very rare (1%). The genera found within the count are – *Cyclobaculisporites* (1%), *Cyclogranisporites* (2%), *Elilasaccites* (10%), *Caheniasaccites* (19%), *Vikkipollenites* (6%), *Parasaccites* (24%), *Divarisaccus* (2%), *Plicatipollenites* (2%), *Crucisaccites* (1%), *Platysaccus* (2%), *Cuneatisporites* (9%), *Striatopodocarpites* (10%), *Valiasaccites* (11%), *Faunipollenites* (9%), *Vittatina* (1%) and *Striasulcites* (1%).

The dominance of monosaccates in the assemblage is once again very much similar to the Talchir or Karharbari (Early Permian) assemblage of India (Potonie & Lele, 1961; Bharadwaj *et al.*, 1976; Kar, 1973; Tiwari & Tripathi, 1992) and Bacchus Marsh Tillite of Australia (Virkki, 1946; Kemp *et al.*, 1977; Segroves, 1970) . However, the presence of striate bisaccate in significant percentage (20%) in the present assemblage favours an Upper Karharbari (Late Asselian, ~ 280–275 Myr ago from present) age. Presence of calcareous microfossils in the thin sections point out that the deposition took place in marine condition. The occurrence of *fusulinid*-bearing limestones (Sinha *et al.*, 1999; Juyal & Mathur, 1996; Gergan & Pant, 1983) is also typical of much of the northern margin of Gondwana (Nakazawa, 1985). Further systematic study is in progress.

PALAEOGEOGRAPHIC IMPLICATION

In recent palaeogeographic reconstruction of Pangea during Late Palaeozoic (Scotese & McKerrow, 1990; Nie *et al.*, 1990; Scotese & Langford, 1995), it appears that a southern belt of Asian microcontinents stretching from Iran and Afghanistan, through southern Tibet, to western Thailand, Malaysia and Sumatra comprise several continental blocks and numerous continental fragments that have coalesced since the mid-Palaeozoic by the closure of various branches of Tethys ocean (Sengor, 1987; Nie *et al.*, 1990; Scotese & Langford, 1995; Enos, 1995; Sinha, 1997; Metcalfe,. 1999). Tectonic constraints include the timing of collisions of the microcontinents which have been regarded to proceed from north to south, range in time from Late Palaeozoic to the Tertiary (Sengor, 1984; Dewey *et al.*, 1988). The origin, migration, assembly and timing of accretion of all of these blocks to their present geotectonic position is not well known, because the palaeogeography of the Indian ocean during the initial break up of Gondwana is poorly constrained and there is no Permo–Triassic crust left in the present–day Indian ocean (Searle, 1991). The oldest ocean crust adjacent to the east African and Antarctic margins is of early or middle Cretaceous age (~ 140–100 Myr) (Searle, 1991). However, on the basis of the occurrence of temperate faunas, floras, and even glacial and glacio–marine deposits (tillites or diamictites) from the Permian sequences, the Central Iran, Helmand, Western Qiangtang, Lhasa and Sibumasu blocks are interpreted as to have rifted off the northern margin of Gondwana in post-Early Permian times (Scotese & Mckerrow, 1990; Scotese & Langford, 1995). It is believed that they belong to a loosely associated continent named Peri–Gondwana or Cimmeria (Sengor, 1984; Sinha & Upadhyay, 1997). Plate tectonic reconstruction of Early Permian (~ 277 Myr ago) show that these Peri–Gondwanan microcontinents were situated between ~ 10^0 - 40^0 southern latitude from the equator ((Nie *et al.*, 1990; Scotese & Langford, 1995).

The Karakoram – Hindukush microplate in the west and the Qiangtang - Lhasa block in the central and eastern segment of south Asia margin are among those blocks (Text-figure 1) which had already been welded on to Asia probably around 130–120 Myr ago (Dewey *et al.*, 1988; Searle, 1991) before the collision of India (~ 50 Myr) with this collage of plates, and has been suspected to be one among the most significant Peri-Gondwanan microcontinents. But it has been always left off from the palaeogeographic reconstruction map of Gondwana and Asian microcontinents mainly because of

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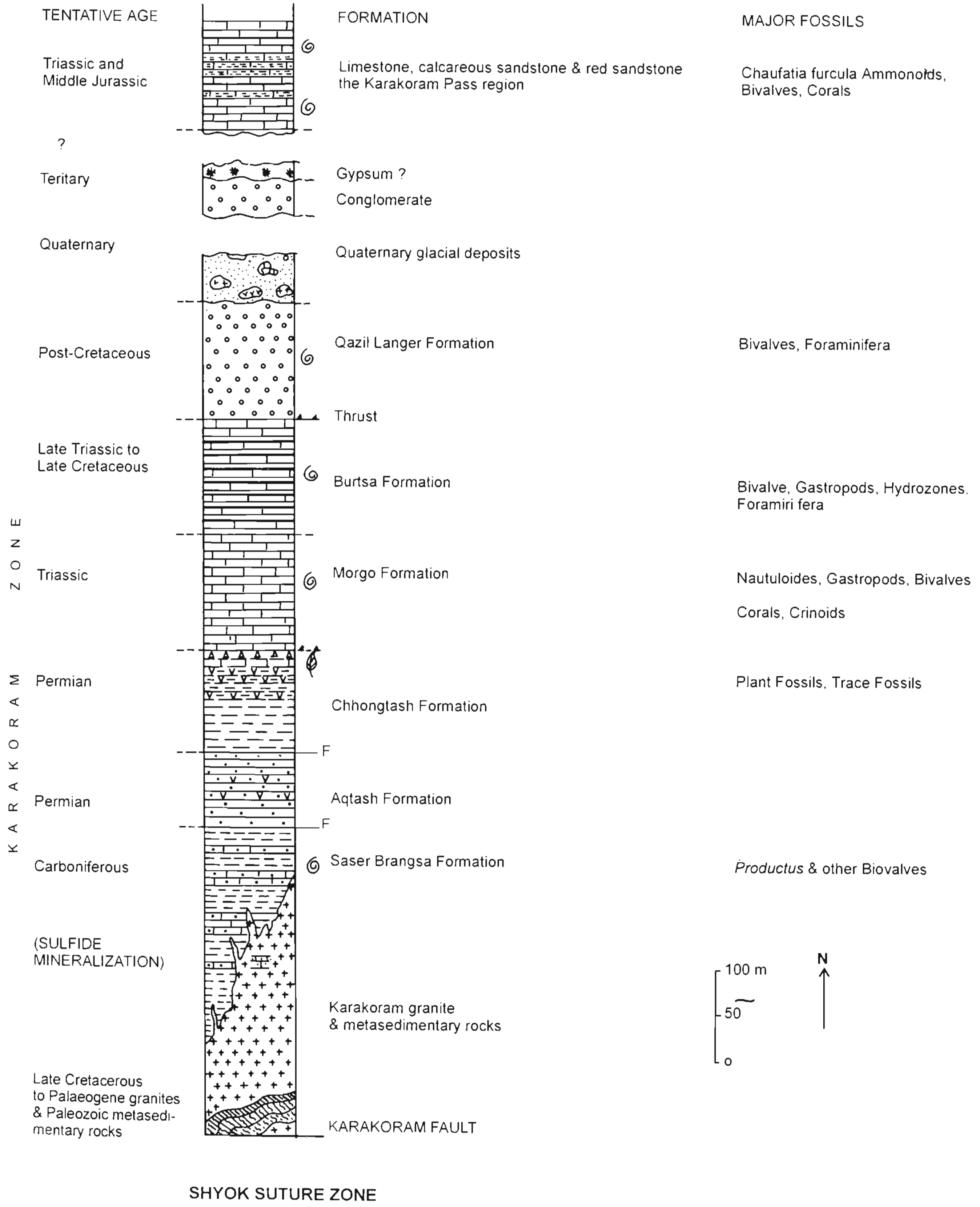
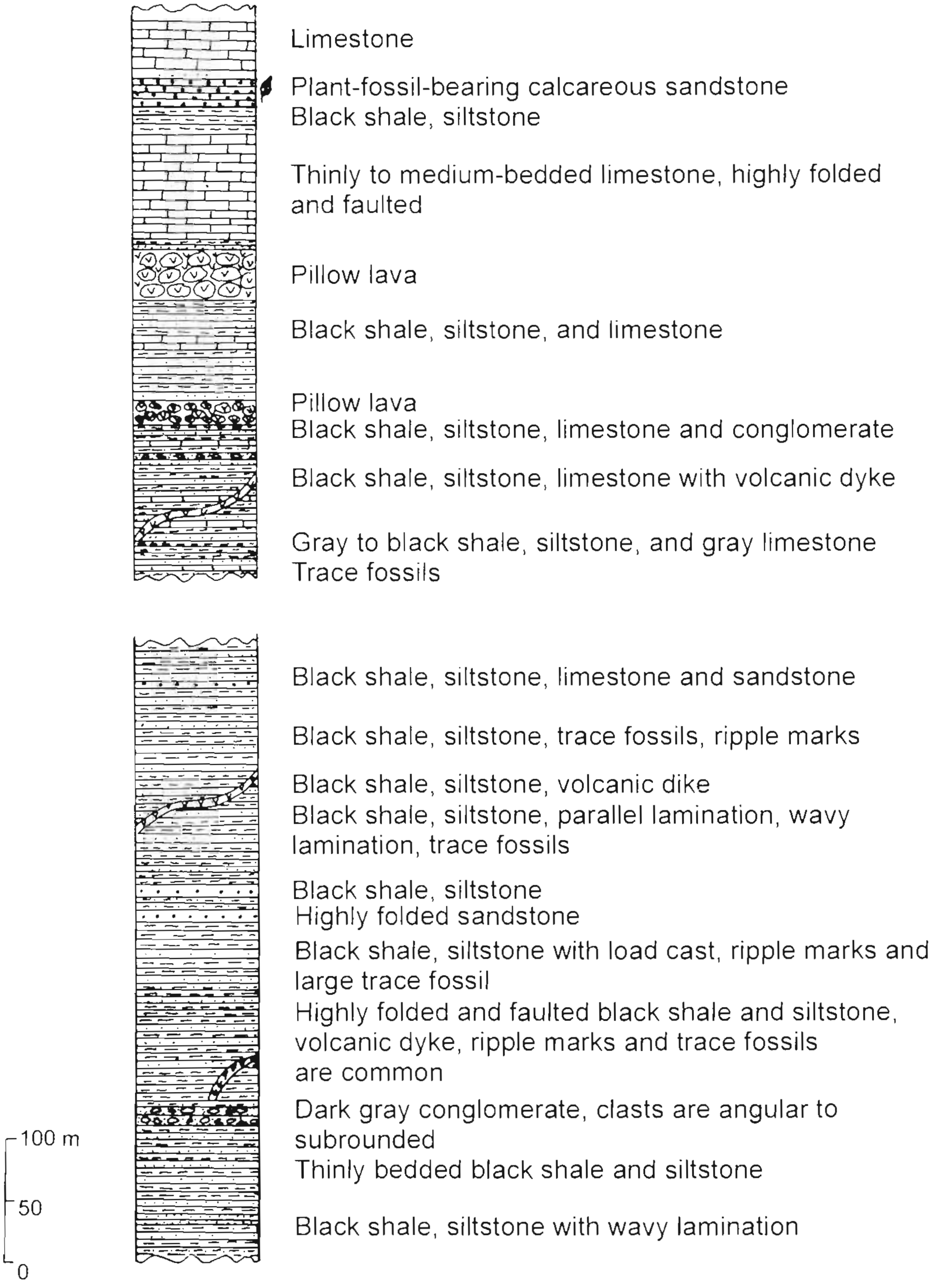
Text-figure 3—Schematic tectonostratigraphic traverse column of eastern Karakoram showing the plant fossil bearing Permian Chhongtash Formation (After Sinha *et al.*, 1999).


TENTATIVE AGE
FORMATION
MAJOR FOSSILS
Triassic and Middle Jurassic
Limestone, calcareous sandstone & red sandstone the Karakoram Pass region
Chaufatia furcula Ammonoids, Bivalves, Corals
?
Teritary
Gypsum ?
Conglomerate
Quaternary
Quaternary glacial deposits
Post-Cretaceous
Qazil Langer Formation
Bivalves, Foraminifera
Thrust
Late Triassic to Late Cretaceous
Burtsa Formation
Bivalve, Gastropods, Hydrozones. Foramiri fera
KARAKORAM ZONE
Triassic
Morgo Formation
Nautuloides, Gastropods, Bivalves
Corals, Crinoids
Permian
Plant Fossils, Trace Fossils
Chhongtash Formation
F
Permian
Aqtash Formation
F
Carboniferous
Saser Brangsa Formation
Productus & other Biovalves
(SULFIDE MINERALIZATION)
100 m
50
0
N
Karakoram granite & metasedimentary rocks
Late Cretacerous to Palaeogene granites & Paleozoic metasedimentary rocks
KARAKORAM FAULT
SHYOK SUTURE ZONE



Text-figure 4—Lithostratigraphic column of a part of the Chhongtash Formation near Chhongtash showing plant fossils and palynomorphs bearing sandstone and shale (After Sinha *et al.*, 1999).

two reasons (1): Scanty geological information available from Pamir, Karakoram and Western Tibet and no Early Permian plant remains and palynomorphs were ever reported from the Karakoram Terrane. Early Permian plant remains have for long been considered as a pointer for Peri–Gondwanan origin of most of the Asian microcontinents, and (2): Owing to the extreme inaccessibility of the Karakoram and also because of the disputed frontiers of Pakistan, India and China, large areas of the region remain unexplored and unstudied.

Our discovery of Early Permian plant remains and Late Asselian (~280-275 Myr ago from present) palynomorphs provides crucial information regarding the palaeogeographic reconstruction of the Karakoram during Permian time. Interestingly, the Early Permian (Artinskian, ~270-265 Myr ago) marine Gondwana sediments with plant remains and palynomorphs have been earlier recorded from the Salt Range in Pakistan (Balme, 1970). Therefore, on the occurrence of Early Permian plant remains and palynomorphs from the eastern Karakoram it could be inferred that during Early Permian time the Karakoram microcontinent was located not far from the Salt Range of Indian subcontinent, and was situated as a Peri–Gondwanan microcontinental fragment around 35^0 southern latitude from equator, somewhere intermediate between the Indian Plate and the Qiangtang–Lhasa microcontinent. The Karakoram microcontinent can not be a part of the Indian Plate because the present geotectonic position suggest that it lies north of the Shyok–Indus sutures (Desio, 1974; Searle, 1991; Gaetani, 1997; Sinha & Upadhyay, 1997; Sinha *et al.*, 1999) (Text-figure 1), and it is a well known fact that the Indus Suture mark the site of collision between the Indian Plate and accreted fragments of Asian microcontinent during ~50 Myr ago (Dewey *et al.*, 1988; Searle, 1991; Rowley, 1996; Sinha & Upadhyay, 1997, Upadhyay & Sinha, 1998). It has been recently suggested that Karakoram microcontinent was welded to Asia probably around 130–120 Myr ago (earliest Early Cretaceous) (Searle, 1991), therefore it should be a part of Peri–Gondwanan collage of microcontinents accreted with the southern margin of Asia before the 50 Myr old India – Asia collision. Interestingly, the present geotectonic position (Nie *et al.*, 1990; Scotese & Langford, 1995) of Karakoram between ~34^0 – 36^0 northern latitude (Text-figure 1) from equator further suggest an ~60^0 latitudinal movement or shift since Early Permian (Late Asselian, ~ 275 Myr ago) to present.

The present discovery of Early Permian plant remains and palynomorphs from the eastern Karakoram is a beginning towards understanding the large scale geological processes and hopefully should trigger the pace of geological exploration programmes to be carried out in near future in the remote regions of eastern Karakoram so that new information would emerge towards understanding the palaeogeography of the Gondwanaland and accretion of Peri-Gondwanan Asian microcontinents vis-a-vis India-Asia collision. Future research programmes are urgently needed to unravel the hidden wealth of information in the Karakoram.

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Permotheca with *in situ* pollen grains from the Lower Permian of the Urals

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ABSTRACT

Krassilov VA, Afonin SA & Naugolnykh SV 1999. *Permotheca* with *in situ* pollen grains from the Lower Permian of the Urals. Palaeobotanist 48(1) : 19-25.

Sporangial heads of the pollen organ *Permotheca* from the Lower Permian of Tschekarda, the Urals, are described as semisynangiate, with sporangia proximally connate for about one-third to half their length. The sporangial walls are three-layered and vascularized. The pollen grains, studied with LM, SEM and TEM, are transitional protomonosaccate-bilobed to protobisaccate, sulcate, with alveolar infrastructure, lamellate nexine and a tryphine-like surface layer. Chitrid zoosporangia occur in the pollen grains. The similarity to *Idanothekion* in the sporangial and pollen morphology may indicate phylogenetic relationships.

Key-words—Pteridosperms, sporangia, pollen morphology, phylogeny, Permian.

सारांश

यूराल के अधो परमियन युग के *परमोथीका* में स्थित स्वस्थाने परागकण

वैलेन्टीन ए. क्रासीलोव, सर्गेइ ए. एफोनिन एवं सर्गेइ वी. नाउगोलिन्ख

यूराल की त्शेकरदा संस्थिति से प्राप्त अधोपरमियनयुगीन पराग अंग *परमोथीका* के स्पोरैन्जियल शीर्ष अर्धसंधानी रूप में वर्णित किये गए हैं, जिनका स्पोरैन्जिया निकटस्थ कोणीय है तथा अपनी लम्बाई की तुलना में एक तिहाई से आधे के बीच हैं। स्पोरैन्जियल भित्तियाँ त्रिस्तरीय तथा संवहनी हैं। परागकणों का सरल सूक्ष्मदर्शी, क्रमवीक्षण इलेक्ट्रॉन सूक्ष्मदर्शी तथा संचारित इलेक्ट्रॉन सूक्ष्मदर्शी द्वारा अध्ययन करने पर ये कूपिका की अवसंरचना, पटलिकीय नेक्साइन एवं ट्रिफाइन की भांति पृष्ठ सतह के साथ संक्रमित आद्य एकसकोशीय द्विपालिक से आद्य द्विसकोशीय सल्कस युक्त प्रदर्शित हुए हैं। परागकणों में काइटरिड चलबीजाणुधानिक भी प्राप्त हुए हैं। स्पोरैन्जियल तथा पराग आकारिकी में *इडेनोथेकियॉन* से इनकी समरूपता जातिवृत्तीय सम्बधों का संकेत कर सकती है।

INTRODUCTION

A puzzling problem in the Permian palynology is a close similarity between contemporaneous palynofloras of different palaeofloristic realms, such as the Angarian, Subangarian, Cathaysian and Gondwana provincies, having widely diverging macrofossil assemblages. Either there were more common elements than suspected on macrofossil evidence or the pollen similarities were due to parallel evolution of phylogenetically unrelated gymnosperm lineages. This problem can be settled only by a comparative analysis of both *in situ* and dispersed pollen grains and their producing organs. However, few pollen grains are found *in situ* and still fewer provide a sufficient morphological information.

The gymnosperm pollen organs studied by Russian palaeobotanists, mostly came from the Permian of Subangarian Province including the Urals and the Volga Basin. These areas were ecotonal between the temperate Angarian and tropical Cathaysian realms, supporting a highly diverse gymnosperm flora (Meyen, 1984). Pollen-producing organs are relatively common in the rich Subangarian localities, but the data on *in situ* pollen grains are as yet fragmentary.

In this paper we report on *in situ* pollen grains of *Permotheca*, a widespread morphotype of sporangial clusters, coming from the Lower Permian Tchekarda locality of fossil plants and insects. Two widely different pollen morphotypes, *Vesicaspora* and *Vittatina* were previously reported from *Permotheca* (Gomankov & Meyen, 1986; Meyen, 1984), a situation that requires a thorough revision.

MATERIAL AND METHOD

The Tchekarda locality has been known since 1920s (Martynov, 1928). It is an outcrop of a sandstone, shale and marl sequence in the historical stratotype area of the Kungurian Stage of the Permian System on the Sylva River in the southern part of the Ufa-Solikamsk Basin, Central Urals (Ponomareva *et al.*, 1998). The fossil plant assemblage is typical of the Bardian flora that was dominated by conifers and callipterids (Zalessky, 1929, 1937; Meyen, 1984). These deposits also contain a marine fauna of foraminifera, bryozoans, brachiopods and cephalopods.

The following description is based primarily on a single sporangial head from palaeontological collection deposited in the Palaeontological Museum, Moscow. Several synangia figured from the same fossil plant bed by Naugolnykh (1998) and deposited in the Geological Institute, Moscow were studied for additional morphological details.

The sporangial head is preserved as a coaly compression spread in the bedding plane. It was photographed with stereomicroscope CITOVAL-2 and mounted for SEM. The microphotographs of sporangial wall structures and *in situ* pollen grains were obtained with the CAMSCAN scanning electron microscope. Parts of the pollen masses were extracted from sporangia, macerated in Schultze mixture and individual grains were studied with the light microscope AXIOPLAN-2, CAMSCAN and transmission electron microscope JEM-100B-1 (JEOL). Pollen grains selected for TEM were fixed in OsO_4 (1%) for two hours, sectioned using an ultratome LKB-3 and then stained with Reynolds lead and uranil acetate.

SYSTEMATICS

Genus—PERMOTHECA Zalessky

PERMOTHECA DISPARIS (Zalessky) Naugolnykh

Pl. 1, figs 1-6; Pl. 2, figs 1-12

Permotheca disparis Naugolnykh 1998; p. 96, fig. 55.

Description—The sporangial head in Pl. 1, fig. 1 shows six sporangia radially spreading in the bedding plane, with a central scar of a stalk. The sporangia are preserved as compressions split in the median plane and partly encrusted with calcium carbonate, proximally appressed, distally diverging. As seen with SEM, the sporangial locules are proximally separated by thick common walls extending one-third to half their length (Pl. 1, fig. 3). There is no evidence of a cushion or pad of basal tissue.

The individual sporangia are obovate-elliptical, up to 4 mm long, with a maximum width 1.4-2 mm above the middle, gradually tapering to the base and more abruptly to the apex which is bluntly pointed. Their inner face is traversed by a median ridge marking the line of dehiscence. At low magnification the sporangial walls show either longitudinal or slightly oblique to midline or else transverse striation. As seen with SEM, the striation marks the cell files of epidermis and inner layers (Pl. 1, figs 3, 4).

The epidermal cells are narrow, fusiform, of uniform width (about 40 μm), arranged in the gently arched axial files. There is at least a single subepidermal layer of slightly broader fusiform cells and the inner layer of transverse interfingering wedge-shaped cells. The latter appear shrivelled, forming broken files with occasional twisted or protruding cells. The vascular bundles occur in the middle layer of the sporangial walls (protruding in the locule when the inner layer is not preserved) extending along the borders of fused sporangia and diverging at their separation. They consist of long fusiform tracheids (about 30-40 μm), with short to long oblique end walls (Pl. 1, fig. 6), spirally thickened with tight coils wider than their intervening spaces (Pl. 1, fig. 5), 5-7.5 μm broad, occasionally anastomosing.

Masses of pollen grains occur in the locule, sometimes directly on the vascular layer where the inner layer is resorbed. Sixty pollen grains were separated from the pollen masses showing variation in shapes and dimensions. The equatorial midplane outline is elliptical, long axis 50-85 (mean 68) μm, short axis 30-56 (mean 45) μm, broadly rounded over the ends of the long axis, flattened or slightly constricted over the ends of the short axis. The body is transversely elliptical or nearly circular, laterally fringed by a narrow strip of the saccus sexine typically about 3 μm wide, occasionally slightly interrupted, proximally embraced by the arcuate saccus roots for about one-fifth its width on both sides, with the sexine of the saccus gradually attenuating over the cappa margins (Pl. 2, figs 7-10). The distal face shows the saccus exine converging over the body or leaving an elongate cappula typically about 6-10 μm wide, traversed by a narrow slit (Pl. 2, fig. 7). In lateral view the body is trapezoid ("keystone-shaped"), with the cappa smoothly arched, the cappula flat, incised in the middle (Pl. 2, fig. 11). The saccus lobes form wedge-shaped extensions over the body meeting at the midline.

The cappa and sacci are psilate, with exterior brochi sometimes marked on the outside as polygonal depressions.

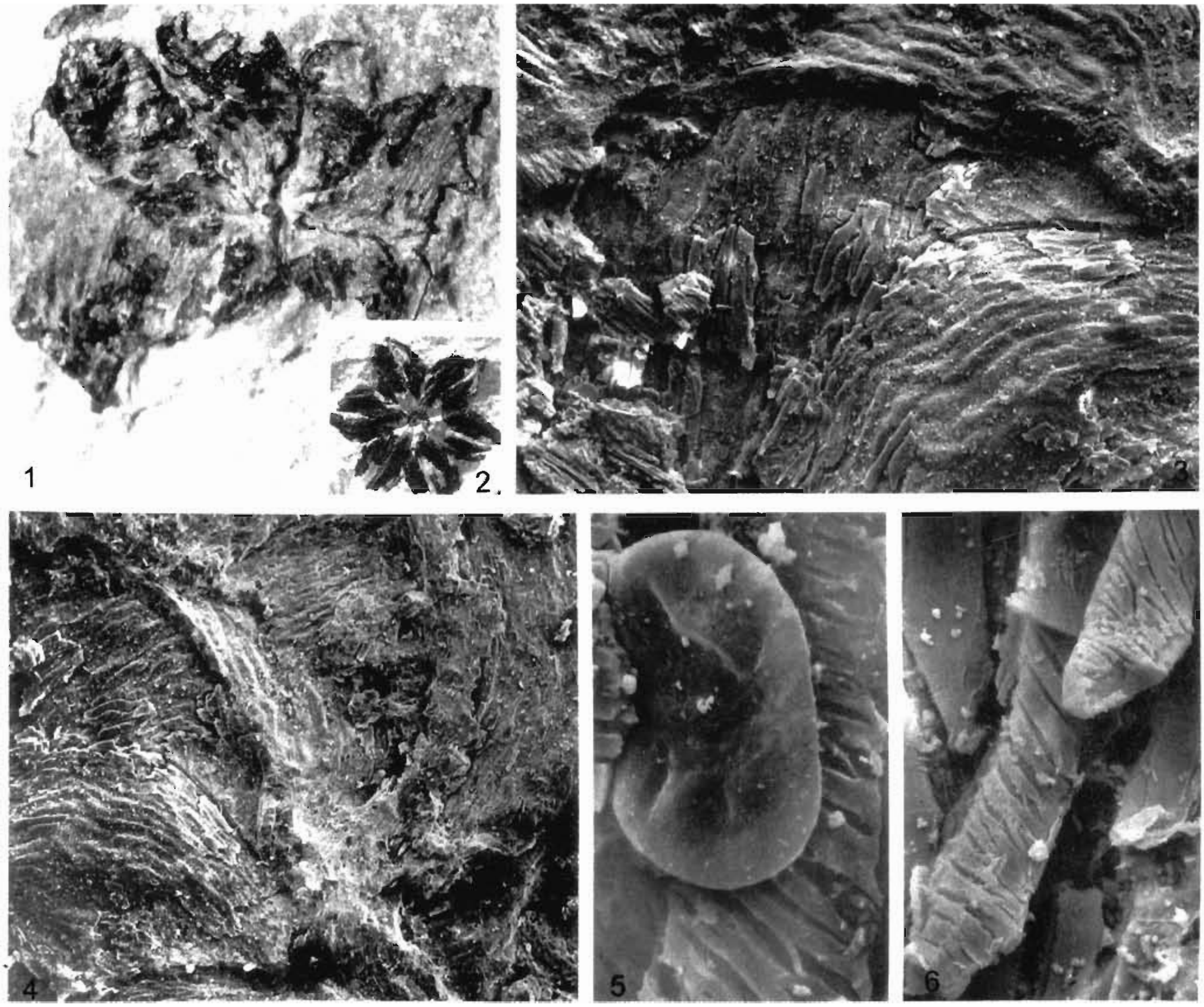

PLATE 1

1. *Permotheca disparis*, compressed sporangial head, Palaeontological Institute, Specimen No. 4748/15, x 9. Other photographs, except fig. 2, are from this specimen.
2. Impression of a similar head from the same locality, Geological Institute, Specimen No. 3737/202, x 4.
3. Sporangia showing longitudinal files of epidermal cells and transverse files lining the locule, SEM, x 55.
4. Base of the sporangial head showing proximal fusion of sporangia, SEM, x 37.
5. Distal view of a pollen grain attached to a tracheid, showing the cappula, SEM, x 950.
6. Tracheids of the sporangial vascular bundles, SEM, x 393.

The cappula is scabrate or irregularly microverrucate. The roots of the sacci are delimited by thick ridges. Split grains show a protosaccate infrastructure of thick endosexinal elements arising from the corpus and traceable halfway to the outer wall, distally branching repeatedly to form a three-dimensional pattern of elongate brochi (Pl. 2, fig. 4), polygonal in surface view. The exterior brochi are up to 4 μm wide.

The sporoderm thin sections show a thick tectum underlain by an alveolate infrastructure with large irregular lumina basally supported by a continuous foot-layer. The innermost layer is electronically denser, 0.12 μm thick, with 6-7 distinct lamellae, each 0.02 μm thick. The sporoderm of cappa is 0.9 μm thick. The distal sporoderm is thinner, with the alveolate infrastructure reduced over the cappula, lacking in the sulcus. In some sections, a layer of small dense bodies covered by a thin membrane, supposedly a tryphine-like material of tapetal origin, is discernible above the tectum (Pl. 2, fig. 12). At the root of the saccus the sporoderm is invaginated inside the body (Text-figure 1).

Some pollen grains contain sporangia of chitrid fungi

Text-figure 1—Section of entire pollen grain showing a thick sporoderm of the cappa (C), a thinner sporoderm of the cappula (Ca), sulcus (S) and infolded nexine at the saccus (Sa) roots. TEM, 4,000.

preserved as spheroidal, slightly angular bodies about 8-16 µm in diameter (Pl. 2, figs 7, 8)

DISCUSSION

The genus *Permotheca* was based on a few radial sporangial heads from the Kazanian (mid-Permian) deposits of Tatarstan briefly described as *Permotheca sardykensis* (Zalessky, 1929). Similar material from the Kungurian of the Urals was assigned by the same author to *Asterodiscus disparis* (Zalessky, 1937). The latter material was revised by Naugolnykh who first published it, together with ovulate disks, under the name *Peltaspermum retensorium* (Naugolnykh & Kerp, 1996), later transferred to *Permotheca disparis* (Naugolnykh, 1998). He also found loose strobili of many spirally attached *Permotheca*-type heads. These finds were used to reconstruct the strobilus shown in Text-figure 2.

Since the dimensions and the number of sporangia vary along the axis, these characters are of a little taxonomic significance. The species of *Permotheca* based on external morphology of dispersed heads alone may well belong in a single species. However, their *in situ* pollen grains were assigned to different morphotypes (Gomankov & Meyen, 1986).

In its strobilate aspect with sporangial heads arranged in a single spiral series *Permotheca* stands apart from pteridospermous pollen organs with sporangia or synangia born in three-dimensional or planate branching systems or else on laminar pinnules (Millay & Taylor, 1979). A taxonomic demarcation of dispersed sporangia remains a problem because radial sporangial clusters or synangia are known in a number of Palaeozoic taxa, such as *Zimmemannitheca, Aulacotheca, Crossotheca, Feraxotheca, Callandrium, Idanothekion*, as well as the Mesozoic *Pteruchus, Pteroma, Harrisithecium, Meeusella* and their allied forms (Millay & Eggert, 1970; Millay & Taylor, 1979; Stidd & Hall, 1970; Harris, 1964; Townrow, 1965; Retallack, 1983; Taylor *et al.*, 1984; Krassilov & Bugdaeva, 1988a, b). In these genera, however, the sporangia are either free, as in the Lower Carboniferous *Zimmemannitheca*, or, if synangiate or semisynangiate, have a basal cushion of parenchymous tissue that is apparently lacking in *Permotheca*. Other distinctive features are vascularization and the degree of sporangial fusion in the semisynangial structures. Vascularization of sporangia is shared by *Permotheca* with *Telangium* and *Idanothekion*, but in these

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PLATE 2

⟶

1. Sporoderm ultrastructure of cappa showing tectum, alveolate infrastructure, and nexine. TEM, x 12,000.
2. Close-up of the same section showing the sexine/lamellate nexine boundary (arrow), TEM, x 40,000.
3. Sulcus area with attenuate alveolar infrastructure and lamellated nexine, TEM, x 12,000.
4. Split grain showing protosaccate structure, SEM, x 2833.
5. Pollen grain, proximal aspect, SEM, x 900.
6. Pollen grain, latero-distal aspect, SEM, x 1150.
7. Two pollen grains with a clearly defined sulcus and the saccus sexine overlapping the cappula; right grain with fungal zoosporangium, LM, x 720.
8. Pollen grain with a fungal zoosporangium, LM, x 720.
9, 10. Pollen grains showing saccus sexine overlapping the cappa, with narrow lateral connections interrupted on one side, LM, x 720.
11. Same pollen grain as in fig. 6, with trapezoid body in proximo-lateral view with the sacci nearly converging over the cappula; note micropunctate infrastructure of the cappa, LM, x 720.
12. Orbicule-like bodies and the tryphine-like membrane over the tectum, TEM, x 5,000.

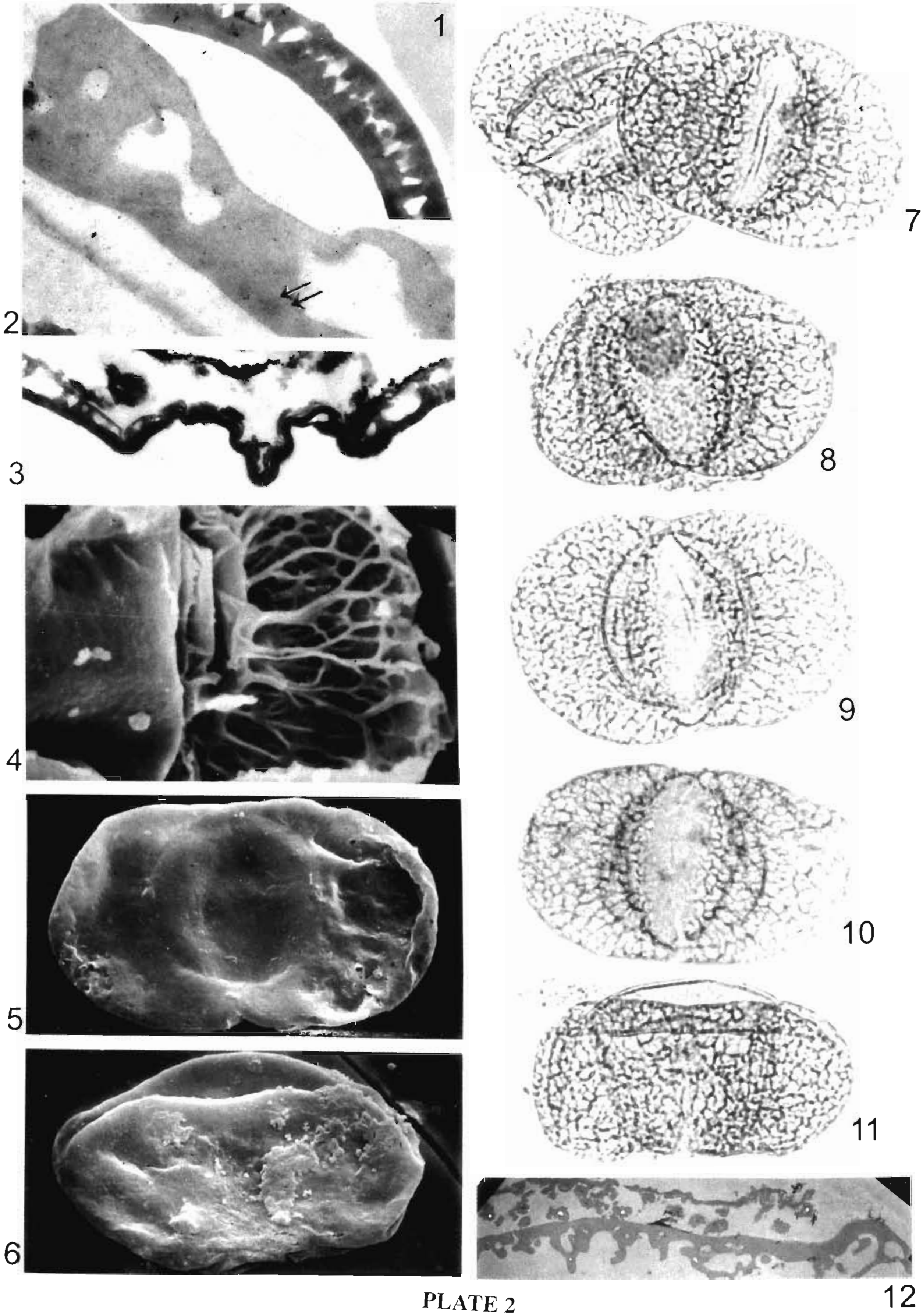


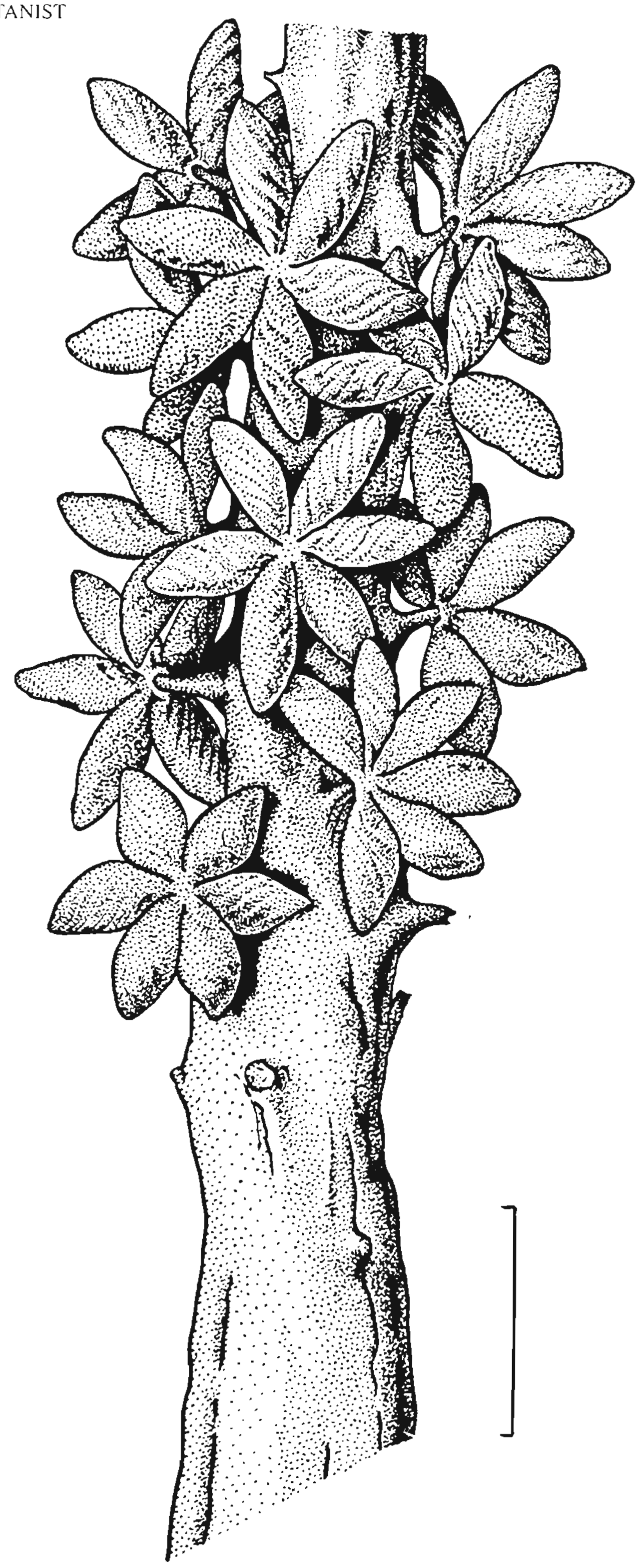
PLATE 2

Carboniferous genera the sporangia are fused for about two-thirds or even four-fifths of their length and the vascular bundle extends in the median plane. Individual sporangia are rather similar to *Arberiella* in general shape and epidermal structure (as shown in Pant & Bhatnagar, 1972; Zavada, 1991) but in the latter genus sporangia are stalked and are arranged in either branching or discoid structures (Rigby & Chandra, 1990).

Notably, in *Permotheca* and other Palaeozoic sporangia, the wall remains multilayered even after shedding of the pollen grains, whereas in the Mesozoic sporangia the inner wall layers are typically resorbed at maturity and the ripe pollen grains are covered only with an epidermal layer. This evolutionary change apparently relates to a more efficient use of sporangial tissues as a trophic resource for developing pollen grains.

Remarks on the pollen grains—The pollen grains are apparently of the same type as found *in situ* in the Upper Permian *Permotheca vesicasporoides* (Meyen, 1984; Gomankov & Meyen, 1986). The latter were described with LM as monosaccate, comparable with *Vesicaspora* Shemel emend. Wilson & Venkatachala (1963) and with the pollen grains of *Idanothekion glandulosum* Millay & Eggert (1970) assigned to the same morphotype. However, Balme (1995) suggested *Falcisporites* Leschik emend. Klaus, rather than *Vesicaspora*, as a more appropriate pollen-genus for the *in situ* pollen grains of *Permotheca vesicasporoides*. He assigned to *Falcisporites* also the *in situ* pollen grains of *Pteruchus africanus* Thomas that are externally quite similar to those of *Permotheca*. *Falcisporites* belongs to a group of the Late Permian to Mesozoic pollen morphotypes including also *Pityosporites* Seward emend. Manum, *Alisporites* Daugherty emend. Nilsson, *Klausipollenites* Jansonius, and some other less frequently used pollen-genera. They allegedly differ in the relative development of sulcus (typically present, elongate-rectangular in *Falcisporites*, but less conspicuous in *Alisporites* and apparently lacking in *Klausipollenites*, see Clarke, 1965, Scheuring, 1970; Jansonius, 1971; Foster, 1979) and the lateral connection of sacci (typically present in *Klausipollenites*, but less conspicuous in *Alisporites* and *Falcisporites*, see Clarke, 1965; Jansonius, 1971). However, these characters vary with developmental stage and preservation. In transitional forms, such as *Vesicaspora* or *Klausipollenites*, a demarcation of bisaccate pollen grains from monosaccate with strongly bilobed saccus is often arbitrary (Jizba, 1962; Clarke, 1965; Lindström *et al.*, 1997). In the *in situ* grains of *Permotheca* both monosaccate-bilobed and bisaccate conditions are met in a single sporangium.

A more profound distinction might have been provided at the ultrastructural level by infrastructure which is alveolar in *Vesicaspora*, but granular in *Pteruchus africanus* and supposedly in the allied dispersed morphotypes. Since the pollen grains of *Permotheca* have an alveolar infrastructure they seem closer to *Vesicaspora*, though differing from the latter in the better defined corpus and a more constantly developed sulcus. Haptotypic marks are lacking in our material, as well as



Text-figure 2—Reconstruction of strobilus with *Permotheca*-type sporangial heads, scale bar 1 cm.

in the Late Pennsylvanian *Vesicaspora*, though sometimes present in the mid-Pennsylvanian representatives of the genus (Millay & Taylor, 1974).

A thin membrane over the tectum is also a feature observed in some Carboniferous seed-fern pollen grains. The membrane was conventionally described as tapetal (Taylor & Taylor, 1987). It is actually comparable to tryphine of angiosperm pollen grains where it is a surface deposit of tapetal origin.

On evidence of both sporangial and pollen grain morphology, *Permotheca* seems most closely related to the Carboniferous callistophytes.

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Denwasporites gen. nov. : A prepollen from the Upper Triassic of India

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ABSTRACT

Kumar P 1999. *Denwasporites* gen. nov. : A prepollen from the Upper Triassic of India. Palaeobotanist 48(1) : 27-29.

Denwasporites a new prepollen genus is recorded from the Upper Triassic Denwa Formation of the Satpura Basin. It is a monolete form with weak intrapunctate exine.

Key-words — Prepollen, Upper Triassic (Denwa Formation), India.

सारांश

डेनवास्पोराइटीज़ नव वंश : उपरिट्रायसिकयुगीन भारत से प्राप्त एक प्रारंभिक परागकण

प्रमोद कुमार

डेनवास्पोराइटीज़ सतपुड़ा द्रोणी के उपरिट्रायसिकयुगीन डेनवा शैलसमूह से अंकित किया गया एक नवीनतम प्रारंभिक परागकण है। यह कमजोर एक्साइन से युक्त एक एकअरीय रूप है।

INTRODUCTION

SOME fossil miospores bearing a monolete-mark are recorded from the clay beds (Text-figure 1; Sample no.7 of Kumar & Kumar, 1999 in the Denwa Formation exposed in an artesian well cutting south of the village of Anhoni in the Chhindwara District, Madhya Pradesh. Monolete spores are known from the Upper Carboniferous-Permian and younger strata in the dispersed condition. These are referred to such miospore genera as *Laevigatosporites* Ibrahim, 1933, *Punctatosporites* Ibrahim, 1933, *Latosporites* Potonié & Kremp, 1954, *Leschikisporis* Bharadwaj & Singh, 1964 and *Monoletes* Cookson ex Potonié, 1956.

Other monolete forms bearing a proximal suture have been reported *in situ* from the genus *Medullosa*, and these prepollen have been described as *Monoletes* Van der Hammen, 1954 (=*Schopfipollenites* Potonié & Kremp, 1954) from the Upper Carboniferous of Germany. Surange and Chandra (1974) described monolete, sculptured spores as *Kendosporites* from the cone of *Kendostrobus* from Permian beds of the Raniganj Coalfield of Damodar Basin in India.

In the present paper, *Denwasporites* is a monolete-sutured prepollen which is described below following detailed study.

SYSTEMATICS

Turma—MONOLETES Ibrahim, 1933

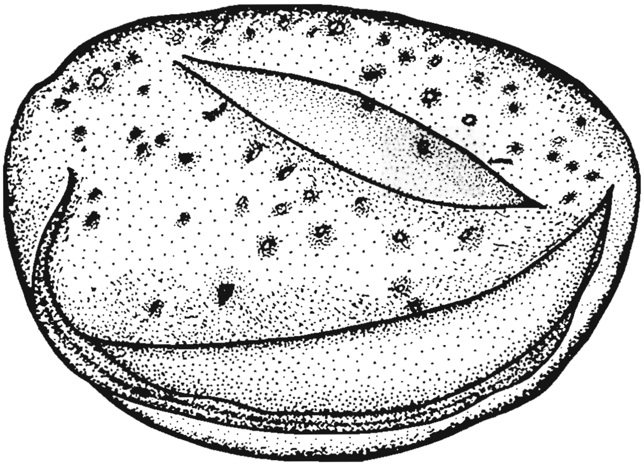
Suprasubturma—ACAVATOMONOLETES Dettmann, 1963

Subturma—AZONOMONOLETES Luber 1935

Infraturma—LAEVIGATOMONOLETI
Dybová & Jachowicz, 1957

Genus—DENWASPORITES gen. nov.

Etymology—Denwa Formation, Satpura Basin, M.P., India.



Text-figure 1—Diagrammatics sketch of *Denwasporites* gen. nov.

Diagnosis—Spores bilaterally symmetrical, equatorial outline oval; bearing proximally monolete suture. Exine smooth to weakly intrapunctate, folded along peripheral margins.

Description—Spores broadly oval in equatorial outline. Proximal face plano-concave or-convex, bearing monolete suture, labra smooth, simple thin. Distal face distinctly convex. Exine smooth to faintly intrapunctate, folded, puncta small and shallow. *Extrema lineamenta* smooth. Size 70-82 μm long and 48-64 μm broad.

Type species—*Denwasporites anhonii* gen. *et* sp. nov.

Comparison—*Denwasporites* gen. nov. is clearly distinct from *Latosporites* Potonié & Kremp, 1954 which has broadly oval to near circular amb and distal side strongly inflated; polar axis 1/2 - 1/1 of the longer axis in the equatorial plane; and shorter laesura. *Monoletes* Cookson ex Potonié, 1956 known from the Tertiary beds, has an oval amb meridian about half circular, and smooth but rigid exine. *Laevigatosporites* Ibrahim, 1933 is a bean-shaped spore and hence is not comparable with *Denwasporites* gen. nov. *Leschikisporis* Potonié emend. Bharadwaj and Singh, 1964 has an asymmetrical trilete mark with granulate exine and circular amb. *Punctatosporites* Ibrahim, 1933 is bean-shaped with punctate exine (like fine sand-paper); hence, it is quite different from *Denwasporites* gen. nov. The *in situ* spore genus *Kendosporites* Surange & Chandra, 1974 differs from the studied spores in featuring a patterned exine (i.e., ridges and grooves) running parallel to the longitudinal axis.

DENWASPORITES ANHONII sp. nov.

Pl. 1, figs 1-3

1969 *Laevigatosporites* sp. Bharadwaj & Srivastava, Pl. 24, fig. 3.

1973 *Laevigatosporites ovatus* Wilson & Webster in Kumar; Pl. 4, fig. 90.

Reconstruction—Text-fig. 1.

Type species—*Denwasporites anhonii* gen. *et* sp. nov.

Holotype—Pl. 1, fig. 1; size 74 μm long and 54 μm broad; BSIP No. 12257.

Locus typicus—Anhoni Village, Chhindwara District, Madhya Pradesh, India.

Stratum typicum—Denwa Formation, Mahadeva Group, Middle Gondwana, Satpura Basin, India.

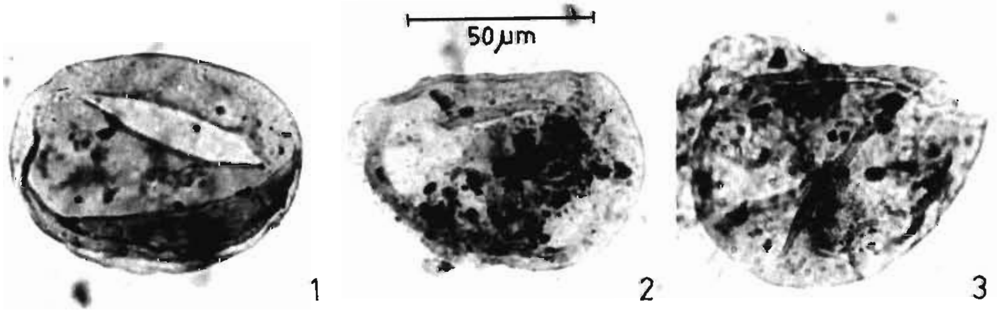


PLATE 1

All photomicrographs x 500. Co-ordinates of the specimens in slides refer to stage of Laborlux D Microscope No. 077055. The figured slides are deposited with the repository of Birbal Sahni Institute of Palaeobotany, Lucknow.

1. *Denwasporites anhonii* gen. *et sp.* nov. Slide no. BSIP 12257 (39 x 107.5).
2. *D. anhonii* Slide no. BSIP 12256 (12.5 x 98.5).
3. *D. anhonii* Slide no. BSIP 12255 (42 x 95.5).

Age—Late Triassic.

Etymology—Village Anhoni, Chhindwara District, M.P.

Diagnosis—Spores bilaterally symmetrical, equatorial outline oval, proximal face plano-concave or slightly convex, but the other (probably distal) face strongly convex, Monolete suture simple on the proximal face, labra thin and simple. Exine slightly intrapunctate, puncta small and folded. *Extrema lineamenta* smooth.

Description—Equatorial outline oval to broadly oval, distally arched face. Monolete-mark, length 2/3 to 3/4 of longitudinal axis, ± straight; labra thin, simple, and open. Exine 1-2.5 μm thick, surface intrapunctate, puncta small and shallow, faintly perceptible and sparse, folded along distal peripheral margin. Size range from 10 specimens; 70-80 μm long and 52-60 μm broad. *Extrema lineamenta* smooth.

Comparison—*Monoletes major* Cookson, 1947 differs from *Denwasporites anhonii* sp. nov. in being smaller (55.5- 77 x 32-42.5μm). *M. indicus* Kumar, 1973 possesses thicker exine (2.5-6.0 μm thick) with larger size range (105-120 x 63-92.5 μm). *M. grandis* Dev, 1961 differs in having intragranulate, transluscent exine and shorter monolete mark. *M. intragranulosus* Singh, Srivastava and Roy, 1964 differs in having finely intragranulate exine and shorter monolete mark. *Monolites* sp. of Kumar (1973) is distinct from *Denwasporites anhonii* in its thicker exine, which is intragranulate with coarse, closely packed grana covering the surface. *Laevigatosporites ovatus* Wilson & Webster in Kumar (1973, Pl. 4, fig. 90) is different in possessing smooth, unfolded exine. *Laevigatosporites* sp. Bharadwaj & Srivastava (1969) is smaller (ca. 50 x 34 μm), than *Denwasporites anhonii*. The *in situ* spore *Kendosporites striatus* Surange & Chandra, 1974, differs in being sculptured with parallel ridges and grooves.

DISCUSSION

Chaloner (1970) defined prepollen as "the microspores of seed plants which must have functioned as pollen but retained the pteridophytic character of proximal germination. It represents an intermediate condition between the microspores of free, sporing plants and the true distally germinating pollen of modern gymnosperm". He further opined that these could be either with or without a saccus. The dispersed prepollen genus *Monoletes* (=*Schopfipollenites*) from the Upper Carboniferous, Germany, is known to occur *in situ* in the vast majority of medullosan pollen organs (Taylor, 1981, p. 353; Stewart & Rothwell, 1993; p. 322). Surange and Chandra (1974; Pl. 2, figs 15 and 18) isolated *in situ* oval-shaped monolete spores having ridged and grooved exinal surface as well as a few smooth walled spores from the cone of *Kendostrobus* belonging to Glossopteridales from the Permian sediments of Raniganj Coalfield, Bengal, India. Bharadwaj and Srivastava (1969) described a monolete spore as *Laevigatosporites* sp. (Pl. 24, fig. 3) from Middle Triassic Nidpur beds, South Rewa Basin in Sidhi District, M.P., India. In (pers. com.) Dr Shyam C. Srivastava has identified monolete spores (similar = *Denwasporites* gen. nov.) in a pollen bearing organ recorded from the Triassic sediments of Nidpur, South Rewa Basin, India.

Occurrences of such monolete spores as *in situ* reported above as well as in dispersed conditions in the Denwa Formation (Upper Triassic) of Indian sediments is suggestive of seed-plants similar to medullosan forms in Satpura Basin, central India.

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Gymnospermous woods from the Upper Triassic of northern Chile

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ABSTRACT

Lutz AI, Crisafulli A & Herbst R 1999. Gymnospermous woods from the Upper Triassic of northern Chile. Palaeobotanist 48(1) : 31-38.

The anatomical study of three gymnosperm fossil woods from the Upper Triassic La Coipa, La Ternera and Las Breas formations is presented. *Prototaxoxylon intertrappeum* is a taxacean wood from India characterized by its tertiary thickenings on their secondary tracheids; *Protochamaecyparixylon klitzschii* is a cupressaceous wood also present in the Nandanga Formation of South Africa while *Protophyllocladoxylon cortaderitaensis* is a Protopinaceae member which was already described from the Upper Triassic of Argentina. The present text is the first description of Triassic woods from Chile.

Key-words— Coniferopsida (Taxales, Coniferales), Anatomy, Upper Triassic, Northern Chile.

सारांश

उत्तरी चिली से प्राप्त उपरिट्रायसिकयुगीन अनावृतबीजी काष्ठ

एलीशिया आई. लुत्ज़, एलेक्ज़ेन्ड्रा, क्रिसाफुल्ली एवं रेफील हर्ब्स्ट

ला कोयपा, ला टर्नेरा तथा लास ब्रीस नामक तीन शैल समूहों से प्राप्त उपरिट्रायसिकयुगीन तीन अनावृतबीजी अश्मित काष्ठों का शारीर वैज्ञानिक अध्ययन इस शोध पत्र में प्रस्तुत किया गया है। *प्रोटोटैक्सोज़ाइलॉन इन्टरट्रेपियम* भारत की एक टैक्सेशियन काष्ठ है, जिसे इनके द्वितीयक वाहिनियों पर स्थित इसकी तृतीयक स्थूलता से अभिलक्षणित किया गया है। *प्रोटोकैमीसाइपेरीज़ाइलॉन क्लिट्शाइ* एक क्यूप्रेससमय काष्ठ है, जो दक्षिण अफ्रीका के नानडांगा शैलसमूह में भी उपस्थित है, जबकि *प्रोटोफ़िल्लोक्लैडोज़ाइलॉन कार्टेडेराइटीन्सिस* प्रोटोपिनेसी कुल का एक सदस्य है, जिसे उपरिट्रायसिकयुगीन अर्जेन्टीना से पहले से ही अंकित किया जा चुका है। प्रस्तुत शोधपत्र चिली से प्राप्त ट्रायसिकयुगीन अश्मित काष्ठ का प्रथम वर्णन प्रस्तुत करता हैं।

INTRODUCTION

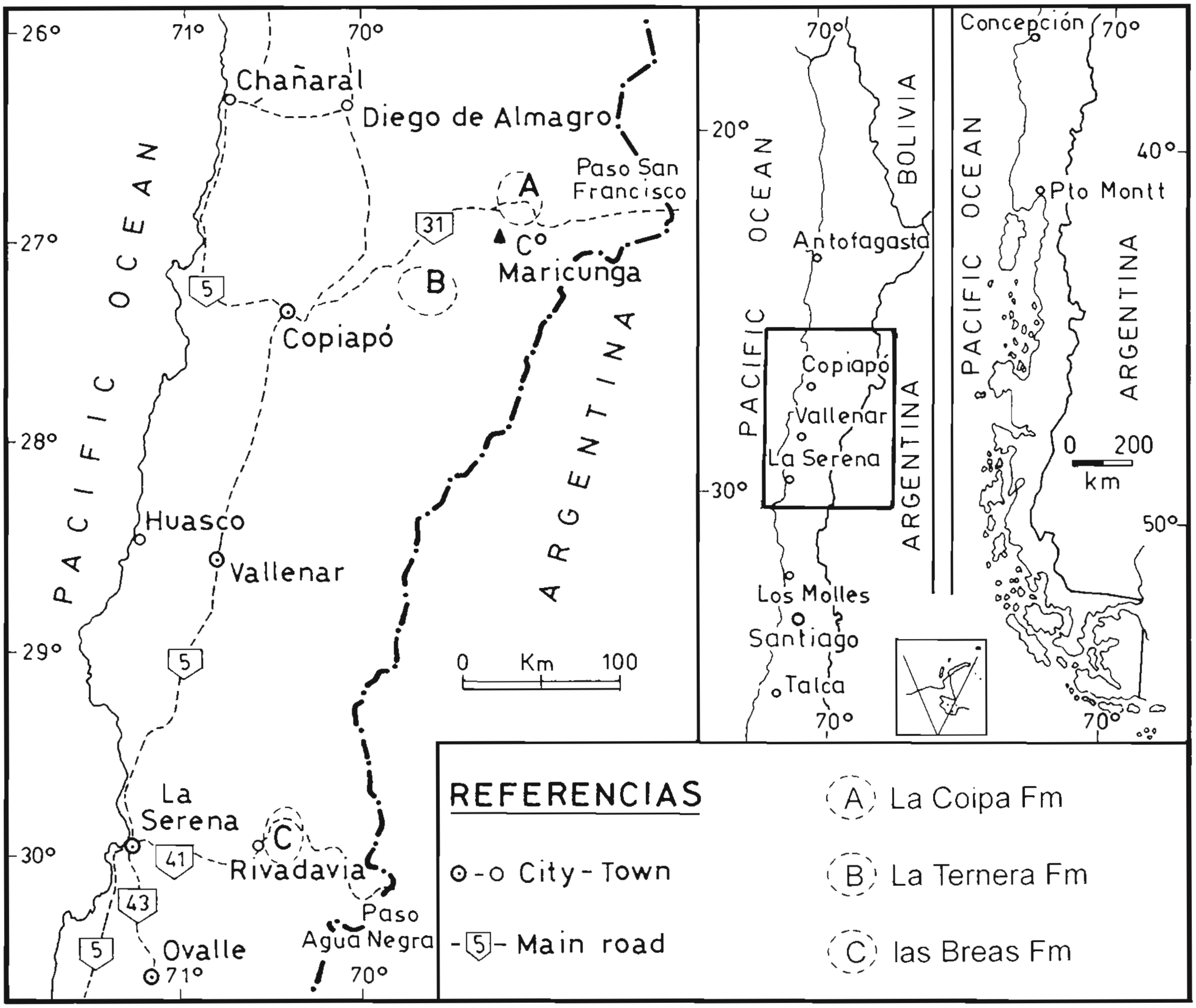
THREE fossil woods are described and cited for the first time from different localities and formations, of northern Chile (Text figure 1). Fossil wood had only been reported as such and to our knowledge had never been described before from these units.

In a recent paper Herbst *et al.* (in press) gave a summary of the scarce former literature related to the megaflora of these formations. They all contain a typical Triassic *Dicroidium* flora composed of abundant Pteridophyta (mainly Marattiales, Osmundales, Gleicheniaceae, Dipteridaceae and the genus *Neocalamites*), Pteridosperms (*Dicroidium, Diplasiophyllum, Lepidopteris*, etc.) Ginkgoales (*Ginkgoites, Sphenobaiera*), Cycadales (*Pseudoctenis*), other leaves (*Taeniopteris, Yabeiella*) and very rare Conifers (*Rissikia* and *Heidiphyllum*). The woods here described belong to the latter Class of plants.

MATERIAL AND METHOD

Sources of the material are as follows:

The material described in this paper has been collected



Text-figure 1—Location map, showing the areas of the formations with fossil woods.

from Hito La Candelaria (close to La Coipa Mine), North of C. Maricunga, Province of Copiapó, III Region, Chile. The wood samples occur in La Coipa Formation which is considered to be Lower Triassic? (Suarez & Bell, 1993).

It seems doubtful to us, as cited in Suarez & Bell (1993) that the La Coipa Formation is of Lower Triassic age as its flora, although locally somewhat distinct, is typically of the Middle-Upper Triassic associations, as are the other floras of northern Chile.

Locality—Quebrada El Carbón, area of C° La Ternera, Province of Copiapó, III Region, Chile.

Horizon—La Ternera Formation.

Age—Upper Triassic (Sepúlveda & Naranjo, 1982).

Locality—Punta del Viento, 20 km East of Vicuña, Province of Elqui, IV Region, Chile.

Horizon—Las Breas Formation.

Age—Upper Triassic (Dediós, 1967; Letelier, 1972).

The specimens are fairly well preserved, completely silicified, but only secondary wood is present in all the specimens, generally with well marked growth rings.

The acetate-peel technique was used with good results, in addition to other observations. A minimun of 15 measurements was made in all cases: the mean size is given while the maximun and minimun values are in parentheses. The terminology used is that of Greguss (1955) and standard measurements as proposed by Chatthaway (1932).

SYSTEMATICS

Class—CONIFEROPSIDA

Order—TAXALES

Family—TAXACEAE

Genus—**PROTOTAXOXYLON** Kräusel & Dolianiti, 1958

Prototaxoxylon intertrappeum Prakash & Srivastava, 1961
(Pl. 1 figs 1, 2, 3, 5, 7 and Text-fig. 2)

Type species—Prototaxoxylon africanum (Walton) Kräusel & Dolianiti, 1958

Description—Decorticated wood fragment with only secondary wood preserved, with well-marked growth rings and abundant "shearing zones". Xylem tracheids are rectangular in outline in transversal section (TS) with about 24 µm (30-15 µm) in tangential x 27 µm (30-15 µm) radial diameters respectively (Pl. 1, fig. 1). In all growth rings the late wood is narrow, with 5 (9-2) rows of cells while early wood has 46 (63-32) rows of cells. Mean sensitivity (Fritts, 1972) could not be obtained as together with true, there are many false rings. In longitudinal radial (LR) section, tracheids are 53 x 900 µm wide / long. Their walls bear rounded, uniseriate araucariod pits, contiguous and spaciate; areole aperture is circular. Pits measure 10 x 12 µm wide / high. The flattening coefficient (e=d / D) is 1 (Pl. 1, figs 2, 3, 5, 7). On the radial walls there are thickened spiral bands running clock- or counterclock- wise over the pits (Pl. 1, figs 2, 3, 5, 7, Text. fig. 2). Cross fields have biseriate, scattered, bordered pits with circular pore apertures; mean number of pits per field is 4 (8-2) (Text-fig 2). The radial system is homogeneous, rays are uniseriate, low, with oval cells in tangential longitudinal (TL) section. Mean height of rays is of 3 cells (7-2). On these walls the uniseriate pits are smaller than those of radial walls. In TS the rays are separated by about 7 (16-2) tracheids (Pl. 1, fig. 1). On TL walls the uniseriate pits are smaller than those of the LR walls.

Material—CTES-PB N° 10252, Sgo- PB N° 1595; CTES-PMP N° 2036-2037 (sections).

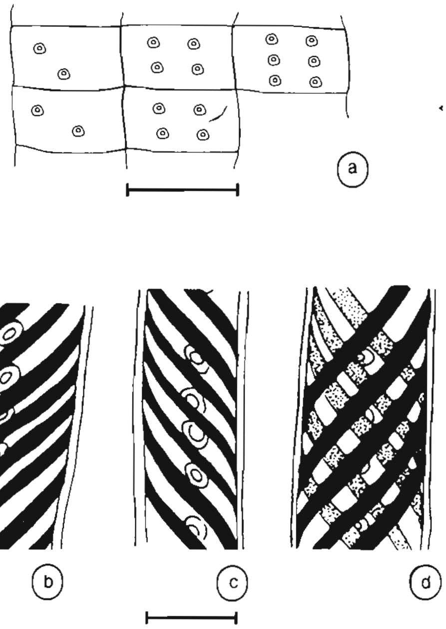
Locality—Hito La Candelaria, Mina La Coipa, Chile (see above).

Horizon—La Coipa Formation.

Age—Upper Triassic.

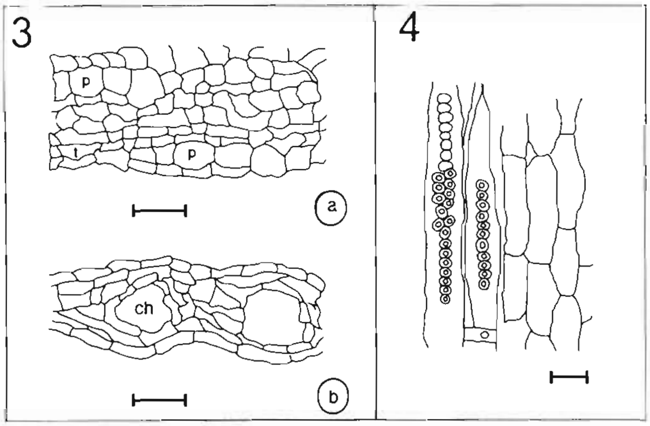
Discussion—The described specimen can be assigned undoubtely to the genus *Prototaxoxylon* Kräusel & Dolianiti (1958), mainly because of the arrangement of the spiral thickening bands on the tracheidal walls (characteristic of all the Taxales), the bordered pits and the field-crossings.

There are some other Gondwana woods with the same type of secondary wood, viz., *Taxopytis* Kräusel, *Taxoxylon* Unger and *Taxaceoxylon* Kräusel & Jain. But these are different in their abietinoid pits on tracheidal walls while in *Prototaxoxylon* they are mid-way between araucarioid and cordaitoid. Incidentally, it seems that this and some other morphological characters in homologous structures of seeds and cones, are the reasons why Bliss (1918), Sahni (1920) and Florin (1948) suggested that the Taxales evolved from some ancestral type of Cordaitales.



Text-figure 2—*Prototaxoxylon intertrappeum* Prakash & Srivastava. Aspect of the cross-field and scheme of the spiral thickening bands running clock and counter clock- wise on tracheidal walls. Scale bar: 35 µm.

Prototaxoxylon has an extensive biochron, from Permian to Tertiary; five species are known from the Gondwana realm: *P. indicum* (Mehta) Prakash & Srivastava, *P. andrewsii* Agashe & Chitnis, both from the Permian of India; *P. brasilianum* Kräusel & Dolianiti from the Permian of Brazil, *P. africanum* (Walton) Kräusel & Dolianiti from the Late Mesozoic or Lower Tertiary of South Africa, and finally *P. intertrappeum* Prakash & Srivastava from the Lower Tertiary of India. *P. feriziense* Fahkr and Marguerier (in Fahkr,1977) is known from the



Text-figures 3, 4—*Protochamaecyparixylon klitzchi* Giraud. Transverse section of secondary woods, ch: secretory canal. Scale bar: 100 µm. **4.** *Protophyllocladoxylon cortaderitaensis* Menéndez. Tracheids with mixed and uniseriate pits and phyllocladoid cross-field in secondary xylem; to the right short tracheids without pits. Scale bar: 38 µm.

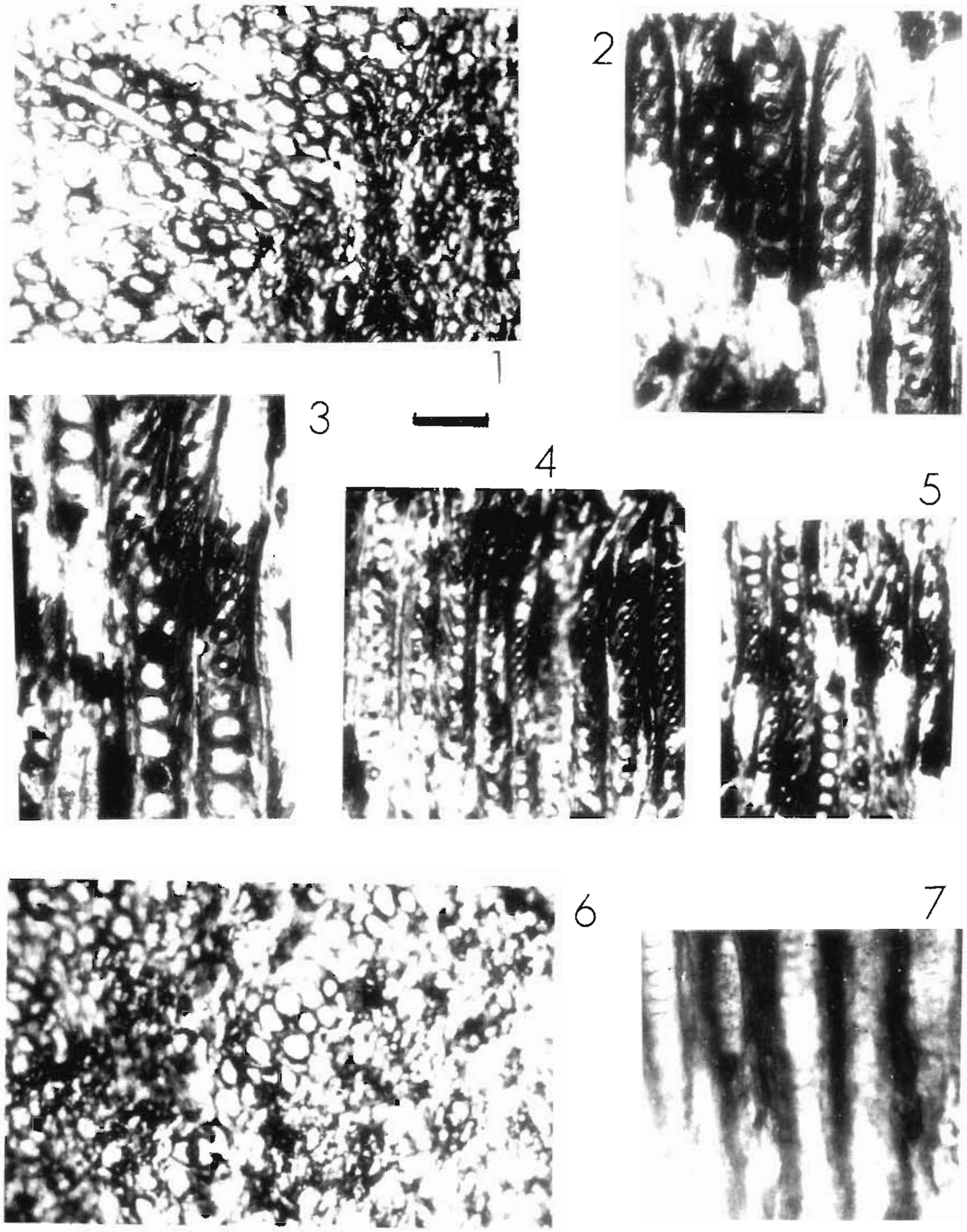


PLATE 1

1, 2, 3, 5, 7 *Prototaxoxylon intertrappeum* Prakash and Srivastava. **1.** transversal section . tracheids of secondary xylem, scale bar: 70 μm. **2, 5**: longitudinal radial sections: spiral thickening bands running clock or counterclock- wise over the tracheidal walls of the secondary xylem and uniseriate pits, scale bars. **3, 7** represents 35 μm; **2**= 70 μm; **5**=15 μm.

4, 6. *Protochamaecyparixylon klitschii* Giraud. **4**. transversal section: tracheids of secondary xylem, partial parenchimatic ring and growth ring, scale bar represents: 80 μm. **6**. longitudinal radial section: uniseriate pits on the tracheidal walls of secondary xylem, scale bar represents 70 μm.

Jurassic of Iran, i.e., outside the classical Gondwana realm.

Comparisons with all these species showed that the Chilean specimen could be assigned to *P. intertrappeum*, with which it shares most characters, mainly the thickness and arrangement of the spiral thickenings, the cross-fields, the predominance of uniseriate bordered pits, smaller tangential than radial pits and the presence of false growth rings.

A few unimportant characters have not been seen in our specimen : Sanio-bars in some tracheids, the number of pits in the cross-fields (1-10 in the Indian specimen and 2-7 in ours) and a small amount of biseriate radial pits. Maheshwari (1972) also found some variations in this latter character which,

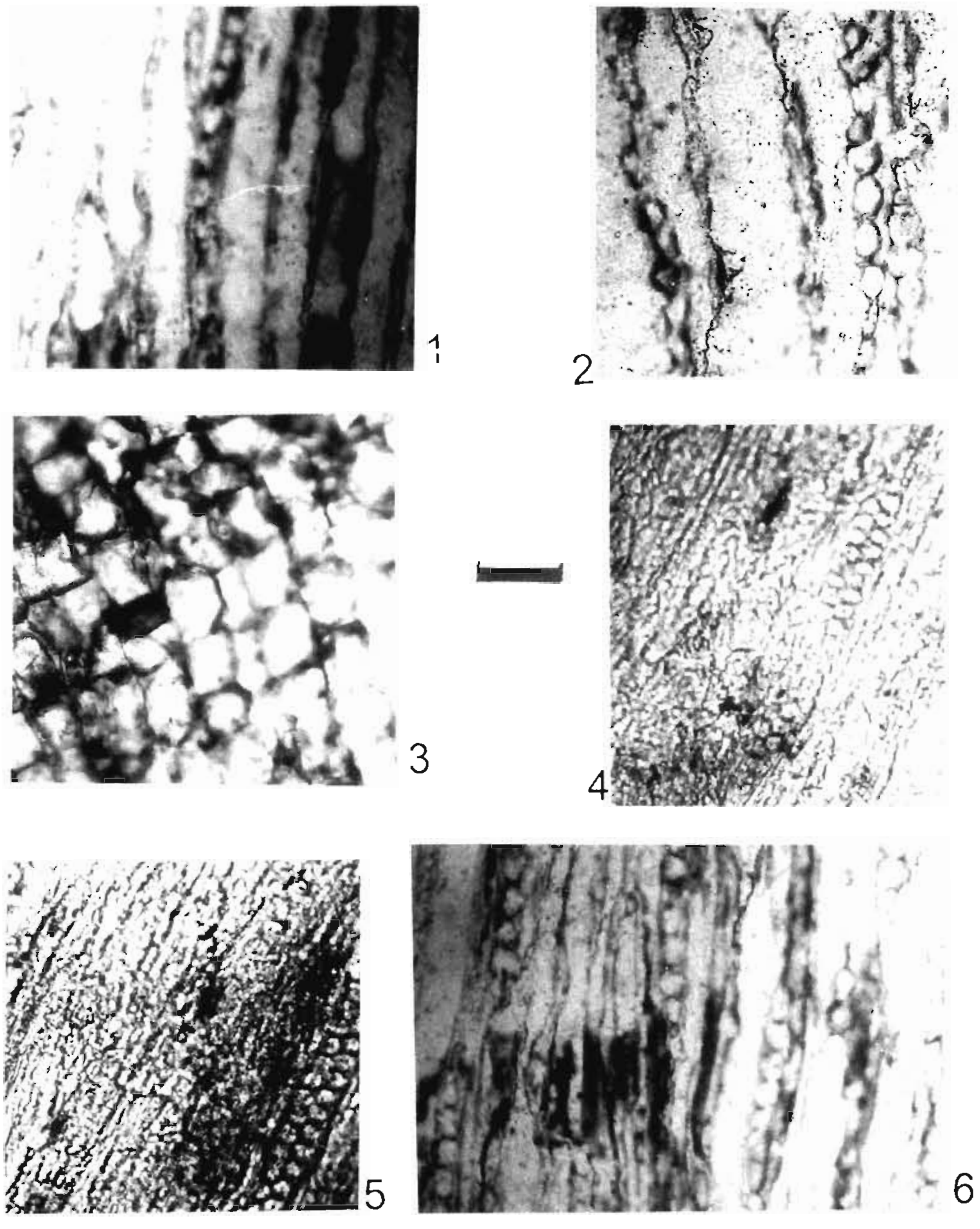


PLATE 2

1, 2. *Protochamaecyparixylon klitszchii*.Giraud. Tangential longitudinal section : frequency and height of secondary xylems rays, scale bar represents 80 µm and 100 µm for figs. 1 and 2 respectively.

3-6. *Protophyllocladoxylon cortaderitaensis*. Menéndez. 4. Transversal section: tracheids of secondary xylem, scale bar represents 100 µm.

3, 6. longitudinal radial section : 3. mixed pits on the tracheidal wall, 6. araucarioid biseriate pits on tracheids, scale bar represents 50 µm.

5. longitudinal tangential section . uniseriate and low rays, scale bar: 80 µm.

TABLE I - Showing the characteristics of the species of *Prototaxoxylon*(*)

Name of the Wood	Growth Rings	Bordered Pitting (Radial Wall)	Bordered Pitting (Tangential Wall)	Spiral Bands	Medullary Rays	Field Pitting
1. *Prototaxoxylon africanum* (Walton) Kräusel & Dolianiti (1958)	Distinct	Uniseriate and contiguous, occasionally biseriate	Not seen	1-2 seriate, confined to the wall between the pits	Almost uniseriate 1-18 cells high	2-8, border not visible
2. *Prototaxoxylon indicum* Prakash & Srivastava (1961)	Well marked	Uniseriate or irregularly biseriate (then alternate or opposite), contiguous, circular or horizontally elliptical in shape	Absent	1-2 seriate, passing in between the pits or across the borders of contiguous pits	Uniseriate(?), one (or more ?) cell deep; ray cells fairly thick-walled	6-7, border elliptical
3. *P. brasilianum*, Kräusel & Dolianiti (1958)	Absent	Single series occasionally 2-seriate and alternate	Absent	Close, narrow and nearly horizontal, bands across the pits, look like scalariform pitting	1-6 (1-2) cell high, uniseriate	1-4, broadly oval, slit like oblique opening
4. *P. intertrappeum*, Prakash & Srivastava. (1961)	Distinct	Normally uniseriate and contiguous, sometimes biseriate, circular or vertically compressed in shape	Scarce, normally uniseriate & separate.	2-seriate. Close both left and right-handed, pass usually across the borders of contiguous pits or through the space between the separate pits	1-seriate, 2-7 cells high, ray cells usually oval	2 (4-8) biseriate, scattered, bordered pits, pore circular
5. *P. andrewsii*, Agashe & Chitnis, (1971)	Very distinct	1-3 seriate circular slightly horizontally compressed bordered pits	Absent	Single or double, closely spaced clockwise or anti-clock wise	1-2 seriate. 1-8 cells high	Cupressoid, ovoid 2-6 per field central pore circular to oblique
6. *P. feriziense*. Fahkr & Marguerier	Poorly marked	1-2 seriate and mixed, circular and contiguous or spaciate	Absent	Horizontal or oblique	Uniseriate, 1-13 cells high	Oculipore, elliptical

(*) Partially adapted from Prakash and Srivastava 1961

according to him, depends on how far from the pith are observations of xylem made.

Differences with the other species of *Prototaxoxylon* are shown in Table 1.

P. intertrappeum was originally described from Lower Tertiary sediments of India, but Prakash and Srivastava (1961) already admitted a close resemblance to more "primitive" Permian species. The present finding in Triassic rocks fills this gap.

Order—CONIFERALES

Family—CUPRESSACEAE

Genus—PROTOCHAMAECYPARIXYLON Giraud 1985

Protochamaecyparixylon klitzchii Giraud
Pl. 1, figs 4, 6; Pl. 2, figs 1, 2; Text-fig. 3

Type species—*P. klitzchii* Giraud, (in Giraud & Hankel) 1985

Description—Decorticated wood fragment, 30 cm in diameter x 35 cm long. Only picnoxylic xylem with weakly marked growth rings is preserved. Tracheids are rectangular in transversal outline, 33 µm (44-23 µm) radially x 37 µm (43-15 µm) tangentially respectively. Transition from early to late wood is gradual, but some disttorion due to shearing zones is observed. In TS traumatic secretory channels are seen, with a mean of 66 µm in radial x 74 µm in tangential diameters; traumatic parenchyma cells of mean 37 x 42 µm radially / tangentially can also be seen (Pl. 1, fig. 4, Text-figure 3).

In LR section, araucariod, mainly uniseriate (few biseriate), contiguous, bordered pits are seen on radial walls (Pl. 1, fig. 6).

Cross-fields show 1-2 cupressoid oculipore-type (elliptical, oblique lumen) pits. No pits have been observed on tangential walls. Radial system is homogeneous, with uniseriate rays; cells are rounded, low, only 4 (8-3) cells high; in TS rays are separated by a mean of 11 (18-5) tracheids (Pl. 2, figs 1, 2).

Material—CTES-PB N° 10253, Sgo- PB N°1596; CTES-PMP N° 2038-2039 (sections).

Locality—Punta del Viento (see above).

Horizon—Las Breas Formation.

Age—Upper Triassic.

Discussion—The presence of diagnostic characters like isolated vertical parenchyma, traumatic secretory channels, radial pits mainly uniseriate and cupressoid cross-fields, shows great affinities with the Cupressaceae and specially with the genus *Protochamaecyparixylon* Giraud. This is a monotypic genus (*P. klitzchii*) from the Nandanga Formation (Upper Triassic of the Karroo Series) from Tanzania.

Our specimen can confidently be identified with this species as all characters coincide, except the number of pits in cross-fields which in present specimen are 1 to 2, while in the African specimens their number is 2 to 4. But this seems to be a very minor difference.

Family—PROTOPINACEAE

Genus—PROTOPHYLLOCLADOXYLON Kräusel, 1939

Protophyllocladoxylon cortaderitaensis Menéndez, 1956
Pl. 2, figs 3-6; Text-fig. 4

Type species—*P. leuchsii* Kräusel, 1939.

Description—Trunk of about 1 m diameter, with well-marked growth rings. Tracheids have a rectangular outline, approximately 57 µm (64-37 µm) radially x 55 µm (58-23 µm) tangentially (Pl. 2, fig. 4). Transition from early to late wood is gradual. On radial walls tracheids bear rounded, contiguous, uniseriate araucarioid pits, with circular pore aperture and biseriate contiguous, rounded to a few polygonal (hexagonal) pits as well as mixed pits (Kräusel, 1939) (Pl. 2, figs 3, 6; Text-figure 4). Cross-fields have only one pit without areoles. Radial system is homogeneous. Rays are homocellular, uniseriate (a few biseriate), low. Mean cell height is 2 with a maximum of 4 (Pl. 2, fig. 5).

Material—CTES-PB N° 10254, Sgo PB- N° 1597 ; CTES-PMP N° 2040-2042 (sections).

Locality—Quebrada El Carbón – Chile (see above).

Horizon—La Ternera Formation.

Age—Upper Triassic.

Discussion—The presence of mixed pits on the radial tracheidal walls is the main character of the Family Protopinaceae.

All the anatomical characters here described are coincident with *Protophyllocladoxylon* Kräusel, which has a large biochron from the Upper Carboniferous to the Cretaceous, and is known from Germany, Russia, Africa, Brazil and Argentina. Specifically, our material is undoubtedly assignable to *P. cortaderitaensis* Menéndez from the Upper Triassic Barreal Formation of Argentina. With this species it shares the simple punctuation of the cross-fields, the uni-, bi- and mixed pits on the radial tracheid walls.

CONCLUDING REMARKS

It is interesting to remark that in spite of the rare Conifers (*sensu lato*) impressions in the megafloras (only *Rissikia* and *Heidiphyllum* have been recorded) these woods belong to Gymnosperms.

The specimens are evidently allochthonous and surely represent, at least partially, the upland flora which surrounded the fluviatile areas into which they have been drifted. This xyloflora is composed of already known genera and species, in some cases with extra-gondwanic distribution (like *Prototaxoxylon* and *Protophyllocladoxylon*); this is in sharp contrast with the "endemism" shown by the leaf-impression megafloras which presumably represent the "typical" floras of each site or locality in our case different lowland associations of *Dicroidium*-flora. This fact shows once more that there was stronger uniformity in upland forests, with a much wider than usually accepted distribution of tree taxa. This seems to be the case in many Triassic and Permian floras. Recently two of us (Crisafulli & Lutz, in press) have described a Permian xyloflora from Uruguay where also several taxa of upland trees of rather wide distribution are present, which are not represented by the leaf–impression flora (Herbst *et al.*, 1992).

Other Permian flora from Brazil and India show the same differential distribution between leaves and woods.

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Lower Cretaceous plant fossils from Bairam-Belkher area, District Amravati, Maharashtra and District Betul, Madhya Pradesh and their significance in stratigraphy

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ABSTRACT

Srivastava AK, Banubakode PD, Kale, VM, Patil GV & Manik SR 1999. Lower Cretaceous plant fossils from Bairam-Belkher area, District Amravati, Maharashtra and District Betul, Madhya Pradesh and their significance in stratigraphy. Palaeobotanist 48(1) : 39-48.

A plant fossil assemblage comprising of *Matonidium indicum, Sphenopteris* sp., *Cladophlebis indica, Ptilophyllum cutchense, P. acutifolium, Taeniopteris spatulata, T. vittata, Pagiophyllum* sp., *Brachyphyllum* sp., *Araucarites cutchense, Elatocladus tenerrimus, E.* sp., E. *kingianus* and *Elatocladus* sp. A has been described from a new locality of Bairam-Belkher area in District Amravati, Maharashtra and District Betul, Madhya Pradesh. *Ptilophyllum* and *Matonidium* are the most abundant genera in this assemblage. An attempt has also been made to compare the present assemblage which show an affinity with the Lower Cretaceous assemblages of Peninsular India, i. e., Himmatnagar, Gardeshwar, Gollapalle, etc. On the basis of various taxa belonging to Bennettitales and Filicales, a warm and humid climate has been interpreted.

Key-words—Plant megafossils, Early Cretaceous, Upper Gondwana (India), Bennettitales, Filicales, Cycadales.

सारांश

महाराष्ट्र के अमरावती जनपद तथा मध्य प्रदेश के बैतूल जनपद के बैरम-बेलखर क्षेत्र से प्राप्त अधोक्रिटेशसयुगीन पादपाश्म तथा उनकी स्तरकीय सार्थकता

अशोक कुमार श्रीवास्तव, प्रदीप देवीदास पंत बानुबकोडे, विवेक मोतीरामजी काले, गणेश व्यंकटराव पाटील एवं सुरेन्द्र राघोबा माणिक

महाराष्ट्र के अमरावती जनपद तथा मध्यप्रदेश के बैतूल जनपद में स्थित बैरम-बेलखर क्षेत्र की एक नई संस्थिति से एक पादपाश्म समुच्चय अंकित किया गया, जिसके अन्तर्गत *मैटोनीडियम इन्डिकम, स्फ़ीनॉप्टेरिस* प्रजाति, *क्लैडोफ़्लेबिस इन्डिका, टिलोफ़िल्लम कचेन्स, पी. एक्यूटीफ़ोलियम, टीनिऑप्टेरिस स्पैच्यूलेटा, टी. विट्टाटा, पैजियोफ़िल्लम* प्रजाति, *ब्रैकीफ़िल्लम* प्रजाति, *आरॉकैराइटीज़ कचेन्स, इलैटोक्लैडस टीनेरिमस, इलैटोक्लैडस* प्रजाति, ई. *किन्जिएनस* तथा *इलैटोक्लैडस* प्रजाति ए सम्मिलित हैं। *टिलोफ़िल्लम* तथा *मैटोनीडियम* इस समुच्चय के सर्वाधिक बाहुल्य वाले वंश हैं। इस समुच्चय की वर्तमान समुच्चय से तुलना करने पर भारत के प्रायद्वीपीय क्षेत्रों (जैसे-हिम्मतनगर, गरदेश्वर, गोलापल्ली इत्यादि) के अधोक्रिटेशसयुगीन समुच्चयों के साथ सजातीयता प्रदर्शित हुई है। बेनेटिटेलीज़ तथा फिलिकेलीज़ से सम्बन्धित विभिन्न वर्गकों के आधार पर एक उष्ण तथा आर्द्र जलवायु का निर्वचन किया गया है।

INTRODUCTION

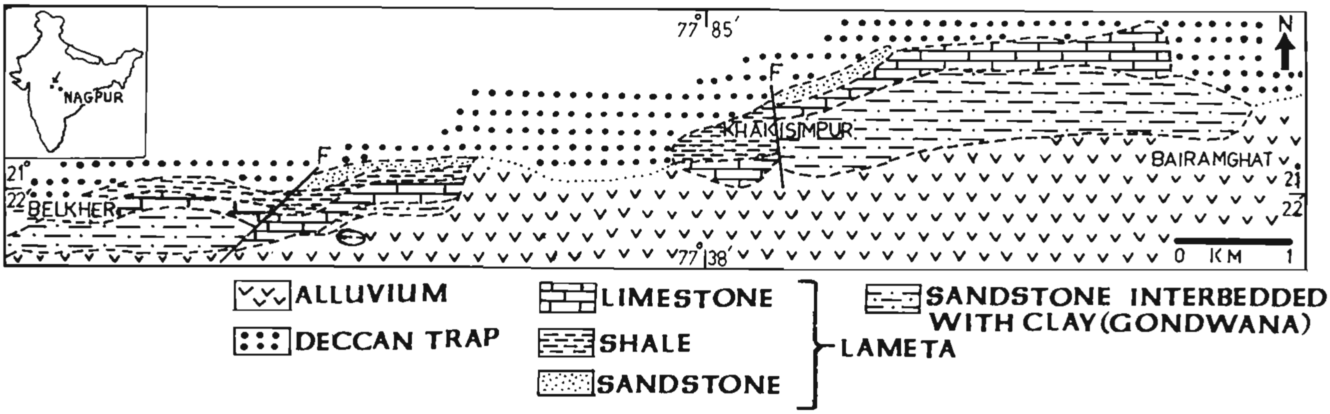
THE sedimentary sequence exposed in the Bairam-Belkher area is represented by the Gondwana and Lametas. The sediments are about 100 m in thickness consisting of sandstone, shale and clay beds having a dip of 10°-15° north (Text-figures 1, 2). The sequence, though reported a century back, could not get much attention. The earlier workers have made very casual comments where as in the past 2-3 decades, the sequence has been locally studied because of the clay deposits having economic value (Arogyaswami, 1968). Blanford (1869) first reported the sequence and correlated it with the Mahadeva. Pascoe (1959) considered it as an inlier and correlated it with Kamathi and (?) Mahadeva. Adyalkar (1975) and Bhusari (1979) ranked it Upper Triassic and equated with Pachmari and Maleri. All the correlations made by these workers are based on the lithological characters and no palaeontological evidences are taken into consideration. Kumar (1990), for the first time, recorded spores and pollen from Belkher area and considered it of Neocomian-Aptian age. Recently, Srivastava *et al.* (1995) collected a huge assemblage of leaf impressions and considered them to be of Lower Cretaceous age.

The plant fossils have been recorded from the clay horizons occurring as lenticular bodies in the sandstones. The clay is exposed at various places, viz., Pandhari, Nimbhora, Kherali, Bairam and Belkher showing variability in colours, i. e., dirty white, grey, dark grey and black. However, dark grey coloured clays of Bairam and Belkher have been found to be productive for plant fossil remains. The generalised stratigraphy of the area is given in Table 1.

Table 1—Generalised stratigraphy of the area.

Age	Formation/Group	Lithology
Quaternary		Soil and alluvium
	----Unconformity----	
Miocene to Late Cretaceous	Deccan Trap	Nonporphyritic to porphyritic basalt
	----Unconformity----	
Late Cretaceous	Lametas	Shale, limestone and sandstone
	----Disconformity----	
Early Cretaceous	Upper Gondwana	Clay, shale, sandstone and conglomerate
	----Unconformity----	
Archaeans		Quartz-feldspathic gneiss

The present paper deals with the identification and detail description of the taxa. Since, all the recorded specimens are in the form of impressions, therefore, only morphological features have been taken into consideration. The comparison of the present assemblage has been made with other known equivalent assemblages. An attempt has also been made for the correlation and assigning the age to the sequence. On the basis of recovered and known taxa, the interpretation of the



Text-figure 1—Geological map of the area (Srivastava *et al.*, 1995 after Gadewar & Sukhatankar, 1990).

PLATE 1

(Scale - one centimeter)

1. *Matonidium indicum* Sahni 1936, detached pinnae showing oval elevations on either side of midrib.
2. *Taeniopteris spatulata* (McClelland 1850) incomplete leaf showing nature of lateral veins.
3. *Elatocladus* sp. A, sterile twig.
4. *Taeniopteris spatulata* (McClelland 1850) showing complete leaf.
5. *Matonidium indicum* Sahni 1939, detached pinnae showing basal and middle portion.
6. *Elatocladus* sp. cf. *E. kingianus* sterile twig.
7. *Matonidium indicum* Sahni 1939, fertile pinnae showing sori.
8. *Cladophlebis indicum* (Oldham & Morris) Sahni & Rao 1933 showing venation pattern.
9. *Brachyphyllum* sp. leafy twig.

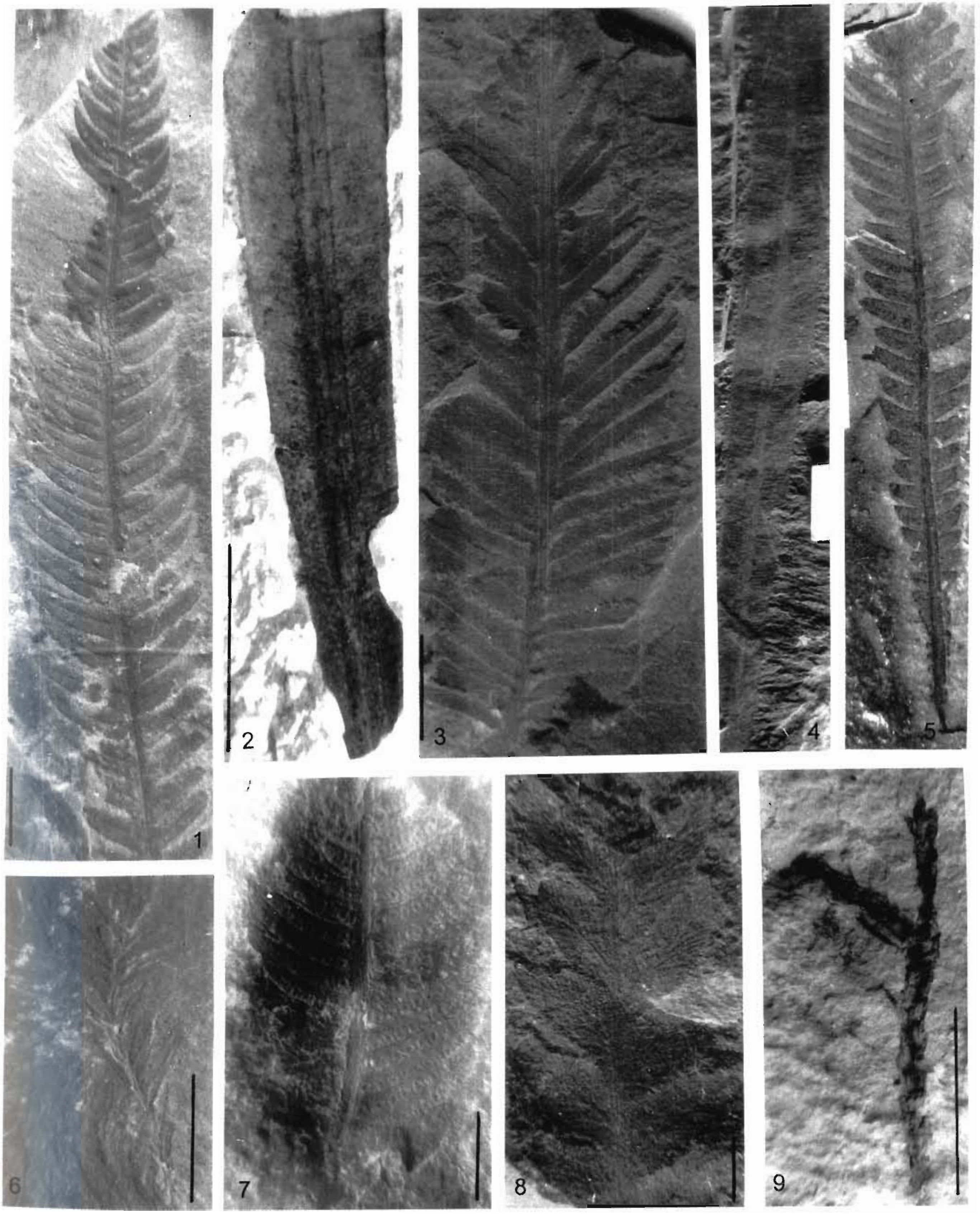
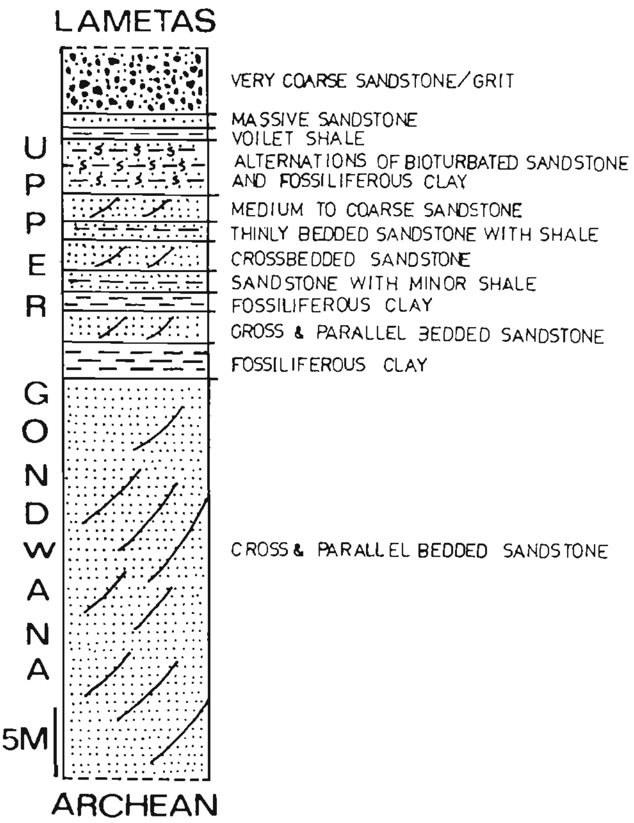


PLATE 1



Text-figure 2—Detailed sedimentary log of Gondwana succession of Bairam area.

palaeoclimate has also been made.

All the samples are kept in the museum of the P.G. Department of Geology, Amravati University, Amravati. The Bairam-Belkher area is approachable from Achalpur (Ellichpur in old records) via Nagpur at about 13 km on Betul road.

SYSTEMATICS

FILICALES

Genus—MATONIDIUM Schenk

MATONIDIUM INDICUM Sahni 1936

Pl. 1, figs 1, 5, 7

Description — Pinnately compound leaf, size 12-14 cm long and 2-3 cm wide. Pinna tends to become shorter at apex and wider towards base. Rachis 1.0-1.5 mm wide. Pinnules about a cm long, 2-3 mm broad at base, slightly falcate, arranged subopposítely, attached by whole base to the rachis with an angle of about 50^{0}-60^{0}. Margin entire. Apex bluntly pointed, midrib distinct persisting upto apex. Veins arising from base nearly at right angle, once forked.

Remarks—This is a frequently recorded taxa in the field, however, our description is based on three part-counterpart and two almost complete specimens. The present specimen resembles *M. indicum* Sahni (1936; pl. 21, fig. 5; pl. 22 figs 1- 4) from Himmatnagar and also *M. indicum* Kumaran *et al.* (1979; pl. 1, fig. 7) from Tarnetar in shape and venation pattern except for the slight variation in the size.

UNCLASSIFIED FERN

Genus—SPHENOPTERIS Sternberg

SPHENOPTERIS sp.

Pl. 2, fig. 4

Description—Single specimen representing frond measuring 7 cm in length and 4.5 cm in width. Pinna rachis stout, 1.5 mm wide, pinnae arranged sub-oppositely with an angle of 45^{0}-50^{0}. Lamina of pinnae is lobed and contracted towards apex. Pinnules oval, alternately disposed, decurrent with rounded apex, margin entire, measuring 5–6 mm, wide at base. Veins arising from the base and diverging to its apex, forked atleast once.

Remarks—The present specimen is identical to *Sphenopteris hislopi* (Surange, 1964, fig. 73) from Rajmahal Hills but differ in the size of the pinna and angle of the attachment to the rachis. Difference in the venation pattern and shape of the pinnules has also been noticed while comparing with *S. rajmahalensis* (Surange, 1964, fig. 74). Our specimen also resembles *Sphenopteris* sp. (Bose *et al.*, 1979, fig. 2B) but differs in having pinnules with finer veins.

Genus—CLADOPHLEBIS Brongniart

CLADOPHLEBIS INDICA (Oldham & Morris) Sahni & Rao 1933

Pl. 1, fig. 8

Description—Two incomplete specimens with counterparts showing pinnately compound leaf having length 8-9 cm and width 1.5-2 cm, rachis 1 mm broad. Pinnules 1.0-1.2 cm long, about 0.3-0.4 cm broad near base, alternately attached at an angle of 40^{0}-50^{0}. Apex subacute, margin entire, midrib

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PLATE 2 ⟶

(Scale - one centimeter.)

1. *Pagiophyllum* sp. showing arrangement of leaf.
2. *Elatocladus tenerrima* (Feistmantel) Sahni 1928 showing arrangement of leaves and midrib.
3. *Ptilophyllum cutchense* Morris 1840 showing distinct midrib and arrangement.
4. *Sphenopteris* sp. showing venation pattern.
5. *Cladophlebis indicum* (Oldham & Morris) Sahni & Rao 1933 showing details of pinnules (scale 0.5mm).


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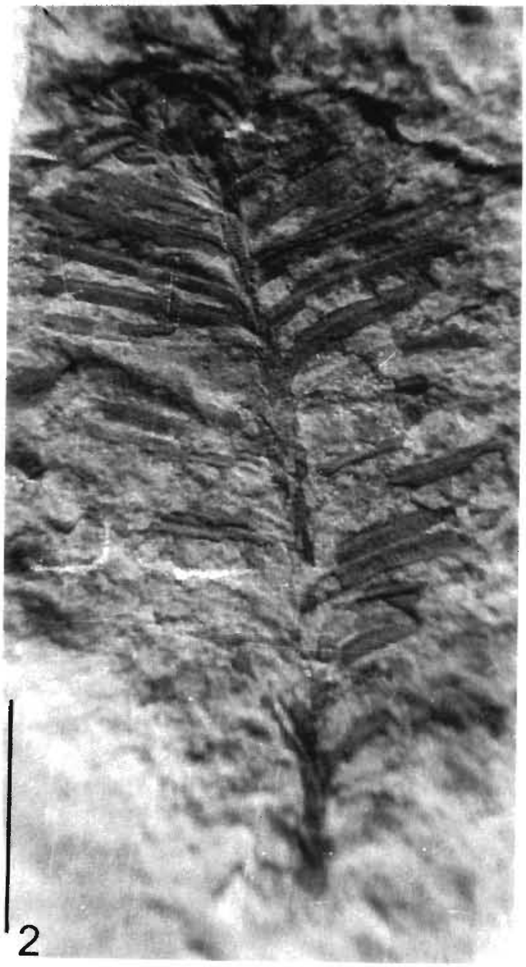
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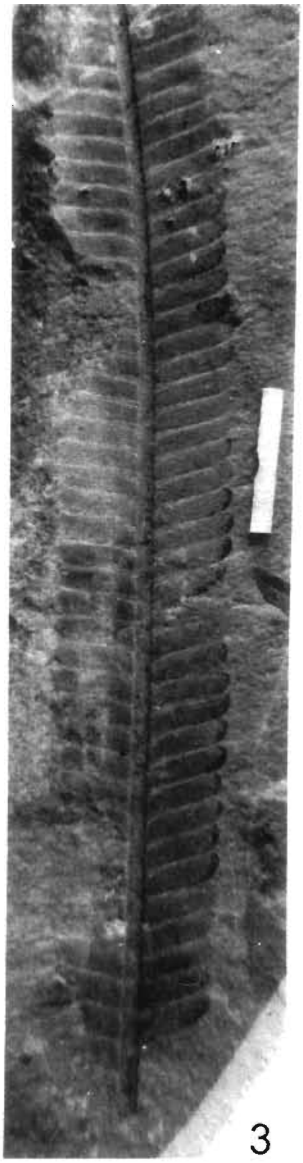
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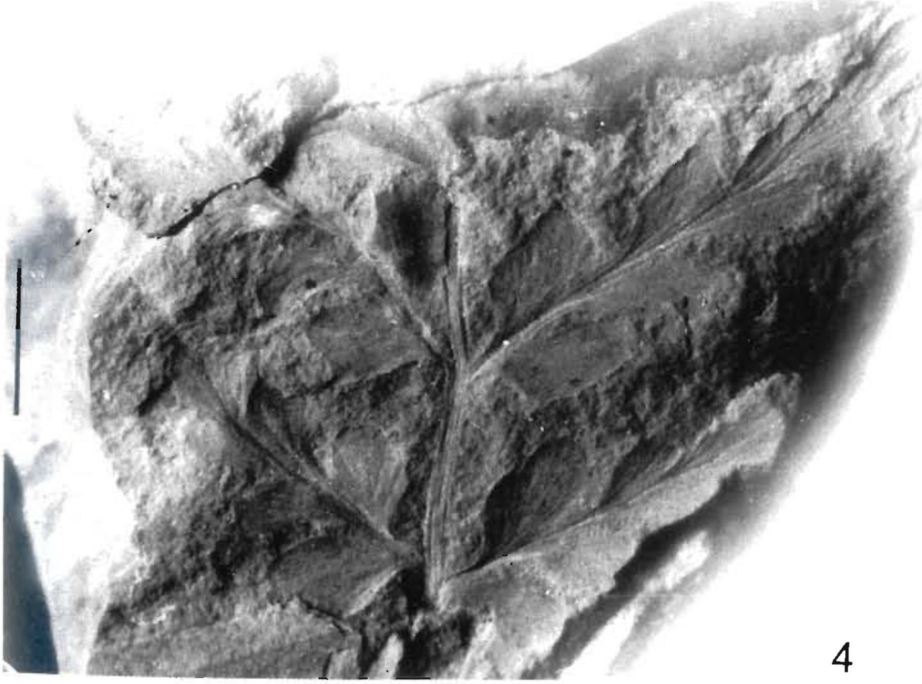
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5

PLATE 2

prominent, persisting up to the apex. Veins arising at an angle of 30°-35° from the midrib, mostly forked, reaching up to margin.

Remarks—Our specimen resembles *Cladophlebis indica* (Oldham & Morris) Sahni and Rao 1933 described by Banerji (1990; pl. 1, fig. 4) from Dubrajpur Formation.

BENNETTITALES

Genus—**PTILOPHYLLUM** Morris

PTILOPHYLLUM CUTCHENSE Morris 1840

Pl. 2, fig. 3; Pl. 3, fig. 3

Description—About a dozen specimens are present in the collection. Leaves pinnately compound, size varies from 14-16 cm in length and 2.0-3.0 cm in width, rachis 0.1 cm wide. Pinnules 0.6-0.7 cm long, 1.5-2.0 mm broad, closely arranged, opposite to suboppositely attached on the upper surface of the rachis by whole base, apex obtuse, acroscopic margin curved rounded, basiscopic margin almost straight. Veins parallel, nearly 4-6 veins arises from the base, simple or forked.

Remarks—The present specimen resembles *P. cutchense* of Banerji (1990; pl. 1, fig. 6) reported from the Lower Cretaceous of Dubrajpur except the smaller size of the pinnules; *P. cutchense* of Bose *et al.* (1982; pl. 1, fig. 6) from the Gollapalle Formation. It is one of the frequently occurring taxa in the study area.

PTILOPHYLLUM ACUTIFOLIUM Morris 1840

Pl. 3, fig. 2

Description—Four incomplete specimens of pinnate leaves are present. Size varies from 5-6 cm in length and 2-3 cm in width. Pinnules 1.5-2.0 cm long, 2 mm broad at the base, closely set, suboppositely attached by whole base on the upper surface of 1 mm wide rachis with an angle of 45°-50°. Apex acute, acroscopic margin curved downward, basiscopic margin straight. Venation parallel, 7-8 veins arising from base, simple or forked.

Remarks—Frequency of the species is comparatively less than *P. cutchense* Morris in the present assemblage. It shows resemblance with *P. acutifolium* reported by Pandya and Sukh-Dev (1990; pl. 1, fig. 8) from Lower Cretaceous of Gollapalle Formation and the specimen of *P. acutifolium* recorded by Banerji (1990; pl. 1, fig. 8) from Lower Cretaceous of Dubrajpur.

CYCADALES

Genus—**TAENIOPTERIS** Brongniart

TAENIOPTERIS SPATULATA McCelland 1850

Pl. 1, figs 2, 4

Description—Six incomplete specimens showing simple, linear lanceolate leaves, size varies from 13.5-14.0 cm in length and 1.4 cm in width. The width of lamina increases gradually from the base and tapers towards apex. Apex obtuse, margin entire, midrib prominent, 2-3 mm wide distinct up to apex. Veins simple, parallel or forked arising from the midrib with an angle of 84°-87°. Vein concentration 22-25 per cm.

Remarks—The specimen matches with *T. spatulata* of Pandya and Sukh-Dev (1990; pl. 1, fig. 4) from Lower Cretaceous of Gollapalle Formation.

TAENIOPTERIS sp. cf. **T. VITTATA** Brongniart

Pl. 3, fig. 1

Description—Leaf simple, 3.5 cm in length and 2.5-3 cm in width. Lamina thin, margin appears to be entire, midrib 2 mm thick. Lateral veins originating from midrib making an angle of 85°-88°, simple or forked once. Concentration of veins 30-35 per cm.

Remarks—Both the recovered specimens show only middle portion of the leaf. Margin of lamina is poorly preserved. Venation distinct at places. However, on the basis of only a few observable characters i. e., parallel lateral venation and shape of the lamina, it is comparable with *T. vittata* of Seward (1991; fig. 332). The specimen is also comparable with the photograph of *T. vittata* of Pascoe (1959; Jabalpur flora) in respect of lamina width and parallel venation.

CONIFERALES

Genus—**PAGIOPHYLLUM** Heer

PAGIOPHYLLUM sp.

Pl. 2, fig. 1

Description—Leafy twigs, 3 cm long and 1 cm wide, irregularly branched, branches 7-9 mm long and 2-2.5 mm wide, emerging at an angle of 40°-45°. Leaves 2 mm long and about 1 mm wide, spirally arranged, closely set, spreading with different angles, apex acute, margin entire.

Remarks—There are three specimens with one counter part. It is closer to *P. peregrinum* (L & H) Schenk, Sahni (1928; pl. III, fig. 43), *P. sherensis* Maheshwari *et al.*, (1976; pl. 2, fig. 8), *P. marwarensis*, Bose *et al.*, (1982; pl. 1, figs 9, 12) in their external characters, reported from Jurassic and Lower Cretaceous bed of India. However, they differ in size and angle of branching. They also resembles *P. gollapallensis* of Pandya and Sukh-Dev (1990; pl. 1, fig. 7; pl. 2, fig. 15) except the arrangement of leaves and their size. Due to lack of epidermal characters, the exact comparison is not possible.

BRACHYPHYLLUM Brongniart

BRACHYPHYLLUM sp.

Pl. 1, fig. 9

Description— Solitary leafy twig, branched, 4 cm in length and 3 cm in width, branching at an angle of 50°-56°. Rhomboidal leaves, closely arranged, margin appears to be entire, apex acute.

Remarks—The specimen is closer to *B. rhombicum* (Feist.) Sahni (1928; pl. 2, fig. 23) from South Rewa, Madhya Pradesh but differs in size and arrangement of the leaves. It also shows similarity with *Brachyphyllum* sp. described by Bose *et al.*, (1979; pl. 1, fig. 20) but exact comparison is not possible due to poor preservation.

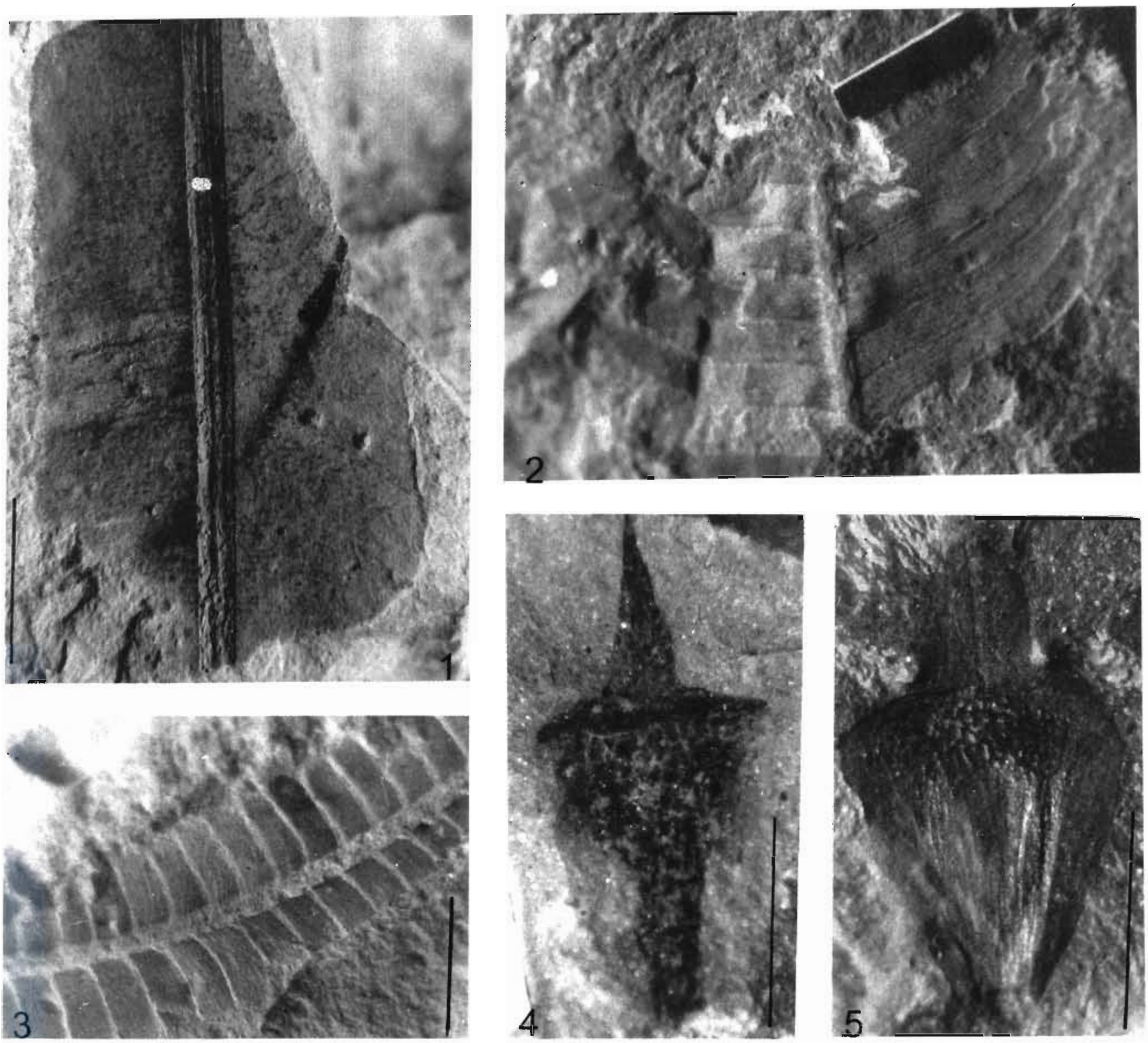

PLATE 3

(Scale - one centimeter.)

1. *Taeniopteris* sp. cf. *T. vittata* Brongniart showing distinct midrib and venation pattern.
2. *Ptilophyllum acutifolium* Morris 1840 showing arrangement of leaf and venation pattern.
3. *Ptilophyllum cutchense* Morris 1840 showing distinct rachis and venation pattern (scale - 0.5 cm).
4. *Araucarites* scale leaf.
5. *Araucarites cutchense* Feistmantel 1876, scale leaf showing site of ovule attachment.

Genus—ARAUCARITES Presl. 1838

ARAUCARITES CUTCHENSE Feistmantel 1876

Pl. 3, figs 4 & 5

Description—Detached seed scale, 2.4 cm long, 1.4 cm broad, truncated base 4 mm wide, rounded to subrounded tip, seed ovate, surface of the scale showing fine longitudinal striations, middle part of scale showing shallow depression of seed measuring 10 x 5 mm.

Remarks—The described specimen closely matches with *A. cutchense* from Jabalpur (Sahni, 1928; pl. V, fig. 67) and the specimen reported from the Lower Cretaceous of Tarnetar, Gujarat (Kumaran *et al.,* 1979, pl. 1, figs 11 & 12).

Genus—ELATOCLADUS Halle

ELATOCLADUS TENERRIMA (Feistmantel) Sahni 1928

Pl. 2, fig. 2

Description—Single branched leafy twig, axis about 1 mm thick. Linear leaves 0.8-1.0 cm long, approximately 1 mm broad, uniformly from base to apex. Leaves spirally, biserially arranged in one plane diverging at wide angle from axis, measuring 70^0-80^0, attached by entire width of decurrent leaf base. Apex obtuse, margin entire, midrib obscure, visible at one or two places, persisting up to apex.

Remarks— Presence of linear and usually straight leaves having obtuse apex and strongly decurrent base giving off at wide angle shows that the present specimen belongs to *E. tenerrimus* (Feistmantel) which was described by Sahni (1928; pl. 1, figs 10, 11) but their cuticular features are not known.

ELATOCLADUS sp. cf E. KINGIANUS

Pl. 1, fig. 6

Description—Solitary slender leafy twig with axis 1 mm wide, leaves narrow, linear-lanceolate, 5-6 mm long, 0.5 mm broad, spirally arranged, spreading out in two rows irregularly at different angles in one plane. Base contracted, apex acute, margin entire, mid-vein faintly marked.

Remarks—Present specimen shows morphological resemblance with *E. heterophylla* Halle (Seward, 1919; vol. IV, fig. 801) from Grahamland and *E. sehoraensis* of Maheshwari and Kumaran (1976; pl. 1, fig. 4) from the Jabalpur Group. It is more akin to *E. kingianus* of Bose *et al.,* (1982; pl. 1, fig. 10) in size, shape and apex of the leaves.

ELATOCLADUS sp. A

Pl. 1, fig. 3

Description—Leafy twig, 5 cm long and 2 cm broad, axis of the twig 1.5 mm wide. Leaves linear-lanceolate, 14 mm in length and 1-1.5 mm in width, arranged in close spiral, laterally spread in one plane, attached at an angle of 50^0-60^0. Leaf base contacted, decurrent. Apex obtuse pointed, margin entire, midrib distinct from base to apex.

Remarks—Present specimen matches with *E. conferta* (O & M) Sahni (1928) in the shape of the leaves and angle of the attachment. It also shows resemblance with *E. tenerrimus* Sahni 1928 and *E. pseudotenerrima* described by Maheshwari and Kumaran (1976) but differs in well spread out leaves and apex.

DISCUSSION AND CONCLUSIONS

A total of thirteen taxa viz., *Matonidium indicum, Sphenopteris* sp., *Cladophlebis indica, Ptilophyllum cutchense, P. acutifolium, Taeniopteris spatulata, T. vittata, Pagiophyllum* sp. *Brachyphyllum* sp. *Araucarites cutchense, Elatocladus tenerrima, Elatocladus* sp. cf. *E. kingianus* and *Elatocladus* sp. A have been described for the first time from a new locality of Bairam-Belkher area of district Amravati, Maharashtra and district Betul, Madhya Pradesh. The plant fossils are preserved in the form of leaf impressions in the clay horizons. These clays are in the form of lenticles or pockets, interbedded with medium to coarse grained sandstones.

The assemblage is dominated by Bennettitales followed by Filicales, Cycadales, Coniferales and unclassified ferns. *Ptilophyllum* and *Matonidium* are the two most dominant genera in the assemblage.

Regarding the age and equivalence, the sequence was a matter of debate. Earlier workers have correlated it with Triassic on the basis of non-palaeontological criteria (Pascoe, 1959; Adyalkar, 1975; Bhusari, 1979) while Kumar (1990) considered it Neocomian-Aptian on the basis of the palynological studies. Recently, Srivastava *et. al.,* (1995) have assigned it Lower Cretaceous age on the basis of megafloral remains.

The assemblage has been compared with the known assemblage from the Upper Gondwana succession of Peninsular India ranging in age from Upper Jurassic to Lower Cretaceous (Table 2). Most of the taxa presently reported are individually less significant for assigning the age because of their wide records from Upper Jurassic to Lower Cretaceous horizons. However, presence of Conifers viz., *Pagiophyllum, Brachyphyllum, Elatocladus* and *Araucarites* show affinity with Lower Cretaceous age. The dominance of *Ptilophyllum* is also comparable with Upper Jurassic to Lower Cretaceous assemblages of Dubrajpur and Jabalpur Formations. *Matonidium* has been found to be one of the most commonly recorded taxa and is comparable with the Lower Cretaceous assemblage of Himmatnagar showing dominance of the same (Sahni, 1936). Considering the overall assemblage, i. e., diversity of Coniferales, dominance of Bennettitales and Filicales, it has been assigned Lower Cretaceous age which also supports the Neocomian-Aptian age as proposed by Kumar (1990) on the basis of the pollen and spores.

Table 2—Comparison of the present plant fossil assemblage with other localities of Peninsular India ranging in age from Late Jurassic to Early Cretaceous.

Taxa/Locality	Present assemblage	Dubrajpur (Late Jura. to Early Cret.) (Banerji 1990)	Gardeshwar (Early Cret.) (Bose *et al.*, 1979)	Gangapur (Early Cret.) (Bose *et al.*, 1982)	Gollapalle (Early Cret.) (Pandya & Sukh Dev 1990)	Himmatnagar (Cret.) (Banerji *et al.*, 1979)	Jabalpur (Late Jura. to Early Cret.) (Pascoe 1959, 1991; Bose *et al.*, 1966)	Tarnetar (Early Cret.) (Kumaran *et al.*, 1979)	Umia (EarlyCret.) (Pascoe 1959; Shah *et al.*, 1991)
Matonidium indicum	Abundant	-	-	-	-	Abundant	-	+	+
Sphenopteris sp.	+	-	+	-	-	+	Common	-	-
Cladophlebis indica	+	+	+	+	+	Common	Common	Common	+
Ptilophyllum cutchense	Abundant	+(*)	-	+	+	-	+	-	+
P. acutifolium	+	+(*)	-	+	+	-	Common	-	+
Taeniopteris spatulata	Common	+(**)	-	+	+	-	Common	-	+
T. vittata	+	+(**)	-	-	-	-	+	-	+
Pagiophyllum sp.	+	+	Abundant	+	+	+	+	-	+
Brachphyllum sp.	+	-	Abundant	-	+	-	+	-	+
Araucarites cutchense	+	-	+	+	+	+	+	+	+
Elatocladus tenerrimus	+	-	+	+(**)	+	-	+	-	+
Elatocladus sp. cf. *E. kingianus*	+	-	-	+(**)	-	-	+	-	-
Elatocladus sp. A	+	-	+	+(**)	-	-	+	-	-

+ Present; - Absent; * Sp. level not specified; ** Information up to genus level.

It has been summarised that the climate was warm and humid as interpreted on the basis of the luxuriant growth of Bennettitales and Cycadales (Ramanujam, 1979). The dominance of the cycadophytes also suggests the prevalence of tropical to subtropical climate during the sedimentation as has been proposed for the Dubrajpur Formation of Lower Cretaceous age by Banerji (1990). The palynological studies of Kumar (1990) also supports the existence of the warm and humid climate. The present palaeoclimatological interpretation also coincide with the generalised interpretation of Surange (1964) of warm and humid climate during Lower Cretaceous to Eocene age.

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Further contribution to the Siwalik flora from the Koilabas area, western Nepal

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ABSTRACT

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The present study on fossil plants comprising well preserved leaf and fruit impressions from the Siwalik sediments exposed near Koilabas in western Nepal is the first detailed and systematic work. The floral assemblage recovered from these sediments is impoverished both in quality and quantity as constituted by 25 species belonging to 22 genera and 15 dicotyledonous families of angiosperms. This assemblage adds significant data to the Siwalik Palaeobotany. On the basis of present assemblage as well as already known data from the area, the palaeoclimate, palaeoecology and phytogeography of the area during Mio-Pliocene in the Himalayan foot hills have been deduced. The significance of the physiognomic characters of the fossil leaves in relation to climate has also been discussed.

Key-words—Leaf & fruit impressions, Angiosperm, Morphotaxonomy, Siwalik (Churia) Formation, Palaeoclimate, Phytogeography, Koilabas, Nepal.

सारांश

पश्चिमी नेपाल के कोयलाबास क्षेत्र का शिवालिक वनस्पतिजात में योगदान

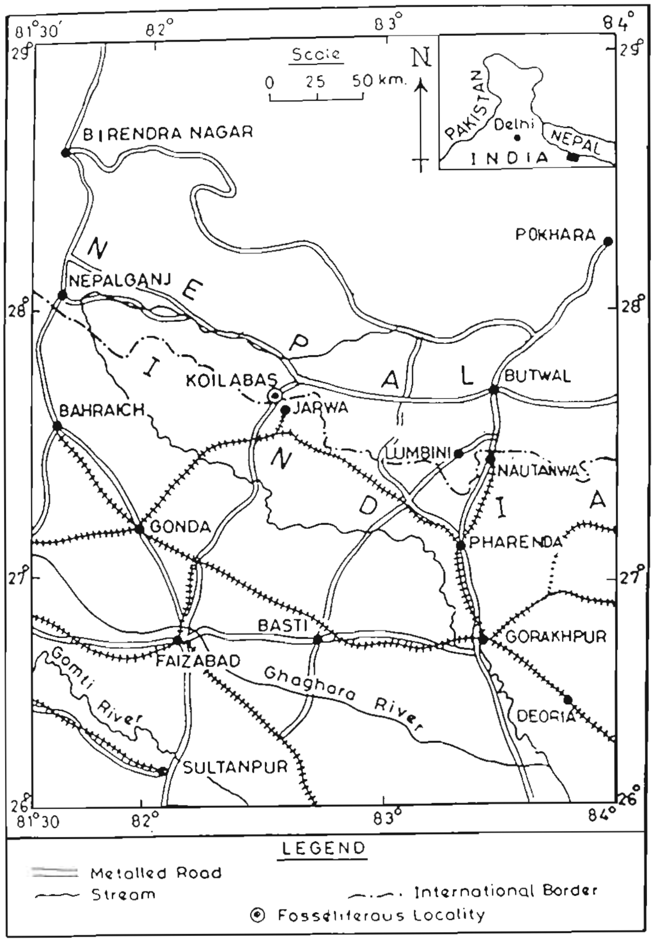
महेश प्रसाद, स्व. जसवंत सिंह अन्तल, पाटेश्वरी प्रसाद त्रिपाठी एवं विनय कुमार पाण्डेय

पश्चिमी नेपाल के कोयलावास क्षेत्र के निकट अनावरित शिवालिक अवसादों से प्राप्त पादपाश्मों, जिनके अन्तर्गत पूर्ण संरक्षित पत्तियाँ एवं फल मुद्राश्म आते हैं, का वर्तमान शोधपत्र के माध्यम से प्रथम बार विस्तृत एवं सुव्यवस्थित अध्ययन किया गया है। इन अवसादों से प्राप्त वनस्पतिजात समुच्चय गुणवत्ता एवं मात्रा दोनों ही के आधार पर अत्यल्प हैं, जो आवृतबीजियों की 25 प्रजातियों, जिसमें 22 वंश तथा 15 कुल हैं, से सम्बन्ध रखता है। यह समुच्चय शिवालिक क्षेत्र के पुरावनस्पति विज्ञान में महत्वपूर्ण आंकड़े जोड़ता है। वर्तमान समुच्चय तथा क्षेत्र के पूर्व ज्ञात आंकड़ों के आधार पर हिमालयी गिरिपादों में मायो-प्लायोसीन युगों के दौरान क्षेत्र की पुराजलवायु, पुरापर्यावरण तथा पादप भूगोल के अनेक निष्कर्ष निकाले गए हैं। पादपाश्म पत्रों के जलवायु सम्बन्धी रूपाकृतिक गुणों के महत्व की चर्चा भी इस शोध पत्र में की गई है।

INTRODUCTION

THE Kingdom of Nepal is a land-locked country physiographically sandwitched between China in the north and India in the south. Nearly two-third of the country, in the northern part, is hilly and one third is Terai plain in south which constitute the northern edge of Indo-Gangetic plain. In fact, Nepal is a middle strip of Himalaya consisting of high hills and plain areas which can physically be divided into following six zones namely, Terai plain, Midlands, Churia Hills, Higher Himalayan zone, Mahabharat Hill and Inner Himalayan Valley.

The fossiliferous locality, Koilabas (27°42' : 82°20') lies



Text figure 1— Showing location of Koilabas at Indo - Nepal Border, western Nepal.

on the Indo-Nepal border in western Nepal. It is bounded by Churia Hills towards north and Terai plain towards south. It is easily approachable by road from both Nepal and India (Text-figure 1).

Churia Hills rise abruptly to about 1300 m above the sea level immediately to the north of the town Koilabas. The hills are merged with Mahabharat range at many places except in area where valleys are developed like Rapti Valley, Hetaura Valley, Surkhet Valley and Dang Valley which lie just north of the Koilabas.

The term 'Siwalik Hills' was introduced by Cautley in 1832 to designate the sub-Himalayan hill ranges occurring between Ganga and Yamuna rivers, which yielded the memorable vertebrate fossils around Haridwar. Falconer (1835) also adopted this term to designate the nearly continuous Series of Tertiary Formation stretching from Punjab down to Irrawadi. Outcrop patterns more or less bounded by a major thrust, the Main Boundary Fault (MBF) in the north and the Indo-Gangetic alluvium on the south and generally 10-12 km wide with a steep scarp towards south and a gentle slope on the north.

GENERAL GEOLOGY

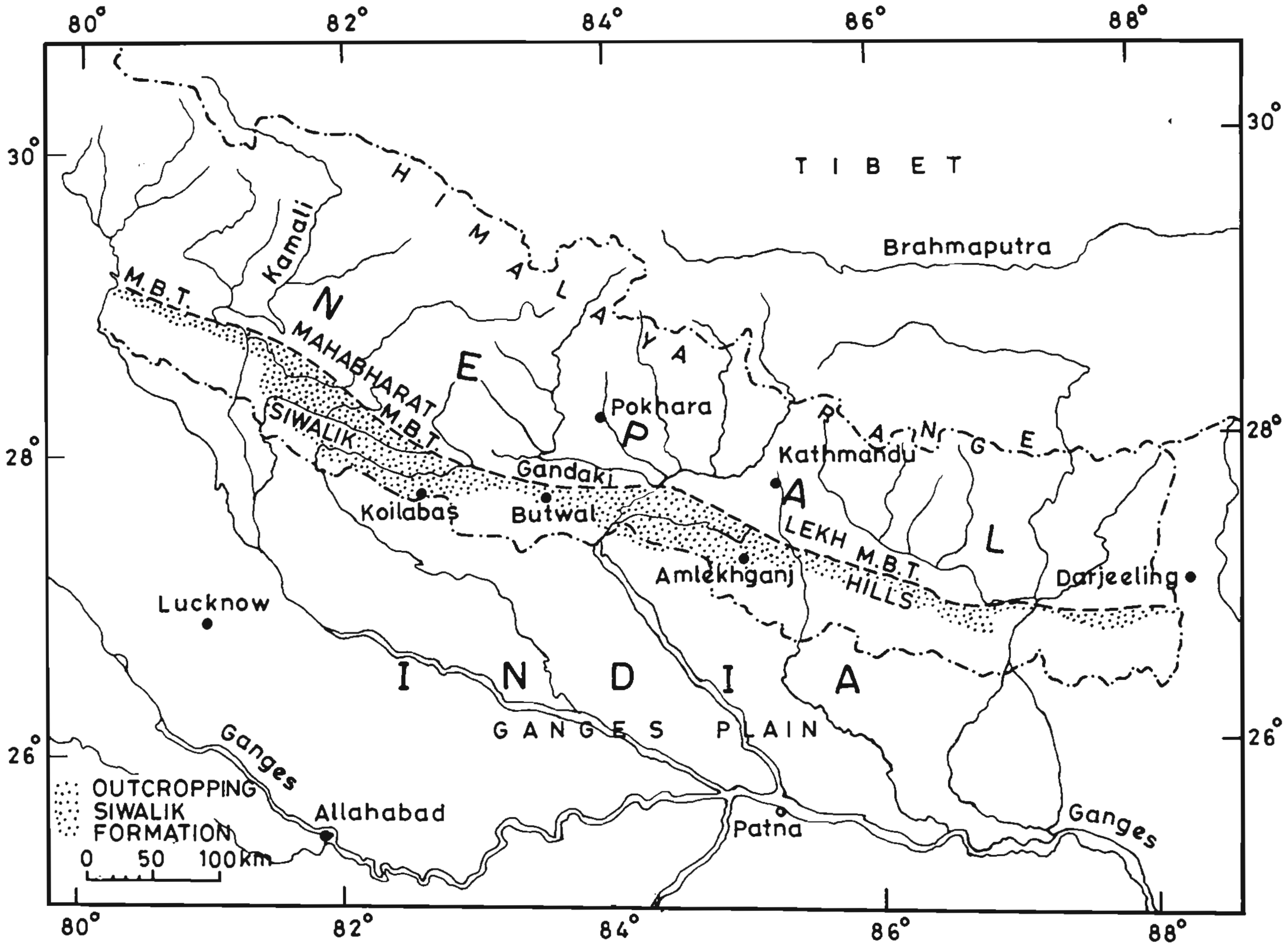
The Siwaliks represent clastic sediments of fresh water molasse which accumulated in a long narrow foredeep formed to the south of the rising Himalaya in the third episode of Himalayan uplift during Middle Miocene. These sediments accumulated under four different environments like, lacustrine, channel and flood plains, outwash plain and piedmont.

The Siwalik Formation ranges in age from Middle Miocene to Middle Pleistocene and is underlain by the Lower Tertiary-Upper Muree/Dharmsala sediments. On the basis of lithology and palaeontological data it has been subdivided into Lower, Middle and Upper Siwaliks. Lithologically, the Siwaliks represent a great thickness of detrital rocks, such as coarsely bedded sandstones, clays and conglomerates measuring between 5000-5500 m in thickness.

The area of present study falls in Dang section of western Nepal Himalaya. In Nepal Himalaya the Siwalik Formation is often called Churia Group which lies south of the Main Boundary Thrust (Text-figure 2). This group pinches in Narayangarh and swollens in Nawalpur due to development of valley and again it is thin in Butwal and thickens maximum to Dang area where two valleys—Dang and Rapti valleys developed. The detailed lithology and stratigraphy of the Siwalik (Churia) Group of Nepal have been given by Auden (1935), Lehner (1943), Hagen (1959), Bordet (1961), Gleinnie and Ziegler (1964), Ohta and Akiba (1973), Sharma (1977, 1980), Kumar and Gupta (1981), Chaudhuri (1983), West (1984), Tokuoka *et al.* (1986, 1988), Corvinus (1990), Appel *et al.* (1991) and Quade *et al.* (1995).

The Churia Group has often been classified into two formations : (i) Lower Churia Formation (sandstone facies), and (ii) Upper Churia Formation (conglomerate facies) by Hagen (1959), Bordet (1961) and Gleinnie and Ziegler (1964). However, a three fold lithostratigraphical classification of the formation in the western Nepal Himalaya has been suggested by Chaudhuri (1983). The Lower Churia Formation with an average thickness of about 1800 m is composed of fine grained green chlorite, biotite, muscovite, calcareous well bedded indurated sandstones and siltstones. The sandstone is interbedded with green nodular withering clay and siltstone and yellow micaceous clay. Sometimes friable white to yellow medium grained arkosic pebbly sandstones interbedded with green to brown fine grained sandstones are seen in the upper part of the formation. The gross composition of sandstone is 80% quartz, 10% muscovite, 5% biotite and black tourmaline and opaque minerals 5%. The rocks generally show simple current bedding.

The Upper Churia Formation consists mainly of boulder pebble bed and loose micaceous sandstone exposed in south of Lower Formation in Dang area, Trijuga area, and east of Dharan. They are graded and cyclic in nature. The lower part



Text figure 2—Showing Siwalik Formation in and around Koilabas area. (After Glennie & Ziegler, 1964).

is composed of rounded boulders consisting mainly of quartzite cemented with clay.

The fossil locality Koilabas is situated in the Dang section of the Churia Hills in western Nepal. In this area, the Lower Churia Formation is observed from Koilabas to Darwaja containing fine grained sandstone beds with variegated clay and some pebbles. From Darwaja to Masot Khola the rocks represent the Upper Churia Formation. In Garudbir pass the Lower Formation is found thrusted above the Upper Formation (Sharma, 1977). According to Chaudhuri's three fold division of Churia (Siwalik) Hills, this area from Koilabas to Darwaja falls in Lower Churia (Siwalik) Formation and beyond Darwaja to Chor Khola onward the rocks are supposed to be belonging to Middle Churia (Siwalik) Formation which is predominantly arenaceous in nature.

Systematic study on plant megafossils especially leaf impressions from Koilabas area has been carried out by Tripathi & Tiwari (1983), Prasad & Prakash (1984), Prasad (1990a, b, 1994e). A number of taxa (about 55 taxa) have been identified belonging to several dicotyledonous families. With a view to generate more palaeobotanical data for precise reconstruction of Siwalik floristics and interpreting the palaeoenvironment and phytogeography of the area, further investigation of leaf and a fruit impressions collected from Koilabas, western Nepal have been undertaken. The morphotaxonomic study reveals the presence of some more new taxa which have been discussed and described in the present communication.

MATERIAL AND METHOD

The fossil locality Koilabas lies at Indo-Nepal border in western Nepal (Text-figure 1). The sections belonging to the Lower Siwalik beds containing excellently preserved leaf-impressions are well exposed on both the sides of Koilabas *Nala* (also known Dang *Nala*). The leaf-impressions are found both on grey as well as brown calcareous shales but are more common and well preserved in the grey shale. A rich collection of well preserved leaf-impressions was made from Dang *Nala* before Darwaja. More than 50 specimens of leaf-impressions were collected and have been described in the present communication.

The leaf-impressions are devoid of cuticles. They were studied morphologically with the help of either hand lens or low power microscope under reflected light. In order to identify the leaf-impressions, a number of herbarium sheets of extant taxa were examined at the herbaria of National Botanical Research Institute, Lucknow, Forest Research Institute, Dehradun and Central National Herbarium, Sibpur, Howrah, West Bengal. The leaf-impressions have been described following the terminology given by Hickey (1973) and Dilcher (1974).

The photographs of leaf-impressions showing various morphological characters were taken on cut-film on Pan-phot Camera. In almost all the cases the leaf-impressions have been found closely resembling the modern leaves. The photographs of the comparable modern leaves showing similar features were also taken at the same magnification and have been pasted along with those of the fossil leaves in plates to show close similarity. All the figured specimens have been deposited at the Post-Graduate Department of Botany, M.L.K. College, Balrampur, Uttar Pradesh.

SYSTEMATICS

DICOTYLEDONS

Family—ANONACEAE

Genus—MILIUSA Leschen. Ex A.Dc.

MILIUSA SIWALICA sp. nov.

(Pl. 1, fig. 1; Pl. 2, fig. 1)

Material—The present species is based on a well preserved incomplete specimen with its counter part which is devoid of cuticle.

Description—Leaf simple, symmetrical, elliptic, preserved size 9.5 x 4.5 cm; apex broken; base indistinct; margin entire; texture coriaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, slightly curved, thicker at the basal region; secondary veins (2^0) 3 pairs visible, 0.8 to 3.5 cm apart, curved up and run upward to a greater length and joined to their superadjacent secondaries, angle of divergence about (40^0) narrow acute, alternate, seemingly unbranched; tertiary veins (3^0) fine, fairly preserved, angle of origin AO-RR, percurrent, seemingly unbranched, oblique to right angle in relation to midvein, predominantly alternate, close to distant. Further details could not be seen.

Holotype—Specimen no. K 20.

Locality—Koilabas *Nala* section near Koilabas Village, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From the Siwalik Formation.

Affinities—The most characteristic features of the present fossil leaf such as symmetrical elliptic shape, entire margin, eucamptodromous, venation, the nature of secondary veins which arise narrow acutely and run upward to a greater length and percurrent, somewhat distantly placed tertiary veins indicate that the present fossil leaf shows close resemblance with the modern leaves of the genus *Miliusa* Leschen. ex A.Dc. of the family Anonaceae. In order to find out the specific affinity, the herbarium sheets of all the available species of this genus were critically examined and concluded that the leaves of *Miliusa thoretii* Finet & Gagnep. (C.N. Herbarium sheet no. 14317) show closest affinity with the fossil leaf in shape, size and venation pattern (Pl. 1, fig. 2; Pl. 2, fig. 2).

Fossil records and comparison—So far, there is no record of any fossil leaf resembling the genus *Miliusa* from the Tertiary sediments of India and Nepal. The present fossil leaf forms its first record from the Siwalik sediments of Koilabas, Nepal and is being described herewith as *Miliusa siwalica* sp. nov., the specific epithet indicates its occurrence in the Siwalik sediments.

The genus *Miliusa* Leschen ex A.Dc. consists of about 40 species distributed mostly in Indo-Malayan region and Australia. Out of which, 7 species are Indian. *Miliusa thoretii* Finet & Gagnep with which fossil shows close resemblance grows in India mainly in Sikkim, Khasi Hills, Travancore, Mysore, Kanara and Konkan (Willis, 1973; Gamble, 1972).

Genus—ANONA Linn.

ANONA KOILABASENSIS sp. nov.

(Pl. 1, figs 3-5)

PLATE 1

→

(All figures are of natural size unless otherwise mentioned)

1. *Miliusa siwalica* sp. nov. - Fossil leaf showing shape, size and venation pattern.
2. *Miliusa thoretii* Finet & Gagnep - Modern leaf showing similar, shape, size and venation pattern.
3. *Anona koilabasensis* sp. nov. - Fossil leaf showing shape, size and venation pattern.
4. *Anona koilabasensis* sp. nov. - Another fossil leaf showing variation in shape, size and nature of base.
5. *Anona koilabasensis* sp. nov. - A part of fossil leaf magnified to show details of venation. x 1.75.

6, 7. *Securidaca miocenica* Prasad *et al.* - Fossil leaves showing shape, size and nature of base, apex and venation pattern.

8. *Securidaca inappendiculata* Hask. - Modern leaf showing similar shape, size and nature of base and apex and venation pattern.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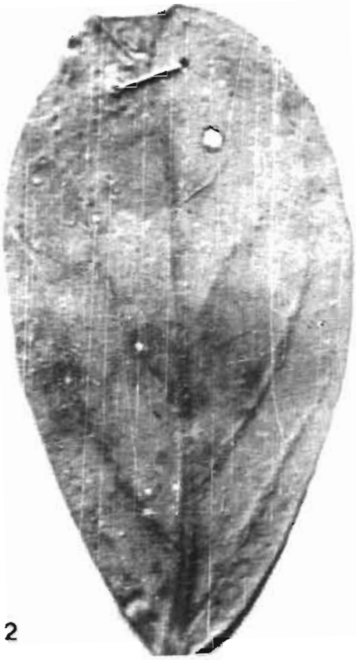
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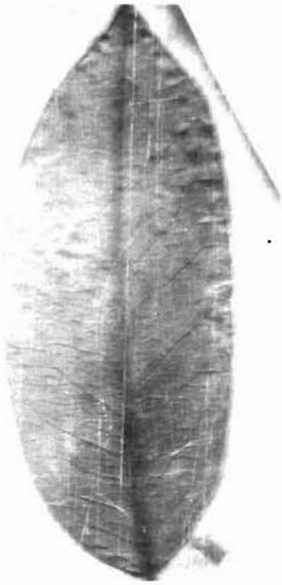
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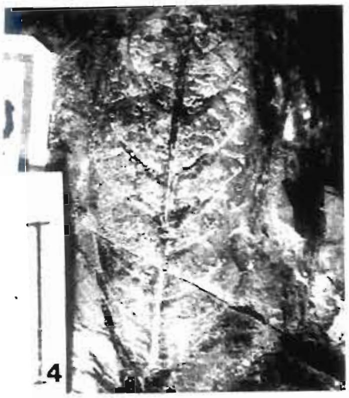
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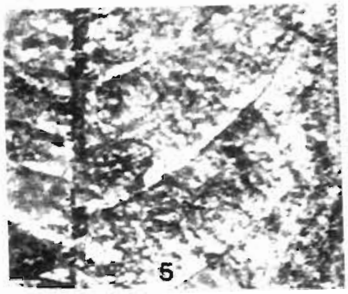
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PLATE 1

Material—It consists of 5 specimens of different sizes. They are well preserved and devoid of cuticles.

Description—Leaves simple, symmetrical, narrow elliptic, preserved size 5.0 x 2.2 cm and 10.5 x 4.0 cm; apex slightly broken; base obtuse, normal; margin entire; texture chartaceous; petiole indistinct; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, curved in apical portion, uniform in thickness; secondary veins (2^0) about 14 pairs visible, 0.8 to 2.0 cm apart, curved up and joined to their superadjacent secondaries, angle of divergence mainly right angle to acute (85^0 to 55^0) usually alternate sometimes opposite, rarely branched; intersecondary veins present, simple, abundant; tertiary veins (3^0) fine, abundant, angle of origin usually RR, percurrent, straight to sinuous, sometimes, branched, oblique in relation to midvein predominantly, alternate, close to nearly distant.

Holotype—Specimen no. K 25.

Locality—Koilabas *Nala* section near Koilabas Village, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From the type locality of Koilabas.

Paratype—Specimen nos. K 22, 23, 26, 27.

Affinities—The diagnostic features of the present fossil leaves are symmetrical narrow elliptic shape, obtuse base, entire margin, eucamptodromous venation, abundant simple intersecondary veins, right angle to acute angle of divergence of secondary veins, percurrent sometimes sinuous and close to nearly distant tertiary veins. These features collectively indicate that the fossil leaves belong to the family Anonaceae. Critical examination of the herbarium sheets of a number of genera of this family it was found that the leaves of the genus *Anona* Linn. show nearest affinity with the fossil leaves. Although the modern leaves of a few species of *Mitrephora* (Bl.) Hook.f. & Th. and *Polyalthia* Bl. also show resemblance in having intersecondaries as well as in nature of secondary veins, but they differ in the course of tertiary veins.

A comparative study of all the available species of the genus *Anona* Linn. was done and concluded that the leaves of *Anona laurifolia* Linn. (C.N. Herbarium sheet nos. 11668 and 11667) show closest affinity with the fossil leaves in shape, size and venation pattern. In both modern and fossil leaves the intersecondaries are frequent and the tertiaries are straight to sinuous.

Fossil record and comparison—As far as the author is aware there is no record of fossil leaves of the genus *Anona* Linn. from Tertiary sediments of India, and abroad. The present leaf-impressions from Siwalik sediments of Koilabas form the first fossil record and hence is being described as a new species, *Anona koilabasensis*.

The genus *Anona* Linn. consists of about 120 species distributed in tropical regions. Only four introduced fruit species are found to grow in India (Willis, 1973). The modern comparable taxon *Anona laurifolia* Linn. is a medium sized evergreen tree distributed in south east Asian regions, especially in Java (Backer & Brink, 1963).

Genus—**FISSISTIGMA** Griff.

FISSISTIGMA MIOELEGANS sp. nov.

(Pl. 6, figs 3, 4, 6)

Material—This species is based on two leaf-impressions which are almost complete and devoid of cuticles.

Description—Leaves simple, almost symmetrical, narrow elliptic; preserved size 7.5 x 2.2 cm and 7.0 x 2.0 cm; apex acute; base obtuse; margin entire; texture thick chartaceous; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) about 12 pairs visible, 0.4 to 0.9 cm apart, alternate to sub-opposite, angle of divergence about 60^0, acute, moderate, uniformly curved up; seemingly unbranched, intersecondary veins present, simple, rare; tertiary veins (3^0) fine, poorly preserved, angle of origin usually RR, percurrent straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—Specimen no. K 16.

Paratype—Specimen no. K 4.

Locality—Koilabas *Nala* section near Koilabas Village, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From extant species *Fissistigma elegans* plus prefix 'Mio'.

Affinities—The most important characters exhibited by the present fossil leaves such as narrow elliptic shape, acute

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PLATE 2 ⟶

(All figures are of natural size unless otherwise mentioned)

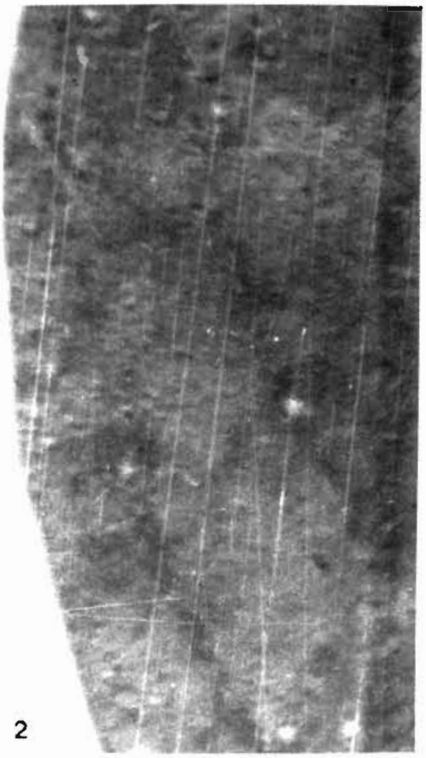
1. *Miliusa siwalica* sp. nov. - A part of fossil leaf magnified to show details of venation. x 2.
2. *Miliusa thoretii* Finet & Gagnep - A part of modern leaf magnified to show similar details of venation. x 2.

3, 4. *Gynocardia mioodorata* sp. nov. - Fossil leaves showing shape, size and nature of base, apex and details of venation.

5. *Gynocardia odorata* R. Br. - Modern leaf showing similar shape, size, and venation pattern.
6. *Garcinia nepalensis* sp. nov. - Fossil leaf showing, shape, size, apex and its venation pattern.


3

2

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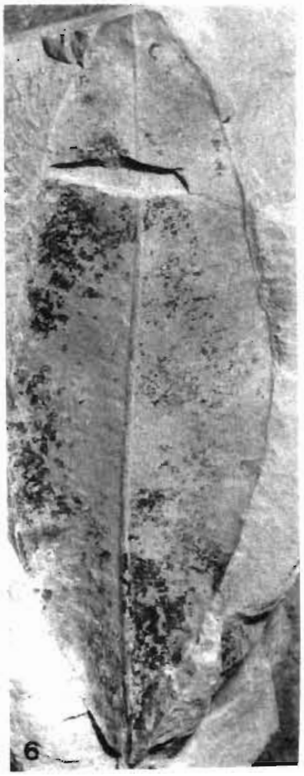
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PLATE 2

apex, obtuse base, entire margin, eucamptodromous venation, moderate acute angle of divergence of secondary veins, presence of intersecondary veins, and percurrent, straight to sinuous tertiary veins indicate its resemblance with the modern leaves of the genus *Fissistigma* Griff. of the family Anonaceae. After a detailed comparison of the present fossil leaves with all the available species of this genus it is concluded that the fossils come closer to *Fissistigma korthatlaii* Mig., *F. manubreatum* Hook.f. and *F. elegans* Hook.f. Th. Further, a critical examination of the herbarium sheets of these species suggests that the leaves of *F. elegans* Hook.f. Th. show closest affinity with the fossils (C.N. Herbarium sheet no. 13815; Pl. 6, figs 5, 7). The leaves of other two species can be differentiated in having more number of secondary veins; Moreover their course and arrangement also differ from fossils.

Fossil record and comparison—So far, three fossil leaves resembling the genus *Fissistigma* Griff. have been described from the Siwalik sediments of India and Nepal. Lakhanpal (1969) described a fossil leaf as *Fissistigma senii* from the Siwalik sediments of Jawalamukhi, Himachal Pradesh. Same species has also been reported by Prasad *et al.* (1997) from the Siwalik sediments of Seria Naka at Indo-Nepal Border in Gonda District of Uttar Pradesh. Both these leaf-impressions have been compared with the extant *Fissistigma wallichii* (Hook.f. & Th.) Merill and have been found different from the present fossil leaves in the nature of secondary veins which arise more acutely and run upward to a little distance. In 1992, Lakhanpal and Awasthi reported a fossil leaf under *Fissistigma siwalika* from the Siwalik sediments of Jawalamukhi, Himachal Pradesh, India. This fossil is large in size (14.5 x 5.3) having oblanceolate shape and rounded apex. So it is also different from the present fossils. As the present fossils are entirely different from already known species, they have been described as a new species, *Fissistigma mioelegans*.

The genus *Fissistigma* Griff. contains about 60 species distributed in tropical Africa, China, northeast Australia and in Indo-Malayan region (Willis, 1973). *F. elegans* Hook.f. & Th. with which the fossils show closest resemblance is a large climber widely distributed in Malaya peninsula, Malucca and Penang (Ridley, 1967).

Family—POLYGALACEAE

Genus—SECURIDACA Linn.

SECURIDACA MIOCENICA Prasad *et al.* 1997

(Pl. 1, figs 6, 7)

Material—This species is based on two specimens. The specimens are somewhat poorly preserved but almost complete and devoid of cuticles.

Description—Leaves simple, slightly asymmetrical, elliptic; preserved size 6.5 x 3.2 cm and 7.5 x 3.1 cm; apex acute to seemingly acuminate; base obtuse, slightly inequilateral; margin entire; texture thick chartaceous; petiole broken; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, slightly curved; secondary veins (2^0) 9-10 pairs, 0.6 to 1.2 cm apart, uniformly curved up, angle of divergence 50^0-60^0, moderately acute, sometimes branched, alternate to opposite; intersecondary veins present, frequent, simple; tertiary veins (3^0) very fine, angle of origin usually AO, percurrent, almost straight, sometimes branched oblique in relation to midvein, predominantly alternate and close.

Holotype—Specimen no. K 32.

Paratype—Specimen no. K 39.

Locality—Koilabas *Nala* near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Affinities—The elliptic shape, acute to acuminate apex, obtuse base, entire margin, moderate acute angle of divergence of secondary veins, presence of frequent intersecondary veins and percurrent tertiaries are the diagnostic features of the present fossil leaves. Besides, the present fossil leaves are also characterised by slightly unequal base as well as lamina on either side of midrib. These features collectively indicate that the present fossil leaves shows closest resemblance with the modern leaves of *Securidaca inappendiculata* Hask. (C.N. Herbarium sheet no. 36383; Pl. 1, fig. 8) of the family Polygalaceae.

Fossil record and comparison—Three fossil leaves resembling the extant taxa *Securidaca inappendiculata* have been described so far under *Securidaca miocenica* from the Siwalik sediments of Seria Naka at Indo-Nepal Border in Gonda District of Uttar Pradesh (Prasad *et al.*, 1997). The present fossil leaves also come closest with the above known fossil leaves and hence they are described under the same species *Securidaca miocenica* Prasad *et al.*

The genus *Securidaca* Linn. comprises 80 species distributed all over tropics exclusively Australia. Only one species is found in India (Willis, 1973). The modern comparable taxon *Securidaca inappendiculata* Hask. is a large woody climber growing in the moist deciduous forests of eastern Bengal, Aracan, and Tenasserim. It is also found in the Kochin Hills near Myitkyina and Java (Gamble, 1972; Hooker, 1872).

Family—FLACOURTIACEAE

Genus—GYNOCARDIA R. Br.

GYNOCARDIA MIOODORATA sp. nov.

(Pl. 2, figs 3, 4)

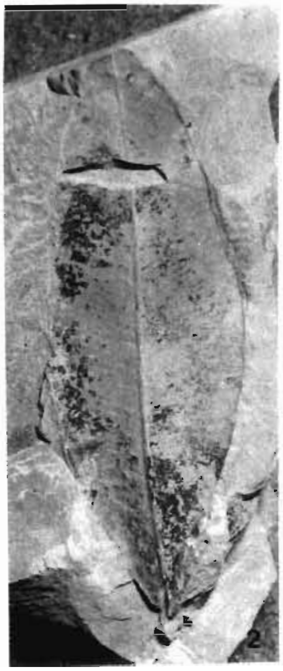

PLATE 3

⟶

(All figures are of natural size unless otherwise mentioned)

1, 2. *Garcinia nepalensis* sp. nov - Fossil leaves showing, shape, size and venation pattern.

3 *Garcinia cowa* Linn. - Modern leaf showing similar, shape, size and venation pattern

4 *Garcinia nepalensis* sp nov. - A part of fossil leaf magnified to show details of venation. x 3.

5. *Isoptera siwalica* sp. nov. - Fossil leaf showing shape, size, nature of base and its venation pattern

6. *Isoptera borneensis* sp. nov. - Modern leaf showing similar, shape, size and venation pattern.

7 *Isoptera siwalica* sp. nov. - A part of fossil leaf magnified to show details of venation pattern. x 2.

Material—The present species is based on two well preserved leaf-impressions. Of them, one is almost complete and the other is broken at apex. The leaf-impressions are devoid of cuticles.

Description—Leaves simple, symmetrical, elliptic, preserved size 9.0 x 4.0 cm and 9.0 x 5.0 cm; apex slightly broken, seemingly acute; base acute; margin entire; texture chartaceous; petiole not preserved; venation pinnate, eucamptodromous to nearly brochidodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) 6 pairs visible, 0.7 to 3 cm apart, uniformly curved up and joined to their superadjacent secondary, sometimes forming loop in the apical portion, angle of divergence about 60^0, moderate acute, alternate to sub-opposite, seemingly unbranched; tertiary veins (3^0) still fine, angle of origin RR, percurrent, the tertiaries arise from midrib looking like a intersecondary veins but they join the secondary veins arising below them; sometimes branched, oblique to right angle in relation to midvein, predominantly alternate and close to distant. Further details could not be seen.

Holotype—Specimen no. K 40.

Paratype—Specimen no. K 55.

Locality—Koilabas *Nala* section near Koilabas Village, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From the extant species *G. odorata* plus prefix 'Mio' for its Miocene age.

Affinities—The present fossil leaves are characterised by symmetrical, elliptic shape, acute apex and base, entire margin, eucamptodromous to brochidodromous venation, moderate acute angle of divergence of secondary veins, RR, close to distant having oblique to right angle in relation to midvein, percurrent tertiaries. The nature of tertiary veins arising from midrib giving an appearance of intersecondary veins is also an important distinguishing character. After a detailed study of the herbarium sheets of different families it was found that the above features are found in the modern leaves of *Gynocardia odorata* R.Br. of the family Flacourtiaceae (C.N. Herbarium sheet nos. 33497, 33499; Pl. 2, fig. 5).

Fossil record and comparison—So far, there is no record of fossil leaf of the genus *Gynocardia* R.Br. from the Tertiary sediments of India and abroad. Thus, present fossil leaves form the first record from the Siwalik sediments of Nepal and have been described here as *Gynocardia mioodorata* sp. nov.

The genus *Gynocardia* R.Br. consists of only one species *G. odorata* R.Br. with which the present fossils show close resemblance. It is moderate sized evergreen tree distributed in northern and eastern Bengal and Assam; Chittagong and Myanmar. Its wood is used in Chittagong for planking and posts and the pulp of the fruit in Sikkim to poison the fishes (Gamble, 1972).

Family—CLUSIACEAE

Genus—GARCINIA Linn.

GARCINIA NEPALENSIS sp. nov.

(Pl. 3, figs 1, 2, 4; Pl. 2, fig. 6)

Material—The present species consists of two specimens which are almost complete with some cuticular remains.

Description—Leaves simple, almost symmetrical, narrow elliptic, preserved size 7.7 x 2.1 cm and 7.8 x 2.5 cm; apex slightly broken, seemingly acute; base acute; margin entire; texture coriaceous; petiole preserved, small, 0.3 cm visible, normal; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) more than 20 pairs visible, closely placed, less than 0.5 cm apart, angle of divergence about 55^0, acute, moderate, almost uniformly curved up, alternate to opposite, sometimes branched, intersecondary veins present, simple, frequent, 2-3 intersecondaries in between two secondary veins; tertiary veins (3^0) fine abundant, poorly preserved, angle of origin AO, percurrent, almost straight, branched, oblique in relation to midvein, alternate to opposite and close. Further details could not be seen.

Holotype—Specimen no. K 31.

Paratype—Specimen no. K 62.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From country name to which fossil locality belongs.

Affinities—The diagnostic features of the present fossil leaves such as narrow elliptic shape, acute base and apex, entire margin, closely placed secondaries and presence of intersecondary veins collectively suggest its resemblance with the family Clusiaceae. These features are found common in the genera, *Kayea* Wall., *Calophyllum* Linn. and *Garcinia* Linn. of this family. Critical examination of the herbarium sheets of these genera and the present fossils revealed that the leaves of *Calophyllum* Linn. differ in the angle of secondary veins which is almost right angle. The genus *Kayea* Wall. can be differentiated in being larger size with more angle of diver-

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PLATE 4 ⟶

Dipterocarpus koilabasensis sp. nov. - Fossil leaf in natural size showing shape, size and venation pattern.

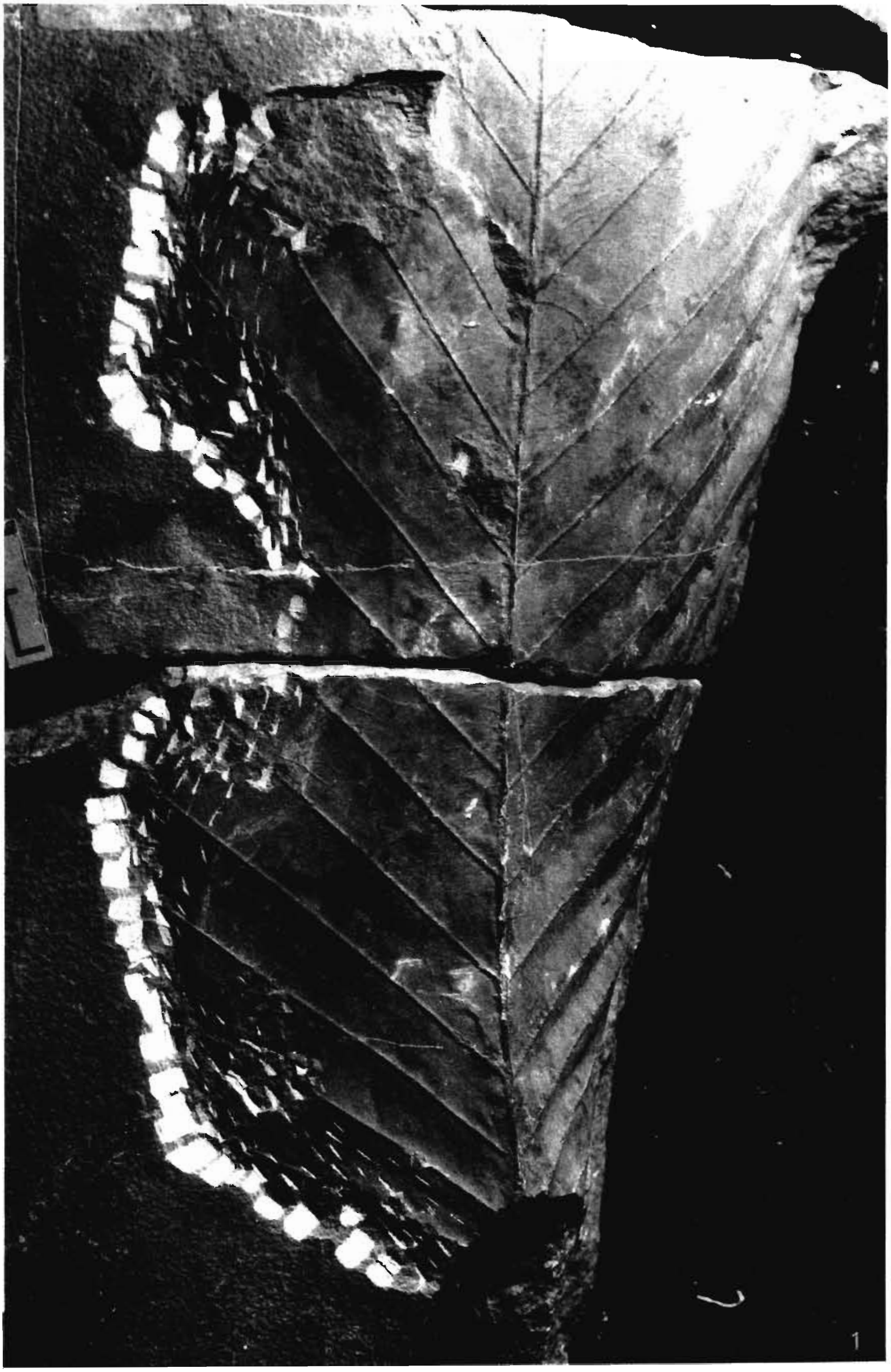

PLATE 4

gence of secondary veins. The only genus *Garcinia* Linn. comes closest with the present fossils. Further, in order to find out the nearest species a number of herbarium sheets of all the available species (about 20) were studied in detail and concluded that the leaves of *Garcinia cowa* Linn. resembles the present fossil leaves in shape, size and venation pattern (C.N. Herbarium sheet no. 46192; Pl. 3, fig. 3).

Fossil record and comparison—The fossil leaves resembling the genus *Garcinia* Linn., known so far, are *Garcinia borooahii* Lakhanpal and *Garcinia* sp. Lakhanpal & Bose from Eocene of Barmer sandstones, Kapurdi, Barmer District, Rajasthan (Lakhanpal, 1964; Lakhanpal & Bose, 1951), *G. neyveliensis* Agarwal from Neyveli lignite (Miocene), south India (Agarwal, 1991) and *G. palaeoluzoniensis* Awasthi & Mehrotra (1995) from the Oligocene of Makum Coalfield, Assam, India. Besides, *G. eucambogia* Prasad from Siwalik sediments of Kathgodam Uttar Pradesh, (Prasad, 1994c), *G. kasaulica* Arya & Awasthi from the Kasauli beds, Himachal Pradesh, (Arya & Awasthi, 1995) and *G. corvinusiana* Prasad & Awasthi from Siwalik sediments of Surai Khola, western Nepal (Prasad & Awasthi, 1996) are also recorded. The present fossil leaves have been compared with all the above known species and found that they are different either in having wide elliptic shape or in the nature and arrangement of secondary veins. In being different with all the known species the present fossil leaves are described as a new species *G. nepalensis*.

The leaf cuticles of the genus *Garcinia* Linn. have also been recorded from lignite beds (Miocene) of Ratnagiri District, Maharashtra (Dalvi & Kulkarni, 1982; Kulkarni & Dalvi, 1981) and its fossil woods are known from Deccan Intertrappean beds of Shahpura, Madhya Pradesh, India.

The genus *Garcinia* Linn. consists of about 400 species of trees and shrubs distributed in the tropical regions of Asia and South Africa (Willis, 1973). Of which, 36 species are found in India. *Garcinia cowa* Linn., with which fossil shows closest resemblance, is a tall evergreen tree found in the evergreen forests of eastern Bengal, Assam, Chittagong, Myanmar and the Andaman Island (Gamble, 1972).

Family—DIPTEROCARPACEAE

Genus—DIPTEROCARPUS Gaertn.

DIPTEROCARPUS KOILABASENSIS sp. nov.

(Pl. 4, fig. 1)

Material—The present species is based on a single well preserved leaf-impression which is devoid of cuticles.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 21.0 x 11.0 cm; apex broken; base obtuse; margin entire; texture coriaceous; petiole not preserved; venation pinnate, craspedodromous to eucamptodromous; primary vein (1^0) single prominent, stout, almost straight; secondary veins (2^0) about 16 pairs visible, 0.5 to 1.7 cm apart; Lowermost pair arise, closely and the rest are almost at same distance, curved up almost straightly before joining the margin or their superadjacent secondaries, angle of divergence about 55^0, acute, moderate, alternate to opposite seemingly unbranched; tertiary veins (3^0) fine, abundant, angle of origin usually RR, percurrent, straight, sometimes branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—Specimen no. K 5.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After the fossil locality—Koilabas, from where the specimens were collected.

Affinities—The large size of the leaf having narrow elliptic shape, obtuse base, entire margin, coriaceous texture, craspedo- to eucamptodromous type of venation, course of secondary veins which run straightly upward with moderate acute angle of divergence and percurrent, straight tertiary veins altogether undoubtedly indicate its resemblance with the modern leaves of the genus *Dipterocarpus* Gaertn. of the family Dipterocarpaceae. The herbarium sheets of all the available species of this genus (about 22) have been critically examined in order to find out the nearest specific affinity. A detailed comparison revealed that most of the species could not be differentiated from each other easily on the basis of leaf size, shape and venation pattern. However, amongst the available 22 modern species, *Dipterocarpus turbinatus* Gaertn.f. (C.N. Herbarium sheet no. 50480) shows closest similarity

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PLATE 5 ⟶

(All figures are of natural size unless otherwise mentioned)

1\. *Shorea eutrapizifolia* sp. nov. - Fossil leaf showing shape, size and venation pattern.

2, 3. *Shorea eutrapizifolia* sp. nov. - Other fossil leaves showing variation in shape, size and nature of base.

4, 5. *Shorea trapizifolia* (Thw.) Ashton - Modern leaves showing similar variation in shape, size and nature of base.

6\. *Shorea eutrapizifolia* sp. nov. - A part of fossil leaf magnified to show details of venation. x 3.5.

7 *Shorea trapizifolia* (Thw.) Ashton - A part of modern leaf magnified to show similar details of venation. x 3.5.

8,9. *Brucea darwajensis* sp. nov. - Fossil leaves showing shape, size and nature of base and apex.

10\. *Brucea mollis* Wall. - Modern leaf showing similar shape, size, nature of base and apex.

11\. *Brucea darwajensis* sp. nov. - A part of fossil leaf magnified to show details of venation. x 2.5.

12\. *Brucea mollis* Wall. - A part of modern leaf magnified to show similar details of venation. x 2.5


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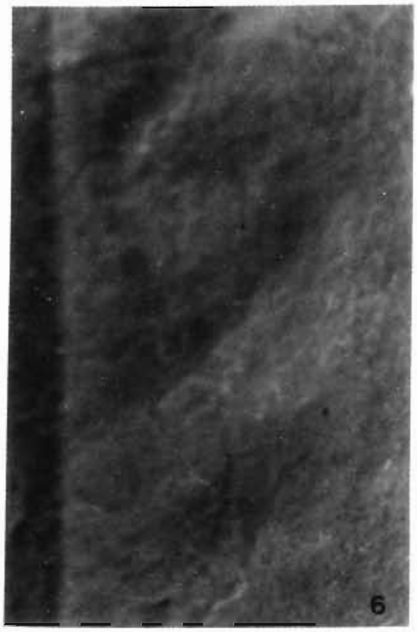
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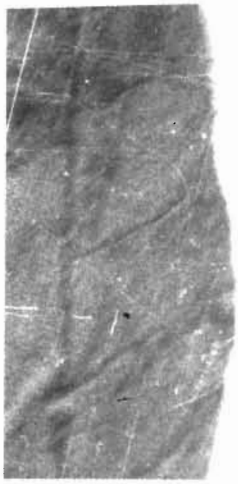
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PLATE 5

with the present fossil leaf in all morphological characters.

Fossil record and comparison—A number of fossil leaves showing close similarity with the genus *Dipterocarpus* Gaertn. have been described from the Tertiary sediments of both India and abroad. They are *Dipterocarpus antiquus* Heer and *D. atavinus* Heer from the Tertiary of Sumatra (Heer, 1883); *D. labuanus* Geyler, *D. nordenspioldi* Geyler and *Dipterocarpus* sp. from the Tertiary of Labuan (Geyler, 1887); *Phyllites dipterocarpoides* Crie 1888 from the Pliocene of Java, *D. siwalicus* Lakhanpal & Guleria 1987 from the Siwalik sediments of Jawalamukhi, Himachal Pradesh. This species has also been described from Siwalik sediments of Koilabas, western Nepal (Prasad, 1990b), Surai Khola, western Nepal (Awasthi & Prasad, 1990) and Kathgodam, Uttar Pradesh, India (Prasad, 1994c). On comparing the present fossil with the above already known species, it has been observed that it does not show similarity with any of them. The present fossil leaf differs from most of them in being larger in size. The course of secondaries is also not common in any of the above specimens. This has, therefore, been described as a new species *Dipterocarpus koilabasensis*.

The genus *Dipterocarpus* Gaertn. contains about 76 species distributed in India and western Malaysia (Willis, 1973). Out of which, 17 species are Indian and 5 are endemic in Ceylon. Two are found in south India and rest in eastern Bengal, Myanmar and Andaman Island. The extant species *Dipterocarpus turbinatus* Gaertn.f., with which the fossil shows closest affinity, is a large evergreen tree occurring in the forest of Cachar and Chittagong Hills. It is also common in the tropical forest throughout Myanmar (Gamble, 1972).

Genus—**ISOPTERA** Scheff. Ex Br.

ISOPTERA SIWALICA sp. nov.

(Pl. 3, figs 5, 7)

Material—This consists of only one well preserved specimen which is complete and devoid of cuticles.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 9.2 x 3.3 cm; apex slightly broken, seemingly acute; base obtuse, slightly inequilateral; margin entire; texture thick, chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, thicker towards basal region, straight; secondary veins (2^0) about 10 pairs visible, 0.5 to 1.8 cm apart, angle of divergence 60^0-65^0, acute moderate, alternate, uniformly curved up, curving more pronounced near the margin, run upward to a little distance joining to the superadjacent secondaries, unbranched; tertiary veins (3^0) moderate in thickness, not so abundant, angle of origin RR, percurrent, mostly straight sometimes sinuous, rarely branched, oblique in relation to midvein prominently alternate and close to nearly distant. Further details are not clearly seen.

Holotype—Specimen no. K 50.

Locality—Koilabas *Nala* section near Imlibasa, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After the Siwalik Formation.

Affinities—The most important features of the present fossil leaf are narrow elliptic shape, acute apex, obtuse, inequilateral base, eucamptodromous venation, straightly running upward secondary veins whose curvature is pronounced near the margin, percurrent and close to distant tertiary veins. These features collectively indicate that the fossil leaf belongs to the genus *Isoptera* Scheff. ex Br. of the family Dipterocarpaceae. In the genus *Isoptera* Scheff ex Br. only two species were available for consultation in the C.N. Herbarium, Sibpur, West Bengal. However, after a detailed comparison of fossil leaf with the extant leaves of this genus it was found that the leaves of *Isoptera borneonsis* show closest affinity with the fossil (C.N. Herbarium sheet no. 52123; Pl. 3, fig. 6).

Fossil record and comparison—So far there is no record of fossil leaves of *Isoptera* Scheff. ex Br. from the Tertiary sediments of any part of the world. Therefore, it has been described as *Isoptera siwalica* sp. nov., the specific epithet indicates its occurrence in the Siwalik sediments.

The genus *Isoptera* Scheff. ex. Br. contains only three species found to grow in tropical forests of western Malaysia (Willis, 1973). *Isoptera borneonsis* with which the fossil specimen shows closest affinity, is an evergreen tree distributed in the forest of Myanmar, Java and Sumatra.

PLATE 6

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(All figures are of natural size unless otherwise mentioned)

1. *Aglaia nepalensis* sp. nov. - Fossil leaf showing shape, size and venation pattern.
2. *Aglaia nepalensis* sp. nov. - A part of fossil leaf magnified to show details of venation. x 2.2.

3, 4. *Fissistigma mioelegans* sp. nov. - Fossil leaves showing shape, size, nature of base, apex and venation pattern.

5. *Fissistigma elegans* Hook.F. & Th. - Modern leaf showing similar shape, size and venation pattern.
6. *Fissistigma mioelegans* sp. nov. - A part of fossil leaf magnified to show details of venation. x 2.5.
7. *Fissistigma elegans* Hook.F. & Th. - Apart of modern leaf magnified to show similar details of venation. x 2.5.
8. *Nephelium palaeoglabrum* Prasad *et al.* - Fossil leaf showing shape, size and venation pattern.
9. *Nephelium glabrum* Noronh. - Modern leaf showing similar shape, size and venation pattern.


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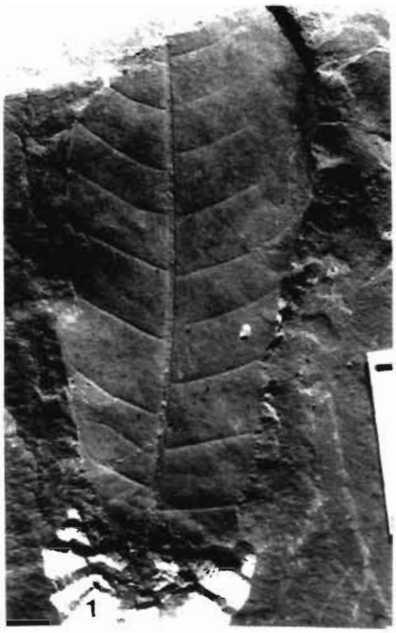
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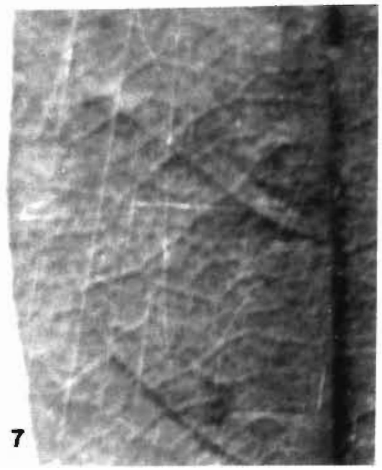
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PLATE 6

Genus—SHOREA Roxb.

SHOREA EUTRAPIZIFOLIA sp. nov.

(Pl. 5, figs 1, 2, 3, 6)

Material—This species is based on three leaf-impressions which are devoid of cuticle.

Description—Leaves simple, symmetrical, elliptic to narrow elliptic; preserved size 4.4 x 2.3 cm, 5 x 2.2 cm and 5.5 x 2.0 cm; apex seemingly acute; base acute to obtuse; margin entire; texture coriaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) about 8 pairs visible, 0.4 to 0.8 cm apart, angle of divergence about 60^0, acute moderate, uniformly curved up, usually alternate, seemingly unbranched, intersecondary veins present, simple; tertiary veins (3^0) fine, poorly preserved, angle of origin usually RR, percurrent, almost straight, sometimes branched, oblique in relation to midvein, predominantly alternate and close. Further details could not be seen.

Holotype—Specimen no. K 9.

Paratype—Specimen nos. K 44, 19.

Locality—Koilabas *Nala* section just before Imlibasa, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From the extant species *Shorea trapizifolia* plus the prefix 'eu'.

Affinities—The characteristic features of the fossil leaves such as elliptic to narrow elliptic shape, acute apex, acute to obtuse base, entire margin, eucamptodromous venation, moderately acute angle of divergence of secondary veins, presence of intersecondary veins and RR, percurrent tertiaries indicate that these are closest to the extant *Shorea trapizifolia* (Thw.) Ashton of the family Dipterocarpaceae (C.N. Herbarium sheet no. 29; Pl. 5, figs 4, 5, 7).

Fossil record and comparison—Seven fossil leaves resembling the genus *Shorea* Roxb. have been described from the Tertiary sediments of India and abroad. Seward (1935) reported two leaves under the form genus *Dipterocarpophyllum, D. blumii* and *D. gerativense* from the Tertiary of Egypt showing resemblance with the extant genus *Shorea* Roxb. Merrill (1923) described two fossil leaves, viz., *Shorea guiso* and *S. polyspermum* from the Pliocene of Philippines. Recently, three more fossil leaves have been reported from the Siwalik sediments of India. These are *Shorea siwalika* Antal & Awasthi (1993) from Siwalik sediments of Ramthi River, Darjeeling District, West Bengal; *Shorea neoassamica* Prasad (1994c) from the Siwalik sediments of Kathgodam, Uttar Pradesh and *Shorea miocenica* Antal & Prasad (1996b) from Ghish River near Oodlabari, Darjeeling District, West Bengal. The present fossil leaves have been compared with all the above known species and found that these are different from them in being smaller in size having intersecondary veins. The course of secondary and tertiary veins is also different from them. Thus, in being different, the present specimens have been described under a new specific name *Shorea eutrapizifolia*.

The genus *Shorea* Roxb. contains about 180 species distributed from Ceylon to South China, western Malaysia and Malaccas. Out of 12 species in which five are endemic in Ceylon, three are found in Myanmar, two in south India, one in Assam and one in the well known Sal forest in northern and central India. *Shorea trapizifolia* (Thw.) Ashton with which the present fossils show closest resemblance is an evergreen tree found to occur in Ceylon (Ashton, 1972).

Family—SIMAROUBACEAE

Genus—BRUCEA J.F. Mill.

BRUCEA DARWAJENSIS sp. nov.

(Pl. 5, figs 8, 9, 11)

PLATE 7

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(All figures are of natural size unless otherwise mentioned)

1. *Swintonia palaeoschwenckii* Prasad & Awasthi. - Fossil leaf showing shape, size and venation pattern.
2. *Swintonia schwenckii*, Teysm. - Modern leaf showing similar shape, size and venation pattern.
3. *Pongamia kathgodamensis* Prasad. - Fossil fruit showing its morphological features.
4. *Pongamia glabra* Vent. - Modern fruit showing similar morphological features.
5. *Dalbergia miovolubilis* Prasad *et al.* - Fossil leaf showing shape, size and venation pattern. x 2.5.
6. *Dalbergia volubilis* Roxb. - Modern leaf showing similar shape, size and venation pattern. x 2.5.
7. *Dalbergia eocultrata* sp. nov. - Fossil leaflet showing shape, size and nature of apex, base and venation pattern.
8. *Dalbergia cultrata* Linn. - Modern leaflet showing similar shape, size and nature of base, apex and venation pattern.
9. *Cynometra palaeoiripa* sp. nov. - Fossil leaflets showing shape, size and its venation pattern.
10. *Cynometra iripa* Kotel. - Modern leaflets showing similar shape, size and venation pattern.
11. *Milletia imlibasensis* sp. nov. - Fossil leaflet showing shape, size and venation pattern.
12. *Milletia brandisiana* Kurz. - Modern leaflet showing similar shape, size and venation pattern.
13. *Milletia imlibasensis* sp. nov. - A part of fossil leaflet magnified to show details of venation. x 4.
14. *M. brandisiana* Kurz. - A part of modern leaflet magnified to show similar details of venation. x 3.

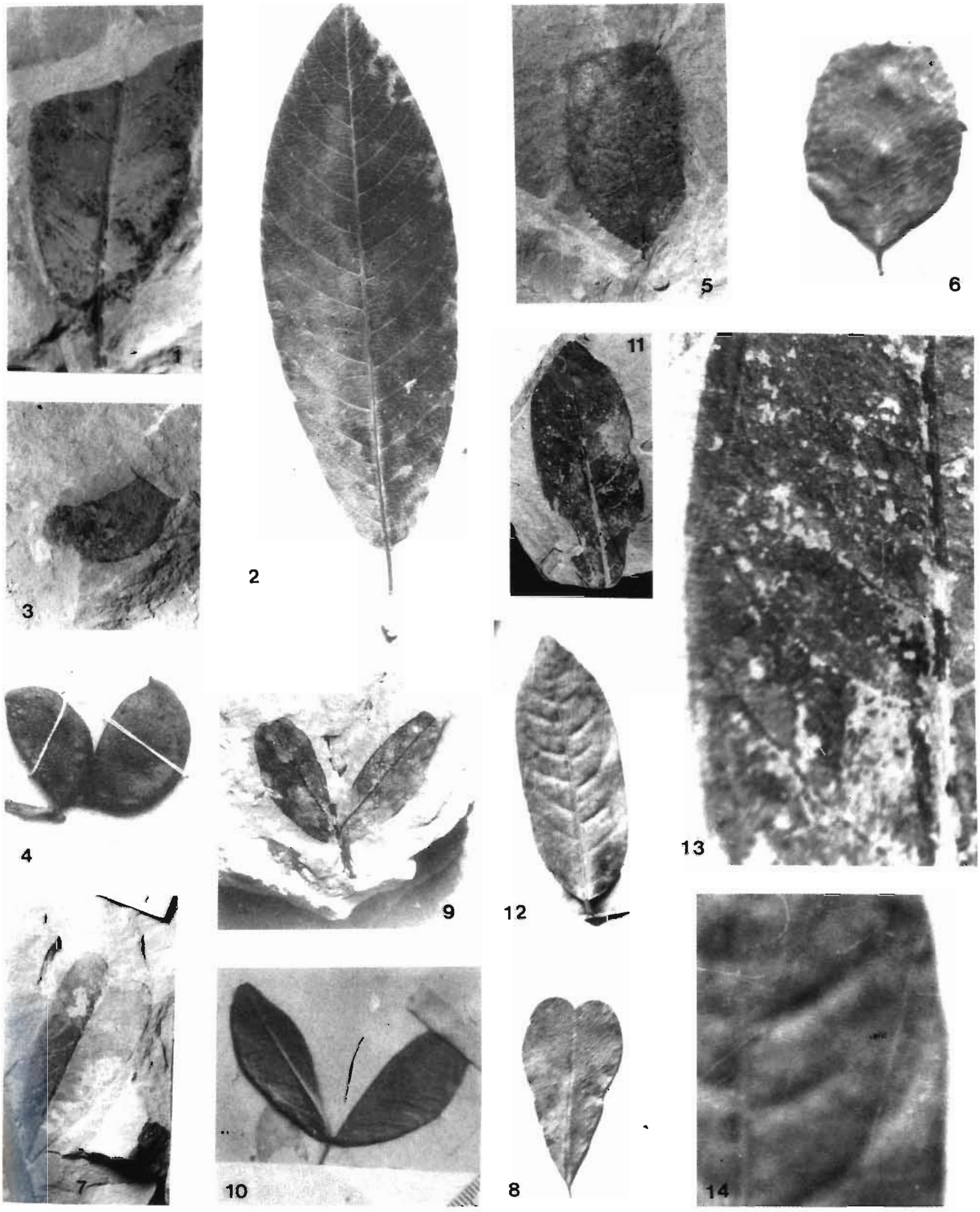

PLATE 7

Material—The present species is based on two leaf-impressions which are almost complete and devoid of cuticles.

Description—Leaves simple, slightly asymmetrical at basal portion, narrow elliptic; preserved size 5.4 x 1.3 cm and 5.8 x 1.3 cm; apex attenuate; base acute, inequilateral; margin entire; texture coriaceous; petiole preserved in one specimen, 0.4 cm long, normal; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) about 10 pairs visible, less than 0.5 cm apart, angle of divergence about 65^0, acute, moderate; uniformly curved up, alternate to opposite, seemingly unbranched; tertiary veins (3^0) fine, poorly preserved, angle of origin usually RR, percurrent, straight, oblique in relation to midvein, alternate to opposite and close. Further details could not be seen.

Holotype—Specimen no. K 58.

Paratype—Specimen no. K 64.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After Darwaja, a place in Koilabas *Nala* from where fossils were collected.

Affinities—The main diagnostic features of the fossil leaf such as narrow elliptic shape, attenuate apex, inequilateral, acute base, coriaceous texture, eucamptodromous venation and the course of secondary and tertiary veins strongly suggest that the fossil leaves show their affinity with the leaves of extant genus *Brucea* J.F. Mill of the family Simaroubaceae. Herbarium sheets of all the available species of the genus *Brucea* J.F. Mill. were examined and it was found that the leaves of *Brucea mollis* Wall. show closest affinity with the present fossil leaves (C.N. Herbarium sheet nos. 77233 and 77234; Pl. 5, figs 10, 12).

Fossil record and comparison—There is no fossil record of the genus *Brucea* J.F. Mill. from the Tertiary sediments of India and abroad. The present fossils show their first occurrence in the Siwalik sediments of Nepal and therefore have been assigned as *Brucea darwajensis* sp. nov.

The genus *Brucea* J.F. Mill. contains about 10 palaeotropical species. Out of which, only two species are found in India and Myanmar. *Brucea mollis* Wall., with which the fossils show closest affinity is an evergreen shrub growing in north east Himalaya and Sylhet ascending to about 6,000 ft. It is also common in Kochin Hills, Karan Hills and Tennasserim in Myanmar (Gamble, 1972).

Family — SAPINDACEAE

Genus — NEPHELIUM Linn.

NEPHELIUM PALAEOGLABRUM Prasad *et al.* 1997

(Pl. 6, fig. 8)

Material—This species is based on a single, well preserved leaf-impression.

Description—Simple, symmetrical; narrow obovate to elliptic; preserved size 8.2 x 5.0 cm; apex broken; base acute; equilateral; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) about 7 pairs visible; 0.7 to 1.5 cm apart, angle of divergence about 60^0, moderate acute; uniformly curved up and joined superadjacent vein, seemingly unbranched usually alternate, rarely sub-opposite; tertiary veins (3^0) fine, angle of origin RR, sometimes branched, percurrent; oblique in relation to mid-vein, sometimes nearly right angle, predominantly alternate and close.

Specimen no.—K 2.

Locality—Near Darwaja in Koilabas *Nala*, Koilabas, western Nepal.

Horizon & age—Lower Siwalik, Middle Miocene.

Affinities — In overall morphological features the present fossil leaf resembles closely with the extant leaves of *Nephelium glabrum* Noronh. of the family Sapindaceae (C.N. Herbarium sheet no. 95476; Pl. 6, fig. 9).

Fossil record and comparison—Four fossil leaves resembling the genus *Nephelium* have been described from Tertiary sediments of India and abroad. These are *Nephelium jovis* Unger 1875 from Tertiary of Europe, *N. verbererianum* Geyler 1875 from Tertiary of Borneo and *N. oligocenicum* Awasthi & Mehrotra 1995 from the Oligocene of Makum Coalfield,

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PLATE 8

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(All figures are of natural size unless otherwise mentioned)

1. *Anisophyllea siwalica* Prasad & Awasthi. - Fossil leaf showing shape, size and its venation pattern.
2. *Anisophyllea siwalica* Prasad & Awasthi. - A part of fossil leaf magnified to show details of venation. x 3.
3. *Syzygium miooccidentalis* sp. nov. - Fossil leaf showing shape, size and its venation pattern.
4. *Syzygium occidentalis* Bourd. - Modern leaf showing similar shape, size and venation pattern.
5. *Diospyros darwajensis* sp. nov. - Fossil leaf showing shape, size and venation pattern.
6. *Diospyros darwajensis* sp. nov. - A part of fossil leaf magnified to show details of venation. x 2.
7. *Helicia eoerretica* sp. nov. - Fossil leaf showing shape, size and its venation pattern.
8. *Helicia eoerretica* sp. nov. - A part of fossil leaf magnified to show details of venation. x 2.5.


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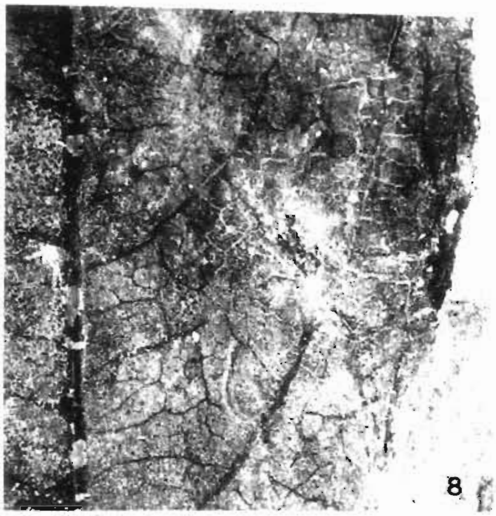
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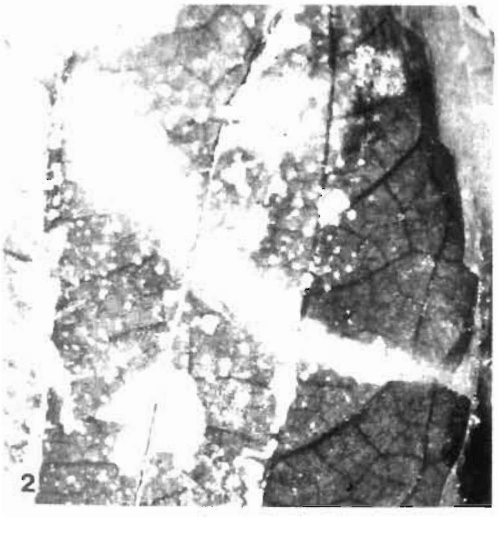
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PLATE 8

Assam, India and *N. palaeoglabrum* Prasad *et al.* 1997 from the Siwalik sediments of Seria Naka near Tulsipur, U.P. On comparison of present fossil leaf with those of above mentioned species. It has been found that the species described from Seria Naka i.e., *N. palaeoglabrum* shows closest resemblance with present fossil in almost all the morphological features.

The extant *Nephelium glabrum* Noronh. is an evergreen tree found to grow in Malayan archipelago (Hooker, 1872).

Family—MELIACEAE

Genus—AGLAIA Lour.

AGLAIA NEPALENSIS sp. nov.

(Pl. 6, figs 1, 2)

Material—This species is based on a well preserved leaf-impression which is devoid of cuticle.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 7.5 x 3.0 cm; apex broken; base indistinct; margin entire; texture thick, chartaceous; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) about 11 pairs visible, 0.3 to 1.0 cm apart, usually alternate rarely sub-opposite, angle of divergence 70^0-80^0, wide acute to nearly right angle, uniformly curved up, curvature is more pronounced near the margin before joining superadjacent secondary, unbranched, intersecondary rarely present, simple; tertiary veins (3^0) fine, poorly preserved, angle of origin usually RR, percurrent, straight to curved, convex, rarely branched, oblique in relation to midvein, predominantly alternate and close. Further details could not be seen.

Holotype—Specimen no. K 86.

Locality—Koilabas *Nala* section near Koilabas Village, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After the name of country to which fossil locality belongs.

Affinities—Medium size of leaf with narrow elliptic shape, eucamptodromous venation, wide acute angle of divergence of secondary veins, basal 1-2 pairs of secondary arise nearly at right angle, RR, percurrent, straight to curved tertiary veins are the important features of the present fossil. These features indicate that the fossil belongs to the modern leaves of the genus *Aglaia* Lour. of the family Meliaceae. A critical examination of the herbarium sheets of a number of species of this genus suggests that the leaves of *Aglaia euryphylla* Koord. & Valeton (C.N. Herbarium sheet no. 80785) has nearest affinity with the fossil leaf.

Fossil record and comparison—As far as the author is aware there is no record of the fossil leaves resembling the genus *Aglaia* Lour. Although, a fossil wood resembling this genus has been described as *Aglaioxylon mandalensis* from the Deccan Intertrappean beds of Parapani, Mandla District of Madhya Pradesh (Trivedi & Srivastava, 1982). The present fossil forms the first occurrence of the fossil leaves of this genus in the Siwalik sediments of Koilabas, western Nepal and has been assigned as *Aglaia nepalensis* sp. nov.

The genus *Aglaia* Lour. consists of 200-300 species found in China, Indo-Malaya, Australia and Pacific. Of these, 23 species are distributed in India, Myanmar and Sri Lanka. *Aglaia euryphylla* Koord. & Valeton, with which the fossil leaf resembles closely, is an evergreen tree found to grow mainly in Java.

Family—ANACARDIACEAE

Genus—SWINTONIA Griff.

SWINTONIA PALAEOSCHWENCKII

Prasad & Awasthi 1996

(Pl. 7, fig. 1)

Material—This is based on a single incomplete leaf-impression which is devoid of cuticle.

Description—Leaf simple, symmetrical, seemingly narrow elliptic, preserved size 4.5 x 3.0 cm; apex broken; base obtuse, indistinct on one side of midrib; margin entire; texture thick, chartaceous; petiole preserved, 0.6 cm long, normal; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) only 6 pairs visible, 0.3 to 1.2 cm apart, lowest two pairs closely placed, alternate, angle of divergence 60^0 to 80^0, wide acute to right angle, lowest pair arises mainly at right angle, uni-

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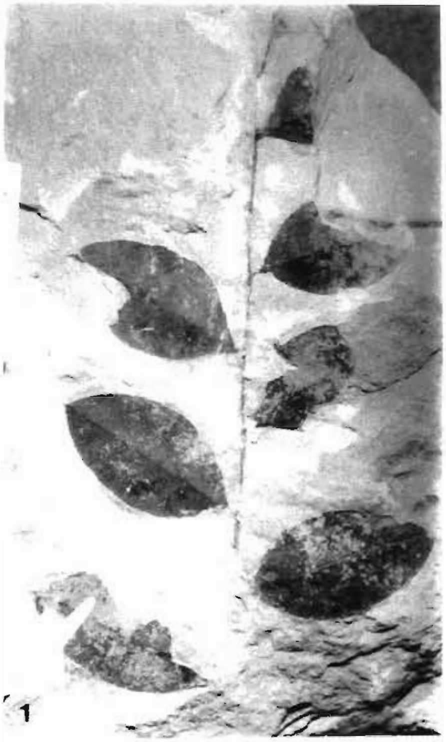
PLATE 9 ⟶

(All figures are of natural size unless otherwise mentioned)

1. *Phyllanthus mioreticulatus* sp. nov. - Fossil leaflets showing shape, size and its arrangement on a twig.
2. *Phyllanthus reticulatus* Poir. - Modern leaflets showing similar shape, size and arrangement.
3. *Phyllanthus mioreticulatus* sp. nov. - A fossil leaflet magnified to show nature of base, apex and venation. x 2.2.
4. *Phyllanthus reticulatus* Poir. - A modern leaflet magnified to show similar type of base, apex and venation pattern. x 2.2.
5. *Phyllanthus koilabasensis* sp. nov. - Fossil leaflet magnified to show details of venation.
6. *Phyllanthus collummaris* Muell.Arg. - A modern leaflet magnified to show similar details of venation.
7. *Antedesma siwalica* sp. nov. - A fossil leaf showing venation pattern.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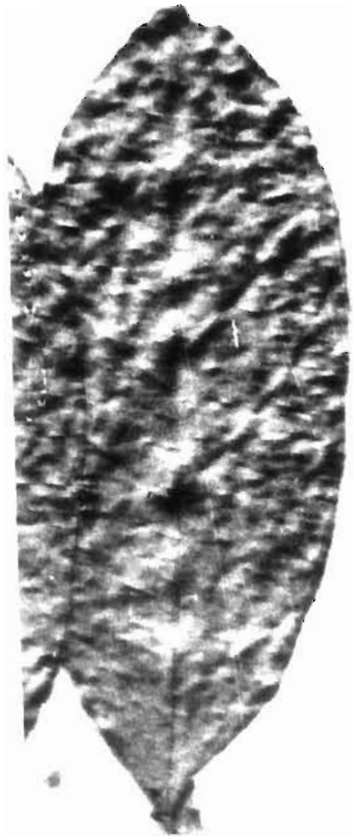
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PLATE 9

formly curved up and joined to their superadjacent secondaries without any pronounced curvature, unbranched intersecondary veins present but poorly preserved; tertiary veins (3^0) fine, poorly preserved, angle of origin usually RR, percurrent, straight to curved, sometime branched, oblique in relation to midvein, predominantly alternate and close.

Specimen—Specimen no. K 108.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Affinities—Symmetrical elliptic shape, obtuse base, entire margin, eucamptodromous venation, wide acute to right angle of divergence of secondary veins, closely placed and with more angle of divergence of lowest pair of secondary presence of intersecondary veins and RR, percurrent, closely placed tertiary veins strongly indicate that the present fossil shows closest affinity with the extant leaves of *Swintonia schwenckii* Teysm. of the family Anacardiaceae (C.N. Herbarium sheet no. 37034; Pl. 7, fig. 2).

Fossil record and comparison—So far, three fossil leaves resembling the genus *Swintonia* Griff. have been described from the Siwalik sediments of India and Nepal. Awasthi and Prasad (1990) described a fossil leaf resembling extant *Swintonia floribunda* Griff. under the form species *S. miocenica* from Siwalik sediments of Surai Khola, western Nepal. Later, Antal and Prasad (1996a) and Prasad and Awasthi (1996) described another fossil leaf separately under *Swintonia palaeoschwenckii* from the Siwalik sediments of West Bengal, India and Surai Khola, western Nepal, respectively.

The present fossil leaf has been compared with above already known Siwalik fossils and found that *S. palaeoschwenckii* Prasad and Awasthi described from Surai Khola, western Nepal shows closest similarity with the present fossil and thus it has been described here under the same species.

The genus *Swintonia* Griff. is represented by 15 species distributed in South east Asia and western Malaysia. Out of these, three species are found to occur in the tropical evergreen forests of Tennasserim, Andaman Island, Bangladesh and Myanmar. *Swintonia schwenckii* Teysm. with which the fossil leaf shows closest affinity is a tall tree found to grow along rivers in the evergreen forests of Chittagong and Myanmar. In the Chittagong forests it is one of the most conspicuous trees specially along the banks of the Karnaful River. It is also found in Malayan region (Willis, 1973; Brandis, 1971).

Family—FABACEAE

Genus—PONGAMIA Vent.

PONGAMIA KATHGODAMENSIS Prasad 1994d

(Pl. 7, fig. 3)

Material—It consists of a single fruit-impression.

Description—Fruit flattened, oblong with decurved points, much thickened on suture; size 2.3 x 1.1 cm; wings absent.

Specimen—Specimen no. K 66.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Affinities—In all morphological features the present fossil fruit shows closest affinity with the extant fruit of *Pongamia glabra* Vent. of the family Fabaceae (C.N. Herbarium sheet no. 15650; Pl. 7, fig. 4).

Fossil record and comparison—The genus *Pongamia* is well known in the fossil record by the occurrence of its petrified woods, fossil leaves, and fruit-impressions from the Tertiary sediments of India and abroad. A number of fossil woods have been described from Tertiary sediments of India under form genus *Millettioxylon* Awasthi (Prasad, 1994b). So far, three fossil leaflets have been recorded from the Siwalik sediments of Haridwar, Uttar Pradesh (Prasad, 1994a), Bhikhnathoree, Bihar (Awasthi & Lakhanpal, 1990) and West Bengal (Antal & Awasthi, 1993), respectively. The fossil fruits resembling *Pongamia glabra* Vent. are also known from the Siwalik sediments of Kathgodam under the form species *Pongamia kathgodamensis* (Prasad, 1994d). Prasad and Awasthi (1996) also described fossil fruit of the same species from the Siwalik sediments of Surai Khola, western Nepal and assigned it to *Pongamia kathgodamensis* Prasad. The present fossil fruit has been compared with all the above known fruits and found to be very similar, hence has been described under the same species.

The genus *Pongamia* Vent. consists of single species *P. glabra* Vent. with which the fossil shows its close resemblance. It is a large tree found common near the banks of stream and water sources in both peninsula in the out forests and subhimalayan tracts. It is also common in tidal and beach forests of India, Sri Lanka, Malaya Archipelago extending to the Coast, South China, Fiji Islands and tropical Australia (Brandis, 1971).

Genus—DALBERGIA Linn.f.

DALBERGIA EOCULTRATA sp. nov.

(Pl. 7, fig. 7)

Material—The present species is based on a single well preserved complete leaf-impression which is devoid of cuticle.

Description—Leaflet asymmetrical due to unequal lamina on either side of midrib, narrow elliptic; preserved size 4.0 x 1.7 cm; apex notched (emarginate); base acute; slightly

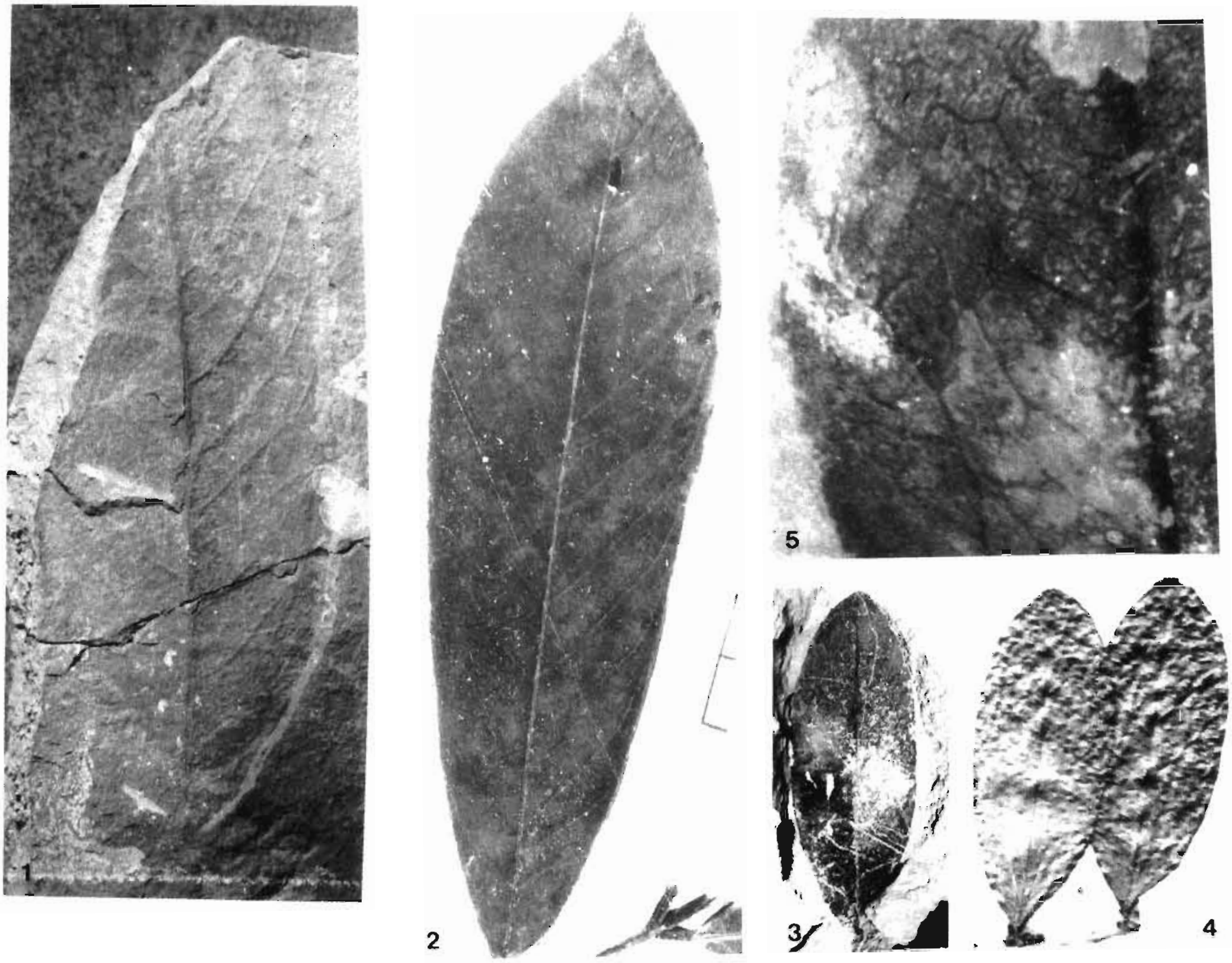

PLATE 10

1. *Antedesma siwalica* sp. nov. - Fossil leaf showing shape, size and venation pattern.
2. *Antedesma montanum* Bl. - Modern leaf showing similar shape, size and venation pattern.
3. *Phyllanthus koilabasensis* sp. nov. - A fossil leaflet showing shape, size, nature of base and apex.
4. *Phyllanthus collumnaris* muell. Arg. Poir. - Modern leaflets showing similar shape, size, nature of base and apex.
5. *Cynometra palaeoiripa* sp. nov. - A part of fossil leaflet magnified to show details of venation. x 5.

inequilateral; margin entire; texture chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) 1-8 pairs visible, 3.0 to 0.7 cm apart, alternate to opposite, angle of divergence about 55^0-60^0 acute, moderate, uniformly curved up and join their superadjacent secondary, lowest pair closely placed, seemingly unbranched, intersecondary veins present, simple; tertiary veins (3^0) fine, poorly preserved, angle of origin usually AO, percurrent and join intersecondary veins, oblique in relation to midvein, predominantly alternate and close.

Holotype—Specimen no. K 121.

Locality—Koilabas *Nala* near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From the extant species *D. cultrata* plus the prefix 'eo'.

Affinities—The dignostic features of the present fossil leaflet such as asymmetrical, elliptic shape, emarginate apex, acute base, entire margin, chartaceous texture, eucamptodromous venation, closely placed secondary veins with moderate angle of divergence, presence of intersecondary veins and percurrent tertiaries strongly suggest its resemblance with the extant leaves of *Dalbergia cultrata* Linn. of the family Fabaceae (C.N. Herbarium sheet no. 130595; Pl. 7, fig. 8).

Fossil record and comparison—The fossil leaflets resembling the genus *Dalbergia* Linn.f. are known from different parts of the world under the genera *Dalbergia* Linn. and *Dalbergites* Berry. So far, about 40 species of *Dalbergia* Linn.f. and 3 species of *Dalbergites* Berry have been described from India and abroad (Ettingshausen, 1869; Schimper, 1874; Geyler, 1875; Berry, 1909, 1916, 1939; Knowlton, 1917; Principi, 1921; Hollick, 1924; Ball, 1931; Salomon-Calvi, 1934; MacGinitie, 1937, 1941; LaMotte, 1952; Heer, 1959; Lakhanpal & Awasthi, 1984; Prasad, 1990b, 1994a, e, Prasad *et al.*, 1997). Besides, there is one more leaflet resembling that of *Dalbergia* described under the form genus *Phyllites* by Tanai (1972) from the Tertiary of Japan. These species have been reported from Africa, Australia, France, Germany, Greenland, Japan, Sumatra, U.S.A., West Indies and India. Besides, two fossil fruits resembling *Dalbergia sissoo* have also been described from the Indian Tertiary sediments. Lakhanpal and Dayal (1966) described it from the Siwalik sediments of Balugoloa, Himachal Pradesh. Later, Awasthi and Mehrotra (1995) reported other fossil fruit under *Leguminocarpon dalbergioides* from the Oligocene of Makum Coalfield, Assam, India. Thus, from fossil records it is clear that the genus *Dalbergia* Linn.f. was cosmopolitan in distribution in geological past.

Four fossil leaflets resembling *Dalbergia* Linn.f. have been described from the Siwalik sediments of India and Nepal. These are *Dalbergia miosericea* Prasad 1990b, *D. siwalika* Prasad 1994e from the Siwalik sediments of Koilabas, western Nepal, *Dalbergia* cf. *D. sissoo* Prasad 1994a from the Siwalik sediments of Haridwar, Uttar Pradesh, *D. miovolubilis* Prasad *et al.* (1997) from the Siwaliks of Seria Naka at Indo-Nepal Border, U.P. and *Dalbergia* sp. Lakhanpal and Awasthi (1984) from the Siwalik sediments of Bhikhnathoree, Bihar. The present fossil leaflet was compared with the available known species of *Dalbergia* Linn.f. and found that none of them shows similarity with the present fossil.

Although the fossil leaflet described as *Dalbergia miosericea* Prasad somewhat shows resemblance in the nature of apex but differs in course of secondary veins and having obtuse base instead of acute base in the present fossil. Thus, being different this fossil leaflet is assigned to a new species *Dalbergia eocultrata*.

The genus *Dalbergia* Linn.f. consists of about 300 species of tropical to sub-tropical region of the world (Willis, 1973; Hooker, 1879). About 36 species are reported to occur in India (Gamble, 1972). *Dalbergia cultrata* Linn. with which the fossil shows closest resemblance is a moderate sized deciduous tree common in all deciduous forests specially the upper mixed savanah and Eng forests throughout Myanmar, the Shah Hills, south wards.

DALBERGIA MIOVOLUBILIS Prasad *et al.* 1997

(Pl. 7, fig. 5)

Material—This species is represented by only one specimen which is almost complete and devoid of cuticle.

Description—Leaflet almost symmetrical, elliptic; preserved size 1.6 x 0.9 cm; apex broken; base nearly obtuse, slightly inequilateral; margin entire; texture thick chartaceous; petiole preserved, 0.2 cm visible, normal; venation pinnate, eucamptodromous; primary vein (1^0) single, not so prominent, weak; secondary veins (2^0) more than 12 pairs visible, closely placed, alternate to opposite, angle of divergence 55^0, acute, moderate, uniformly curved up, branching not clear, intersecondary veins present; tertiary veins (3^0) fine, poorly preserved, angle of origin RR-AO, percurrent, sometimes branched, oblique in relation to midvein, alternate to opposite and close. Further details not observed.

Specimen—Specimen no. K 82.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Affinities—The most important distinguishing features of the present fossil leaflet such as small size, nearly obtuse base, entire margin, small petiole, eucamptodromous venation, closely placed secondary veins arising at moderate acute angle from the midvein, presence of intersecondary veins and percurrent tertiaries collectively indicate that the fossil leaflet shows closest affinity with the extant leaflets of *Dalbergia volubilis* Roxb. of the family Fabaceae (C.N. Herbarium sheet no. 130772; Pl. 7, fig. 6).

Fossil record and comparison—So far, about 42 species of *Dalbergia* Linn.f. are known from the Tertiary sediments of India and abroad (Prasad *et al.*, 1997). The present fossil leaf was compared with all the available species and concluded that the fossil leaflet described from the Siwalik sediments of Seria Naka (Gonda District) at Indo-Nepal Border shows closest affinity in shape and venation pattern and hence has been described under the same species. This fossil leaflet was also compared with the extant taxa *D. volubilis* Roxb. but it is larger in size with somewhat distantly placed secondaries. We would like to mention that these variations in the morphological features may be due to different ecological conditions of the regions.

The extant taxa *D. volubilis* Roxb. with which the fossil shows closest affinity is a large climbing shrub growing in central and eastern Himalaya from Kumaon to Sikkim, Bihar, Central Provinces, south and west India and Myanmar (Gamble, 1972).

Genus—CYNOMETRA Linn.

CYNOMETRA PALAEOIRIPA sp. nov.

(Pl. 7, fig. 9; Pl. 10, fig. 5)

Material—This species is based on two well preserved and complete leaflets attached with a small twig.

Description—Leaflets asymmetrical, elliptic, 2.1 x 1.0 cm and 2.5 x 1.0 cm; apex slightly broken, seemingly wide acute; base wide acute; margin entire; texture chartaceous; petiole very small, indistinct; venation pinnate, eucamptodromous to brochidodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) about 8 pairs, 0.2 to 0.5 cm apart, alternate to subopposite, angle of divergence about 60^0, acute, moderate, uniformly curved up and joined to their superadjacent secondary, sometimes forming loop, rarely branched, intersecondary veins present, simple, frequent; tertiary veins (3^0) fine, angle of origin RR-AO, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate, close. Further details are not clearly seen.

Holotype—Specimen no. K 80.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From extant species *Cynometra iripa* plus suffix 'palaeo'.

Affinities—The most characteristic features of the present fossil leaflets are asymmetrical elliptic shape, wide acute apex and base, entire margin, chartaceous texture, eucamptodromous to brochidodromous venation, closely placed secondary veins arising at moderate angle of divergence, presence of intersecondary veins and percurrent, straight to sinuous tertiary veins. These features are found common in the extant leaflets of the genus *Cynometra* Linn. of the family Fabaceae. In order to find out its specific affinity, the herbarium sheets of about 12 species of this genus have been critically examined and concluded that the extant leaflets of *Cynometra iripa* Kotel (C.N. Herbarium sheet nos. 138727, 138745; Pl. 7, fig. 10) closely match in shape, size and venation pattern.

Fossil record and comparison—Awasthi and Prasad (1990) described the fossil leaflets resembling the genus *Cynometra* Linn. from the Lower Siwalik sediments of Surai Khola, western Nepal under *C. siwalika*. Later, Antal and Awasthi (1993) reported another species *C. tertiara* from the Lower-Middle Siwalik of Oodlabari, Darjeeling District, West Bengal. Both these fossil leaflets are compared with the present fossil leaflet and found that the present fossil is entirely different specially being smaller in size. The course of secondary veins too, is also different from them. In view of these the present fossil leaflet has been described as a new species *Cynometra palaeoiripa*. The specific epithet indicates its resemblance with extant *C. iripa* Kotel.

The genus *Cynometra* Linn. consists of about 60 tropical species. Of which five are found to occur in the Indian region. The extant taxa *C. iripa,* with which the fossil shows resemblance, is distributed in Indo-Malayan region.

Genus—MILLETTIA W. & A.

MILLETTIA IMLIBASENSIS sp. nov.

(Pl. 7, figs 11, 13)

Material—This species is based on a single well preserved, almost complete leaflet impression, which is devoid of cuticle.

Description—Leaflet symmetrical, narrow elliptic; preserved size 4.3 x 1.6 cm; apex wide acute; base obtuse; margin entire; texture chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight, thicker towards basal half region. Secondary veins (2^0) about 10 pairs, 0.3 to 0.6 cm apart, alternate to subopposite, angle of divergence about 60^0, acute, moderate, uniformly curved up and joining to the superadjacent secondary, unbranched, intersecondary veins present, simple; tertiary veins (3^0) fine, angle of origin usually RR, percurrent, straight to sometimes sinuous, oblique in relation to midvein, predominantly alternate and close. Further details could not be seen.

Holotype—Specimen no. K 114.

Locality—Koilabas *Nala* section near Imlibasa, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After a place, Imlibasa in Koilabas *Nala* from where the fossil was collected.

Affinities—The most characteristic features of the present fossil leaflet are symmetrical, narrow elliptic shape, wide acute apex, obtuse base, entire margin, chartaceous texture, eucamptodromous venation, moderate acute angle of divergence of secondary veins, presence of intersecondary veins and RR, percurrent, straight sinuous tertiary veins. These features are found common in the genus *Millettia* W. & A. of the family Fabaceae. A critical observation of a number of herbarium sheet of more than 30 species of *Millettia* W. & A. indicates that the present fossil is very similar to the extant leaflets of *Millettia brandisiana* Kurz. (C.N. Herbarium sheet no. 112443; Pl. 7, figs 12, 14).

Fossil record and comparison—So far, 12 fossil leaflets showing resemblance with *Millettia* W. & A. have been recorded from all over the world. They are *M. impressa* (Harms) Menzel 1920 from the Tertiary of West Africa; *M. notoensis* Ishida 1970 from the Middle Miocene of central Japan; *Millettia* sp. Huzioka & Takahasi 1970 from the Late Eocene of south Honshu, Japan; *M. asymmetrica* and *M. miocenica* Lakhanpal & Guleria 1982 from the Miocene of Kachchh, western India; *M. koilabasensis* Prasad 1990b, *M. siwalica* Prasad 1990a and *Millettia miobrandisiana* Prasad (1994e) from the Lower Siwalik sediments of Koilabas, western Nepal; *M. palaeoracemosa* Awasthi & Prasad 1990, *M. churiensis* Prasad & Awasthi 1996 from Siwalik sediments of Surai Khola, western Nepal; *M. palaeoracemosa* Awasthi & Prasad from Siwalik sediments of Kathgodam, Uttar Pradesh (Prasad, 1994c) and *M. oodlabariensis* Antal & Prasad 1996a from the Lower Siwaliks of Darjeeling District, West Bengal. After comparative study it is observed that the earlier known species are distinguishable from the present fossil in possessing narrow elliptic shape with different course of secondary and tertiary veins. In being different from all the known species a new specific name *M. imlibasensis* is proposed for the new fossil.

The genus *Millettia* W. & A. consists of 80 species (Willis, 1973) of trees, shrubs and woody climbers distributed in the tropical regions of Africa, Asia and Australia. About 30 species are reported to occur in the Indian region, half of which are trees and other half are large climbing shrubs and are mostly distributed in West Bengal and Myanmar. *M. brandisiana* Kurz. with which the fossil resembles closely is a large tree distributed in the forests of Peguyoma and Myanmar (Brandis, 1971).

Family—ANISOPHYLLEACEAE

Genus—ANISOPHYLLEA R. Br.

ANISOPHYLLEA SIWALICA Prasad & Awasthi 1996

(Pl. 8, figs 1, 2)

Material—It consists of a well preserved, almost complete specimen.

Description—Leaf simple, symmetrical, narrow ovate to elliptic; preserved size 6.3 x 3.0 cm; apex acute; base obtuse; slightly indistinct; margin slightly non-entire; texture thick chartaceous; venation acrodromous, basal, perfect; primary veins (1^0) three, one midvein and two lateral, one on each side of the midvein, prominent, stout, unbranched, midvein straight, lateral primary veins, slightly curving while approaching towards apex; secondary veins (2^0) numerous, arising acutely from lateral midveins and run upwards and join thin superadjacent veins and making appearance of intramarginal vein; tertiary veins (3^0) fine, angle of origin RR, percurrent, usually straight, sometimes curved to sinuous, rarely branched, oblique to right angle in relation to midvein, predominantly alternate and close; quaternary veins (4^0) still fine with RR origin, forming triangular to polygonal meshes.

Specimen—Specimen no. K 87.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Affinities—The diagnostic features of the present fossil leaf are narrow ovate to elliptic shape, acute apex, obtuse base, non-entire margin, acrodromous venation, acute angle of divergence of secondary veins arising from lateral midvein and making an appearance of intramarginal vein and RR, percurrent, straight to sinuous tertiary veins. These features collectively indicate its near resemblance to those of *Anisophyllea apetala* Scort. of the family Anisophylleaceae.

Fossil record and comparison—In fossil record the genus *Anisophyllea* R. Br. is known by the occurrence of its fossil leaves *Anisophyllea siwalica* from the Siwalik sediments of Surai Khola, western Nepal (Prasad & Awasthi, 1996). These fossil leaves were compared with the present fossil leaf and found that both are almost similar in shape, size and venation pattern showing no marked difference in between them. Hence, the present fossil leaf is described under the same species *Anisophyllea siwalica* Prasad & Awasthi.

The genus *Anisophyllea* R.Br. contains about 30 species distributed in the tropical regions of South Africa, Asia and South America. *Anisophyllea apetala* Scort. with which the fossil shows near resemblance is an evergreen tree found to grow in the Malayan regions (Ridley, 1967).

Family—MYRTACEAE

Genus—SYZYGIUM Gaertn.

SYZYGIUM MIOOCCIDENTALIS sp. nov.

(Pl. 8, fig. 3)

Material—It is based on a single well preserved complete leaf-impression which is devoid of cuticles.

Description—Leaf simple, symmetrical, very narrow elliptic; preserved size 7.2 x 1.5 cm; apex slightly broken, seemingly attenuate; base acute; margin entire; texture chartaceous; petiole preserved, 0.4 cm long, normal; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, slightly curved, thicker towards basal regions, secondary veins (2^0) about 17 pairs visible, usually less than 0.6 cm apart, alternate to opposite, angle of divergence about 55^0, acute, moderate, rarely branched, uniformly curved up and joined to their superadjacent forming intramarginal veins all along the margin; intersecondary veins present, frequent, 1-4 intersecondary in between two secondary veins; tertiary veins (3^0) fine, angle of origin RR-AO, percurrent, straight, branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—Specimen no. K 47.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From extant taxa *Syzygium occidentalis* plus prefix 'Mio'.

Affinities—The important distinguishing features of the fossil leaf are very narrow elliptic shape, attenuate apex, acute base, entire margin, eucamptodromous venation, presence of intersecondary and intramarginal veins and RR-AO, percurrent, tertiary veins. These morphological features suggest that the present fossil leaf shows its affinity with the leaves of extant genus *Syzygium* Gaertn. of the family Myrtaceae. A critical examination of the modern leaves of about 50 species of the genus was done and found that the modern leaf of *S. occidentalis* Bourd (*Eugenia occidentalis*) closely resembles the present fossil leaf (C.N. Herbarium sheet no. 66156; Pl. 8, fig. 4).

Fossil record and comparison—So far, six species of *Syzygium* Gaertn. based on fossil leaves, have been reported from the Tertiary sediments of India and abroad. These are *Syzygium floribundoides* Engelhardt (Muller, 1934) from the Middle Miocene of West Germany; *S. chaneyi* Huzioka & Takahasi 1970 from the Eocene of Japan; *S. kachchense* Lakhanpal & Guleria 1981 from the Eocene of Kachchh, India; *S. miocenicum* Prasad & Prakash 1984 from the Siwalik beds of Koilabas, western Nepal; *S. palaeobracteatum* Awasthi & Lakhanpal 1990 from the Siwaliks of Bhikhnathoree, Bihar; and *S. palaeocumini* Prasad & Awasthi 1996 from the Siwalik sediments of Surai Khola, western Nepal and Antal & Prasad 1997 from the Siwaliks of Darjeeling District, West Bengal. On comparing the present fossil with the already known species it is found that none of them is similar to the present fossil and hence it is being described as a new species—*S. miooccidentalis*.

The genus *Syzygium* Gaertn. consists of about 500 species of trees, shrubs and rarely climbers. They are palaeotropical in distribution (Willis, 1973). There are 79 species in India, of which about 76 species are indigenous which thrive in moist localities along the banks or in the beds of streams. It occurs in wet evergreen, semi-evergreen, moist deciduous, littoral and swamp, dry evergreen and dry deciduous forests of tropical India. *S. occidentalis* with which the fossil specimen shows closest affinity is found in the Indian region.

Family—EBENACEAE

Genus—DIOSPYROS Linn.

DIOSPYROS DARWAJENSIS sp. nov.

(Pl. 8, figs 5, 6)

Material—It consists of a well preserved almost complete leaf-impression which is devoid of cuticle.

Description—Leaf simple, symmetrical, narrow oblanceolate; preserved size 13.2 x 4.2 cm; apex broken; base obtuse; margin entire; texture coriaceous; petiole not preserved; venation pinnate, eucamptodromous to brochidodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) 7-8 pairs visible, 0.5 to 2.0 cm apart, lowest pair closely placed, usually alternate, rarely subopposite, angle of divergence about 50^0, acute, moderate, uniformly curved up and join to their superadjacent secondary at obtuse angle, sometimes join before meeting the margin and giving the appearance of brochidodromous type of venation pattern, seemingly unbranched; intersecondary veins rarely seen; tertiary veins (3^0) fine, angle of origin RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate, close; quaternary veins (4^0) still fine with RR angle of origin, branched, forming orthogonal to polygonal meshes.

Holotype—Specimen no. K 12.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After a place Darwaja in Koilabas *Nala* from where the fossil was collected.

Affinities—The most characteristic features of the present fossil leaf like narrow oblanceolate shape, obtuse base, entire margin, coriaceous texture, eucamptodromous to brochidodromous venation, course and nature of secondary vein, rare occurrence of intersecondary veins, RR, percurrent, straight to sinuous tertiary veins undoubtedly indicate its resemblance with the leaves of *Diospyros* Linn. of the family Ebenaceae. In order to find out its nearest modern equivalent, about 55 species of *Diospyros* Linn. were examined critically and found that the present fossil leaf shows closest affinity with the leaves of extant *Diospyros dasyphyllea* Kurz. (F.R.I. Herbarium sheet no. 39889).

Fossil record and comparison—The fossil leaves showing close resemblance with those of *Diospyros* have been described under two generic names, i.e., *Diospyros* Linn. and *Diospyrophyllum* Velenovsky. The later consists of only one species *Diospyrophyllum provectum* Velenovsky 1889 from the Upper Cretaceous of Bohemia. However, *Diospyros* Linn. contains about 70 species reported from different parts of the world, viz., Africa, Bohemia, Canada, Europe, England, Greek, Greenland, Japan, Panama, Switzerland and U.S.A. (Schimper, 1874; Heer, 1874; Lesquereux, 1878, 1891-92; Probost, 1884; Berry, 1916, 1918, 1919, 1930; Principi, 1921; Gothan, 1933; Salomon Calvi, 1934; Hollick, 1936; MacGinite, 1937, 1941; LaMotte, 1952; Jahnichen, 1958; Chaney & Axelrod, 1959; Kilpper, 1969; Huzioka & Uemura, 1973; Tanai, 1976). Thus it is obvious that this genus was cosmopolitan in distribution in the geological past. From the geological distribution of fossil *Diospyros* it is evident that its earliest record goes back to the Upper Cretaceous (Velenovsky, 1884).

So far, seven species have been reported from the Siwalik sediments of India and abroad. These are *Diospyros embryopterisites* Verma 1968 from the Middle Siwalik of Hardwar, Uttar Pradesh, India; *D. miocenica* Prasad & Awasthi 1996, *D. miokaki* Awasthi & Prasad 1990 from the Lower Siwalik sediments of Surai Khola, western Nepal; *D. kathgodamensis* Prasad 1994c and *D. palaeoebenum* Prasad 1994d from the Lower Siwalik of Kathgodam, Uttar Pradesh, India; *D. pretoposia* Prasad 1990a and *D. koilabasensis* Prasad 1990a from the Lower Siwalik sediments of Koilabas, western Nepal. The later species has also been reported from the Lower-Middle Siwalik of Darjeeling District, West Bengal, India and *D. tulsipurensis* Prasad *et al.* 1997 from the Lower Siwaliks of Seria Naka, at Indo-Nepal Border, in Gonda District of Uttar Pradesh, India. The present fossil leaf is compared with all the above available species and found entirely different from them in the course and nature of secondary and tertiary veins. Therefore, it has been described under a new species *Diospyros darwajensis*.

The genus *Diospyros* Linn. consists of about 500 species of trees or rarely shrubs distributed in tropical and mild temperate regions of the world, a few in South Africa and North America (Hooker, 1882; Purkayastha, 1982). About 55 species are found in the Indian region. *D. dasyphyllea* Kurz., with which the fossil resembles closely, is an evergreen tree of Martaban Hills.

Family—PROTIACEAE

Genus—HELICIA Lour.

HELICIA EOERRETICA sp. nov.

(Pl. 8, figs 7, 8)

Material—It is represented by a well preserved almost complete leaf-impression and it is devoid of cuticle.

Description—Leaf simple, symmetrical, oblanceolate; preserved size 11.5 x 4.0 cm; apex broken; base cuneate; margin entire; texture chartaceous; petiole preserved, 0.8 cm long, normal; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) 5-6 pairs visible, 1.3 to 2.8 cm apart, usually alternate, seemingly unbranched, angle of divergence about 60^0 acute, moderate, lowest pair of secondary arising more acutely, curved up and run upwards to a little distance and join to their superadjacent secondary; intersecondary veins present, simple, frequent; tertiary veins (3^0) fine, angle of origin RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, right angle near the margin, predominantly alternate and close; quaternary veins (4^0) still fine, angle of origin RR, forked, forming orthogonal to polygonal meshes.

Holotype—Specimen no. K 10.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From extant taxa *H. erretica* plus prefix 'eo'.

Affinities—The most important distinguishing features of the fossil leaf such as oblanceolate shape, cuneate base, entire margin, chartaceous texture, eucamptodromous venation, distantly placed secondaries with moderate angle of divergence running upward to a little distance, presence of intersecondary veins and RR, percurrent, straight to sinuous, tertiary veins strongly suggest that the present fossil leaf shows closest affinity with the modern leaves of *Helicia erretica* Hook.f. of the family Proteaceae (C.N. Herbarium sheet no. 13457).

Fossil record and comparison—As far as the author is aware there is no fossil record of the genus *Helicia* Lour. from the Indian subcontinent. Therefore, the present fossil leaf form its first record from the Siwalik of Koilabas, western Nepal and it has been assigned as *Helicia eoerretica* sp. nov.

The genus *Helicia* Lour. consists of about 90 species distributed in Europe, South-east Asia, Indo-Malaya, and eastern Australia. Of these, only 8 species are found to occur in the Indian region. *H. erretica* Hook.f., with which fossil resembles closely, is a small evergreen tree found in the forests of Sikkim and Shan Hills of Martaban. It is common in Darjeeling forests chiefly in open ground (Gamble, 1972).

Family—EUPHORBIACEAE

Genus—PHYLLANTHUS Linn.

PHYLLANTHUS MIORETICULATUS sp. nov.

(Pl. 9, figs 1, 3)

Material—This species is represented by seven leaflets attached on a twig.

Description—Leaflets symmetrical, elliptic, average size 2.5 x 1.3 cm; apex wide acute; base wide acute to obtuse; margin entire; texture thick chartaceous; petiolule small, 0.2 to 0.3 cm long; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) 5-6 pairs, less than 0.5 cm apart, alternate to opposite, unbranched, angle of divergence about 55^0, acute moderate, uniformly curved up and join their superadjacent secondary; intersecondary veins occasionally seen; tertiary veins (3^0) poorly preserved, fine, angle of origin RR, percurrent, straight, oblique in relation to midvein, predominantly alternate and close.

Holotype—Specimen no. K 130.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—From extant taxa *Phyllanthus reticulatus* plus prefix 'mio'.

Affinities—The diagnostic features of the present fossil leaves such as small size, elliptic shape, wide acute apex and base, entire margin, eucamptodromous venation, closely placed secondary arising at moderate angle of divergence, rare intersecondary veins and RR, percurrent, straight tertiary veins undoubtedly indicate their resemblance with the genus *Phyllanthus* Linn. of the family Euphorbiaceae. In order to find out the nearest resembling species a number of herbarium sheet of about 55 species were critically examined and concluded that the present fossils show affinity with the extant leaflets of *Phyllanthus reticulatus* Poir in shape, size and venation pattern (C.N. Herbarium sheet no. 13875; Pl. 9, figs 2, 4)

Fossil record and comparison—Four fossil leaves are known so far showing close resemblance to those of *Phyllanthus* (= *Glochidion*) from the Siwalik sediments of India and Nepal. Of these, three are from India and one is from Nepal. They are *Glochidion siwalica* Prasad 1994c from the Lower Siwalik sediments of Kathgodam, Uttar Pradesh, India; *Glochidion palaeohirsutum* Antal & Prasad 1996a from the Lower Siwaliks of Oodlabari, West Bengal, India; *Phyllanthus siwalica* Prasad 1994d from the Lower Siwaliks of Kathgodam, Uttar Pradesh, India and *Phyllanthus palaeoreticulatus* Prasad & Awasthi 1996 from the Lower Siwalik sediments of Surai Khola, western Nepal. A comparative study of both the above known fossil leaves as well as present fossil specimens indicates that the present fossils differ in being smaller in size and having different course and arrangement of secondary veins. The fossil leaf described under *Phyllanthus palaeoreticulatus* and comparable with the same extant species differs in the nature of apex and having more secondary veins as compared to the present fossils. Thus, being different, the present fossil is assigned to a new species *P. mioreticulatus*.

The genus *Phyllanthus* Linn. contains about 600 species distributed in tropical to subtropical regions of the world exclusively Eurasia and North Asia. It is a large genus comprising the plants varying in sizes, many of them more or less shruby. *Phyllanthus reticulatus* Poir. with which fossil shows closest affinity is a struggling shrub distributed throughout the greater part of India, Myanmar, and Sri Lanka. In the drier region it is commonly found in ravines and along streams (Gamble, 1972).

PHYLLANTHUS KOILABASENSIS sp. nov.

(Pl. 9, fig. 5; Pl. 10, fig. 3)

Material—It is based on a single complete leaf-impression which is devoid of cuticle.

Description—Leaflets symmetrical; preserved size 4.8 x 1.7 cm; narrow elliptic; apex obtuse; base acute; margin entire; texture coriaceous; petiolule preserved, small, 0.2 cm long; venation pinnate, eucamptodromous; primary vein (1^0) single, prominent, stout, almost straight; secondary veins (2^0) about 7-8 pairs visible, 0.3 to 0.7 cm apart, alternate to subopposite, seemingly unbranched, angle of divergence about 60^0, acute, moderate, uniformly curved up and join to their superadjacent secondary; intersecondary veins present, simple, frequent; tertiary veins (3^0) fine, poorly preserved, angle of origin RR-AO, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close. Further details could not be seen.

Holotype—Specimen no. K 138.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After the fossil locality Koilabas from where the fossil was collected.

Affinities—The important distinguishing features of the present fossil are narrow elliptic shape, obtuse apex, acute base, entire margin, small petiolule, eucamptodromous venation, somewhat closely placed secondaries with moderate acute angle of divergence, presence of intersecondary veins and percurrent tertiary. These features are found common among the species of the genus *Phyllanthus* Linn. of the family Euphorbiaceae. After a critical examination of those species it has been concluded that the extant taxa *Phyllanthus collumnaris* Muell. Arg. shows closest affinity with the present fossil in all morphological features (C.N. Herbarium sheet no. 401998; Pl. 9, fig. 6; Pl. 10, fig. 4).

Fossil record and comparison—So far five fossil leaflets resembling the genus *Phyllathus* Linn. are known from the Siwalik sediments of India and Nepal. The present fossil has been compared to those of all already known fossils and found that it is entirely different from them either in shape or in the nature of secondary and tertiary veins. Thus, being different, it is assigned to a new species *Phyllanthus koilabasensis*.

The modern comparable taxa *Phyllanthus collumnaris* is a small deciduous tree of mixed forests in Myanmar. It is common all along the rivers (Gamble, 1972).

Genus—ANTEDESMA Linn.

ANTEDESMA SIWALICA sp. nov.

(Pl. 9, fig. 7; Pl. 10, fig. 1)

Material—This species is represented by two well preserved almost complete leaf-impressions.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 11.5 x 3.6 cm and 7.2 x 3.5 cm; apex broken; base wide acute; margin entire; texture thick, chartaceous; petiole not preserved; venation pinnate, eucamptodromous venation; primary vein (1^0) single prominent, stout, slightly curved; secondary veins (2^0) about 10 pairs visible, 0.5 to 1.5 cm apart, alternate to subopposite, seemingly unbranched, angle of divergence 55^0 to 60^0, acute, moderate, uniformly curved up and run upward to join the superadjacent secondary veins, curvature more pronounced near the margin; intersecondary veins present; tertiary veins (3^0) fine, angle of origin, RR, percurrent, usually straight, branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—Specimen no. K 2.

Locality—Koilabas *Nala* section near Darwaja, Koilabas, western Nepal.

Horizon & Age—Lower Siwalik, Middle Miocene.

Etymology—After Siwalik Formation.

Affinities—Narrow elliptic shape, wide acute base, entire margin, eucamptodromous venation, specific course of secondary veins, presence of intersecondary veins and RR, percurrent tertiary veins undoubtedly indicate that the present fossils resemble closely to the extant leaves of *Antedesma montanum* Bl. and *A. cuspidatum* Muell. Arg. (C.N. Herbarium sheet no. 408750; Pl. 10, fig. 2).

Fossil record and comparison—As far as author awares there is no record of fossil leaves resembling the genus *Antedesma* Linn. from the Tertiary sediments of India and abroad. The present fossil leaves form its first occurrence in the Siwalik sediments of Koilabas, Nepal and therefore they have been described under a new species *Antedesma siwalica*.

The genus *Antedesma* Linn. consists of about 170 species distributed in tropical to subtropical regions especially in Asia. About 23 species are found to occur in India. The extant *A. montanum* Bl. is a small tree distributed in the Malayan region (Desch, 1957).

FLORISTIC ANALYSIS

The investigation on plant megafossils including mainly leaf-impressions and a fruit-impression from the Lower Siwalik sediments of Koilabas in western Nepal enhanced our knowledge of the angiospermic flora during Lower Siwalik sedimentation. The present record of fossil flora consists of a variety of mostly woody plants belonging to 25 species as listed below :

Anonaceae
- *Miliusa siwalica* sp. nov.
- *Anona koilabasensis* sp. nov.
- *Fissistigma mioelegans* sp. nov.

Polygalaceae
- *Securidaca miocenica* Prasad *et al.* 1997

Flacourtiaceae
- *Gynocardia mioodorata* sp. nov.

Clusiaceae
- *Garcinia nepalensis* sp. nov.

Dipterocarpaceae
- *Dipterocarpus koilabasensis* sp. nov.
- *Isoptera siwalica* sp. nov.
- *Shorea eutrapizifolia* sp. nov.

Simaroubaceae
- *Brucea darwajensis* sp. nov.

Sapindaceae
- *Nephelium palaeoglabrum* Prasad *et al.* 1997

Meliaceae
- *Aglaia nepalensis* sp. nov.

Anacardiaceae
- *Swintonia palaeoschwenckii* Prasad & Awasthi 1996

Fabaceae
- *Pongamia kathgodamensis* Prasad 1994c
- *Dalbergia eocultrata* sp. nov.
- *Dalbergia miovolubilis* Prasad *et al.* 1997
- *Cynometra palaeoiripa* sp. nov.
- *Millettia imlibasensis* sp. nov.

Anisophylleaceae
- *Anisophyllea siwalica* Prasad & Awasthi 1996

Myrtaceae
- *Syzygium miooccidentalis* sp. nov.

Ebenaceae
- *Diospyros darwajensis* sp. nov.

Protiaceae
- *Helicia eoerretica* sp. nov.

Euphorbiaceae
- *Phyllanthus mioreticulatus* sp. nov
- *P. koilabasensis* sp. nov.
- *Antedesma siwalica* sp. nov.

With the addition of 25 new taxa described above the megafossil assemblage of the Siwalik Group from Koilabas now consists of 79 species belonging to 53 genera of 30 angiospermous families (Table 1). They are mainly based on leaf-impressions and a fruit and seed. The fruit and seed show close affinity with the extant fabaceous genera *Pongamia* and *Entada* respectively. The assemblage is overall dominated by trees representing 59 species. The remaining species are shrubs (14 species) and climbers (6 species). The herbs are totally absent. The fabaceous taxa show overall dominance consisting of about 17 taxa in the assemblage. The earlier fossil records also show their abundance from other localities in the Siwalik foot-hills of Uttar Pradesh, Himachal Pradesh, Bihar and West Bengal in India and Nepal during Mio-Pliocene (Prakash & Tripathi, 1992; Prasad, 1993, 1994a-d; Prasad *et al.*, 1997; Antal & Awasthi, 1993; Antal & Prasad, 1995, 1996a-c, 1997; Antal *et al.*, 1996). These fabaceous taxa have not been authentically recorded from the Palaeogene sediments of India and Nepal, which indicate that they might have entered later in the Indian sub-continent during Miocene Period after the establishment of land connections from where they were flourishing. Besides, the other tropical subdominant families are Combretaceae and Dipterocarpaceae which consist of 6 and 5 taxa respectively. They are mainly distributed in India, Nepal and South east Asian regions. The genera like *Miliusa, Anona, Isoptera, Brucea, Helicia* and *Antedesma* in the present assemblage and *Sabia, Carissa, Anacolosa, Otophora* and *Tapiria* described already from Koilabas area are represented in the Tertiary flora. The present day distribution of the modern equivalents of the fossil taxa known from Koilabas area indicates their wider distribution in different geographical regions all over India and other places. In India they are distributed mostly in north east and southern regions due to prevalence of favourable climatic conditions there. The Koilabas fossil assemblage comprises those 18 taxa which are found to grow both in India and Malaya Peninsula. These are *Dillenia indica, Securidaca inappendiculata, Mesua ferrea, Dipterocarpus tuberculatus, Evodia fraxinifolia, Euphorea longana, Sabia paniculata, Bouea burmanica, Mangifera indica, Swintonia schwenckii,.Albizia lebbek, Pongamia glabra, Cassia siamea, Dalbergia sericea, Morinda umbellata, Cinnamomum inuctum* and *Ficus glaberrima*. This indicates that there has been a fair exchange of taxa between the two sub-continents. The taxa like *Ryparosa kunstelri, Otophora fruticosa, Isoptera borneonsis, Antedesma montanum*, restricted to the Malaysian region, have also been found in the present assemblage. Besides, few taxa are also found to grow in the tropical regions of Africa, China and Sri Lanka, etc.

On the basis of nearest living relatives the floral assemblage consists of 3 major types of elements : (1) Evergreen, (2) Evergreen and moist deciduous, and (3) Moist deciduous. Out of 25 taxa recorded herewith from Koilabas area, 16 taxa are evergreen, one evergreen to moist deciduous, and 8 moist deciduous. Thus, the evergreen elements dominate the fossil flora of Koilabas area (Table 2, 3) during Middle Miocene in contrast to mixed deciduous vegetation occurring today in the area (Kanji Lal, 1950).

Comparison with other Neogene flora

In order to find out the degree of resemblance with other Siwalik as well as Neogene flora of India, a comparison of the present fossil assemblage with known fossil flora has been made. Other than Siwaliks, the Neogene flora of Indian subcontinent is known from Dupitila Series, Tipam Sandstones, Namsang beds, and Dihing Group in north east India; Tertiary of West Bengal in eastern India; Cuddalore Sandstones, Neyveli lignite and Varkala beds, in south India and Tertiary of Kutch and Rajasthan in western India; Kasauli, Dharamsala and Dagshai Formations in the Himalayan foot-hills of Himachal Pradesh, India.

Himalayan foot-hills (Siwalik) flora – A variety of plant megafossils including fossil woods, leaves, flowers, fruits and seeds are known from various localities of Siwaliks and pre-Siwaliks in the Himalayan foot-hills of Uttar Pradesh, Himachal Pradesh, Bihar and West Bengal in India and Surai Khola, Arjun Khola, Arun Khola, Koilabas in western Nepal and Sindhuli District in eastern Nepal (Awasthi, 1992; Prasad, 1994a-e; Prasad *et al.*, 1997; Prasad & Awasthi, 1996; Awasthi *et al.*, 1996; Mehra *et al.*, 1990a, b, 1995; Mishra *et al.*, 1995; Antal & Awasthi, 1993; Antal & Prasad, 1996a-c; Antal *et al.*, 1996; Arya & Awasthi, 1995; Lakhanpal & Awasthi, 1992). The taxa like *Securidaca inappendiculata, Dipterocarpus turbinatus, Swintonia schwenckii, Pongamia glabra, Dalbergia volubilis, Millettia brandisiana*, found in the present assemblage are already known from other localites in the Himalayan foot-hills. It indicates that these taxa were widely distributed all along the foot-hills and flourished under equitable climate.

North east Indian flora – It is a vast area including Tipam sandstones, Dupitila Series, Namsang beds, Dihing Series and Makum Coalfield areas. A large number of fossil woods and leaves have been reported from this area by different workers. They belong to different families of Angiosperms, Gymnosperms and Pteridophytes (Chowdhury & Ghosh, 1946; Chowdhury & Tandon, 1949; Ghosh & Kazmi, 1958; Prakash & Tripathi, 1970a, b, 1972, 1974, 1975, 1976, 1977; Prakash & Lalitha, 1978; Awasthi & Mehrotra, 1997). The common taxa occurring in this region as well as in the Siwaliks of Koilabas, western Nepal are : *Mesua ferrea, Kayea floribunda, Euphorea longana, Mangifera indica, Pongamia glabra, Cassia siamea, Dalbergia sissoo, Albizia lebbek* and *Terminalia tomentosa*.

Eastern Indian flora – It includes the Bengal region and the flora comprises mainly fossil woods reported by different workers from the Tertiary sediments (Deb & Ghosh, 1974; Ghosh & Roy, 1978, 1979a, b, 1980, 1981, 1982; Roy & Ghosh, 1979a, b, 1980, 1981a, b, 1982; Bande & Prakash, 1980; Srivastava & Prakash, 1984; Srivastava & Srivastava, 1998). The common genera occurring in this region as well as in the Siwaliks of Koilabas, are *: Dipterocarpus, Shorea, Mangifera, Pongamia, Millettia, Albizia, Cynometra, Ormosia, Sophora, Terminalia, Anogeissus, Diospyros* and *Cinnamomum*.

Table 1—A list of fossil taxa recovered from the Siwalik sediments of Koilabas, western Nepal.

Fossil Taxa	Modern Equivalents	References
Anonaceae		
Miliusa siwalica sp. nov.	*M. thoretii* Finet & Gagnep.	-
Anona koilabasensis sp. nov.	*A. laurifolia* Linn.	-
Dilleniaceae		
Dillenia palaeoindica Prasad & Prakash	*D. indica* Linn.	Prasad & Prakash, 1984
Polygalaceae		
Securidaca miocenica Prasad *et al.*	*S. inappendiculata* Hask.	-
Flacourtiaceae		
Ryparosa prekunstelri Prasad	*R. kunstelri* King.	Prasad, 1990a
Gynocardia mioodorata sp. nov.	*G. odorata* R. Br.	-
Clusiaceae		
Mesua tertiara Lakhanpal	*M. ferrea* Linn.	Prasad, 1994e
Kayea kalagarhensis Prasad	*K. floribunda* Wall.	-do-
Garcinia nepalensis sp. nov.	*G. cowa* L.	-
Dipterocarpaceae		
Isoptera siwalica sp. nov.	*I. borneonsis* Br.	-
Dipterocarpus siwalicus Lakhanpal & Guleria	*D. tuberculatus* Roxb.	Prasad, 1990b
D. koilabasensis sp. nov.	*D. turbinatus* Gaertn.f.	-
Hopea mioglabra Prasad	*H. glabra* W. & A.	Prasad, 1994e
Shorea eutrapizifolia sp. nov.	*S. trapizifolia* Thw.	
Rutaceae		
Evodia koilabasensis Prasad	*E. fraxinifolia* Hook. f.	Prasad, 1994e
Murraya khariense Lakhanpal & Guleria	*M. paniculata* (Linn.) Jacq.	-do-
Atlantia miocenica Prasad	*A. monophylla* Corr.	-do-
Simaroubaceae		
Brucea darwajensis sp. nov.	*B. mollis* Wall.	-
Meliaceae		
Chloroxylon palaeoswietenia Prasad	*C. swietenia* DC.	Prasad, 1990b
Aglaia nepalensis sp. nov.	*A. euryphylla* Koor. & Valeton	-
Rhamnaceae		
Fissistigma mioelegans sp. nov.	*F. elegans* Hook.f. Thw.	Prasad. 1994e
Zizyphus miocenica Prasad	*Z. jujuba* Lam.	
Sapindaceae		
Filicium koilabasensis sp. nov.	*F. decipience* Thw.	Prasad, 1994e
Euphorea nepalensis sp. nov.	*E. longana* Lamk.	-do-
Otophora miocenica sp. nov.	*O. fruticosa* Blume	-do-
Nephelium palaeoglabrum Prasad *et al.*	*N. glabrum* Noronh.	-
Sabiaceae		
Sabia eopaniculata Prasad	*S. paniculata* Seem.	Prasad, 1994e
Anacardiaceae		
Swintonia palaeoschwenckii Prasad & Awasthi	*S. schwenckii* Teysm.	-
Bouea koilabasensis Prasad	*B. burmanica* Griff.	Prasad, 1994e
Tapiria chorkholiense Prasad	*T. hirsuta* Hook.f.	-do-
Mangifera someshwarica Lakhanpal & Awasthi	*M. indica* Linn.	-do-
Fabaceae		
Albizia siwalica Prasad	*A. lebbek* Gamble	Prasad, 1990b
Pongamia kathgodamensis Prasad	*P. glabra* Vent.	-
Cassia nepalensis Prasad	*C. hirsuta* Linn.	Prasad. 1990a
C. miosiamea sp. nov.	*C. siamea* Lam.	Prasad, 1994e
C. neosophora sp. nov.	*C. sophora* Wall.	-do-
Dalbergia eocultrata sp. nov.	*D. cultrata* Linn.	-
Dalbergia miosericea Prasad	*D. sericea* Boj.	Prasad, 1990a
D. siwalika Prasad	*D. sissoo* Roxb.	Prasad, 1994e
D. miovolubilis Prasad *et al.*	*D. volubilis* Roxb.	-
Millettia siwalica Prasad	*M. ovalifolia* Kurz.	Prasad, 1990a
M. koilabasensis Prasad	*M. macrostachya* Coll.& Hemsl.	Prasad, 1990b

M. imblibasensis sp. nov.	*M. brandisiana* Kurz.	-
M. miobrandisiana sp. nov.	*M. brandisiana* Kurz.	Prasad, 1994e
Ormosia robustoides Prasad	*O. robustoides* Jacq.	Prasad, 1990a
Cynometra palaeoiripa sp. nov.	*C. iripa* Kotel.	-
Samanea siwalica Prasad	*S. saman* Merr.	Prasad, 1994e
Entada palaeoscandens Awasthi & Prasad	*E. scandens* Benth.	-do-
Combretaceae		
Anogeissus eosericea Prasad & Prakash	*A. sericea* Brandis	Prasad & Prakash, 1984
Clycopteris floribundoides Prasad	*C. floribunda* Lam.	Prasad, 1990a
Terminalia koilabasensis Prasad	*T. angustifolia* Jacq.	-do-
T. siwalica Prasad	*T. pyrifolia* Kurz.	-do-
T. panandhroensis Lakhanpal & Guleria	*T. tomentosa* W.A.	Prasad, 1994e
Combretum sahnii Antal & Awasthi	*C. decandrum* Roxb.	-do-
Lythraceae		
Lagerstroemia siwalika Prasad	*L. lanceolata* Wall.	Prasad, 1994e
Woodfordia neofruticosa Prasad	*W. fruticosa* Kurz.	-do-
Anisophylleaceae		
Anisophyllea siwalica Prasad & Awasthi	*A. apetala* Scort.	-
Myrtaceae		
Syzygium mioceniccum Prasad & Prakash	*S. claviflorum* Roxb.	Prasad & Prakash, 1984
S. miooccidentalis sp. nov.	*S. occidentalis* Bourd.	-
Caprifoliaceae		
Lonicera mioquinquelocularis Prasad	*L. quinquelocularis* Hardw.	Prasad, 1990a
Rubiaceae		
Randia miowallichii Prasad	*R. wallichii* Hook.f.	Prasad, 1994a
Morinda siwalika Prasad	*M. umbellata* Linn.	Prasad, 1994e
Ebenaceae		
Diospyros koilabasensis Prasad	*D. montana* Roxb.	Prasad, 1990a
D. pretoposia Prasad	*D. toposia* Ham.	-do-
D. darwajensis Prasad	*D. dasyphyllea* Kurz.	-
Apocynaceae		
Tabernaemontana precoronaria Prasad	*T. coronaria* Willd.	Prasad, 1990a
Carissa koilabasensis Prasad	*C. paucinervia* A. Dc.	Prasad, 1994e
Loganiaceae		
Gaertnera siwalica Prasad	*G. bieleri* (D.Willd. E. Petit)	Prasad, 1990a
Solanaceae		
Datura miocenica Prasad	*D. fastuosa* Linn.	Prasad, 1994e
Oleaceae		
Anacolosa mioluzoniensis sp. nov.	*A. luzoniensis* Merr.	Prasad, 1994e
Verbenaceae		
Vitex prenegundo Prasad	*V. negundo* Linn.	Prasad, 1990a
V. siwalica Prasad	*V. pubescens* Vahl.	-do-
Lauraceae		
Cinnamomum mioinuctum Prasad	*C. inuctum* Meissn.	Prasad, 1990a
Moraceae		
Ficus precunia Lakhanpal	*F. cunia* Ham.	Prasad, 1990a
F. retusoides Prasad	*F. retusa* Linn.	-do-
F. nepalensis Prasad	*F. glaberrima* Blume	-do-
Protiaceae		
Helicia eoerretica sp. nov.	*H. erretica* Hook.f.	-
Euphorbiaceae		
Phyllanthus koilabasensis sp. nov.	*P. collumnaris* Muell-Arg.	-
P. mioreticulatus sp. nov.	*P. reticulatus* Poir.	-
Antedesma siwalica sp. nov.	*A. montanum* Bl.	-

Table 2—Present day distribution and forest types of comparable taxa of fossils recovered from the Siwalik sediments of Koilabas, western Nepal.

Fossil Taxa	Modern Equivalents	Distribution	Forest type
Anonaceae			
Miliusa siwalica sp. nov.	*M. thoretii* Finet & Gagnep.	India, China	Moist deciduous
Anona koilabasensis sp. nov.	*A. laurifolia* Linn.	Java	Evergreen
Dilleniaceae			
Dillenia palaeoindica Prasad & Prakash, 1984	*D. indica* Linn.	India, Myanmar	Moist evergreen
Polygalaceae			
Securidaca miocenica Prasad *et al.* 1997	*S. inappendiculata* Hask.	N.E. India, Java	Evergreen to Moist deciduous
Flacourtiaceae			
Ryparosa prekunstelri Prasad, 1990a	*R. kunstelri* King.	Malaya	Evergreen
Gynocardia mioodorata sp. nov.	*G. odorata* R.Br.	N.E. India, Burma	Evergreen
Clusiaceae			
Mesua tertiara (Lakhanpal) Prasad, 1990a	*M. ferrea* Linn.	North east India, Myanmar, Malaya	Evergreen
Kayea kalagarhensis Prasad, 1993	*K. floribunda* Wall.	North east India, Myanmar	Evergreen
Garcinia nepalensis sp. nov.	*G. cowa* L.	N.E. India, Bangladesh, Burma	Evergreen
Dipterocarpaceae			
Isoptera siwalica sp. nov.	*I. borneonsis* Br.	Java, Burma	Evergreen
Dipterocarpus siwalicus (Lakhanpal & Guleria) Prasad, 1990b	*D. tuberculatus* Roxb.	North east India, Myanmar, South east Asia	Evergreen to moist deciduous
D. koilabasensis sp. nov.	*D. turbinatus* Gaertn.f.	N.E. India, Bangladesh, Burma	Evergreen
Hopea mioglabra Prasad, 1994e	*H. glabra* W. & A.	South India	Evergreen
Shorea eutrapizifolia sp. nov.	*S. trapizifolia* Thw.	Ceylon	Evergreen
Rutaceae			
Evodia koilabasensis Prasad, 1994e	*E. fraxinifolia* Hook. f.	North east India, Malaya, Nepal	Evergreen to Moist deciduous
Murraya khariensis (Lakhanpal & Guleria) Prasad, 1994e	*M. paniculata* (Linn.) Jacq.	Sub Himalayan region, Myanmar, Andman, Sri Lanka, Australia	Moist deciduous to evergreen
Atlantia miocenica Prasad, 1994e	*A. monophylla* Corr.	South and North India, Myanmar, Andman	Evergreen
Simaroubaceae			
Brucea darwajensis sp. nov.	*B. mollis* Wall.	N.E. India, Burma	Evergreen
Meliaceae			
Chloroxylon palaeoswietenia Prasad, 1990a	*C. swietenia* DC.	India, Sri Lanka	Moist deciduous
Aglaia nepalensis sp. nov.	*A. euryphylla* Koor. & Valeton	Java	Evergreen
Rhamnaceae			
Zizyphus miocenica Prasad, 1994e	*Z. jujuba* Lam.	India, Myanmar	Deciduous
Fissistigma mioelegans sp. nov.	*F. elegans* Hook.f.Thw.	Malaya, Malucca	Evergreen
Sapindaceae			
Filicium koilabasensis Prasad, 1994e	*F. decipience* Thw.	South India, Sri Lanka, Tropical Africa	Evergreen
Euphorea nepalensis Prasad, 1994e	*E. longana* Lamk.	South and North India, Myanmar, Malaya	Evergreen to moist deciduous
Otophora miocenica Prasad, 1994e	*O. fruticosa* Blume.	Malaya	Evergreen

Nephelium palaeoglabrum Prasad *et al.*, 1997	*N. glabrum* Noronh.	Malaya	Evergreen
Sabiaceae			
Sabia eopaniculata Prasad, 1994e	*S. paniculata* Seem.	Sub-Himalayan region, Myanmar, Malaya	Evergreen to moist deciduous
Anacardiaceae			
Swintonia palaeoschwenckii Prasad & Awasthi, 1996	*S. schwenckii* Teysn.	India, Burma, Malaya	Evergreen
Bouea koilabasensis Prasad, 1994e	*B. burmanica* Griff.	South India, Andman, Myanmar	Evergreen
Tapiria chorkholiense Prasad, 1994e	*T. hirsuta* Hook. f.	North east India, Nepal, Bhutan	Moist deciduous
Mangifera someshwarica (Lakhanpal & Awasthi) Prasad, 1994e	*M. indica* Linn.	India, Malaya	Evergreen to deciduous
Fabaceae			
Pongamia kathgodamensis Prasad 1994a	*P. glabra* Vent.	India, Sri Lanka, Malaya	Evergreen to moist deciduous
Albizia siwalica Prasad, 1990b	*A. lebbek* Gamble	North east India, Myanmar	Moist deciduous
Cassia nepalensis Prasad, 1990a	*C. hirsuta* Linn.	Central India	Deciduous
C. miosiamea Prasad, 1994e	*C. siamea* Lam.	India, Myanmar, Malaya	Moist deciduous
C. neosophora Prasad, 1994e	*C. sophora* Wall.	South east Asia	Moist deciduous
Dalbergia eucultrata sp. nov.	*D. cultrata* L.	India, Burma	Moist deciduous
D. miovolubilis Prasad *et al.*, 1997	*D. volubilis* Roxb.	India, Nepal	Moist deciduous
D. miosericea Prasad, 1990b	*D. sericea* Boj.	Sub-Himalayan region, Madagascar	Deciduous
D. siwalika Prasad, 1994e	*D. sissoo* Roxb.	Sub-Himalayan region,	Deciduous
Millettia siwalica Prasad, 1990a	*M. ovalifolia* Kurz.	Sub-Himalayan region, Myanmar	Moist deciduous
M. inlibasensis sp. nov.	*M. brandisiana* Kurz.	Myanmar	Moist deciduous
M. koilabasensis Prasad, 1990b	*M. macrostachya* Coll.& Hemsl.	Myanmar	Evergreen
M. miobrandisiana Prasad, 1994e	*M. brandisiana* Kurz.	Myanmar	Moist deciduous
Ormosia robustoides Prasad, 1990b	*O. robusta* Jacq.	Northeast India, Myanmar	Evergreen
Samanea siwalika Prasad, 1994e	*S. saman* Merr.	Tropical Africa, America	Evergreen
Entada palaeoscandens (Awasthi & Prasad) Prasad, 1994e	*E. scandens* Benth.	India, Burma	Moist deciduous
Cynometra palaoirripa sp. nov.	*C. irripa* Kotel.	India	Moist deciduous
Combretaceae			
Anogeissus eosericea Prasad & Prakash, 1984	*A. sericea* Brandis	Central India	Deciduous
Clycopteris floribundoides Prasad, 1990a	*C. floribunda* Lam.	North east India, Myanmar, Western Peninsula	Deciduous
Terminalia koilabasensis Prasad, 1990a	*T. angustifolia* Jacq.	Malaya	Evergreen
T. siwalica Prasad, 1990a	*T. pyrifolia* Kurz.	Myanmar	Evergreen to moist deciduous
T. panandhroensis (Lakhanpal & Guleria) Prasad, 1994e	*T. tomentosa* W.A.	Sub-Himalayan region, Myanmar	Moist deciduous
Combretum sahnii (Antal & Awasthi) Prasad, 1994e	*C. decandrum* Roxb.	Sub-Himalayan region, Bangladesh, Central India	Deciduous
Lythraceae			
Lagerstroemia siwalica Prasad, 1994e	*L. lanceolata* Wall.	Western Peninsula	Moist deciduous

Woodfordia neofruticosa Prasad, 1994e	*W. fruticosa* Kurz.	Sub-Himalayan region, Tropical Africa, Arabia, Both Peninsula	Moist deciduous
Anisophylleaceae			
Anisophyllea siwalica Prasad & Awasthi, 1996	*A. apetala* Scort.	Malaya	Evergreen
Myrtaceae			
Syzygium mioceniccum Prasad & Prakash, 1984	*S. claviflorum* Roxb.	North east India, Andman, Myanmar	Evergreen to moist deciduous
Syzygium miooccidentalis sp. nov.	*S. occidentalis* Bourd.	India	Moist deciduous
Caprifoliaceae			
Lonicera mioquinquelocularis Prasad, 1990a	*L. quinquelocularis* Hardw.	North west Himalaya, Nepal, India	Deciduous
Rubiaceae			
Randia miowallichii Prasad, 1990a	*R. wallichii* Hook. f.	North east India, Myanmar, Andman	Evergreen
Morinda siwalica Prasad, 1994e	*umbellata* Linn.	South and North east India, Sri Lanka, Malaya	Evergreen
Ebenaceae			
Diospyros koilabasensis Prasad, 1990a	*D. montana* Roxb.	India, Myanmar, Sub-Himalayan region	Deciduous
D. pretoposia Prasad, 1990a	*D. toposia* Ham.	North east India, Bangladesh, Sri Lanka	Evergreen
D. darwajensis sp. nov.	*D. dasyphyllea* Kurz.	Martaban	Evergreen
Apocynaceae			
Tabernaemontana precoronaria Prasad, 1990a	*T. coronaria* Willd.	Sub-Himalayan region, Sri Lanka, Myanmar	Deciduous
Carissa koilabasensis Prasad, 1994e	*C. paucinervia* A. Dc.	North east India, Myanmar	Evergreen
Loganiaceae			
Gaertnera siwalica Prasad, 1990a	*G. bieleri* (D. Willd.) E. Petit	Tropical Africa	Evergreen
Solanaceae			
Datura miocenica Prasad, 1990a	*D. fastuosa* Linn.	India, Malaya, Tropical Africa	Deciduous
Oleaceae			
Anacolosa mioluzoniensis Prasad, 1994e	*A. luzoniensis* Merr.	South east Asia	Evergreen
Verbenaceae			
Vitex prenegundo Prasad, 1990a	*V. negundo* Linn.	India, Sri Lanka, China	Deciduous
V. siwalica Prasad, 1990a	*V. pubescens* Vahl.	India, Myanmar	Evergreen
Lauraceae			
Cinnamomum mioinuctum Prasad, 1990a	*C. inuctum* Meissn.	Myanmar, Malaya	Evergreen to moist deciduous
Moraceae			
Ficus precunia (Lakhanpal) Prasad, 1990a	*F. cunia* Ham.	Sub-Himalayan region, Assam, Myanmar	Deciduous
F. retusoides Prasad, 1990a	*F. retusa* Linn.	India, Malaya	Evergreen
F. nepalensis Prasad, 1990a	*F. glaberrima* Blume	India, Malaya	Evergreen
Protiaceae			
Helicia eoerretica sp. nov.	*H. erretica* Hook.f.	N.E. India, Martaban	Evergreen
Euphorbiaceae			
Phyllanthus koilabasensis sp. nov.	*P. collumnaris* Muell.Arg.	Burma	Deciduous
P. mioreticulatus sp. nov.	*P. reticulatus* Poir.	India, Burma, Ceylon	Deciduous
Antedesma siwalica sp. nov.	*A. montanum* Bl.	Malaya	Evergreen

South Indian flora – The Neogene flora of south India is known from the Cuddalore Sandstones, Neyveli lignite and Varkala beds. The Cuddalore Sandstones are well known for the occurrence of petrified woods which have been studied in detail by Awasthi, 1974, 1975a, b, 1977a, b, 1979, 1980, 1981). The Neyveli lignites in Tamil Nadu are rich in almost all botanical entities such as carbonised woods, leaf-impressions and compressions, stems, roots, pollen, spores, algal and fungal bodies. The plant megafossils from this area have been studied by Ambwani (1982), Awasthi (1984), Awasthi and Agarwal (1986) and Agarwal (1989, 1991).

The study on the carbonised woods from the Varkala beds in Kerala Coast reveals the occurrence of a number of taxa belonging to different angiospermous families (Awasthi & Ahuja, 1982; Awasthi & Panjwani, 1984; Awasthi & Srivastava, 1989, 1990, 1992; Srivastava & Awasthi, 1994, 1996; Srivastava, 1998). After comparison of the present Koilabas assemblage with those of south Indian floral assemblages it has been surmised that most of genera like *Mesua, Dipterocarpus, Hopea, Shorea, Mangifera, Bouea, Garcinia, Euphorea; Albizia, Cassia, Millettia, Pongamia, Cynometra, Anogeissus, Terminalia, Anisophyllea; Lagerstroemia, Diospyros* and *Cinnomomum* are found common in both of them.

Western Indian flora – It includes the area of Rajasthan and Kutch. From the Tertiary (Palaeogene and Neogene) of Kutch a large number of fossil woods, leaves, fruits and seeds have been reported by Lakhanpal and Guleria (1981, 1982) and Guleria (1983, 1984). While, from Rajasthan area only fossil woods are known belonging to different families of angiosperms and gymnosperms (Lakhanpal & Bose, 1951; Guleria, 1990). A comparison of the present Koilabas assemblage with that of Western Indian flora shows that the common genera *Mesua, Dipterocarpus Murraya, Mangifera, Pongamia, Albizia, Millettia, Cassia, Cynometra, Terminalia, Syzygium, Lagerstroemia, Diospyros, Cinnamomum* and *Ficus* are common, which obviously indicates that there was more or less equitable climate and homogeneity in the floristic composition of various Neogene assemblages in the Indian subcontinent.

PALAEOCLIMATE AND PALAEOECOLOGY

The present is the key to the past. The principal basis to any study of the past is the principle of 'Uniformity in the order of nature'. This principle implies on the physical and biological processes which like todays environment as well as vegetation must have been in the operation since past. Likewise, the type of weather variation and climatic conditions as observed today must also occurred in the past. Cain (1944) further opines that the best approach to the study of palaeoclimate or palaeoecology of a particular area is to compare the fossil floras with the modern vegetation and to know the existing climatic conditions. It is rather difficult to deduce the precise palaeoecology of an area prior to the Tertiary Period, because the modern vegetation is quite different from those of earlier periods. The study becomes more accurate as we go from Palaeocene upward until the Pliestocene as the modern equivalents of the fossil forms still exist in the present day vegetation and obviously the fossils could satisfactorily be compared and identified with the modern taxa.

Thus, the Tertiary fossil plants are supposed to be the reliable indicators of past climate specially those that are referable to modern taxa. The accuracy of interpretations based on them is inversely proportional to the geological ages of the deposits from which the fossils are collected. As the plant fossils for the present study have been collected from the Middle Miocene sediments and the modern equivalents of these fossil forms still exist in the forests, it has, therefore become easier to deduce the palaeoclimate and palaeoecology of the Koilabas area in the Himalayan foot-hills of western Nepal during sedimentation.

The other parameters for deducing palaeoclimate are the physiognomic characters of plant fossils. In the presence of exclusively leaf-impressions in any floral assemblage, this parameter plays a deciphering role in interpreting the palaeoclimate and palaeoecology. Further, this is an independent of systematic relationship of the species and therefore, it is likely that the errors in interpretation are minimum.

On the basis of plant megafossils especially leaf-impressions, the interpretation regarding palaeoclimate and palaeoecology can be drawn by two methods :

(i) Nearest living relative method, i.e., from comparison of the leaf-impressions with the extant taxa.
(ii) Foliar physiognomy method, i.e., from study of the structural features of leaf-impressions.

Nearest living relative method

This extrapolates known climatic requirement of modern taxa with the comparable and related taxa in the past. The plant fossils recovered from Koilabas localities have been compared with their modern equivalents and it has been observed that a few of them still exist in the area. Therefore, it is easier to infer the palaeoclimate of the region during sedimentation.

The fossil plants obtained so far from the Siwalik sediments of the Koilabas area comprise 79 elements which were compared with modern taxa (Table 1). The present habit and habitat of the recorded taxa show that they mostly occur in the tropical evergreen and moist deciduous forests of north east India, Bangladesh, Myanmar and Malaya and adjoining areas receiving higher rainfall (Gamble, 1972; Hooker, 1879, 1882, 1885; Champion & Seth, 1968; Desch, 1957; see Ta-

Table 3—Distribution of comparable extant taxa of fossils recovered from the Siwalik sediments of Koilabas in various tropical forest types.

	TROPICAL FOREST TYPES						
Modern Equivalent TAXA	Wet evergreen forest	Semi evergreen forest	Moist deciduous forest	Littoral and Swamp forest	Dry deciduous forest	Thorn forest	Dry evergreen forest
1	2	3	4	5	6	7	8
Anona laurifolia	+	+	+				
Miliusa thoretii	+	+	+				
Dillenia indica	+	+	+				
Securidaca inappendiculata			+				
Ryparosa kunstelri	+						
Gynocardia odorata	+	+					
Mesua ferrea	+	+					
Kayea floribunda	+						
Garcinia cowa	+	+					
Dipterocarpus tuberculatus	+		+				
D. turbinatus	+	+					
Hopea glabra	+						
Isoptera borneonsis	+	+					
Shorea trapizifolia	+	+	+				
Evodia fraxinifolia	+		+				
Murraya paniculata			+		+		
Atlantia monophylla	+						
Brucea mollis		+	+				
Chloroxylon swietenia			+		+		
Agalia euryphyllea	+	+					
Zizyphus jujuba			+		+		
Filicium decipiense	+						
Nephelium glabrum	+						
Euphorea longona	+		+				
Otophora fruticosa	+						
Sabia paniculata	+		+				
Bouea burmanica	+						
Swintonia schwenckii	+		+				
Tapiria hirsuta			+				
Mangifera indica	+		+				
Pongamia glabra			+	+			
Albizia lebbek	+	+	+				
Cassia hirsuta			+		+		
C. laevigata			+				
C. siamea			+				
C. sophora		+	+				
Dalbergia sericea			+				
D. cultrata		+		+			
D. sissoo			+				
D. volubilis		+		+			
Millettia ovalifolia	+						
M. macrostachya	+	+					
M. brandisiana			+				
Ormosia robusta	+	+					
Cynometra iripa	+	+					
Samanea saman	+						
Entada scandens		+	+				
Anogeissus sericea			+				
Calycopteris floribunda			+		+		
Terminalia angustifolia	+	+					
T. pyrifolia	+	+	+				
T. tomentosa			+				
Combretum decandrum		+	+				
Lagerstroemia lanceolata		+	+				
Woodfordia fruticosa			+		+		
Anisophyllea apetala	+	+					
Syzygium claviflorum	+	+	+	+			
S. occidentalis		+					
Lonicera quinquelocularis	+		+				
Randia wallichii	+		+				
Morinda umbellata	+						
Diospyros montana			+		+		
D. dasyphyllea	+	+					
D. toposia	+						
Tabernaemontana coronaria			+				
Carissa paucinervia	+	+					
Gaertnera bieleri	+	+	+				
Datura fastuosa			+				
Anacolosa luzoniensis	+						
Vitex negundo			+		+		
V. pubescens	+						
Cinnamomum inuctum	+	+					
Ficus cunia			+		+		
F. retusa	+						
F. glaberrima	+	+					
Helicia eratica	+						
Phyllanthus collumnaris		+	+	+			
P. reticulatus		+	+	+			
Antedesma montanum	+	+	+				

bles 2, 3). Thus it may be surmised that a warm and humid climate prevailed in the Koilabas area at the time of deposition in contrast to the present relatively dry climate. The predominance of evergreen elements in the assemblage further indicates the prevalence of tropical (warm humid) climate with plenty of rainfall. Most of the taxa represented in the fossil assemblage do not occur in the Koilabas area or all along the Himalayan foot-hills of both India and Nepal (Table 2). This obviously indicates that changes in the climate must have taken place after the deposition of Siwalik sediments in the Koilabas area.

The change in climate since the Middle Miocene can also be explained by a general global cooling and by the events within the region, particularly the Himalayan uplift and shallowing of the Tethys sea which progressively changed from marine through estuarine to fresh water environment (Mukherjee, 1982). These climate and physiographic changes made the environment hostile for the endemic flora which was gradually replaced by the present day mixed deciduous forest.

Foliar physiognomy method

The study of structural features of fossil angiospermous leaves such as size, venation, density, texture, margin, shape and tip, etc. has a great relationship with climate and thus provides more reliable results (Table 4). As this method is independent of the systematic relationship of the species, the errors in the interpretation of palaeoclimate are minimized as compared to the above nearest living relative method. The detailed physiognomic study of the fossil leaves recovered from the Siwalik sediments of Koilabas area, Nepal provides considerable data on climatic conditions prevailing at the time of sedimentation.

The best indicator of climate appears to be the leaf margin, viz., entire versus non-entire. Typical entire margined leaves of woody families like Anonaceae, Lauraceae, Ebenaceae, Clusiaceae, Sapotaceae, Dipterocarpaceae and Apocynaceae, etc. are practically absent from mesophytic cold temperate regions. On the contrary, non-entire leaved families as Betulaceae, Aceraceae, Platanaceae, etc. are absent from low land tropical areas. Nevertheless, the families like Malvaceae, Rosaceae, Ulmaceae, Fagaceae, Tiliaceae, Flacourtiaceae, Anacardiaceae and Fabaceae bear both types of leaf margins, i.e., entire and non-entire. According to Bailey and Sinnott (1916) the woody plants of tropical low lands possess entire margins, while in temperate they possess non-entire margins. Similarly, Wolfe (1969) concluded that the tropical rain forests have the highest percentage of entire margined species. This percentage decreases with decreasing temperature either with increasing altitude to the submontane and montane rain forests or with increasing latitude to the warm temperate forest. This criterion, when applied to the Siwalik flora of the Koilabas area, reveals that all the species except three taxa, i.e., *Dillenia palaeoindica, Datura miocenica* and *Anisophyllea siwalica*, have entire margin indicating a warm tropical climate (Table 4).

Besides, leaf size is another important indicator of climate. It has been seen that leaf size distribution in any forest type is correlated with available moisture and it is found bigger in the understory elements of humid evergreen forests but decreases with low temperature or precipitation. Raunkiaer (1934) suggested that the percentage of species having large leaves should be highest on the piedmont somewhat higher on the mountain in order to correlate with precipitation. Further, Givinish (1976) has also postulated that optimal size, as determined by the balance between transpiration rate and phytosynthesis, should be greatest in the tropics, decreases in the subtropics and increases in the warm temperate forests.

According to Raunkiaer (1934) and later modified by Webb (1959) the leaf size may be measured typically by 5 size classes, viz., leptophyll (up to 0.25 sq cm), nanophyll (0.25-2.25 sq cm), microphyll (2.25-20 sq cm), mesophyll (20-182 sq cm) and macrophyll (182-1640 sq cm). According to this classification the floral elements obtained from Koilabas area possess mainly microphyll and mesophyll type of leaves as shown below :

Application of the above criterion to the Koilabas assemblage in which most of the taxa possess optimal sized leaves (Table 4) again indicates that a tropical humid climate prevailed in the area during Middle Miocene.

The 'Drip tip', an extended leaf tip, is also another important physiognomic feature of angiospermous leaves and is generally seen in wet tropical forest elements (Dorf, 1969). The function of the drip tip is to hasten the run off of water from the leaf. Richards (1952) pointed out that it facilitates them to retard the growth of epiphytes. The deciduous leaves generally lack drip tip because of their short life span. In the present assemblage about 22 taxa possess conspicuous drip tips. In some specimens the tips either got broken or indistinct due to bad preservation. Thus, it also shows the prevalence of tropical humid climate around Koilabas area during Siwalik sedimentation.

Five other physiognomic features that have been used as an aid in determining the past climate are :

1. Organisation–compound versus simple leaves
2. Major venation pattern
3. Venation density
4. Leaf texture
5. Leaf base shape

These characters are less useful than margin type, leaf size and drip tips and some of them are also difficult to analyse in the fossil material. The organisation of leaves as simple or compound has been correlated with available moisture or precipitation. Dolph and Dilcher (1979) postulated that the percentage of simple leaves increases from piedmont to both mountain and coastal regions where precipitation is higher. Since majority of elements in the Siwalik flora of Koilabas area possesses simple leaves indubitably indicating higher precipitation during Middle Miocene.

Thus from the foregoing discussion it may be concluded that the Himalayan foot-hills near Koilabas in western Nepal enjoyed a tropical climate with plenty of rainfall during the Siwalik sedimentation. This is, however, contrary to the present day climate of the area with reduced precipitation.

PHYTOGEOGRAPHY

Phytogeography is the other important aspect of palaeobotany which deals with the study of fossil flora to know the past distribution and migration of vegetation especially since Tertiary Period. In the orogenic movement of Himalaya, Middle Miocene Period has been considered as the most important. During this period several significant changes occurred in physiography, environment and floral characteristics. With the result, the older life forms which could not accommodate themselves to the new environment gradually perished and in their place new plants or animals came into existence and flourished. The geological events in the region strongly influenced the phytogeography of the region during Siwalik Period through the establishment of land connections between India and South-east Asia (Smith & Briden, 1979). A number of plants migrated from South-east Asia to India via Myanmar and vice versa. With the result, many taxa, especially members of Dipterocarpaceae and Fabaceae which were present during the Palaeogene in South-east Asia appeared in the Neogene on the Indian subcontinent.

The present day distribution of modern equivalents of all 79 species recovered from the Siwaliks of Koilabas, western Nepal shows that they are presently known to grow in different geographical regions all over India, Nepal and other places (Table 2). In India, they are distributed mostly in north east and southern regions wherever favourable climatic conditions are available. In this assemblage, there are those 18 taxa which are found to grow both in India and Malaya peninsula. They are *Dillenia indica, Mesua ferrea, Securidaca inappendiculata, Dipterocarpus tuberculatus, Evodia fraxinifolia, Euphorea longana, Sabia paniculata, Bouea burmanica, Mangifera indica, Swintonia schwenckii, Albizia lebbek, Cassia siamea, Dalbergia sericea, Pongamia glabra, Morinda umbellata, Cinnamomum inuctum, Ficus retusa* and *F. glaberrima* which clearly indicate that there has been a fair exchange of floral elements between the two subcontinents after the land connections were established during the Miocene Period.

Similarly, 7 taxa in the Koilabas assemblage have a restricted distribution in the Malayan region. These are *Ryparosa kunstelri, Otophora fruticosa, Isoptera borneonsis, Nephelium glabrum, Anisophyllea apetala, Aglaia euryphylla* and *Antedesma montanum* obviously suggesting that these taxa migrated from Malaya to India during Neogene and flourished around Koilabas area at the time of deposition of Siwaliks. Later, they disappeared from the area probably due to unfavourable environmental conditions.

About 23 taxa in the Koilabas assemblage still grow in north-east India, Bangladesh and Myanmar (Table 2). These are *Kayea floribunda, Tapiria hirsuta, Gynocardia odorata, Garcinia cowa, Dipterocarpus turbinatus, Brucea mollis, Dalbergia cultrata, Millettia ovalifolia, M. macrostachya, M. brandissiana, Ormosia robusta, Calycopteris floribunda, Terminalia pyrifolia, T. tomentosa, Syzygium claviflorum, Randia wallichii, D. diospyros, D. montana, D. toposia, D. dasyphyllea, Helicia erretica, Tabernaemontana coronaria, Carissa paucinervia* and *Ficus cunia*. This suggests that these taxa were present during Middle Miocene in the foot-hills near Koilabas area but do not grow now a days there and thus they have migrated toward east in Assam, Bengal, Sikkim, Meghalaya, Bangladesh and Myanmar because of better favourable conditions.

Table 2 indicates that there are few taxa which are found to grow still at different altitudes in the foot-hills near Koilabas and adjoining areas. These are *Murraya paniculata, Zizyphus jujuba, Mangifera indica, Dalbergia sissoo, D. volubilis, Terminalia tomentosa, Combretum decandrum, Woodfordia fruticosa, Diospyros montana, Datura fastuosa, Vitex negundo* and *Ficus cunea* suggesting that they have susceptibility to adopt in the new climatic conditions prevailing after Middle Miocene mainly due to further rise of Himalaya.

Leaf size	No. of fossil taxa	Percentage
Leptophyll	-	-
Nanophyll	1	1.25
Microphyll	41	50.50
Mesophyll	36	45.75
Macrophyll	2	2.50

Thus, the survey of the fossil plants obtained from the Lower Siwaliks of Koilabas area and the present day distribution of their modern equivalents indicate that all the taxa can be classified into 3 types :

1. Extant taxa – Those taxa which have their living counterparts growing in or near the fossil locality.
2. Exotic taxa – Those taxa which grow in other parts of India and Nepal.
3. Extinct taxa – Those taxa which have disappeared from India and Nepal regions and now grow in other parts of the world.

There may be two possible explanations for the different

Table 4—Physiognomic characters of the fossil flora recovered from the Siwalik sediments of Koilabas area, western Nepal.

	PHYSIOGNOMIC CHARACTERS							
Fossil Taxa	Average leaf size sq. cm	Leaf margin entire(E) non-entire(N)	Drip tips presence (P) absenence (A) indistinct(-)	Nature of Petiole normal(N) indistinct(-)	Leaf texture chartaceous (CH) coriaceous (CO)	Leaf base shape acute(A) obtuse(O) cuneate(C) cordate(CR) attenuate(AT) indistinct (-)	Leaf Organization Compound VS Simple	Venation pattern Close(C) Distant(D)
1	2	3	4	5	6	7	8	9
Anona koilabasensis	13.8 49.5	E	-	-	CH	O	S	C
Miliusa siwalica	42.75	E	-	-	CO	-	S	C
Dillenia palaeoindica	52.50	N	-	-	CH	-	S	C
Securidaca miocenica	24.00	E	-	-	CO	O	S	C
Ryparosa prekunstelri	61.92	E	-	N	CO	A	S	D
Gynocardia mioodorata	32.75	E	-	-	CO	A	S	D
Mesua tertiara	10.00	E	P	N	CH	A	S	C
Kayea kalagarhensis	41.60	E	-	N	CO	A	S	C
Garcinia nepalensis	35.00	E	-	N	CO	A	S	C
Dipterocarpus siwalicus	66.00	E	P	N	CH	O, CR	S	D
	190.00	E	-	N	CH	O	S	D
D. koilabasensis	236.25	E	-	-	CO	-	S	C
Shorea eutrapizifolia	13.25	E	-	-	CO	A	S	C
Hopea mioglabra	28.44	E	-	-	CO	A	S	D
Isoptera siwalica	34.20	E	-	-	CH	O	S	D
Evodia koilabasensis	20.90	E	-	-	CH	O	C	C
Murraya khariense	07.30	E	A	-	CO	A	C	D
Atlantia miocenica	05.22	E	-	-	CH	A	C	C
Brucea darwajensis	O8.27	E	P	N	CO	A	S	C
Chloroxylon palaeoswietenia	05.60	E	-	-	CH	A	C	C
Aglaia nepalensis	25.50	E	-	-	CH	-	C	C
Zizyphus miocenica	05.60	E	-	-	CH	O	S	D
Fissistigma mioelegans	17.48	E	P	-	CO	O	S	C
Filicium koilabasensis	26.25	E	P	N	CH	A	S	C
Euphorea nepalensis	27.00	E	P	-	CO	A	S	C
Nephelium palaeoglabrum	41.00	E	-	-	CO	A	S	C
Otophora miocenica	14.25	E	A	S	CO	-	S	D
Sabia eopaniculata	21.98	E	P	-	CH	-	S	C
Bouea koilabasensis	12.00	E	P	N	CO	A	S	D
Swintonia palaeoschwenckii	13.50	E	-	N	CH	O	S	C
Tapiria chorkholiense	11.25	E	-	-	CO	O	S	D
Mangifera someshwarica	26.40	E	P	N	CH	A	S	D
Albizia siwalica	07.50	E	A	N	CO	A	C	D
Casssia. nepalensis	10.08	E	P	-	CH	O	C	D
C. miosiamea	05.25	E	A	N	CH	O	C	C
C. neosophora	03.80	E	A	N	CH	O	C	C
Dalbergia miosericea	14.40	E	A	N	CH	A	C	D
D. eucultrata	06.46	E	A	-	CH	A	C	C
D. siwalica	07.20	E	-	-	CH	O	C	C

D. miovolubilis	02.00	E	-	N	CH	A	C	C
M. koilabasensis	28.40	E	P	-	CH	A	C	D
M. miobrandisiana	02.53	E	-	-	CH	O	C	D
M. imlibasensis	07.48	E	-	-	CH	O	C	C
Ormosia robustoides	35.00	E	P	-	CH	O	C	C
Cynometra iripa	02.80	E	A	N	CH	A	C	C
Samanea siwalica	02.00	E	-	-	CH	O	C	D
Anogeissus eosericea	10.75	E	-	N	CH	O	S	D
Calycopteris floribundoides	12.48	E	P	-	CO	O	S	D
Terminalia koilabasensis	11.20	E	P	-	CH	A	S	D
T. siwalica	35.60	E	P	N	CO	A	S	D
T. panandhroensis	57.60	E	-	N	CO	O	S	D
Combretum palaeodecandrum	15.75	E	P	-	CH	-	S	D
Lagerstroemia siwalica	42.00	E	-	-	CH	-	S	D
Woodfordia neofruticosa	03.00	E	-	-	CO	CR	C	D
Anisophyllea siwalica	20.80	N	-	-	CH	O	S	C
Syzygium miocenicum	24.44	E	-	N	CH	C	S	C
S. miooccidentalis	08.00	E	-	N	CH	A	S	C
Lonicera mioquinquelocularis	08.75	E	-	-	CH	O	C	D
Randia miowallichii	13.80	E	-	N	CH	C	S	D
Morinda siwalica	07.56	E	P	-	CH	-	S	C
Diospyros koilabasensis	09.00	E	-	-	CH	CR	S	D
D. darwajensis	55.90	E	-	-	CO	O	S	C
D. pretoposia	108.00	E	-	N	CO	O	S	D
Tabernaemontana precoronaria	13.86	E	P	N	CH	C	S	D
Carissa koilabasensis	05.60	E	A	-	CH	A	S	D
Gaertnera siwalica	12.00	E	-	-	CH	A	S	D
Datura miocenica	59.20	N	P	N	CH	A	S	C
Anacolosa mioluzoniensis	23.12	E	A	N	CO	A	S	D
Vitex prenegundo	20.90	E	P	N	CH	A	S	C
V. siwalica	31.50	E	-	-	CH	-	S	C
Cinnamomum mioinuctum	06.48	E	A	N	CH	C	S	D
Ficus precunia	20.25	E	-	-	CO	CR	S	D
F. retusoides	31.32	E	P	N	CH	A	S	C
F. nepalensis	28.00	E	-	-	CO	O	S	D
Helicia eoerretica	42.00	E	-	N	CH	A	S	C
Phyllanthus koilabasensis	08.93	E	A	N	CH	A	C	C
P. mioreticulatus	03.50	E	A	N	CH	A	C	C
Antedesma siwalica	47.15	E	-	-	CH	A	SC	

patterns of plant distribution. The exotic taxa may have had a wider distribution in the Miocene, which subsequently contracted perhaps due to a changing climate. On the other hand, these taxa may have reached the Himalayan foot-hills in the Koilabas area by dispersal mechanism from other subcontinents, most probably at the time of former existed land connections or from other areas of India and Nepal, but subsequently became extinct.

The Koilabas assemblage is mainly represented by the members of the tropical families Fabaceae, Dipterocarpaceae and Anacardiaceae (Table 1). The fossil record of these families shows that they were abundant in other parts of India and Nepal in the Neogene Period (Bande & Prakash, 1984; Prasad & Awasthi, 1996; Prasad *et al.*, 1997), whereas during Palaeogene the family Fabaceae was hardly represented and Dipterocarpaceae was absent throughout the Indian subcontinent. It indicates that these two families may have entered India during the Neogene after the establishment of land connections with areas where they were flourishing in the Palaeogene Period.

Phytogeographically, Dipterocarpaceae may be regarded as an important family. The present and past distribution of the family indicates that it is pantropical and specially belong to tropical Asia except that two genera *Marquesa* and *Monotes* which are distributed in the African regions. The fossil record suggests that Dipterocarpaceae originated during the early Middle Oligocene (Merril, 1923; Muller, 1970). Lakhanpal (1974) further envisaged that the family originated in western Malaysia, where about two third of all dipterocarps species occur today (Desch, 1957). This region is also quite rich in the fossil record (Lakhanpal, 1974; Bande & Prakash, 1986). From western Malaysia dipterocarps spread east ward to Phillippines and northward through Myanmar to India. The possible time of the southwest migration was Early Miocene when the land connnections between Malaya, Myanmar and eastern India were established. The abundance of dipterocarps such *as Dipterocarpus, Anisoptera, Hopea, Dryobalanops* in eastern India as well as in southern India during Miocene-Pliocene times indicates that they spread from eastern India to south west to Sri Lanka via Himalayan foot-hills where they are still flourishing. The occurrence of dipterocarpaceous remains (fossil woods, leaves, fruits, flowers and seeds in the Himalayan foot-hills (Antal & Awasthi, 1993; Antal & Prasad, 1996b; Awasthi, 1982; Prasad, 1994a-e; Prasad & Awasthi, 1996) and the Tertiary beds of Africa (Bancroft, 1933; Chiarugi, 1933) suggests that from eastern India the dipterocarps also spread westward into Africa most probably via Arabia (Lakhanpal, 1970; Seward, 1935).

In the floral assemblage recovered from Siwalik sediment of Koilabas area, three types of elements have been identified, viz., (i) Evergreen, (ii) Evergreen and Moist deciduous and (iii) Moist deciduous elements (Table 2). The evergreen elements dominate the assemblage as compared to other elements. This obviously indicates that the tropical evergreen forests were growing around Koilabas area during Middle Miocene as compared to the present mixed deciduous forests in the region. It is further inferred that the evergreen taxa which were growing in the vicinity of Koilabas have got migrated to other phytogeographical regions due to unfavourable climatic conditions prevailed after Mio-Pliocene Period most probably due to the uplift of Himalaya.

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T.M. Harris Medal 1998

Introduction by Professor A.K. Sinha

Dr David J. Batten was born on 26.4.1943 at Watford (London), England. He attained secondary education in London and after two years of schooling in Canada joined Queen's University (Kingston, Ontario) for graduation, first with a B.A. in liberal arts in 1964 and then with an Honours B.Sc. in Geology in 1965, with Biology as a subsidiary subject. This was followed by a year at University College, London where, among other things, he was introduced to palynology and palaeobotany by Professor Bill Chaloner. He graduated with M.Sc. from there in 1966 and was awarded a Ph.D. in Geology/Palynology by Cambridge University in 1969 under the guidance of Dr Norman Hughes.

Dr Batten spent further two years in Cambridge on a post-doctoral fellowship before working for Robertson Research International in North Wales as a palynologist/stratigrapher. Then he moved to similar position in British Petroleum in 1973 first in London, then in Aberdeen. He was appointed to the staff of the Geology Department of Aberdeen University in 1976 thus beginning his teaching career and here he remained for 15 years. During this period he was promoted to Senior Lecturer and then Reader. Subsequent move to the University of Wales, Aberystwyth in 1990, awarded a Personal Chair (Professorship) in 1992. He has supervised 23 M.Sc. and 14 Ph.D. students during his academic career. Here he is also the Director of the Palynological Research Centre at the University of Wales.

His research interests have been directed at all aspects of the morphology and occurrence of organic matter in sediments, regardless of age, but especially at Mesozoic palynology, palaeobotany and palaeoenvironments. Currently he is working on possible and probable early angiosperm 'mesofossils'. Dr Batten's publications are concerned with a variety of topics and organic walled fossils including small spores and pollen grains, megaspores, seeds, plant macrofossils, dinoflagellate cysts and non-marine algal palynomorphs. He has special interest in the stratigraphy and palaeontology of the Cretaceous Period and has been Editor of the International Journal *Cretaceous Research* for just over 10 years and is also on the Editorial Board of the Review of Palaeobotany and Palynology. He has been the Councillor and then the Vice- President of the International Federation of Palynological Societies. He was also the chairman of the Palynology Group, British Micropalaeontological Society.

Dr Batten's contribution on Palynofacies in palaeoenvironmental interpretation and petroleum potential published in *Palynology : principles and applications* (editors- Jan Jansonius & D.C. McGregor), American Association of Stratigraphic Palynologist Foundation, Vol. 3, pages 1011-1084 in the year 1996 has been adjudged to be the best for the award of Professor T.M. Harris Medal for the year 1998.

Response by Professor D.J. Batten

Professor Sinha, Ladies and Gentlemen

I am honoured to receive the Professor T.M. Harris Medal 1998, and most grateful to the Expert Committee for having selected me for the award. I am sorry that I am unable to attend the Founder's Day Function, but look forward to coming to the BSIP at a later date.

I have visited the Institute once before, on the occasion of the very successful and enjoyable Fourth International Palynological Conference at the end of 1976/beginning of 1977. Among the many people, I met for the first time in Lucknow was Mrs Savitri Sahni, though to her I was probably just a face in the crowd. Both this conference, and the field trip led by G. 'Thani' Thanikaimoni to southern India in which I participated afterwards, are among the highlights of my career in palynology and palaeobotany. This began in 1965 when I started working for an M.Sc. in micropalaeontology at University College, London. I subsequently spent three years in Cambridge as a Ph.D. student, followed by two more there as a post-doctoral fellow before joining Robertson Research in North Wales and then British Petroleum in London and Aberdeen, Scotland. I returned to academia in 1976 when I was appointed to a lecturership in Geology at Aberdeen University. I transferred to the University of Wales, Aberystwyth in 1990.

I have been keen on plants ever since I was old enough to dig, with a small hand-fork, a patch of ground the size of a postage stamp outside my parents' ground-floor flat in south

London. This was a couple of years before Professor Birbal Sahni's untimely death. As a teenager I used to get cross with my mother if she 'interfered' with my work in the rather bigger garden we had at that time, especially because she liked to prune things and I preferred a more natural look. Not being a keen gardener my father was happy to leave me to it! Together with an enthusiasm for the countryside outside London, which I would often explore on my bicycle, and the opportunity I had to visit some of the wilder parts of North America in my late teens, the seeds of a life-long interest in vegetation, and the soils, sediments and rocks beneath it, were sown.

I began my university studies at Queen's University in Ontario, Canada, intending to study biology, with emphasis on botany and ecology, but was sufficiently inspired by the first year course I took in geology that I decided to concentrate on it, relegating biology to a subsidiary subject. It was quite by chance that I returned to London to pursue the M.Sc. course in micropalaeontology I have mentioned. I knew very little about microfossils and absolutely nothing about those derived from plants, but it was during this important period of study that I found I could get back to my roots, so to speak, and think about vegetation and habitats again, albeit mainly in a geological context. Three things in particular that year inspired me to continue in palynology : (1) Dr, now Professor, Bill Chaloner's enthusiasm for the subject, and his encouragement; (2) the fact that the 'mystery sample' I had to process and write up proved to contain some very pretty Early Cretaceous spores and pollen grains; and (3) the possibility of using sedimentological and palaeontological data as a basis for imagining dim and distant but exciting ancient worlds. I especially liked to think about dinosaurs and early mammals roaming amongst exotic subtropical vegetation in southeast England where there are now farms, towns and the sprawl of London.

The desire to interpret sedimentary successions from a palaeoenvironmental viewpoint led me to collect several hundred samples from the Lower Cretaceous, Wealden, succession of southern England for my Ph.D. project, and to examine not only the spores and pollen grains I recovered but also all the other organic bits and pieces that made up my assemblages. During the 1960s most palynologists, including my supervisor Dr Norman Hughes, considered that the main purpose of studying pre-Quaternary palynomorphs was to provide a basis for dating and correlating rocks. With few exceptions, published palaeoenvironmental interpretations based on palynological data were broad generalisations that relied largely on relative abundances of only major groups of spores and pollen grains, and on the presence or absence of marine dinoflagellate cysts and/or acritarchs. Less well-characterised organic matter, such as cuticles, wood fragments and amorphous detritus, was regarded as a nuisance to be removed, if possible, from preparations by oxidation or other means.

The fact that from the start I tried to take into account the entire palynological content of rock samples in my studies has paid dividends in the long run. It proved to be particularly useful when British Petroleum began to develop organic geochemical studies in connection with its oil exploration programmes during the 1970s. At that time, the geochemists involved were keen to know whether their conclusions regarding maturation and source potential for hydrocarbons could be correlated reliably with data on the colour and physical characteristics of palynological matter recovered from the same samples.

In recent years, many biostratigraphic jobs in the major oil companies have been lost, and at times the future of palaeopalynology as a discipline has looked a little bleak. Fortunately it has survived because palynostratigraphy not only continues to have a role to play in the exploration for hydrocarbons but also, when combined with intelligent use of palynofacies data, can be of considerable value in sequence stratigraphic analyses, interpretations of sedimentary environments of reservoir successions, and other geological studies. The key to survival has been the willingness of the majority of palynologists to collaborate with specialists in other disciplines. This applies also to those involved in the many multidisciplinary investigations of Quaternary environmental changes that are currently being undertaken.

Although my palynological work was somewhat removed from the palaeobotanical endeavours of Professor Harris, our paths crossed during the early 1970s when I had the good fortune to benefit from his wisdom in my attempts at drawing palaeoenvironmental conclusions from my Ph.D. and postdoctoral studies on the Wealden flora. He was critical but also encouraging, and I learned a lot from our correspondence of several years and from my one visit to his home where I was made very welcome. I especially appreciated the fact that, whereas some of my palynologist acquaintances were rather dismissive of palynofacies studies, he could see that they had considerable potential. It is, therefore, a particular pleasure for me not only to be awarded a medal by the Birbal Sahni Institute of Palaeobotany but also that it is named after someone I knew and whose work I have admired and often cited. I thank you again.

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Chunnilal Khatiyal Award 1998

Introduction by Professor A.K. Sinha

I am pleased to introduce Dr Amit K. Ghosh as the 1998 recipient of Dr Chunnilal Khatiyal Medal. Dr Chunnilal Khatiyal established the award in 1952. It carries a medal and a citation. In order to motivate and recognize excellence in research, this award has been made on the recommendations of Expert Committee constituted by the Director and Chairman of Birbal Sahni Institute of Palaeobotany (BSIP) for carrying out best piece of research work during the three years, preceding the year of award.

Amit has a consistently good academic record. He has achieved different scholarships since the beginning of his academic life. Amit completed his schooling in Durgapur (Burdwan District, West Bengal), an industrial town, adjacent to Raniganj and Asansol area, one of the greatest coal measures of India. During his intermediate course of studies he received the Merit Scholarship sponsored by Steel Authority of India Limited, Durgapur. He is also the recipient of National Merit Scholarship during his M.Sc. course of study. His undergraduate degree (B.Sc. Honors in Botany), Masters (M.Sc., Botany with special paper Palaeobotany & Palynology) and Ph.D. degree are from the University of Burdwan. Later on, he successfully completed a Professional Training Course in Geology from the Geology Department, Lucknow University.

Dr Ghosh began his research career as a Junior Research Fellow in the Department of Botany, University of Burdwan. He obtained Ph.D. degree in 1992 for his Ph.D. thesis entitled "Contributions to the Triassic Palaeobotany and Stratigraphy of Peninsular India". Amit continued his research activities in the same university as a Research Associate of Council of Scientific and Industrial Research before joining BSIP.

Amit joined Birbal Sahni Institute of Palaeobotany in April 1994 as a Junior Scientific Officer. Since then, he was inspired to work on the morphotaxonomy, biostratigraphy, palaeoecology and palaeobathymetry of Phanerozoic calcareous algae. Not much attention was paid earlier on this aspect of palaeobotany in our organization. The Chunnilal Khatiyal Medal-1998 has been awarded to him specifically for his significant contributions on the morphotaxonomic study including the biostratigraphical, palaeoecological and palaeobathymetrical importance of calcareous algae from the Cretaceous-Tertiary sediments of Bagh beds, Cauvery and Kutch basins. In addition, Dr Ghosh has made some important findings on the sponges and dasyclads from the Ordovician (Takche Formation) of Spiti Basin in 'Tethys' Himalaya and megaspores from the Lower Cretaceous (Athgarh Formation) of Mahanadi Basin. In the 9th Five Year Plan he is actively engaged in a very significant Thrust Area "Petroliferous basins of India". Under this Thrust Area Programme Amit is carrying out intensive studies on Calcareous Skeletal Algae from the Tertiary sequences of Meghalaya and Kutch basins under the project entitled "Marine Micropalaeontology of Petroliferous basins". Each year he used to go to field for collecting samples from measured sections of specified localities which are potentially suitable for his studies.

Personally, I always encourage him for working very hard. In true sense, this young scientist of our institute deserves the honour which he has achieved for his devotion to research work. I feel proud of him and wish him all round success in his future research programme. I will indeed be very happy if Amit continues his studies on calcareous algae and make further meaningful contributions on this aspect.

Response by Dr Amit K. Ghosh

I am indeed deeply honoured and at the very outset I would like to thank the authorities of BSIP for the award of Chunnilal Khatiyal Gold Medal-1998. I should take this occasion to recapitulate the major points in my love affair with fossil plants. Perhaps, my budding interest in palaeobotany was nurtured in my early teens when I was a graduate student of Botany. As an honours graduate student of Botany, I first visited Permian plant fossil localities around Raniganj and Asansol area of Raniganj Coalfield, West Bengal. My fascination on Palaeobotany intensified further when I joined as a Junior Research Fellow in the Palaeobotany and Palynology Section of Botany Department, Burdwan University after passing the M.Sc. (Botany) examination with Palaeobotany and Palynology as a special paper from the same department in 1987. At that time my greatest interest was in morphotaxonomy of Triassic plant megafossils, megaspores and miospores and their stratigraphical and palaeoecological significance. Later on, in 1992 I submitted my Ph.D. dissertation on Triassic Palaeobotany and Stratigraphy while I was working as a Senior Research Fellow. In the same year I received the Degree of Doctor of Philosophy in Science (Ph.D.) from Burdwan University. I devoted my research activities in the same University after receiving the award of Research Associateship of Council of Scientific and Industrial Research (CSIR) till I joined Birbal Sahni Institute of Palaeobotany.

In BSIP, I started working on the morphotaxonomy, biostratigraphy, palaeoecology and palaeobathymetry of Phanerozoic calcareous algae. These aquatic (moist loving), autotrophic and nonvascular plants (which failed to reach the higher level of archegoniates) mainly from the marine carbonate sediments of Ordovician, Cretaceous and Tertiary sequences of India in true sense captivated my mind.

Dr Chunnilal Khatiyal Medal (for the year 1998) which was established in 1952 has been awarded to me for the best piece of research work done during the years 1995-1998 (on calcareous algae from Cretaceous-Tertiary sequences of Bagh beds, Cauvery and Kutch basins). In this context I must convey that I have always been very fortunate with my teachers, supervisors, research colleagues, advisers as well as collaborators. In fact, I feel they are all part of my achievement to get this award.

I would like to thank my mother, wife and other family members on this occasion. Though, my father is no more in this world, his departed soul always boosted me to do hard work throughout my research career.

I desire to take this opportunity to thank Professor A.K. Sinha, Director, BSIP for his constant encouragement and keen interest on the study of fossil algae. I am indebted to the Chairman of Governing Body and Research Advisory Council of BSIP and also to the members of Governing Body and Research Advisory Council, BSIP. Last, but not the least I would like to pay my gratitude to the expert committee, constituted by the Director and Chairman, BSIP for recommending me to the Chunnilal Khatiyal Medal-1998. Before I close, I want to express that this award will always cheer me to make further significant contributions in my ongoing studies on calcareous fossil algae.

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Conference Reports

5th International Symposium on the Jurassic System, Vancouver, Canada 12-25, August, 1998.

Main theme of this Symposium was the choronostratigraphy of the Jurassic System. In view of the incoming information in various disciplines of geological sciences, the stages and stratotypes need reframing. The presentations of research papers were held mainly under General Session, Special Session and Poster Session. In this Symposium, around one hundred fifty geoscientists and biostratigraphers participated from about twenty five countries. About hundred research papers were presented.

General Session—Mainly dealt with biostratigraphy of Lower, Middle and Upper Jurassic sequences explored in various parts of the world. The invertebrate fauna hold the key in Jurassic Biostratigraphy, which include - Ammonoids, Brachiopods, Radiolarians, etc. Study of spore-pollen, although not worked-out in much detail in Jurassic sequences, still accountable as supportive tool in biostrastigraphy. However, dinoflagellate cysts attain priority in palynostratigraphy. Isotopic studies have drawn attention as an important tool in chronostratigraphy.

Special Session—Focussed on research papers, further grouped into following themes, so that the precise information could be obtained.

(i) The Jurassic of Western Canada
(ii) Extinction and Recovery
(iii) Terrestrial Ecosystems
(iv) Tethyan-Pacific connections : The Hispanic corridor
(v) Time scale calibration
(vi) Sequence Stratigraphy

Poster Session—About twenty-five posters were displayed having wide spectrum of the studies for detailed discussions on-Sequence Stratigraphy in lithofacies, correlation of Ammonoid based stratigraphy with other fungal zones or Isotopic studies.

Presentations at the Symposium—Numerical ocean-models are proposed to unravel the Jurassic seaways. Besides, an updated data of bivalve mollusks are analysed to understand Hispanic corridor during Late Triassic to Middle Jurassic times. Search for possible GSSP candidate as stratotypes for various stages-Oxfordian-Kimmeridgian, Callovian-Oxfordian, and Sinemurian-Pliensbchian, have put forth a serious problem of biostratigraphic correlation between different biogeographic provinces. The reasons offerered are not so good collectively for microfossils, geochemical and chemostratigraphical studies. The selection of reference section needs an integrated stratigraphic approach. The potential GSSP candidates have been proposed in NW Spain and south west Germany.

Sequence Stratigraphic analysis in Jurassic sedimentation is favoured by both excellent outcrop conditions and well established biostratigraphic scale. The deposit sequences display significant variations in their thickness and facies which help to analyse and interpret depositional environments. In Western Tethys, review of available data has revealed stratigraphy within the palaeogeographic domain of Alpine Belt and Saharian Craton.

The correlation between the stable Carbon-isotope curves to ammonite zonations is attempted in southern Spain. The applicability of Strontium-isotope stratigraphy as a global tool has been attempted and results show that in most cases biostrastigraphy correlates well with Sr-isotope data through most of Jurassic and Early Cretaceous sequences.

Plant communities help interpret palaeoclimatic and palaeoecologic impacts during the sedimentation in a time span as derived from the studies of Jurassic flora in New Zealand, Scotland and North China. Worldwide correlation of ammonite faunal zones based on Euroboral and Alpine data for the Upper Sinemurian, Early Hettangian have been putforth. Besides, preservational variations in ammonite associations have been observed. These enable to distinguish taphonomic cycles resulting in relative sea-level changes. Such taphonomic data are important for sequence stratigraphy.

Extinction and recovery of fauna in both marine and nonmarine realms suffered heavy losses among the invertebrates, ammonoids, bivalves, etc. The timing of extinction has appeared to be restricted to a short interval that is at or top of the Rhaetain stage. Due to the lack of complete fossiliferous stratigraphic sections, causes of extinction patterns remain unknown.

The taphonomic mode of preservation of-Dinosaurs and foraminiferal fossils that also have diverse groups including small vertebrates–invertebrates and plants indicate significantly the ranges of time of exposure to taphonomic processes. These findings are useful in interpreting palaeoenvironment and accumulation of sediments in the depositional basin.

Palynostratigraphic studies have also supplemented in the Jurassic sequences, besides dinoflagellatge cysts in the assemblages are significantly accounted for biostratigraphy.

Multidisciplinary Chronostratigraphy has been attempted on terrestrial Jurassic-Cretaceous sequences in China. It includes-Tethyan Ammonite Zonation, Magnetostratigraphy, Isotopic-geochronology and Sequence Stratigraphy.

In the areas of NE China, located in Circum-Pacific active belt of volcanic structure, the chronostratigraphic analysis is being attempted through Jurassic-Cretaceous volcanic-rocks. Abundant fossils including-fauna, plants and spore-pollen found in the sediments deposited in between volcanics have proved significant in the chronology of Mesozoic stratigraphic sequences.

Biostratigraphy and sedimentary developments have been worked out in the Jurassic strata from Central Nepal and Southern Tibet. The Jurassic depositional cycle in this region has been interpreted in having two major depositional diastems during which chamositic oolite had deposited.

The numerical and analytical results show that potentially palaeobiogeographical and isotopic investigations in target areas could contribute significantly in the palaeoclimatic understanding of the Jurassic period. The hypotheses for extinction and recovery of fauna and flora at boundary levels need further testing with geochemical and paleoecological data from a wider variety of facies. The Sequence Stratigraphy is still in its developing phase. It needs principal concern towards sedimentary cyclicity, astronomical time scales and sequence recognition. In the domain of western Tethys, comparisons have to be made along the northern edge or Tethys and adjoining territories. Study of spore-pollen in the faunally controlled sections is being suggested. So that palynoevent-sequence of species could find its placement along with other biostratigraphic zonations. To refine the Sr-isotopic curves, more data base is needed, so that it could be calibrated with global cross-correlation of different biostratigraphic schemes. Further work is required with multidisciplinary approaches for chronostratigraphy to resolve the ages of the Stages, Zones and Biohorizons.

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Systematic Wood Anatomy Symposium 7th Latin American Botanical Congress, Mexico, October 18-24, 1998.

The conference jointly organised by various Latin American associations/societies of Botany such as Sociedad Botanica be Mexico, A.C., Association Latinoamericana de Botanica; Red Latinoamericana de Botanica; Univ. Autonoma Metropolitana Mexico; Univ. National Autonoma de Mexico; Inst. de Ecologia, UNAM, Comision Nac. para et Concocimiento y Uso de la Biodiversidad & CONABIO and dealt with all aspects of botany. It was attended by about 1000 delegates belonging to over 25 countries from American Continents, Europe and Asia. However, most of the delegates were from Latin American countries. More than one hundred seventy papers were presented orally in 35 sessions arranged simultaneously. Posters of over 1000 papers were put up in different sessions.

A number of papers were presented on anatomy of wood, leaf, fruit, stem, root and rhizome of various genera. Wood anatomy of family Anacardiaceae was dealt in great deal based on large data comprising 60 genera and 800 species. Xylotomy of 26 species of *Quercus* growing in Mexico was reported. Different species of oaks (Red, Black & White) have been separated on the basis of wood anatomy. Quantity of crystals in parenchyma cells and quantity of fibre cells have been considered as an important differentiating characters.

Stilt roots of *Rhizophora* have been called as Rhizophore as in the case of *Selaginella*. Stilt roots of *Rhizophora* are not the roots but stems which ultimately give rise to very small roots. Such type of rhizophores have also been reported in *Vernonia, Dioscoria* and *Smilax*. A tropical genus *Tebeuia* of Bignoniaceae occurring from Argentina to Mexico has been found suitable for the dendrochronological studies. A paper discussed the current status of comparative wood anatomy. Data was presented on the wood anatomy of Brazil, Chile and Mexican woods. New data on the anatomy of *Cheilanthus, Dryopteris* and *Lycopodium* was presented. Perforated ray cells were reported in the wood of genus *Cordia* of family Boraginaceae. Tracheid cavities were reported in Cycadaceae (*Cycas revoluta*).

Some interesting papers on palaeobotany reported lycopods from Carboniferous sediments of Peru, microfossils from the Permian of Brazil, and 70 million years old Cretaceous fossils representing infructescence, leaves etc. belonging to various families such as Isoetaceae, Taxodiaceae, Musaceae, Strelitizaceae, Araceae, Pandanaceae, Halorgaceae, Hemamelidaceae, Rhamnaceae, Lauraceae and Moraceae were reported from Mexico. Microalgae has also been reported from the sediments.

Dicot fossil woods were reported for the first time from the Tertiary sediments of Guatemala. Some dicots were also reported from the Oligocene deposits of Mexico. A paper discussed the palaeogeograhpy of Cycadales. Role of Tertiary highlands in biogeography and evolution of North American Tertiary flora was discussed. A paper discussing interaction between the vegetation of North and South America during Tertiary was presented.

There were papers on history of botany, history of herbaria, ethnobotany, on medicinal plants, extraction of alkaloid/flavonoids from *Ageratum, Dioscoria* and from the members of Annonaceae and Melastomaceae. Papers on morphology and taxonomy of pollens belonging to various genera and families and on pollination biology were presented.

A number of papers were presented on foliar anatomy and on family Cactaceae, impact of El Nino in forest fire, on the phylogeny of *Quercus* molecular phylogeny of *Desmodium* using nucleotide sequence of the rbcl gene and bryophytic and pteridophytic diversity in rain forests of South America.

It was recommended to increase the growth of froests in order to increase the biomass, production of quality timber and its proper and maximum utilization.

There was general agreement that there should be better co-operation amongst the various botanical bodies/organisations of the Latin American countries as well as with other botanical organisations to achieve excellence in botanical researches and in the efforts of conserving rare plant material. The wider co-operation will also help in procuring rare and other relevant living material from different parts of the world.

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4th International Conference on Biodeterioration of Cultural Property, Teheran, Iran, 21 - 25 November, 1998 and 3rd International Symposium on Conservation and Restoration of Historical objects and Architectural decorations, Teheran, Iran, 29 November - 2 December, 1998

The "4th International Conference on Biodeterioration of Cultural Property" was held at Iranian National Museum Teheran, Iran from 21st-25th November, 1998. Over 100 participants from Australia, Britain, China, Egypt, France, Germany, India, Iran, Italy, Japan, Korea, Norway, Poland, Romania, Thailand, Turkey and U.S.A., assembled in Teheran. The Main objectives of the conferences were to find out ways for co-operation between scientists and conservators from different countries to understand problems of biodeterioration and to make precise identification of biodeteriorants in order to prevent their harmful effects. During his address, the Director, RCCCR, Dr Abdolrasool Vatandoust, emphasised that due to emergence of new deteriorants the deterioration rate has increased during the 20th century. Second speaker Dr Hideo Arial, President ICBCP stressed promotion of the multidisciplinary approaches to control the biodeterioration problem. Dr H.M.M. Najafi, Director, Ayat-Allah-Al-Uzma-Marashi-Najafir-Library considered the microrganisms more important destructive elements than fire and suggested precautionary measures can play important role than remedy for the prevention of properties. He further emphasized climatic characters and told that Iran is located in hot and arid area so its properties are more exposed to the biodeterioration factors. Under 10 scientific sessions 40 contributions dealt with General principles of biodeterioration, Manuscripts, Books, Stones, Wood, Textiles, Architecture, Experiments, Treatment and preservation, and Control methods, etc. were presented and discussed. The study on "Fungal remains from Tertiary deposits exposed at Sirmaur District, Himachal Pradesh, India". revealed that during Subathu, Dagshai formations the environment of deposition at Dadahu-Jamtah area was favourable for the growth of numerous fungi and saprophytic forms which destroyed the palaeovegetation. The corresponding taxa grow on various materials and effective measures can be taken to control the biodeterioration of cultural properties wherever it is caused by similar fungi.

The "3rd International Symposium on Conservation and Restoration of Historical objects and Architectural decorations" was held at same venue, from 29th November-2nd December, 1998. Over 400 participants (generally Iranians) were assembled. Other participating countries were Britain, India, Japan, Romania and Jordan. Its main objective was to create a proper platform for experts of different countries to exchange their views and to review the potentials in the restoration activities at international level. During the inaugural address Dr Vatandoust said that if biodeterioration rate continues we will lose not only our properties but also contact with past. Second speaker Madam Parvin Partouie, Vice-Chancellor for Research, University of Art gave emphasis for establishment of communication network among different countries through which relevant activities can be exchanged. Third speaker Mr Seied Mohammad Baheshti, Director, Iranian Cultural Heritage Organization emphasized that any historical object is like a window to the past so we should preserve them. Scientific sessions encompassed Theoretical principals of conservation, General conservation for papers, manuscripts, books; Conservation science, archaeology and conservation, Pathology and conservation projects, Deterioration processes, Materials science and Technology. 38 papers dealing with different aspects of conservation and restoration were presented and discussed.

An exhibition displaying latest developments in the field of biodeterioration, conservation and restoration methods, relevant projects, materials, tools and literatures, etc. was arranged. Two excursions (1. to Tehran-Qom-Esfahan and 2. to Tehran-Ghomrud-Kashan-Abyanes) were organized to visit ancient sites and historic monuments in order to investigate and discuss problems related with biodeterioration and conservation, etc.

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Instructions to Authors

EDITORIAL POLICY

The Palaeobotanist is published in three numbers per volume every year and issued in April, August and December. It publishes original articles on all aspects of palaeobotany and biostratigraphy including comments on previous articles, replies and palaeontological and taxonomic notes and research communications of regional and international interest. All plant groups and aspects of living botany having bearing on palaeobotany including plant micro- and mega-fossils and plant-animal relationship are published. Some issues of the Journal will be devoted to a single theme. Besides, papers dealing with academic and applied aspects of palaeobotany as well as papers solving diverse geological problems which generate interest for palaeobotany among broad spectrum of readers are welcome.

Authors submitting a manuscript must ensure that it has not been submitted elsewhere and if it is accepted for publication, the copyright of the article will be transferred to the Birbal Sahni Institute of Palaeobotany, Lucknow, India. All the submitted manuscripts are subject to peer review, a process that is the responsibility of the editorial board. All the manuscripts will be reviewed by at least two referees. The editor's decision is sent to authors along with the referees' comments and evaluation as early as possible. In normal course this process takes 3-4 months. Manuscripts will generally be published in the order in which they are accepted. Efforts are made to publish articles well within a year.

MANUSCRIPT SUBMISSION

1. Submit three copies of the manuscript, including tables, plates and text figures, for review purposes. One copy each of original photoplate and two copies of good quality laser Xerox of the photoplates are acceptable. Only two copies of the revised manuscript are required. Authors are responsible for the accuracy of the text in the revised version of the manuscript.
2. Double space the entire manuscript, including abstract, text, references, tables, figure legends and appendices.
3. Number all pages including title page.
4. Use a standard font (Helvetica or Times New Roman) 12 points only, submit inkjet or laser printouts on A4 size paper only.
5. Do not justify the right margin. Leave 3 cm margin on top, bottom, right and left margins.
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7. Use appendices for bore-hole data or long tables and locality information.
8. Avoid using foot-notes.
9. Authors are encouraged to suggest three potential reviewers of the manuscript with their complete addresses, E-Mail and Fax numbers, although the final choice will be made by the editors.
10. Article exceeding 40 published pages must be submitted to Memoir or Monograph series. Approximately 3·5 manuscript pages make each published page, plus space for text figures and plates.

FORMAT

Typescripts should be single sided, double spaced, preferably on International A4 size (297 x 210 mm) paper. There is no need to use separate title page. Leave 35 mm blank at the top of first page before the title. Rest of the manuscript should have 3 cm (30 mm) margin on all sides.

Title of the manuscript in capital and lower case letters and centred.

Title should be as short as possible, informative, normally include botanical affinity/ geographical and stratigraphical limits of the work. Capitalize and centre author's names. Addresses are in capital and lower case letters with affiliation, state, Country and Pin or Zip codes, E-Mail addresses may also be given.

In case of multi authored papers/articles, corresponding author should be marked invariably with an asterisk and should provide an e-mail address.

Capitalize, bold and centre word **ABSTRACT**.

The abstract should provide relevant details of the research and conclusions. Enumerate all new taxa and combinations in the abstract. Avoid using references. The abstract should not exceed in any case beyond 300 words. Palaeobotanical, taxonomical and Research Communications do not have abstracts. Provide maximum six Key-words that may be used for indexing and information retrieval. Take help of most recent American Geological Institute GeoRef Thesauraus in selecting the key words.

Capitalize, bold and centre word **INTRODUCTION**

Text headings-The Palaeobotanist uses four level of text headings. The first is in capitals, bold and centre; the second is in upper and lower case, bold and centre; and the third is italicised in upper and lower case, abut the left hand margin. In taxonomic dealings fourth level of heading is used and separated from the text by long hyphen.

Text custom

The text of the manuscript should be as brief as possible without compromising clarity and important information.

Two categories of illustrative materials are referred in the text. All the line diagrams, maps and tables are referred as figure, photoplates and are denoted by Arabic numbers (Pl. 2) with individual specimen also marked by Arabic numbers, from 1-10 and greater. The numbering of each plate starts afresh. Abbreviate figures and plate(s) as Fig., Figs and Pl.

Capitalize illustrative material referred in the text (e.g. Fig. 1 or Fig. 1·2; if the reference denotes to a singular entity put a dot after it.

Plural numbers are without a dot. Reference from other sources are put in lower case (Pant 1999, fig. 3). Provide the author name(s) and date(s) in the manuscript text only for taxa that are formally treated in Systematics section and citation must be included in the bibliography. In the systematics section of palaeobotany, provide author names and dates for all genera and species. Spell out the complete generic names when used for the first time in the text, in subsequent usage only abbreviated forms are acceptable. Similarly new genera and new species are spelled out in full in the heading within the Systematic section. In subsequent references 'gen. nov.' and 'sp nov.' can be used. Capitalize the formally proposed and accepted time and time - rock designation (e.g. Early Cambrian, Middle Cambrian) whereas informal designations (e.g. late Mesozoic, middle Cretaceous) are not Capitalized.

Any reference to the published work should be referred in the past tense. Open nomenclature in Systematic section should be dealt with care. For more details consult Mathews SC 1973. Notes on open nomenclature and synonymy lists. Palaeontology, 16 : 713-719 and Bengston P 1988. Open nomenclature. Palaeontology. 31 : 223- 227.

When entries are listed in a sentence, follow : (1) ......, (2) ...., (3) ......

Numerals and measurements

Use Arabic numbers with abbreviated unit of measurement (e.g., 13 mm) and for values greater than 10. Sentence beginning with numbers are spelled out. Ordinary numbers are also spelled out (e.g. third millennium). Decimal points should be raised e.g., 4·5 not 4.5. Numerical ranges can be given as "size is 10-15 mm" use a space between number and unit of measurement. References to previously published figure and plate numbers, etc. that were originally given in Roman numbers should be transliterated into Arabic numbers.

The *Système International* (SI) must be used for measurement units, but some non-standard measurement, in centimetres for example, are acceptable. The following abbreviations of length- measurements are used in singular number without a full stop: km m cm mm. Use 63% (not per cent), 24°C (not degree C), Pb/Pb method, ^{40}Ar/^{39}Ar ratios.

Abbreviations, contractions, hyphenations and quotations

As a general rule, abbreviations are followed by a full stop and contractions are not: hence ed. Pl. e.g., i.e., aff., cf., but eds, pls, Dr, Mr, Jr etc. Acronyms and commonly used abbreviations and symbols should be defined for the first time they are used. They are also mentioned without stops; for example IOP, IPC, IUGS, IPA, DSDP, USA, PhD. Use capital letter for compass points, e.g. N, NE, SW, without full stop. The geological age may be expressed as years before present. The recommended abbreviations are Ga, Ma and Ka.

An ampersand (&) should be used when referring to authors within parenthesis as in (Sahni & Seward, 1932), 'and' is to be used when only the year is given within parenthesis, as in Sahni and Seward (1932). Do not hyphenate the words as semicircular and epicentre, or split word at the end of line. Double inverted commas(") are to be used while quoting the text directly from the source, this should be accompanied by a reference, year and page number. Any other usage of unorthodox words demand only single inverted commas.

Latin words and abbreviations- Most Latin words, whether in full or abbreviated should be in italics: for examples, *in situ, inter alia, sensu lato, sensu stricto, sic, et al., nom, nud.* Only exceptions are cf. e.g., i.e. and vice versa.

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1979	Golubic and Campbell, figs 2E-J, 3C, D.
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Dominant gymnosperms of the Glossopteris flora

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ABSTRACT

Pant DD 1999. Dominant gymnosperms of the Glossopteris flora. Palaeobotanist 48(2) : 111-123.

The paper presents new ideas about the Lower Gondwana forests which the author believes were dominated by deciduous gymnospermous trees of *Glossopteris* and its allied genera. It is suggested that the larger trees of glossopterids may have been 30 to 40 m or more in height and below them grew shorter trees and shrubs of *Glossopteris* and its allies. The large size of glossopterid trees is suggested by that of tree trunks assigned to *Dadoxylon* sp. from the Raniganj Stage where *Glossopteris* is the commonest fossil and the genus *Noeggerathiopsis*, to which they had been assigned earlier, is a rarity. Such trees could have been supported by horizontally spreading axes or roots at the base of the trunks as suggested by fossil axes or roots around missing trunks reported from the bed of Vaal River in South Africa which too had been assigned to *Noeggerathiopsis*.

The deciduous glossopterid trees are compared with those of modern *Ginkgo biloba*. It is suggested that the gradate series of glossopterid leaves with *Glossopteris* having a midrib and anastomosing laterals at one end of the series followed by leaves of *Gangamopteris* with anastomosing laterals and no midrib, *Rhabdotaenia* with a midrib and dichotomising non-anastomosing laterals *Palaeovittaria* with a midrib in the lower half and non-anastomosing spreading laterals, in the distal part, *Rubidgea* without a midrib and spreading arched laterals and *Noeggerathiopsis* with dichotomising spreading straight veins at the other end may form a series of leaves which may be related to each other. It is considered that *Noeggerathiopsis* may not be a cordaite.

The morphological nature of the fertiligers of glossopterids are discussed and compared with certain abnormal peduncles of *Ginkgo biloba* and it is pointed out that 10 per cent of the leaves of this genus show anastomoses and this genus may be allied to *Glossopteris*.

In addition, indubitable evidence in support of the *in situ* or autochthonous mode of formation of Lower Gondwana coal is also discussed.

Key-words — Deciduous trees, *Ginkgo biloba,* leaf-borne axillary fructifications, autochthonous coal.

सारांश

ग्लॉसोप्टेरिस वनस्पतिजात के प्रमुख अनावृतबीजी

दिव्यदर्शन पन्त

इस शोध पत्र में अधोगोण्डवाना वनों के विषय में कुछ नए विचार व्यक्त किए गए हैं, जिनके बारे में लेखक का विश्वास है कि ये *ग्लॉसोप्टेरिस* तथा इससे सम्बद्ध वंशों के पर्णपाती अनावृतबीजी वृक्षों द्वारा आच्छादित थे। यह प्रस्तावित किया जाता है कि *ग्लॉसोप्टेरिड* के दीर्घतर वृक्ष ऊँचाई में 30 से 40 मीटर के बीच रहे होंगे अथवा इससें अधिक ऊँचे रहे होंगे तथा उनके नीचे *ग्लॉसोप्टेरिस* एवं उससे सम्बन्धित लघुतर वृक्ष एवं गुल्म विकसित हुए होंगे। रानीगंज शैलसमूह से प्राप्त *डैडॉक्सीलॉन* प्रजाति के वृक्ष तने से ग्लॉसोप्टेरिड वृक्षों के दीर्घ आकार का अनुमान होता है। जहां *ग्लॉसोप्टेरिस*

अत्यंत सामान्य रूप से प्राप्त पादपाश्म है तथा जिस निओगैराथियॉप्सिस से वे पूर्व में सम्बन्धित किए गए थे, अत्यल्प है। ऐसे वृक्ष तनों के आधार विस्तृत क्षैतिज अक्ष अथवा जड़ों द्वारा अवलंबित हो सकते है, जिसका अनुमान दक्षिण अफ्रीका के वाल नदी संस्तर से प्राप्त लुप्तप्राय तनों के चारों ओर के पादपाश्म अक्षों अथवा जड़ों से किया जा सकता है, जो *निओगैराथियॉप्सिस* से भी सम्बद्ध हैं।

लेखक ने पर्णपाती ग्लॉसोप्टेरिड वृक्षों की तुलना आधुनिक *गिंको बिलोबा* वृक्षों से की है। उन्होंने ग्लॉसोप्टेरिड पत्तियों को एक श्रेर्णाकृत श्रेर्णी के रूप में प्रस्तावित किया है। इस श्रेणी के एक सिरे पर *ग्लॉसोप्टेरिस* है, जिसमें एक मध्यशिरा तथा शाखामिलनी पार्श्व है। तत्पश्चात क्रमशः *गैंगामॉप्टेरिस* है, जिसमें शाखामिलनी पार्श्व के साथ कोई मध्यशिरा नहीं है। इस श्रेर्णा की अगली कड़ी में *रैब्डोटीनिया* आता है, जिसमें मध्यशिरा तथा द्विभाजित अशाखामिलनी पार्श्व आते हैं, तत्पश्चात *पेलियोविट्टेरिया* आता है, जिसके निम्न अर्ध में मध्यशिरा तथा दूरस्थ अंश में अशाखामिलनी विस्तारित पार्श्व आते हैं। इसके पश्चात मध्यशिरा विहीन तथा चापाकार पार्श्वयुक्त *रूबिडजिया* आती है तथा श्रेणी के दूसरे सिरे की द्विभाजित एवं विस्तारित ऋजु शिराओं युक्त *निओगैराथियॉप्सिस* पत्तियों की एक श्रेणी बना सकती है, जो परस्पर अन्तर्सम्बन्धित हो सकते हैं। *निओगैराथियॉप्सिस* कार्डेट नही हो सकता।

लेखक ने ग्लॉसोप्टेरिड के फलनों के संख्यात्मक गुणों की भी चर्चा की है तथा इनकी तुलना *गिंको बिलोबा* के कुछ असामान्य पुष्पावलि वृन्तों से की है तथा इंगित किया है कि इस वंश की 10 प्रतिशत पत्तियाँ शाखामिलन प्रदर्शित करती हैं। अतः यह वंश *ग्लॉसोप्टेरिस* से सम्बद्ध हो सकता है।

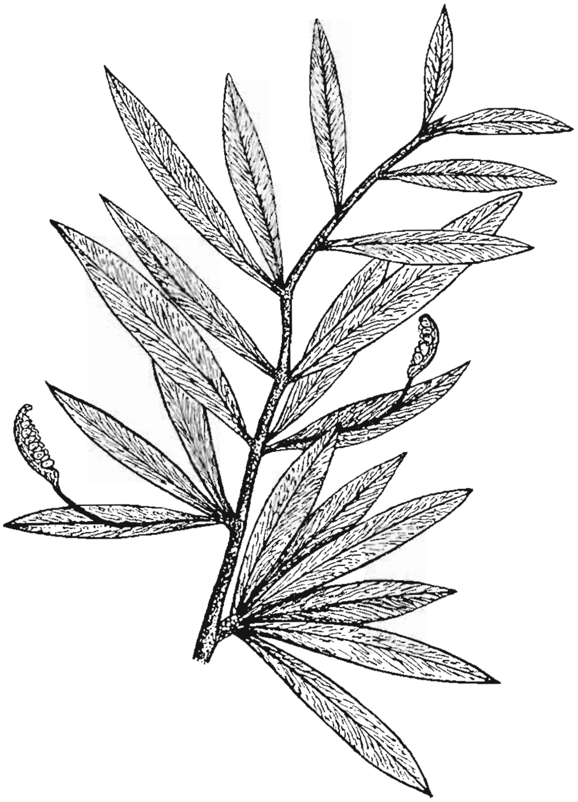
इसके अतिरिक्त लेखक ने अधो गोण्डवाना कोयले की निर्मिति के स्वस्थाने अथवा स्वस्थानिक मोड के समर्थन में कुछ असन्दिग्ध प्रमाणों की भी चर्चा की है।

INTRODUCTION

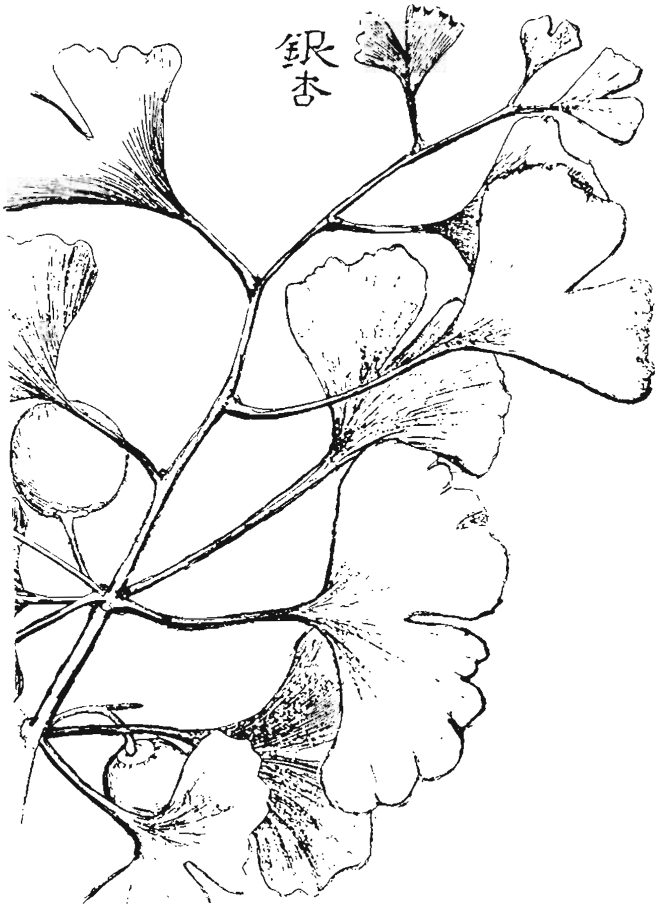
THE dominant constituents of the Lower Gondwana Glossopteris flora seem to have been the gymnosperms of the Glossopteridales which appear to have formed rich forests all over Gondwanaland. In India the coal deposits of Bihar, West Bengal, Madhya Pradesh and Maharashtra have thick coal-seams where a single seam may be as thick as 31 m, e.g., in Kargali and Korba of Bokaro and Hasdo valleys, respectively (Krishnan, 1949, p. 253) and about 46 m at Singrauli. In many coal basins there are multiple coal-seams placed one over the other interbedded with shale. The commonest fossils of the flora are leaves of *Glossopteris*. Some allies of *Glossopteris* e.g., *Gangamopteris, Rhabdotaenia, Rubidgea, Palaeovittaria, Pteronilssonia, Belemnopteris* and *Sagittophyllum* along with *Noeggerathiopsis* also occur. In the earlier stages of the flora, leaves of *Gangamopteris* and *Noeggerathiopsis* are predominant. Axes of *Vertebraria* and petrified woods showing well marked growth rings are quite common throughout the Lower Gondwanas. Among less frequent gymnospermous fossils of the Glossopteris flora there are a few narrow-leaved conifer-like remains as well but these are not discussed in the present article.

ATTACHED LEAVES OF GLOSSOPTERIDS

Although the leaves of *Glossopteris* and its allies generally occur in detached state, rarely some of them have been found attached to *Vertebraria* axes (Zeiller, 1896; Oldham, 1897; Arber, 1902; Dolianiti, 1954; Pant, 1977). In other cases glossopterid leaves have been found attached to axes which lack *Vertebraria* characters (Bunbury, 1861; Feistmantel, 1881; Etheridge, 1894; Seward, 1910; Walton & Wilson, 1932; Plumstead, 1956; Pant, 1967; Pant & Singh, 1974; Pant & Chauhan, 1995). Etheridge (1994) found leaves of *Glossopteris* attached in apical clusters to small axes which show rhomboidal leaf base scars below the clusters. Seward (1910) has illustrated a whorl of *Noeggerathiopsis hislopii* leaves from India which shows a stem in the centre. Bunbury (1861) and Feistmantel (1881) also found them attached around twigs which they mistook for raches of compound leaves and called them *Filicites* and *Sagenopteris*, respectively. Besides such clusters laterally attached single alternate leaves of *Glossopteris* have also been described by Pant, 1967. Accordingly, a reconstruction of the tree of *Glossopteris* made by Pant & Singh (1974) and Pant (1977) shows lateral spirally attached leaves around apical parts of the stem and apical clusters of leaves in short spur shoots as depicted in a reconstructed twig of *Glossopteris* in Text-figure 1. Attachment of leaves like that mentioned above for *Glossopteris* and allies actually occurs in modern *Ginkgo biloba* which has apical clusters of deciduous leaves in short spur shoots with rhomboidal leaf base scars below. Towards the tips of long shoots one can also see alternately attached deciduous leaves in whose axils arise the short shoots (see Text-figures 2 & 3) or the long shoot apices may themselves give rise to spurs (as seen in Text-figure 3). The manner in which this transformation takes place has been analysed by Gunkel & Wetmore, 1946 and Gunkel *et al.*, 1949.



Text-figure 1—*Glossopteris*, reconstructed twig with spirally arranged leaves and axillary spurs. Two of the spurs bear fertiligers with *Ottokaria* fructifications.

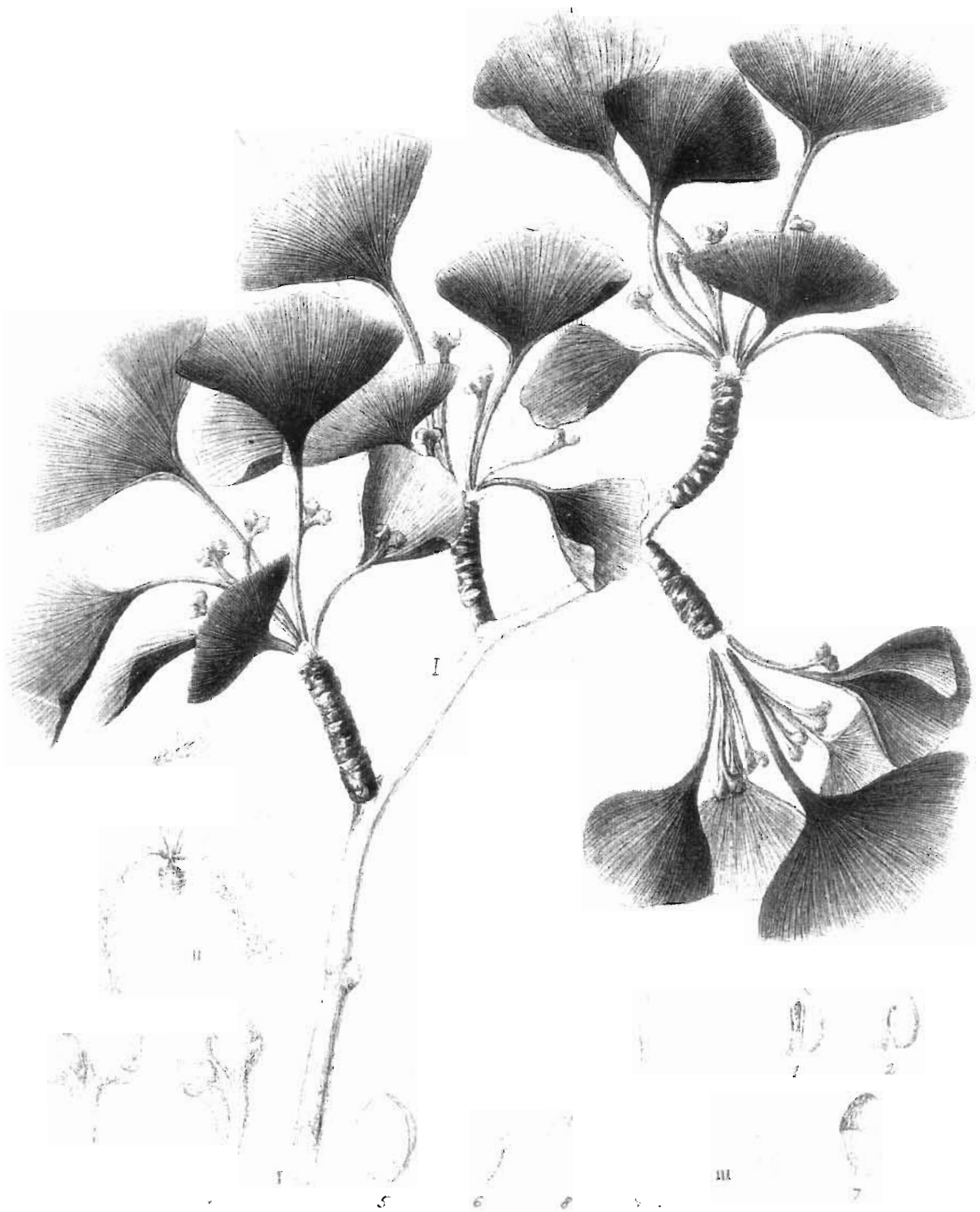


Text-figure 2—*Ginkgo biloba*, a twig from female tree with spirally arranged leaves; some of them have developed spurs in their axils (after Kaempfer, 1712).

MODIFIED RECONSTRUCTION OF TREES OF GLOSSOPTERIDS

The above mentioned similarities between the attachments of leaves of glossopterids and those of modern *Ginkgo* prompt me to review earlier reconstructions of trees of *Glossopteris* (see Pant, 1977) and I can hereby suggest a few additions and modifications. Firstly, the trees seem to have been deciduous as first envisaged by Plumstead (1958) and as the abundance of fallen leaves and paucity of attached ones in Lower Gondwana beds also indicates. Secondly, the presence of well marked growth rings in Lower Gondwana woods suggests that the glossopterid trees were producing and living in a cold or warm temperate climate with marked changes of seasons. They were bearing green foliage leaves during summers followed by their autumnal yellowing and fall during cold winters as they do in modern *Ginkgo biloba* (see Text-figures 4, 5 and 6). While growing in Lower Gondwana forests the larger trees of *Glossopteris* may have reached diameters of nearly a metre or more at their bases. Spreading branched roots or rhizomes and their usually upright, sometimes bifurcated trunks may have been about 30 to 40 m or more in height. The above ideas about the size of trees of *Glossopteris* are based on the dimensions of large tree trunks first discovered in 1923 by W.W. Whitney of the East Indian Railway at a place about 3 km from Asansol in an area which Bradshaw in Bradshaw & Sahni (1925) attributed to the Panchet Series of the Lower Gondwanas but which actually belongs to the coal beds of Raniganj Stage in the Damuda Series. The dimensions of one of these tree trunks (see Text-figure 7) which is bifurcated in its lower part (a major part of this tree is placed in G.S.I. Museum at Calcutta) are mentioned as being about 93 feet (= 28.6 m) and a maximum diameter of only the central preserved column of wood as 2 feet 7 inches (= 78.76 cm) by Bradshaw in Bradshaw & Sahni (1925). Making an allowance for the possible missing top and bottom parts of the tree, I estimate its length to have been at least 30 m or more. Its maximum diameter with surrounding soft wood and bark which are not preserved may have been about a metre or more.

Soon after the discovery of the trunks, Sahni (in Bradshaw & Sahni, 1925) assigned one of them to *Dadoxylon* sp. and thought that it may have belonged to *Noeggerathiopsis*, a *Cordaites*-like leaf genus which occurred in the Glossopteris flora and which had been assigned earlier to the genus *Cordaites* itself by Seward & Sahni (1920). Later, Sahni (1931)



Text-figure 3—*Ginkgo biloba* **I**, painting of a twig from a female tree showing a number of spur shoots with scars of fallen leaves and apical clusters of leaves with ovulate peduncles in their axils The lower spur shoot has broken off Note that the long shoot apex has also become a spur. **II**, a spur from a male tree showing peduncles with stalked paired sporangia. **III**, faintly drawn outline of a twig showing the long shoot apex; **1, 2**, pairs of pollen sacs below a hump, **3, 4**, details of apical portions of two ovulate peduncles with collars below two ovules; **5-8**, different views of seeds; **9**, a developing leaf (all from Siebold & Zuccarini, 1835-1842)

Text-figure 4—*Ginkgo biloba*, a part of a tree showing leafy branches during summer (from Michel, 1986).

reported several more trunks of the same kind and reaffirmed his earlier attribution of such *Dadoxylon* trunks to the Cordaitales. It is possible that he did not consider the eligibility of *Glossopteris* to be the leaf of such large gymnospermous trunks because Feistmantel (1886) had described structures which he believed to be sori in *Glossopteris* leaves and also due to a general belief at that time about the leaves of *Glossopteris* being those of a fern (as indicated by the inclusion of *Glossopteris* in the second volume of Seward's *Fossil Plants* 1910 and by the finding of sori of sporangia on the scales of *Glossopteris* (Arber, 1905b).

However, the situation has now completely changed and lately some leaves of *Glossopteris* and allies have emerged out as fertiligers producing seeds and pollen organs and their attached or detached stems, rhizomes or roots were first shown to have a good deal of secondary xylem with araucarioid or other types of gymnosperm-like pittings in the tracheids (Walton & Wilson, 1932). Grouped pitting like that of *Vertebraria* is also found in *Catervoxylon, Paracatervoxylon, Australoxylon, Tordoxylon, Myelontordoxylon* and *Paratordoxylon* as pointed out by Pant & Singh (1987) and these could be the woody trunk fragments of *Glossopteris*. Grouped pitting of this kind had been noticed earlier by Holden (1916) and Sahni (1931) who called it "somewhat *Callixylon*-like grouping of radial pits on the tracheids". However Sahni regarded it as a possible Cordaitalean character. The secondary xylem of the above mentioned wood genera show abundant narrow medullary rays and well marked growth rings

Text-figure 5—*Ginkgo biloba*, trees with golden leaves during autumn (from Michel, 1986).

which are typical of gymnospermous wood (Walton & Wilson, 1932; Pant, 1956; Pant & Singh, 1987; Pigg & Taylor, 1993; Pigg & Trivett, 1994). Moreover, the leaves themselves show thick cuticles with sunken stomata surrounded by papillate subsidiaries around sunken guard cells showing gymnosperm type of lignin lamellae (Pant, 1958). The midrib xylem of the leaves of *Glossopteris* often shows bordered pits (Pant, 1958; Surange & Maheshwari, 1962) and none of their well preserved leaves shows any sori. In contrast the cuticles of fern leaves are delicate and their stomata lack lignin lamellae. Further the fructification bearing leaves or fertiligers of *Glossopteris* bear seeds pollinated by disaccate *Striatites* type of pollen which are produced by *Arberiella* type of pollen sacs borne on male fertiligers called *Eretmonia*, *Glossotheca* or *Nesowalesia* (see Pant, 1977, 1987; Pant & Nautiyal, 1984; Pigg & Trivett, 1994; Chandra & Singh, 1995). Further the internal structure of axes of *Vertebraria* and leaves of *Glossopteris* and its allies as well as that of the attached or detached fructifications (fertiligers) attributed to them, as revealed by earlier studies of compressions, has been vividly confirmed by subsequent studies of their permineralized fossils (see Pant, 1997 and references cited therein). In addition to the above facts *Glossopteris* should be more eligible to be the leaf of the numerous large tree trunks called *Dadoxylon* sp. by Sahni (1925, 1931) instead of *Noeggerathiopsis*, since *Glossopteris* is the commonest leaf form occurring in the Raniganj Stage wherefrom the large tree trunks have been described, and *Noeggerathiopsis*, at this stage, had become quite a rarity.

Unlike the short, only 4 metres high, trees envisaged by Gould and Delevoryas (1977) dense forests of such high deciduous trees of glossopterids showing well marked growth rings in their secondary xylem would seemingly go well with the rich deopsits of coal in the Lower Gondwana beds and also with the frequent occurrences of petrified woods in association with remains of *Glossopteris* (Pant & Singh, 1987). I think that the thinner branches of a number of these diverse woods may have borne leaves of *Glossopteris* and its allies. However, leaves of some of the species of *Glossopteris* or its allies may have been borne on branches of small trees like the one reconstructed by Gould and Delevoryas (1977) and still others could have been borne by shrubs and lianas, e.g., *Belumoopteris* (Pant & Choudhury, 1977). All the same, the rather unnatural rosettes of leaves around the trees of *Glossopteris* depicted by Gould and Delevoryas (1977) may have been less regular with smaller and larger leaves in the apparent whorls.

As a matter of fact the coal and shales of the Lower Gondwanas appear to have been formed by thick layers of

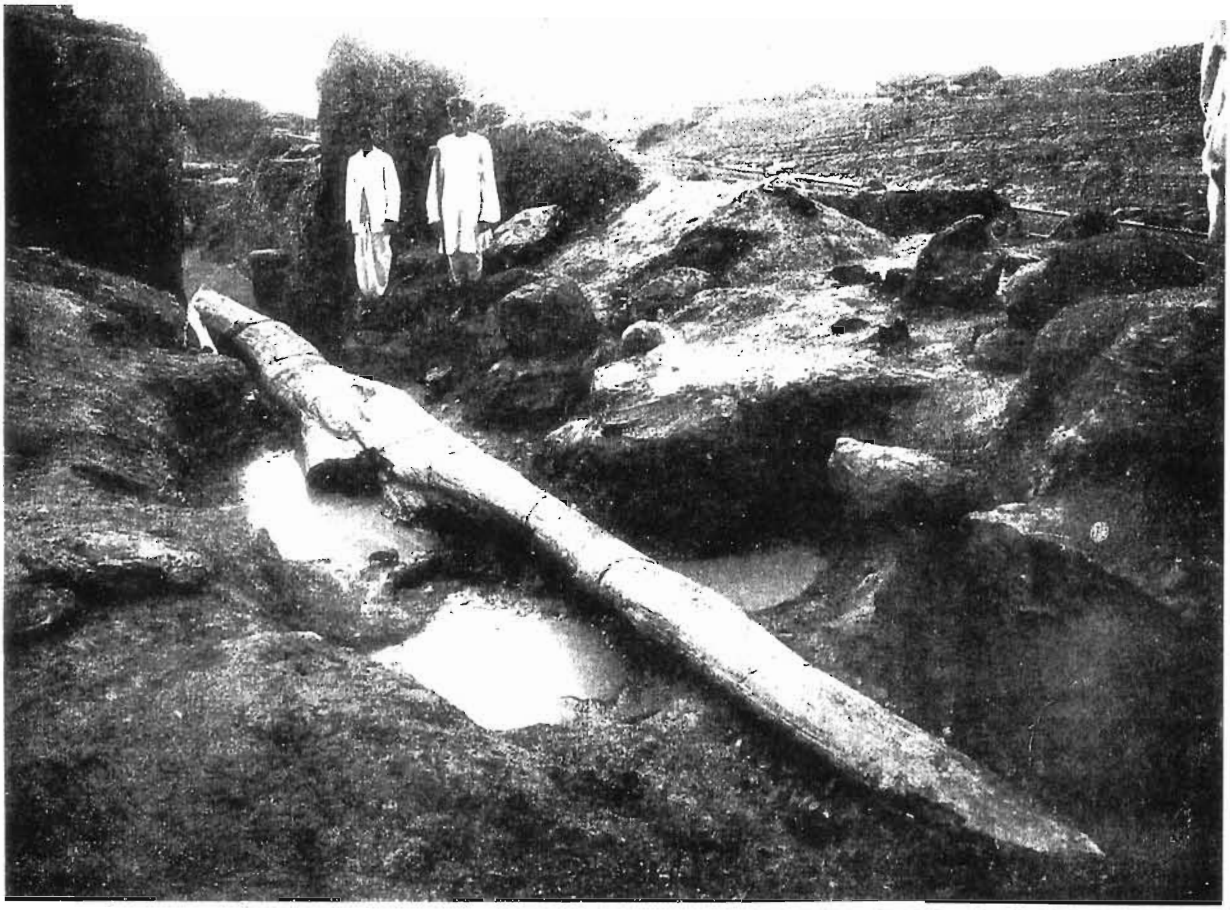
Text-figure 6—*Ginkgo biloba*, basal parts of tree trunks with fallen leaves around them forming a thick carpet in Toji Park, Tokyo during late autumn (photo by Random from Michel, 1986).

fallen leaves strewn heletr skelter and these may have accumulated repeatedly in thick annual carpets on the forest floor, as they do under the trees of modern *Ginkgo* (see Text-figure 6) whose size of 30 to 40 m, as mentioned by Pilger (1926) and Chamberlain (1935), seemingly corresponds with that of the fossil trees from Asansol. I therefore, imagine that during the Lower Gondwana times India was having rather dense deciduous forests of *Glossopteris* and its allies whose taller trees (see Text-figures 8, 9) were towering over shorter trees and shrubs so that in the words of Humboldt in these primeval woods "forest was piled upon forest" and dense humid shade of trees and shrubs provided ideal habitat for blattoid insects. The shrubs possibly had undergrowth of ferns, other pteridophytes and lower plants below them. The carpet of leaves on the undisturbed forest floor (Text-figure 10), with no records of any voracious consumers of fallen leaves, except some blatttoids (see Pant & Srivastava, 1995), in the course of time, must have piled up and become mixed up with broken twigs (rarely with attached leaves) and branches, as well as broken or fallen tree trunks as seen at the locality near Asansol.

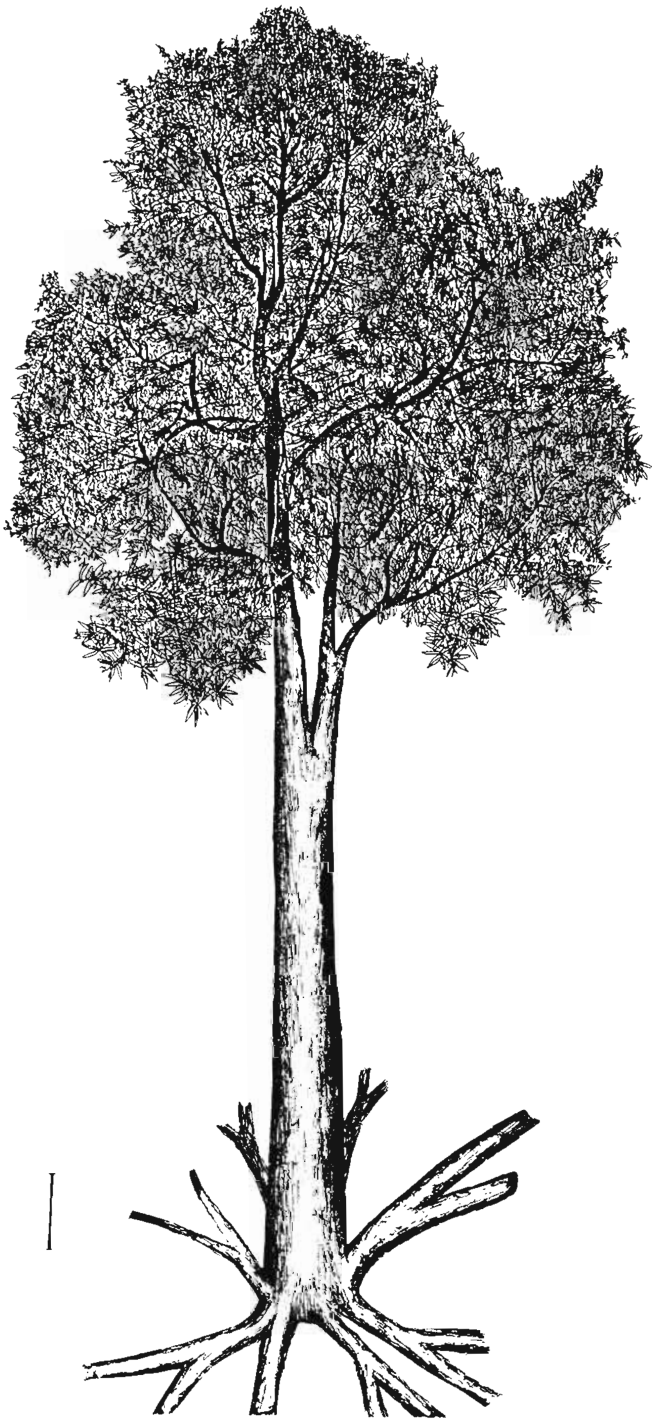
The underground or overground dead roots or root bearing axes of glossopterid trees and shrubs may also have ultimately become part of the dead organic material covering them in the forest floor. This is indicated by the greater frequency of *Vertebraria* axes at the bottom of coal seams. Wetting by rain water and fine silt displaced by rain or its drops between leaves and other plant material may have compacted the litter of leaves on the forest floor. New trees would have been coming up from germinating seeds on such a rising forest floor (Text-figure 10). In the course of millions of years the fallen leaves and other plant material became buried so that with arrested bacterial action due to lack of oxygen, it became further compacted and thereafter it was gradually converted by pressure and chemical processes of condensation and polymerisation under the influence of temperature, high pressure and time into the alternating dull and bright layered bands of the seams of coal. Occasional floods or advances of water bodies may have given rise to the intervening thin or thick layers of shale in between the coal seams.

Contrary to the *in situ* or autochthonous mode of formation of Lower Gondwana coal envisaged above and also suggested earlier by me (see Pant, 1989), some geologists like Fox, 1931 (see Krishnan, 1949) have earlier assumed that the Lower Gondwana coal is allochthonous or drift coal formed by plant material drifted into water bodies from unknown other localities. However, the presence of *Vertebraria* axes with thin roots spreading around them (Bunbury, 1861; Pant, 1956), broken tree stumps with horizontally spreading branched roots or rhizomatous axes around them as seen in a Permo-Carboniferous, sandstone bed of Vaal River at Vereeniging South Africa (Seward, 1917, p. 240, fig. 478), show that glossopterid trees were supported by such roots or axes. *In situ* vertically preserved *Vertebraria* axes called *Vertebraria radiata* by Royle (1840), vertically compressed seedlings of *Glossopteris* called *Diphyllopteris* (Pant & Nautiyal, 1987), occurrence of rootlet beds in the floor of coal seams reported by Chowdhury, 1985 and Manjrekar *et al.*, 1986 as mentioned by Banerjee *et al.* (1991), and horizontal roots and upright stems and *Vertebraria* axes later reported by Banerjee *et al.* (1991) and Singh and Chandra (1995) and Srivastava (1995) also vividly confirm that Lower Gondwana coal is autochthonous.

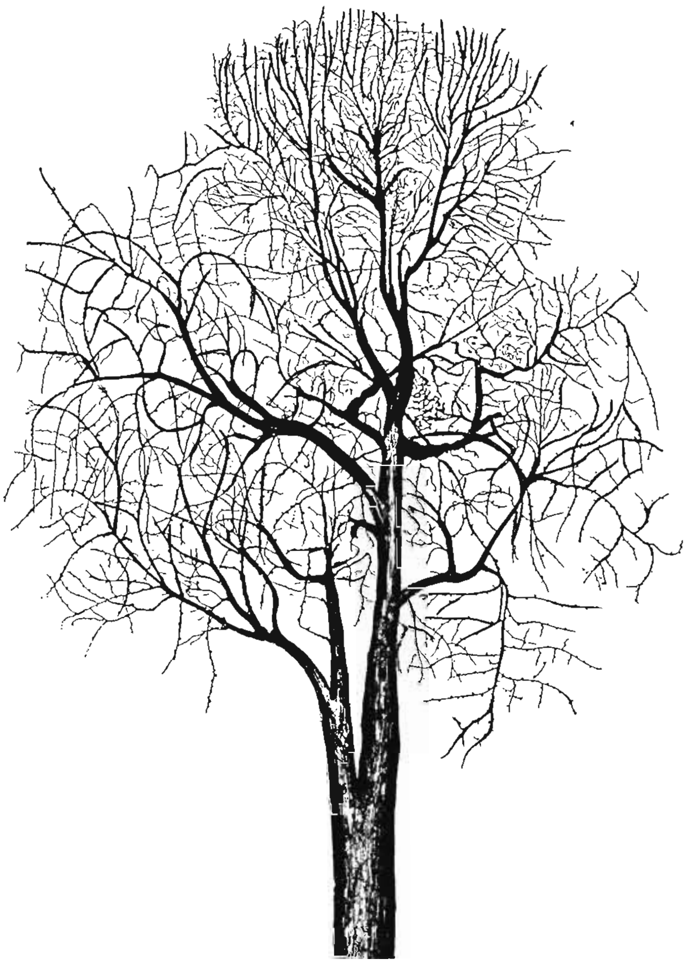
The paucity of genera of gymnospermous leaves and the multiplicity of species of *Glossopteris* has been noticed by Pant (1967) and Pant and Singh (1971) as a striking feature of the Glossopteris flora and this is particularly true about *Glossopteris* but the present day genus *Pinus* having over one hundred species spread over the entire north temperate zone from Japan in the East to western United States and western Canada in the West, with three species spreading northwards beyond the Arctic Circle in Eurasia and one species reaching or slightly overstepping the Equator in Sumatra (see Mirov, 1967; Little & Critchfield, 1969) presents a living parallel among the present day gymnosperms. Another parallel is provided by *Gnetum* which is distributed all over the tropical and humid regions of the world from Pacific Islands like New Guinea, Philippines and the East Indies, Siam, Malaysia, Indo-China, India, Tropical Africa, Guiana, Northern Brazil, Surinam and Amazon. Its diverse species are climbers, trees, shrubs and one of them, *Gnetum trinerve*, is a parasite (see Maheshwari & Vasil, 1961). Pant & Singh (1987) have already suggested that some Lower Gondwana woods showing excentric xylem cylinders could have belonged to lianas thereby implying that some glossopterids could have been woody climbers. Alternatively, the multiplicity of associated wood genera and leaf attached fructifications of *Glossopteris* and its allies may ultimately prove that they are divisible into a number of more natural genera, subgenera and sections on the basis of their stems and attached fructifications.



Text-figure 7—Fossil tree trunk discovered near Asansol by W.W. Whitney in 1923 (from Bradshaw & Sahni, 1925).



Text-figure 8—*Glossopteris*, reconstructed tree with leaves during summer showing spreading axes or roots around the tree.

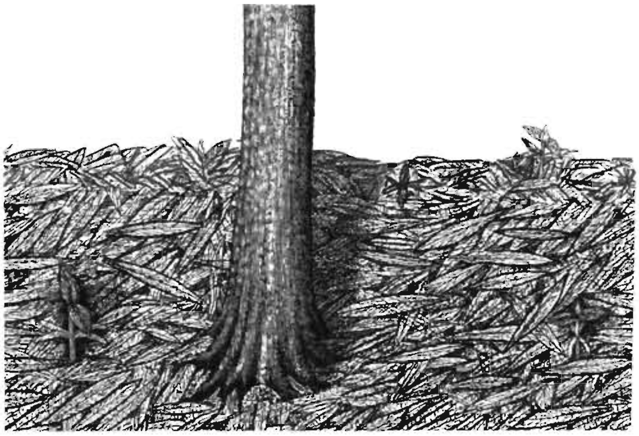


Text-figure 9—*Glossopteris*, reconstructed crown of leafless tree during winter.

FERTILIGERS OF GLOSSOPTERIDS AND THEIR MORPHOLOGICAL NATURE

Plumstead (1952) described a number of leaf attached fructifications of *Glossopteris* and called them by separate adjectival generic names although as pointed out by Edwards, Krausel and Lakhanpal in the discussion of the paper by Plumstead (1952) and also as pointed out by me in 1977 the nomenclature is violative of two articles of the International Code of Botanical Nomenclature. The case of *Ottokaria* was different because Zeiller (1902) believed that the fructification was lying over a *Glossopteris indica* leaf. Subsequently after the discoveries of a number of leaf attached fructifications by Plumstead (1952), many other authors have also given separate generic names to such fructifications. So much so that the names of such fertile leaves or fertiligers have become legitimate by wide practice and accordingly I propose that such names may be treated as *nomina generica coservanda* and no longer violative of the code.

However, the topic which I wish to discuss at this point is the morphological nature of the leaf attached fructifications. A search for comparable leaf attached fructifications among present day vascular plants leads me to (1) the fertile spikes of Ophioglossaceae, (2) the abnormal female "flowers" of *Ginkgo* described by Fujii (1896), which could be taken to be reversions, (3) the flowers of *Ruscus, Danae* and *Semele* at-



Text-figure 10—Reconstructed basal part of the trunk of a *Glossopteris* tree with fallen leaves forming a thick carpet around it. Note a few seedlings of *Diphyllopteris verticillata*.

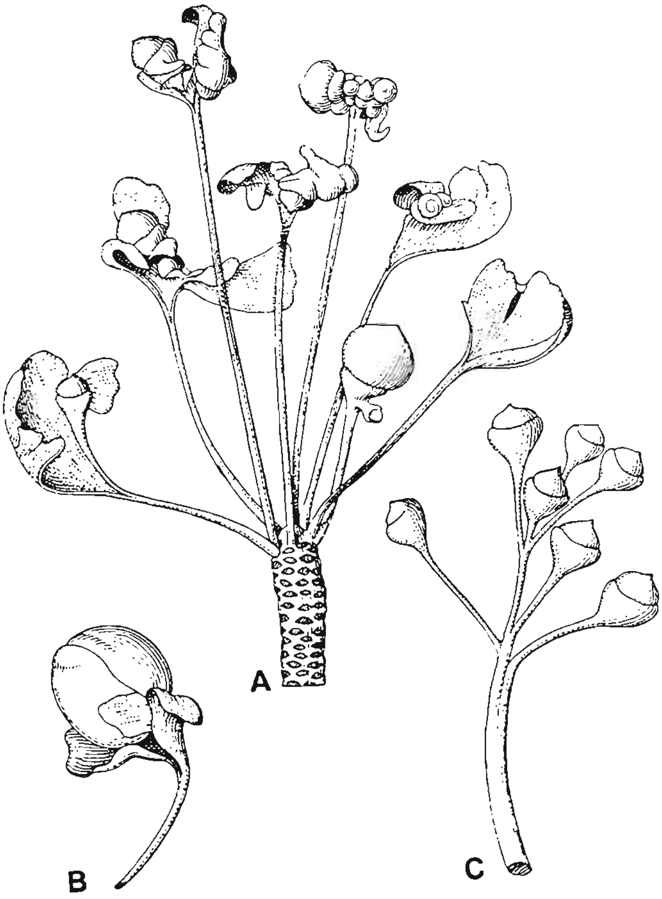
tached to their prophylls and (4) the bract attached inflorescences of *Tilia*. All these structures occurring in such diverse plants may be regarded as examples of the incorporation of the axillary fertile shoots in the subtending prophylls or bracts as suggested by Arber (1950). Indeed the widespread occurrence of such structures suggests that they are not peculiar to *Glossopteris* but they have arisen repeatedly in pteridophytes, gymnosperms, monocots and dicots. The latest interpretation of the fertile spikes of Ophioglossaceae regards the frond as a modified, reduced, dichotomous branch system (Zimmermann, 1942; Chrysler, 1945). In fact Nozu (1950, 1955) and Nishida (1957) regard the sterile and fertile segments as phylogenetically equivalent to fronds and therefore homologous. However, if we compare the two segments with the axillary fertile shoots of Rusceae and *Tilia* which become adnate to the subtending prophylls and bracts, they could be regarded as fertile axes adnate to phyllomes. The leaf attached fructifications of *Glossopteris* would thus appear to be quite comparable with those of the above living forms.

The axillary fructifications of *Glossopteris taenioides* described by Pant and Singh (1974) seemingly support the axillary nature of the fructifications of *Glossopteris* even when they seem to be coming out of their midribs. The abnormal female fructifications or "flowers" of *Ginkgo* described by Fujii, 1896 (see Text-figure 11A, B) could likewise be interpreted as fused to the leaves in whose axils they were produced. Some of the abnormal fructifications of *Ginkgo* described by Sprecher (1908) are branched (see Text-figure 11C) and in this connection it is important to point out that such branched fructifications of *Ginkgo* and the multiple fertile spikes of *Ophioglossum palmatum* too have their parallels in *Eretmonia, Glossotheca, Partha, Denkania, Lidgettonia* and these would perhaps require to be explained as being branched and the branches being adnate to the lamina.

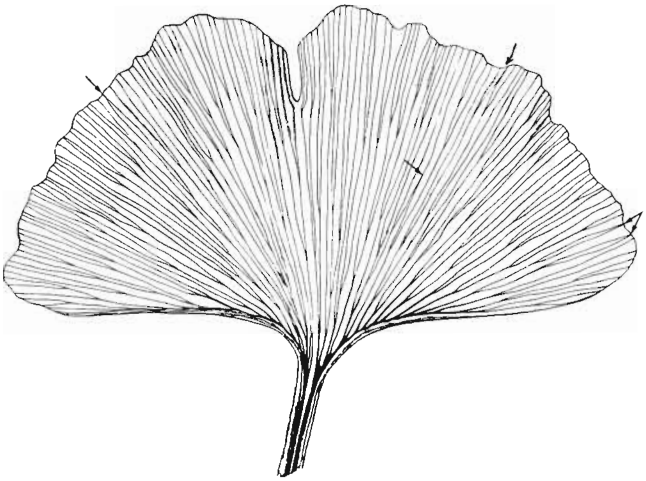
The position of the fertile leaves on the plants of *Glossopteris* is, however, unknown and we do not even know whether they are similar to or different from ordinary leaves of their plants (cf "bracts" of *Tilia*). Accordingly the term fertiliger used by Schopf (1974) seems to be quite appropriate. Further, we are completely ignorant about the plants of glossopterids being monoecious or dioecious. A method of determining this could be the occurrence of male and female fertiligers in close proximity or far away but this too is presently unknown.

RELATIONSHIPS OF GLOSSOPTERIDS

The similarity of the size of trees, deciduous habit and abnormal female fructifications of *Ginkgo* (Text-figure 11A, B) with the envisaged size of the deciduous trees and the leaf attached fructifications (fertiligers) of *Glossopteris* could even prompt us to look for relationships between the Ginkgoales and the Glossopteridales. Both the groups appear to be having deciduous leaves borne on short as well as long shoots,



Text-figure 11—*Ginkgo biloba*, **A**, spur shoot with a number of abnormal ovulate peduncles fused to leaf stalks, some of them showing seeds borne on laminae and single almost normal peduncle. **B**, a single abnormal peduncle with a seed showing longitudinal striation along fleshy part of seed and the lamina below the seed. **C**, an abnormal peduncle with seven stalked single ovules and their collars (A, B, from Fujii, 1896; C, from Sprecher, 1907).



Text-figure 12—*Ginkgo biloba*, cleared leaf showing dichotomous venation with a few anastomoses of veins marked by arrows (redrawn after Arnott, 1959).

and both kinds of shoots showing secondary xylem with well marked growth rings. The haplocheilic stomata of *Ginkgo* (Pant & Mehra, 1964) and glossopterids have similar rings of papillate subsidiaries overarching sunken guard cells. However, the net veined leaves of *Glossopteris* having well defined midribs would, appear to be quite different from the dichotomously veined leaves of *Ginkgo* and the Ginkgoales. All the same Arnott (1959) has reported various kinds of cross connections in 10% leaves of *Ginkgo biloba* (Text-figure 12) and there are other glossopterids which seemingly bridge the gap between acostate leaves with fan like spreading furcate veined leaves of Ginkgoales and net veined costate leaves of *Glossopteris*. These are *Gangamopteris* which is netveined but it has no midrib, *Rhabdotaenia* which is costate but its lateral veins are usually non-anastomosing, and there are species like *Glossopteris angustifolia* var. *taeniopteroides* with almost complete absence of anastomoses between lateral veins (see Seward, 1910) which are quite like *Rhabdotaenia*. Next comes *Palaeovittaria* which has an ill-defined midrib in the basal half of the leaf and only furcate non anastomosing parallel or sub parallel veins in the lamina and there is *Rubidgea* which has no midrib and only furcate veins in the distal part of the lamina which are, however, arched and not straight like those of *Ginkgo*. At the end of the series is *Noeggerathiopsis* which is acostate with furcate and spreading parallel veins. This genus is believed to be a cordaite, so much so that Seward & Sahni (1920) had actually merged it with the genus *Cordaites*. However, it appears to me that *Noeggerathiopsis* may not only be different from *Cordaites*, as already suggested by Pant & Verma (1964a) on the basis of (1) prevalent differences in structural features of its leaves from those of *Cordaites*, (2) the usual absence of stems with discoid pith or *Artisia* pith casts and (3) the absence of *Cordaitanthus*-like fructifications in the Lower Gondwana beds. Indeed, it occurs to me now that it may belong to an alliance approaching the Glossopteridales which I have earlier called Noeggerathiopsidales (Pant, 1882).

Another resemblance between *Ginkgo*, Cordaitales and Glossopteridales (Arberiales of Meyen, 1987) lies in their platyspermic seeds which, according to Meyen (1987), is a character of fundamental importance and he actually includes his Arberiales in his Ginkgopsida. Although he regards *Ginkgo* as having evolved from some pteridospermous ancestors which were rather different from cordaites and conifers. On the contrary Crane (1985), Doyle and Donoghue (1986) and Hart (1987) regard *Ginkgo*, conifers and *Cordaites* as having evolved from a common ancestor. Another point which may favour the relationships of glossopteridales and ginkogoales is the early appearance of ginkgophytic leaves in the Jurassic (Archanelsky, 1965) and Lower Permian (Cuneo, 1987) of Argentina and also those of *Ginkgophyllum diazii* in the carboniferous of Rioja Province of the same country as mentioned by Taylor & Taylor (1993) after S. Archangelsky. These finds may suggest the dispersal of the group from the southern latitudes as also envisaged by Stewart & Rothwell (1993). My conclusions about the habit of the deciduous plants of *Glossopteris* and its allies and the series of leaves of the glossopterids with *Palaeovittaria* and *Rubidgea* placed between them and *Noeggerathiopsis* also seemingly support the relationships of Glossopteridales Ginkgoales and Cordaitales.

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A supplementary study on *Protoblechnum* Lesquereux from China

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ABSTRACT

Bainian S & Guanglong S 1999. A supplementary study on *Protoblechnum* Lesquereux from China. Palaeobotanist 48(2) : 125-129.

The frond structure of *Protoblechnum* and the other similar plants is examined. These plants are like the neuropterids of the Late Palaeozoic Era, with forked or unforked rachides, whose fronds are simple pinnate or pinnately compound leaf and unequally or equally pinnate fronds. Based on the new materials of the bipinnatifid fronds of *Protoblechnum contractum* (Gu & Zhi) from Henan in China, it may be seen that other species of *Protoblechnum* besides *Protoblechnum wongii* Halle may also be bipinnatifid fronds. The discovery provides important materials for making a clear distinction among *Protoblechnum* and similar plants.

Key-words—China, Shihhotze Formation, Plant megafossils, *Protoblechnum, Compsopteris.*

सारांश

चीन से प्राप्त *प्रोटोब्लेक्नम* लेस्क्वीरियक्स का एक सम्पूरक अध्ययन

सन बेनियान एवं शेन गुआंग्लाँग

प्रोटोब्लेक्नम तथा अन्य मिलते-जुलते पौधों की प्रपर्ण संरचना का परीक्षण किया गया। ये पौधे अन्तिम पेलियोजोइक कल्प के द्विशाखित अथवा अशाखित अक्ष युक्त न्यूरॉप्टेरिडों की भांति के हैं, जिनके प्रपर्ण सरल, पिच्छाकार अथवा पिच्छकित संयुक्त पत्तियां एवं असमरूप अथवा समरूप पिच्छाकार प्रपर्ण हैं। चीन के हेनान प्रान्त से प्राप्त *प्रोटोब्लेक्नम कॉन्ट्रेक्टम* (ग एवं झी) के द्विपिच्छकित प्रपर्णों से नवीनतम प्राप्त पदार्थों के आधार पर यह देखा जा सकता है कि *प्रोटोब्लेक्नम वोंगाई* हाले के अतिरिक्त *प्रोटोब्लेक्नम* की अन्य प्रजातियाँ भी द्विशाखित प्रपर्ण युक्त हैं। इस अनुसन्धान से *प्रोटोब्लेक्नम* एवं अन्य मिलते-जुलते पौधों में स्पष्ट विभेद करने हेतु अत्यन्त महत्त्वपूर्ण सूचना प्राप्त हुयी हैं।

INTRODUCTION

A dispute exists since long over the relationship between *Protoblechnum* and other similar plants, such as, *Compsopteris, Glenopteris* and *Supaia* in Permian floras of China, but it has not been completely solved up to now. The difference of opinion as how to choose suitable generic name still exists because of obvious form variation in the fossils collected by researchers.

BACKGROUND OF *PROTOBLECHNUM*

Halle (1927) while studying the fossil plants from the Late Palaeozoic strata in Shanxi, China placed a few simple pinnate fronds from the Shihhotze Formation in the genus *Protoblechnum* and named them *Protoblechnum wongii* Halle. Lesquereux (1880) had erected the genus *Protoblechnum* for specimens of *Alethopteris holdeni* described by Andrews (1875), which are simple pinnate fronds with unforked rachides. Halle (1927) while discussing the distinction between *Protoblechnum* and other relative fossils pointed out that it would also be necessary to place forked *Danaeopsis hughesi* Feistmantel from the Indian Triassic under the genus *Protoblechnum*. Thus it can be seen that he did not think forked or unforked fronds as an important condition to distinguish genera. Yabe and Oishi (1928a, b) accepted Halle's opinion and put under the genus *Protoblechnum* a few similar specimens from Permian strata of Shandong Province that were also simple pinnate fronds and did not have forked rachides.

White (1929), on the other hand, while researching the fossil plants collected from the Permian Hermit shale of Grand Canyon, America did not agree with views of Halle and Yabe and Oishi. He expressed the opinion that he would prefer to refer the Chinese species, which had simple pinnate fronds and unforked rachis, to the genus *Glenopteris* Sellards (1900), and the Indian species *Danaeopsis hughesi* Feistmantel, whose rachis is forked, to his new genus *Supaia*. Zalessky (1934, 1935) also found some specimens in the Permian of Russia similar to Chinese *Protoblechnum*. He did not approve of using the genus *Protoblechnum*, either. He grouped some specimens with forked rachides into *Supaia* White and the others showing simple pinnate fronds and without forked rachides to his new genus *Compsopteris*.

After the People's Republic of China was founded, the fossil plants of this type have often been recorded in the Permian strata of China and their form structure is also different. Sze (1955) first reported a forked frond from Permian System of southeast Shanxi. He did not adopt the name *Supaia* White and supported Halle's view and used the name *Protoblechnum*, which obtained support of many scholars such as Zhou Zhiyan and Li Xingxue. Townrow (1957) pointed out that the original *Protoblechnum* and *Supaia* of forked rachides from China and America, respectively should be placed in the genus *Dicroidium* with Indian *Danaeopsis hughesi*.

PROTOBLECHNUM AND *COMPSOPTERIS* FROM CHINA

Gu & Zhi (in Li Xingxue *et al.*, 1974) considered that Chinese *Protoblechnum* was quite similar to *Compsopteris*, and thus the former should be transferred to the latter. According to their opinion, *Protoblechnum wongii* Halle including *Protoblechnum hallei* Yabe & Oishi described in China should be merged as *Compsopteris wongii* (Halle) Zalessky. They also set up two new species, that is, *Compsopteris imparis* Gu & Zhi and *Compsopteris contracta* Gu & Zhi. The above mentioned three fossils were all simple pinnate fronds and the rachides forked once or not at all. Many scholars agreed with the opinion and the name *Compsopteris* has been gradually accepted in China since then (Feng Shaonan *et al.*, 1977; Chen Ye & Duan Shuyin, 1978; Zhang Jihui, 1978; Yang Guanxiu & Chen Feng, 1979; Zhao Xiugu *et al.*, 1980; Chen Lizhu, 1982; Wang Guoping *et al.*, 1986; Li Peijuan & He Yuanliang, 1986; Yang Guangrong *et al.*, 1986; Huang Lianmeng *et al.*, 1987; Zhu Tong, 1990; Kong Xianzheng *et al.*, 1990).

In 1977, Huang Benhong found a great number of fossils of this type from Xiao Xin'an Mountains in Northeast China, too. He considered that the forked or unforked nature of rachis should be an important basis for generic distinction. He, therefore, put the forked fronds into *Supaia* and the unforked specimens into *Compsopteris*. Shen Guanglong (1995), however, included Chinese specimens of *Protoblechnum wongii* Halle with forked rachides in *Supaia* and for those with unforked rachides and simple pinnate he still reserved the name *Protoblechnum* as a form genus. *Compsopteris* has not been used until it has been confirmed as the same kind of plants as in the Angara flora on the basis of cuticular studies.

Liu Lujun (1989) discovered a lot of fossil plants from southeast Shanxi, among which were some bipinnatifid fronds. After reading relative references, he expressed the views to use *Protoblechnum* in the Cathaysian flora and limit *Compsopteris* in the Angaran flora. In conformity with his view, it is clearly seen that the formerly described specimens of *Protoblechnum* type from China may be placed in the genus *Protoblechnum* no matter simple pinnae or bipinnae they are; no matter forked or unforked rachides they have.

Wang (1996) has recently pointed out that *Supaia* which had simple pinnate fronds and forked rachis might have evolved from *Protoblechnum wongii* Halle which had bipinnatifid fronds and unforked rachis. It is a result of palaeoclimatic changes, which can be well explained by Asama's Growth Retardation Theory (1960). According to Wang's study, there are two types of the pinnule base in *Supaia* from the Upper Shihhotze Formation in Shanxi, China. One has a decurrent base as in *Protoblechnum wongii* and the other has a contracted base like *Protoblechnum contractum*. Among published records from China, the specimens of *Protoblechnum contractum* are all simple pinnate fronds, contracted bases of pinnule and unforked rachides. It is of vital significance to get a specimen of bipinnatifid fronds of *Protoblechnum contractum* from Permian strata in China if Wang's guess is correct about the origin of *Supaia* from the Upper Shihhotze Formation of Shanxi, China. Furthermore, it may show that both *Protoblechnum wongii* and *Protoblechnum contractum*, which are all bipinnatifid fronds but whose bases of pinnules are different (one decurrent, the other contracted), possibly represent two directions of the evolution from *Protoblechnum* to *Supaia*.

Kapoor *et al.* (1992) considered that *Kashmiropteris meyenii* Kapoor, a possible cycadalean leaf from the Early Permian Mamal Formation in the Kashmir Himalaya, showed a certain resemblance to *Protoblechnum* Lesquereux 1880 and *Compsopteris* Zalessky 1934, but leaves of both these genera

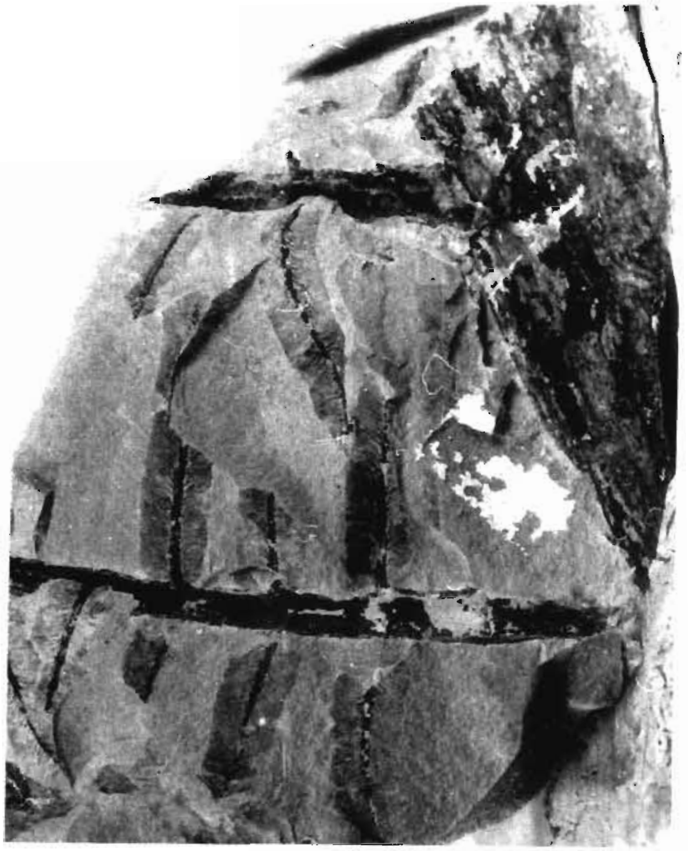
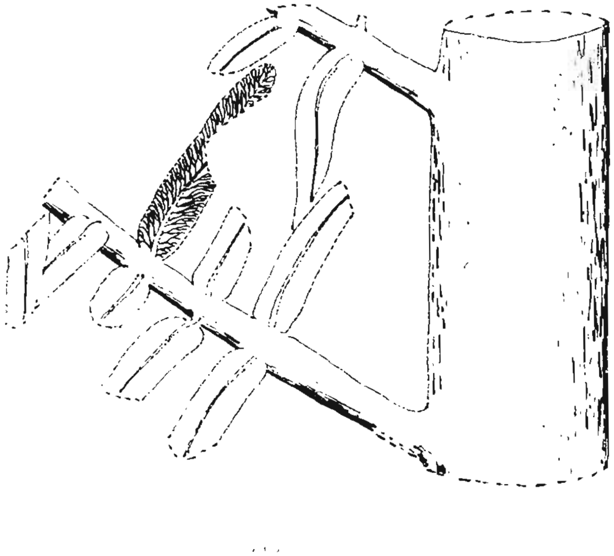


Figure 1—*Protoblechnum contractum* (Gu & Zhi) emend. x1.



Text-figure 1 :—*Protoblechnum contractum* (Gu & Zhi) emend. x 1

differ from that of *Kashmiropteris meyenii* in the venation pattern of the pinnae. It is very interesting that *Kashmiropteris meyenii* has also two type bases of pinnae or pinnules, one contracted (Kapoor *et al.*, p. 143, pl.1, figs 1-3), the other decurrent (p. 145, pl. 2, figs 1-2).

DISCUSSION

According to present materials, the rachides of both *Protoblechnum* and *Glenopteris* in North America are unforked and their leaves are simple pinnate fronds. They are almost showing no difference in other shape features and may be merged. The former should be kept and used because of its priority. As to the similar fossils with a forked rachis, the genus *Supaia* erected by White can be applied because the forked or unforked rachides is an important basis for generic segregation. The leaf of *Compsopteris* is simple frond. Although the appearance of the genus is the same as that of *Protoblechnum*, the cuticular structure of *Compsopteris* ascertained by Meyen & Migdissova (1969) is different from that of *Protoblechnum*. And the former with an unforked rachis, which differs from the *Supaia*, ought to be reserved and limited in the Angara area. As for Indian species *Danaeopsis hughesi* with a forked rachis, it has been transferred to another genus because the reproductive organ and the cuticular structure of *Danaeopsis hughesi* have been clearly studied. The genus has nothing to do with *Supaia* and is also one of local plant members in the Angara area.

It may be seen from the foregoing review that the frond structure of *Protoblechnum* and the other similar taxa is rather complex. Based on accumulated materials, these plants may be like neuropterids of the Late Palaeozoic Era, whose rachides were forked or unforked, fronds were simple pinnate or pinnately compound leaf and unequally or equally pinnate fronds. All of these will depend on further field work and study so that the kind of plant can be identified reasonably. Therefore, it is very important that a new specimen which can reveal detailed structure of the plant is discovered.

NEW MATERIALS

In the Summer of 1994, one of the authors (Sun Bainian) collected many good specimens of *Protoblechnum* from the Upper Shihhotze Formation at Dengfeng Coalfield in Henan, among which there are several specimens of bipinnatifid fronds. The authors of present paper think that these bipinnae should be *Protoblechnum contractum* (Gu & Zhi). This discovery not only indicates that other species of *Protoblechnum* besides *Protoblechnum wongii* Halle can be bipinnatifid fronds but also provides important materials for making a deep distinction between *Protoblechnum* and similar plants. In accordance with the new materials from Henan, an emended diagnosis of *Protoblechnum contractum* (Gu & Zhi) is given.

PROTOBLECHNUM CONTRACTUM

(Gu & Zhi) Sun Keqin emend

(Fig. 1; Text-figure 1)

1974 *Compsopteris contracta*, Gu & Zhi (in Li Xingxue *et al.*), p.115, pl. 82, figs 4-6; pl. 83, figs 1-3, Text-figure 79.
1977 *Compsopteris contracta*, Feng Shaonan *et al.*; p. 659, pl. 245, figs 6-7.
1978 *Compsopteris contracta*, Chen Ye & Duan Shuyin, p. 465, pl. 152, figs 2-3.
1978 *Compsopteris contracta*, Zhang Jihui, p. 475, pl. 159, figs 2-3.
1979 *Compsopteris contracta*, Yang Guanxiu & Chen Feng, p. 126, pl. 35, figs 7-8.
1980 *Compsopteris contracta*, Zhao Xiugu *et al.*, p. 82.
1982 *Compsopteris contracta*, Chen Lizhu, p. 517, pl. 331, fig. 8.
1982 *Compsopteris contracta*, Wang Guoping *et al.*, p. 366, pl. 153, fig. 10.
1986 *Compsopteris contracta*, Yang Guangrong *et al.*, p. 11, 32, pl. 18, fig. 10.
1987 *Compsopteris contracta*, Huang Lianmeng *et al.*, p. 44, pl. 22, fig. 5; pl. 23, fig. 1-2.
1990 *Compsopteris contracta*, Zhu Tong, p. 96, pl. 3, 6, pp. 34, figs 1-3.
1991 *Protoblechnum contractum*, Sun Keqin, p. 40-41, pl.13, fig. 2.
1991 *Protoblechnum contractum*, Yang Jinyao, p. 41, table 2-9.
1995 *Protoblechnum contractum*, Shen Guanglong, p. 101, 108, 130, 139.
1996 *Protoblechnum contractum*, He Xilin, Liang Dunshi & Shen Shuzhong, p. 59, pl. 45, fig. 4.
1996 *Compsopteris contracta*, Kong Xianzheng *et al.*, p. 188-189, pl. 13, fig. 1,1a.

Description—Frond very large, bipinnate, rachis thick, attaining 2.8 cm in width, obviously thin drops on the surface of rachis; ultimate pinnae 8 cm in width and unknown in length; ultimate rachis thick, 5-7 mm broad; pinnule 9 mm wide, scattered in arrangement, long linear or strap-shaped, margin entire, base contracted; midrib strong, 1-1.5 mm in width, nearly reaching to the apex, at a right angle extended from the rachis; lateral veins fine and close, curving outside at a small angle from the midrib, dichotomizing twice or thrice, 20-25 veins per cm on the margin.

Comparison—The present specimen with unforked rachis, bipinnate frond, shape and veins of ultimate pinnae is like *Protoblechnum wongii* Halle, but the distinction lies in the obviously contracted base of pinnules in the former.

Locality and Horizon—Dengfeng, Henan; Upper Shihhotze Formation.

Specimen No. and Repository—PB93174; Palaeontologic laboratory of Geological Department, Lanzhou University.

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Saksenasporites gen. nov. – A Permian megaspore from Birsinghpur Pali, Madhya Pradesh

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ABSTRACT

Tripathi RP 1999. *Saksenasporites* gen. nov. — A Permian megaspore from Birsinghpur Pali, Madhya Pradesh. Palaeobotanist 48(2) : 131-135.

A new taxon of Permian megaspore, *Saksenasporites* gen. nov., is described from Birsinghpur Pali, Madhya Pradesh (India). The new megaspore is characterised by unequal trilete laesurae, one or two of them extending beyond arcuate ridges, mixed verrucose- baculose sexine sculpture, distinct contact areas delimited by arcuate ridges and unpitted nexine. A new suprainfraturma, *Verrucosi-baculati* nov., is proposed in the text. Taxonomic consideration of the new megaspore is based on SEM and LM studies.

Key-words—Megaspore, Permian, Lower Gondwana, India.

सारांश

मध्य प्रदेश के बीरसिंहपुर पाली क्षेत्र से प्राप्त एक परमियनयुगीन गुरूबीजाणु : *सक्सेनास्पोराइटीज़* नव वंश

आर.पी. त्रिपाठी

मध्य प्रदेश के बीरसिंहपुर पाली क्षेत्र से *सक्सेनास्पोराइटीज़* नव वंश नामक परमियनयुगीन गुरूबीजाणु का एक नया वर्गक अंकित किया गया। यह नया गुरूबीजाणु असमरूप त्रिअरीय लीज़्यूरी द्वारा अभिलक्षणित है। इनमें से एक अथवा दो चापाकार कटक आगे तक बढ़े हुए हैं तथा ये मिश्रित किणमय-बाकुलामय सेक्साइन लक्षण (स्कल्पचर) हैं। इनके सुस्पष्ट सम्पर्क क्षेत्र चापाकार कटकों तथा अगर्तमय नेक्साइन तक असीमित हैं। शोध पत्र द्वारा *वेरूकोसी - बाकुलाटी* नामक एक नया महाअवुटर्मा (सुपराइन्फ्राटुर्मा) प्रस्तावित किया जाता है। नवीनतम गुरूबीजाणु का वर्गकीय मूल्याकंन क्रमवीक्षण इलेक्ट्रॉन सूक्ष्मदर्शी तथा सरल सूक्ष्मदर्शी द्वारा किए गए अध्ययन पर आधारित है।

INTRODUCTION

PERMIAN rocks possess diversified assemblages of megaspores (Bharadwaj & Tiwari, 1970; Pant & Mishra, 1986; Maheshwari & Tewari, 1987). Megaspores from Birsinghpur Pali were first reported by Saksena (1971); since then, Lele and Chandra (1974), Pant and Mishra (1986), Mishra and Tripathi (1991), Maheshwari and Tewari (1991) and Tripathi (1997) have described a wide variety of megaspores from the locality. The present investigation on *Saksenasporites* gen. nov. adds further to our knowledge of dispersed megaspores from the Permian rocks of India.

MATERIAL AND METHOD

Carbonaceous shales were collected from the North bank of Johilla river, about 150 m from its confluence with Ganjra nalla, in Birsinghpur Pali Coalfield, District Shahdol (Madhya

Pradesh). The shales are full of incrustations of leaves of *Noeggerathiopsis* sp., *Glossopteris* sp., *Gangamopteris* sp., equisetalean axes, coniferous shoots and cordaitalean seeds (Feistmantel, 1882; Saksena, 1955; Pant *et al.*, 1995). Coal samples were collected for the present purpose from the coal mines of the area and macerated by usual techniques (Tripathi & Mishra, 1997a).

The Holotype and figured slides are stored in Palaeobotany Laboratory, Botany Department, Govt. Autonomous Science College, Rewa, M.P., India. The descriptive terms used in the text are in accordance with Kremp (1965) and Pant and Mishra(1986).

SYSTEMATICS

Remarks—Pant & Mishra (1986), while emending the genus *Jhariatriletes* Bharadwaj & Tiwari 1970, stated that the megaspores of type species *J. baculosus* Bharadwaj & Tiwari and *J. damudicus* (Srivastava) Bharadwaj & Tiwari have mixed verrucose-baculose ornamentations over the sexine. This feature is also seen in text-figures and photographs given by Bharadwaj and Tiwari (1970) and, further, the megaspores of the genus *Saksenasporites* gen. nov., in the present study, under SEM, confirm the presence of mixed verrucose- baculose ornamentations over sexine of megaspores. Hence, the new suprainfraturma *Verrucosi- baculati* nov. is proposed here for the trilete megaspores having mixed verrucose- baculose sexine sculpture.

Supraturma—SPORITES H. Potonié 1893

Anteturma—MEGASPORITES Pant 1962

Turma—TRILETES (Reinsch) Potonié & Kremp 1954

Suprasubturma—AZONOTRILETES Luber 1935

Subturma—APICULATI (Bennie & Kidston) Potonié 1956

Suprainfraturma—VERRUCOSI - baculati nov.

SAKSENASPORITES gen. nov.

Diagnosis—Megaspores trilete, amb circular to subtriangular, trilete laesurae unequal, one or two of them extending beyond arcuate ridges but falling short of margin; contact areas distinct and bounded by arcuate ridges, sexine covered with mixed verrucose-baculose sculptures, nexine membranous and unpitted.

Type species—Saksenasporites rewaensis sp. nov.

Comparison—Genus *Saksenasporites* nov. is comparable with *Jhariatriletes* (Bharadwaj & Tiwari) Pant & Mishra 1986 in having mixed verrucose-baculose sexine sculptures, nature of contact areas, arcuate ridges and nexine but differs in having unequal trilete laesurae, being one or two of them extending beyond arcuate ridges (trilete laesurae in *Jhariatriletes* reach only up to arcuate ridges and never extend beyond them). It is comparable with *Duosporites* (Høeg, Bose & Manum) Bharadwaj & Tiwari 1970 in extension of trilete laesurae beyond arcuate ridges but differs in having mixed verrucose-baculose sexine sculptures and unpitted nexine (sexine sculptures in *Duosporites* are granulose to finally verrucose and nexine is always pitted). *Saksenasporites* differs from *Neoraistrichia* potonié 1956 in having mixed verrucose- baculose sexine sculptures, distinct contact areas and arcuate ridges (Sexine sculptures in *Neoraistrichia* are exclusively baculose, contact areas indistinct and arcuate ridges are absent). It differs from *Rewatriletes* Pant & Mishra 1986 in having differentially distributed mixed verrucose-baculose sexine sculptures and extension of trilete laesurae beyond arcuate ridges (In *Rewatriletes* sexine sculpture is exclusively baculose showing uneven distribution).

SAKSENASPORITES REWAENSIS sp. nov.
Pl. 1, figs 1- 6; Text-fig. 1A-I

Diagnosis—Megaspores trilete, amb circular to subtriangular, trilete laesurae prominent, straight to sinuous, gradually widening towards peripheral ends, widest and highest at trijunctions with arcuate ridges; contact areas well developed, circular to subcircular or subtriangular in shape, depressed, radius 1/2 to 2/3 or more of the spore, delimited by unevenly raised arcuate ridges; sexine covered with differentially distributed mixed verrucose- baculose sculpture, verrucae and beculae sparse and small in contact areas, dense and large elsewhere; nexine faintly preserved, thin, membranous, diameter about 2/3 of the spore, unpitted.

Dimensions :

		Dry megaspores	*Macerated and mounted megaspores*
Equatorial diameter		350-560 μm	400-680 μm
Trilete laesurae	Length	95-315 μm	100-480 μm
	Width	15-80 μm	15-115 μm
	Height	15-30 μm	
Contact area	Diameter	220-345 μm	235-480 μm
Arcuate ridges	Width	18-30 μm	15-50 μm
	Height	15-30 μm	
Verrucae			

PLATE 1

⟶

(*Saksenasporites rewaensis* sp. nov.)

1, 2. Megaspores showing sinuous trilete laesurae, one of them extending beyond arcuate ridges and depressed contact areas delimited by arcuate ridges. Fig. 1. Slide no. 358, x 200; fig. 2. Slide no. 352, x 200.

3, 4. Megaspores showing swollen peripheral trijunctions and extension of one laesurae beyond arcuate ridge. Sculptured sexine is clear in fig. 3., Slide no. 359 , x 300, fig. 4, Holotype, Slide no. 374, x 300.

5. Megaspore with central opening. Slide no. 354, x 200.

6. Macerated megaspore. Note extension of two laesurae beyond arcuate ridges (arrows). Slide no. 360, x 200.

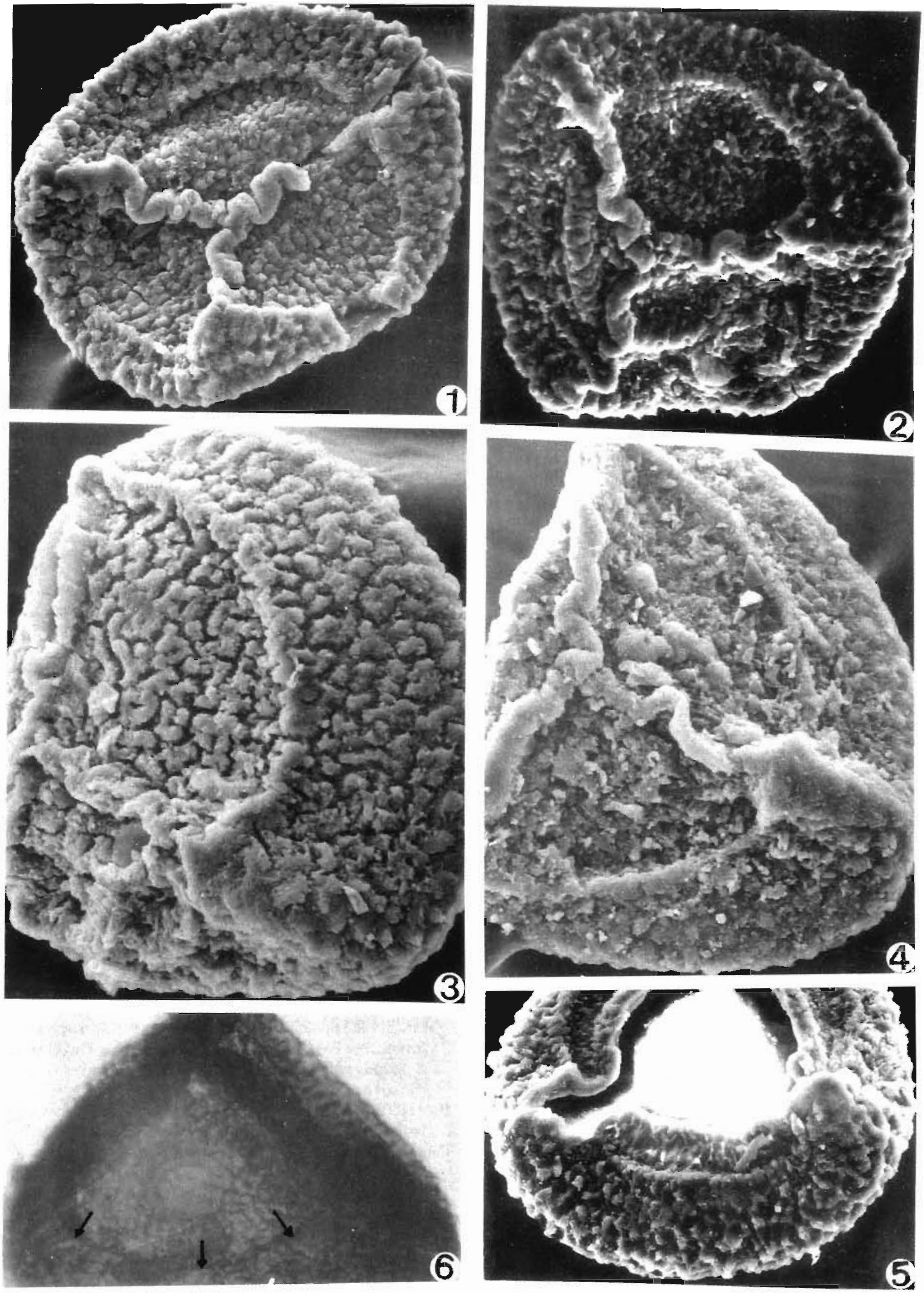


PLATE 1

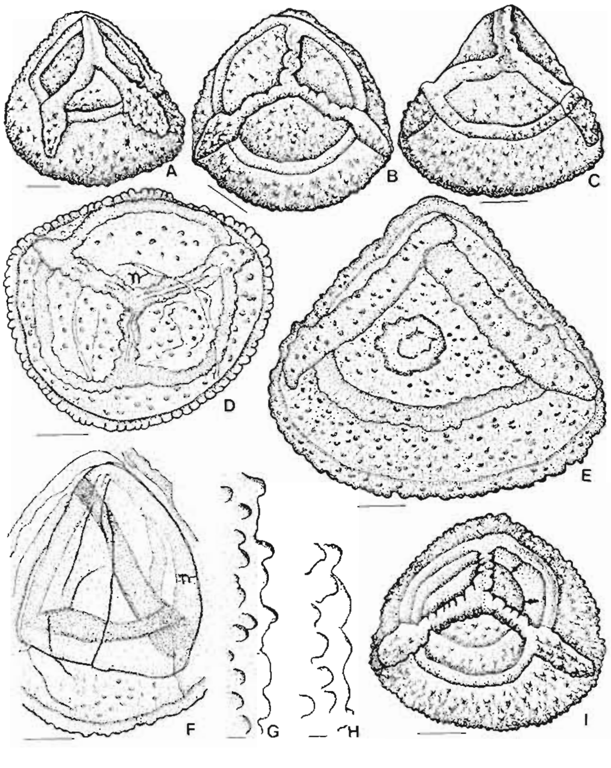
(a) In contact areas	Length	4-8 μm	4-10 μm
	Width	6-12 μm	6-15 μm
(b) Outside contact area	Length	4-20 μm	4-25 μm
	Width	6-25 μm	10-37 μm
Baculae	Length	5-20 μm	6-30 μm
	Width	4-10 μm	4-20 μm
Sexine	Thickness		20-30μm
Nexine	Diameter		200-400 μm

Holotype—Plate 1, figure 4; slide no. 374.

Locality & Horizon—Birsinghpur Pali Coalfield, Madhya Pradesh, Lower Gondwana (Lower Permian), India.

Derivation of name—After Professor S.D. Saksena who contributed a lot to the Gondwana Palaeobotany.

Description and discussion—Fifty six specimens of megaspores are assigned to *Saksenasporites rewaensis* sp. nov. Forty six of them are subtriangular in shape and compressed in various planes suggesting that their polar as well as equatorial axes were more or less equal. Seven spores, subcircular in shape, are preserved in dorsi-ventral orientation while only three of them show a little deviation of proximal trijunctions from the centre of the spores. Under SEM, these spores show prominent trilete laesurae which are widest and highest at their peripheral ends and join the inwardly curved arcuate ridges (Pl. 1, figs 1, 2, 4). Distal ends of one or two laesurae may extend beyond the arcuate ridges but never touch the margins. The peripheral ends of trilete laesurae are lip-like in appearance (Pl. 1, figs 4, 6; Text-figure 1A-C, E). Laesurae are straight to sinuous. In a megaspore an opening is observed due to splitting of trilete sutures on proximal face. This opening extends beyond arcuate ridged (Pl. 1, fig. 5). In few specimens central portions of the contact areas are seen slightly raised (Text-figure 1 I). Sexine of the spores is covered with mixed verrucose and baculose ornamentations. Verrucae are wider than the height whereas reverse is found in case of baculae (Pl. 1, fig. 3; Text-figure 1G, H.).



Text-figure 1A-I—*Saksenasporites rewaensis* sp. nov. **A-C, I.** Dry megaspores showing leasurae extending beyond arcuate ridges and forming lip-like structures. Central portion of contact area in fig I is slightly raised (arrows); **D-F.** Macerated megaspores showing faintly preserved circular (Fig. D) and subtriangular (Fig. F) nexine (n) and extension of two laesurae beyond arcuate ridges (Fig. E). **G, H.** Marginal portions of megaspores, enlarged, showing mixed verrucose-baculose sexine sculpture (Scale bar = A-F. I=100 μm. G, H =10 μm).

On treatment with alkali spores of *S. rewaensis* sp. nov. increase slightly in size and the sexine cracks into a number of segments and the membranous nexine is seen through these cracks (Text- figure 1D, F.). Nexine could be observed only in 20 percent of the macerated megaspores. It is circular or subtriangular in shape, membranous, unpitted and fills nearly 2/3 portions of inner spore cavity.

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On an enigmatic fossil plant from the Early Permian of South Karanpura Coalfield, India

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ABSTRACT

Bajpai Usha & Singh SM 1999. On an enigmatic fossil plant from the Early Permian of South Karanpura Coalfield, India. Palaeobotanist 48(2) : 137-140.

An apparent whorl of heterophyllous leaves is reported from the Barakar Formation of South Karanpura Coalfield, Bihar. The leaves are heterophyllous and their non-stomatiferous cuticle shows cells in longitudinal series with thick anticlinal walls. The specimen presents superficial resemblance with leaf whorls of the sphenophylls; the latter, however, differ in having sinuous-walled cells in the epidermis of both the surfaces. There is a distinct possibility that this specimen represents a bunch of immature leaves of a taxon related either to *Euryphyllum* or *Pantophyllum*, regarded as members of the cordaitean group of plants.

Key-words—Gondwana, Permian, South Karanpura, Cordaitales, India.

सारांश

भारत के दक्षिणी करनपुरा कोयला क्षेत्र से प्राप्त एक प्रारंभिक परमियनयुगीन रहस्यमय पादपाश्म के बारे में

ऊषा बाजपेई एवं शिवमोहन सिंह

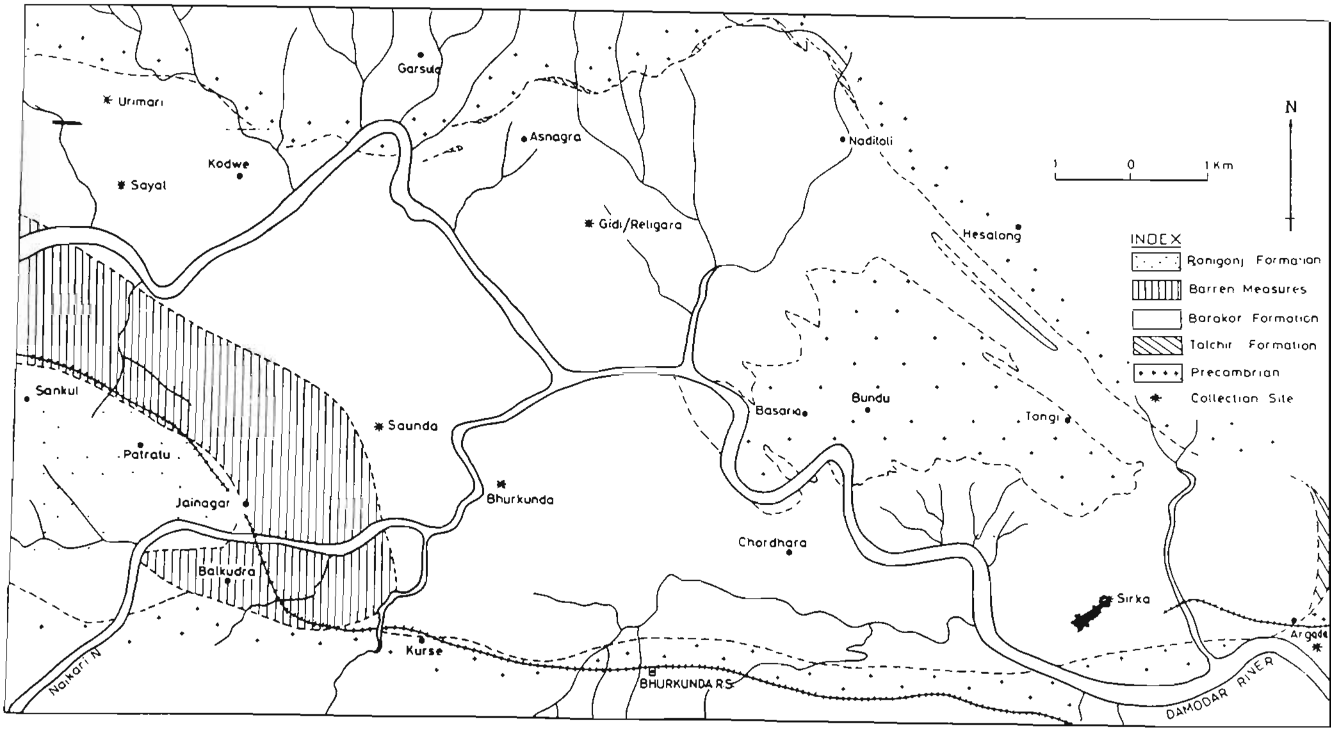
बिहार के दक्षिणी करनपुरा कोयला क्षेत्र के बराकर शैलसमूह से विषमपर्णी पत्तियों का एक आभासी चक्र प्राप्त हुआ है। इसकी पत्तियाँ विषमपर्णी हैं तथा उनका अरंध्रधर उपचर्म स्थूलअपनतिक भित्तियों के साथ अनुदैर्ध्य श्रेणी में कोशिकाएँ प्रदर्शित करता है। प्रादर्श स्फ़ीनीनोफ़िल के पत्तियों युक्त चक्के के साथ पृष्ठीय सादृश्य प्रस्तुत करता है, परन्तु यह दोनों पृष्टों की बाह्यत्वचा की कोटर-भित्ति युक्त कोशिकाओं के मामले में भिन्नता रखता है। एक दूरस्थ सम्भावना हो सकती है कि यह प्रादर्श *यूरीफ़िल्लम* अथवा *पन्तोफ़िल्लम* से सम्बन्धित एक वर्गक की अपरिपक्व पत्तियों का गुच्छ प्रदर्शित करता हो, जिसे कार्डेट समूह के पादपों का सदस्य कहा जाता था।

INTRODUCTION

THE Karanpura Coalfield, situated between Hazaribagh and Ranchi Plateau, lies between 85°28' – 84°46' east longitudes and 23°38' – 23°50' north latitudes. The southern part of the coalfield is separated by a narrow bridge of Archaean rocks from the northern part. The northern and southern parts, however, are connected by a narrow corridor comprising Talchir rocks.

SOUTH KARANPURA COALFIELD

The South Karanpura Coalfield, situated in the western part of the Damodar Valley, exposes all the main Permian for-



Text-figure 1—Geological map of a part of South Karanpura Coalfield showing the fossil plant localities. The collection locality of the present specimen is marked by an arrow.

mations of the Gondwana Supergroup. The Karanpura Coalfields were mapped in detail by Hughes (1871). Albert Jowett (1925) remapped the area. C.S. Raja Rao of the Geological Survey of India remapped a large part of the South Karanpura Coalfield. A generalised stratigraphical sequence in the coalfield is shown in Table 1 (after Raja Rao, 1987, p. 144).

Surange and Kulkarni (1968) reported *Phyllotheca ampla* and *P. angusta* from the Barakar ("Karharbari") Formation of this coalfield. Kulkarni (1971a, b) described *Sphenopteris, Gangamopteris buriadica, G. cyclopteroides, G. intermedia, G. spatulata, Glossopteris angustifolia, G. barakarensis, G. browniana, G. communis, G. damudica, G. decipiens, G. fusa, G. indica, G. karanpuraensis, G. linearis, G. spathulocordata* and *G. stricta* from the shales of Argada, and Lower and Upper Nakkari Seams. She suggested that dominance of *Gangamopteris* is indicative of a Karharbari age. Maithy (1978) reported two new forms, namely, *Paratrizygia rhodesii* and *Parasphenophyllum crenulatum* from the Lower Nakkari Seam.

In recent years, one of us (SMS) made a large collection of plant fossils from the Gondwana sediments of the South Karanpura Coalfield (Text-figure 1). The fossils include species of the genera *Neomariopteris, Gangamopteris, Glossopteris, Pantophyllum, Euryphyllum, Kawizophyllum, Gonophylloides, Scutum, Cordaicarpus* and *Vertebraria* besides a unique 'whorl' of lanceolate leaves; the last named fossil forms the subject of this report.

SYSTEMATICS

INCERTAE SEDIS

(Pl. 1, figs. 1-4)

Specimen no.—BSIP 38162/4738 (cp. BSIP 38163/4738).

Locality—Sirka Colliery, South Karanpura Coalfield, Bihar.

Horizon—Barakar ("Karharbari") Formation, shale associated with the Naditoli Seam.

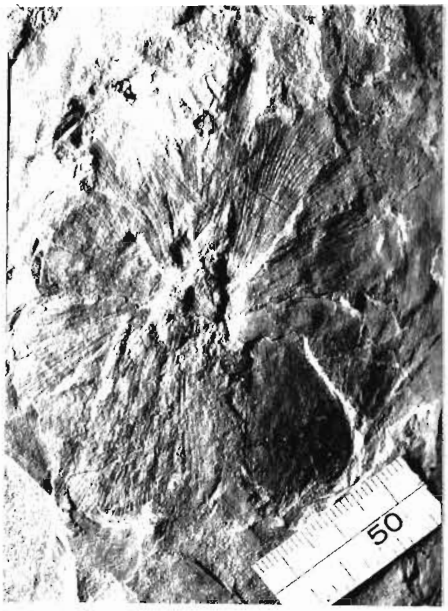
PLATE 1

⟶

1 & 2. Specimen showing a bunch of heterophyllous leaves arranged in a tight spiral on a swollen node; Specimen no. BSIP 38162/4738 and 38163/4738, respectively. x 0.8.

3. The specimen in figure 1 enlarged to show the variation in size and shape of the leaves, and the dichotomous, non-anastomosing venation, Specimen no. BSIP 38162/4738. x 2.

4. A portion of the non-stomatiferous surface showing elongated cells with straight walls. Slide no. BSIP 38162-1. x 100.



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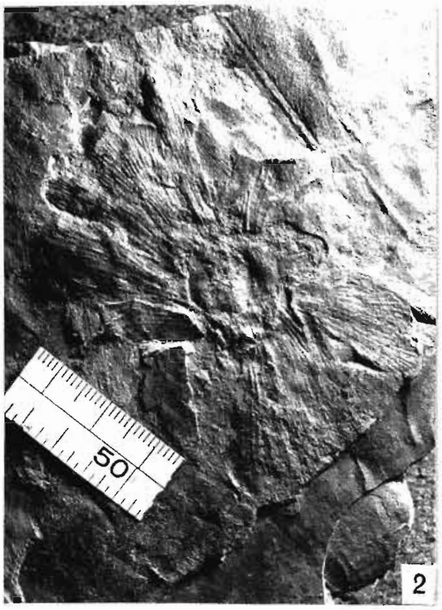

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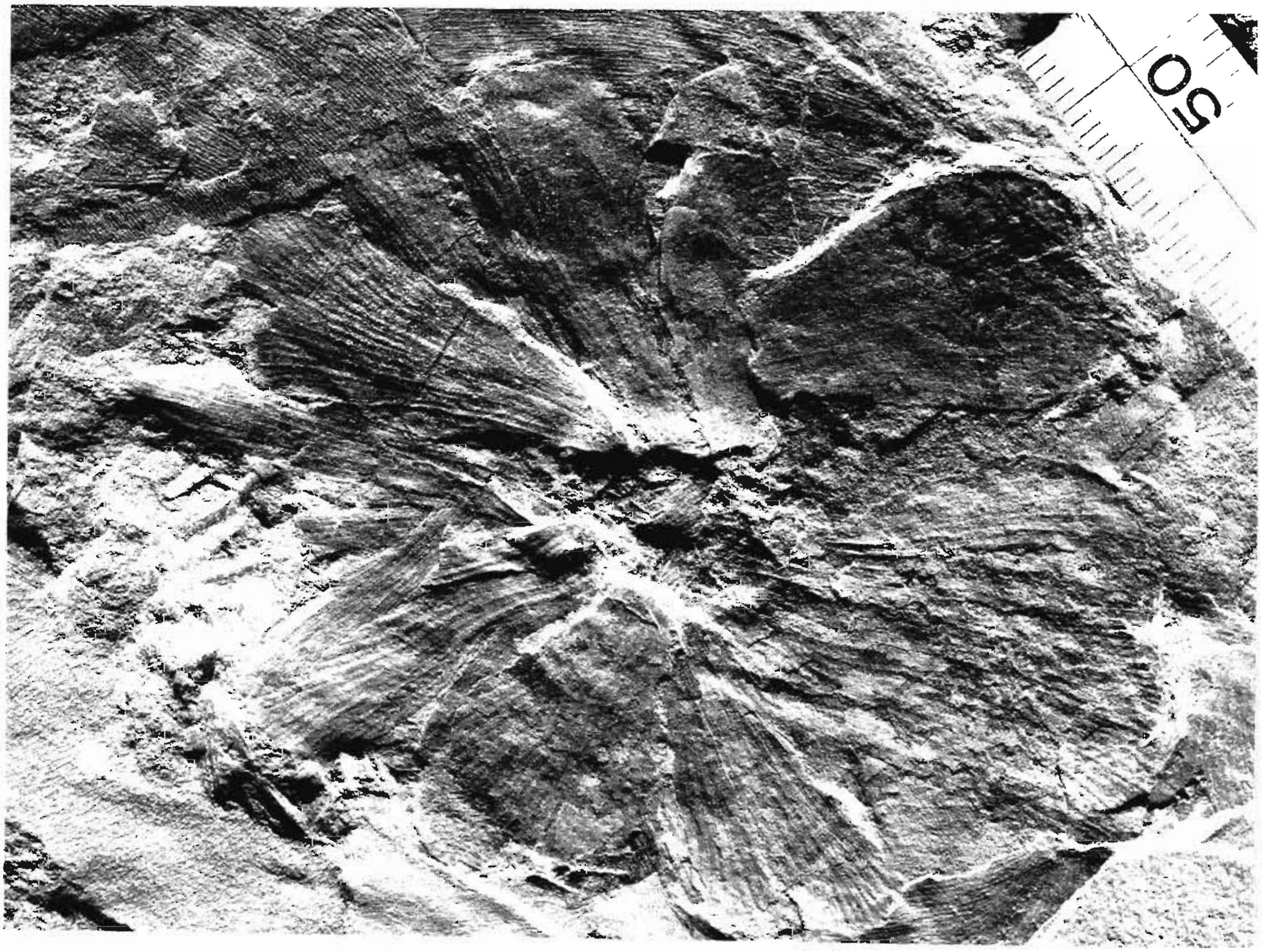

3

PLATE 1

Table 1–Stratigraphical sequence in the South Karanpura Coalfield

AGE	FORMATION	LITHOLOGY AND THICKNESS
Cretaceous		Dolerite and mica-peridotite intrusive
Upper Permian	Raniganj	Fine-grained sandstones, micaceous sandy shale and carbonaceous shales. (610 m)
	Barren Measures	Medium-grained sandstones, ironstone shales, siltstones, micaceous and carbonaceous shales. (304-457 m)
Lower Permian	Barakar	Coarse-grained sandstones, shales and coal. (1053 m)
	Karharbari	Coarse-grained, pebbly sandstones, shales and coal seam. (74 m)
	Talchir	Conglomerates, fine-to medium-grained sandstones and olive-green shales. (3-16 m)
~~Unconformity~~~~~~~~		
Precambrian		Granite, mica schists, quartzite and limestone?

Description—In the present collection there is one specimen (with counterpart, and poorly preserved carbonified crust) of uncertain taxonomic status. At first glance it looked apparently like a whorl of heterophyllous leaves. However, after excavation of some part of the rock, particularly from the part presumed to represent the axis, it became clear that the specimen comprises approximately 12 leaves arranged in a tight spiral at a swollen node (Pl. 1, figs 1, 2). Of these, about 8 leaves are comparatively large, obovate to sub-cuneate in shape, and with obtuse rounded apex, cuneate base and entire margin. The leaves are 2.8–3.5 cm long and 1–1.5 cm broad. The other four leaves are much less in breadth and are lanceolate in shape; they are up to 0.4 cm at the widest and have acuminate apices (Pl. 1, fig. 3). Two (possibly only one) veins enter the base of each leaf, dichotomise a few times, do not anastomose, further up in the lamina become slightly curved and end up at the upper margin as well as the apex. In the narrower leaves, the veins simulate that of *Pantophyllum* and run straight up to the apex. On acid-alkali treatment, the carbonified crust yielded small pieces of cuticle, but only of the non-stomatiferous surface. The cuticular membrane is thick, with straight-walled cellular outlines (Pl. 1, fig. 4). The cells are rectanguloid, longer than broad, 55-110 μm x 20-35 μm, and arranged end-to-end.

Comparison—This specimen shows a superficial resemblance with specimens of the genera *Trizygia* and *Sphenophyllum*. *Trizygia* no doubt is heterophyllous but it has only six cuneate leaves and that too arranged in three distinct pairs in a whorl. *Sphenophyllum* also has six symmetrical leaves (sometimes may be 9) which again are arranged in a whorl. The cell walls in both *Trizygia* and *Sphenophyllum* are sinuous on both the surfaces (Pant & Mehra, 1963; Pant & Srivastava, 1985; Boureau, 1964). Therefore, any affinity with the sphenophylls is definitely ruled out.

Presence of an acid resistant cuticle and the arrangement of leaves in a tight spiral indicate a definite gymnospermous affinity. From the general shape of the leaves, there seems to be a distinct possibility that this specimen represents a bunch of immature leaves of either *Euryphyllum* or *Pantophyllum* or of a taxon related to these genera. The exact identification of the taxon may be possible only after recovery of the stomatiferous surface and/or more specimens.

***Acknowledgements**—We are grateful to Professor D.D. Pant and Dr H.K. Maheshwari for very kindly reviewing the manuscript and for valuable suggestions. One of us (SMS) is grateful to the Director and authorities of the Birbal Sahni Institute of Palaeobotany, Lucknow for the award of Birbal Sahni Research Fellowship.*

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Late Barakar flora from the Chaturdhara *Nala* section, Ib-River Coalfield, Sundargarh, Orissa, India

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ABSTRACT

Meena KL 1999. Late Barakar flora from the Chaturdhara *Nala* section from Ib-River Coalfield, Sundargarh, Orissa, India. Palaeobotanist 48(2) : 141-145.

The Chaturdhara *Nala* section is located in the north-western side of Gopalpur Village, Sundargarh District, Orissa. The surface palynological investigation found the samples collected from Chaturdhara *Nala* section near to junction of Basundhara *Nala* section. In the present occurrence *Faunipollenites* and *Striatopodocarpites* prominance and followed by *Rhizomaspora, Scheuringipollenites, Distriatites, Cyclogranisporites, Cyclobaulisporites, Densipollenites, Striatites* and *Alisporites* etc. On the basis of palynoassemblage it is suggested that these sediments were deposited in the Late Barakar age. The similar palynoassemblage is found in earlier study of bore-hole number IBH-6 from this area. The dominance of striated disaccate taxa followed by non striated disaccate spores in present study hence, the present palynoassemblage is equal to Late Barakar age of other basins, India.

Key-words—Palynology, Palynodating, Chaturdhara *Nala*, Ib-River Coalfield, Sundargarh, Orissa, Son-Mahanadi Graben, (India).

सारांश

भारत के उड़ीसा प्रान्त के सुन्दरगढ़ अवस्थित ईब-नदी कोयलाक्षेत्र के चतुर्धारा नाला परिच्छेद से प्राप्त अंतिम बराकारयुगीन वनस्पतिजात

किन्डु लाल मीणा

चतुर्धारा नाला परिच्छेद उड़ीसा के सुन्दरगढ़ जनपद के गोपालपुर नामक ग्राम के उत्तर-पश्चिमी छोर पर स्थित है। वसुन्धरा नाला परिच्छेद के निकटवर्ती संयोजन से एकत्र सतह के प्रादर्श का परागाणविक अन्वेषण किया गया। इन प्रादर्शों में *फॉनिपोलेनाइटीज़* तथा *स्ट्राइटोपोडोकारपाइटीज़* और इनके अनुवर्ती *राइजोमास्पोरा, श्युरिंगीपोलेनाइटीज़, डिस्ट्रायटाइटीज़, साइक्लोग्रैनिस्पोराइटीज़, साइक्लोबाउलोस्पोराइटीज़, डेन्सीपोलेनाइटीज़, स्ट्रायटाइटीज़* तथा *एलिस्पोराइटीज़* इत्यादि की प्रधानता है। परागाणविक समुच्चय के आधार पर इन अवसादों का अन्तिम बराकार युग में निक्षेपित होना प्रस्तावित किया गया है। इसी क्षेत्र के छिद्र संख्या आई.बी.एच.-6 के अध्ययन में भी इसी प्रकार के परागाणविक समुच्चय प्राप्त हुए हैं। चूंकि वर्तमान अध्ययन से रेखित वर्गकों तथा इनके अनुवर्ती अरेखित सपुट बीजाणुओं की प्रधानता लक्षित हुयी है, अतः वर्तमान परागाणविक समुच्चय भारत की अन्य द्रोणियों के अंतिम वराकार युग के समतुल्य है।

INTRODUCTION

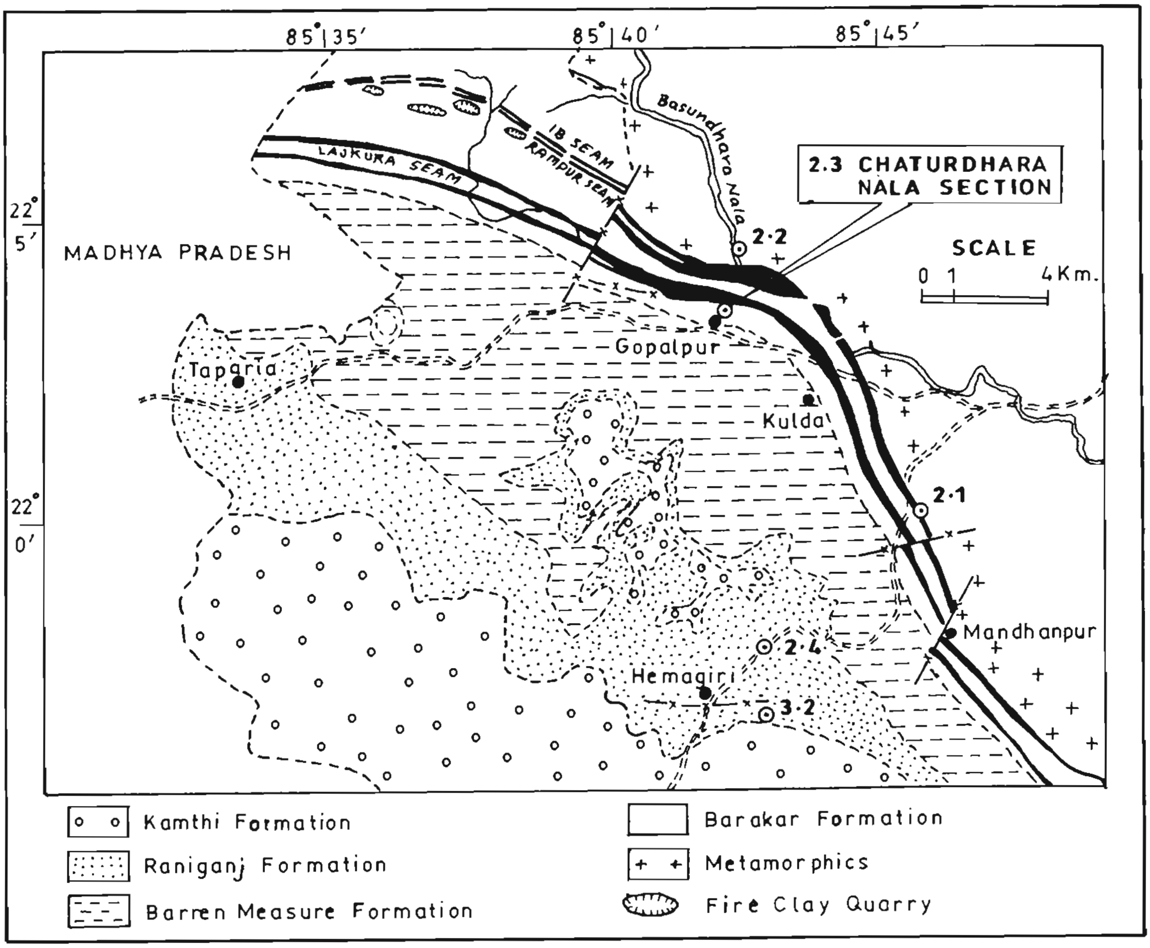
THE general geological succession in Ib-River Coalfield, Son-Mahanadi Basin, India exhibits the presence of Barakar Formation overlain by the Kamthi Formation (Raja Rao, 1982). The Lower part of Kamthi Formation deposited in Late Raniganj period (Meena, 1997). The Barren Measures Formation is not demarcated. Hence the dating and correlation is necessary in this basin with this object I have studied bore hole IBH-6 from Sundargarh district and IBSH-6 from Belpahar area, Jharrugnda district, Orissa. The palynological report from this area suggests that Raniganj Formation overlies Barakar Formation. The palynological report from the Belpahar area, Ib-River Coalfield is almost non existant except a brief report (Maiti, 1994) and studied two bore-hole myself earlier.

MATERIAL AND METHOD

I have collected surface samples from Chaturdhara *Nala* section near the half km of Basundhara *Nala* Junction and processed the samples with HCl, HF and HNO_3. I have found four samples which contained rich palynoflora for the palynological study. The material was collected from Chaturdhara *Nala* section near to Junction of Basundhara *Nala* Location Text-figure 1.

PALYNOLOGICAL ASSEMBLAGE

The quantitative floral composition has been determined after count 200 specimens from each samples. A perusal of Text-figure 2 reveals the assemblages has the dominance of the genus *Faunipollenites* and sub dominance *Striatopodocarpites* with significant association of the genera are *Rhizomaspora, Distriatites, Scheuringipollenites, Cyclogranisporites, Cyclobaculisporites, Densipollenites striatites, Alisporites,* etc. The lack of younger elements as *Lundbladispora, Densoisporites, Densipollenites magnicorpous, Lunatisporites,* etc. Hence the palynological investigation suggests the age of strata comparable to Upper Barakar.



Text-figure 1—Showing the location map of Chaturdhara *Nala* section, Sundargarh disrict, Ib-river Coalfield, Orissa.

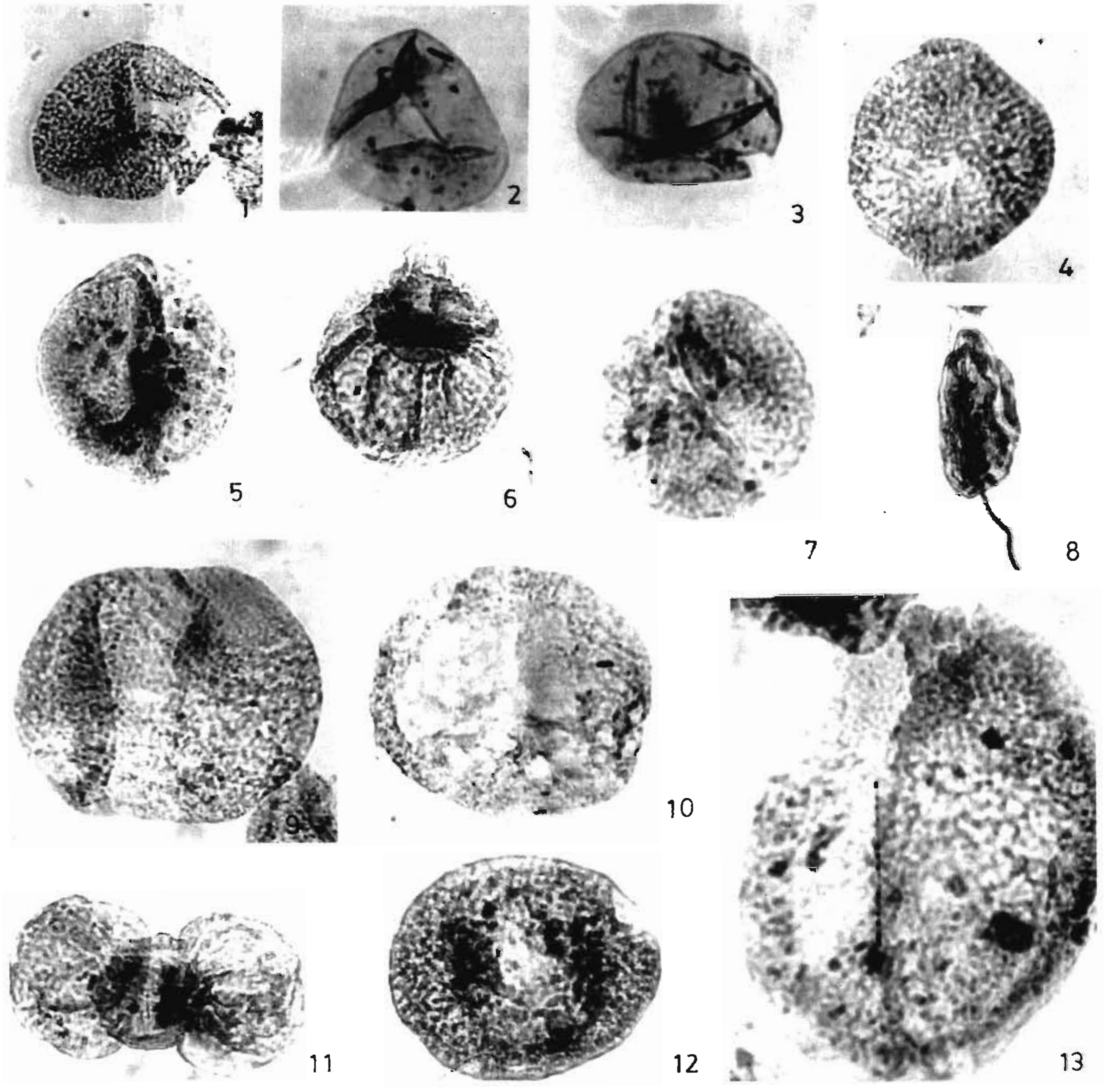


PLATE 1

(All x 500)

1. *Microbaculispora gondwanensis*, Bharadwaj, 1962. BSIP Slide No. 12091
2. *Latosporites falkenvergensis*, Venkatachala & Bharadwaj, 1964. BSIP Slide No. 12091
3. *Inaperturopollenites nebulosus*, Balme, 1970. BSIP Slide No. 12091
4, 12. *Cyclobaculisporites minutus*, Bharadwaj & Salujha, 1964. BSIP Slide No. 12090.
5. *Scheuringipollenites maximus*, (Hart) Singh, 1964, Tiwari, 1973. BSIP Slide No. 12091
6. *Densipollenites indicus*, Bharadwaj, 1962. BSIP Slide No. 12091
7, 10. *Faunipollenites perexigus*, Bharadwaj & Salujha, 1965. BSIP Slide No 12090.
8. *Ephedripites mesozoica*, Maheshwari, Bose & Kumaran, 1977. BSIP Slide No. 12091
9. *Striatites irregularis*, Tiwari, 1965 BSIP Slide No. 12090.
11 *Rhizomaspora indica*, Tiwari, 1965. BSIP Slide No 12091
13. *Parasaccites bilateralis*, Tiwari, 1965. BSIP Slide No. 12090.

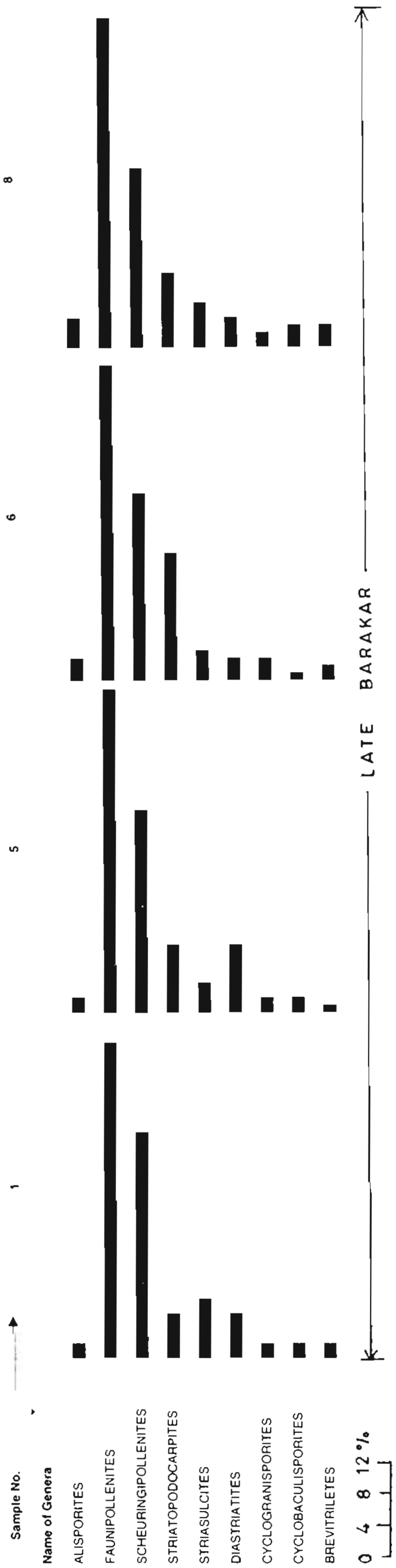
Age	Group	Formation	Lithology & Thickness.
Recent		Alluvium/ Laterite	Recent gravel and conglomerate.
Upper Permian to Lower Triassic	Lower Gondwana	Kamthi	Conglomerate, red shale, ferruginous sandstone (300 m).
Lower Permian	Lower Gondwana	Barakar	Feldspathic with conglomerate bands and lenses, white, grey and carbonaceous shales fireclay and coal seams (600 m).
		Karharbari	Mostly coarse grained sandstone with one thin coal seam (90 m-125 m).
		Talchir	Diamictite greenish sandstones, olive and chocolate coloured needle shales bands, rhythmites (130 m +).
Unconformity			
Pre-Cambrian			Granite, Gneisses, Cambrian Amphibolites, Migmatites etc.

Based on the work carried out by the earlier workers, the following geological succession for Ib-Himgir Valley was proposed (after Raja Rao, ed, 1982):

Table 1—The sample list of studied surface sediments from Chaturdhara Nala section near to Junction of Basundhara *Nala*, District Sundargarh.

Sl. No.	Lithology	Remark	Lithological age	Palynological age
1.	Grey shale	++		
2.	—do—	-		U
3.	—do—	-		
4.	—do—	-		P
5.	—do—	++	B	
6.	—do—	++	A	P
7.	—do—	-	R	
8.	—do—	+++	A	E P
9.	—do—	-	K	A
10.	—do—	-	A	R L
11.	—do—	-	R	Y
12.	—do—	-		N
13.	—do—	-		O
14.	—do—	+		B
15.	—do—	-		A
16.	—do—	-		A S
17.	—do—	+		S
18.	—do—	-		R E
19.	—do—	-	F	M
20.	—do—	-	O	A B
21.	—do—	-	R	L
22.	—do—	+	M	K A
23.	—do—	-	A	G
24.	—do—	-	T	A E
25.	—do—	-	I	
26.	—do—	-	O	R
27.	—do—	-	N	
28.	—do—	+		
29.	—do—	-		
30.	—do—	-		

+ rare ++ common +++ rich - absent



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Text-figure 2—Histogram showing the percentage distribution of palynotaxa in surface samples from Chaturdhara Nala section Ib-River Coalfield, district Sundargarh, Orissa.

CORRELATION

The Upper Barakar palynoflora recovered from the surface samples were collected from northern side of Chaturdhara *nala* near to junction of Basundhara *nala*. This palynoassemblage resemble with the results of B.H. IBH-6 K.L. Meena (*in press*) from IB-River Coalfield, Jharesuguda, Orissa. The results correlate with the result of B.H. TP-8 studied by Tripathi (1996) and also with results of B.H. TP-9 and TP-10 studied by Meena (*in press*) from Talchir coalfield, Orissa. This palynoassemblage has resemble with Upper Barakar age (Lower Permian) recovered from B.H. RGP-7 studied from Mand-Raigarh Coalfield, M.P. by Meena (1999). The results of there surface sediments has been correlate with the other basins of India (Bharadwaj, 1962; Bharadwaj & Tiwari, 1977; Tiwari & Singh, 1986; Srivastava, 1973, 1980; Srivastava & Anand-Prakash, 1984; Tiwari & Meena 1989).

CONCLUSION

Palynological results suggest that these sediments were deposited in Late Barakar age. The palynoassemblage is similar to palynological results recovered from Upper Barakar sediments of other basins, India.

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Diversity of *Nypa* in the Indian subcontinent : Late Cretaceous to Recent

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ABSTRACT

Singh RS 1999. Diversity of *Nypa* in the Indian subcontinent : Late Cretaceous to Recent. Palaeobotanist 48(2) : 147-154.

Nypa, a monotypic genus of the family Arecaceae, is restricted to the mangrove ecosystem in the tropical coasts of south-east Asia and Australia. In the Indian subcontinent, it grows in Gangetic delta, Andamans and Sri Lanka. The fossil remains including fruits, roots, cuticles and pollen assigned to this genus are well-documented since Late Cretaceous to Pliocene having pantropical distribution. Fruits cf. *Nypa*, described under several species on the basis of size and shape variations, are now considered as a single species because of wide variations in the living plants. Similarly, the roots and cuticle described show affinity with modern *Nypa fruticans*. Fossil pollen attributed to the pollen of *Nypa* are referred to *Spinizonocolpites* Muller 1968 which is represented by 13 species in India. Out of them, 8 species and two specimens are found to be distinct by virtue of their morphological differences in exine and its sculptural type. Only one fossil species is similar, if not identical, with the pollen of *Nypa fruticans;* other fossil pollen show considerable morphological variations but the pollen of extant *Nypa* do not show such variations. This suggests that *Nypa fruticans* is a relict species of a large group of early *Nypa*-complex prevalent in India during Late Cretaceous to Eocene but more diverse during Palaeocene. In the Palaeocene sediments of north-eastern India *Spinizonocolpites* is an important element both in terms of diversity and preservation and probably the richest record of the world. After Eocene, the fossil pollen records are represented by only one species — *S. prominatus* showing similarity with the pollen of *Nypa fruticans*. Thus it seems that the early *Nypa*-complex may have experimented with the various habitats and due to other successful competitors may have perished except its living counterpart which occupied only mangrove habitat.

Key-words—Palynology, *Nypa*, *Spinizonocolpites*, Diversity, Late Cretaceous-Palaeocene, India.

सारांश

अन्तिम क्रिटेशस से अद्यतन युग के बीच भारतीय उपमहाद्वीप में *नाइपा* की विविधता

रमा शंकर सिंह

नाइपा, जो एरिकेसी वंश का एक एकलप्ररूपी है, दक्षिणी पूर्व एशिया तथा आस्ट्रेलिया के उष्णकटिबन्धीय समुद्र तट में मैंग्रोव पारिस्थितिक तंत्र में विशेष रूप से प्रतिबन्धित है। भारतीय उपमहाद्वीप में यह गंगा के डेल्टा, अण्डमान तथा श्रीलंका में पाया जाता है। इस वंश के पादपाश्म, जिनके अन्तर्गत फल, मूल, उपचर्म तथा परागकण आते हैं, उत्तर क्रिटेशस में प्लायोसीन युग तक भली-भाँति प्रलेखित हैं तथा इनका सार्वउष्णकटिबन्धीय वितरण है। यद्यपि अपने आकार तथा आमापन के कारण *नाइपा* के समतुल्य फलों को अनेक प्रजातियों के अन्तर्गत रखा गया है, परन्तु इनके जीवित पादपों में पाए जाने वाले परिवर्तनों के कारण ये अब एक एकल प्रजाति के रूप में जाने जाते हैं। इसी प्रकार वर्णित मूल एवं उपचर्म आधुनिक *नाइपा फ्रूटिकन्स* के साथ सजातीयता प्रदर्शित करते हैं। *नाइपा* के परागकणों से सूचित पादपाश्म परागकण '*स्फ़ीनीज़ोनोकॉल्पाइटीज*' मुलर 1968 को संदर्भित है, जिसे भारत में 13 प्रादर्श अपने बाह्यचोल तथा इसके तक्षित रूप की आकृतिक असमानताओं के कारण सुस्पष्ट रूप में प्राप्त हुए हैं। यह मात्र एक

पादपाश्म प्रजाति *नाइपा फ्रूटिकन्स* के कारण परागकण के साथ यदि समरूप नहीं है, तो अभिन्न अवश्य है। अन्य पादपाश्म परागकण आकारिकी में पर्याप्त परिवर्तन प्रदर्शित करते हैं, परन्तु विद्यमान *नाइपा* के परागकण इस प्रकार के परिवर्तन प्रदर्शित नहीं करते। इससे प्रस्तावित होता है कि अन्तिम क्रिटेशस से इओसीन युग के दौरान भारत में *नाइपा फ्रूटिकन्स* आरंभिक संकुल *नाइपा* के वृहद समूह में अविशिष्ट प्रजाति के रूप में विद्यमान हैं, किन्तु यह पेलियोसीन युग के दौरान अधिक बहुविध है। उत्तर पूर्वी भारत के पेलियोसीन अवसादों में *स्पीनीजोनोकालपाइटीज़* विविधता एवं संरक्षण दोनों ही दृष्टिकोण से एक महत्वपूर्ण तत्व है तथा यह सम्भवतः विश्व का सम्पन्नतम अभिलेख है। इओसीन युग के पश्चात पादपाश्म परागकण अभिलेखों का प्रतिनिधित्व मात्र एक प्रजाति *स्पीनीजोनोलपाइटीज़ प्रामिनेटस* करती है, जो *नाइपा फ्रूटिकन्स* के परागकणों के साथ अभिन्नता प्रदर्शित करती है। ऐसा प्रतीत होता है कि आरम्भिक संकुल *नाइपा* ने विभिन्न आवासियों के साथ प्रयोग किये होंगे तथा अन्य प्रतिस्पर्धियों के कारण अपने जीवित सहभागियों के अतिरिक्त अन्य सभी नष्ट हो गए होंगे, जिन्होने मात्र मेंग्रोव आवास प्राप्त कर लिया होगा।

INTRODUCTION

NYPA fruticans van Wurmberg — It is an interesting to note that prior to the recognition of living *Nypa* from Asia by van Wurmberg in 1779, its fossil fruits were described from the Eocene deposits of London Clay by Parsons (1758). *Nypa fruticans* van Wurmberg is the only species of this genus possessing a distinct vegetative and reproductive system. It differs from other palms by lacking an upright stem and having dichotomously branched creeping stem, and its large pinnate leaves reaching up to nine meters in length. The fruits are large, woody drupes borne on a compact fruiting head. Despite its characteristic morphological features which make it easily identifiable there have been several systematic positions proposed for it. It is treated within the family Palmae (Arecaceae) by Endlicher (1837), Drude (1887), Hutchinson (1959), Beccari and Hooker in Hooker (1894) . A subfamily of its own, Nypoideae, is advocated by Engler and Gilg (1924) which is followed by modern taxonomists, viz., Burret (1953), Potztal (1964), Dransfield and Uhl (1986) and Uhl (1972). A family status was proposed much earlier by Brongniart (1843) which was also followed by Tralau (1964) and Muller (1964).

Nypa fruticans occurs in a narrow restricted tropical area of south-east Asia (including India in Sunderbans and Andamans Island, Bangla Desh) to Australia in the mangrove ecosystem. The plant forms sometimes pure stands because of its rhizomatous branching habit and favours quite estuarine or shallow lagoons in which fresh water runs. It does not grow on the shores with much wave action and in hypersaline conditions (Tomlinson, 1986).

The present day ecology of *Nypa* is taken to deduce the palaeoenvironment of the past on the basis of occurrence of fossil remains of cf. *Nypa*. Such deductions should be worked out cautiously with the help of other parameters of sedimentology primarily because this does not consider the evolution of the species over such a large span of time and also probable adaptability of the plant in the different habitats.

Nypa fruiticans (Pl. 2, figs 2-4) — Pollen grain elliptic, 60-80 x 33-50 µm. Sulcus meridional. Exine tectate, spinose; spine 4-10 µm long, 5-6 µm wide at the base, 2-5 µm apart, base swollen with gradually tapering apices, tips pointed, thin, flexible, sometime curved forming hook-like structure. Spine attachment supraexinal. Interspinal area microreticulate, lumina about 1 µm wide, uniform, polygonal; muri 1 µm thick, tectum with 1-2 µm high bacula and a fine sole.

Fruits of *Nypa fruticans* are large, woody drupes produced in a compact fruiting head showing variations in its shape and size; interestingly the differences or variations are also connected by transitional forms even on the same plant.

PLATE 1

⟶

England Finder reading and magnification are given for each figure. The photographs illustrated are from the Palaeocene of Langrin Coalfield, Meghalaya and the extant pollen are from the Sunderbans, West Bengal.

1 *Spinizonocolpites bulbospinosus* Singh, Slide no. BSIP 9946, O44/0 x 1000.

2-4. SEM photomicrographs of the above species showing the gross morphology and detail exinal characters. 2 = x 750, 3 = x 1200 & 4 = x 1400.

5,6,8,9. *S. indicus* Singh, SEM photomicrographs showing the gross morphology and details of the exine. 5 = x 750, 6 = x 1200, 8 = x 1500, 9 = x 700.

7. *S. indicus* under light microscope. Slide no. BSIP 9979, U33/O x 1000.

10. *Spinizonocolpites* sp. Singh, Slide no. BSIP 9986, X 47/4 x 1000.

11 *S. prominatus* a part of the pollen showing the spinal morphology under SEM. x 750.

12. *Spinizonocolpites* sp. (=Pollen type - 2, in Singh 1990) showing the gemmae and the annulocolpate aperture. Slide no. BSIP 9949, R59/1, x 1000.

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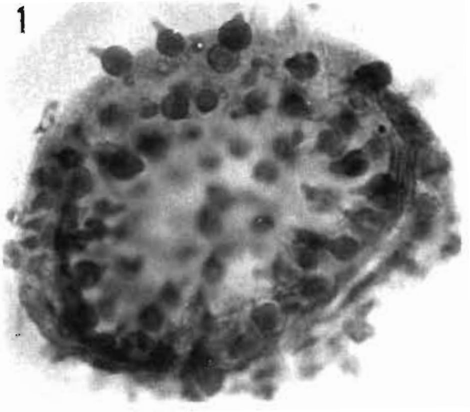

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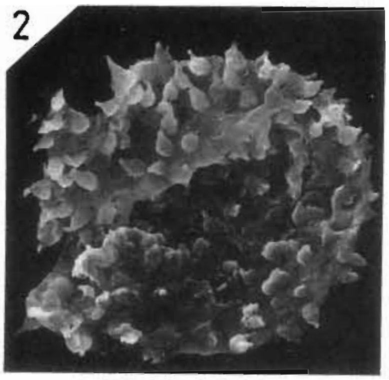

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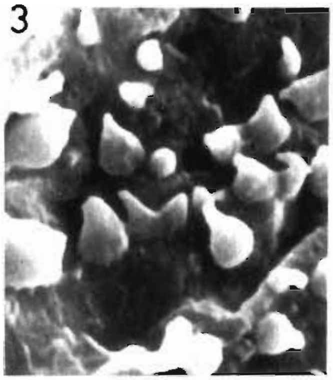

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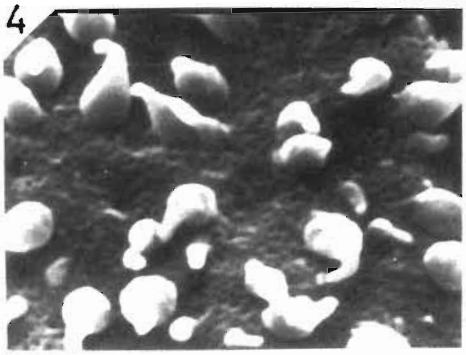

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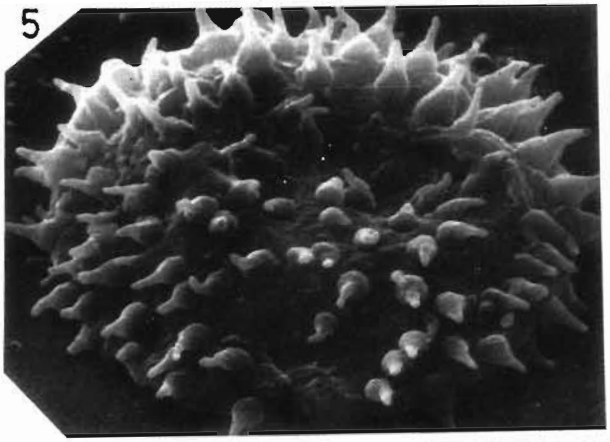

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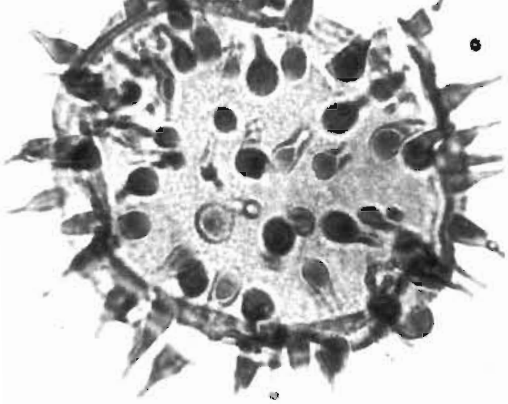

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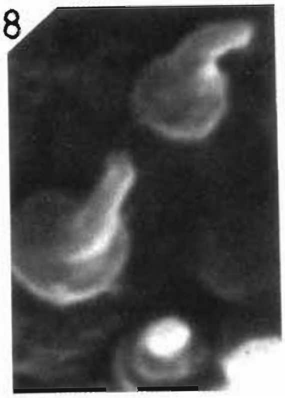

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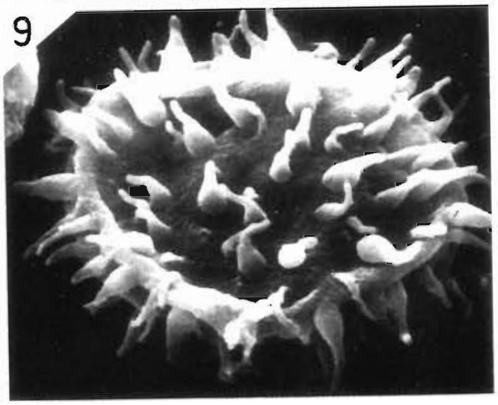

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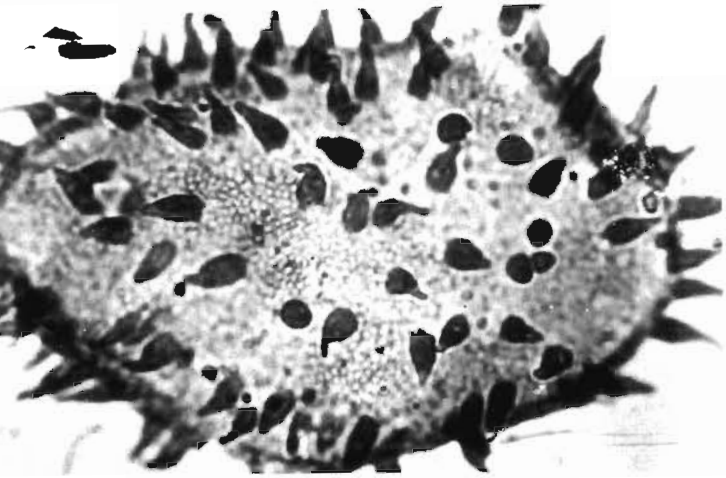

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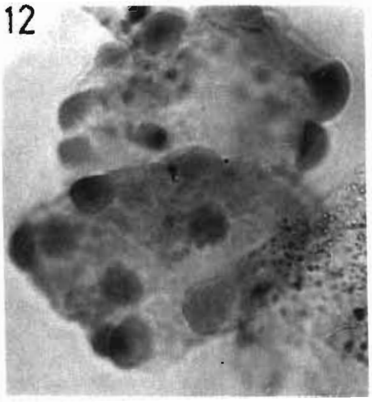

PLATE 1

FOSSIL RECORDS

Fossil cf. *Nypa* is well documented by fruits, pollen, roots and cuticles.

Fruits — Parsons (1758) described fossil fruits from the Eocene deposits of London Clay and since then numerous fossil fruits have been recorded from the Eocene deposits in Europe, Africa, America and Asia including India. A large number of species fossil fruits are instituted by various workers on the basis of minor variations in shape and size. In the Indian subcontinent fossil fruits cf. *Nypa* is recorded from the Deccan Intertrappean sediments exposed in Madhya Pradesh as *Nipadites hindi* Rode 1933, *Nipa hindi* (Rode) Sahni in Sahni & Rode 1937, *Nipa* Chitaley 1960, *Nypa* Nambudiri 1966 and from Maharashtra as *Nipadites* sp. Carter 1854. The Deccan Intertrappean beds were earlier considered to be Early Eocene but now most of the beds are considered to be Late Cretaceous (Sahni, 1990). From north-eastern India it is known from Tura Sandstone (Palaeocene but earlier considered as Eocene) of Garo Hills as *Nipa* Lakhanpal 1948, Sylhet Limestone (Eocene) of Khasi Hills as *Nipadites* sp. (Bhattacharyya, 1967) and from the Miocene sediments of Garo Hills as *Nipa sahnii* Lakhanpal 1952 (Table 1). In other parts of the world, all fossil fruits described are now being considered under a single species, viz., *Nipa burtini* (Brongniart) Ettingshausen (see Tralau, 1964), because of the fact that *Nypa fruticans* produces fruits with wide variations in shape and size even on the same plant. Thus, recognisation of diversity on the basis of fossil fruits of *Nypa* is rather impossible unless a finer morphological work is done.

Pollen — Extinct Pollen related to *Nypa* are referred to *Spinizonocolpites* Muller 1968 which is widely recorded from Late Cretaceous to Eocene sediments. From the Late Cretaceous it is known from South America (Germeraad *et al.*, 1968), Venezuela and Colombia (Regali *et al.*, 1974a, b), Brazil (Jardine & Magloire, 1963), Cameroon and Borneo (Muller, 1968), South Arabia (Schrank, 1984) and India (Venkatachala & Sharma, 1974; Baksi & Deb, 1981; Nandi, 1990). Its record from the Cretaceous-Tertiary transition comes from south-east Asia (Muller, 1968; Herngreen & Chlonova, 1981). In the Eocene sediments *Spinizonocolpites* is widely reported from North America, Europe, Australia, Malaysia, Pakistan and India (Table 1). During Miocene *Nypa* disappeared from the most parts of the world and almost reached its present status.

Root and Cuticles — Roots cf. *Nypa* is described from the Late Cretaceous sediments of Deccan Intertrappean beds (Verma, 1974) and cuticle cf. *Nypa* is also known from the Miocene of Ratnagiri of Maharashtra (Kulkarni & Phadtare, 1980).

DISCUSSION

Nypa had a wide geographical distribution during the past but at present grows in a narrowly restricted areas of tropical coasts of south-east Asia in mangrove ecosystem. Fossil representation of this genus is also well documented (Table 1). Several species of these fruits were instituted simply on the basis of variations in their size and shape, but in living *Nypa* such variations may be seen even in the same plant. Thus, it is very much possible that the fossil fruits of *Nypa* assigned to different fossil species actually belonged to one species of *Nypa*. But this needs further finer morphological studies of the fruits of both living as well as fossil. Similarly, fossil roots and cuticles assigned to various species of *Nypa* should be studied critically. Pollen of *Nypa fruticans* have characteristic morphology and do not show much variations and thus provides an opportunity to compare with the extinct pollen in detail. *Spinizonocolpites prominatus* (MacIntyre) Stover & Evans (= *S. echinatus* Muller 1968; Pl. 1, fig. 11; & Pl. 2, figs 5, 8-11) is the most common species reported from various parts of the world. In India, it ranges from Late Cretaceous to Neogene (Table 1). It has more or less similar morphology of the spines as that of the pollen of *Nypa* but the size of the pollen grains is generally smaller (average 50 µm). Nevertheless, the smaller size of the fossil pollen may be due to the loss of moisture during the fossilization. One of the closely related species with the above fossil pollen is *S. indicus* Singh 1990 (Pl. 1, figs 5-9) which has comparatively much longer (7-15 µm) and bulbous base of spines (Pl. 1, figs 6, 8). It is observed that *S. indicus* is a dominant element in the Tura Sandstone while *S. prominatus* is widely distributed species in the Tertiary sediments of India and abroad. Thus, it seems that either the above two species may have been produced by two ecotypes of the same species or possibly produced by two distinct species belong-

PLATE 2

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1 *S. wodehousei* Singh, Slide no. BSIP 9965, F68/3, x 1000.
2-3. Pollen of *Nypa fruticans* van Wurmberg. Specimens from the Sunderbans. x 1000.
4. SEM photomicrograph of the pollen of *Nypa fruticans* showing the detail morphology (courtesy Dr K. Ambwani, BSIP). x 850.
5,8-10. SEM photomicrographs of *S. prominatus* showing the various types of spines and the gross morphology. 5 = x 1500, 8 = x 1200, 9 = x 750 & 10 = x 1000.
6,7 SEM photomicrographs of *S. baculatus* Muller. 6 = x 1500, 7 = x 750.
11. *Spinizonocolpites prominatus* (MacIntyre) Stover & Evans, Slide no. BSIP 9949, Q33/3, x 1000.
12 *S. intrarugulatus* Muller, de Di Giacomo & van Erve, Slide no. BSIP 9973, O44/2, x 1000.
13-14. *S. baculatus* Muller, Slide no. BSIP 9953, W28/3, x 500 & BSIP 9959, R33/O, x 500.
15. *S. bulbospinosus* Singh, Slide no. BSIP 9947, G46/4, x 500.

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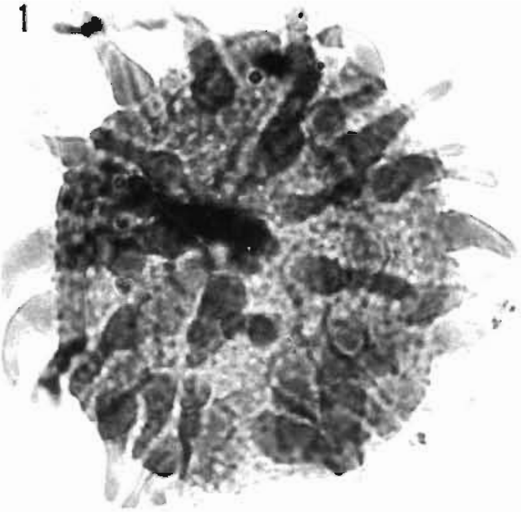

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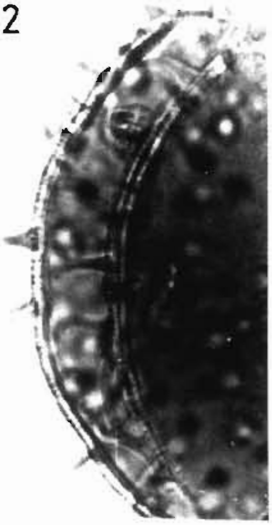

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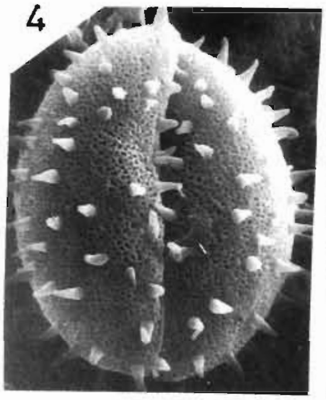

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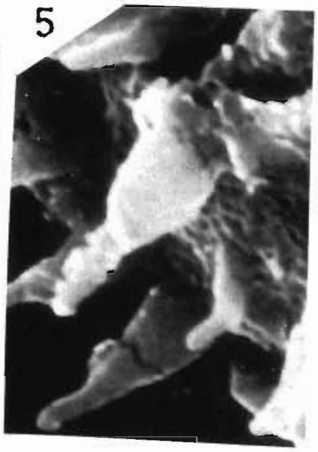

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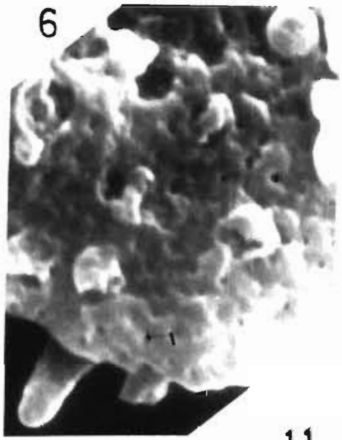

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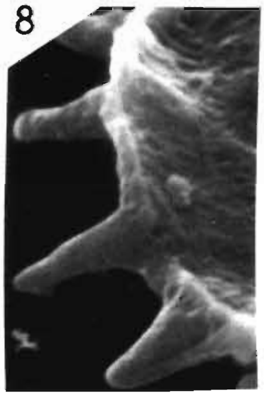

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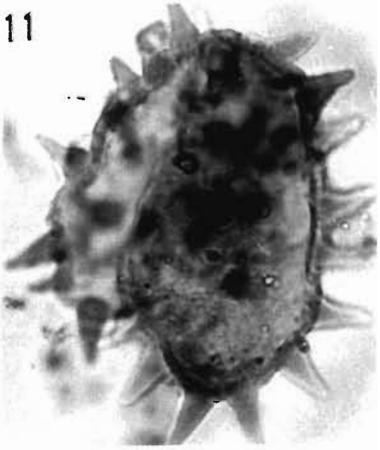

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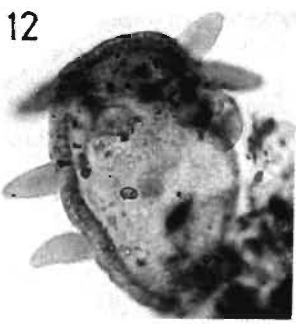

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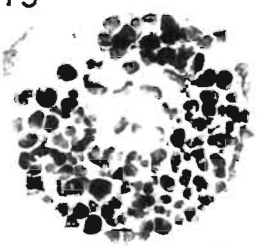

PLATE 2

Table 1 — Showing the distribution of species related to *Nypa* in the Indian sediments

Taxa	Late-Cretaceous	Palaeocene	Eocene	Oligocene	Neogene		Quaternary
					Miocene	Pliocene	
POLLEN							
Spinizonocolpites							
S. baculatus	II*, XII; 1, 13, 25						
S. prominatus	I to XII; 28, 27 15, 14, 7, 29, 30, 24, 6, 16, 8.12, 25, 1, 13, 18						
S. mulleri	II*; 1						
S. mucus	V*; 29						
S. decoris	V*; 29						
S. intrarugulatus		XII; 25					
S. bulbospinosus		XII.25					
S. indicus		XII; 25					
Spinizonocolpites sp. 1		XII; 25					
S. wodehousei		II*; IX; 22, 1, 25					
S. brevispinous		II*; 1					
S. sahii			II*; 1				
Spinzonocolpites sp. 2			IV; 6				
Spinizonocolpites sp. 3			I; 16				
S. quilonensis					X; 19, 20. 17, 26		
S. spinulosus					X; 17		
Spinizonocolpites sp. 4					X; 17		
FRUITS							
Nipa hindia	VII 21, 23						
Nipa sp. 1	VI; 5						
Nipadites compressure	VI; 23						
Nipadites sp.	VI; 4						
Nipadites sp. 3			XII; 2				
Nipadites sp. 4			VII; 10				
Nipa sahnii		VII; 3			VII; 11		
ROOTS & CUTICLES							
Nypa (Root)	VI; 31						
Nypa (cuticle)					XI; 9		
NYPA FRUTICANS							XII, XIV

BASIN/AREAS — I= Arunachal Pradesh, II- Bengal, III= Cambay, IV= Kutch, V= Cauvery, VI= Deccan interappean, VII= Garo Hills, VIII= Krishna-Godavari, IX= Neyveli (Cauvery), X= Kerla-Lakshadeep, XI= Ratnagiri (Maharashtra), XII= Khasi & Jaintia Hills XIII= Sunderbans, XIV= Andamans, * Borehole Data.

1= Baksi & Deb (1980). 2= Bhatacharyya (1967). 3= Bhattacharyya (1983), 4= Carter (1854). 5= Chitaley (1960). 6= Kar (1985). 7= Kar & Jain (1981). 8= Kar & Kumar (1986). 9= Kulkarni & Phadtare (1980). 10= Lakhanpal (1948). 11= Lakhanpal (1952). 12= Mandal (1987). 13= Mathur & Chopra (1987). 14= Nandi (1990). 15= Prakash *et al.* (1990). 16= Prasad & Dey (1986). 17= Ramanujam (1987). 18= Ramanujam & Rao (1977). 19= Rao & Ramanujam (1975). 20= Rao & Ramanujam (1978). 21= Rode (1933). 22= Dutta & Sah (1970). 23= Sahni & Rode (1937). 24= Sarma *et al.*(1984). 25= Singh (1990). 26= Srisailam & Ramanujam (1982). 27= Venkatachala (1973). 28= Venkatachala & Rawat (1972). 29= Venkatachala & Sharma (1974). 30= Venkatachala & Sharma (1984). 31= Verma (1974).

ing to the genus *Nypa*. Two other fossil pollen species, viz., *S. baculatus* Muller 1968 (Pl. 2, figs 6-7, 13-14) and *S. intrarugulatus* Muller, de Di Giacomo & van Erve 1987 (Pl. 2, fig. 12) are closely related with each other in gross morphology having baculate sculptural elements but again differ in size range and exinal characters below the bacula. Though the baculate sculptural elements are absent in the pollen of *Nypa*, but similar general organization of the pollen as that of *Nypa* strongly suggests that the baculate type of the pollen were produced by plants related to *Nypa*. *S. wodehousei* Singh 1990 (Pl. 2, fig. 1) is characterised by "long beaked flask shaped" sculptural elements (8-18 µm) and wide lumina at the interspinal area, whereas *S. bulbospinosus* Singh 1990 (Pl. 1, figs 1-4; Pl. 2, fig. 15) also has sculptural elements but they are gemmae-like with small protruding spines. *S. duplispinosus* Ambwani 1993 described from the Palaeocene of north-eastern India seems as a specimen of *S. bulbospinosus* Singh 1990 having some fused spines. *S. decoris* Venkatachala & Sharma 1974 has thick exine at the base of each spine, such thickening do not occur in *Nypa* pollen. *S. spinolosus* Ramanujam 1987 is characterised with very small spines (about 1 µm long) but *S. quilonensis* Rao & Ramanujam 1975 can be related with the species of *Salaca* since the pollen have smaller sculptural elements (about 3 µm long) with psilate exine in between the spines. *S. mucus* Venkatachala & Sharma 1974 is characterised by curved tipped spines but in the original diagnosis the authors state that the apertural type is not clearly observed. Curving of spine may be due to artifact of compression (Babajide-Salami, 1985). Baksi and Deb (1980) illustrated *S. mulleri*, *S. sahii* and *S. brevispinosus* but neither provided any description nor diagnosis of any of the above species and hence all are invalid. But from the photographs it seems that *S. mulleri* is a specimen of *S. intrarugulatus*, whereas *S. sahii* resembles *S. prominatus*. The photograph of the *S. brevispinosus* is not clear to make any comment. *Spinizonocolpites* sp. described by Singh 1990 (Pl. 1, fig. 10) is exceptionally large (68-92 µm) with small spines (3-10 µm). *Spinizonocolpites* sp. (Kar, 1985) has spines slightly constricted at the middle and then broadened and gradually tapers towards the ends. "Pollen type 2" described in Singh 1990 from the Palaeocene possesses gemmae as sculptural element (Pl. 1, fig. 12) but the other characters are same as that of *Spinizonocolpites* and hence it also represents and species of early *Nypa*-complex. *Spinizonocolpites* sp. in Prasad and Dey (1986) and *Spinizonocolpites* sp. in Ramanujam and Rao (1977) are comparable to *S. prominatus*.

Thus, the fossil pollen species, viz., *S. prominatus*, *S. baculatus*, *S. intrarugulatus*, *S. indicus*, *S. bulbospinosus*, *S. wodehousei*, *S. spinolosus*, *S. decoris*, *Spinizonocolpites* sp., and "Pollen type 2" (Singh, 1990) instituted on the basis of morphological variations represent an early *Nypa*-complex comprising different species or subspecies of the genus. The highest diversity of early *Nypa*-complex is recorded in India during Palaeocene (Table 1) which suggests rapid evolution of this early *Nypa* complex. Most of the reports of *Nypa*-complex are from the coastal areas which indicate to be the mangrove plants but their occurrence in the non-marine Deccan Intertrappean beds of central India associated with megafossils mostly belonging to other palms prompt to suggest that the early *Nypa* may have been growing in the habitats other than the mangrove, probably lacustrine environment. After Eocene it may be very much possible that due to competitive co-association of other floral elements the early *Nypa*-complex could not compete with and thus got extinct leaving the only relict species of the present in its specialized habitat. In Sunderbans, the genus *Nypa* being over exploited for its leaves used in thatching is in verge of extinction.

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Fluorescence microscopic investigations of the main lignite seam from the Neyveli Lignitefield, Tamil Nadu, India*

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ABSTRACT

Singh A & Misra BK 1999. Fluorescence microscopic investigations of the main lignite seam from the Neyveli Lignitefield, Tamil Nadu, India. Palaeobotanist 48(2) : 155-162.

The organic (maceral) composition of the main lignite seam encountered in bore-holes NLE-27, 35 and 36 from mine III of Neyveli Lignitefield has been investigated under fluorescence mode (blue light excitation). The lignites are of sub-bituminous C stage (R_o max. 0.39% ASTM classification) and predominate in the huminite group of macerals followed by those of the liptinite and inertinite groups. Liptinite macerals, viz., liptodetrinite, bituminite, chlorophyllinite and various forms of resinite and perhydrous huminite, usually indistinct under normal mode, are recognized and more information about their characters and mode of occurrences has been presented. The data generated have led to a more detailed understanding of the source material, swamp type, and genesis of Neyveli main lignite seam.

Key-words—Petrology, Fluorescence, Neyveli lignite, Tertiary.

सारांश

भारत के तमिलनाडु प्रान्त के नयवेली लगुडांगार (लिग्नाइट) क्षेत्र से प्राप्त मुख्य लगुडांगार सीम का प्रतिदीप्ति सूक्ष्मदर्शी की सहायता से अन्वेषण

अल्पना सिंह एवं बसन्त कुमार मिश्र

नयवेली लगुडांगार क्षेत्र की खदान सं. 3 के वेध छिद्र सं. एन.एल.ई.- 27, 35 एवं 36 में समागमित प्रमुख लगुडांगार सीम के कार्बनिक (मैसेरल) संघटन का प्रतिदीप्तीय अवस्था (नीले प्रकाश उत्तेजन) के अन्तर्गत अन्वेषण किया गया। यह लगुडांगार उप बिटुमेनी 'सी' अवस्था ($R_{o\ \text{अधिकतम}}$ 0.39% ए.एस.टी.एम. वर्गीकरण) का है तथा इसमें मैसेरलों के ह्यूमीनाइट वर्ग की प्रधानता है, तत्पश्चात क्रमशः लिप्टीनाइट तथा इनर्टीनाइट वर्ग आते हैं। लिप्टीनाइट मैसेरल, जैसे - लिप्टोडेट्रीनाइट, बिटुमिनाइट, क्लोरोफ़िल्लीनाइट तथा रेज़िनाइट एवं परहाइड्रस ह्यूमीनाइट के विभिन्न रूप प्रायः सामान्य अवस्था में अस्पष्ट स्थिति में पहचाने गए हैं तथा उनके अभिलक्षणों एवं प्राप्ति की अवस्था के विषय में अधिक जानकारी प्रस्तुत की गई है। उपलब्ध आंकड़े स्रोत पदार्थ, अनूप प्ररूप तथा मुख्य लगुडांगार सीम की उत्पत्ति से सम्बन्धित अधिक विस्तृत सूचनाएँ प्रदान करते हैं।

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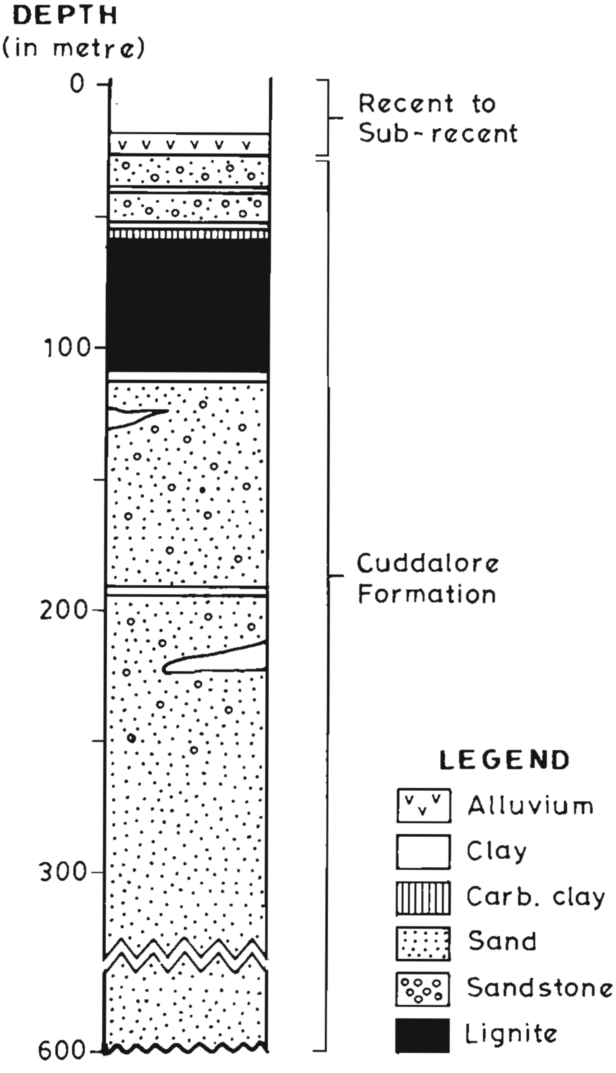
INTRODUCTION

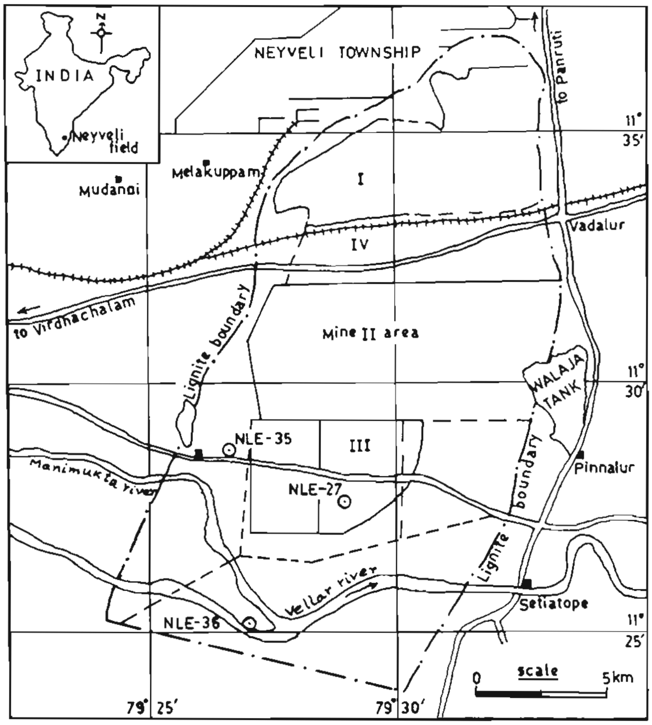
NEYVELI Lignitefield, extending in an area of about 480 sq. km between the latitudes 11°15' : 11°40'N and longitudes 79°25' : 79°40'E in the State of Tamil Nadu, is the largest mining lignitefield of India with an estimated reserve of about 3,300 million tonnes. The lignite occurs in and around village Neyveli in South Arcot Basin or Ariyalur-Pondicherry sub-basin of the Cauvery main Basin.

In the area, the Precambrian metamorphic rocks (schists and gneisses) form the basement over which lies a sedimentary sequence of Ariyalur Group (Late Cretaceous). The Cretaceous rocks (fossiliferous limestones, calcareous sandstones and marlstones) are unconformably overlain by the Tertiary sediments. The Cuddalore Formation (Mio-Pliocene), containing the lignite deposit, tops the sequence and is in turn covered completely by recent alluvium (Text-figure 1; for details refer Gowrisankaran *et al.*, 1987; Singh *et al.*, 1992).

The Cuddalore Formation comprises alternating beds of sandstone, clayey sandstone, sandy clay, carbonaceous clay, besides a thick lignite seam— the main seam in its upper part. The seam is encountered at a depth of about 40 to 150 m below ground level. Its thickness varies between 6 to 27 m and it tends to split into two or three (sometimes more) seams towards southern and western periphery of the area. There are few local and uneconomic seams overlying the main seam.



Text-figure 1—A generalized lithological succession of the Neyveli Lignitefield, Tamil Nadu (not to scale).



Text-figure 2—A Map showing mining blocks in Neyveli Lignitefield and location of investigated bore-holes NLE-27, 35 and 36.

PLATE 1

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(All photomicrographs were taken on polished surface under incident blue light excitation using oil immersion)

1. Fluorescing (perhydrous) huminite associated with liptodetrinite, ca x 400.
2. Suberinite (suberinized cell walls), ca x 400.
3. Cutinite showing epidermal cells and stomata. Note elongated cuticular ledges in oblique section at the bottom, ca x 400.
4. Resinite filled in cell lumina, ca x 600.
5. Resinite- single elongated body fluorescing with yellowish-brown colour, ca x 400.
6. Sporinite- a trilete and a monolete spores, ca x 600.
7. Alginite (*Botryococcus*), ca x 700.
8. Chlorophyllinite fluorescing with red colour inside the leaf tissue, ca x 800.

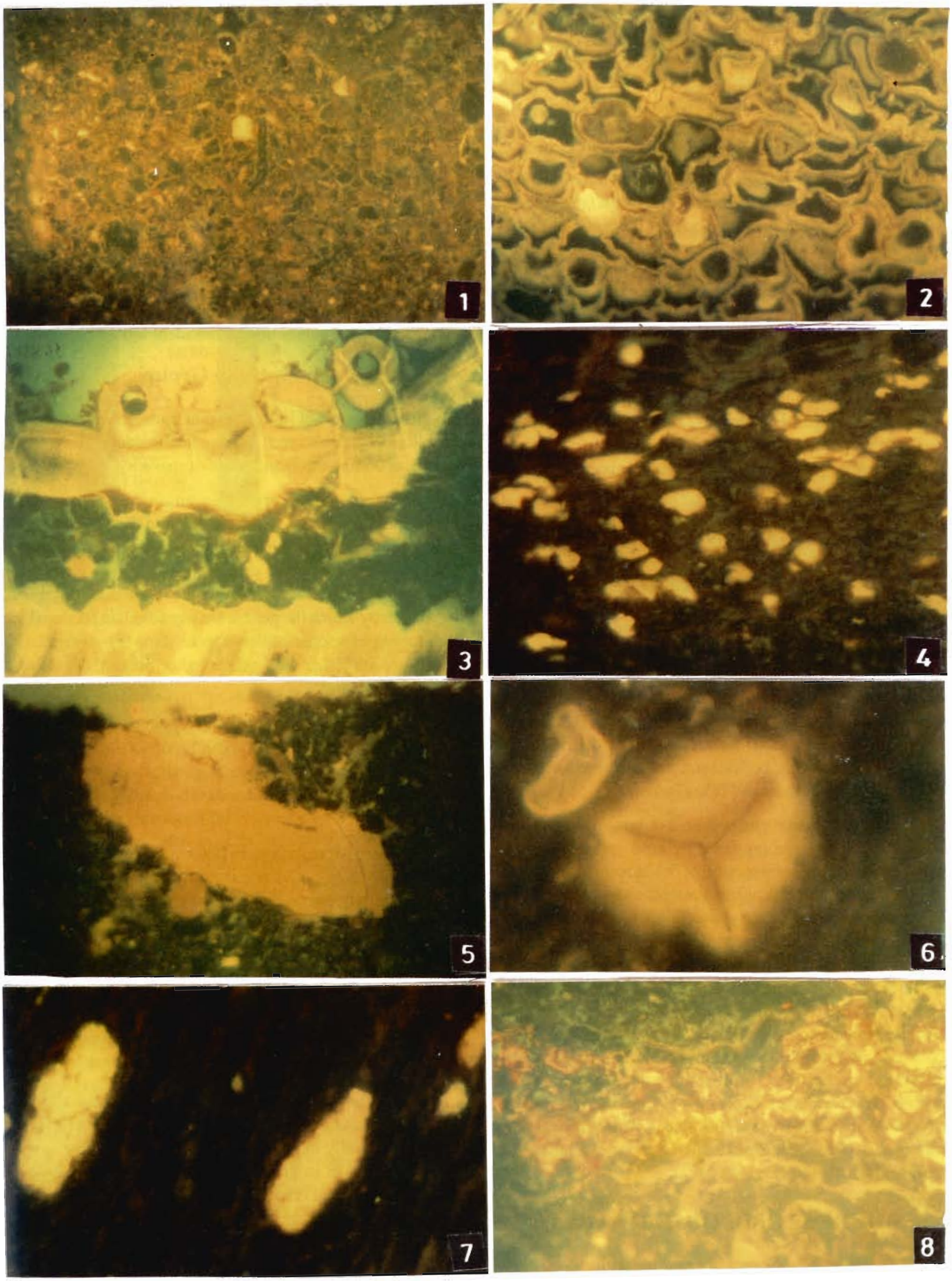


PLATE 1

Stupendous information on palaeobotanical constituents of the Neyveli lignite has been gathered since latter part of the 1950 (for detail references see Singh *et al.*, 1992) . The data accumulated have been potentially used to interpret palaeofloristics and palaeoclimate of the deposit. However, the studies on petrological constituents of lignites, much useful to understand the process of coalification and the genesis of the organic deposit, started during the late sixties (Navale, 1968). The available information on petrology of Neyveli lignite is mainly based on incident white light microscopy (Navale, 1971; Navale & Misra, 1980; Singh *et al.*, 1992; Singh & Singh, 1993).

A considerable advancement in the microscopic techniques during recent years necessitates the assessment of lignite deposit by newer techniques. The fluorescence microscopy, a better and more reliable method to evaluate and to assess the hydrogen-rich macerals (liptinites and perhydrous or fluorescing huminite) in particular, has been used presently and the information gathered on liptinite macerals has been utilized for a critical evaluation of the lignites.

MATERIAL AND METHOD

Thirty-nine core samples (37 lignite and 2 lignitic clay) from three bore-holes NLE-27 (25.0 m lignite), NLE-35 (5.85 m lignite) and NLE-36 (7.50 m lignite and 6.20 m lignitic clay) from mine III of Neyveli Lignitefield (Text-figure 2), obtained through the courtesy of the Geological Survey of India, have been used for the present study. The samples collected vertically (approximately metre by metre) represent the main lignite seam in different sections. The distribution of lignite and lignitic clay beds encountered in the three boreholes are shown in lithologs (Text-figure 3).

The samples were crushed (± 1-2 mm grain size) and particulate pellets were prepared by cold embedding using epoxy resin and hardner in a ratio of 5:1 at room temperature. The fluorescence microscopic investigations were carried out under violet-blue light excitation (Filter block H3: 420-490 nm) on Leitz MPV-3 unit using 150 Watt ultra high pressure Xenon lamp as a source of illumination, 25x NPL Fluotar oil objectives with 0.75 numerical aperture and fluorescence free immersion oil following the recommendations of ICCP (1971, 1975). By using automatic point counter (James-Swift Model F), 500 counts per sample have been counted for quantitative assessment of various fluorescing and non-fluorescing macerals. The results are expressed as volume per cent (vol. %) on mineral matter-free (m.m.f.) basis. The descriptive terminology for fluorescing macerals is given by Stach *et al.* (1982) and Misra and Navale (1992).

MICROSCOPIC OBSERVATION

Of the three main maceral groups of lignite— huminite, liptinite and inertinite (ICCP, 1971, 1975), the fluorescence is shown mainly by relatively hydrogen-rich liptinite macerals. A fraction of huminite designated as fluorescing or perhydrous huminite (=fluorescing or perhydrous vitrinite in bituminous coals) fluoresces with low intensity. On the contrary, the macerals of inertinite group do not fluoresce at all.

Huminite Group

The huminite maceral fluoresces with yellowish-brown to dark brown colours when it is associated with very small fluorescing particles of liptinite group (Pl. 1, fig. 1). The perhydrous huminite generally forms the groundmass for other macerals. Fluorescing huminite appears low reflecting and spongy in nature under normal incident light.

Liptinite Group

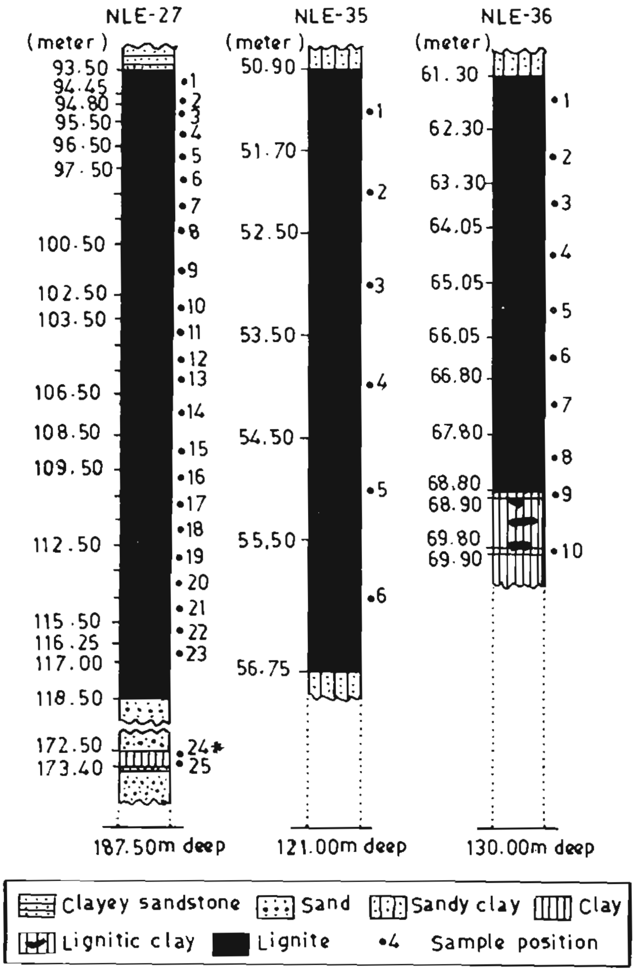
The macerals of liptinite group fluoresce with wide range of colours (green to red) and intensities depending on their chemical composition and stage of maturity.

Sporinite—It incorporates angiospermic pollen and pteridophytic spores. It exhibits dull and dark yellow, brownish-yellow, yellowish-brown and reddish-brown fluorescence colours. The outer wall of pollen and spores is invariably brighter than the inner wall. The outer wall also contain ornamentation by which the genera are identified. In sectional view, the lumina of spores-pollen appear dark (Pl. 1, fig. 6). The sporinites are either well-preserved or broken, degraded and in granular forms.

Suberinite—The maceral fluorescing with brownish-yellow to yellowish-brown colours incorporates periderm and covering of fruits and roots. It generally occurs as tabular multicellular thick or thin bands (Pl. 1, fig. 2) but sometimes it is represented by a few-celled fragments or shreds.

Cutinite—It incorporates outer covering of leaves, shoots and thin stems, etc. Cutinite is easily recognized by cuticular ledges (cutin between the walls of the epidermis). In surface view it exhibits underlying polygonal epidermal cells. Both tenui- (thin) and crassicutinites (thick) have been recorded. Generally the first type fluoresces with brown to reddish-brown colours, whereas the second type fluoresces with brownish-yellow colour with relatively higher intensity. Cutinite with well-preserved cuticular ledges and stomatal structures have also been observed (Pl. 1, fig. 3).

Alginite—It is mostly represented by the algae *Botryococcus* which is formed by numerous unicellular algae arranged radially in groups. Its colonies have been found either discretely or in groups (Pl. 1, fig. 7). In most cases it is well-preserved and is recognized by the cup-shaped openings. Degraded and broken, but still identifiable specimens have also been observed. Alginite emits bright yellow and orangish-yellow fluorescence colours with higher intensities in comparison to other liptinite macerals.



Text-figure 3—Core logs showing lignite seam and associated sediments along with position of samples in bore-holes NLE-27, 35 and 36.

Resinite—It occurs as circular, sub-circular, elongated and irregular bodies either discretely (Pl. 1, fig. 5) or in rows or groups. The latter are mostly cell-filling resinite aquiring the shapes of cell lumina (Pl. 1, fig. 4). The resinite exhibits widest range of fluorescence colours, viz., yellowish-green, greenish-yellow, pale, deep and orangish-yellow, yellowish-brown, reddish-brown, and greyish-brown. The fluorescence intensity generally varies between low to moderately high.

Chlorophyllinite—It fluoresces with red colour and is occasionally observed inside the leaf tissues (Pl. 1, fig. 8) and also as disperse small particles. The blood-red colour of the chlorophyllinite easily distinguishes it from the other liptinite macerals.

Liptodetrinite—All the detrital and unidentifiable liptinite macerals consisting the fragments or relics of sporinite, cutinite, resinite, suberinite, alginite, etc. constitute liptodetrinite which fluoresces with different colours and intensities. The fluorescence colour and intensity of liptodetrinite depend upon original material, chemical or biological decomposition and degree of diagenesis.

Bituminite—A secondary maceral fluorescing with dull yellow colour. Mostly it is found as groundmass for other macerals in Neyveli lignite and rarely as small spongy granules inside the cells lumina emitting light of very low intensity. 'Mineral bituminite', that is the fluorescing groundmass formed by close association of mineral and bituminite is quite significant in lignitic clay bed.

Besides the preceding liptinite macerals, multicellular spindle shape fluorescing bodies in association with cutinite have also been recorded. These bodies, occurring discretely or in a chain, fluoresce with yellow, orangish-yellow and brownish-yellow colours with moderately high to low intensities. Source of origin of these fluorescing bodies is yet to be confirmed (Singh & Misra, 1998).

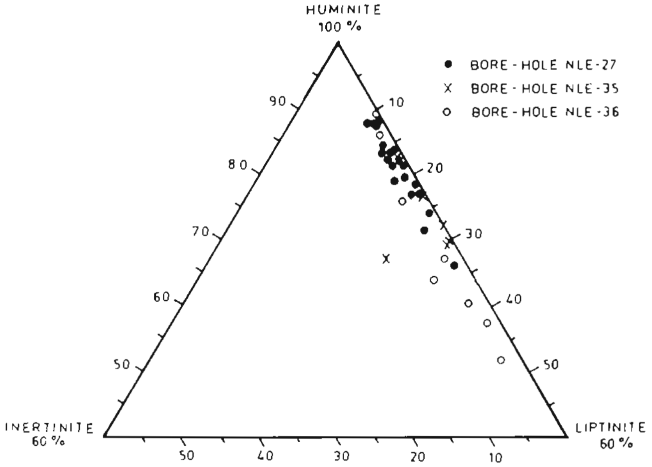
MACERAL COMPOSITION

(Table 1, Text-figure 4)

Bore-hole NLE-27—The lignite seam encountered in this bore-hole is dominated by the huminite (65.8-88.2%) followed by liptinite (10-33%) and inertinite (0.2-2.8%). The huminite includes a high proportion of non-fluorescing

Table 1—Maceral composition (mean and range, under fluorescence mode) in the main lignite seam sections of Neyveli Lignitefield.

Bore-hole	NLE-27	NLE-35	NLE-36
No. of samples	23	6	8
Macerals :			
Fluorescing huminite	6.5 0.0-21.2	9.0 2.8-25.8	4.4 1.0-13.8
Non-fluorescing huminite	74.4 59.0-87.0	63.9 43.6-78.6	64.6 49.8-83.4
Total huminite	80.9 65.8-88.2	73.0 66.8-83.4	69.0 52.6-88.8
Sporinite	0.1 0.0-0.6	0.1 0.0-0.6	0.1 0.0-0.4
Cutinite + Suberinite	1.0 0.0-5.6	1.3 0.0-6.4	1.3 0.0-8.2
Resinite	8.1 1.4-20.4	7.5 4.4-11.0	5.1 1.2-16.2
Liptodetrinite	6.4 2.0-18.0	13.6 4.6-21.6	20.6 10.4-31.2
Unidentified fluorescing bodies	0.8 0.2-6.8	0.8 0.8-2.0	0.1 0.0-0.6
Total Liptinite	18.0 10.0-33.0	25.0 16.4-30.2	28.6 10.6-44.8
Total Inertinite	1.1 0.2-2.8	2.0 0.2-1.0 10.0 in one sample	2.3 0.6-5.0



Text-figure 4—Ternary diagram showing composition of three main maceral groups in lignite of bore-holes NLE-27, 35 and 36.

huminite (59.0-87.0%) and a subordinate amount of fluorescing huminite (0.2-21.2%).

Among the liptinite macerals, the resinite has the highest frequency (1.4-20.4%, av. 8.1%) followed by the liptodetrinite (2.0-18.0%, av. 6.4%), suberinite (0.2-5.4%, av. 1.3%), cutinite (0.4-5.6%, av. 0.8%) and sporinite (up to 0.6%). The chlorophyllinite and alginite (*Botryococcus*) have been also observed, but they are quantitatively insignificant. The unidentified fluorescing bodies are recorded in relatively higher proportion (0.2-6.8%, av. 0.8%) than the seams encountered in other two bore-holes.

Bore-hole NLE-35—The lignite encountered in this bore-hole is dominated by huminite (66.8-83.4%) fraction followed by liptinite (16.4-30.2%) and inertinite (0.2-10.0%) fractions. The huminite fraction as a whole does not show any particular trend in distribution, however the fluorescing huminite (2.8-25.8%) indicates a decreasing trend towards the bottom of the seam. The amount of inertinite macerals sharply increases in the middle part of the seam (10% in one sample) which otherwise is almost uniform throughout (0.2-1.0%).

Among the liptinite macerals, the liptodetrinite is dominant (4.6-21.6%, av. 13.6%) followed by resinite (4.4-11.0%, av. 7.5%), cutinite (0-6.4%, av. 2.2%), suberinite (0.2-1.0%, av. 0.5%), sporinite (up to 0.6%) and alginite (up to 0.2%). The latter three macerals, though distributed throughout the seam, are non-recordable in few samples. The unidentified fluorescing bodies are present throughout the seam and range from 0.8 to 2.0 per cent (av. 0.8%).

Bore-hole NLE-36— The lignites of the main seam encountered in this bore-hole shows dominance of huminite macerals (52.6-88.8%; non-fluorescing: 49.8-83.4%, fluorescing: 1.0-13.8%). The concentration of inertinite macerals is relatively higher (0.6-5.0%) than the seam sections encountered in other two bore-holes.

The macerals of the liptinite group (10.6-44.8%, av. 28.6%), in decreasing order of abundance are represented by the liptodetrinite (10.4-31.2%, av. 20.6%), resinite (1.2-16.2%, av. 5.1%), suberinite (0.6-8.2%), cutinite (up to 0.8%) and sporinite (up to 0.4%). The unidentifiable fluorescing bodies are recorded in low proportion (up to 0.6%). No specific trend in the distribution of macerals is discernible in this seam section.

The lignitic clay bed, associated with bottom part of the seam, also has a high huminite content (63-79%, av. 71.2%). The liptinite maceral content is relatively lower (12.0-15.5%, av. 13.7%) than those in lignite sections. 'Mineral bituminite' is recorded in appreciable amount (9-21%, av. 15%). The inertinite macerals have been found to be quantitatively insignificant. The required 500 counts could not be made on lignitic clay samples because of the scarcity of clean particles.

A comparative data of lignite seam encountered in three bore-holes, on the basis of frequency distribution of fluorescing and non-fluorescing macerals, are provided in Table 2 and Text-figure 5. The data indicate that the lignite in bore-hole NLE-27 has relatively higher proportion of non-fluorescing macerals than in the lignite seams in other two bore-holes. The content of fluorescing macerals have been found to be higher in the lignite seam of bore-hole NLE-35 than in the seams of bore-holes NLE-27 and 36.

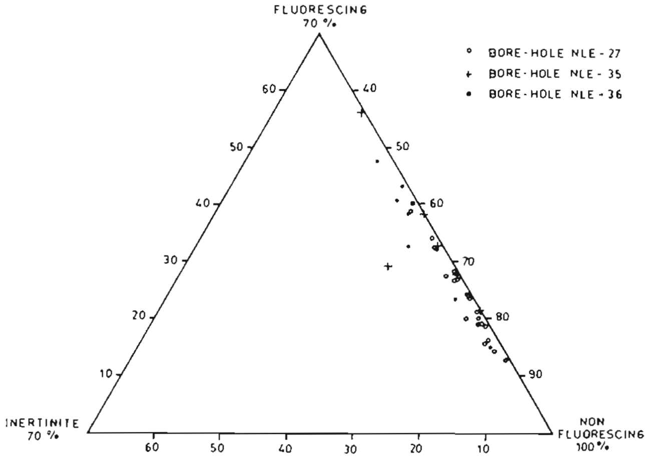
Table 2— Frequency of fluorescing and non-fluorescing macerals in lignites of bore-holes NLE-27, 35 and 36 from Neyveli Lignitefield.

Bore-hole	NLE-27	NLE-35	NLE-36
No. of samples	**23**	**6**	**8**
Macerals			
Fluorescing	24.4 12.6-38.8	34.0 21.2-56.0	33.0 15.2-47.6
Non- fluorescing huminite	74.4 59.0-87.0	63.9 43.6-78.6	64.6 56.6-83.4
Inertinite	1.1 0.2-2.8	2.0 0.4-10.0	2.3 0.6-5.0

Note: Fluorescing macerals incorporate all the liptinites, fluorescing huminite and unidentifiable fluorescing bodies.

DISCUSSION AND INFERENCE

Each organic constituent (maceral) provides important information about an organic deposit because its origin is dependent on climate, peat-forming plant communities, ecological conditions (pH, Eh of water) and degree of carbonification (Stach *et al.*, 1982; Teichmüller, 1989). Proper recognition of organic constituents is, therefore, important to obtain information about these aspects. A better distinction of liptinite



Text-figure 5—Ternary diagram showing composition of fluorescing and non-fluorescing macerals in the lignite seams of bore-holes NLE-27, 35 and 36.

macerals, under fluorescence mode, has made it possible to generate useful data and to establish a generalized picture of the depositional conditions. The inferences drawn from the earlier studies and also from the present investigations under fluorescence mode, are as follow:

Earlier evidences gathered from mega- and microfloral investigations carried out on the main lignite seam (mine I, II, and III) indicated the predominance of angiospermic vegetation which served as source material in the formation of lignite seam (Refer to Singh *et al.*, 1992). Besides, deciduous forest vegetation of tropical climate with high rainfall together with coastal elements were responsible for lignite formation.

The petrographic data from the lignites of mine I (normal reflected mode) and mine III (reflected and fluorescence modes) also corroborate the existence of wood dominated forest vegetation as evidenced by higher proportion of huminite macerals (Misra, 1992; Singh *et al.*, 1992). Appreciable amount of resinite in the absence of gymnospermous flora suggests the existence of resin producing angiospermic plants. Thick bands of suberinite also indicate the dominance of angiosperms (Kantsler, 1980). Variation in resinite morphology, nature of occurrence and fluorescing colours suggest it's origin from different sources (oil, fat, wax, latex, etc.). The presence of alginite (*Botryococcus*) throughout the entire thickness of the seam indicate marine influenced fresh water (brackish water) conditions for the formation of lignite (Misra *et al.*, 1997). The petrological and palynological studies on Neyveli lignites also indicate its origin in lagoons or back swamps having more fresh water influence than brackish (Pareek, 1984; Ramanujam *et al.*, 1984; Singh *et al.*, 1992). Fluctuations in frequency and size of algal colonies indicate the seasonal changes and also the changes in the pH of swamp water.

In view of the predominance of humodetrinite over humotelinite and humocollinite, high degree of vegetal degradation in the middle part of the main seam was suggested by Misra (1992). However, degradation effects were found to be pronounced in different portions of the seam encountered in three bore-holes of mine III area. Well-preserved leaf sections and epidermal tissues with stomata, which are normally easily decomposed, indicate low energy reducing environment. Preservation of chlorophyllinite, which most easily decomposes among all the liptinite macerals, also suggests a non-oxidizing environment. This suggests a rapid burial of vegetal matter growing at or very near to the site of peat formation (autochthonous or hypautochthonous deposition). The presence of perhydrous huminite, liptodetrinite and bituminite which are generally formed during the later stages of diagenesis reflect an undisturbed swampy condition. Relatively higher proportion of inertinite in the lignite seam of bore-hole NLE-36 (Table 1) indicate that the ancient peat which formed the lignite was exposed to oxidative conditions periodically in the particular area. High amount of inertinite (10%) in the middle part of the seam of bore-hole NLE-35 appears to suggest such periodic dryness.

From the earlier palaeobotanical and petrological information, besides that of the present investigation, it has been inferred that predominantly woody angiospermous forest vegetation including beach, back-mangrove and mangrove plants, besides associated pteridophytes were responsible for the formation of Neyveli lignite. The identification of newly recorded multicellular fluorescing bodies (Singh & Misra, 1998) will further add to our knowledge about palaeoflora and palaeoclimate of the lignite-bearing region.

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Plant fossils from Arung Khola and Binai Khola formations of Churia Group (Siwalik), west central Nepal and their palaeoecological and phytogeographical significance

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ABSTRACT

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Systematic study of plant megafossils comprising dicotyledonous leaves and seeds collected from the Arung Khola and Binai Khola formations of the Churia Group, exposed in Tinau Khola and Mahendra Highway between Barghat and Dumkibas, Nepal, has revealed 15 taxa out of which 14 are new belonging to 14 genera of 12 families. They are named as *Orophea siwalika* sp. nov., *Miliusa brochidodroma* sp. nov. (Annonaceae); *Gynocardia butwalensis* sp. nov. (Flacourtiaceae); *Shorea miocenica* sp. nov., *S. nepalensis* sp. nov., *Hopea siwalika* Antal & Awasthi (Dipterocarpaceae); *Grewia mallotophylla* sp. nov. (Tiliaceae); *Chisocheton ellipticus* sp. nov., *Ventilago ovatus* sp. nov. (Rubiaceae), *Swintonia butwalensis* sp. nov. (Anacardiaceae), *Mitragyna tertiara* sp. nov., *Mussaendopsis suborbiculatus* sp. nov. (Rubiaceae); *Alangium nepalensis* sp. nov. (Alangiaceae); *Homonoia lanceolata* sp. nov. (Euphorbiaceae) and *Ficus miocenicus* sp. nov. (Moraceae). The modern counterparts of these fossils are mostly distributed in the tropical evergreen to semi-evergreen forests of Indo-Malayan region which indicate the existence of similar type of forests in the frontal Himalayan foot-hill zone during Middle Miocene-Pliocene. Absence of tropical evergreen dipterocarps and their associates in the present day flora of this region reflects changes in the annual mean temperature and rainfall caused by further uplift of the Himalaya and northward movement of the Indian Plate.

Key-words—Fossil leaves, Angiosperms, Churia (Siwalik) Group, Middle-Upper Miocene, Nepal.

सारांश

पश्चिम-मध्य नेपाल के चूड़िया समूह (शिवालिक) अवस्थित अरुंगखोला तथा बिनाईखोला शैल समूहों से प्राप्त पादपाश्मों का पुरापर्यावरणीय एवं पादपभूगोलीय महत्व

एम. कोनोमात्सु एवं नीलाम्बर अवस्थी

नेपाल के वड़घाट एवं दुमकीवास नामक स्थानों के वीच स्थित तिनाऊखोला तथा महेन्द्र राजमार्ग से अनावरित चूड़िया समूह के अरुंगखोला एवं विनाईखोला शैल समूहों से संग्रहीत गुरूपादपाश्म पादपों का व्यवस्थित अध्ययन किया गया। इन गुरुपादपाश्म पादपों में द्विवीजपत्री पत्तियाँ तथा वीज पाए गए, जिनमें 15 वर्गक प्रदर्शित हैं, इनमें से 14 अपेक्षाकृत नए हैं, जो 12 कुलों के 14 वंशों से सम्बन्ध रखते हैं। इनके नाम-*ओरोफ़िया शिवालिका* नवप्रजाति,

मिलीयूसा ब्रोकीडोड्रोमा नवप्रजाति, (एनोनेसी), *गाइनोकार्डिया बुटवालेन्सिस* नवप्रजाति (फ्लैकोर्टिएसी), *शोरिया मायोसीनिया* नवप्रजाति, *शोरिया नेपालेन्सिस* नवप्रजाति, *होपियाशिवालिका* अन्तल एवं अवस्थी (डिप्टेरोकार्पेसी), *ग्रीविया मैलोटोफाइला* नवप्रजाति, (टीलिएसी), *चाइसोकिटॉन इलिप्टिकस* नवप्रजाति, (मीलिएसी), *वेन्टिलेगो ओवेटस* नवप्रजाति, (रैमेनेसी), *स्विन्टोनिया बुटवालेन्सिस* नवप्रजाति, (एनाकार्डियेसी), *मित्रेगाइना टर्शियरा* नवप्रजाति, *मुसैन्डॉप्सिस सबआर्बिकुलेटस* नवप्रजाति, (रूबिएसी), *एलैन्जियम नेपालेन्सिस* नवप्रजाति, (एलैन्जिएसी), *होमोनोइया लेन्सियोलेटा* नवप्रजाति, (यूफ़ोर्बिएसी) तथा *फ़ाइकस मायोसीनिकस* नवप्रजाति, (मोरेसी) हैं। इन पादपाश्मों के प्रतिरूप मुख्य रूप से भारत के मलाया क्षेत्र के कटिबन्धीय सदाबहारी से लेकर अर्द्धसदाबहारी वनों में वितरित हैं, जिनसे मध्य मायोसीन-प्लायोसीन युग के दौरान अग्र हिमालयी पाद पहाड़ी क्षेत्र में इसी प्रकार के वनों की विद्यमानता का संकेत मिलता है। इस क्षेत्र के वर्तमान वनस्पतिजात में उष्ण कटिबन्धीय सदाबहारी डिप्टेरोकार्प्स तथा इनके सहयोगियों की अनुपस्थिति से हिमालय के और अधिक उच्चावचन होने तथा भारतीय प्लेट के उत्तरवर्ती दिशा में खिसकने के कारण वार्षिक औसत तापमान एवं वर्षा में परिवर्तन प्रदर्शित हुआ हैं।

INTRODUCTION

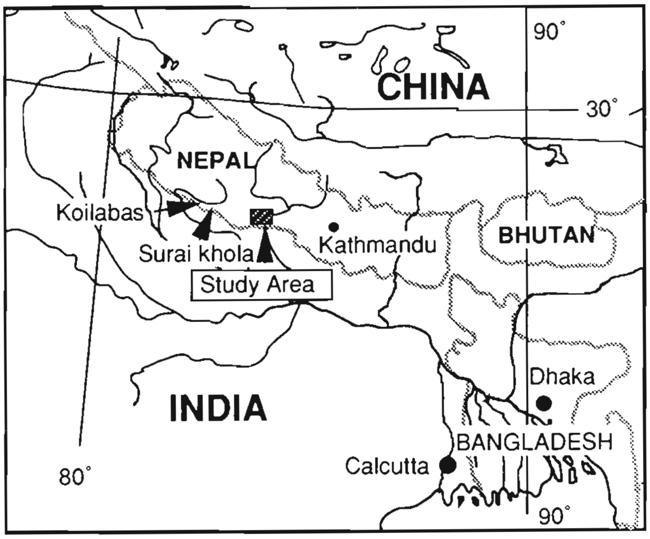
THE Neogene sediments of the Siwalik Group are widely distributed along the southern Frontal Hills of the Himalaya. In Nepal they are generally known as the Churia Group after the Churia Hills (Tokuoka *et al.*, 1986). The Churia Group is very rich in plant-remains, the leaves being most dominant among them. In order to reconstruct the floristic patterns and climatic conditions of the Middle Miocene-Pleistocene time, systematic study of plant fossils of the Churia (Siwalik) Group of Nepal has been undertaken by Awasthi & Prasad (1990), Prasad & Awasthi (1996) and Prasad (1990a, b) from the Surai Khola and Koilabas, West Nepal who identified a large number of fossils in terms of extant genera and species from the Surai Khola and Koilabas, Western Nepal. However, considering wide extent of the Siwalik (Churia) sediments and the amount of plant material preserved therein the number of taxa recognised so far is still small which represents only a small part of the Siwalik flora. Therefore, identification and documentation of more and more taxa from different localities and areas of the known stratigraphic sequence are of utmost importance for precisely reconstructing the floristics and climate through the Siwalik succession.

Another important aspect of extensive study of plant fossils of the Siwalik (Churia) Group is to assess the magnitude of diversification and proliferation of tropical angiosperms in the northern part of peninsular and the extra peninsular regions of the Indian subcontinent with the advent of African and Malaysian elements.

The present authors have initiated the morphotaxonomic study of plant megafossils from the west central Nepal. In their previous study, Konomatsu & Awasthi (1996) have recorded a few significant genera, viz., *Clinogyne, Bambusa, Dipterocarpus, Calophyllum, Ziziphus, Bauhinia* and *Cinnamomum* from the Arung Khola Formation, exposed in Tinau Khola and Jhumsa Khola near Butwal and from the Binai Khola Formation along Mahendra Highway between Barghat and Dumkibas, Nepal (Text-figures 1, 2).

GEOLOGICAL SETTING

The Siwalik (Churia) sediments of Arung Khola and Tinau Khola area west central Nepal lie between the Main Boundary Thrust (MBT) to the north and the Frontal Churia Thrust (FCT) to the south, and are separated by Central Churia Thrust (CCT) (Text-figure 2). It consists of about 6000 m thick fluvial deposits, dominated by mudstones, siltstones, sandstones and conglomerate. The Group exhibits a gradual coarsening upward in the sequence, reflecting the rise of the Himalaya. Detailed work on geological mapping, lithostratigraphy, sedimentology and magnetostratigraphy of the Churia (Siwalik) Group of Arung Khola and Binai Khola area Nepal, has been carried out by Tokuoka *et al.* (1986, 1988, 1990).



Text-figure 1— Index map of the study area.

Lithostratigraphically the Churia Group is divided into Arung Khola Formation, Binai Khola Formation, Chitwan Formation and Deorali Formation in ascending order (Tokuoka *et al.*, 1986, 1988, 1990). The former two are further divided into Arung Khola lower (Al), Arung Khoal middle (Am), Arung Khola upper (Au); Binai Khola lower (Bl), Binai Khola middle (Bm) and Binai Khola upper (Bu). Magnetostratigraphically, the Al and Am members are correlated with the Chinji zone (lower half of Middle Siwalik including Chron 9). The Binai Khola Formation corresponds mostly to the Dhok Pathan zone (upper half of Middle Siwalik) and Tatrot zone (lower half of Upper Siwalik) which ranges from Chron 8 to the Gilbert Reversed Polarity Chron. The Chitwan Formation is correlatable to the Pinjor zone (upper half of Upper Siwalik), and the Deorali Formation to the Boulder Conglomerate (Text-figure 3). Of these, the Arung Khola and Binai Khola formations are highly fossiliferous consisting of mostly leaves and occasionally flowers, fruits/seeds and carbonised woods. They are mostly preserved in the mudstones, claystones and calcareous sandstones as impressions and compressions with poorly preserved fragile cuticles.

MATERIAL AND METHOD

The material for the present study was collected from Tinau Khola and Jhumsa Khola (a tributary of Tinau river near Butwal), Mahendra Highway between Barghat and Dumkibas and from Arung Khola, west central Nepal. The terminology used in describing fossil leaves is after Hickey (1973) and Dilcher (1974). The identification was done by comparing them with the herbarium sheets at the Central National Herbarium, Howrah, India. All the type and duplicate specimens are deposited in the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATICS

Family—ANNONACEAE

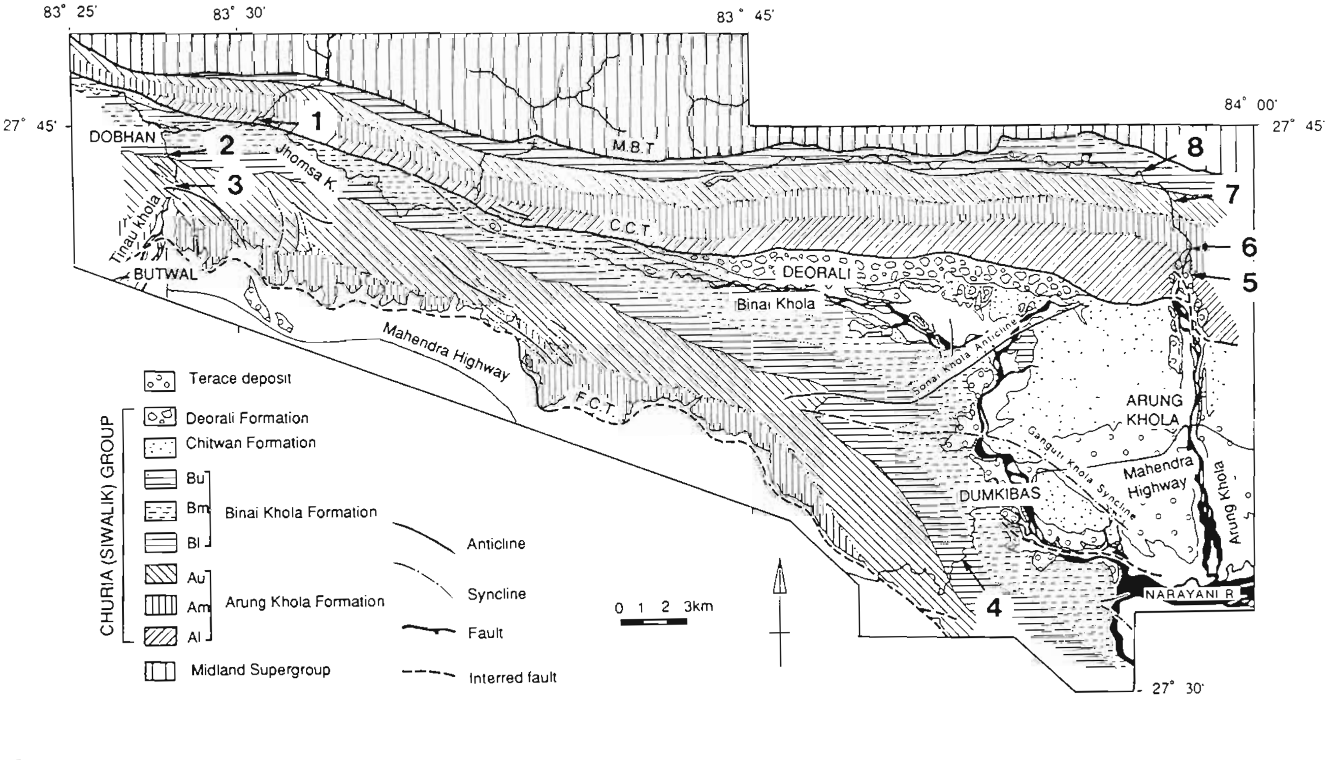
Genus—OROPHEA BL.

OROPHEA SIWALIKA sp. nov.

Pl. 1, figs 5-7

The species is represented by two specimens, of which one is with counterpart.

Description—Leaves simple, symmetrical, narrow elliptic, the bigger and complete one about 9.0 cm in length and 3.5 cm in width; apex acute; base obtuse; margin entire; texture coriaceous; petiole not preserved; venation pinnate, primary vein straight, moderately thick; secondary veins 5 pairs, alternate to subopposite, angle of divergence 45°-50°, prominent, moderately thick, uniformly curving and joining with superadjacent secondaries forming marginal loop; intersecondary veins not seen; tertiary veins present, angle of origin seemingly RR, pattern percurrent, straight, relation with



Text-figure 2—Geological map of the Arung Khola area, west central Nepal (Tokuoka *et al.*, 1990), showing plant fossil localities (1-8).

midvein oblique with constant angle; further details not clearly discernible.

Holotype—Specimen no. BSIP 37676.

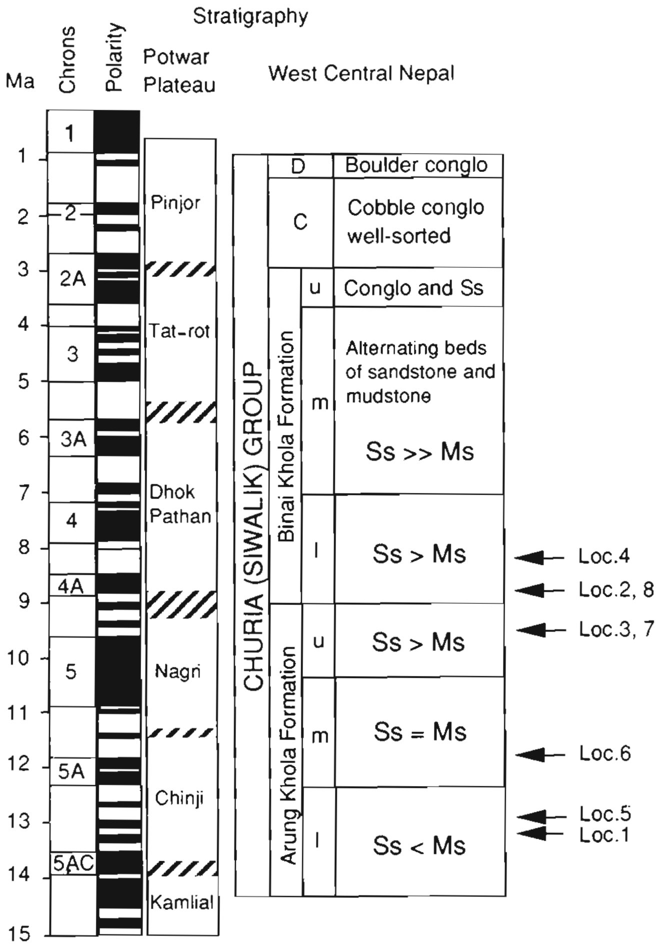
Paratype—Specimen no. BSIP 37677.

Locality—Tinau Khola near Butwal, Nepal (Loc. 1).

Horizon—Al Member.

Age—Middle Miocene.

Discussion—From their shape, size and venation pattern the fossil leaves appear very similar to those of *Orophea* of Annonaceae and *Pterospermum* of Sterculiaceae, but more so with the former. Leaves of *Pterospermum,* though resembling in many features, differ in having basal pairs of secondary veins given off from a single point, i.e. they are opposite, whereas in the fossil as well as in *Orophea* they are alternate to sub-opposite. Among the species of *Orophea*, leaves of *O. uniflora* and *O. polycarpa* A.D. (C.N.H., Sibpur, Howrah Sheet no. 5709) show close similarity with our fossil leaves.



Text-figure 3— Stratigraphic position of fossiliferous horizons with the standard polarity time scale (Cande & Kent, 1992) of Churia Group correlated with the Potwar plateau of Pakistan.

Orophea Bl. is a genus of small tree of shrubs. *O. uniflora* Hook. f. & Thoms, is a middle-sized tree occurring in Western Ghats from Coorg to Travancore. *Orophea polycarpa*, which also resembles the fossil leaves, is found in Andamans, Martaban and Tennasserim (Brandis, 1971).

Genus — MILIUSA Lesch ex A.DC.

MILIUSA BROCHIDODROMA sp. nov.

Pl. 1, fig. 3

There are six well preserved specimens representing the fossil species.

Description—Leaves simple, symmetrical, elliptic, one of the leaves 6.8 x 3.2 cm in length and width; apex acute; base obtuse; margin entire; texture chartaceous to subcoriaceous; petiole very small; venation pinnate; simple, brochidodromous; primary vein prominent, moderately thick, straight; secondary veins 8 pairs, alternate, angle of divergence about 60°, prominent, moderately thick, uniformly curved; intersecondary vein one, seemingly simple; tertiary veins visible at some places, angle of divergence seemingly OR, pattern percurrent, further details not seen.

Holotype—Specimen no. BSIP 37678.

Locality—Arung Khola, Nepal (Loc. 7).

Horizon—Au Member.

Age—Upper Miocene.

Discussion—Brochidodromous venation pattern is the most characteristic feature of the fossil leaves described above. Taking into consideration a combination of other morphographic features as described above the fossil leaves resemble those of *Miliusa* in general and *M. roxburghiana* Hook. f.T. in particular of the family Annonaceae.

Miliusa roburgliama is a tree occurring in the sub-Himalayan tract in Sikkim, ascending to 700 m, Assam, Chittagong Hills and Myanmar.

Owing to their close similarity with the leaves of *Miliusa*, the fossil leaves are assigned to it and named *Miliusa brochidodroma* sp. nov. The specific name indicates brochidodromous venation pattern of the fossil leaves.

Family—FLACOURTIACEAE

Genus—GYNOCARDIA R. Br.

GYNOCARDIA BUTWALENSIS sp. nov.

Pl. 1, fig. 1

The leaf is represented by a single specimen with counterpart.

Description—Leaf simple, symmetrical, elliptic, almost complete, 13.5 x 6.5 cm in length and width; apex acute; base seemingly acute; margin entire; texture subcoriaceous; petiolar part broken; venation eucamptodromous to brochidodromous; primary vein moderately thick, straight; secondary veins 6-7 pairs, alternate, angle of divergence about 60°-65°, curving upward and joining with superadjacent secondary veins; intersecondary veins present, many; tertiary veins present, arising from secondary veins as well as from primary vein, those arising from primary vein numerous, their angle of divergence almost 90°, running straight and joining with those of other tertiary veins arising from secondaries as well, angle of origin of tertiary veins from secondaries OA, random, reticulate, relation with midveins perpendicular or straight to somewhat oblique; further details not discernible.

Holotype—Specimen no. BSIP 37680.

Locality—Tinau Khola near Butwal Nepal (Loc. 1).

Horizon—Al. Member.

Age—Middle Miocene.

Discussion — In its shape, size, texture and venation pattern the fossil leaf resembles those of *Gynocardia odorata* of the family Flacourtiaceae. Its closeness with this extant taxon can be seen in the venation pattern. In addition to intersecondary veins, the tertiary veins arising from midvein are numerous, extending straight and joining with those of superadjacent secondaries (Pl. 1, fig. 1) which is a characteristic feature of the leaves of *Gynocardia orodata*.

Gynocardia orodata R.Br. is a large evergreen tree occurring in the sub-Himalayan tract, ascending to 1300 m from Sikkim eastward, Khasi Hills, Chittagong, Myanmar (Brandis, 1991).

The fossil leaf is named *Gynocardia butwalensis* sp. nov. the specific name is after Butwal town in Nepal.

Family—DIPTEROCARPACEAE

Genus—SHOREA Roxb. & Gaertn.

SHOREA MIOCENICA sp. nov.

Pl. 2, fig. 3

There are four specimens of leaf-impressions representing this species.

Description—Leaves simple, symmetrical, very narrow to narrow elliptic, biggest one (Pl. 2, fig. 3) about 12 cm in length and 3.5 cm in width, apex not discernible; base seemingly acute; margin entire; texture subcoriaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein prominent, stout, straight; secondary veins about 20 visible in the preserved part, might have been 2 to 4 more in the basal and apical portion, each 6 mm apart, angle of divergence 50°-60°, alternate to sub-opposite, running almost straight and then turning upward before terminating at the margin; intersecondary veins absent; tertiary veins percurrent, angle of origin RR, simple, unbranched to occasionally forked, sometimes curving before joining the superadjacent secondary veins, relationship to midvein oblique, further details not seen.

Holotype—Specimen no. BSIP 37681.

Paratype—Specimen no. BSIP 37682.

Locality—Tinau Khola, near Butwal, Nepal (Loc. 3).

Horizon—Al Member.

Age—Middle Miocene.

Discussion — In shape, size and venation patterns together with other morphological features the fossil leaves clearly show affinities with those of the extant *Shorea* of the family Dipterocarpaceae. Since the leaves of *Dipterocarpus* are mostly large to very large, they need not to be referred to *Dipterocarpus* for comparison.

After going through the herbarium sheets of a large number of species of *Shorea* it was observed that the leaves of *Shorea* do show considerable variation in shape and size and in number of secondary veins. However, considering further the above morphological details, the fossil leaves show close resemblance with *Shorea sericea* (C.N.H. sheet no. 21784) and also to some extant with *S. macroptera* and *S. rigida*.

Two fossil leaves assigned to the genus *Shorea* are so far known from Cenozoic rocks of the Indian subcontinent. They are *Shorea siwalika* Antal & Awasthi (1993) from the Siwalik sediments of north Bengal and *Shorea robusta* Roxb. Bande & Srivastava (1990) from the late Tertiary (probably Pleistocene-Holocene) sediments of Mahuadanr, Palamu District, Bihar. These are comparable to the leaves of *Shorea assamica* and *Shorea robusta* respectively. In shape, size and in the number of secondary veins our fossil leaves are quite different from the known species and therefore they are being placed under a new species, *Shorea miocenica*.

Shorea sericea Dyer occurs in the evergreen forest of Malaya, Borneo and Malacca.

SHOREA NEPALENSIS sp. nov.

Pl. 2, figs 4, 5

This species is represented by three specimens.

Description — Leaves simple, symmetrical, elliptic, two of them 5.5 x 2.3 cm-5.0 x 2.4 cm in length and width; apex acute; margin entire; texture subcoriaceous; petiole present in one specimen, about 2.0 mm in length; venation pinnate; eucamptodromous; primary vein prominent, straight, secondary veins about 14-15 pairs, angle of divergence moderate, 50°-60°, moderately thick, uniformly curving upward, unbranched; tertiary veins fine angle of origin RR, seemingly percurrent, further details not discernible.

Holotype—Specimen no. BSIP 37683.

Paratype—Specimen no. BSIP 37684.

Locality—Mahendra Highway between Barghat and Dumkibas, Nepal (Loc.4).

Horizon—B1 Member.

Age—Upper Miocene.

Discussion—The general features of fossil leaves suggest their affinities with those of the family Dipterocarpaceae. On critical examination the most favourable comparison is noticeable with the leaves of *Shorea lamellosa* and *S. leprosula*, especially in shape, size, texture and venation pattern, although the leaves of the former are slightly bigger. In shape, size and number of secondary veins they are also comparable to the leaves of *Anisoptera curtisii*, but markedly differ in the absence of marginal loop.

Since these fossil leaves are different from the known species, they are being assigned to a new species, *Shorea nepalensis*. The specific name is after Nepal from where the fossil material was collected.

Shorea leprosula Miq. is a tall tree of 50-60 m. high, about 1 m with buttresses. It is distributed in Sumatra and Borneo (Ridley, 1922).

Genus—HOPEA Roxb.

HOPEA SIWALIKA Antal & Awasthi

Pl. 2, fig. 1

There is one specimen representing the species from Nepal.

Description—Leaf simple, slightly symmetrical, narrow elliptic to oblong, length 14.2 cm and maximum width 3.8 cm, one side of the midrib slightly more in width than the other; apex acute; base acute to obtuse; margin entire; texture subcoriaceous; petiole small, preserved length about 5 mm; venation pinnate, simple, eucamptodromous; primary vein prominent, thick in the lower half and gradually thinning toward apex, moderately stout, markedly curved; secondary veins 9 pairs visible, alternate, fine in thickness, angle of divergence 50°-60°, basal two pairs narrow, acute, uniformly curving upward and seemingly forming marginal loop with superadjacent secondary veins through cross veins; intersecondary veins present, faint and not easily recognisable; tertiary veins faint, angle of origin seemingly right angle (RR), percurrent to orthogonal reticulate, relationship with midvein oblique, further details not discernible.

Paratype—Specimen no. BSIP 37685.

Locality—Mahendra Highway between Barghat and Dumkibas (Loc. 4).

Horizon—B1 Member.

Age—Upper Miocene.

Discussion—The fossil leaf is characterised by narrow elliptic to oblong shape with midvein markedly curved and the lamina of one side of the midvein slightly wider than the other. Although the tertiary and quaternary veins are not so well preserved, and venation pattern the fossil leaf appears very similar to that of *Hopea wightiana* Wall. It has been found that the leaves of this species show wide range of variation in size and shape but their venation pattern and curvaturing of midvein remain unchanged. The curvaturing of midvein is one of the most important features of *H. wightiana*.

There is a single record of fossil leaf of *Hopea*, i.e. *H. siwalika*, by Antal & Awasthi (1993) from the Siwalik sediments of Darjeeling foot-hills, India. Although this leaf is much smaller in size, but in shape, venation pattern and coarse of midrib it is more or less similar to our fossil leaf. Moreover, both the fossil leaves are comparable to different specimens of the same extant species, *Hopea wightiana*. Therefore it is being assigned to *Hopea siwalika* Antal & Awasthi.

Hopea wightiana is a tree occurring in the evergreen forests at the foot of Western Ghats from North Kanara southward, often gregarious, covering large tracts in the low country of South Kanara (Brandis, 1971).

Family—TILIACEAE

Genus—GREWIA L.

GREWIA MALLOTOPHYLLA sp. nov.

Pl. 3, fig. 7

This species is based on a single specimen.

Description—Leaf simple, incomplete, apical and marginal parts broken, symmetrical, seemingly ovate to elliptic, preserved length and width 9.0 x 6.0 cm; apex not preserved; base probably obtuse margin not clearly discernible; texture chartaceous; petiole not preserved; venation pinnate, acrodromous, two strongly developed secondary veins arising from a single point at the base, secondary veins arising from midrib at acute angle, about 45°-50°, only two pairs

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PLATE 1 ⟶

(All photographs are of natural size unless otherwise mentioned)

1. *Gynocardia butwalensis* sp. nov., Specimen no. BSIP 37680.
2. *Gynocardia odorata*, showing similarity with fossil leaf (C.N.H., Howrah Specimen no. 512).
3. *Miliusa brochidodroma* sp. nov., Specimen no. BSIP 37678.
4. *Miliusa roxburghiana*, showing similarity with fossil leaf.
5, 6, 7. *Orophea siwalika* sp. nov., Specimen nos. BSIP 37676-37677a b.


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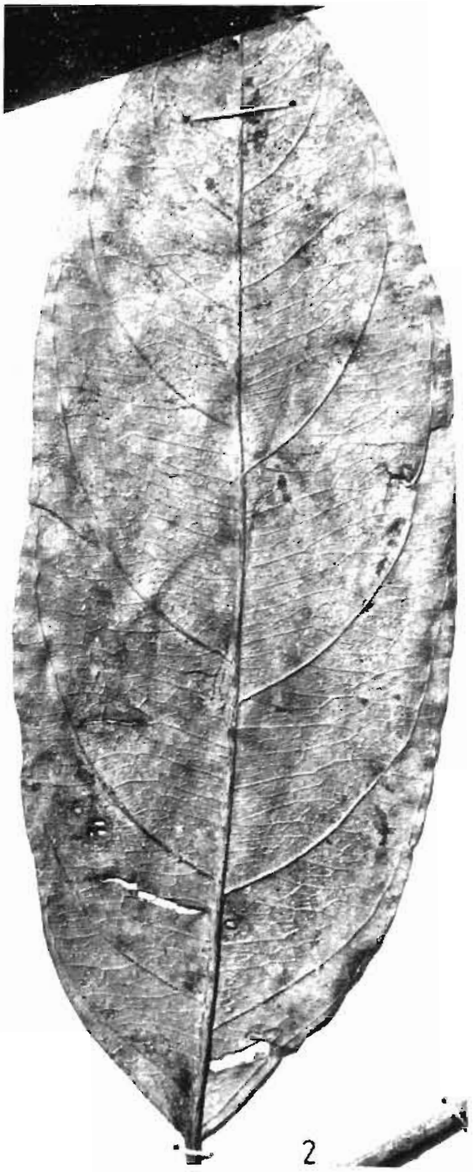
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PLATE 1

present in the available part; tertiary veins arising almost at right angles from midvein as well as from secondary veins, convex, percurrent, forked, relation to midvein perpendicular; quaternary veins thin, orthogonal.

Holotype—Specimen no. BSIP 37686.

Locality—Arung Khola (Loc. 7).

Horizon—Au Member.

Age—Upper Miocene.

Discussion—The above features of the fossil leaf are met with in the leaves of *Grewia* of Tiliaceae. Among *Grewia* it shows resemblance with a number of species, namely *Grewia laevigata, G. tiliaefolia, G. microcos* and *G. umbellata* (C.N.H., sheet no. 161767). In the venation pattern it is also comparable to some extent with *Mallotus philippense* of Euphorbiaceae. Since the fossil leaf is slightly incomplete and further morphological details of the apical part are not available to arrive at definite conclusion as to which of the species of *Grewia* it resembles most. Since it also shows some resemblance with the leaves of *Mallotus philippense,* we prefer to name it as *Grewia mallotophylla* sp. nov..

The above species of *Grewia* with which the fossil leaf resembles are generally small trees, distributed in India and Southeast Asia in the evergreen forests. *Mallotus philippense* Muell. is widely distributed in tropical to subtropical regions of India, Southeast Asia, Australia and China, mostly in evergreen and moist deciduous forests (Brandis, 1971).

Family—MELIACEAE

Genus—CHISOCHETON Bl.

CHISOCHETON ELLIPTICUS sp. nov.

Pl. 3, figs 1-4s

This species is represented by 4 specimens.

Description—Leaves simple, symmetrical, narrow elliptic to very narrow elliptic, preserved length of bigger leaf 11.2 cm and width 3.0 cm; apex broken; base acute to slightly inequilateral; margin entire; texture subcoriaceous; petiole not preserved; venation pinnate, eucamptodromous, primary vein prominent, stout, straight; secondary veins 12 pairs visible, angles of divergence about 70°-80°, almost uniform, alternate to sub-opposite, moderate in thickness, unbranched, uniformly curving upward and joining with superadjacent secondaries forming marginal loop; intersecondary veins many, arising at right angle, straight, simple; tertiary veins present, angle of origin RO, percurrent to random reticulate, relation with midvein oblique.

Holotype—Specimen no. BSIP 37687.

Paratype—Specimen no. BSIP 37688.

Locality—Tinau Khola near Butwal (Loc. 3).

Horizon—Au Member.

Age—Upper Miocene.

Discussion—The fossil leaves are characterised by narrow elliptic shape with 11-12 secondary veins arising at an angle of about 80°-85° and numerous intersecondary veins arising at right angles, running straight and joining with the tertiary veins. In these features the fossil specimens closely resemble the leaves of *Chisocheton*, particularly *C. patens* Bl. and to some extent *C. divergence* BC. of the family Meliaceae (C.N.H., sheet no. 79990).

Among the known fossil leaves of Meliaceae, no such leaf has been described so far. Therefore these fossil leaves are being assigned to a new species, *Chisocheton ellipticus*. The specific name indicates the narrow elliptic shape of leaves.

FAMILY—RHAMNACEAE

GENUS—VENTILAGO Gaerthn.

VENTILAGO OVATUS sp. nov.

Pl. 4, fig. 1

There is a single specimen representing the species.

Description—Leaf simple, symmetrical, narrow ovate, preserved length and width 9.5 x 4.2 cm; apex acute; base seemingly obtuse; margin entire or serrate, serration not discernible; texture subcoriaceous; petiole missing; venation pinnate, eucamptodromous, primary vein moderately thick, straight; secondary veins 6 pairs, alternate, angle of divergence 45°-60°, upper secondaries more acute; intersecondaries not visible; tertiary veins not clearly seen.

Holotype—Specimen no. BSIP 37689.

Locality—Mahendra Highway between Barghat and Dumkibas.

Horizon—Bl Member.

Age—Upper Miocene.

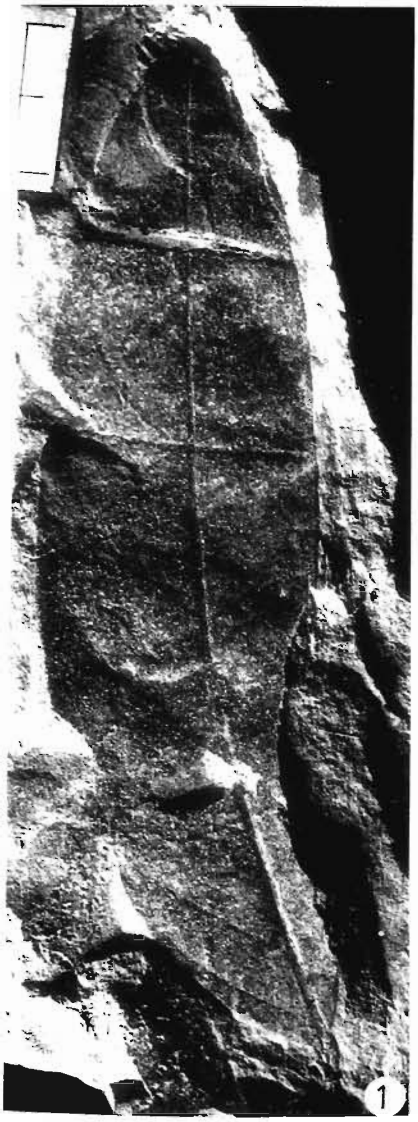
PLATE 2 ⟶

(All photographs are of natural size unless otherwise mentioned)

1. *Hopea siwalika* Antal & Awasthi. Specimen no. BSIP 37685.
2. *Hopea wightiana*, showing similarity in shape and venation pattern with fossil leaf.
3. *Shorea miocenica* sp. nov. Specimen no. BSIP 37686.

4, 5. *Shorea nepalensis* sp. nov. Specimen no. BSIP 37683, 37684.

6, 7. *Shorea lamellosa* and *Shorea leprosula*, showing similarity with fossil leaves.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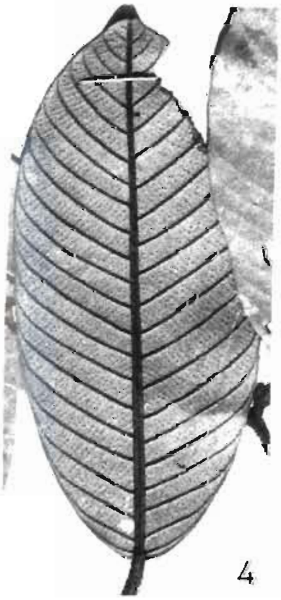
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PLATE 2

Discussion—Although the tertiary veins and further details of venation pattern are not clearly visible due to bad preservation, in its shape, size and number of secondary veins and their angle of divergence, the fossil leaf appears very similar to the leaves produced by *Ventilago calyculata* of the family Rhamnaceae.

There is no record of fossil leaves comparable to *Ventilago,* therefore, present fossil specimen is named *Ventilago ovatus* sp. nov., the specific name signifies ovate shape of the leaf.

Ventilago calyculata Tul. is found in the sub-Himalayan tract from Jamuna eastward, Nepal, Bihar, Central Assam and Myanmar in evergreen to moist deciduous forests.

Family—ANACARDIACEAE

Genus—SWINTONIA Griff.

SWINTONIA BUTWALENSIS sp. nov.

Pl. 4, figs 3, 6

The species is based on a leaf impression and a seed collected from the same locality.

Description—Leaf simple, symmetrical, narrow elliptic, 11.5 cm in length and 4.3 cm in width; apex broken; base normal, acute; margin entire; texture coriaceous; petiole not preserved; venation pinnate, simple, eucamptodromous; primary vein prominent, stout, markedly curved, secondary veins 12 pairs, alternate to opposite and sub-opposite, angle of divergence 60°-80°, upper secondaries more acute than the lower, moderately thick, course curved, uniformly forming marginal loop with superadjacent secondary veins through cross veins, intersecondary veins present, 1-2, simple; tertiary veins present, angle of origin AO, percurrent to random reticulate, further details not seen.

Fruit—(Pl. 4, fig. 6) represented by a prominent wing, seemingly drupe, subtended by enlarged petal, about 2.0 cm, with longitudinally fine nerves, irregularly intersected by prominent cross lines.

Holotype—Specimen no. BSIP 37690a, b.

Locality—Tinau Khola, near Butwal, Nepal.

Horizon—Arung Khola Formation.

Age—Middle Miocene.

Discussion - In its shape, size, venation pattern and texture, the fossil leaf is comparable to those of *Swintonia* and *Mangifera* of the family Anacardiaceae. Critical examination of the venation pattern and other morphological details revealed that the fossil leaf is closer to *Swintonia* compare to *Mangifera*. The secondary veins in fossil leaf are mostly opposite to sub-opposite which may be considered as a characteristic feature of the leaves of *Swintonia schenckii* as well of *S. floribunda*. However, in the nature and course of tertiary veins it is more closer to *S. schenckii* (Pl. 4 fig. 4). Thus it combines the characters of leaves of both the extant species of *Swintonia*. The fruit is also closely comparable to those of *S. floribunda* and *S. schenckii*.

As far as the authors are aware there is only a single record of fossil leaf of *Swintonia, Swintonia miocenica*, described by Awasthi & Prasad (1990) from the Siwalik sediments of Surai Khola area, Nepal. Although this fossil leaf is shown to resemble that of *S. floribunda*, the same species with which the present fossil leaf is also comparable, the latter is somewhat different in the nature and course of the tertiary veins and in other minor characters. Therefore, the present fossil leaf is assigned to a new species, *Swintonia butwalensis*.

Swintonia schenckii T. et B. frequently occurs in the tropical forest of Martaban down to Tenasserim in Myanmar. *S. floribunda* is found in Chittagong and also in Myanmar. It is common in Tenasserim.

Family—RUBIACEAE

Genus—MITRAGYNA Korth.

MITRAGYNA TERTIARA sp. nov.

Pl. 6, fig. 5

This species is based on a single specimen.

Description—Leaf simple, symmetrical, narrow obovate, 9.0 cm in length and 4.5 cm in width, apex broken, seemingly obtuse; base obtuse; margin entire; texture chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein prominent, moderate in thickness, straight; secondary veins 9 pairs visible, might have been 1 or 2 more in the apical portion, angle of divergence acute 30°-40°, alternate to sub-opposite, running almost straight or slightly recurved been moderate in thickness; intersecondary veins not visible; tertiary veins thin, angle of origin seemingly AA to RR.

Holotype—Specimen no. BSIP 37691.

Locality—Tinau Khola, near Butwal, Nepal (Loc. 3).

Horizon—Au Member.

Age—Upper Miocene.

PLATE 3 ⟶

(All photographs are of natural size unless otherwise mentioned)

1-4. *Chisocheton ellipticus* sp. nov. Specimen no. BSIP 37687, 37688a, b, c.

5, 6. *Chisocheton patens* Bl., showing similarity with fossil leaves.

7. *Grewia mallotophylla* sp. nov. Specimen no. BSIP 37686.

8. *Grewia umbellata* (C.N.H. Sheet no. 161767) showing resemblance with fossil leaf.


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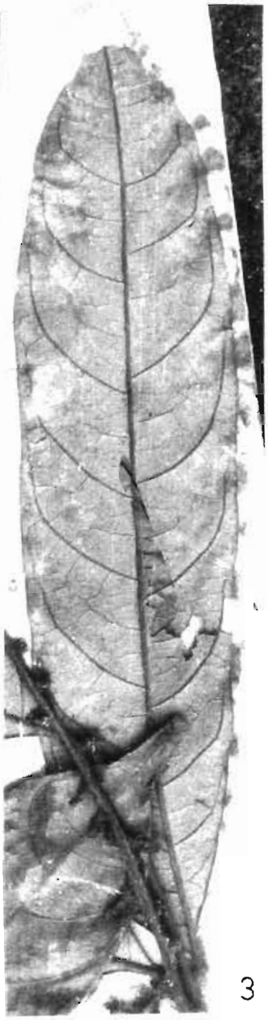
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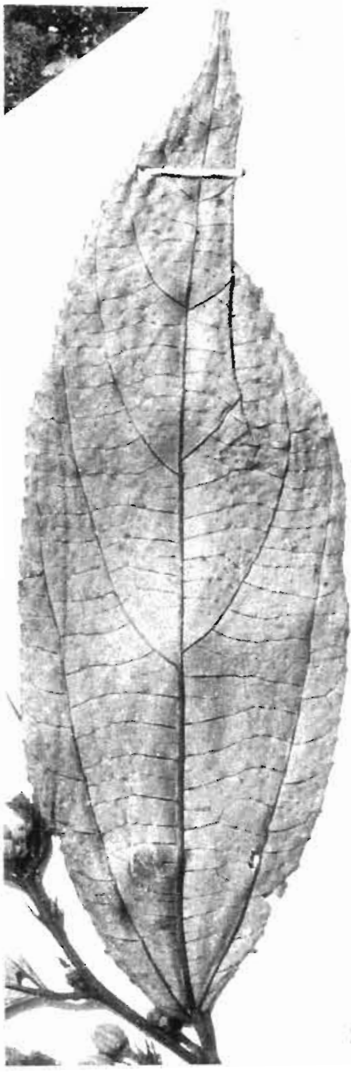
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PLATE 3

Discussion—In shape, size, number and angle of divergence of secondary veins and their course, the fossil leaf appears very similar to the medium-sized leaves of *Mitragyna parvifolia* belonging to the family Rubiaceae. In this context it may be mentioned that the leaves of this species vary in size from small to large, i.e., they are about 2.0-18.0 cm in length and 2.0-10.0 cm in width, without much noticeable difference in the venation pattern.

As far as the authors are aware there is no record of fossil leaves of *Mitragyna*. The fossil leaf is therefore placed under a new species, *Mitragyna tertiara*.

The genus *Mitragyna* Korth. consists of 12 species, distributed in tropical Africa and Asia (Willis, 1977), *Mitragyna parvifolia* Korth. with which the fossil leaf resembles is a large deciduous tree, often irregularly shaped and butteressed. It is found in the foot-hills of North-West Himalaya from the Beas eastwards, ascending to 1,300 m, Bihar, central India and Myanmar, common in both peninsulas, often gregarious, particularly in moist places (Brandis, 1971).

Genus — MUSSAENDOPSIS Baill.

MUSSAENDOPSIS SUBORBICULATUS sp. nov.

Pl. 5, figs 1, 2

This species is represented by two specimens.

Description—Leaves simple, symmetrical, seemingly wide elliptic to suborbicular, about 14 cm in length and 10 cm in width; apex obtuse or mucronate; base broken; margin entire; texture coriaceous, petiole broken; venation pinnate, eucamptodromous; primary vein thicker, straight; secondary veins 6-7 pairs visible, alternate, angle of divergence of lower secondaries 60° and upper pairs 45°-50°, moderately thick, uniformly curving up towards margin, unbranched; 1 to 3, intersecondary veins visible in the apical parts angle of origin of tertiary veins AA to AO, seemingly percurrent, simple, unbranched, relation with midvein oblique, higher order of venation not discernible.

Holotype—Specimen no. BSIP 37692.

Paratype—Specimen no. BSIP 37693.

Locality—Mahendra Highway between Barghat and Dumkibas, Nepal (Loc. 4).

Horizon—BI Member.

Age—Upper Miocene.

Discussion—Wide elliptic to suborbiculate shape with coriaceous texture and 6-7 secondary eucamptodromous veins are the characteristic features of the fossil leaves, which suggest their affinity with those of *Mussaendopsis* of the family Rubiaceae. *Mussaendopsis baccariana* Baill., the only species available for comparative study, shows close resemblance with our fossil leaves. The only difference between the two is that the fossil leaves are slightly smaller and less orbicular. This could be due to variation which is commonly observed among the leaves of the same species.

Because of their resemblance with the leaves of *Mussaendopsis*, the fossil leaves are assigned to it and named *Mussaendopsis suborbiculatus* sp. nov. The specific name denotes the sub-orbiculate shape of the leaves.

The genus *Mussaendopsis* Baill. consists of only two species, distributed in west Malaysia (Willis, 1976). *M. baccariana* Baill. is a big glabrous tree occurring in the evergreen forest in Malaysia, Borneo and Sumatra (Rindley, 1923).

Family — ALANGIACEAE

Genus — ALANGIUM Lam.

ALANGIUM NEPALENSIS sp. nov.

Pl. 6, fig. 1

There are two specimens representing this species, the one is more or less complete except the apical portion.

Description—Leaf simple, pinnate asymmetrical, seemingly narrow elliptic, preserved length about 10.0 cm in length and 4.0 cm in width; apex broken; base inequilateral, one side slightly bigger; margin entire; texture chartaceous to subcoriaceous; petiole small; venation pinnate, seemingly brochidodromous, primary vein prominent, moderate in thickness, straight; secondary veins 5 pairs visible, basal pair arising alternately just above the petiolar point and each running upward up to 2/3 of lamina leaving a distance of 5 mm from the margin, angle of divergence 45°-60°, moderately thick, curving upward and joining superadjacent secondary veins forming marginal loop; intersecondary veins well developed, many, simple, arising at right angles from midvein, running straight or slightly zig-zag towards right and joining tertiary veins arising from the secondaries, angle of origin of tertiary veins and intersecondary veins AO to RO, percurrent, straight to forked, relation to midvein oblique, unbranched; quaternary veins thin, randomly oriented to orthogonal; marginal ultimate veins looped.

PLATE 4

⟶

(All photographs are of natural size unless otherwise mentioned)

1. *Ventilago ovatus* sp. nov. Specimen no. BSIP 37689.
2. *Ventilago calyculata* Tulasue, showing similarity with fossil leaf.
3. *Swintonia butwalensis* sp. nov. Specimen no. BSIP 37690a.
4. *Swintonia schenckii* to show general similarity with fossil leaf.
5. *Swintonia floribunda* to show general similarity with fossil leaf.
6. A part of fossil fruit resembling that of *Schenckii* x 4, sp. nov. Specimen no. BSIP 37690b.


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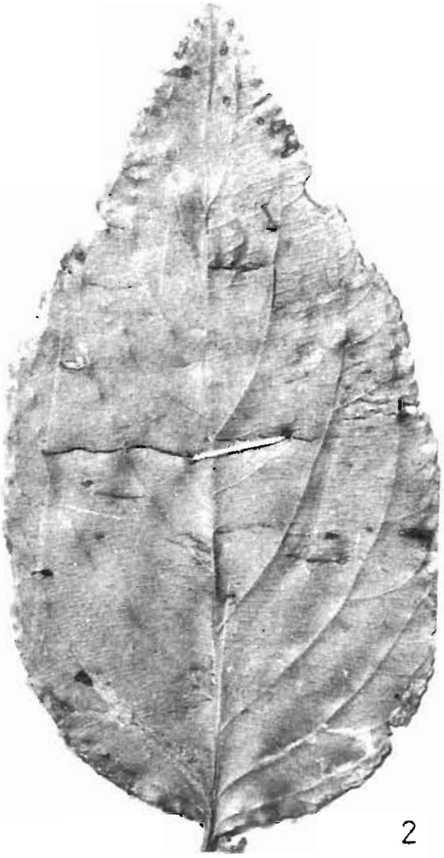
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PLATE 4

Holotype—Specimen no. BSIP 37694.

Locality—Tinau Khola, near Butwal, Nepal (Loc. 2).

Horizon—Bl Member.

Age—Upper Miocene.

Discussion—The most important character of the fossil leaves is that the venation is brochidodromous, two pairs of secondary veins arising at the base alternately and running upward up to 2/3 lamina, leaving a distance of about 5 mm from margin and joining with those of tertiary veins given off by upper pairs of secondary veins and forming prominent loop. Besides, marginal loop is also formed by the tertiary veins given off by the two secondary veins in the 2/3 basal part. There are many intersecondary veins arising from the primary veins at right angle. Taking all these features into consideration, the fossil leaves show close similarity with those produced by *Alangium* in general and *A. salvifolium* var. *hexapetalum* (Pascal & Ramesh, 1987; p. 71, p. 1, fig. 1) in particular.

Since our fossil leaves are different from the known species, they are being placed under a new species, *Alangium nepalensis*. The specific name indicates its occurrence in Nepal.

Alangium salvifolium is a small tree found in the sub-Himalayan tract of Uttar Pradesh and Gangetic plains, central India and western peninsula (Brandis, 1971).

Family — EUPHORBIACEAE

Genus — HOMONOIA Lour.

HOMONOIA LANCEOLATA sp. nov.

Pl. 6, figs 2, 3

Homonoia cf. *H. riparia* auct. non Lour., Prasad 1994.

There are five specimens representing the species.

Description—Leaves simple, symmetrical, linear to lanceolate, the complete one smaller, measuring 7.0 x 0.8 cm in length and width; the incomplete one bigger, about 9.2 x 1.5 cm; apex acute; base acute; margin entire, slightly upturned; texture sub-coriaceous; petiole seemingly short; venation pinnate, eucamptodromous; primary vein prominent, massive in thickness, gently decreasing towards apex, straight; secondary veins numerous, alternate to sub-opposite, angle of divergence about 45°-60° fine, uniformly curving upward forming marginal loop with superadjacent secondary veins through cross veins; intersecondary veins present, 1-2; tertiary veins present, angle of origin seemingly AO, reticulate pattern, further details not seen.

Holotype—Specimen no. BSIP 37695.

Paratype—BSIP Museum no. 37696.

Locality—Tinau Khola, near Butwal, Nepal (Loc. 3).

Horizon—Au Member.

Age—Upper Miocene.

Discussion—The most important character of fossil leaves is that they are linear to lanceolate in shape and eucamptodromous in venation pattern with numerous secondary veins. Leaves having such characters are met with in the genus *Homonoia* of Euphorbiaceae. From a careful examination of the leaves of *Homonoia* it was found that there is close similarity between fossil leaves and those of *H. riparia* Lour. Hence the fossil leaves are placed under the genus *Homonoia* and named *H. lanceolata* sp. nov. Regarding fossil record of *Homonoia* (Prasad, 1994) reported a leaf as *Homonoia* cf. *H. riparia* Lour. from Middle Siwalik sediments near Hardwar, India. This fossil leaf is not different from ours. Therefore it is also being placed under *H. lanceolata*.

Homonoia riparia Lour. is an evergreen gregarious shrub in the rocky and stony river beds and is distributed in the foothills of Sikkim, Assam, Khasi Hills, Upper and Lower Myanmar, Bihar, central India, western peninsular India, Sri Lanka, Malay Peninsula and Archipelago and China (Brandis, 1971).

Family — MORACEAE

Genus — FICUS Linn.

FICUS MIOCENICUS sp. nov.

Pl. 6, fig. 7

This species is based on one specimen.

Description—Leaf simple, symmetrical, elliptic, 14.5 x 7.7 cm in length and width; apex obtuse; base obtuse, margin entire; texture coriaceous; petiolar portion missing; venation pinnate, eucamptodromus; primary vein prominent, massive at the base and gradually turning to moderate towards apex, straight; secondary veins 7-8 pairs, alternate, angle of divergence about 45° a pair of basal secondaries arising from a single point (opposite) and running straight and forming marginal loop with superadjacent secondary veins through cross veins; tertiary veins occasionally visible, angle of origin seemingly OA, weakly percurrent, further details not visible.

PLATE 5 ⟶

(All photographs are of natural size unless otherwise mentioned)

1, 2. *Mussaendopsis sub-orbiculatus* sp. nov. Specimen no. BSIP 37692-93.

3, 4. *Mussaendopsis baccariana* Baill. (CNH Sheet no. 198620) showing general similarity with the fossil leaf.


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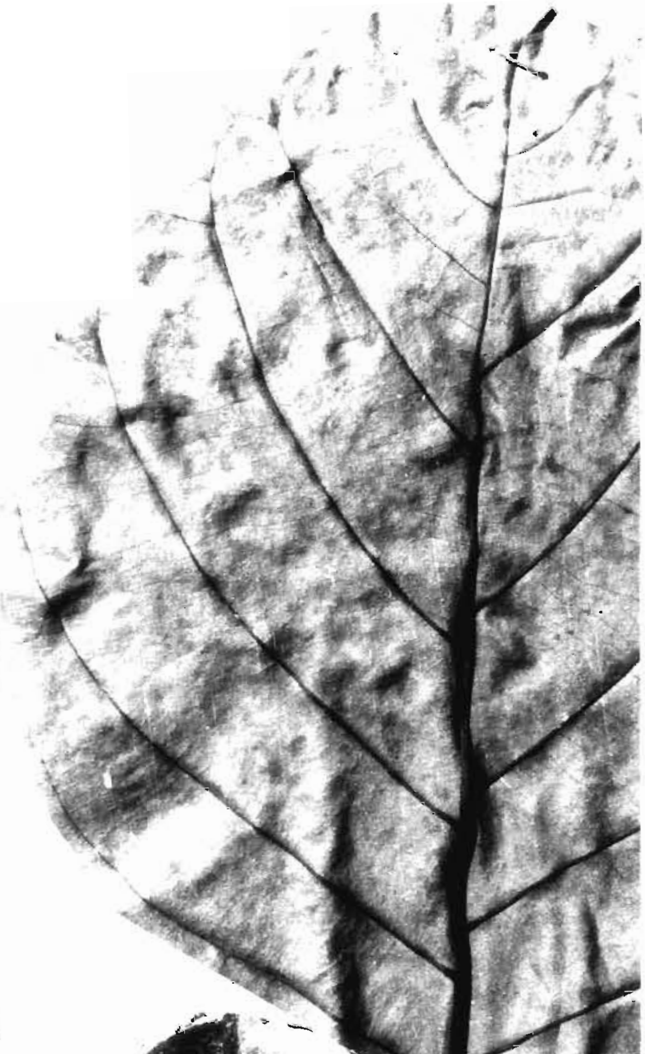
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PLATE 5

Holotype—Specimen no. BSIP 37697.

Locality—Mahendra Highway between Barghat and Dumkibas, Nepal (Loc. 4).

Horizon—BI Member.

Age—Upper Miocene.

Discussion—In its shape, size, texture and secondary venation pattern, the fossil leaf shows resemblance with those of *Ficus bengalensis* Linn., *F. tomentosa* Roxb. and *F. callosa* Willd. Since the tertiary and quaternary venation pattern is not clearly discernible, it is rather difficult from a solitary specimen to suggest which of these species could be the nearest modern equivalent of the fossil. However, from its shape, size and venation pattern the possibility of its being closer to *Ficus bengalensis* cannot be ruled out.

Although there are a number of fossil leaves assigned to the genus *Ficus* from the Indian Tertiary sediments (see Antal & Awasthi, 1993), the present fossil leaf being typically a *Ficus* - like, differs from all the known species in their shape, size and venation pattern. Therefore, it is described as a new species of *Ficus, Ficus miocenica*, the specific name indicates Miocene age of the fossil leaf.

Ficus bengalensis Linn. is a large tree, indigenous in the sub-Himalayan Tract and western peninsula, commonly planted in the forest of the Western Coast and Ghats from Konkan southward. In Travancore, it is common up to 1,000 m, and also occurs in Andamans, Myanmar, Sri Lanka, central India, western peninsula, Bihar and Chota Nagpur (Brandis, 1971).

GENERAL DISCUSSION

Floristic Composition, Palaeoecology and Phytogeography—

Out of a large number of fossil leaves studied from Arung Khola and Binai Khola formations of the Siwalik (Churia) Group, west central Nepal, 22 species of angiosperms belonging to 21 genera of 16 families have been identified (Table 1). Of these the genera *Orophea, Gynocardia, Ventilago, Mussaendopsis, Miliusa, Chisocheton* and *Mitragyna* are new to the Siwalik (Churia) flora. The floral assemblage shows overall dominance of Dipterocarpaceae with three genera, viz., *Dipterocarpus, Shorea* and *Hopea,* already identified from this area. The other genera of the assemblage which are also known from other localities of Siwalik (Churia) of India and Nepal include *Calophyllum, Grewia, Ziziphus, Swintonia, Bauhinia, Cinnamomum, Homonoia, Bambusa, Clinogyne* (Awasthi, 1992; Awasthi & Prasad, 1990; Prasad & Awasthi, 1996; Antal & Awasthi, 1993; Konomatsu & Awasthi, 1996). The extant species comparable to the Churia fossils are mostly distributed in the tropical evergreen to semi-evergreen forests of Western Ghats, northeast India, Andaman and Nicobar Islands, Myanmar and Malayan region, and a few of them still continue to occur in the sub-Himalayan tract, mostly in the valleys and along the river banks (Table 1). From the distribution pattern of its components, it is evident that the flora of Arung Khola and Binai Khola formations flourished under tropical climate with very warm and humid conditions during the Miocene.

In its composition and the type of forest indicated, the floral assemblage is not much different from those of other localities of the Siwalik (Awasthi; 1992; Antal & Awasthi, 1993) although it includes some new tropical evergreen and moist deciduous taxa, viz., *Gynocardia, Orophea, Miliusa, Chisocheton, Ventilago, Mitragyna* and *Mussaendopsis.* These genera further strengthen the above palaeoclimatic interpretation of the flora.

From the distribution of modern equivalent species of fossils in the Indo-Malayan region and the climate they indicate (Table 1) it may be inferred that the physical conditions controlling the distribution pattern of plant remained nearly equable throughout the Himalayan frontal zone during laying down of the Arung Khola and Binai Khola sediments. Owing to several water bodies, such as lakes, swamps and rivers occupying vast area in the region, excessive humid condition seems to have prevailed all along favouring maximum development and proliferation of evergreen mesophytic lowland and tropical vegetation. Further, the climatic conditions became so conducive that the tropical evergreen families, migrated to the Indian subcontinent (Awasthi, 1992; Guleria, 1992). The genus *Mussaendopsis* of Rubiaceae, *Orophea, Chisocheton patens* and *Swintonia* which have been recovered from Arung Khola and Binai Khola sediments are among other probable migrants of Southeast Asian origin.

The periodic orogeny of the Himalayan ranges continued to change the climatic, geomorphologic and ecological conditions, thus adversely affecting the vegetational dynamics especially of the extra-peninsular region. Consequently, the tropical conditions started disappearing from all over during the upper part of the Middle Siwalik, i.e., Middle Binai Khola Formation. Evidence to this effect is provided by the

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PLATE 6 ⟶

(All photographs are of natural size unless otherwise mentioned)

1. *Alangium nepalensis* sp. nov. Specimen no. BSIP 37694.
2, 3. *Homonoia lanceolata* sp. nov. Specimen no. BSIP 37695-96.
4. *Homonoia riparia* Lour. showing similarity with fossil leaves.
5. *Mitragyna tertiara* sp. nov. Specimen no. BSIP 37691.
6. *Mitragyna parvifolia* showing similarity with fossil leaves.
7. *Ficus miocenicus* sp. nov. Specimen no. BSIP 37697.

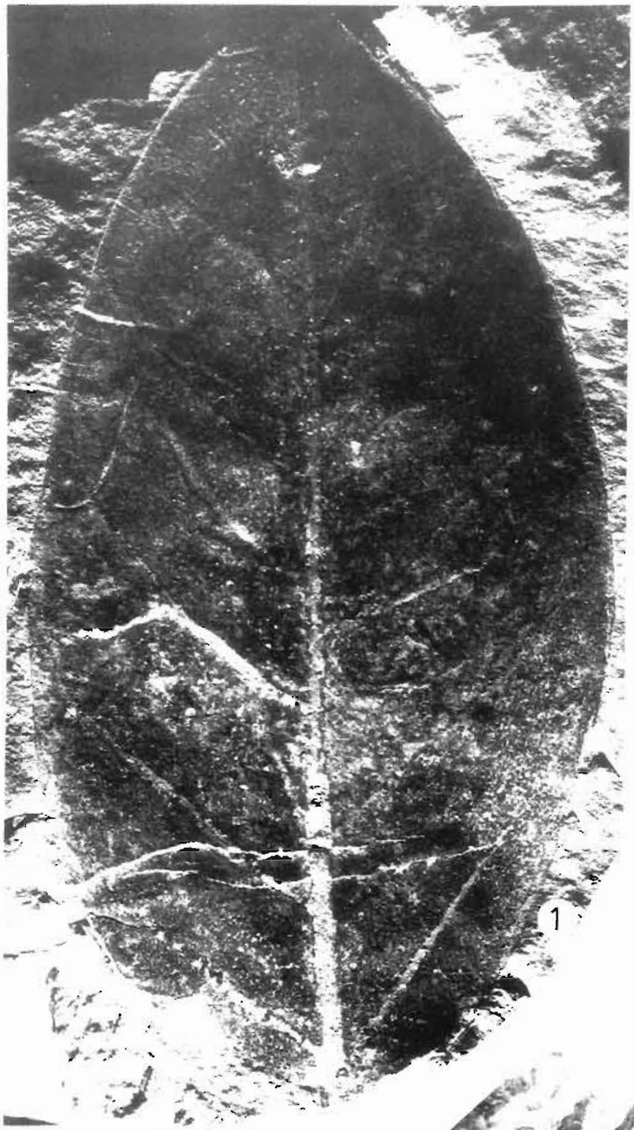
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PLATE 6

Table 1—Churia (Siwalik) plant fossils from Tinau-Khola, Binai Khola and Arung Khola, west central Nepal

NAME OF FORMATION			Name of fossil	Family	Comparable extant species	Distribution of extant species	Type of forest
DEORALI			—	—	—	—	—
CHITWAN			—	—	—	—	—
CHURIA (SIWALIK) GROUP	BINAI KHOLA FORMATION	UPPER	—	—	—	—	—
		MIDDLE	—	—	—	—	—
		LOWER	*Shorea nepalensis* sp. nov.	Dipterocarpaceae	*Shorea lamellosa, S. leprosula*	Malayan region	Tropical evergreen
			Hopea siwalika Antal & Awasthi	-do-	*Hopea wightiana*	Western Ghats	Tropical evergreen
			Ventilago ovatus sp. nov.	Rhamnaceae	*Ventilago calyculata*	Sub-Himalayan tract and Myanmar	Evergreen to moist deciduous
			**Ziziphus siwalicus* Lakhanpal	-do-	*Ziziphus xylopyrus, Z. incurva*	India and Myanmar	Tropical semi-evergreen to moist deciduous
			**Bauhinia siwalika* Lakhanpal & Awasthi	Fabaceae	*Bauhinia* spp.	Sub-Himalayan tract and Western Ghats	Tropical evergreen
			**Cinnamomum palaeotamala* Lakhanpal & Awasthi	Lauraceae	*Cinnamomum tamala*	Indo-Malayan region	Tropical evergreen
			Mussaendopsis sub-orbiculatus sp. nov.	Rubiaceae	*Mussaendopsis baccariana*	Malayan region	Tropical evergreen to moist deciduous
			Alangium nepalensis sp. nov.	Alangiaceae	*Algangium salvifolium*	Sub-Himalayan tract	Tropical evergreen to deciduous
			Ficus miocenicus sp. nov.	Moraceae	*Ficus bengalensis, F. tomentosa,*	Sub-Himalayan tract	Tropical evergreen to deciduous
					F. callosa	Indo-Malayan region	Tropical evergreen
	ARUNG KHOLA FORMATION	UPPER	*Miliusa brochidodroma* sp. nov.	Annonaceae	*Miliusa roxburghiana*	sub-Himalayan region	Tropical evergreen
			**Dipterocarpus siwalicus* Lakhanpal & Guleria	Dipterocarpaceae	*D. tuberculatus, D. turbinatus*	Northeast India Myanmar, Thailand.	Tropical evergreen
			**Calophyllum* sp.	Clusiaceae	*Calophyllum* spp.	Indo-Malayan region	Tropical evergreen
			Grewia mallotophylla sp. nov.	Tiliaceae	*Grewia umbellata, G. tiliaefolia G. microcos*	Indo-Malayan region	Tropical evergreen
			Chisocheton ellipticus sp. nov.	Meliaceae	*Chisocheton patens*	Malayan region	Tropical evergreen
			Swintonia butwalensis sp. nov.	Anacardiaceae	*Swintonia schenckii S. burmanica*	Myanmar	Tropical evergreen
			**Bauhinia siwalica* Lakhanpal & Awasthi	Fabaceae	*Bauhinia* spp.	Indo-Malayan region	Evergreen to moist deciduous
			Mitragyna tertiara sp. nov.	Rubiaceae	*Mitragyna parvifolia*	Sub-Himalayan region	Tropical moist deciduous
			Homonoia lanceolata sp. nov.	Euphorbiaceae	*Homonoia riparia*	Sub-Himalayan region	Tropical evegreen
			**Clinogyne ovatus* Awasthi & Prasad	Marantaceae	*Clinogyne grandis*	Sub-Himalayan region	Tropical moist deciduous
		MIDDLE	*Swintonia butwalensis* sp. nov.	Anacardiaceae	*Swintonia schenckii*	Myanmar	Tropical evergreen
		LOWER	*Orophea siwalika* sp. nov.	Annonaceae,	*Orophea uniflora*	Western Ghats, Andamans, Myanmar	Tropical evergreen
			Gynocardia butwalensis sp. nov.	Flacourtiaceae	*Gynocardia odorata*	sub-Himalayan tract, Khasi Hills, Myanmar	Tropical evergreen
			Shorea miocenica sp. nov.	Dipterocarpaceae	*Shorea sericea*	Malayan region	Tropical evergreen
			**Ziziphus siwalicus* Lakhanpal	Rhamnaceae	*Ziziphus xylopyrus, Z. incurva*	India and Myanmar	Semi-evergreen to moist deciduous
			**Bambusa* sp.	Bambusaceae	*Bambusa* spp.	Indo-Malayan region	Evergreen to moist deciduous

Species marked with (*) reported earlier by Konomatsu & Awasthi (1996) flora of Surai Khola succession in west Nepal. In this context, it may be mentioned here that in Surai Khola area a complete and uninterrupted sequence of the Siwalik Group, measuring about 5500 m in thickness, is exposed along Mahendra Highway between Bankas and Dhan Khola. On the basis of lithology Corvinus (1990) informally divided the whole sequence into five formations, viz., Bankas, Chor Khola, Surai Khola, Dobatta and Dhan Khola. Of these the first three formations corresponding to Arung Khola Formation and Lower Binai Khola Formation of west central Nepal (Tokuoka *et al.*, 1986) consist of deposits containing rich plant megafossils. The upper part of Surai Khola Formation which corresponds to Middle Binai Khola Formation exhibits significance change in the floristic composition. The evergreen dipterocarps and their associates which had been growing luxuriantly during the Lower and Middle Siwalik (Awasthi & Prasad, 1990; Awasthi, 1992, Awasthi *et al.*, 1994) seem to have disappeared during the middle part of the Middle Siwalik as none of them has been found in the beds of the Surai Khola Formation exposed just before and after Surai Khola bridge. The shift in the floral composition from wet evergreen and semi-evergreen to moist and dry deciduous habitats cannot be regarded a local phenomenon but seemingly occurred throughout the Himalayan foot-hills. Obviously it was due to changes in the geomorphology, temperature and climate caused by further uplift of the Himalaya and northward movement of the Indian Plate.

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Subduction and collision related magmatism in the Shyok Suture and eastern Karakoram

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ABSTRACT

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The Shyok Suture is represented by distinct sets of volcano-plutonic rock assemblages. The high-Mg tholeiitic basalt and calc-alkaline andesites of the Shyok Volcanics have a subduction zone chemical signatures. The REE data on tholeiitic basalt suggest chemical affinity between primitive N-MORB to E-MORB. The calc-alkaline andesites, however, resembles to transitional nature of basalt between E-MORB to OIB. The geochemical data and regional tectonic setting suggest a close similarity between the Shyok Volcanics of northern Ladakh and Chalt Volcanics of Kohistan.

The mildly deformed trondhjemite-tonalite-granodiorite of the Tirit Granitoids are composite plutons located south of the Shyok Suture melange. These granitoids are subalkaline, I-type and represented by volcanic arc chemical signatures. The regional tectonic setting, the nature of occurrence and the composition of Tirit Granitoids are similar to the plutonic suites of northern Kohistan (Gindai, Matum Das and Nomal plutons).

The eastern Karakoram Batholith is dominated by quartz monzonite-tonalite-granodiorite and granite. The subalkaline to calc-alkaline Karakoram Batholith is constituted by both I-and S-type granitoids with volcanic arc and syn-collision chemical signatures. REE data suggest that the I-type granitoids of eastern Karakoram are calc-alkaline magmatism of a subduction zone environment. In contrast, most of the S-type granitoids are crust-derived peraluminous granitoids. New Rb/Sr isotopic whole rock age data indicates that a S-type intrusive phase was active in the eastern Karakoram region during 83±9 Ma. The syn-collision nature of these granitoids are similar to those of north Sost pluton and Karambar pluton of northern Kohistan. This indicates that the collision between Kohistan-Ladakh arc and Karakoram block was active during 83±9 Ma.

Key-words—Subduction, Collision, Magmatism, Shyok Suture, Karakoram, India.

सारांश

श्योक सन्धिस्थल एवं पूर्वी कराकोरम में अपक्षय तथा संघट्टन से सम्बन्धित मैग्माभवन

राकेश चन्द्रा, राजीव उपाध्याय एवं अंशु कुमार सिन्हा

श्योक सन्धिस्थल ज्वालामुखीय-वितलीय (प्लूटोनिक) शैल समुच्चयों के सुस्पष्ट सेटों द्वारा निरूपित हैं। श्योक ज्वालामुखी शैलों के उच्च-मैग्नीशियम के थोलीआइटी बेसाल्ट तथा कैल्क क्षारीय ऐन्डेज़ाइट में अपक्षय मण्डल के रासायनिक चिहन हैं। थोलीआइटी बेसाल्ट के दुर्लभ खनिज तत्व आंकड़ों से आद्य एन-एम.ओ.आर.बी. तथा ई.-एम.ओ.आर.बी. के बीच रासायनिक बन्धुता प्रस्तावित हुई है।

बहरहाल,कैल्क-क्षारी ऐन्डेजाइट ई-एम.ओ.आर.बी. तथा ओ.आई.बी. के बेसाल्ट की संक्रमी प्रकृति से सादृश्य प्रदर्शित करता है। भूरासायनिक आंकड़े तथा क्षेत्रीय विवर्तनिक सेटिंग उत्तरी लद्दाख के श्योक ज्वालामुखी शैल तथा कोहिस्तान के चाल्ट ज्वालामुखी शैलों के बीच गहन समरूपता को प्रस्तावित करती है।

तिरित् ग्रेनाइटाभ के हल्के विरूपित ट्रॉन्डझेमाइट-टोनेलाइट-ग्रेनोडायोराइट मिश्र प्लूटोन हैं, जो श्योक सन्धिस्थल मेलांज के दक्षिण में स्थित हैं। ये ग्रेनाइटाभ उपक्षारीय, आई. प्ररूपी हैं तथा ज्वालामुखीय चाप रासायनिक अवशेषों द्वारा निरूपित हैं। तिरित ग्रेनाइटाभों की क्षेत्रीय विवर्तनिक सेटिंग उपस्थिति की प्रकृति तथा संघट्टन उत्तरी कोहिस्तान (गिन्डाई, माटुम डैस एवं नोमाल प्लूटोन) की वितलीय (प्लूटोनिक) संजातियों के समतुल्य हैं।

पूर्वी कराकोरम महास्कन्ध में क्वार्ट्ज़ मोन्ज़ोनाइट-टोनेलाइट-ग्रेनोडायोराइट एवं ग्रेनाइट की प्रमुखता है। उपक्षारीय से कैल्क-क्षारीय के बीच कराकोरम महास्कन्ध ज्वालामुखीय चाप एवं सहसंघट्टन के रासायनिक अवशेषों से युक्त 'आई' एवं 'एस' दोनों ही प्ररूपों के ग्रेनाइटाभों द्वारा निर्मित है। दुर्लभ खनिज तत्व आंकड़ों से प्रस्तावित होता है कि पूर्वी कराकोरम के 'आई' प्ररूप के ग्रेनाइटाभ अपक्षय मण्डल के कैल्क-क्षारीय मैग्माभवन हैं। इसके विपरीत अधिकांश 'एस' प्ररूप के ग्रेनाइटाभ भूपटल से प्राप्त परएल्यूमिनस ग्रेनाइटाभ हैं। नवीनतम् रूबीडियम/स्ट्रॉन्शियम समग्र समस्थानिक शैल आयु निर्धारक आंकड़ों से संकेत मिलता है कि 8.3 ± 0.9 करोड़ वर्ष पूर्व के दौरान पूर्वी कराकोरम मण्डल में एक 'एस' प्ररूप की अन्तर्वेधी प्रावस्था सक्रिय थी। इन ग्रेनाइटाभों की सहसंघट्टन प्रकृति उत्तरी सास्ट प्लूटोन एवं करमबार प्लूटोन के समतुल्य है। इससे संकेत मिलता है कि 8.3 ± 0.9 करोड़ वर्ष पूर्व के दौरान कोहिस्तान-लद्दाख चाप तथा कराकोरम ब्लॉक के बीच संघट्टन सक्रिय था।

INTRODUCTION

The sequence of magmatic events as envisaged by the Indus Suture in Ladakh is believed to have started with a northward-directed intra-oceanic subduction of the Neo-Tethyan oceanic lithosphere in the Late Jurassic and Cretaceous (Honegger *et al.*, 1982). The Neo-Tethyan ocean probably closed along the Indus Suture around 50-60 Ma (Beck *et al.*, 1995; Sinha & Upadhyay, 1997; Upadhyay & Sinha, 1998).

The Ladakh block is in an intermediate position between the Indian Plate in the south and the Karakoram-Tibetan Plate in the north (Text-figure 1). To the west it is separated from the Kohistan arc by the Nanga Parbat syntaxis, to the east it is cut off from the Lhasa block by the Karakoram fault (Text-figures 1, 2). In the Ladakh block two important tectonic structures have been recognised and described by Gansser (1977) as the southern Indus Suture Zone (ISZ) and the northern Shyok Suture Zone (SSZ) (Northern Suture in Pakistan) (Text-figure 1). Located between the two sutures is the Trans-Himalayan Ladakh Batholith with mainly Cretaceous and Tertiary calc-alkaline intrusives which is subdivided from west to east into the Kohistan arc, the Ladakh magmatic arc and the Gangdese pluton of southern Tibet. The basaltic to andesitic Dras volcanics follow the Indus Suture and represent an island arc, which was active between the Late Jurassic and the Late Cretaceous (Honegger *et al.*, 1982; Dietrich *et al.*, 1983; Sharma, 1990). The Ladakh Batholith is unconformably overlain along its southern boundary by the molassic Indus Group of Miocene-Pliocene age.

The arc-batholith growth in Ladakh is discussed in terms of the Dras arc on the south side of the Ladakh Batholith (Schorer *et al.*, 1980; Dietrich *et al.*, 1983; Sharma, 1990) whereas in Kohistan it is related to the Chalt island arc volcanics which are on the north side of the batholith (Tahirkheli *et al.*, 1979; Coward *et al.*, 1986). Recently, it has been suggested that the Kohistan island arc was initiated offshore of Asia during the middle-Cretaceous and was sutured to Asia along the Northern Suture between 100 and 85 Ma (Petterson & Windley, 1985, 1991; Treloar *et al.*, 1996). So far very little is known about the subduction and closure of

PLATE 1 ⟶

1a. Panoramic view of the Nubra-Shyok rivers confluence near the village of Tirit and Sumur. At the confluence point the Tirit Granitoids and associated rocks belong to Saltoro hills. The background snow covered peaks belong to the Ladakh Batholith, the foreground mountain belongs to Shyok Volcanics and Saltoro Formation as seen near the village of Diskit in Text-figure 2. View looking towards southwest.

1b. Outcrops of Shyok Volcanics as seen near the village of Diskit. View looking towards southwest.

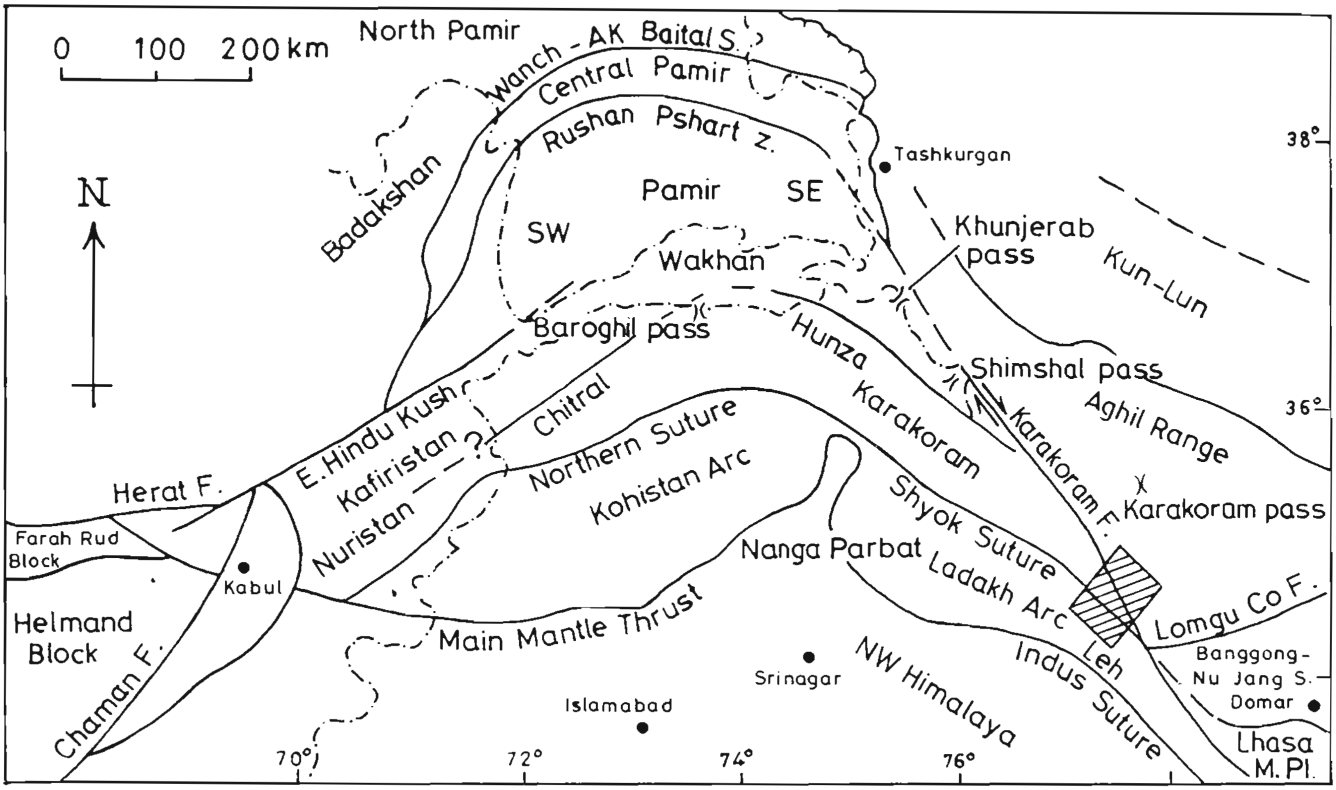
1c. Panoramic view of the Nubra river valley showing the tectonoc juxtaposition of Shyok Ophiolitic Melange and Karakoram Batholith. View looking towards northeast as seen from the village of Charasa in Text-figure 2.

1a

1b

1c

PLATE 1



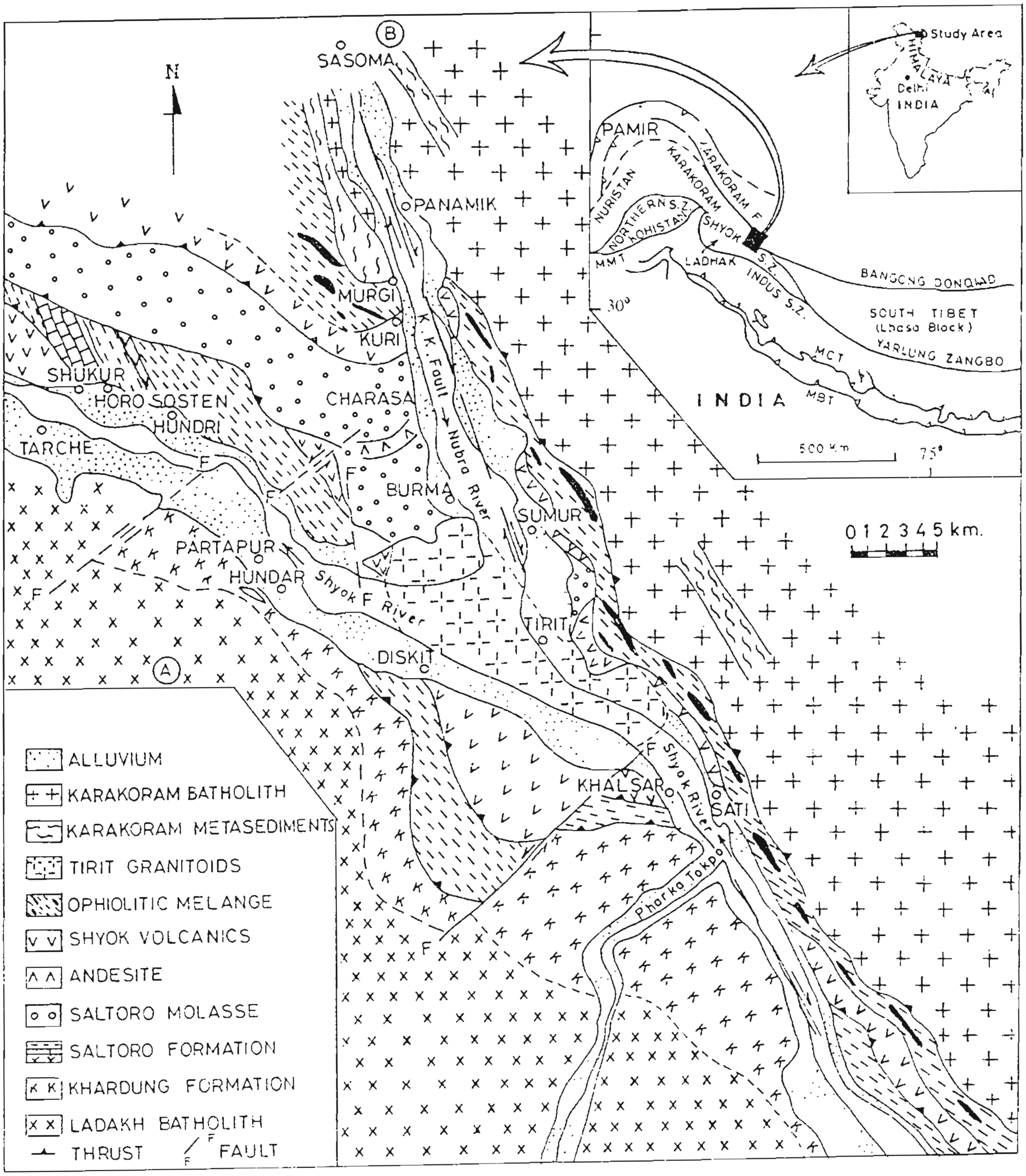
Text-figure 1–General tectonic map of Pamir, Karakoram, Kohistan and Ladakh showing the location of the Indus and Shyok Sutures together with the Kohistan and Ladakh arc terranes (modified after Gaetani (1997). Shaded box represent the area of study.

the Shyok Suture in northern Ladakh. Earlier, Rai (1982) presented evidence against subduction along the Shyok Suture. Brookfield and Reynolds (1981) and Reynolds *et al.* (1983) concluded that the Shyok Suture did not close until Miocene and therefore considered it as younger than the southern Indus Suture. However, Thakur and Mishra (1984) suggested that the Shyok Suture was the relict of a back-arc basin, whereas Srimal (1986) thought that the Shyok tectonic belt is one among several blocks that form a composite terrain between the northern margin of the Indian Plate and the southern margin of the Asian Plate and correlated the Shyok Suture with Jurassic-Early Cretaceous Bangong-Nujiang Suture in Tibet. Based on geological information from the poorly known Nubra-Shyok region it appears that there are major stratigraphic and structural differences along the Shyok Suture Zone exposed in northern Ladakh and Kohistan (Sinha & Upadhyay, 1997).

This paper deals primarily with the results of a recent study on the Shyok Suture and adjoining eastern Karakoram batholith exposed in the Shyok-Nubra valleys in northern Ladakh, which forms an accretionary complex immediately north of the Ladakh magmatic arc. We present new field observations together with regional geology, petrography, geochemical and geochronological data on magmatism. We also discuss these data to deduce tectonic setting and tectonomagmatic evolution of the Shyok Suture and eastern Karakoram Batholith . An attempt has also been made for regional correlation of presently investigated area with the geologically better known sections of northern Kohistan.

GEOLOGICAL SETTING

The rocks of the SSZ, trending northwest-southeast (Text-figures., 2, 3) across the Nubra-Shyok valleys, occur in a number of intensely deformed tectonic slices between the Ladakh Batholith to the southwest and Karakoram Batholith to the northeast (Text-figures 2,3, Plate 1 a, c). These tectonic slices comprise a variety of sedimentary, volcanic and plutonic rocks hence referred an accretionary complex (Sinha & Upadhyay, 1997). To the south, the lowermost imbricate of the Shyok Suture is built up by Late Jurassic to Early-middle Cretaceous Saltoro Formation (Upadhyay *et al.*, 1999). The Saltoro Formation is in tectonic contact along a steeply dipping thrust with the calc-alkaline volcanics and volcanoclastics of Khardung Formation of the ISZ (Text-figures 3, 4). The tectonic contact between Shyok Ophiolitic Melange and Karakoram Batholith mark the northern limit of the Shyok Suture (Text-figures 2, 3, 4, Plate 1c). Geological account of Shyok Suture has recently been given and discussed elsewhere (Rai, 1991; Upadhyay *et al.*, 1999). Apart from other rock types the Shyok Suture is represented by a variety of different sets of volcano-plutonic rock assemblages. For the purpose

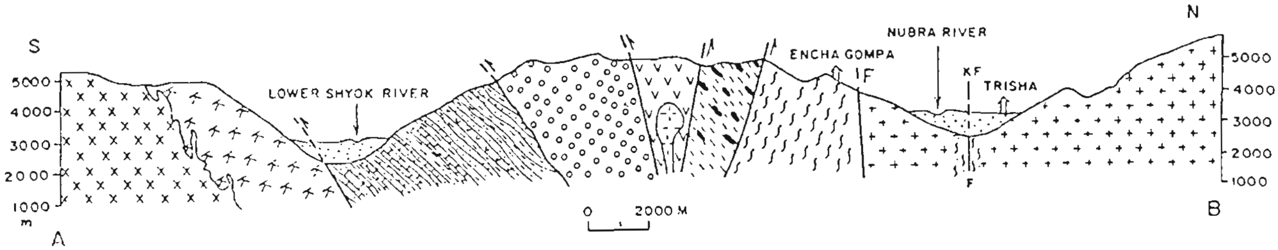


Text-figure 2–Geological map of the Shyok Suture Zone and eastern Karakoram in the Nubra-Shyok valley, northern Ladakh, India.

of present study, the occurrences of several Volcano-plutonic bodies have been grouped and discussed as: 1. Shyok Volcanics; 2. Tirit Granitoids; 3. Karakoram Batholith.

Shyok Volcanics

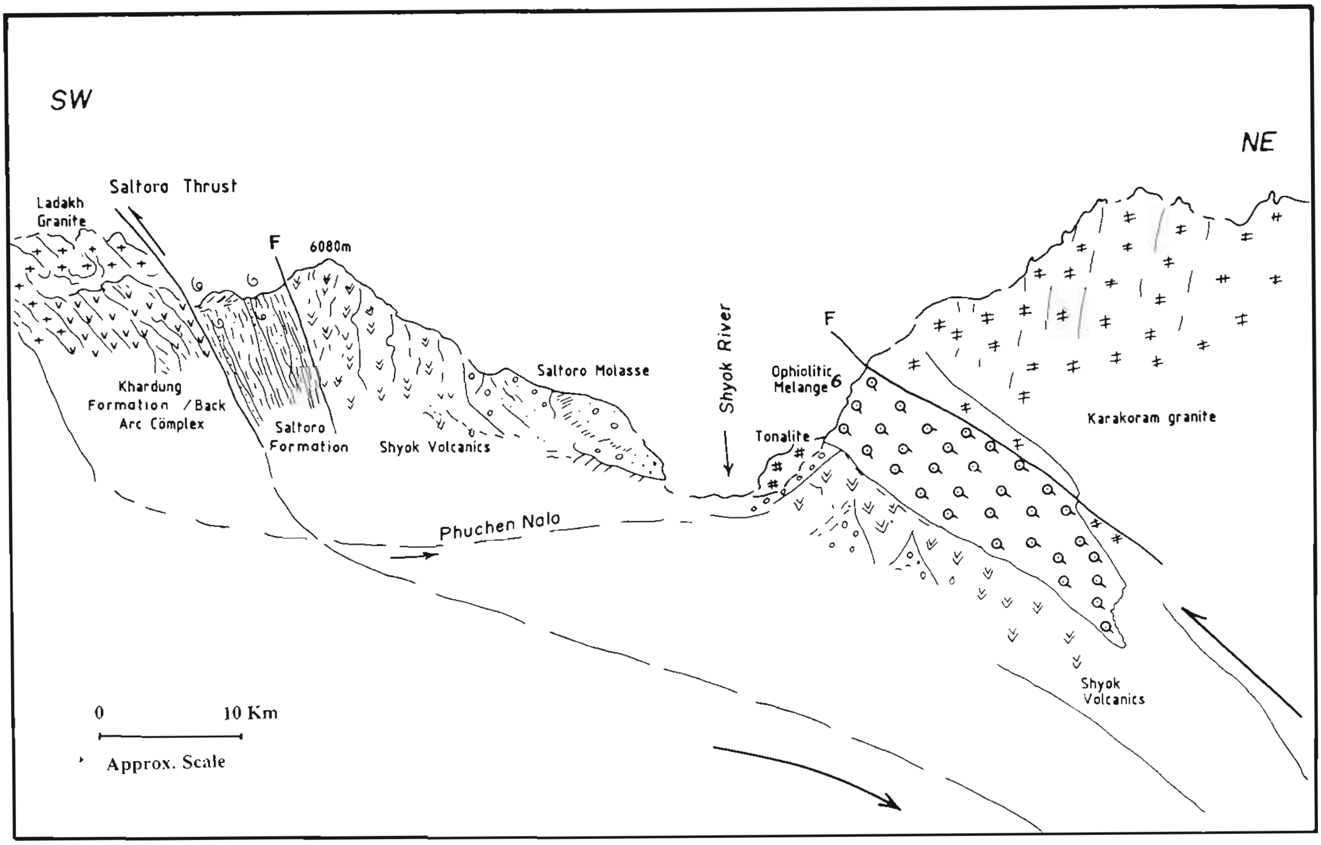
Under the heading of Shyok Volcanics we describe different occurrences of volcanics in the Nubra-Shyok valleys of which we do not know their original palaeogeographic position (Plate 1a, b). Sporadic outcrops occur below the Saltoro Formation (Upadhyay *et al.*, 1999) near Shukur (Text-figure 2). Southeast of Diskit the Saltoro Formation is tectonically overlain along a steeply dipping thrust by chlorite schists, basic volcanics and cherts of the Shyok Volcanics (Text-figures 2, 3). West of the Karakoram Fault they also



Text-figure 3–Geological cross-section along line A-B on Text-figure 2.

occur tectonically sandwiched between the underlying Saltoro Molasse and Ophiolitic Melange, above. East of the Karakoram Fault, they crop out between the villages of Panamik and Tirit and near confluence of the Nubra-Shyok rivers (Plate 1a). Rai (1991) estimated that they are up to 4 km thick, consisting of a heterogeneous sequence of basalts and andesites with ignimbrites. Individual flows could not be traced across the inaccessible outcrops. At several places, the Shyok Volcanics are intruded by granodiorite, tonalite to gabbrodiorite plutonic bodies known as Tirit Granitoids (Text-figures 2, 3, 4).

Compositionally, the Shyok Volcanics range from basalt, basaltic andesite to andesite. The basaltic rocks exposed near the village of Shukur and Sati bridge are fine-to medium-grained, massive and highly fractured, with rare vesicles. These rocks are essentially made up of plagioclase, hornblende and augite whereas olivine is present in accessory amount. Plagioclase and augite occurs as minute radiating laths and showing sub-ophitic texture. The basaltic andesites exposed near the village of Trisha and Tegar are medium-grained, agglomeratic and ophitic in texture; vesicles are well developed and vary from a few mm to 1 cm in diameter, which are filled with calcite, zeolite and chlorite. The basaltic andesites are strongly epidotised. These rocks are also cut by hydro-



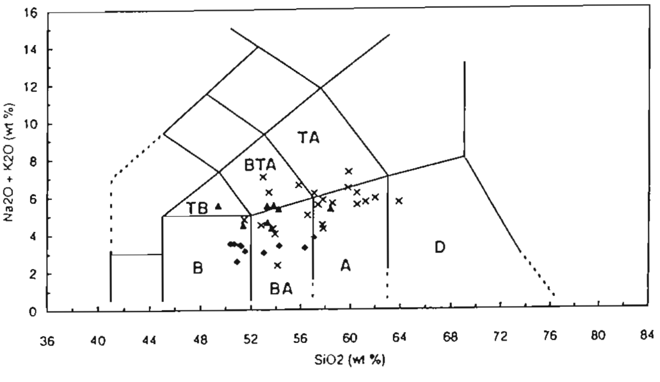
Text-figure 4–Field sketch cross-section across the Shyok Suture Zone near the village of Khalsar.

thermal veins rich in sulphide mineralisation, mainly chalcopyrite and flaky hematite. These rocks are made up of plagioclase, hornblende, biotite and quartz. Sphene, zircon, epidote and chlorite present as secondary minerals. The twinned plagioclase crystals are intensively altered. The pyroxene and hornblende is also present in the fine-grained groundmass which is dominated by plagioclase microlites. The hornblende crystals show two distinct sets of cleavage. Flakes of biotite represent characteristic diachroism from light brown to deep brown. Black iron ore, opaques and chlorite are also present. The andesites show well developed laths of plagioclase phenocrysts showing porphyritic texture. Plagioclase laths are zoned, clouded, twinned and are embedded in fine-grained, epidotized groundmass. Augite occurs as prismatic crystals. The groundmass is composed of micro-phenocrysts and microlites of augite and plagioclase. Hornblende show typical bluish-green colour and exhibiting simple twinning.

Geochemistry of Shyok Volcanics

A total of 43 samples of Shyok Volcanics were analyzed and are presented in Table 1. Major, trace and rare earth elements (REE) were determined by X-ray fluorescence spectrometry (Siemens SRS 3000) and inductively coupled plasma-atomic emission spectrometry (Jobin Yvon JY-70 plus) at the Geochemical Laboratory of the Wadia Institute of Himalayan Geology, Dehradun. International rock geo-standards BHVO-1, MBH and DGH were used for calibration. Major elements have been used to determine the CIPW norms.

The Shyok Volcanics show a wide variation in their geochemical ranges. On the basis of sampling from different localities, the analysed samples have been classified and discussed as volcanic rocks from Shukur village, Tegar village and Sati bridge. According to chemical classification proposed by Peccerillo and Taylor (1976), Winchester and Flyod (1977) and Cox *et al.* (1979) the Shyok Volcanics ranges from basalts, basaltic - andesite to andesites. The total alkali silica (TAS) ($Na_2O + K_2O$ % versus SiO_2%) chemical classification scheme (Cox *et al.*, 1979) show that the Shyok Volcanics are basalt, trachy-basalt, basaltic-andesite, basaltic trachy-andesite, andesite, trachy-andesite and dacite (Table 1; Text-figure 5).



Text-figure 5–$Na_2O + K_2O$ versus SiO_2 chemical classification diagram for Shyok Volcanics (plotted on the diagram after Cox *et al.*, 1979). **B** = basalt; **BA** = basaltic andesite; **A** = andesite; **D** = dacite; **TB** = trachy basalt; **BTA** = basaltic trachy andesite; **TA** = trachy andesite. Filled rhombus = Shukur Volcanics; cross = Tegar Volcanics; filled triangles = Sati bridge volcanics.

The basalt samples have a range of SiO_2 content from 47.16 to 52.57%. Similarly basaltic-andesite with 52.97 to 57.63 % and andesites 58.07 to 62.1 % (Table 1). The systematic increase in SiO_2 from basalt to andesite through basaltic - andesite suggests that no compositional gap seems to exist between the geochemical characters of Shyok Volcanics which may represent a common parent magma. All the samples are characterised by low values of TiO_2 wt% which ranges from 0.47 to 1.48%, and comparable with island arc volcanics. These volcanics are moderately enriched in Al_2O_3 (13.96 to 17.58%), MgO (4.9 to 12.01%) and total iron (Fe_2O_3) (4.15 to 11.27%). It is evident from petrography that rocks of the Shyok Volcanics have suffered post magmatic secondary alterations and therefore have very high values of LOI (Table 1). This suggests that these rocks must have induced the effect of element mobilization, particularly the alkali elements which are highly mobile and showing a wide range of their concentrations. In most samples the Na_2O content is generally higher than K_2O values and ranges from 0.44 to 5.88%. The K_2O values ranges from 0.01 to 4.12 %. Some samples are exceptionally enriched in their soda content (> 4%). This may be due to spilitization of the volcanic rocks. The trace element data (Table 1) of these volcanics suggest that radioactive elements, such as Rb, Th and U contents are very low. These elements are generally associated with continental crust. The Shyok Volcanics have very low values of Nb (0.1 to 26 ppm), Pb (5 to 24 ppm) and Ga (13 to 22 ppm). The depletion of Nb is generally associated with calc-alkaline subduction related magmatism. The Zn, Cu, Ni, Cr are moderately enriched in basalts and their concentration decreases toward andesite samples. All the samples are moderately enriched in Ba, Ni, Cr and Sr elements. Higher Sr content like 605 ppm suggest either the fractionation of calc-plagioclase or the hydrothermal enrichment.

In major oxide versus MgO% plots (Text-figure 6) the concentration of SiO_2, Al_2O_3, Na_2O and K_2O decreases with increasing value of MgO%. Whereas, total iron Fe_2O_3(t), MnO and TiO_2 shows a positive correlation with increasing value of MgO%. All the samples are depleted in TiO_2 except for high Mg volcanics of Shukur village. The total iron and TiO_2 variation plots for Shukur village volcanics show a tholeiitic to transitional tholeiitic/calc-alkaline nature of magma. The samples from Tegar village and Sati bridge represent calc-alkaline trend and a positive correlation with MgO% (Table 1). The A ($Na_2O + K_2O$) - F (FeO*) – M (MgO) diagram further confirm the tholeiitic and calc-alkaline characters for Shyok Volcanics.

Table 1—Geochemical data for Shyok Volcanics

Locality	**Shukur village**							
S.No.	**SV R59**	**SV R58**	**SV R66**	**SV R62**	**SV R63**	**SV R60**	**SV R65**	**SV R64**
Rock Type	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**B**
Major Oxides (wt%)								
SiO_2	47.16	47.87	48.27	48.64	49.1	49.16	49.23	52.22
TiO_2	1.25	0.56	0.7	0.64	0.69	0.47	0.77	0.78
Al_2O_3	16.12	14.08	14.61	15.49	14.81	14.59	14.77	15.05
FeO(t)	14.31	10.99	11.06	10.84	11.93	9.12	11.81	10.39
MnO	0.16	0.19	0.2	0.22	0.18	0.19	0.2	0.2
MgO	8.77	10.62	9.44	7.53	8.26	10.11	8.92	10.65
CaO	2.54	8.35	9.14	10.22	8.87	9.59	5.47	4.58
Na_2O	1.85	1.66	3.2	3.131	2.23	1.74	2.5	2.85
K_2O	1.26	0.74	0.14	0.22	0.95	1.22	0.28	0.41
P_2O_5	0.09	0.07	0.18	0.14	0.12	0.15	0.12	0.15
LOI	6.43	3.73	3.8	4.6	3.8	3.7	5.59	3.75
Total	99.94	98.86	100.74	101.671	100.94	100.04	99.66	101.03
Trace Elements (ppm)								
Ba	n.d	261.6	764.1	195.4	296.8	230.9	154.4	n.d
Cr	156	430	147	126	248	233	86	132
Ni	77	242	24	18	109	57	27	144
Cu	137	109	122	33	148	27	567	1756
Zn	165	102	91	88	104	94	104	103
Ga	19	13	18	16	18	15	17	16
Pb	8	6	11	7	12	47	13	10
Th	1.24	1.32	67	1.6	0.99	3.57	3.15	2.01
Rb	42	28	n.d	10	19	41	14	20
U	0.86	1.06	0.53	0.96	0.55	1.65	0.85	1.05
Sr	90	119	530	810	225	164	556	351
Y	23	15	18	17	19	20	18	19
Zr	83	35	73	76	58	67	80	69
Nb	5	4	1	1	2	1	1	1
Rare Earth Elements (ppm)								
La	n.d	5.2	15.6	13.5	17.5	17.3	n.d	n.d
Ce	n.d	8.2	29.8	21.1	30.9	28.7	n.d	n.d
Nd	n.d	5.5	15.5	12.1	15.8	14.3	n.d	n.d
Sm	n.d	1.81	4.15	3.22	4.18	3.48	n.d	n.d
Eu	n.d	0.519	1.01	0.975	1.17	1.06	n.d	n.d
Gd	n.d	1.73	3.66	2.9	3.86	2.89	n.d	n.d
Dy	n.d	2.01	3.38	2.88	3.48	2.79	n.d	n.d
Er	n.d	1.3	2.13	1.78	2.04	1.69	n.d	n.d
Yb	n.d	1.2	1.85	1.66	2.01	1.69	n.d	n.d
Lu	n.d	0.2	0.293	0.252	0.31	0.276	n.d	n.d
CIPW Norm								
q	7.71	-	-	-	-	-	4.06	4.58
or	7.45	4.37	0.83	1.3	5.61	7.21	1.65	2.42
ab	16.65	14.05	27.08	26.49	18.27	14.72	21.35	24.12
an	12.01	28.78	25.09	27.57	27.6	28.4	26.35	21.74
hy	34.15	31.35	9.97	9.45	25.03	23.93	32.92	35.82
mt	5.6	4.29	4.32	4.23	4.67	3.57	4.61	4.06
il	2.37	1.06	1.33	1.22	1.31	0.89	1.46	1.48
ap	0.21	0.16	0.42	0.32	0.28	0.35	0.28	0.35
di	-	9.8	15.38	18.02	12.67	14.59	-	-
C	7.31	-	-	-	-	-	0.7	1.95
ol	-	0.45	11.7	7.67	0.22	2.01	-	-
ne	-	-	-	-	-	-	-	-
Plagioclase	An43	An67	An48	An51	An59	An66	An55	An47

Contd.

Locality	**Shukur village**			**Sati bridge**				
S.No.	**SV R61**	**SV R67**	**SV R78**	**SB R33**	**SB R34**	**SB R38**	**SB R31**	**SB R37**
Rock Type	**BA**	**BA**	**A**	**B**	**B**	**B**	**B**	**B**
Major Oxides (wt%)								
SiO_2	53.18	54.37	58.54	48.95	49.29	50.75	51.52	52.17
TiO_2	0.77	0.93	0.61	0.96	1.11	0.85	1.07	0.97
Al_2O_3	15.24	15.14	16.22	16.49	14.63	15.56	14.62	15.27
Fe(t)	9.59	10.03	5.58	10.01	9.58	8.36	9.12	8.6
MnO	0.16	0.18	0.1	0.15	0.14	0.12	0.13	0.14
MgO	6.77	10.07	5.11	8.3	10.31	8.52	9.66	8.24
CaO	4.78	3.56	5.28	9.55	7.26	6.95	6.72	6.84
Na_2O	3.16	3.08	2.72	0.44	3.1	2.95	3.14	3.43
K_2O	0.39	0.05	2.65	5.03	1.17	1.14	1.31	1.92
P_2O_5	0.12	0.12	0.18	0.27	0.33	0.25	0.28	0.28
LOI	6.34	3.32	4.8	2.3	3.95	4.69	3.26	2.95
Total	100.5	100.85	101.79	102.45	100.87	100.14	100.83	100.81
Trace Elements (ppm)								
Ba	112.6	120.5	n.d	n.d	n.d	574.3	403.8	502.9
Cr	91	32	164	262	256	164	295	203
Ni	32	20	25	96	120	217	146	81
Cu	28	201	24	6	35	68	66	47
Zn	107	95	81	99	85	76	83	86
Ga	16	16	18	15	16	14	18	17
Pb	12	5	13	11	24	5	135	9
Th	1.41	1.6	3.23	3.9	4.97	5.8	6.07	4.31
Rb	15	7	88	152	39	53	47	71
U	0.98	0.64	2.54	4.19	1.56	1.9	1.74	2.24
Sr	119	154	220	176	477	5.1	389	380
Y	24	24	13	17	23	24	22	22
Zr	68	87	120	121	136	124	139	149
Nb	4	4	6	7	7	8	7	8
Rare Earth Elements (ppm)								
La	n.d	8.89	n.d	n.d	n.d	18.9	22.2	18.1
Ce	n.d	16.05	n.d	n.d	n.d	32.8	37.45	32.2
Nd	n.d	10.94	n.d	n.d	n.d	18.3	21.7	17.4
Sm	n.d	3.85	n.d	n.d	n.d	4.41	5.04	4.07
Eu	n.d	1.06	n.d	n.d	n.d	1.33	1.4	1.22
Gd	n.d	4.03	n.d	n.d	n.d	4.08	4.04	3.48
Dy	n.d	4.69	n.d	n.d	n.d	3.9	3.48	3.39
Er	n.d	2.86	n.d	n.d	n.d	1.95	1.59	1.69
Yb	n.d	2.4	n.d	n.d	n.d	1.91	1.63	1.61
Lu	n.d	0.349	n.d	n.d	n.d	0.284	0.248	0.237
CIPW Norm								
q	9.46	10.02	12.06	-	-	0.64	-	-
or	2.3	0.3	15.66	29.73	6.91	6.74	7.74	11.35
ab	26.74	25.06	23.03	3.73	26.23	24.96	26.57	29.02
an	22.93	16.88	24.22	28.17	22.55	25.85	21.93	20.6
hy	25.32	33.75	17.38	4.28	13.82	25.57	23.99	15.97
mt	3.74	3.91	2.29	3.91	3.74	3.26	3.57	3.36
il	1.46	1.77	1.16	1.82	2.11	1.61	2.03	1.84
ap	0.28	0.28	0.42	0.63	0.76	0.58	0.65	0.65
di	-	-	0.64	14.06	9.05	5.61	7.66	9.23
C	1.22	3.83	-	-	-	-	-	-
ol	-	-	-	13.09	11.03	-	2.76	5.21
ne	-	-	-	-	-	-	-	-
Plagioclase	An46	An39	An51	An88	An46	An51	An45	An42

Contd.

Locality	**Sati Bridge**				**Tegar village**			
S.No. **Rock Type**	**SB R36** **B**	**SB R35** **BA**	**SB R32** **BA**	**SB R39** **B**	**TV R74** **B**	**DB R83** **B**	**SB R82** **B**	**CH R75** **BA**
Major Oxides (wt%)								
SiO_2	52.3	52.57	57.49	50.71	50.71	51.01	51.94	52.97
TiO_2	0.64	0.88	0.88	0.84	0.82	1.08	0.92	0.96
Al_2O_3	15.26	16.98	16.59	15.46	15.48	15.54	17.58	15.55
FeO(t)	8.59	8.64	6.66	8.31	7.6	8.41	6.67	6.96
MnO	0.15	0.12	0.09	0.12	0.06	0.11	0.07	0.08
MgO	8.41	7.02	5.77	8.49	12.01	10.59	8.3	9.64
CaO	6.31	7.66	6.13	6.92	3.04	8.32	6.17	2.98
Na_2O	3.44	1.31	3.22	2.92	4.39	3.76	3.44	5.13
K_2O	1.69	4.12	2	1.14	2.33	0.96	2.59	1.11
P_2O_5	0.27	0.27	0.28	0.25	0.16	0.26	0.23	0.19
LOI	2.89	1.99	2.05	4.97	3.2	2.78	3.78	4.7
Total	99.95	101.56	101.16	100.13	99.8	102.82	101.69	100.27
Trace Elements (ppm)								
Ba	n.d	n.d	n.d	176	313.7	n.d	n.d	n.d
Cr	209	215	155	161	159	254	146	170
Ni	84	72	34	43	124	131	58	122
Cu	10	5	3	5	13	5	6	78
Zn	99	71	58	41	27	34	31	47
Ga	19	16	17	18	19	21	18	18
Pb	7	9	7	11	10	7	5	13
Th	5.15	6.52	10.23	3.64	4.45	4.04	3.02	4.04
Rb	62	132	67	49	58	19	67	26
U	2.08	3.5	2.13	1.86	1.97	1.14	2.19	1.61
Sr	248	159	402	240	339	477	320	260
Y	22	17	21	20	18	21	20	17
Zr	154	142	184	160	182	142	148	191
Nb	8	7	9	6	6	7	7	5
Rare Earth Elements (ppm)								
La	n.d	n.d	n.d	n.d	15.7	n.d	n.d	n.d
Ce	n.d	n.d	n.d	n.d	32.6	n.d	n.d	n.d
Nd	n.d	n.d	n.d	n.d	16	n.d	n.d	n.d
Sm	n.d	n.d	n.d	n.d	4.43	n.d	n.d	n.d
Eu	n.d	n.d	n.d	n.d	0.848	n.d	n.d	n.d
Gd	n.d	n.d	n.d	n.d	3.67	n.d	n.d	n.d
Dy	n.d	n.d	n.d	n.d	3.27	n.d	n.d	n.d
Er	n.d	n.d	n.d	n.d	1.95	n.d	n.d	n.d
Yb	n.d	n.d	n.d	n.d	1.36	n.d	n.d	n.d
Lu	n.d	n.d	n.d	n.d	0.206	n.d	n.d	n.d
CIPW Norm								
q	-	1.48	8.56	0.9	-	-	-	-
or	9.99	24.35	11.82	6.74	13.77	5.67	15.31	6.56
ab	29.11	11.08	27.25	24.71	36.75	31.82	29.11	43.41
an	21.21	28.29	24.91	25.71	14.04	22.69	24.88	13.54
hy	21.57	21.65	18.21	25.47	-	2.74	8.91	16.13
mt	3.35	3.38	2.6	3.25	2.9	3.29	2.61	2.71
il	1.79	1.67	1.67	1.6	1.56	2.05	1.75	1.82
ap	0.63	0.63	0.65	0.58	0.37	0.6	0.53	0.44
di	6.68	6.41	2.95	5.6	-	13.5	3.37	-
C	-	-	-	-	0.59	-	-	0.95
ol	2.41	-	-	-	25.8	17.11	10.96	9.48
ne	-	-	-	-	0.22	-	-	-
Plagioclase	An42	An72	An48	An51	An28	An42	An46	An24

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Locality	**Tegar village**							
S.No. **Rock Type**	**DV R84** **BA**	**SB R41** **BA**	**TV R69** **BA**	**SB R40** **BA**	**TV R72** **BA**	**CH R76** **BA**	**TV R68** **BA**	**CHK R81** **BA**
Major Oxides (wt%)								
SiO_2	52.98	53.38	54.65	54.9	55.27	56.44	56.84	56.97
TiO_2	0.96	0.72	0.51	0.47	1.19	1.48	0.85	1.14
Al_2O_3	15.77	13.96	14.18	17.08	15.37	16.18	14.76	16.61
FeO(t)	9.9	7.68	11.27	10.39	9.44	8.59	7.62	6.13
MnO	0.18	0.16	0.12	0.1	0.04	0.1	0.11	0.11
MgO	7.92	8.5	5.31	4.9	6.58	5.55	7.12	7.16
CaO	8.94	11.28	5.42	12.07	3.81	7.05	6	6.3
Na_2O	2.21	3.8	4.02	1.37	4.36	3.34	4.53	3.6
K_2O	2.29	0.17	0.01	1.01	0.97	1.64	1.18	1.73
P_2O_5	0.2	0.16	0.17	0.2	0.19	0.3	0.15	0.34
LOI	3.35	1.31	4.7	1.25	2.31	2.3	2.7	2.71
Total	104.7	101.12	100.36	103.74	99.53	102.97	101.86	102.8
Trace Elements(ppm)								
Ba	n.d	266.5	81.06	299.7	187.1	234	n.d	435
Cr	156	234	88	230	188	139	168	209
Ni	30	28	29	29	98	19	46	101.4
Cu	64	57	7	0	35	49	13	20.3
Zn	112	49	90	15	18	52	37	62.1
Ga	17	15	19	40	19	20	17	18.5
Pb	9	119	10	11	4	6	8	7
Th	4.5	2.44	1.77	1.24	2.54	5.86	0.48	3.9
Rb	84	5	6	31	33	40	60	35
U	2.75	0.9	0.29	1.77	1.37	1.62	2.07	1
Sr	420	495	114	495	295	503	207	605
Y	26	28	32	30	21	29	24	19
Zr	111	95	151	96	142	190	102	220
Nb	4	6	12	4	4	8	5	14
Rare Earth Elements (ppm)								
La	n.d	n.d	21.1	33.2	16.5	21.8	n.d	n.d
Ce	n.d	n.d	53	52.7	29	39.8	n.d	n.d
Nd	n.d	n.d	28.9	21.9	18.06	21.1	n.d	n.d
Sm	n.d	n.d	7.69	5.29	4.54	5.44	n.d	n.d
Eu	n.d	n.d	1.19	1.37	1.03	1.65	n.d	n.d
Gd	n.d	n.d	6.65	4.7	3.83	5.04	n.d	n.d
Dy	n.d	n.d	6.36	4.81	3.5	4.64	n.d	n.d
Er	n.d	n.d	3.79	2.39	1.98	2.45	n.d	n.d
Yb	n.d	n.d	3.28	2.32	1.36	1.89	n.d	n.d
Lu	n.d	n.d	0.482	0.331	0.215	0.289	n.d	n.d
CIPW Norm								
q	0.71	-	8.52	10.64	5.39	7.26	2.71	5.29
or	13.53	1	0.06	5.97	5.73	9.69	6.97	10.22
ab	18.7	32.15	34.02	11.59	36.89	28.26	38.33	30.46
an	26.35	20.53	20.62	37.47	17.66	24.31	16.46	24.06
hy	21.27	9.81	21.63	13.31	23.78	16.62	19.31	20.29
mt	3.87	3	4.35	4.06	3.68	3.35	2.9	2.39
il	1.82	1.37	0.97	0.89	2.26	2.81	1.61	2.17
ap	0.46	0.37	03.9	0.46	0.44	0.7	0.35	0.79
di	13.46	27.52	4.24	17.32	-	7.02	9.9	3.96
C	-	-	-	-	0.68	-	-	-
ol	13.46	3.48	-	-	-	-	-	-
ne	-	-	-	-	-	-	-	-
Plagioclase	An58	An39	An38	An76	An32	An46	An30	An44

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Locality	**Tegar village**							
S.No.	**TV R70**	**SB R30**	**TV R71**	**CHK R80**	**SB R42**	**SB R29**	**SB R45**	**SB R43**
Rock Type	**BA**	**BA**	**BA**	**A**	**A**	**A**	**A**	**A**
Major Oxides (wt%)								
SiO_2	57.4	57.51	57.63	58.07	58.53	6.04	60.37	60.51
TiO_2	1.07	0.85	1.03	1.03	0.66	0.72	0.68	0.72
Al_2O_3	14.93	15.93	15.21	16.79	16.26	15.94	15.52	14.75
FeO(t)	7.81	8.82	6.87	6.29	5.99	5.4	4.76	6.43
MnO	0.05	0.25	0.05	0.09	0.06	0.1	0.07	0.11
MgO	7.14	5.89	7.62	6.33	5.52	5.41	5.13	5.36
CaO	7.13	6.02	5	5.67	3.5	5.78	4.92	7.29
Na_2O	3.1	4.59	3.67	3.14	3.75	5.88	4.75	4.59
K_2O	1.35	1.6	1.86	2.73	1.68	1.41	1.93	1.91
P_2O_5	0.2	0.19	0.2	0.26	0.25	0-.25	0.28	0.18
LOI	2.78	2.08	2.5	2.05	4.02	1.91	2.78	1.05
Total	102.96	103.73	101.64	102.45	100.22	102.84	101.19	102.9
Trace Elements (ppm)								
Ba	124.6	230.2	176.9	735	n.d	232.1	n.d	n.d
Cr	252	142	188	190	157	182	n.d	268
Ni	65	25	71	109.6	28	18	30	59
Cu	7	12	188	18.7	30	5	47	8
Zn	23	86	25	74.2	39	17	45	68
Ga	18	19	16	19.2	17	18	18	17
Pb	9	13	6	5	13	13	9	17
Th	4.72	6.32	5.44	1.6	7.64	11.97	2.24	6.85
Rb	48	75	74	62	77	65	78	65
U	1.83	2.36	2.28	1.6	2.22	2.15	2.58	2.22
Sr	553	328	444	682	285	307	413	398
Y	23	44	19	20	17	47	25	21
Zr	129	172	127	189	192	225	111	169
Nb	6	15	5	11	7	26	4	6
Rare Earth Elements (ppm)								
La	15.8	n.d	9.1	n.d	n.d	27.8	n.d	n.d
Ce	29.7	n.d	16.5	n.d	n.d	54.3	n.d	n.d
Nd	15.9	n.d	9.7	n.d	n.d	28.1	n.d	n.d
Sm	4.53	n.d	2.84	n.d	n.d	7.92	n.d	n.d
Eu	1.43	n.d	0.727	n.d	n.d	1.16	n.d	n.d
Gd	4.3	n.d	2.63	n.d	n.d	7.28	n.d	n.d
Dy	4.03	n.d	2.94	n.d	n.d	8.88	n.d	n.d
Er	2.03	n.d	1.63	n.d	n.d	5.15	n.d	n.d
Yb	1.44	n.d	1.14	n.d	n.d	6.08	n.d	n.d
Lu	0.194	n.d	0.1496	n.d	n.d	0.816	n.d	n.d
CIPW Norm								
q	8.53	2.26	6.17	6.98	12.86	1.78	6.87	5.5
or	7.98	9.46	10.99	16.13	9.93	8.33	11.41	11.29
ab	26.23	38.84	31.05	26.57	31.39	49.76	40.19	38.84
an	22.84	18.14	19.54	23.66	15.73	12.94	15.33	14
hy	19.48	18.34	22.62	19.36	18.65	12.37	15.76	10.56
mt	3.04	3.33	2.68	2.45	2.33	2.1	1.86	2.51
il	2.03	1.61	1.96	1.96	1.25	1.37	1.29	1.37
ap	0.46	0.44	0.46	0.6	0.58	0.58	0.65	0.42
di	9	8.5	3.16	2.22	-	11.29	5.86	16.89
C	-	-	-	-	2.46	-	-	-
ol	-	-	-	-	-	-	-	-
ne	-	-	-	-	-	-	-	-
Plagioclase	An47	An32	An39	An47	An33	An21	An28	An27

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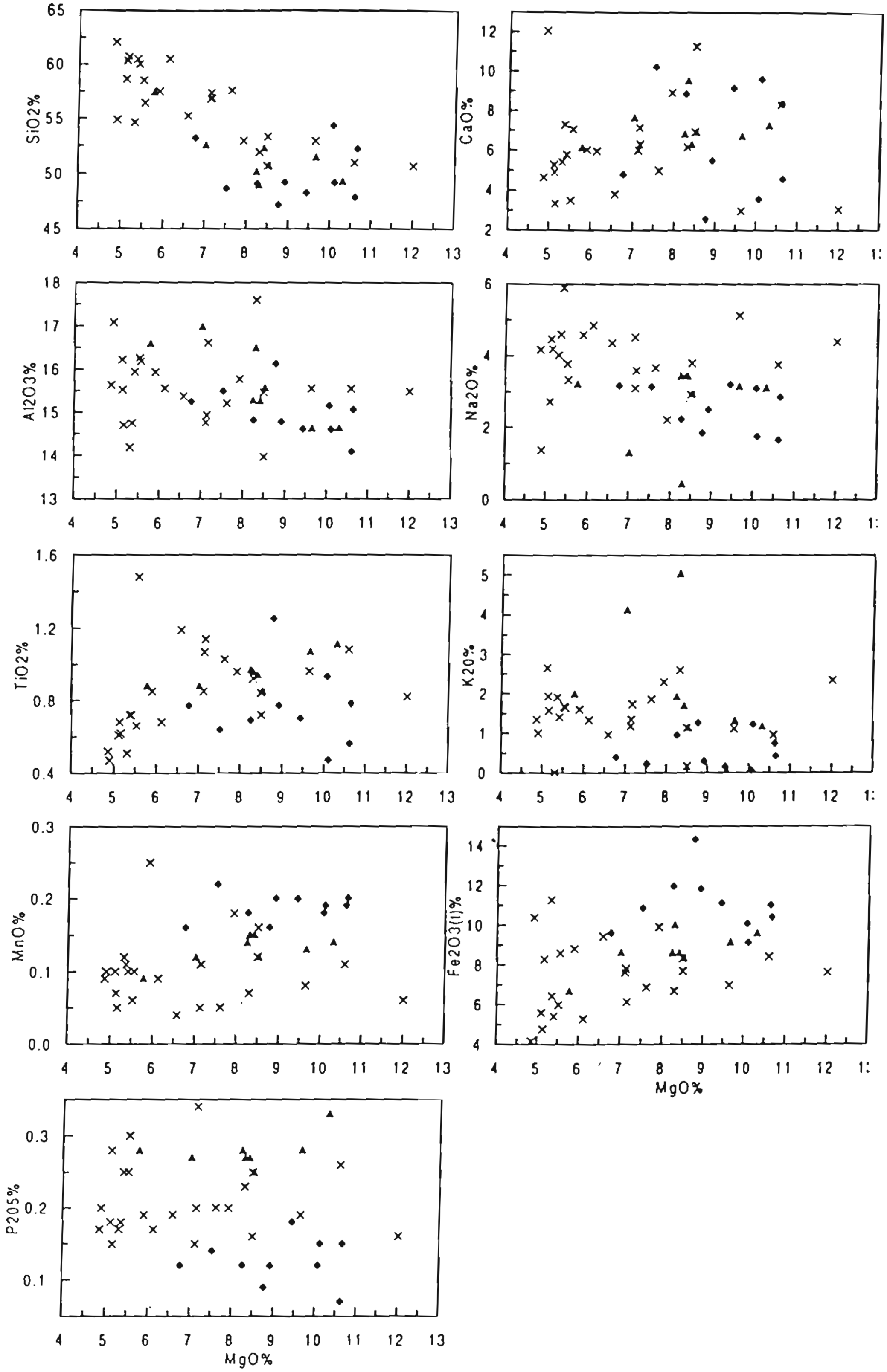
Locality	Tegar village		
S.No.	SB R44	TV R73	SV R77
Rock Type	A	A	A
Major Oxides (wt%)			
SiO_2	60.57	60.72	62.1
TiO_2	0.68	0.62	0.52
Al_2O_3	15.56	14.7	15.64
FeO(t)	5.28	8.29	4.15
MnO	0.09	0.05	0.09
MgO	6.12	5.16	4.86
CaO	5.96	3.34	4.64
Na_2O	4.85	4.19	4.17
K_2O	1.33	1.57	1.35
P_2O_5	0.17	0.15	0.17
LOI	1.45	2.78	3.2
Total	102.06	101.57	100.89
Trace Elements (ppm)			
Ba	483.4	n.d	296.4
Cr	244	130	220
Ni	52	84	37
Cu	5	245	11
Zn	57	22	73
Ga	17	18	19
Pb	13	8	10
Th	5.96	1.62	8.16
Rb	42	73	43
U	1.77	2.25	1.57
Sr	392	300	460
Y	16	17	12
Zr	137	134	129
Nb	5	4	5
Rare Earth Elements (ppm)			
La	21.7	n.d	19.5
Ce	34.2	n.d	35.6
Nd	19.3	n.d	15.1
Sm	4.24	n.d	2.95
Eu	1.13	n.d	0.868
Gd	3.12	n.d	2.33
Dy	2.61	n.d	1.77
Er	1.33	n.d	0.673
Yb	1.01	n.d	0.868
Lu	0.169	n.d	0.144
CIPW Norm			
q	6.46	12.63	14.85
or	7.86	9.28	7.98
ab	41.04	35.45	35.29
an	16.76	15.59	19.97
hy	15.01	20.07	14.74
mt	2.06	3.23	1.62
il	1.29	1018	0.99
ap	0.39	0.35	0.39
di	9.39	-	1.55
C	-	0.39	-
ol	-	-	-
ne	-	-	-
Plagioclase	An29	An31	An36

The trace element versus MgO% variation diagram show consistent correlation between trace elements (Text-figure 7) except Ba and Sr. The scattering of Sr/CaO is mainly attributed to post crystallization alteration or metamorphism. A negative correlation can be seen in Rb, Zr, Ga, Th and U elements. The concentration of these elements decreases systematically with the increasing value of MgO%. A positive correlation can also be inferred for Ni versus MgO%. The total iron and TiO_2 bivariation plots depicts that there is a compositional gap between the high Mg tholeiitic basalt of Shukur village and low Mg calc-alkaline rocks of Tegar village and Sati bridge. Similar geochemical gaps are also present in Ni, Cr, Y and Nb. Hence, it is inferred that these volcanics are either representing two different magma types or the effect of secondary alterations.

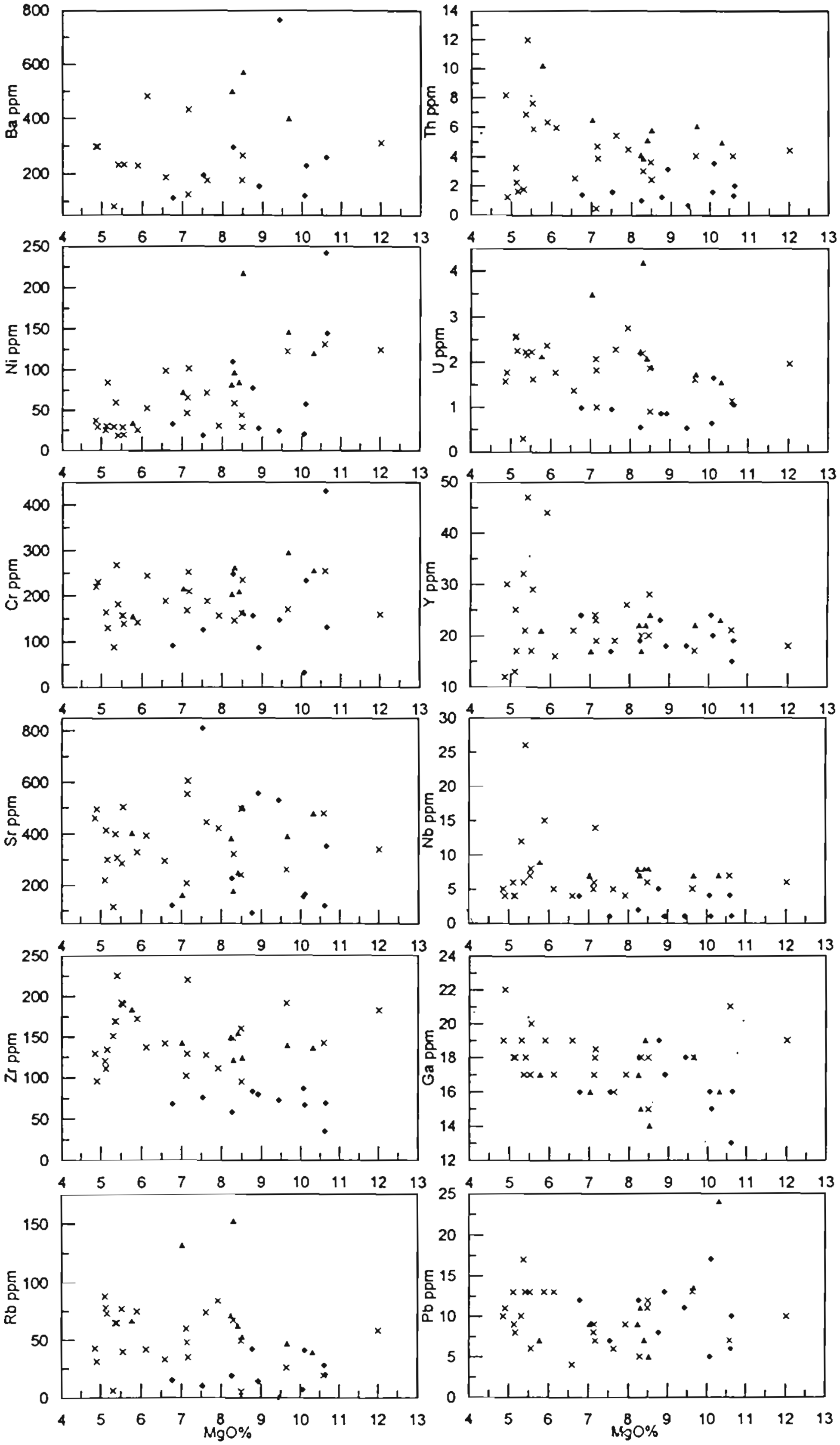
Nineteen representative samples were analyzed for Rare Earth Elements (REE) (Table 1). The geochemical results are compared with the Normal Mid Oceanic Ridge Basalt (N - MORB), Enriched Mid Oceanic Ridge Basalt (E - MORB), and Oceanic Island Basalt (OIB) (Sun and Mc Donough, 1989). It is observed that some of the samples are moderately enriched in all the REE, whereas, few samples show depletion which is similar to those found in N- and E-MORB. Samples from Shukur village (Table I; Text-figure 8) are characterised by depletion in all the REE {$(Ce - Yb)_N$= 1.85 to 4.47}. The samples from Tegar village and Sati bridge are moderately enriched in REE. Volcanics of Tegar village show REE enrichment from 101 -141 x chondrite for Light Rare Earth Elements (LREE) and 9 - 14 x chondrite for Heavy Rare Earth Elements (HREE) with low to moderate negative Eu anomaly (Eu/Eu*= 0.46 - 1.02) (Text-figure 9). The chondrite normalized REE pattern of Sati bridge volcanics (Text-figure 10) suggest that the LREE are comparatively less enriched with ratio {$(La/Sm)_N$ = 1.7 - 4.3} whereas in Shukur the ratio is very low {$(La/Sm)_N$= 1.4 - 3.2}. The HREE contents are almost uniform for all the samples {$(Gd/Yb)_N$= 0.99 - 2.5}. The chondrite normalized REE pattern (Text-figure 8) for Shukur volcanics indicate that these rocks may belong to a primitive N - MORB to E - MORB. The Tegar village and Sati bridge volcanics, however, resembles to transitional nature of the basalts between E - MORB to OIB (Text-figures 9, 10). No radiometric data are available from the Shyok Volcanics.

Tirit Granitoids

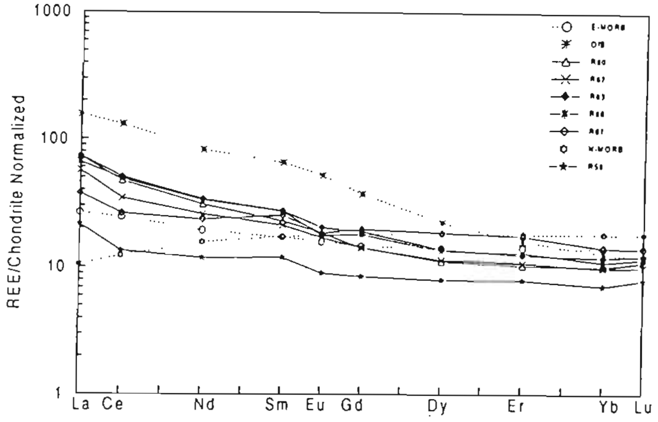
Several granitic plutons are exposed immediately in the south of the Shyok Suture (Text-figures 2, 3, 4, Plate 1a). We call these WNW-ESE aligned plutons collectively the Tirit Granitoids. They consist of mildly deformed medium-to coarse-grained rocks, subleucocratic to mesocratic, relatively rich in ferromagnesian minerals and compositionally ranging from granodiorite-tonalite to gabbrodiorite. At several places they were intruded by vertical, undeformed, NW-SE trending



Text-figure 6–Major oxides versus MgO% variation diagrams for Shyok Volcanics. Symbols as in Text-figure 5.



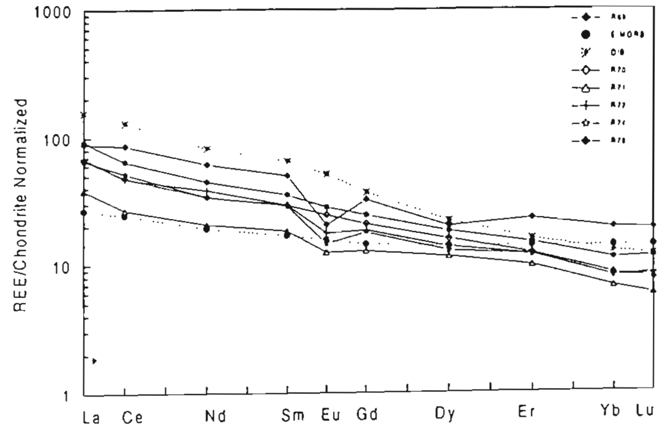
Text-figure 7–Trace element versus MgO% variation diagrams for Shyok Volcanics. Symbols as Text-figure 5.



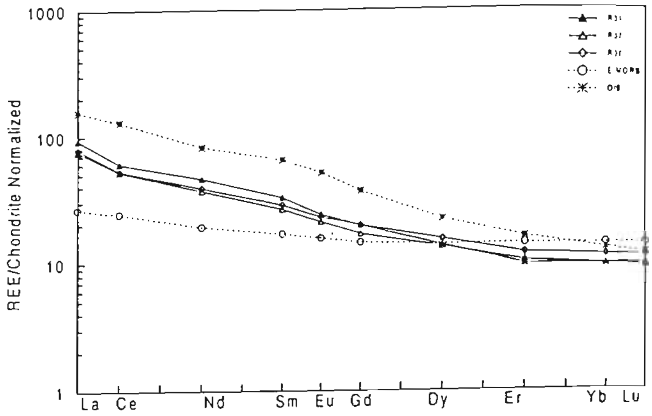
Text-figure 8–Chondrite normalised REE pattern for Shukur volcanics (normalising values and data for N-MORB, E-MORB and OIB after Sun & Mc Donough, 1989).

basic dykes that are 0.5-1 m thick. The granitoids are more basic at their margins than in the core and show hybridization and chilled margins along the intrusive contacts with the Shyok Volcanics. Fine-to medium-grained mafic xenoliths with sharp boundaries are common and range from a few mm to 50 cm in diameter. At some places metasedimentary enclaves are also present.

The Tirit Granitoids consist of plagioclase (oligoclase-andesine), K-feldspar, quartz and mafic minerals. Plagioclase laths are euhedral and enclosed within subhedral grains of K-feldspar and quartz. Most plagioclase crystals contain secondary sericite and epidote. Hornblende is abundant in diorites. The granodiorites display graphic intergrowth between quartz and feldspar, and plagioclase laths exhibit oscillatory zoning. Biotite is partly altered to green chlorite. The tonalites have lower K-feldspar and quartz contents than the granodiorites. Zircon, apatite, opaques and epidote are common accessory minerals.



Text-figure 9–Chondrite normalised REE pattern for Tegar volcanics (normalising values and data for N-MORB, E-MORB and OIB after Sun & Mc Donough, 1989).



Text-figure 10–Chondrite normalised REE pattern for Sati bridge volcanics (normalising values and data for N-MORB, E-MORB and OIB after Sun & Mc Donough, 1989).

Geochemistry of the Tirit Granitoids

A total of 31 samples of Tirit Granitoids were analyzed and 10 representative examples are presented in Table 2. The analytical procedures are the same as for the Shyok Volcanics.

The Tirit Granitoids have a wide range of SiO_2 content (56.39 to 70.83 wt% , Table 2). The rocks thus range from quartz-diorite to tonalite, granodiorite and granitic rocks (Text-figure 11). The Al_2O_3 and CaO contents are generally high (15.3 to 17.08 wt% and 2.48 to 7.07 wt%, respectively). The high concentration of Al_2O_3 and CaO may be related to the plagioclase composition that remains relatively calcic even in silica-rich rocks. In most samples the relative concentration of Na_2O exceeds that of K_2O. According to AFM (Na_2O+K_2O-FeO*-MgO) and QBF diagrams (Text-figures 12, 13) where Q = {Si/3-(K+Na+2Ca/3)}, B = (Fe+Mg+Ti) and F = {555-(Q+B)} the Tirit Granitoids reflect at least for their major part a subalkaline trend intermediate between calcalkaline and alkaline.

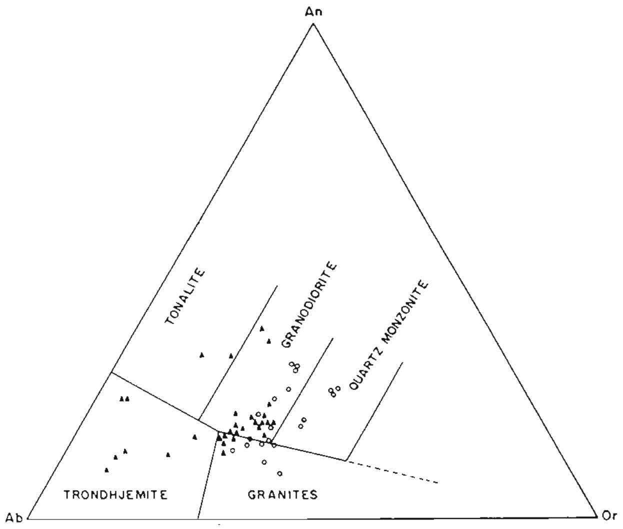
Major element Harker variation diagrams (Text-figure 14) show a marked decrease in MgO with increasing SiO_2. Similar trends are shown by Fe_2O_3 and TiO_2. Though a general decrease is shown by Al_2O_3, CaO and P_2O_5 the trends are not well defined. Both major alkali oxides (Na_2O and K_2O) increase with increasing values of SiO_2, but the data points are more scattered. The co-linear, smooth and coherent variation trends of most major oxides suggest magmatic differentiation. In general, no compositional gap seems to exist among the Tirit Granitoids. All rocks of this suite appear to be comagmatic.

A wide variation of trace elements has been measured (Table 2, Text-figure 15) particularly in Ba (163 to 629 ppm), Rb (5 to 158 ppm), Sr (237 to 507 ppm) and Zr (117 to 338 ppm) but also in Ni (3 to 33.2 ppm), Pb (1 to 28 ppm) and Cu (1 to 57.3 ppm). The granitoids are depleted in Nb (5 to 14

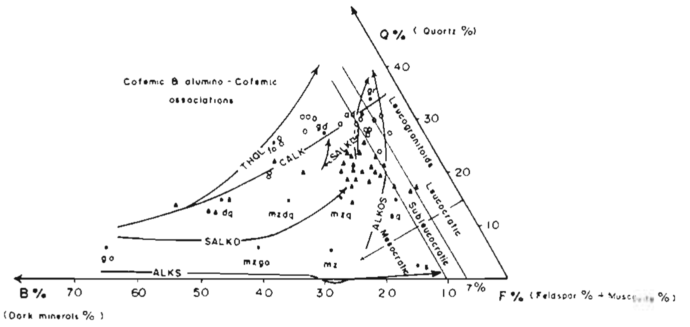
Table 2—Representative geochemical composition of Tirit granitoids.

Rock Type	**mzdq, IV**	**dq, IV**	**mzdq, IV**	**gd, IV**	**ad, IV**	**mzdq, IV**	**gd, IV**	**gd, IV**	**gd, IV**	**gd, IV**
S. No.	**R57**	**R2**	**R6**	**R9**	**R3**	**R16**	**R28**	**R12**	**R24**	**R19**
Major Oxides (wt%)										
SiO_2	56.39	57.16	65.62	66.18	66.59	67.72	68.3	69.04	69.09	70.19
TiO_2	1.1	0.68	0.53	0.53	0.53	0.48	0.47	0.4	0.44	0.39
Al_2O_3	16.11	15.88	16.54	16.25	15.96	16.15	16.1	16.13	15.98	15.5
Fe_2O_3(t)	8.25	7.27	3.93	4.03	3.9	3.59	2.67	2.61	2.6	2.81
MnO	0.12	0.13	0.04	0.04	0.04	0.05	0.04	0.02	0.03	0.05
MgO	5.85	5.24	1.59	1.52	1.47	1.23	1.12	1.06	1.05	0.83
CaO	7.03	7.01	2.97	3.28	2.95	3.33	3.65	2.98	3.52	2.48
Na_2O	3.05	3.7	4.36	4.31	4.04	4.34	4.62	5	4.84	4.17
K_2O	2.63	2.13	4.07	3.62	4.11	3.71	3.37	3.61	3.42	3.99
P_2O_5	0.31	0.24	0.19	0.21	0.19	0.23	0.21	0.19	0.21	0.17
LOI	0.57	0.64	0.93	0.62	0.86	0.81	0.47	0.41	0.43	0.52
Total	101.41	100.08	100.77	100.59	100.64	101.64	101.02	101.45	101.61	101.1
Trace Elements (ppm)										
Ba	342	358	468	441	524	551	467	570	513	572
Ni	18.5	n.d	31	33	33	25	15	19	15	18
Cu	57.3	n.d	10	27	22	8	6	7	5	6
Zn	77.9	n.d	0	0	1	2	b.d	b.d	b.d	6
Ga	16	n.d	17	17	15	16	19	17	15	15
Pb	4	n.d	15.2	11.5	19.5	5.3	8.7	14.5	9	13.4
Th	1.6	n.d	26	30	28	21	17	20	16	19
Rb	117	n.d	158	146	149	125	81	96	76	127
U	0.9	n.d	8.4	7.3	7.8	6.1	3.1	4.3	2.7	6.7
Sr	315	n.d	289	294	263	282	309	311	299	237
Y	20	n.d	34	31	31	31	31	27	30	24
Zr	117	n.d	239	219	237	206	211	182	200	173
Nb	6	n.d	8	7	7	6	5	7	6	5
Rare Earth Elements (ppm)										
La	n.d	29.3	36.8	34.2	43.6	23	23.8	17.6	21.9	21.5
Ce	n.d	37.2	57.1	52.6	64.4	35.1	42	29.8	38	32.8
Nd	n.d	15.7	24.1	20.5	25	15.8	19.3	13.3	17.1	14.1
Sm	n.d	3.82	5.07	4.65	5.14	4.04	4.87	3.25	4.36	3.3
Eu	n.d	1.15	1.08	0.88	0.99	0.9	1.06	0.76	1	0.78
Gd	n.d	3.09	3.68	3.5	3.7	3.23	3.11	2.47	2.74	2.43
Dy	n.d	2.63	3.5	3.2	3.34	3.17	3.44	2.42	3.12	2.36
Er	n.d	1.61	1.96	1.85	1.93	1.74	1.99	1.4	1.79	1.37
Yb	n.d	1.73	2	1.87	1.75	1.7	2.2	1.47	1.9	1.4
Lu	n.d	0.246	0.281	0.259	0.259	0.237	0.283	0.197	0.25	0.2
CIPW Norm										
q	4.94	5.23	15.09	17.24	19.09	18.97	19.5	18.4	19.4	23.58
or	15.54	12.59	24.05	21.39	24.29	21.93	19.92	21.33	20.21	23.58
ab	25.81	31.13	36.89	36.47	34.19	36.72	39.09	42.31	40.96	35.29
an	22.5	20.43	13.49	14.3	13.28	13.63	13.24	10.91	11.78	11.19
di	8.36	10.33	-	0.49	0.09	1.15	2.86	2.16	3.53	0.22
C	-	-	0.02	-	-	-	-	-	-	-
hy	17.06	14.33	7.02	6.7	4.31	5.32	3.33	3.52	2.78	4.28
mt	3.22	2.84	1.54	1.57	5.65	1.39	1.04	1.01	1.01	1.09
il	2.09	1.29	1.01	1.01	1.01	0.91	0.89	0.76	0.84	0.74
ap	0.72	0.56	0.44	0.49	0.44	0.53	0.49	0.44	0.49	0.39
Plagioclase	An47	An39	An27	An28	An28	An27	An25	An20	An22	An24
A/CNK	0.67	0.74	0.97	0.96	0.97	0.94	0.9	0.92	0.88	0.99

n.d. = not determined

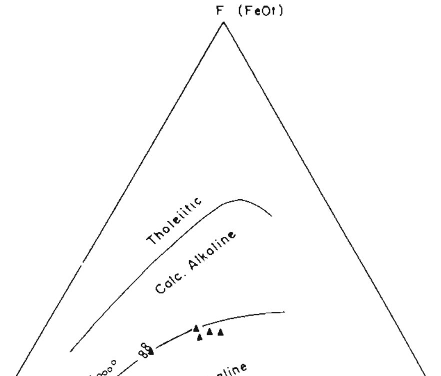


Text-figure 11–An-Ab-Or classification diagram for the Tirit and Karakoram Granitoids (plotted on the diagram after 'O' Connor (1965). Dark triangles = Tirit Granitoids; open circles=Karakoram granitoids.



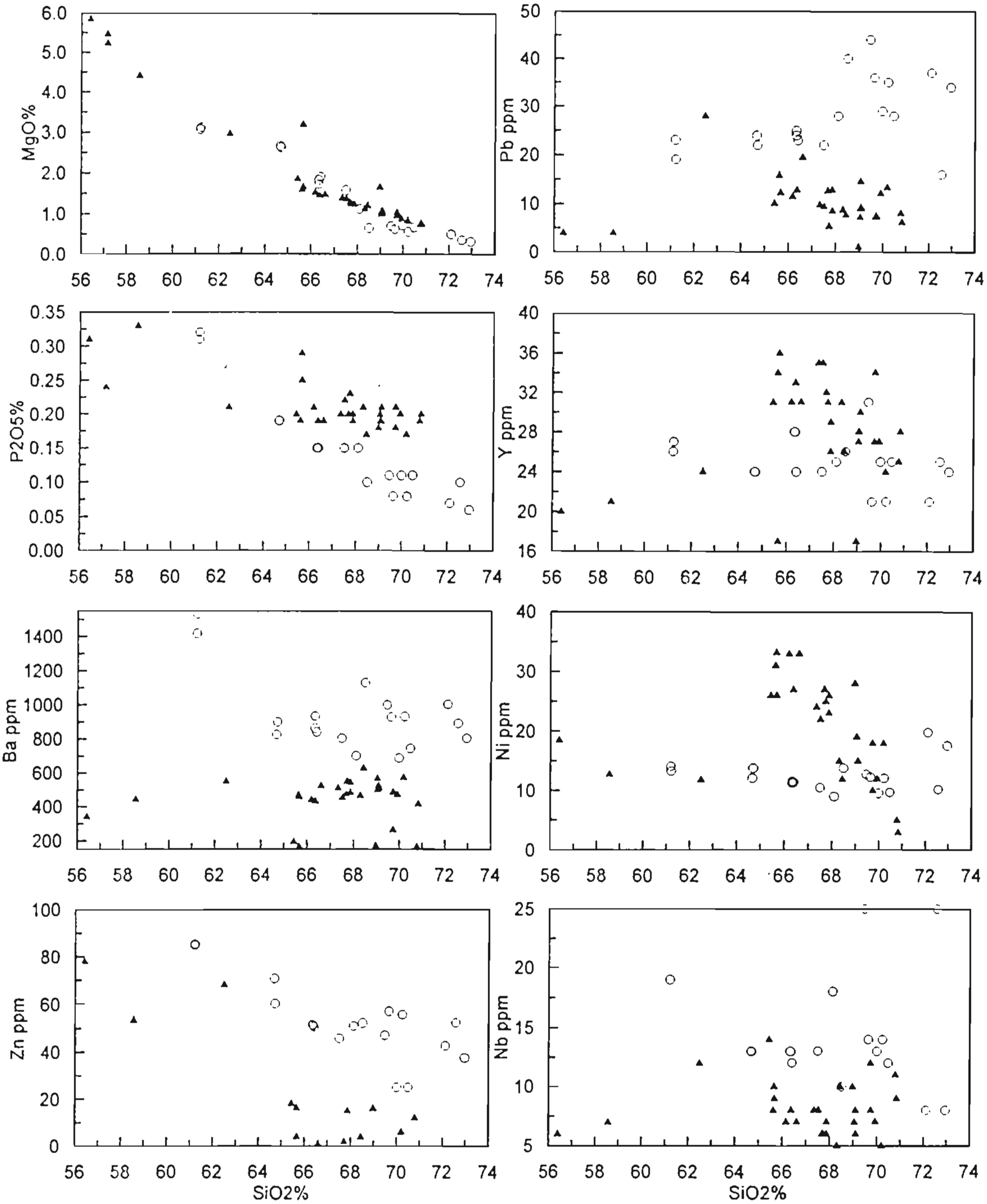
Text-figure 13–Q-B-F diagram shows the subalkaline to calcalkaline trend with cafemic association for Tirit Granitoids, and cafemic and alumino-cafemic associations for Karakoram Granitoids (plotted on the diagram after Debon & Le Fort 1983, 1988). Dark triangles = Tirit Granitoids; open circle = Karakoram granitoids. Different rock types presented in the diagram are: **gr**=granite, **ad**=adamellite, **gd**=granodiorite, **to**=tonalite, **sq**=quartz syenite, **mzq**=quartz monzonite, **mzdq**=quartz monzodiorite, **dq**=quartz diorite, **s**=syenite, **mz**=monzonite, **mzgo**=monzogabbro, **go**=gabbro.

ppm) which suggests arc magmatism. All the samples are rich in Sr (237 to 507 ppm); the tonalite samples have very low contents of Rb (5 to 59 ppm) and very high Sr contents (314 to 507 ppm). This may reflect the higher plagioclase percentage in these rocks. The Rb/Sr value for Tirit Granitoids is low (<1). Similarly, the molar A/CNK value (Aluminous Saturation Index (ASI) of Zen (1986); where molar A/CNK = Al_2O_3/Na_2O+K_2O+CaO ratio) in the Tirit Granitoids ranges between 0.67 to 1.04 (Table 2) and suggests a metaluminous nature of these intrusions. A similar relationship can also be evidenced from a A/CNK versus SiO_2% diagram (Text-figure 16) and also by high normative diopside and corundum values (Table 2). Furthermore, if we follow the classification scheme of Chappel and White (1974) and plot our data, it could be suggested that the Tirit Granitoids are I-type (Text-figure 16). The Y/Nb ratio is > 2 what further suggests island arc magmatism. The trace elements versus SiO_2 variation diagrams for the Tirit Granitoids (Text-figure 15) mostly show that the concentrations of Rb, Y, Zr, Zn, Nb, U and Ga are systematically decreasing with increasing contents of silica. The scattering of some trace elements (Ba, Sr, Th) may be due to a heterogeneous accumulation of some essential and accessory mineral constituents which are rich in these elements (Pearce & Norry, 1979).



Text-figure 12–AFM diagram for the Tirit and Karakoram granitoids. Dark triangles=Tirit Granitoids; open circles = Karakoram granitoids.

The chondrite normalised (Sun & Mc Donough, 1989) REE patterns (Text-figures 17 a, b) are similar for most samples. According to Holtz (1989) the REE concentration in a batholith is strongly enriched in Light Rare Earth Elements (LREE) (La = 20-100 x Chondrite) and depleted in Heavy Rare Earth Elements (HREE) (Yb = 0.5-8 x Chondrite). In the case of the Tirit Granitoids these values are: La = 17-43.6 x chondrite, and Yb = 1.4 -2.37 x chondrite which is consistent with the values of granitoids. All the samples are moderately fractionated in their REE contents {$(La/Lu)_N$ = (8.05-18.1)}. Over all the REE patterns show an enrichment and a good fractionation in LREE {$(La/Sm)_N$ = 2.92 to 5.47} than HREE {$(Gd/Lu)_N$ = (1.35-1.78)} with marked negative Eu anomalies, which indicates feldspar fractionation. The Eu/Eu* values range from 0.66 to 1.02. The chondrite normalised REE patterns further show a flat MREE (Middle Rare Earth Element)-HREE pattern with Gd = 2.43-4.44 x chondrite and Yb = 1.4-2.37 x chondrite. Such a MREE-HREE flat pattern is due to the presence of garnet in the residue melt (Henderson, 1984). The depletion in HREE contents is mainly controlled by the fractionation of garnet from the source melt. The primitive mantle (Sun & Mc Donough, 1989) normalized trace-element patterns (Text-figure 18) show a systematic depletion in Ti, P, Sr, Nb and Ba. This depletion is typical of the calcalkaline magmatism of a subduction zone environment. The Nb versus Y, and Rb versus Y+Nb plots (Text-figure 19)



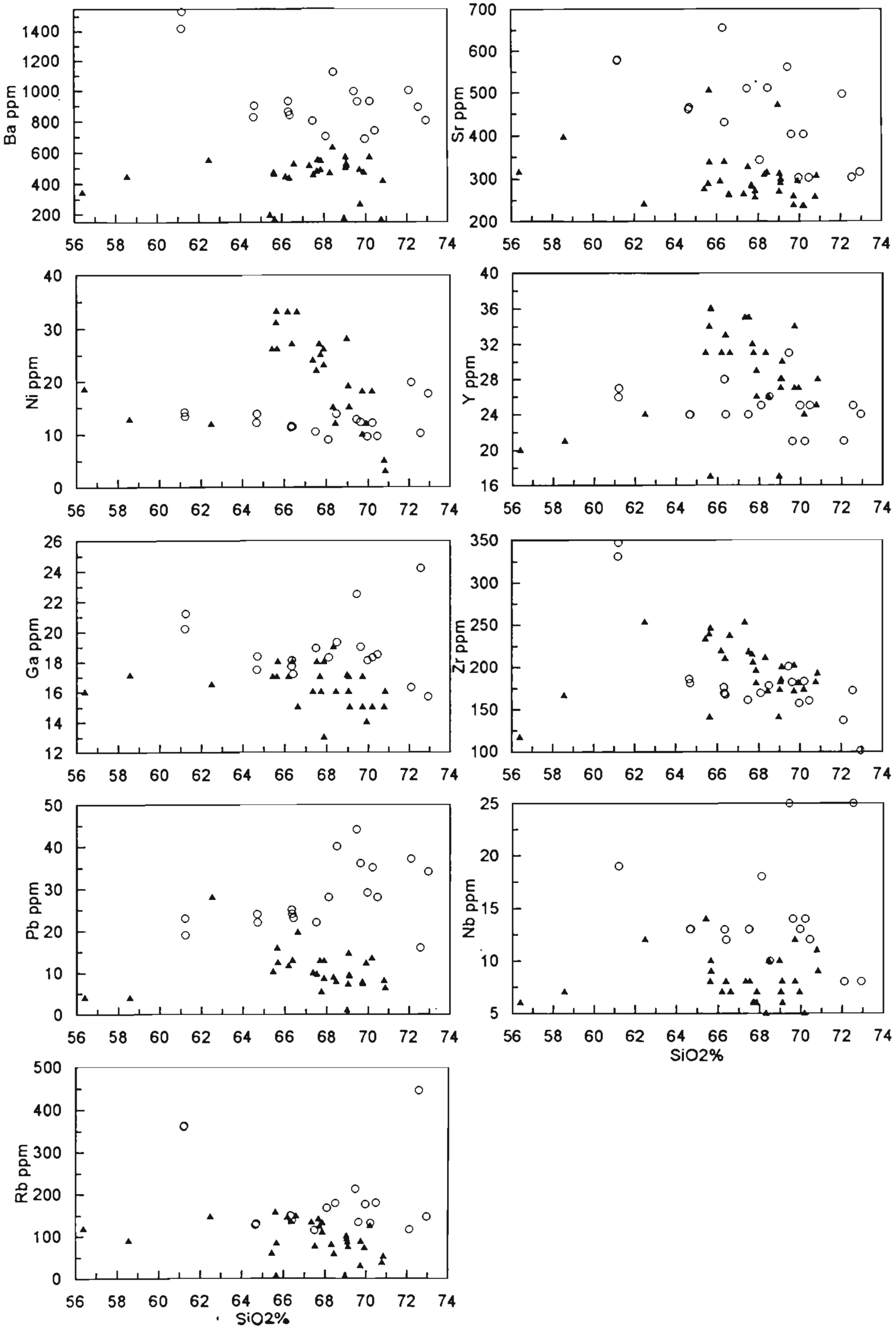
Text-figure 14–Harker variation diagrams for major oxides. Dark triangles = Tirit Granitoids; open circles = Karakoram granitoids.

further confirm the volcanic arc origin of the Tirit Granitoids.

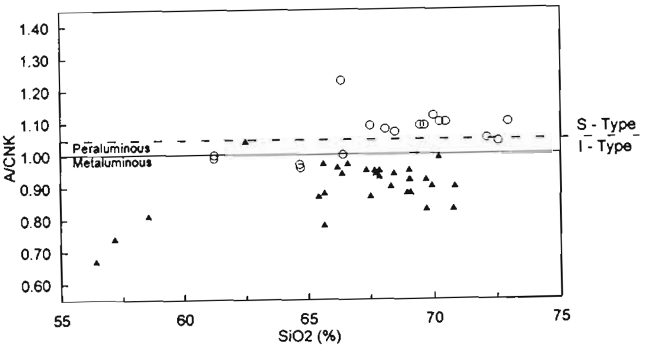
According to Pearce *et al.* (1984) this type of granitoid may be designated as a post-collision granitoid which is formed by melting of the lower crust as a result of thermal relaxation followed by collision and/or also from the melting of the upper mantle due to adiabatic decompression which accompanies post-collision uplift and erosion.

Karakoram Batholith

The Karakoram Batholith, which lies immediately in the north of the Shyok Suture Melange is one of the most important terrane in the eastern Karakoram, which alongwith its metamorphic assemblages represent the southern margin of Asia (Sinha *et al.*, 1999) (Text-figures 2, 3, 4, Plate 1c). The batholith and its associated metamorphic rocks constitutes the



Text-figure 15–Harker variation diagrams for trace elements. Dark triangles = Tirit Granitoids: open circles = Karakoram Granitoids.



Text-figure 16–SiO_2 versus A/CNK diagram for Tirit and Karakoram Granitoids showing metaluminous, I-type and peraluminous, S-type granitoids respectively (plotted on the diagram after White & Chappell 1977). Dark triangles = Tirit Granitoids; open circles = Karakoram granitoids.

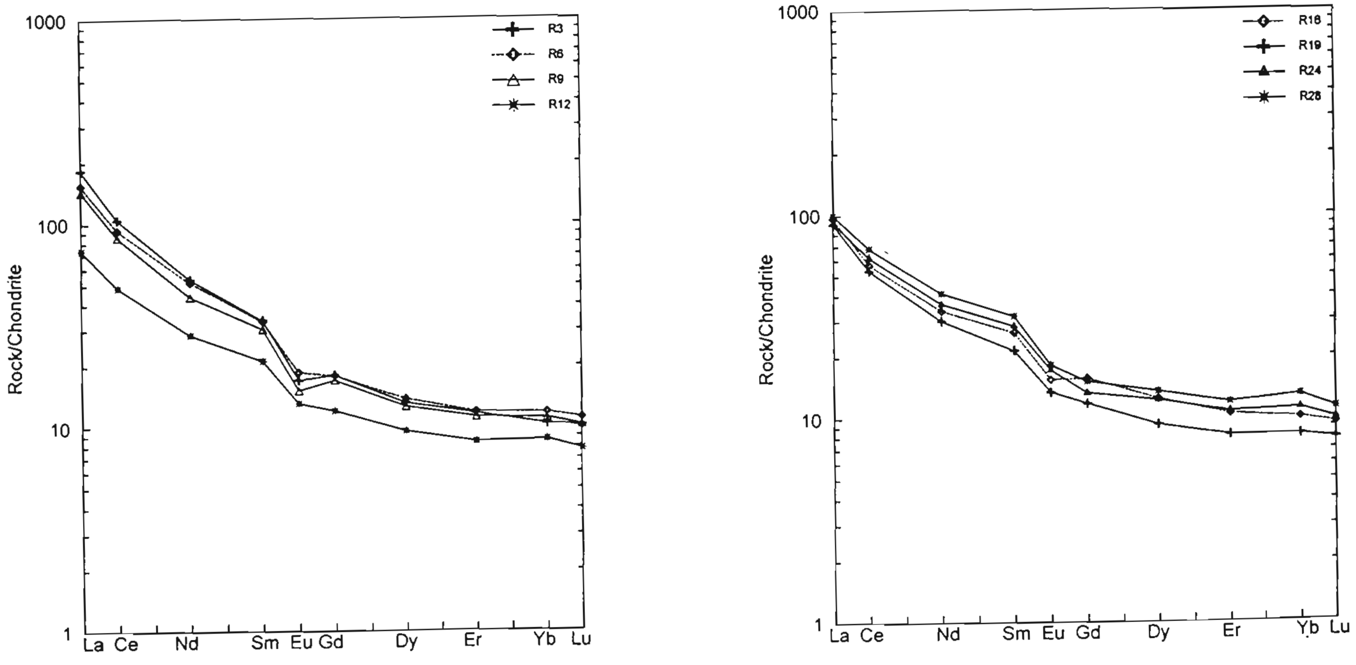
southern part of the eastern Karakoram. The southern contact of the batholith is partly intrusive into, partly faulted against the Shyok Suture Melange (Text-figures 2, 3, 4). The batholith represents a morphologically elevated terrain in the north of the Nubra-Shyok valleys, extending almost parallel to the Shyok Suture (Text-figures 2, 4, Plate 1c). At several places, the sharp contact between the Shyok Suture and Karakoram Batholith is defined by the NW-SE trending Karakoram strike-slip fault zone, which is punctuated by hot springs. The southern boundary of the Karakoram Batholith is defined by mylonites and a ~ 50 m wide zone of metamorphic rocks. The metamorphic rocks are strongly foliated carbonaceous slates, marbles, metaconglomerates, quartzites, micaschist and gneisses.

Near the Shyok Suture Melange the Karakoram Granitoids are leucocratic, coarse-grained, porphyritic orthogneiss. The gneissic character of these rocks decreases northward and the rocks gradually pass into porphyritic granites and granodiorites. The most common rocks of the Karakoram Batholith are weakly to moderately deformed muscovite- and biotite-bearing two mica granites, hornblende-biotite granitoids and medium- to coarse-grained K-feldspar rich granites, enclosing large xenoliths of metasedimentary and mafic rocks. Compositionally, the Karakoram Batholith ranging from granite to quartz monzonite, granodiorite, and tonalite (Text-figure. 11). Aplites, pegmatite dykes, fine grained quartz-feldspathic veins and dykes of intermediate composition are common. The granitic batholith intruded the Carboniferous-Permian sequence of the Karakoram Tethyan zone to the north (Sinha *et al.*, 1999).

Geochemistry of the Karakoram Batholith

Eighteen representative samples of Karakoram Granitoids were analysed for major, trace and rare earth elements (REE); nine representative analyses are given in Table 3. The analytical procedures are the same as for the Shyok Volcanics.

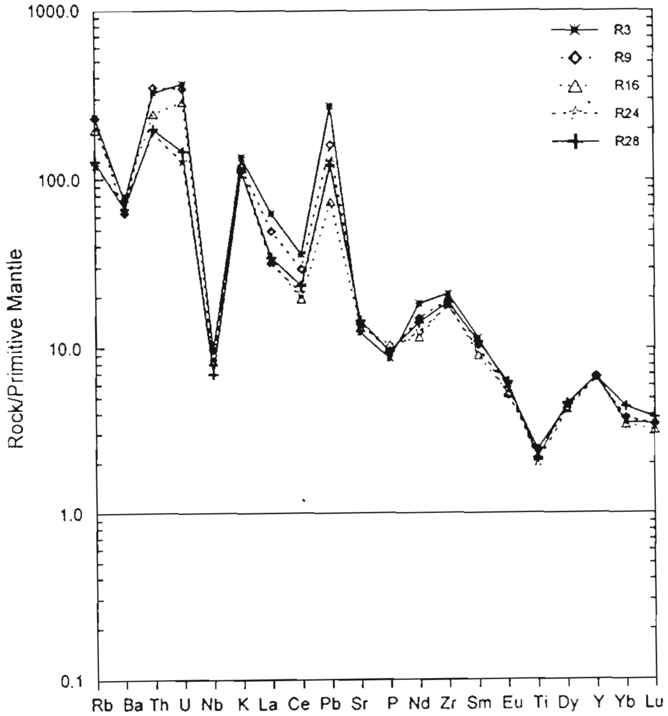
The Karakoram Granitoids have a range of SiO_2-content from 61.2 to 72.95 wt%. This composition ranges from quartz monzonite to granodiorite and granite, they further show a wide range in Al_2O_3 (14.77 to 16.67 wt%) and CaO (1.14 to 4.32 wt%). Granitoids with lower silica contents (61.22 to 64.7 wt%) have higher values of Al_2O_3 (16.53 wt%), CaO (3.85



Text-figure 17a, b.–Chondrite-normalised REE plots for Tirit Granitoids (normalising values after Sun & Mc Donough 1989).

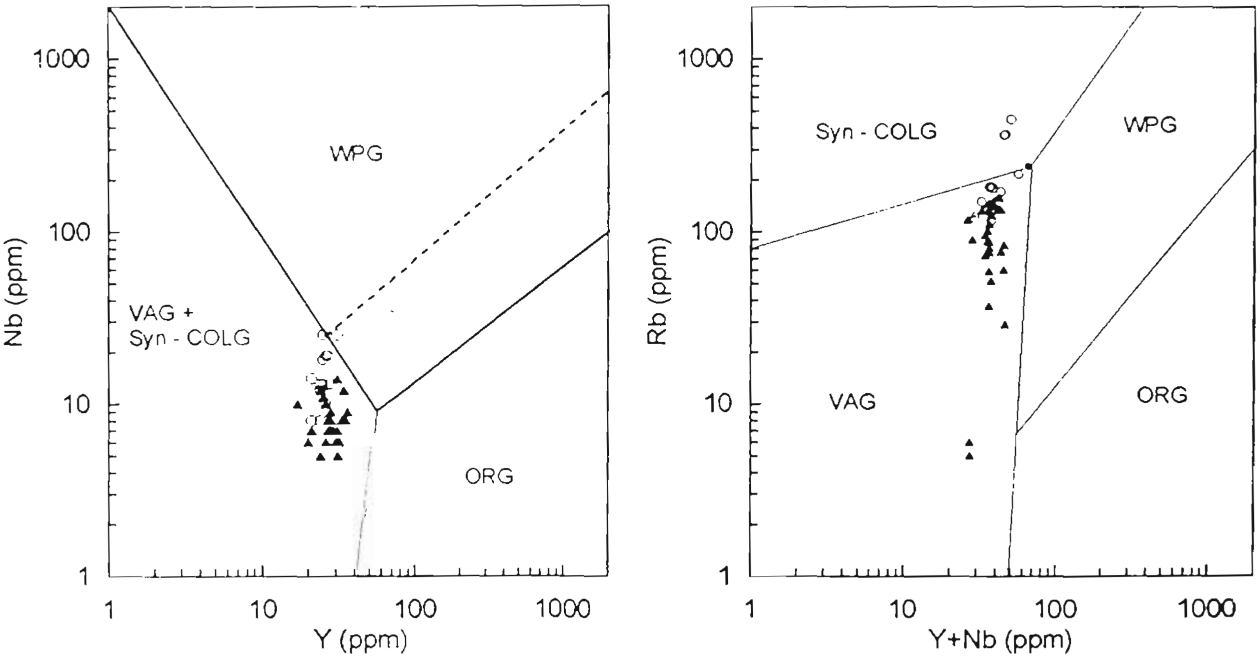
Table 3—Representative geochemical composition of Karakoram granitoids.

Rock Type	mzq, IV	ad, III	gd, III	gd, IV	gd, II	gd, II	ad, II	ad, I	ad, I
S.No.	**K20**	**K18**	**K14**	**K11**	**K9**	**K6**	**K17**	**K13**	**K4**
Major Oxides (wt%)									
SiO_2	61.22	66.33	66.4	67.49	68.1	68.49	69.93	72.11	72.57
TiO_2	0.76	0.5	0.5	0.45	0.45	0.33	0.29	0.23	0.2
Al_2O_3	16.67	15.96	15.41	15.47	15.46	16.46	15.63	15.13	14.77
Fe_2O_3(t)	6.11	3.89	4.3	3.6	3.22	2.36	2.35	1.87	1.51
MnO	0.09	0.08	0.08	0.06	0.05	0.03	0.04	0.03	0.04
MgO	3.12	1.82	1.9	1.57	1.11	0.64	0.62	0.49	0.35
CaO	3.87	2.29	3.5	3.04	2.53	2.17	2.02	1.91	1.14
Na_2O	2.76	2.9	3.14	3.2	3.56	4.3	4.3	4.47	4.28
K_2O	4.74	3.75	3.56	3.2	3.56	3.99	3.52	3.3	4.74
P_2O_5	0.32	0.15	0.15	0.15	0.15	0.1	0.08	0.07	0.1
LOI	0.62	2	1.8	1.7	1.04	0.7	0.8	0.8	0.7
Total	100.37	99.67	100.74	99.93	99.23	99.57	99.58	100.41	100.26
Trace Elements (ppm)									
Ba	1531	933	841	804	702	1129	927	1004	893
Ni	13.3	11.3	11.4	10.5	9	13.8	12.3	19.8	10.2
Cu	14.7	10.1	10.9	7.9	8.9	5.5	5.8	4.9	5.1
Zn	85.3	51.4	50.6	45.7	50.9	52.1	57	42.6	52.3
Ga	21.2	17.7	17.2	18.9	18.3	19.3	19	16.3	24.2
Pb	19	25	23	22	28	40	36	37	11.6
Th	16.3	23.9	15.2	11.8	13.4	25.9	24.8	27.2	11.8
Rb	364	150	139	116	170	181	136	119	447
U	3.1	5.3	4.3	2.2	4	3.7	3.3	3.8	6.1
Sr	579	654	430	509	343	511	402	496	303
Y	27	28	24	24	25	26	21	21	25
Zr	347	176	167	161	169	178	182	137	172
Nb	19	13	12	13	18	10	14	8	25
Rare Earth Elements (ppm)									
La	113.1	62.2	42.4	36.5	39.35	41.9	31.1	33.3	52.2
Ce	221.2	125.3	78.9	62.9	69.3	76.3	60.8	63.3	96.2
Nd	72.8	38.9	28.1	25.7	27.6	28.8	21.2	22.7	35.3
Sm	12.2	6.99	5.54	5.98	6.24	5.86	3.11	4.2	6.53
Eu	2.08	1.17	1.07	1.204	0.995	0.964	0.505	0.963	0.904
Gd	7.6	4.81	4.27	3.89	4.11	3.45	2.08	2.73	3.4
Dy	4.18	3.39	3.4	3.06	3.14	1.97	0.94	1.59	1.82
Er	1.46	1.37	2.08	1.7	1.62	0.93	b.d	0.71	0.9
Yb	1.51	1.62	1.76	1.49	1.32	0.58	0.243	0.56	0.685
Lu	0.213	0.255	0.351	0.225	0.175	0.133	0.019	0.239	0.104
CIPW Norm									
q	12.74	26.48	22.99	26.88	25.95	22.04	25.25	28.16	26.29
or	28.01	22.16	21.04	18.91	21.04	23.58	20.8	19.5	28.01
ab	23.35	24.54	26.57	27.08	30.12	36.39	36.39	37.82	36.22
an	17.11	10.38	16.38	14.1	11.57	10.11	9.5	9.02	5
di	0.73	3.33	0.39	1.57	1.51	1.36	1.57	0.9	0.77
C	-	-	-	-	-	-	-	-	-
hy	12.69	7.67	8.27	6.81	5.33	3.46	3.45	2.74	2.11
mt	2.38	1.52	1.68	1.41	1.16	0.87	0.92	0.72	0.58
il	1.44	0.95	0.95	0.85	0.85	0.63	0.55	0.44	0.38
ap	0.74	0.35	0.35	0.35	0.35	0.23	0.19	0.16	0.23
Plagioclase	An42	An30	An38	An34	An28	An22	An21	An19	An12
A/CNK	1	1.23	1	1.09	1.08	1.07	1.09	1.05	1.04

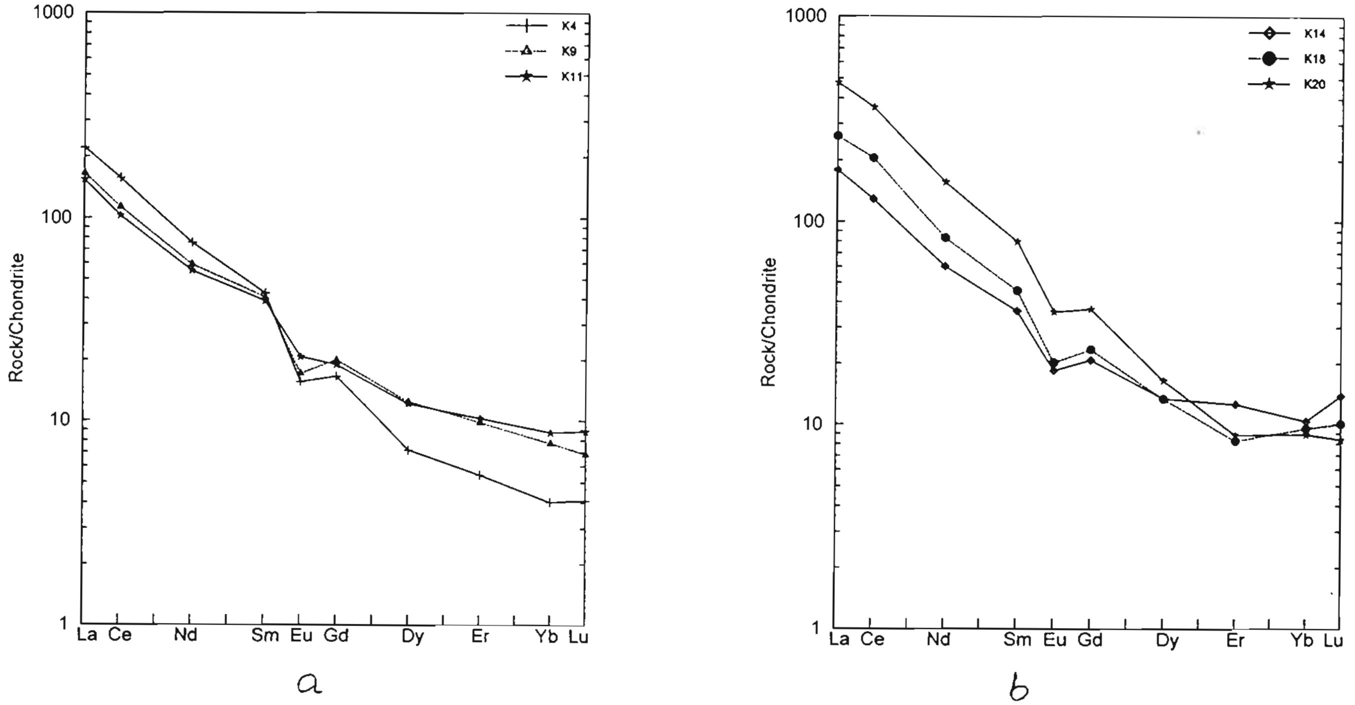


Text-figure 18–Primitive mantle normalised trace element plots for the Tirit Granitoids (normalised values after Sun & Mc Donough 1989).

wt%), TiO_2 (0.75 wt%), $Fe_2O_3(t)$ (6.1 wt%) and P_2O_5 (0.32 wt%) which suggests a quartz-monzonite composition. Except for the quartz monzonite, most of the major oxide versus SiO_2 plots show a systematic decrease in major oxides with increasing values of silica (Table 3; Text-figure 14). According to the AFM and QBF diagrams (Text-figures 12, 13) the Karakoram Granitoids are following both calcalkaline and subalkaline trends. The Karakoram Granitoids have higher A/CNK values which ranges between 0.96 to 1.23 and suggests both a metaluminous and peraluminous nature (Table 3). According to SiO_2 versus A/CNK diagram (Text-figure 16) the Karakoram Granitoids are both I- and S-types. Trace elements versus SiO_2 variation diagrams (Text-figure 15) show that Rb, Y, Zr, Sr and Nb elements systematically decrease with increasing values of silica; Pb shows a good negative correlation. Chondrite normalised REE patterns (Text-figures 20 a, b) suggest that all samples are strongly enriched in Light Rare Earth Elements (LREE) (La=31.1-113.1 x Chondrite) and depleted in Heavy Rare Earth Elements (HREE) (Yb=0.56-1.76 x Chondrite). This indicates that the Karakoram Granitoids are more LREE enriched than the Tirit Granitoids. All the samples are highly fractionated in their total REE contents with a $(La/Lu)_N$ ratio of 12.95 to 56.94. An enrichment in LREE is also observed in the ratio $(La/Sm)_N$=3.94 to 5.98 and a depletion in HREE in the ratio $(Gd/Lu)_N$=1.41 to 4.41. The primitive mantle normalised trace-element patterns (Text-figure 21) show a systematic depletion in Ti, P, Sr, Nb and Ba. This depletion is typical of a calcalkaline magmatism in a subduction zone environment. Similarly the Nb versus Y, and Rb



Text-figure 19–Nb-Y and Rb-Y+Nb tectonic discrimination diagrams showing volcanic arc granite (VAG) + syn-collision granite (Syn-COLG) setting for the Tirit and Karakoram Granitoids respectively (plotted on the diagram after, Pearce *et al.*, 1984). Dark triangles = Tirit Granitoids; open circle = Karakoram Granitoids.



a

b

Text-figure 20 a, b–Chondrite-normalised REE plots for the Karakoram Granitoids (normalised values after Sun & Mc Donough 1989).

versus Y+Nb diagrams (Text-figure 19) suggest that the Karakoram Granitoids display chemical characters of both the VAG (volcanic arc granite) and the Syn-COLG (syn-collision granite).

The volcanic arc granitoids of the Karakoram also show a close compositional affinity with the continental arc plutonism recorded from the Chile arc (Baldwin & Pearce, 1982), which is further supported by the occurrence of both the I- and S-type granitoid signatures and the depletion in Ti, P, Sr, Nb, and Ba (Text-figure 21). Similarly, samples K4 and K20 (Table 2) from the Karakoram Granitoids show a significant enrichment in Rb, Ba, Large Ion Lithophile Elements (LILE) and a strong depletion in High Field Strength Elements (HFSE), which suggests a chemical signature similar to those of syn-collision granitoids.

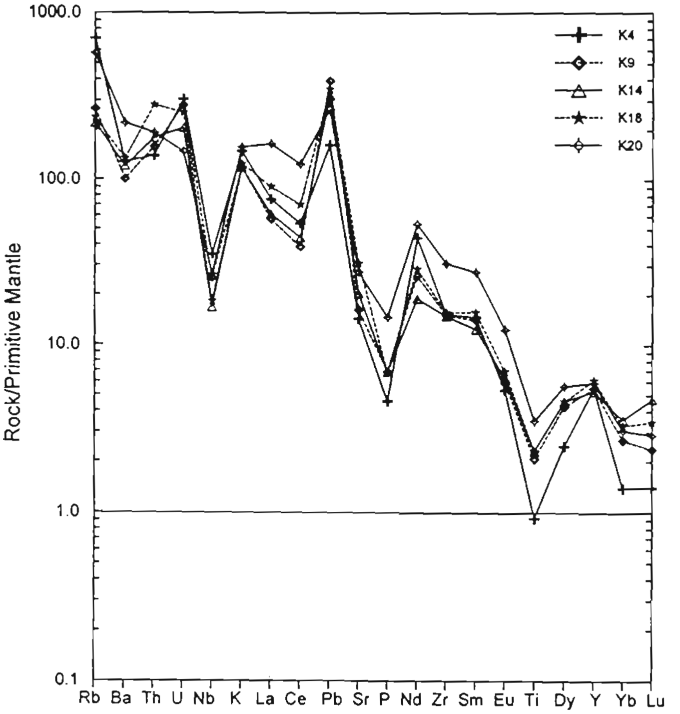
We have dated three samples of the S-type granite collected from the middle part of eastern Karakoram Batholith by using Rb/Sr isotopic whole rock technique. These samples document syn-collisional arc magmatic signatures (Rakesh Chandra, 1999). This S-type granite is 83 ± 9 Ma old with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7994 ± 0.00023 (Sinha *et al.*, 1997) (Text-figure 22).

Tectonic implication and Discussion

In the Shyok Suture Zone the high-Mg tholeiitic basalt and calc-alkaline andesites of the Shyok Volcanics have a subduction zone chemical signature; the calcalkaline andesites are intruded by the Tirit Granitoids, whereas the high-Mg tholeiitic basalt are overlain by Albian-Aptian *Orbitolina*-bearing limestones and turbidites of the Saltoro Formation (Upadhyay *et al.*, 1999). REE data on Shyok Volcanics indicate that at Shukur village these rocks show chemical signatures intermediate between primitive N-MORB to E-MORB). The Tegar village and Sati bridge volcanics, however, resembles to transitional nature of basalt between E-MORB to OIB. Interestingly, if we look into the data from the Northern Suture in Kohistan (Petterson & Windley, 1985, 1991; Pudsey, 1986; Coward *et al.*, 1986; Treloar *et al.*, 1996; Khan *et al.*, 1998), it appears that the Chalt Volcanics and overlying Aptian-Albian sediments (limestone and turbidites) of the Yasin group have a close similarity with the Shyok Volcanics and the Saltoro Formation (Upadhyay *et al.*, 1999).

Petterson and Windley (1985) stated that the arc-batholith growth in Ladakh is characterised by the Dras volcanic arc on the south side of the Ladakh Batholith, whereas in Kohistan the Chalt island arc volcanics are on the north side of the batholith. However, our data show that the Shyok Volcanics are exposed on the north side of the Ladakh Batholith which further suggest a correlation between the Chalt volcanics and Shyok Volcanics.

The mildly deformed trondhjemite-tonalite-granodiorite- and granite of the Tirit Granitoids are composite plutons located south of the Shyok Suture Melange. They intrude the Shyok Volcanics and Shyok Suture Melange. These granitoids



Text-figure 21–Primitive mantle normalised trace element plots for the Karakoram Granitoids (normalised values after Sun & Mc Donough 1989).

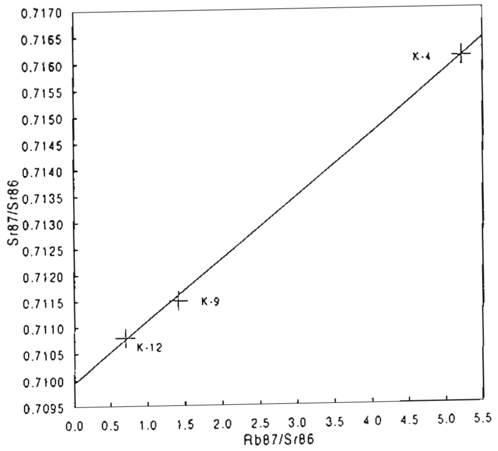
are subalkaline, I-type with volcanic arc chemical signatures. Incidently, the regional tectonic setting, the nature of occurrence and the composition of the Tirit Granitoids are very similar to the plutonic suites of northern Kohistan (Gindai, Matum Das and Nomal plutons of Petterson & Windley 1985, 1991; Debon *et al.* 1987). The northern Kohistan plutonic suites are also located immediately south of the Northern Suture Zone and intrude the Chalt Volcanics (Coward *et al.*, 1986), a tectonic situation similar to that of the Tirit Granitoids. This infers that similarity exist between the Tirit Granitoids and the plutonic suites of northern Kohistan. If this is true then the Tirit Granitoids should also yield ages similar to those reported by Petterson and Windley (1985) for the northern Kohistan plutons as 102 ± 12 Ma, 54 ± 4 Ma and 40 ± 6 Ma. No radiometric data are available on the Tirit Granitoids.

The eastern Karakoram Batholith is dominated by quartz monzonite-tonalite-granodiorite and granite. Unlike the Tirit Granitoids, the subalkaline to calcalkaline Karakoram Batholith is constituted by both I- and S- type granitoids with volcanic arc and syn-collision chemical signatures. Based on REE patterns the I-type granitoids document typical calcalkaline magmatism of a subduction zone environment. In contrast, most of the S-type granitoids are crust-derived, anatectic peraluminous granites.

Age data recorded from the Karakoram Batholith exposed along the Karakoram highway in northern Pakistan range mostly between the Jurassic & Early Cretaceous to Eocene and the Miocene (Brookfield and Reynolds, 1981; Reynold *et al.*, 1983; Le Fort *et al.*, 1983; Debon *et al.*, 1987; Zeitler, 1985). The occurrence of Eocene to Miocene ages from the Karakoram Batholith has been interpreted by some workers to indicate that the Northern Suture of Kohistan and the Shyok Suture of Ladakh are younger than the 50-60 Ma Indus Suture (Brookfield & Reynolds, 1981). However, based on Rb-Sr and ^{40}Ar/^{39}Ar data, Srimal *et al.* (1987) suggested an age range between 130 and 50 Ma for the eastern Karakoram batholith. According to them the composite Karakoram batholith represents at least two major sources for the magmas. The earlier Jurassic-Early Cretaceous phase represents a continental margin arc magmatism (I-type with δ ^{18}O values < + 8 ‰) and results from subduction along the North Saltoro (Shyok Suture) – Bangong-Nujiang Zone. The later Miocene S-type granites (δ ^{18}O value > + 9.5 ‰) are derived from crustal anatexis in the Miocene due to intracontinental thrusting along the rejuvenated North Saltoro Suture following the India-Asia collision. Recently, Ogasawara *et al.* (1994) dated hornblende and biotite from the Khunjerab pluton as 107 ± 5 Ma and 96.9 ±4.8 Ma respectively. A slightly younger K-Ar biotite ages of 84.2 ± 4.2 and 85.9 ± 4.3 Ma have been obtained by them for the north Sost pluton. Similarly, Debon and Khan (1996) obtained Rb-Sr age of 88±4 Ma (^{87}Sr/^{86}Sr = 0.70440 ± 7) for the Karakoram Batholith located along the Karambar valley in northern Pakistan.

Recently acquired isotopic age data by us on three S-type granite samples of Karakoram batholith (Sinha *et al.*, 1997) indicates that this intrusive phase is 83 ± 9 Ma with an initial ^{87}Sr/^{86}Sr ratio of 0.7994 ± 0.00023 (Text-figure 22). This new age datum suggests a close similarity with the north

S. No.	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}	Age
K4	5.21	0.7161	
K9	1.41	0.7115	83±9 Ma
K12	0.7	0.7108	



Text-figure 22–Rb-Sr whole rock isotopic data for Karakoram granitoid. ^{87}Rb/^{86}Rb versus ^{87}Sr/^{86}Sr isochron for three S-type Karakoram granitoid samples. Age = 83±9 Ma; initial ratio = 0.70994 ±0.00023.

Sost pluton and Karambar valley pluton of main Karakoram Axial batholith exposed in northern Kohistan. The syn-collision nature (Rakesh Chandra, 1999) of these granitoids may indicate that the collision between Kohistan-Ladakh arc and Karakoram block was active 83 ± 9 Ma; which is in close agreement with the age of suturing of the Kohistan and Asia between 100 and 85 Ma (Petterson & Windley, 1991; Treloar *et al.*, 1996) . The above datum is also compatible with the fact that subduction-related magmatism may continue after initial collision for a period of as long as 30-50 Ma (Bonin, 1990). The above mentioned points further suggest that there are at least three stages of batholith growth in the eastern Karakoram region. The Jurassic-Early Cretaceous I-type granitoids most likely formed during subduction of the northern Ladakh margin beneath the Karakoram block followed by the collision-related S-type plutonism during 83 ± 9 Ma. The younger Miocene granitoids may perhaps indicate crustal anatexis along the Shyok Suture following the collision of Indian Plate along the Indus Suture during 50-60 Ma. The different stages of plutonic activity and batholith growth along the Shyok Suture and eastern Karakoram may represent an example of stitching pluton and accretion of terrane between Indian and Asian plates.

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On the genus *Pantophyllum* Rigby 1984

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ABSTRACT

Maheshwari HK & Singh SM 1999. On the genus *Pantophyllum* Rigby 1984. Palaeobotanist 48(3): 211-216.

The nomenclature of *Cordaites*-type of leaves in the Permian Gondwana of India is re-examined. The authors agree that on the basis of the cuticular features these leaves may not be assigned to the genus *Cordaites* Unger. The hitherto commonly used name *Noeggerathiopsis* Feistmantel 1879 is also unacceptable because the type specimen of the generic type [*Noeggerathiopsis hislopii* (Bunbury 1861) Feistmantel 1879a] is a fragment of a leaf that probably had ginkgopsid affinities. The type specimen originates from the Kamthi Formation which according to new interpretation is dated as Triassic in age. It is therefore proposed that all *Cordaites*-type leaves from the Permian Gondwana of India earlier placed in the genus *Noeggerathiopsis* should be transferred to the genus *Pantophyllum*.

Key-words—*Pantophyllum*, *Noeggerathiopsis*, *Cordaites*, Nomenclature, India, Gondwana, Permian.

सारांश

पन्तोफिल्लम रिग्बी 1984 वंश के बारे में

हरिकृष्ण माहेश्वरी एवं शिवमोहन सिंह

परमियन युग में भारत के गोण्डवाना क्षेत्र की *कॉर्डेटीज़* प्रकृति की पत्तियों के नामकरण का पुनः परीक्षण किया गया। लेखक इस बात पर एकमत हैं कि उपचर्मी लक्षणों के आधार पर इन पत्तियों को *कार्डेट अंगर* के अन्तर्गत नहीं रखा जा सकता। अभी तक सामान्यतः प्रचलित नाम *नोएगेरियाथियॉप्सिस फाइस्टमन्टेल* 1879 भी स्वीकार नहीं किया जा सकता, क्योंकि जाति प्ररूप के प्रादर्श *नोएगेरियाथियॉप्सिस हिस्लोपाई* {(बनवरी 1861) फाइस्टमन्टेल} वर्णांश हैं, जो संभवतः गिंगकॉप्सिड के सजातीय थे। प्ररूप प्रादर्श कामथी शेल शैलसमूह से उत्पन्न हैं, जो नई व्याख्या के अनुसार ट्रायसिक युग के हैं। अतः यह प्रस्तावित किया जाता है कि भारत के गोण्डवाना क्षेत्र की समस्त *कॉर्डेटीज़* प्ररूप की पत्तियाँ, जो पहले *नोएगेरियाथियॉप्सिस* वंश में थीं, को *पन्तोफिल्लम* वंश में स्थानान्तरित कर दिया जाना चाहिए।

INTRODUCTION

THE first *Cordaites*-type leaf to be reported from the Gondwana Supercontinent was *Zeugophyllites elongatus* from Tasmania (Morris, 1845). This species and comparative forms were later placed under the genus *Noeggerathia* Sternberg by Dana (1849) in his work on Australian plant fossils. Probably unaware of Dana's publication, Bunbury (1861) described somewhat similar forms as *Noeggerathia? (Cyclopteris?) hislopii* from the beds he considered to be Mesozoic; but which later were considered to be of Late Permian age (Kamthi Formation). More recently it has been suggested that the Kamthi Formation represents a Triassic sequence (Srivastava & Jha, 1997).

Feistmantel (1877), while discussing the identification of similar looking leaves from the Indian Gondwana sediments, expressed his reservation about the use of the name

Table 1.

Name of species	Shape	Apex	Base	Venation	Cuticle
Pantophyllum bihariensis	Spathulate	Not known	Tapering	Veins thick, fibrous, dichotomising but not anastomosing, concentration of veins in basal region 10/cm, 22/cm in middle region.	Hypostomatic, veins not marked on nonstomatiferous surface.
Pantophyllum bunburyana	Narrow spathulate or lanceolate	Obtuse	Narrow tapering	Veins 10-13/cm in basal region, 13-19/cm in middle and apical regions, 429 μm thick in basal region and 312 μm thick elsewhere.	Amphistomatic, stomatiferous and nonstomatiferous bands outlined. Stomatal rows in each band 6-8. Papillae present only on some cells of lower cuticle. Stomatal frequency per mm^2 170-206, subsidiary cells 4-7.
Pantophyllum fibrosa	Spathulate	Obtuse	Narrow tapering	Veins 9-11/cm in basal region, 12-16/cm in middle and apical regions. Veins up to 367 micron thick in basal region, thicker towards apex. Interstitial fibres possibly present.	Hypostomatic, stomatiferous and nonstomatiferous bands present, 8-17 rows of stomata in each band. Cells of lower cuticle papillate; of upper rarely. Stomatal frequency per mm^2 251-300. Subsidiary cells 5-7.
Pantophyllum gondwanensis	Linear ± lanceolate	Bluntly pointed	Tapering	Veins ± indistinct, fine, close, about 22-25/cm in the broadest part.	Hypostomatic, cells of stomatiferous surface papillate. Stomata sparse, 1-4 across a band, subsidiary cells 4-6. Cells weekly cutinised, subsidiary cells, relatively thicker specially along their inner walls.
Pantophyllum indica	Linear spathulate	Broadly rounded	Tapering blunt base	Veins dichotomising, about 13-20 veins/ cm in widest region.	Cuticle amphistomatic, stomatiferous and nonstomatiferous bands outlined. Cells of stomatiferous surface papillate. 2-10 rows of stomata in each band, frequency 140-170 mm^2. Subsidiary cells 4-8. Cells of stomatiferous band and specially the subsidiary cells heavily cutinised.
Pantophyllum papillosa	Spathulate	Obtuse	Tapering	Veins 10-13/cm in basal region and 13-19/cm in middle and apical regions. Veins normally up to 222 μm thick, interstitial fibres absent.	Hypostomatic, stomatiferous and nonstomatiferous bands present, stomatal rows in each band 2-8. Papillae present on most cells of lower cuticle, absent on upper. Stomatal frequency per mm^2 186-284. Subsidiary cells 4-7.

Name of species	Shape	Apex	Base	Venation	Cuticle
Pantophyllum saharjuriensis	Linear spathulate	not known	Tapering	Veins straight, dichotomising but not anastomising. Concentration in the middle region being 26/cm.	Stomata present only on one surface, vein and inter-vein areas not marked on nonstomatiferous surface. On stomatiferous surface stomatiferous and nonstomatiferous bands outlined, cells of non-stomatiferous band rectangular, arranged end-to-end, those of stomatiferous bands polygonal. Stomata haplocheilic, arranged 2-5 in linear rows. Stomatal apparatus monocyclic, subsidiary cells 4-8.
Pantophyllum spatulata	Broadly spathulate or rhomboidal	Acute	Narrow-tapering	Veins thin, erect, frequently dichotomise, veins 16-18/cm, angle of divergence between two veins about 9°-13°.	Not known.
Pantophyllum zeilleri	Lanceolate	Bluntly pointed	Gradually tapering	Veins clear, arising straight from base, divergent, dichotomising frequently, about 13-14 veins/cm in the broadest part.	Stomata occur only on one surface. Cells of stomatiferous surface non-papillate. Stomata sparse, 1-3 or 4 across a band, subsidiary cells 5-6, hardly distinguishable from other epidermal cells.

Noeggerathia for these leaves. He believed the latter to be "more allied to *Zamia* than any other genus". Feistmantel (1879a) brought out the fact that the leaves of the genus *Noeggerathia* Sternberg 1822 (Type species: *N. foliosa*, Upper Carboniferous of Bohemia) had simple, and not forked veins; on the other hand, the Indian leaves had distinctly dichotomous veins. He also compared the Indian leaves with those of the genus *Cordaites* Unger. The latter are, however, strap-shaped with parallel margins, only slightly narrower at the base whereas the Indian leaves are usually spathulate in shape. He, therefore, proposed a new genus "*Noeggerathiopsis*" for all leaves formerly referred to *Noeggerathia* and which were distributed in sedimentary deposits ranging from the Talchir to the Kamthi. He again emphasised on their cycadalean connection. Bunbury's *N. hislopii* was included under this genus as *Noeggerathiopsis (Zamia?) hislopii*. In the following years this species came to be regarded as the type species of the genus.

Feistmantel (1879b) transferred Dana's species to his new genus while maintaining their separate specific identities. This being the case, *N. spatulata* (Dana 1849) Feistmantel 1879 has priority over *N. hislopii* (Bunbury 1861) Feistmantel 1879, and hence the latter species was merged with *N. spatulata* by Rigby, Maheshwari and Schopf (1980). Thus *N. spatulata* replaced *N. hislopii* as type species of the genus. *Zeugophyllites elongatus* Morris, that was considered by Dana (1849) as another species of *Noeggerathia*, was transferred to *Podozamites* by Feistmantel (1890) and to *Phoenicopsis* by Seward (1903). Interestingly, specimens of *Noeggerathiopsis hislopii* reported by Zeiller (1902/1903) from Tonkin (Vietnam) were also included under *Phoenicopsis elongata* (Morris) Seward (Seward, 1903).

Zeiller (1896) recovered cuticles from specimens which he believed belonged to *Noeggerathiopsis hislopii*. The specimens, collected from the area near Johannesburg, South Africa, are a mixed lot. One of the specimens (Zeiller, 1896, pl. 18, fig. 6) is closer to *Noeggerathiopsis (Glossozamites) stoliczkanus* (Feistmantel) Arber 1905 than to *N. hislopii*. Another specimen (*loc. cit.*, pl. 18, fig. 7) has a very narrow base unlike that known in any *N. hislopii*-type leaf. The line drawings of cuticular pieces apparently show sunken stomata, a character not noticed in later investigations on cuticular anatomy of *Noeggerathiopsis* leaves (Lele & Maithy, 1964; Pant & Verma, 1964; Bajpai, 1990).

The creation of the genus *Noeggerathiopsis* by Feistmantel has been disputed by many later workers. Seward (1903) pointed out that "had the leaves referred to *Noeggerathiopsis* been found in European Palaeozoic rocks there can be little doubt that they would have been described under the name *Cordaites*". Seward and Leslie (1908), Seward (1912, 1917), Seward and Sahni (1920), Walton (1929), Feruglio (1951), Meyen (1963, 1964), Archangelsky and Arrondo (1973), Rigby, Maheshwari and Schopf (1980), and others followed this line of argument and used the name *Cordaites*. Meyen (1964, p. 98) remarked "I consider that the genus *Noeggerathiopsis* was based on a mistake and should be abolished. Most Gondwana Cordaiteans should be referred to *Cordaites* s.l.". He also did not believe that the Gondwana and Angaran cordaitean leaves belonged to the same genus. He observed presence of dorsal furrow in some Angaran leaves, a character of great significance in taxonomy, and established the genus *Rufloria* for the same. *Cladostrobus*, the male fructification assigned to this genus (Maheshwari & Meyen, 1975), has an organisation not known in the fructifications associated with *Cordaites*. McLoughlin and Drinnan (1996) have shown that in leaf anatomy, as observed in permineralised specimens from Antarctica, leaves of *Noeggerathiopsis* are quite different from the Northern Hemisphere cordaites.

Rigby, Maheshwari and Schopf (1980, p. 20) were of the opinion that all the leaves referred to different species of *Noeggerathiopsis* on the basis of differences in cuticular features belong to a single morphological type and went on to propose "that all non-cuticular cordaitalean leaves from Lower Gondwana strata identified to date be given the name *Cordaites spatulata*". They left out Gondwana cordaitalean leaves with cuticles from the circumscription of *C. spatulata*. Rigby (1984) proposed the generic name *Pantophyllum* "for species formerly attributed to *Noeggerathiopsis* that have distinctive cuticles, thus can not be recombined with *Cordaites*". Bajpai (1990), however, disagreed. She pointed out that if new genera were created simply because a leaf had yielded cuticle one would have to create new genera for all the species/specimens with cuticle in the genera *Glossopteris, Gangamopteris, Palaeovittaria, Buriadia*, etc. She hence maintained the genus *Noeggerathiopsis*. Bajpai (1992), however, observed that Bunbury's specimens from Late Permian Kamthi sediments, which formed the base of Feistmantel's *Noeggerathiopsis*, may have ginkgopsid, rather than cordaitalean affinities. The Early Permian *Cordaites*-type leaves from the Gondwana were thus left without a formal generic name. She therefore adopted the generic name *Pantophyllum* Rigby for all *Noeggerathia spatulata*-type leaves.

Kovács-Endródy (1987) raised another problem, that is, the presumed difficulty of separation of *Palaeovittaria* from *Noeggerathiopsis*. Of the seven specimens illustrated in her paper as leaves of *Palaeovittaria*, probably none belongs to this genus. The single specimen that she assigns to *Noeggerathiopsis* is more likely to be a ginkgopsid leaf.

To summarise the above discussion:

1- Cordaites-type leaves are reported from Early Permian or Gondwana Supergroup;
2- Similar looking leaves from the Late Permian/Early Triassic Kamthi Formation probably are not related;
3- The name *Noeggerathiopsis* (because of its association with species *hislopii)* thus needs to be restricted to Late Permian/Early Triassic forms;
4- For Early Permian leaves one may use either of the generic names *Cordaites* or *Pantophyllum*.

Zeiller (1896), Pant and Verma (1964), and Maithy (1965) have made a valid point for not using the name *Cordaites* for Gondwana leaves. Therefore the name *Pantophyllum* Rigby can be adopted; its circumscription being the same as proposed by Pant and Verma (1964) and Maithy (1965) for "*Noeggerathiopsis*".

Diagnosis (based on Rigby, Maheshwari & Schopf, 1980; Maithy, 1965, and Pant & Verma, 1964):

Leaves simple, broadly symmetrical, lamina broadening gradually upwards from a narrow and truncate base, widest in the region near the apex, linear, oval-spathulate, spathulate, or obovate. Apex acute, obtuse or broadly rounded. Margin entire. Lamina tapering towards the base, broadening slightly at base. Midrib absent. Veins numerous, radiating from base where there are four equally sized veins; veins dichotomising once or several times, spreading very gradually, appearing parallel over a short distance, and running straight up to the margin without curving or anastomosing; interstitial fibers occasionally present. Lamina amphistomatic or hypostomatic. Upper cuticle comparatively thick, showing no differentiation of cells in areas between and above veins and all cells arranged in rows parallel to veins; stomata, where present, fewer than those of lower cuticle. Lower cuticle showing alternately arranged non-stomatiferous and stomatiferous bands, respectively above and between veins; stomata haplocheilic, arranged in one to many ill-defined longitudinal rows between veins. Guard cells longitudinally orientated, subsidiary cells usually six.

Speciation in *Pantophyllum*

Morphographically, i.e., in external characters, such as, shape, venation, etc. almost all the leaves can be assigned, and actually have been assigned to one species. This species is now named as *Pantophyllum spatulata* (Dana, 1849) Bajpai 1992.

The investigation of the cuticular features of these leaves, however, has led to institution of several new species (Lele & Maithy, 1964; Pant & Verma, 1964; Bajpai, 1990) which were earlier placed under the genus *Noeggerathiopsis*. Now with the proposed restriction of the name *Noeggerathiopsis* to possibly ginkgopsid leaves of *N. hislopii* Bunbury-type from the Late Permian/Early Triassic, the other species need to be transferred to the genus *Pantophyllum*.

1. *Pantophyllum spatulata* (Dana) Bajpai 1992

[=*Noeggerathia spatulata* Dana, 1849; Australia. *non*

Noeggerathia hislopii Bunbury, 1861; Late Permian/Early Triassic, Kamthi Formation, India]

[=*Noeggerathiopsis densinervis* Maithy, 1965; Early Permian, Karharbari Formation, Giridih Coalfield, India]

2. *Pantophyllum bunburyana* (Pant & Verma) Rigby 1984

[=*Noeggerathiopsis bunburyana* Pant & Verma, 1964; Early Permian, Karharbari Formation, Manendragarh Coalfield, India]

3. *Pantophyllum papillosa* (Pant & Verma) Rigby 1984

[=*Noeggerathiopsis papillosa* Pant & Verma, 1964; Early Permian, Karharbari Formation, Manendragarh Coalfield, India]

4. *Pantophyllum fibrosa* (Pant & Verma) Rigby 1984

[=*Noeggerathiopsis fibrosa* Pant & Verma, 1964; Early Permian, Karharbari Formation, Manendragarh Coalfield, India]

5. *Pantophyllum indica* (Lele & Maithy) comb. nov.

[=*Noeggerathiopsis indica* Lele & Maithy, 1964; Early Permian, Karharbari Formation, Ganjra Nala Beds, South Rewa Basin, India]

6. *Pantophyllum gondwanensis* (Lele & Maithy) comb. nov.

[=*Noeggerathiopsis gondwanensis* Lele & Maithy, 1964; Early Permian, Karharbari Formation, Ganjra Nala Beds, South Rewa Basin, India]

7. *Pantophyllum zeilleri* (Lele & Maithy) comb. nov.

[=*Noeggerathiopsis zeilleri* Lele & Maithy, 1964; Early Permian, Karharbari Formation, Giridih Coalfield, India]

8. *Pantophyllum saharjuriensis* (Bajpai) comb. nov.

[=*Noeggerathiopsis saharjuriensis* Bajpai, 1990; Early Permian, Karharbari Formation, Saharjuri Outlier, Deogarh Coalfield, India]

9. *Pantophyllum bihariensis* (Bajpai) comb. nov.

[=*Noeggerathiopsis bihariensis* Bajpai, 1990; Early Permian, Karharbari Formation, Saharjuri Outlier, Deogarh Coalfield, India]

The morphographic and cuticular characters of different species are plotted in Table 1.

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Palynostratigraphic studies of sub-surface Raniganj – Barren Measures sediments from Mand-Raigarh Coalfield, Son-Mahanadi, Madhya Pradesh, India

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ABSTRACT

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The dispersed spore and pollen grains preserved in Mand-Raigarh Coalfield, Madhya Pradesh. In the present investigation studied the bore-hole RGP-7. This bore-hole run through Raniganj-Barren Measures Formations as well as lithologically, while the palynofloral composition show the Raniganj period (Late Permian flora). The dominance of *Striatopodocarpites* and *Faunipollenites* alongwith *Alisporites, Crescentipollenites, Densipollenites, Rhizomaspora, Verticipollenites, Lunatisporites* etc. This palynoassemblage is similarly found in Raniganj as well as Barren Measure sediments, hence, whole strata deposited in Late Permian time (Raniganj Formation).

Key-words—Palynostratigraphy, Correlation, Gondwana, Son-Mahanadi Graben.

सारांश

भारत के मध्य प्रदेश के सोन महानदी के थाले में स्थित मण्ड-रायगढ़ कोयला क्षेत्र से प्राप्त अधोस्तर रानीगंज, बैरेन मेज़र अवसादों का परागाणुस्तरिकीय अध्ययन

किन्डु लाल मीणा

परिक्षिप्त बीजाणु एवं परागकण मध्य प्रदेश के मण्ड-रायगढ़ कोयला क्षेत्र में संरक्षित हैं। वर्तमान अन्वेषण में वेध छिद्र आर.जी.पी.-7 का अध्ययन किया गया है। यह वेध छिद्र रानीगंज बैरेन मेज़र शैलसमूह के साथ आशिमक रूप से होकर जाता है, जबकि परागाणुवनस्पतिजात संघटन रानीगंज आयु (अन्तिम उपरिपरमियन वनस्पतिजात) को प्रदर्शित करता है। *स्ट्रायटोपोडोकार्पाइटीज़* तथा *फॉनीपोलेनाइटीज़* के साथ -साथ *एलिस्पोराइटीज़, क्रीसेन्टीपोलेनाइटीज़, डेन्सीपोलेनाइटीज़, राइजोमोस्पोरा, वर्टीसीपोलेनाइटीज़, ल्यूनेटिस्पोराइटीज़* इत्यादि की प्रचुरता भी प्रदर्शित हुई है। यही परागाणु समुच्चय रानीगंज के साथ-साथ बैरेन मेज़र अवसादों में भी इसी प्रकार प्राप्त हुआ है, अतः सम्पूर्ण संस्तर अंतिम उपरि परमियन युग (रानीगंज शैलसमूह) में निक्षेपित हुए हैं।

INTRODUCTION

GEOLOGY — The Mand-Raigarh Gondwana Basin is the north western continuity of the Ib-River Coalfield of Orissa and has more or less a similar stratigraphic and tectonic setting.

The coal measures in Mand-Raigarh Basin, however, are exposed in three well defined patches due to erosion of the overlying Kamthi rocks along the drainage of the prominent rivers, as by Kurket and Kelo rivers about 20 km north of Raigarh Coalfield, secondly Barakar rocks crop out by Mand-River due to removal of Kamthi sediments towards north west of Raigarh Coalfield (Raja Rao, 1983). Thirdly Barakar coal exposed due to erosion of Kamthi sediments by drainage of Kelo river and Bagadia *Nala*. All there coal bearing area, however, have common stratigraphic succession which is indicated below:

Age	Formation	Lithology
Recent		Alluvium, Soil, Laterite/ Gravel and Conglomerate.
Cretaceous to Eocene	Deccan Trap	Basalt flows and dolerite.
Lower Permian to Lower Triassic	Kamthi Formation	Variegated sandstones with lenses with clay, Arnaceous shale, clay beds, Carbonaceous shales and coal seams.
	Barakar Formation	Coarse to medium grained sandstones, grits, grey shales and coal seams.
	Talchir Formation	Diamictites, fine to medium grained sandstones, olive green shale, rythmities & turbidites.
------------------------------Unconformity-------------------------		
Precambrian		Quartizites and red, hard, fine grained sandstones and Limestones.
------------------------------Unconformity-------------------------		
Archaean		Granitic gneisses, mica schists, quartzites intruded by pegmatites and quartz veins.

THE PRECAMBRIAN BASEMENT

The Gondwana sediments rest unconformably over the Precambrian basement comprising. Archaean rocks in the northern part of the basin. The Proterozoic Cuddapah rocks occur at place in the northern part.

The Archaean rocks comprise biotic granite, sericite chlorite schists, quartzites, mica dolerite quartz veins and pegmatites.

TALCHIR FORMATION

The Talchir Formation occurs as a continuous strip along the northern periphery of the basin. The contact with the Archaean rocks is as erosional surface. The extent of Talchir exposures around Dharmyaygarh, Sisringa, Rat Khand and Laripani. Along the southern boundary discontinuous patches of Talchir rocks crop out in the vicinity of Kharsia and further southeast in the Sambalpuri *Nala* in South of Raigarh area. In this Basin the clast of granite and gneisses, the tillite contains fragments of banded hematite jasper breccia and pinkish, current bedded quartzite and the bright coloured clasts are characteristic of the tillites of the Mand Valley. A few of the clasts are highly polished and striated.

The Mand-Raigarh Basin shows widespread development of basal tillite pointing to advancement of ice from surrounding Precambrian uplands. The till fabric study points to a south eastern direction of transport in the northern part (Bharadwaj, 1971), north western in the eastern and west-north westernly in the southern part of the basin.

BARAKAR FORMATION

The Barakar Formation conformably overlies the Talchir sediments and comprises crudely developed cyclic sequence of arkose, grey shale, carbonaceous shale and coal seams. The sandstones are greyish, white to milky white in colour and are disposed as multi storeyed cross bedded units. They consist of subangular grains of quartz and kaolinised felspars. Based on gross lithology, the Barakar Formation can be broadly sub divided into lower Barakar are usually coarse grained, with predominance of Kaolinised felspar. The upper member is more argillaceous sandstones and occur as thin unit. Interlaminations of shales and siltstone are more frequent in the Upper Barakar Formation. The megafossils assemblage—*Glossopteris indica, G. communis* and *Schizoneura* sp. were identified by Deshmukh 1965-66 from Saria *Nala* East of Khargaon (Text-figure 1).

PLATE 1

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1. *Lundbladispora brevicula*, Balme, 1963. BSIP Slide No. 12097.
2. *Horriditrilites brevis*, Bharadwaj & Salujha, 1964. BSIP Slide No. 12098.
3. *Striapollenites obliquus*. Bharadwaj & Salujha, 1964 BSIP Slide No. 12103.
4. *Navalesporites spinosus*, Sarate & Ram-Awatar, 1984. BSIP Slide No. 12103.

5, 11. *Rhizomaspora indica* Tiwari,1965. BSIP Slide No. 12102.

6. *Arcuatipollenites pellucidus* (Goubin) Maheshwari & Bose, 1975. BSIP Slide No. 12102.

7,14. *Faunipollenites perexiguus*, Bharadwaj & Salujha, 1965. BSIP Slide No. 12101.

8. *Distriatites bilateris*, Bharadwaj, 1962. BSIP Slide No. 12099.
9. *Verticipollenites secretus*, Bharadwaj, 1962. BSIP Slide No. 12100.
10. *Striatites tectus*, Venkatachala & Kar, 1968. BSIP Slide No. 12099.
12. *Parasaccites bilateralis*, Tiwari, 1965. BSIP Slide No. 12098.
13. *Striatopodocarpites decorus* Bharadwaj & Salujha, 1964. BSIP Slide No. 12098.
15. *Striamonosaccites ovatus*, Bharadwaj, 1962. BSIP Slide No. 12098.
16. *Ibisporites diplosaccus*, Tiwari, 1968. BSIP Slide No. 12102.

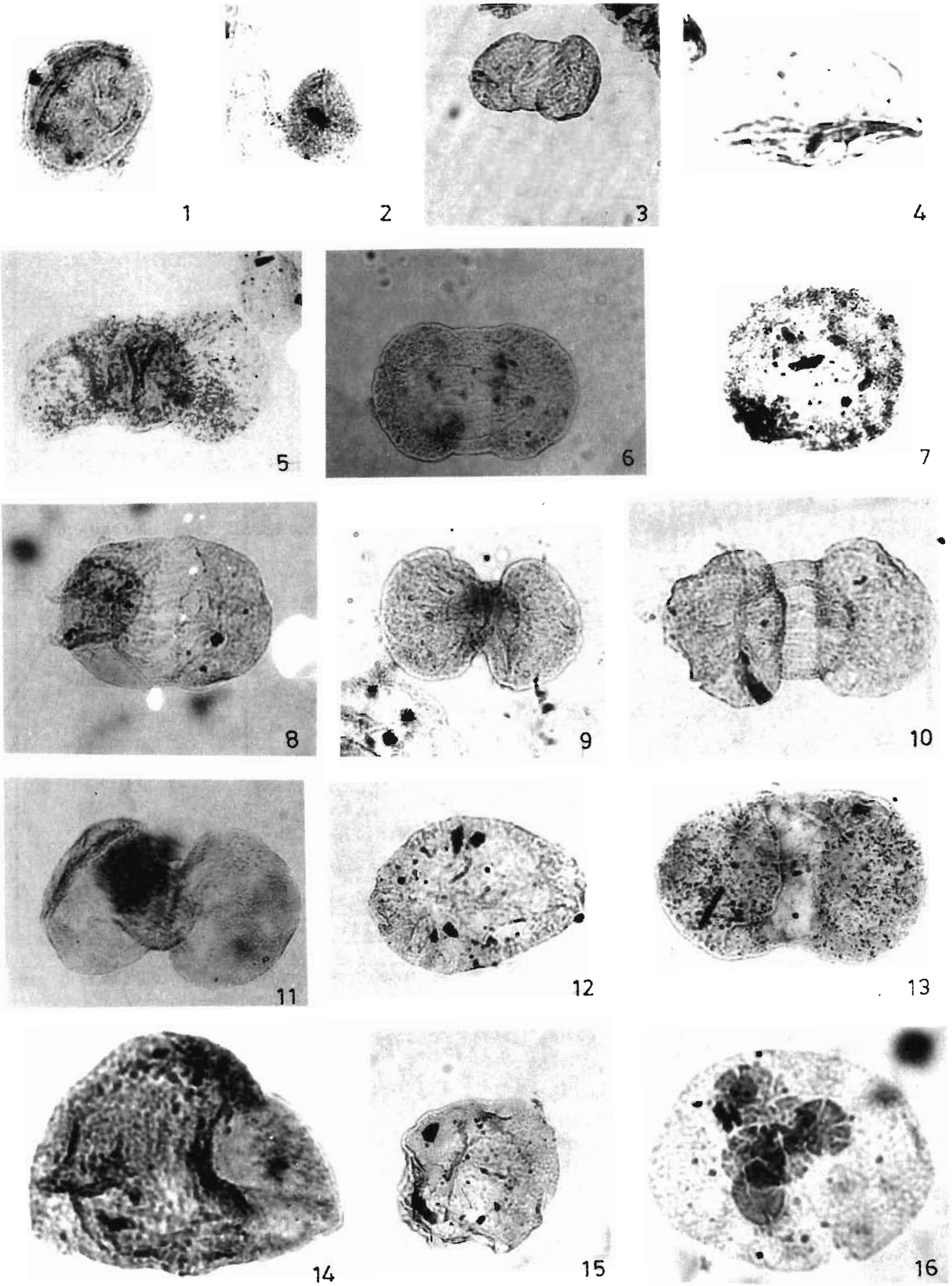
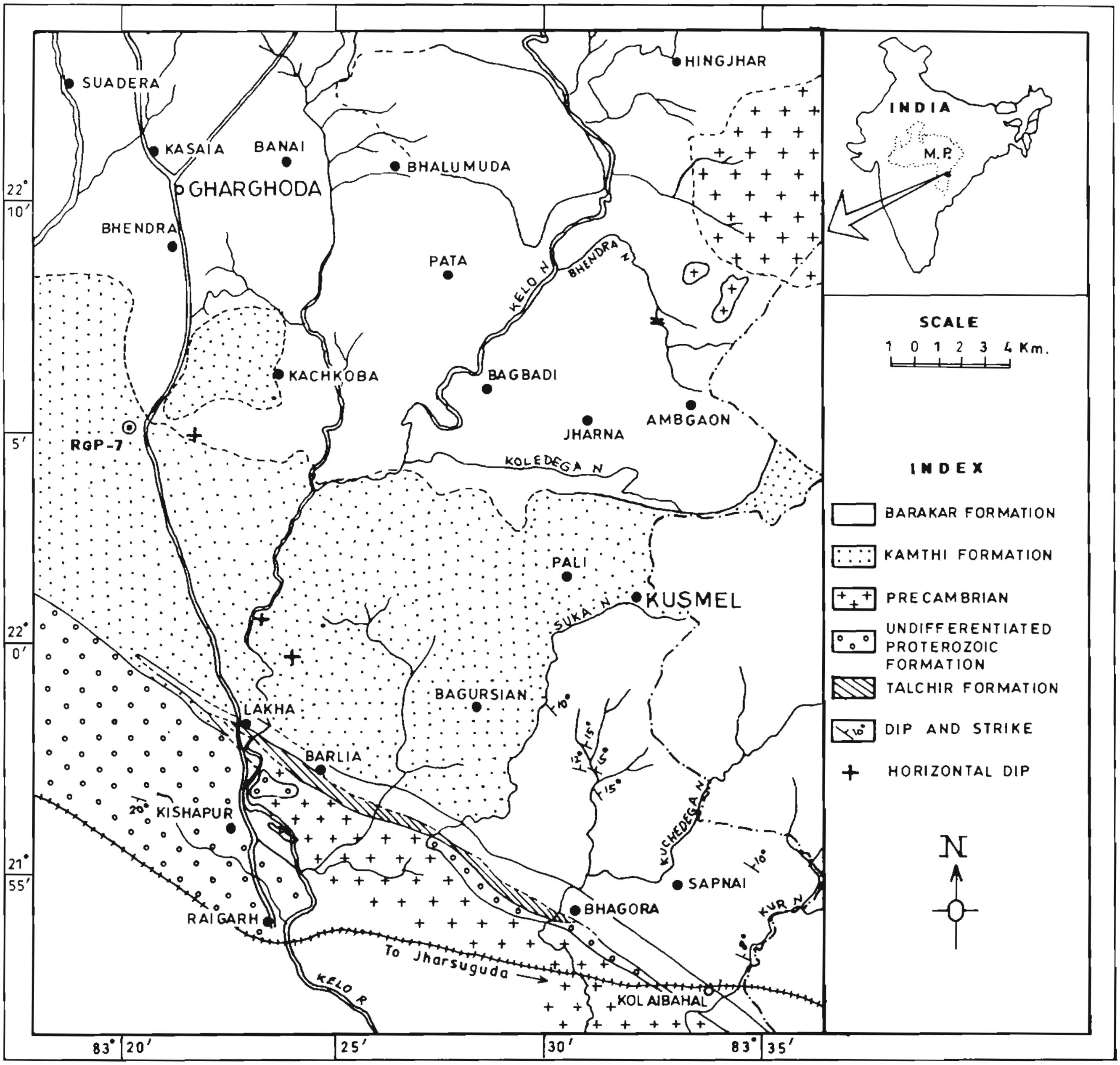


PLATE 1



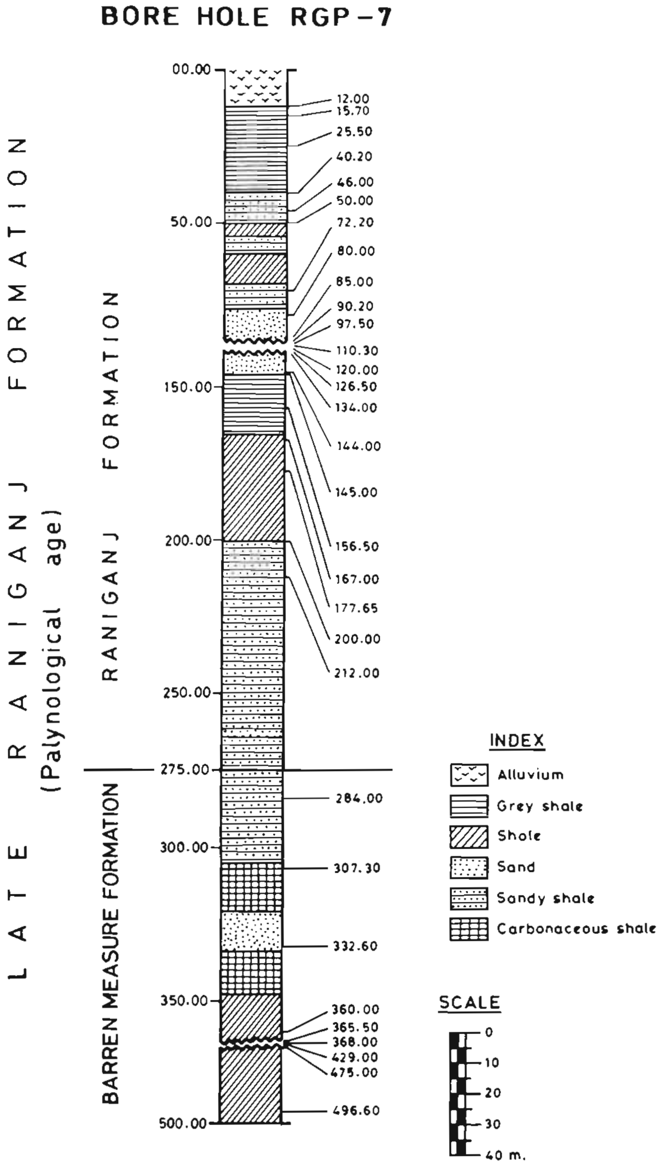
Text-figure 1— Location map of bore-hole RGP-7, Raigarh Coalfield, M.P.,India

KAMTHI FORMATION

These sediments comprise dominantly coarse, friable, porous, brownish to red sandstones. The sandstones are profusely cross bedded and contain pebbles of quartz up to 12 cm in diameter. In the area north and west of Amaldiha, Carbonaceous shales interbedded with coal are found at places within the Kamthi Formation. The megafloral assemblage— *Glossopteris* sp., *Vertebraria indica*, and *Schizoneura gondwanensis* have been found. The Kamthi beds exposed north-west of Amaldiha also contain impression of *Glossopteris* and *Vertebraria*.

MATERIAL AND METHOD

The bore-hole RGP 7 was collected from Mand-Raigarh Basin, Madhya Pradesh. This bore-core passes lithologically through the Raniganj Formation and also Barren Measures Formation. Total 191 samples were collected from this borehole from different lithologies (see Text figure 2). These samples were processed for palynological study by HF, HNO_3 and Alkali treatment. The preservation of palynomorphs is

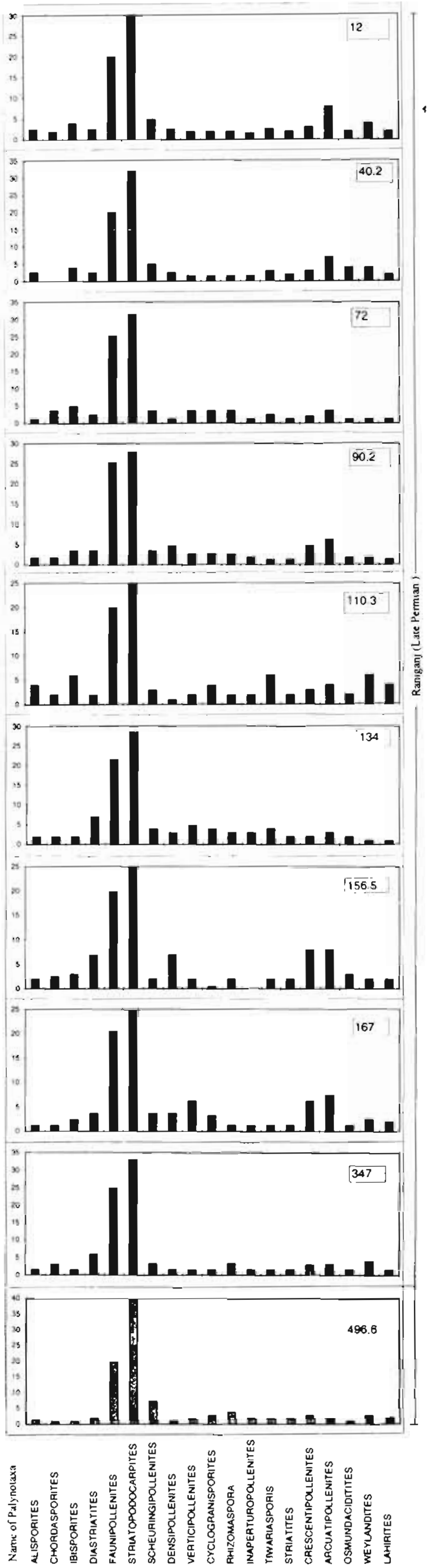


Text-figure 2—Showing the lithological details of samples from bore-hole RGP-7, Manda-Raigarh Coalfield, M.P.

very poor in 50 samples. Only 10 samples have yielded palynofossils in countable numbers as shown in Text-figure 3 (Text-figure 3). On the basis of which percentage frequencies of various palynotaxa have been plotted.

PALYNOLOGICAL ASSEMBLAGE BORE- HOLE RGP 7

On the basis of quantitatively as well as qualitatively analysis significant palynological assemblage have been identified (Text-figure 3). After palynological investigation I have found the striated disaccate flora (*Striatopodocarpites* and *Faunipollenites*) is in prominance along with *Alisporites*, *Densipollenites*, *Scheuringipollenites*, *Rhizomaspora*, *Vertici-*



Text-figure 3—Histogram showing the percentage distribution of palynotaxa in subsuface samples of B.H.No., RGP-7, Mand-Raigarh Coalfield, Madhya Pradesh *pollenites, Crescentipollenites, Lunatisporites, Striatites, Tiwariasporis* etc. shows the Late Permian affiliation rather than Barren Measures Formation (Depth from surface 12.00 to 496.00 m). The above thick strata is classified into Raniganj/Barren Measures according to lithology while here it is found that palynologically similar palynoassemblage is continued up to 4964 m).

COMPARISON WITH OTHER BASINS

The palynoflora from bore-hole RGP 7 designated here to be Raniganj equivalent, resemble those of Upper Permian from other basins (Bharadwaj, 1962; Bharadwaj & Tiwari, 1977; Tiwari & Singh, 1986; Tiwari & Ram-Awatar, 1989; Srivastava, 1973, 1980; Srivastava & Anand-Prakash 1984; Tiwari & Meena, 1989) in the prominance of striate disaccate (*Striatopodocarpites* and *Faunipollenites*) are in prominance along with *Alisporites, Crescentipollenites, Rhizomaspora, Verticipollenites, Striatites* etc. The absence of *Indospora, Thymospora* and *Gondisporites* and presence of *Densipollenites, Arcuatipollenites* further make that the present assemblage is different from other basins beside the results of Son-Mahanadi Graben (Tiwari & Ram-Awatar, 1989; Meena, MS). The palynoassemblage is similar to the results of bore-hole TP-9 and TP-10 from Talchir Coalfield, Orissa and bore-hole results of IBH-6 and IBSH-6 from Ib-River Coalfield, Orissa (Meena, 1997) and it is also similar with results of Johilla Coalfield reported by Tiwari & Ram-Awatar, 1989.

CONCLUSION

This bore-hole cross lithologically the Raniganj/Barren Measures formations, while, the palynological data suggest the whole sediments deposited in Raniganj period (Late Permian time). The dominance of striated disaccate palynoflora (*Striatopodocarpites* and *Faunipollenites*) alongwith *Alisporites, Densipollenites, Scheuringipollenites, Rhizomaspora, Distriatites, Striatites, Crescentipollenites, Arcuatipollenites* etc. shows the Late Permian affiliations rather than Barren Measure, Formation.

Table 1—Showing the details of bore-hore RGP7 samples collected from Raigarh coalfield.

Sample no.	Depth in m.	Lithology	Remarks
1	12.00	Grey shale	++
2	12.10	Silty shale	_
3	14.14	Grey shale	_
4	15.00	Sandy shale	+
5	15.50	Grey silty sst.	-
6	15.70	Grey shale	-
7	16.00	—do—	+
8	16.50	—do—	-
9	16.90	—do—	-
10	19.40	—do—	-
11	20.00	—do—	-
12	20.60	Sandy shale	-
13	21.7	—do—	-
14	24.10	—do—	-
15	25.50	—do—	++
16	26.10	Grey shale	-
17	26.60	—do—	-
18	27.00	—do—	-
19	39.70	—do—	-
20	40.20	Sandy shale	++
21	41.40	—do—	-
22	42.20	—do—	-
23	43.20	—do—	-
24	45.10	—do—	-
25	45.90	—do—	-
26	46.00	—do—	++
27	47.00	Shale with Iron band	-
28	48.00	—do—	-
29	49.50	—do—	-
30	50.00	—do—	++
31	51.10	—do—	-
32	52.00	Grey shale	-
33	53.45	—do—	-
34	54.45	—do—	-
35	55.00	—do—	+
36	56.00	—do—	-
37	57.00	—do—	-
38	58.00	—do—	+
39	58.70	Grey shale with sst.	-
40	60.00	Thin compact shale	-
41	60.50	Sandy shale	-
42	61.50	Iron content grey shale Iron sst.	+
43	62.50	Grey Shale	-
44	63.20	—do—	+
45	64.00	—do—	-
46	65.00	—do—	-
47	66.20	—do—	+
48	68.00	—do—	-
49	69.00	—do—	-
50	72.00	—do—	++
51	73.50	Grey hard shale	-
52	75.05	—do—	-
53	78.20	—do—	-
54	79.50	—do—	-
55	80.00	—do—	+++
56	81.60	Grey shale	-
57	83.40	—do—	+
58	84.50	—do—	-
59	89.25	—do—	-
60	90.20	—do—	++
61	92.20	—do—	-
62	93.00	—do—	-
63	95.00	—do—	-
64	96.00	Grey shale & sst.	-
65	97.50	F. grain sst.& shale	+++
66	100.00	Grey shale	-
67	105.50	—do—	+
68	106.50	—do—	-
69	108.25	—do—	-
70	100	—do—	+++

71	112.00	—do—	-
72	114.15	—do—	-
73	116.20	—do—	+
74	119	Grey shale hard band	+
75	120	Grey shale	+++
76	121	—do—	-
77	123	Grey shale & coal	-
78	124	—do—	+
79	125	Grey shale	-
80	126.50	—do—	++
81	128.00	—do—	-
82	129.10	—do—	-
83	129.80	—do—	-
84	132.10	—do—	-
85	134.00	—do—	++
86	135.15	—do—	-
87	142.70	—do—	-
89	144.00	—do—	+
90	146.00	—do—	-
91	147.20	—do—	+
92	149.30	—do—	-
93	152.00	—do—	+
94	154.00	—do—	-
95	156.50	—do—	+++
96	159.50	—do—	-
97	160.25	G. Sh + Coal streak	-
98	162.00	Grey shale	+
99	164.60	—do—	-
100	165.50	—do—	-
101	167.00	Sandy shale	++
102	168.00	—do—	-
103	169.50	Grey shale	+
104	175.50	—do—	-
105	177.65	Carb. shale	+++
106	183.75	Siltstone	-
107	187.00	Grey shale	-
108	190.00	Coaly streaks	+
109	193.65	Grey shale	-
110	194.85	—do—	+
111	195.85	Carb. shale	-
112	199.00	Grey shale	+
113	201.00	Black sh + Coal	+
114	204.00	Black shale	-
115	204.50	—do—	+
116	205.00	Grey shale	-
117	206.70	—do—	-
118	209.60	Coaly streaks	+
119	212.00	Grey shale	-
120	226.00	—do—	-
121	233.00	—do—	-
122	234.00	—do—	+
123	237.80	—do—	-
124	241.50	Sandy shale	-
125	245.00	Black shale	+
126	247.40	Black shale	-
127	249.30	Grey shale	-
128	253.00	—do—	-
129	254.50	—do—	+
130	259.20	Black shale	-
131	263.00	Grey shale	-
132	268.60	—do—	-
133	270.70	—do—	+
134	276.10	—do—	-
135	277.30	—do—	-
136	279.00	—do—	-
137	281.00	—do—	+
138	281.75	—do—	-
139	283.15	—do—	+
140	284.00	—do—	+++
141	286.00	Coal	-
142	288.35	Carb. shale	+
143	289.00	Grey shale	-
144	293.00	—do—	-
145	295.00	—do—	-
146	296.00	Shale	+
147	297.50	Grey shale	-
148	304.70	—do—	-
149	305.50	Coal	-
150	307.50	Shale	+
151	314.00	Silty shale	-
152	328.00	Black shale	-
153	329.50	Micaceous sh.	-
154	331.50	Sst.	-
155	332.60	Grey shale	+
156	334.00	Coaly shale	-
157	336.50	—do—	-
158	339.50	—do—	-
159	341.50	—do—	-
160	347.00	—do—	++
161	350.75	—do—	-
162	354.00	Silty Sst	-
163	357.00	Coal streaks + sst.	-
164	358.50	Sst.	++
165	360.50	Sst.	-
166	362.00	Black shale	-
167	364.50	Black shale	-
168	365.50	Silty Grey shale	+
169	367.00	Grey shale	-
170	368.00	Black shale	++
171	369.75	Silty shale	-
172	370.40	Coal streaks + Sst.	-
173	373.00	—do—	-
174	374.00	—do—	+
175	375.00	—do—	-
176	382.00	Shale	+
177	385.00	—do—	-
178	388.00	—do—	-
179	391.30	—do—	+
180	392.30	—do—	-
181	393.80	—do—	+
182	395.00	Black shale	-
183	403.10	Shale	-
184	405.00	—do—	-
185	429.00	—do—	+
186	436.20	—do—	-
187	475.75	—do—	-
188	492.00	Shale + Sst.	+
189	492.50	—do—	-
190	496.60	—do—	+

* Barren Measures/Raniganj lithoboundry at 275 m.

Legend + = rare, ++ = common, +++ = rich, – = absent.

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The plant of *Neomariopteris hughesii* (Zeiller) Maithy

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ABSTRACT

Singh KJ & Chandra S. 1999. The plant of *Neomariopteris hughesii* (Zeiller) Maithy. Palaeobotanist 48(3) : 225-238.

An attempt has been made to reconstruct the plant of *Neomariopteris hughesii* based on fifty five hand specimens collected from the Barakar Formation exposed near Brijraj Nagar Railway Station in the Ib-River Coalfield, Orissa. The limitations of this reconstruction have been realised by the authors as the main trunk of the plant and the fertile structures are not recorded from this very location, however, combined evidences put together from other sources as well suggest that this fern plant could be a small tree based on branched stems of considerable length and width rather than a usual prostrate fern habit. An up to date list of all the specimens recorded under the genus *Neomariopteris* and its six species by various workers from different localities and formations of India has also been given.

Key-words—*Neomariopteris hughesii*, Reconstruction, Pinnae, Pinnule, Rachis, India.

सारांश

निओमेरियॉप्टेरिस ह्यूगेसाइ (ज़ीलर) माइती का पौधा

कमलजीत सिंह एवं शैला चन्द्रा

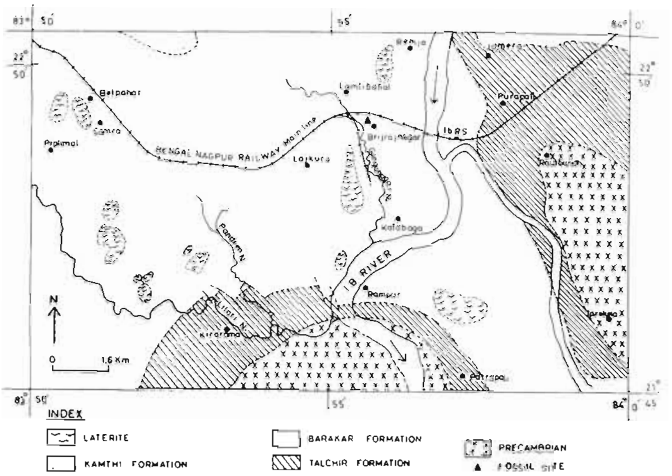
उड़ीसा के ईब नदी कोयला क्षेत्र में बृजराज नगर रेलवे स्टेशन के निकट अनावरित बराकर शैलसमूह से संगृहीत 55 हस्त प्रादर्शों के आधार पर *निओमेरियॉप्टेरिस ह्यूगेसाइ* के पौधे की पुनर्रचना करने का एक प्रयत्न किया गया। इस पुनर्रचना के लिए लेखकों को अनेक अवरोधों का सामना करना पड़ा क्योंकि पौधे का मुख्य स्तम्भ तथा उर्वर संरचनाएं इस संस्थिति से अंकित नहीं की जा सकीं, परन्तु अन्य स्रोतों से प्राप्त प्रमाणों को संयुक्त करने से प्रस्तावित होता है कि इस पर्णांग का पौधा अत्यन्त लघु वृक्ष रहा होगा, जो लम्बे तथा चौड़े शाखित तनों पर अवलम्बित होगा तथा यह सामान्य प्रॉस्टेट प्रकृति का पर्णांग नहीं रहा होगा। भारत की विभिन्न संस्थितियों एवं शैल समूहों से विभिन्न लोगों द्वारा 6 प्रजातियों के अन्तर्गत *निओमेरियॉप्टेरिस* वंश के समस्त अंकित प्रादर्शों की अद्यतन सूची भी दी गई है।

INTRODUCTION

OUR knowledge on the morphology and anatomy of filicalean group of plants from Permian of Gondwana has significantly improved during the last two decades (Gould, 1970; Maithy, 1974, 1975, 1977; Pant & Misra, 1976, 1977, 1983; Pant & Khare, 1974; Galtier & Taylor 1994). Detail studies on the morphology and the fertile parts of Permian Gondwana ferns established the differences between southern & northern forms hence placed under new generic and specific names. Of such forms *Neomariopteris* was proposed by Maithy 1974 for fern fronds having sphenopteroid venation, decurrent pinnules and winged rachis. In subsequent year (1975) he also recorded fertile pinnules, sporangium and spore types of the genus *Neomariopteris* and emended his own diagnosis. Later, Pant and Khare (1974) instituted *Damudopteris* to accommodate sphenopteroid ferns based on the same lectotype specimen of Feistmantel 1880. On the basis of priority *Damudopteris* is recognised as a junior synonym of *Neomariopteris*.

Though the fern genus *Neomariopteris* is recognized by six species viz., *N. polymorpha* (Feistm.) Maithy, *N. hughesii* (Zeiller) Maithy, *N. lobifolia* (Morris) Maithy, *N. talchirensis* Maithy, *N. khanii* Maithy and *N. barakarensis* Srivastava, no attempt has been made to reconstruct the plant for any of the species under this genus. Of the six species of this genus, *N. hughesii* is the best understood and most commonly occurring species in the Permian strata of India.

A fresh collection of impressions and casts from the Middle Permian beds in Ib-River Coalfield has enabled us to reconstruct the plant of *Neomariopteris hughesii* (Text-figures 1, 2). Observations on this species by various other workers have also been incorporated for such an attempt.



Text-figure 1—Geological map of IB River Coalfield, District Sambalpur, Orissa showing the fossil site.

PLATE-1 ⟶

1. Part of stem cast of *Neomariopteris hughesii* (Zeiller) Maithy showing smooth surface. x 1.5, B.S.I.P. Specimen number 36870.
2. Broader portion of stem cast showing longitudinal striations and also two branches coming out of the stem indicated by arrows marks. x 1, B.S.I.P. Specimen number 36871(A).
3. Another stem specimen of *N. hughesii* with a distinct branch of equal width shown by arrow. x 1, B.S.I.P. Specimen number 36872.
4. Widest stem cast specimen in the collection with longitudinal striations on the surface. x 1, B.S.I.P. Specimen number 37364.

PLATE-2 ⟶

1. Stem cast specimen of *Neomariopteris hughesii* with longitudinal striations on the surface. x 1, B.S.I.P. Specimen number 37365.
2. Three pinnae with less lobed pinnules having sphenopteroid venation, appears to be from the terminal portion of the branch. x 1.5, B.S.I.P. Specimen number 37366.
3. Another cast of the stem portion of the plant of considerable length. x 1, B.S.I.P. Specimen number 37367.
4. Pinnules showing distinct serrate margins and distinct sphenopteroid venation. x 2, B.S.I.P. Specimen number 37368(A).

PLATE 3 ⟶

1. Stem cast of *Neomariopteris hughesii* shown still embedded in the sediment. x 1 B.S.I.P. Specimen number 37368(B).

2-5. Pinnae with pinnules showing serrate margins and sphenopteroid venation in various specimens. 2-x1.5; 3-5-x 2,. B.S.I.P. Specimen numbers from 2-5 - 37369, 36871(B), 37370 and 37371 respectively.

PLATE 4 ⟶

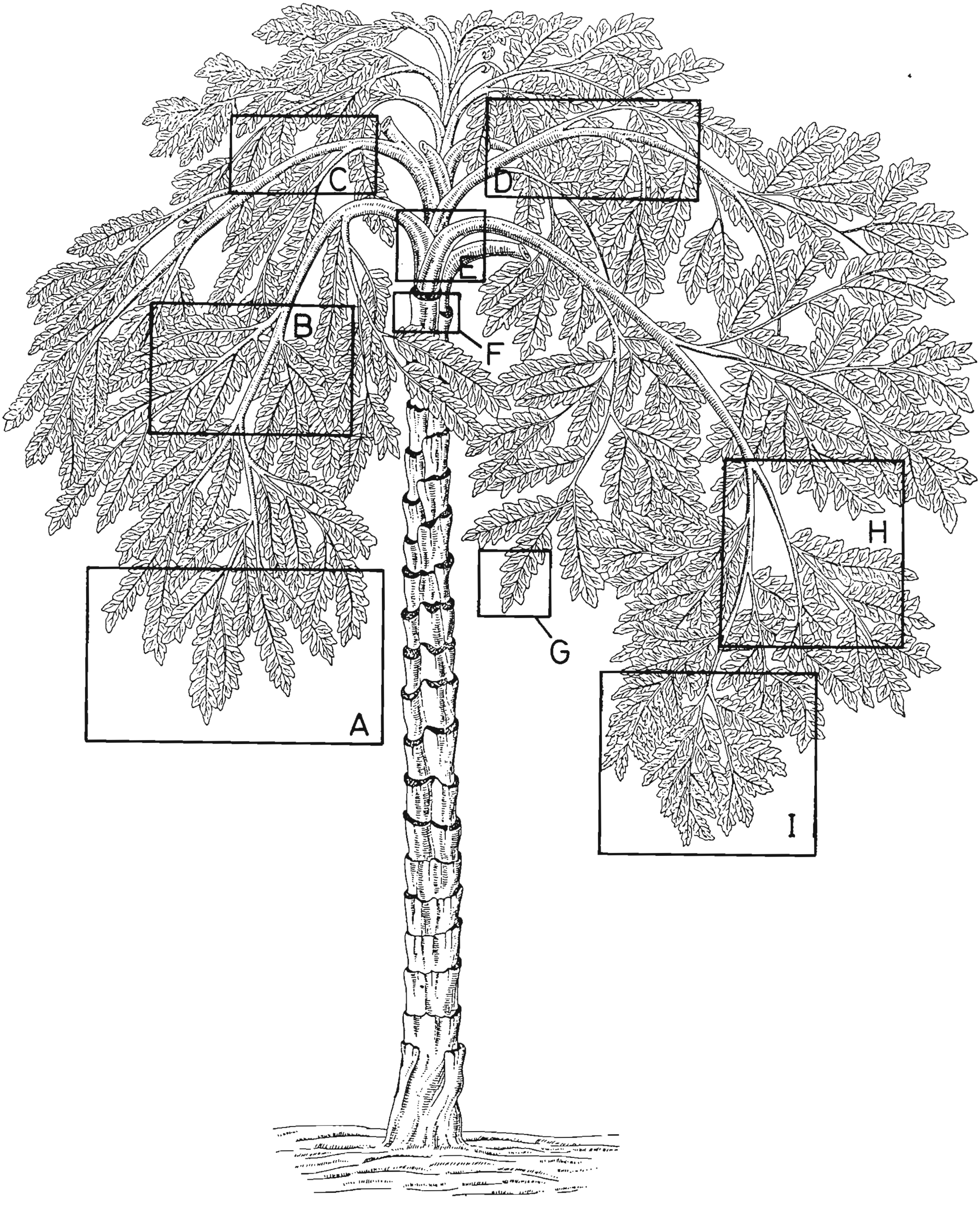
1 & 2. Cast of rachis of the plant of *Neomariopteris hughesii* with three branches shown by arrows. Longitudinal striations on the rachis are distinctly seen. x 1, & x 2 respectively. B.S.I.P. Specimen number 37372 (Both the figures showing the same specimen).

PLATE 5 ⟶

1. Secondary and tertiary branching of rachis of *Neomariopteris hughesii* , branches indicated by arrows. Pinnae with pinnules showing distinct sphenopteroid venation. x 1.5, B.S.I.P. Specimen number 37375.
2. Terminal portion of frond with sub-opposite branching. x 1.5, B.S.I.P. Specimen number 37376.
3. Pinna with serrate pinnules showing distinct sphenopteroid venation. x 2, B.S.I.P. Specimen number 37377.

PLATE 6 ⟶

1. The specimen of *Neomariopteris hughesii* showing two branches attached alternately on the rachis with pinnae, serrate pinnules with distinct sphenopteroid venation. x 1.5, B.S.I.P. Specimen number 37378.
2. Two pinnae attached on the rachis, appears to be from the apical portion of the frond, rachis and venation are preserved in the form of cast, laminar portion of pinnules are preserved as impression. x 2, B.S.I.P. Specimen number 37379.
3. Pinnae shown attached to rachis alternately. x1.5, B.S.I.P. specimen number 37380.
4. Another specimen of *Neomariopteris hughesii* showing branching pattern of pinnae and rachis attachment. Pinnules are preserved as impression and their venation as cast. x 1.5, B.S.I.P. Specimen number 37381.



Text-figure 2— Reconstruction Model Boxes A - I indicate the portions of fossil specimens in different photo plates and is the basis for the reconstruction. **A.** Pl. 3, fig. 4 **F.** Pl. 1, fig. 4 **B.** Pl. 5, fig. 1 **G.** Pl. 2, figs 2,4 **C.** Pl. 1, figs 2,3 **H.** Pl. 6, fig. 4 **D.** Pl. 4, figs 1,2 **I.** Pl. 6, figs 1-3 **E.** Pl. 2, figs 1,3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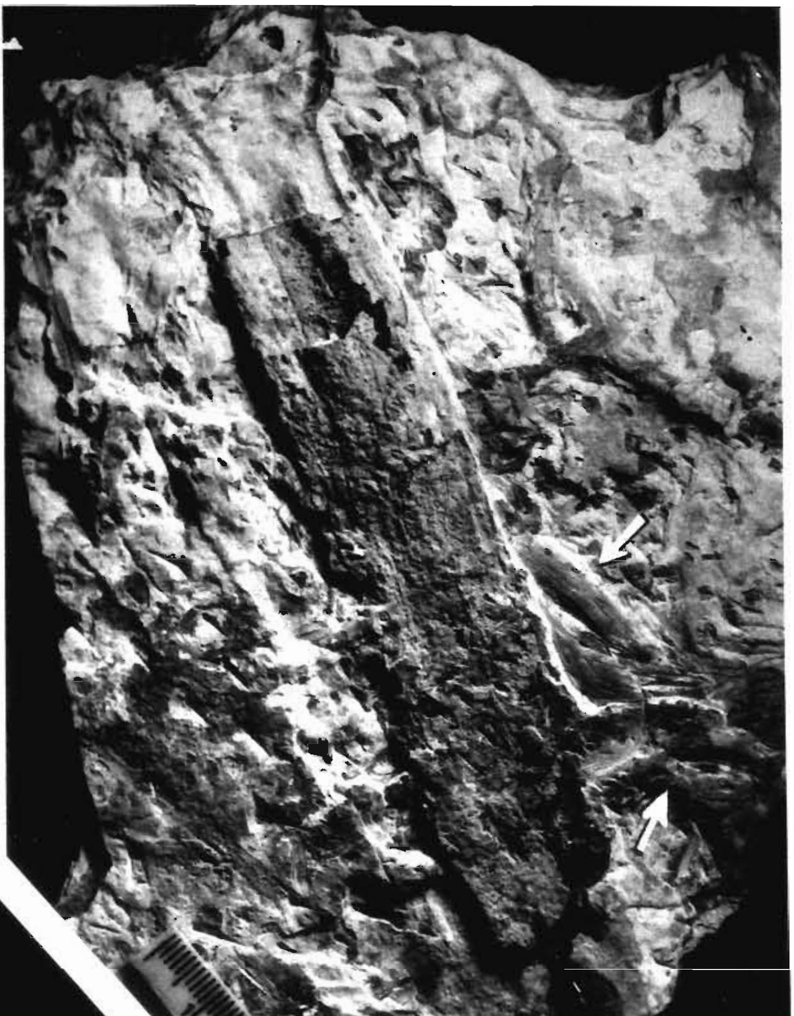
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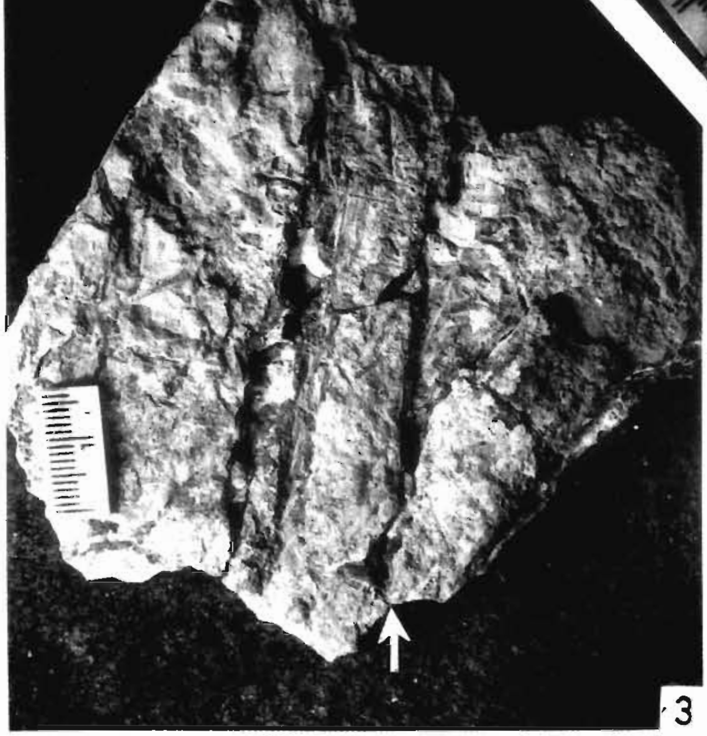
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PLATE 1


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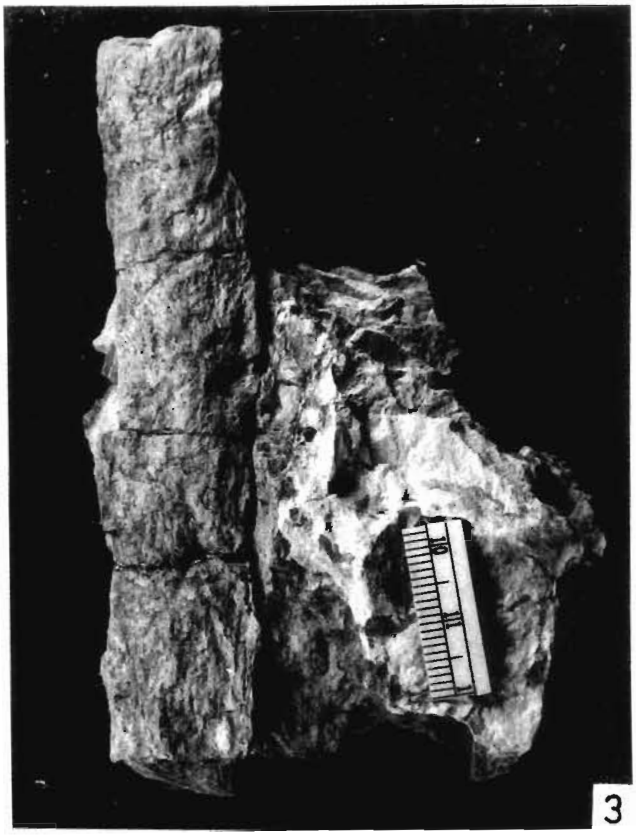

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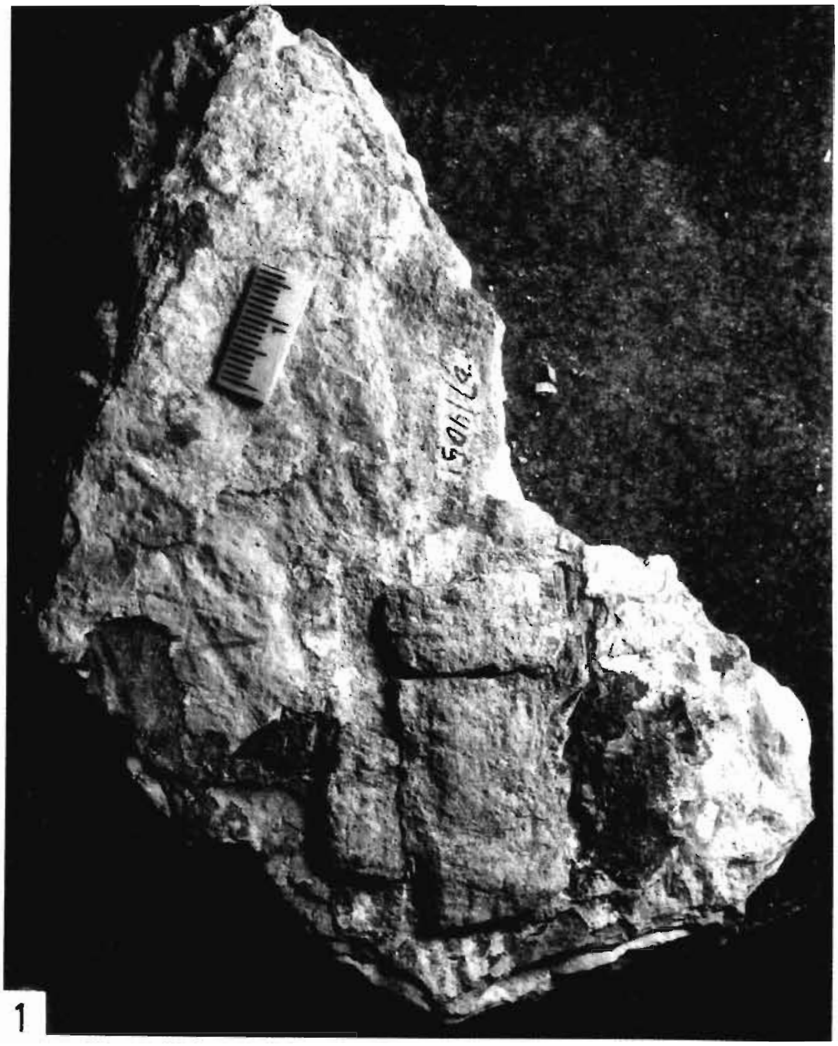
PLATE 2



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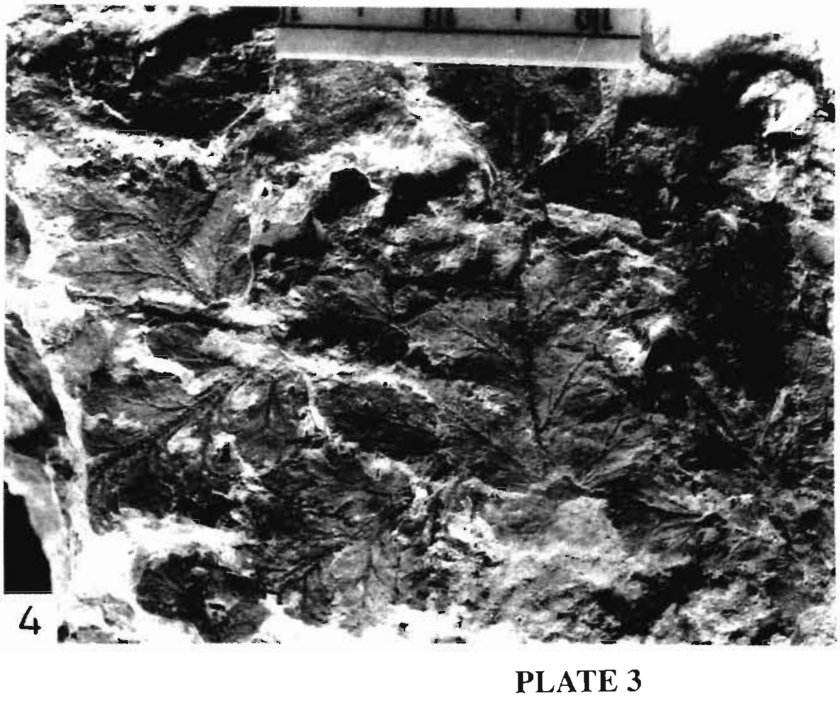

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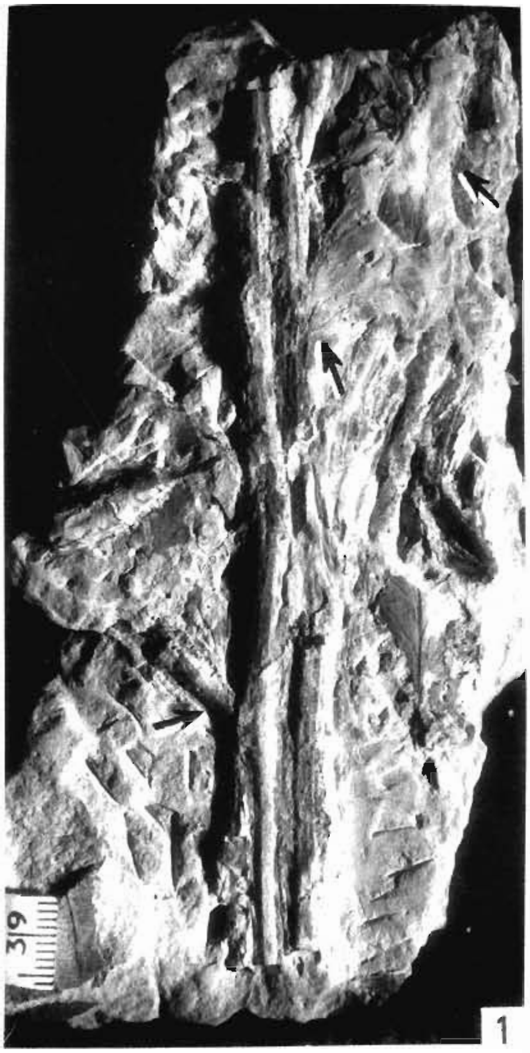
PLATE 3



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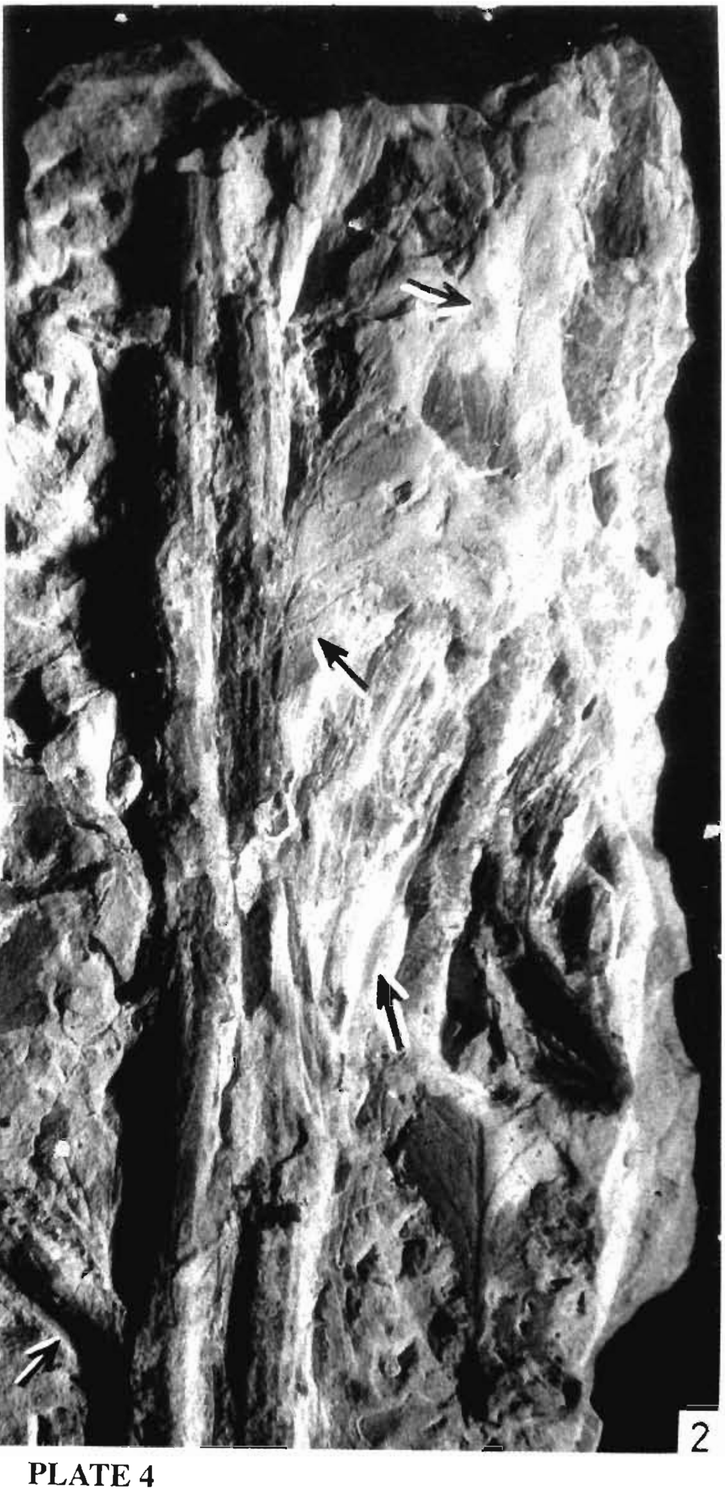

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PLATE 4


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PLATE 5


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PLATE 6

MATERIAL AND LOCALITY

The fern specimens were collected from the surface outcrop of the Barakar beds exposed in the Ganga Nagar *Nala* Section near Brijraj Nagar Railway Station in the Ib-River Coalfield, District Sambalpur, Orissa (Text figure 1). The total length and width of the collected site is about 3 x 1 m. The 55 specimens of fern pinnae and pinnules are preserved as impressions on pinkish yellow, fine to coarse grained shales and the stems and petioles of the fronds as cast. Anatomical studies of these stems and petioles could not be made as the internal structures are not preserved. All the fern pinnules are sterile and no fertile structures are seen preserved. Just a few meters from this fern fossil site, vertically and diagonally preserved *in-situ Vertebraria* axes are also collected. These are the only two fossil forms recorded and collected from this Middle Permian locality. All the fern specimens are deposited at the Museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATICS

Order—FILICALES

Family—DAMUDOPTERIDACEAE Pant & Khare

Genus—NEOMARIOPTERIS (Feistmantel) Maithy

NEOMARIOPTERIS HUGHESII (Zeiller) Maithy

(Pl. 1, figs 1-4; Pl. 2, figs 1-4; Pl. 3, figs 1-5; Pl. 4, figs 1-2; Pl. 5, figs 1-3; Pl. 6, figs 1-4; Text-figs 1, 2, 3 & Table-1)

Of the 55 hand specimens, 12 are casts of stems and petioles and the other specimens are impression of pinnae and pinnule fronds. Some of the specimens are tripinnate and bipinnate fronds. The longest stem is 12 cm and length of other stems vary between 3.8 to 11.5 cm. The widest stem cast is 3.2 cm (Pl. 1, fig. 4) and the width of other stems vary between 1.3 cm to 2.8 cm (Pl. 4, fig. 1; Pl. 1, figs 1, 2, 3; Pl. 2, figs. 1, 3). The maximum preserved thickness of these casts of the stems or petioles is 8 mm. The surface of all the preserved stem casts show longitudinal striations (Pl. 2, fig. 1; Pl. 5, fig. 1), in some of the stems the surface is rough (Pl. 1, figs 1-4; Pl. 2, fig. 3; Pl. 3, fig. 1). The rachis width is between 1 - 2.5 mm with a narrow wing. The secondary branches are arranged alternately (Pl. 6, figs 1 & 3; Pl. 5, fig. 1) and sometimes sub-oppositely (Pl. 5, fig. 2) on the primary stems. The pinnae are generally linear in shape measuring 2 -3.9 cm in length, becoming smaller towards apex side of the plant. The pinnules in general have serrate margins and show typical sphenopteroid venation as mentioned by Maithy (1974). Details of epidermal features of the pinnae and fertile structures including sporangia and their spores have been investigated by earlier authors (Pant & Khare, 1974; Maithy, 1974, 1975) and are incorporated in our studies. The details are not discussed here to avoid repetition.

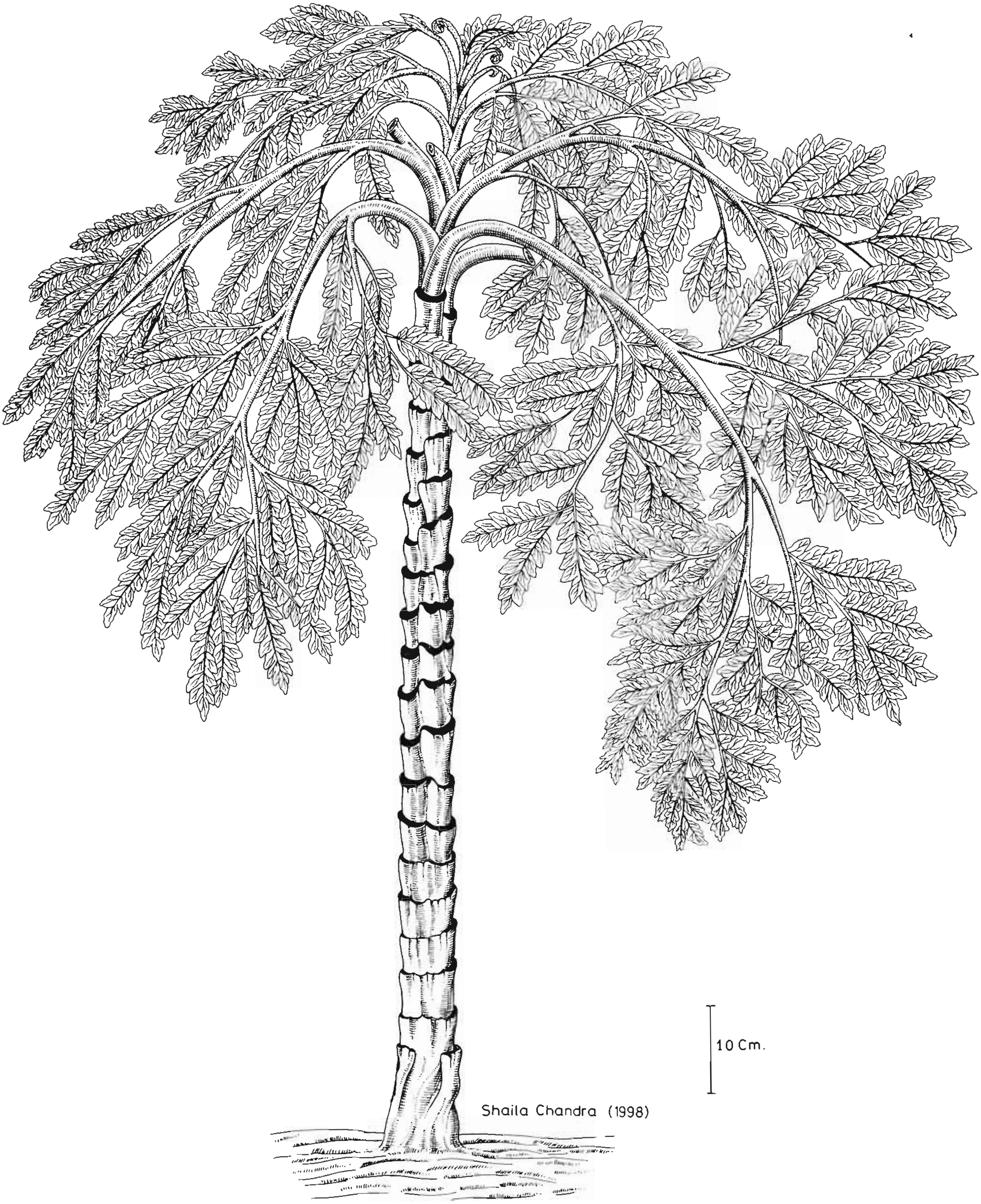
RECONSTRUCTION

As evidenced by the repeatedly branching stems of considerable length and width of common occurrence in the sediments, the plant of *Neomariopteris hughesii* must have had an upright self supporting habit with elongate tapering stem and closely adpressed relatively large petioles with stout rachises bearing vegetative pinnae. The reconstruction drawing of the plant is marked to indicate fossil evidences as shown by the photographs (Text figure 2). The reconstruction (Text-figure 3) is based mainly on the large size of branched stems, occurrence of several pinnae on the rachis and large size of pinnae and pinnules. The ferns with usual prostrate habit do not possess branched stems. The main stem part or the trunk of this plant is missing. The authors have collected several fern specimens from various Permian formations of Indian Gondwana during last several years but have never come across such branched stems in any of the fern species nor has been recorded by any other author (see Table 1).

The consistently occurring fern parts at Ganga Nagar *Nala* Section suggest that the plants of *Neomariopteris hughesii* were growing together as a "fern glen" during moist, humid and warm temperate climate of Barakar time period suitable for fern growth, although the pinkish yellow colour of the sediments suggests adverse conditions of dry climate. Similar conditions of red buff coloured shales also show luxuriant plant growth during Late Permian at Handapa in Talchir Coalfield in Angul District of Orissa. Colour of the sediment, therefore, need not in every case indicate the climatic conditions. Abundance and the luxuriant plant growth certainly proves to be more reliable climate indicator. Absence of any other plant type, except for pieces of fragments of *Glossopteris* leaves from these beds, can not be explained. The only other possible explanation could be that this particular fern plant got preserved at the same place where they were growing and there was no chance for other plants to grow at the same site because of the thick vegetation of fern plants. Similar such conditions of *in-situ* preservation are also reported for *Vertebraria* axes preserved a few meters away from *Neomariopteris hughesii* fossil site.

The absence of attached or obviously associated reproductive structures among the vegetative pinnae suggest that this plant may have reproduced primarily by vegetative means under favourable conditions of Barakar swamps as many modern ferns do and produce spores only when conditions were poor and unfavourable.

It is considered, on the basis of large size and greater number of fern plant specimens, that ferns were also important and dominant constituent of Barakar coal forming flora along with *Glossopteris* species, at least it is so in Ib-River Coalfield. *Skaaripteris minuta* Galtier and Taylor 1994 from Permian of Antarctica is considered as a sub aquatic scram-



Text-figure 3—Reconstruction of the plant of *Neomariopteris hughesii* (Zeiller) Maithy.

Table 1—Distribution of various species of *Neomariopteris* (*Sphenopteris*) in Lower Gondwana of India

S.N.	Species	Author(s)	Formation	Age	Locality
1	*Neomariopteris barakarensis. Srivastava, 1978*	Srivastava, 1978.	Barakar Fm.	Middle Permian	Churulia fire clay pit, Auranga Coalfield, Bihar
2.	*Neomariopteris hughesii (Zeiller) Maithy, 1974*	Maithy, 1974.	Barakar Fm.	Middle Permian	Churulia pit, East Raniganj coalfield, West Bengal
	(Dicksonia hughesii)	Feistmantel, 1881	Raniganj Fm.	Late Permian	Jharia Coalfield, Bihar
	(D. hughesii)	Feistmantel, 1882.	Raniganj Fm.	Late Permian	Sohagpur area, Madhya Pradedsh
	(Sphenopteris hughesii)	Zeiller, 1902.	Raniganj Fm.	Late Permian	Raniganj Coalfield, West Bengal
	(S. hughesii)	Maheshwari & Prakash, 1965.	Barakar Fm.	Middle Permian	Tattitola, Bansloi Valley, Rajmahal Hills, Bihar
	(S. hughesii)	Maheshwari, 1966.	Barakar Fm.	Middle Permian	Tattitola, Bansloi Valley, Rajmahal Hills, Bihar
	(S. hughesii)	Kar, 1968.	Barren Measures	Late Permian	Katri Nala, Jharia Coalfield, Bihar
	(Sphenopteris polymorpha)	Khan, 1969.	Kamthi Fm.	Late Permian	Handapa Village, Angul District Orissa
	(S. polymorpha)	Kulkarni, 1970.	Barakar Fm.	Middle Permian	Saunda Section, South Karanpura Coalfield, Bihar
	Neomariopteris hughesii	Maithy, 1975.	Raniganj Fm.	Late Permian	Raniganj Coalfield, West Bengal
	N. hughesii	Srivastava, 1977.	Karharbari Fm.	Early Permian	Auranga Coalfied, Bihar
	N. hughesii	Chandra & Prasad, 1981	Kamthi Fm.	Late Permian	Kanhargaon Village, District Chandrapur, Madhya Pradesh
	N. hughesii	Lele, Maithy & Mandal, 1981	Raniganj Fm.	Late Permian	Searsole Colliery, Raniganj coalfield, West Bengal
	N. hughesii	Srivastava & Chandra, 1982.	Raniganj Fm.	Late Permian	Damodar Colliery, Raniganj Coalfield, West Bengal
	N. hughesii	Chandra & Rigby, 1983.	Kamthi Fm.	Late Permian	Hinjrida Ghati near Handapa Village, Angul District, Orissa
	N. hughesii	Chandra, Srivastava & Singh, 1990.	Raniganj Fm.	Late Permian	Marhwas area, Sidhi District Madhya Pradesh
	N. hughesii	Tewari, 1994	Raniganj Fm.	Late Permian	Bhatdih Colliery, Jharia Coalfield, Bihar
	N. hughesii	Srivastava & Tewari, 1996.	Barakar Fm.	Middle Permian	Tubed Area (Sukri river Section) and Sikni Open Cast Mine, Auranga Coalfield, Bihar
	N. hughesii	Tewari & Srivastava, 1996.	Barakar Fm.	Middle Permian	Kusunda area, Jharia Coalfield, Bihar
	N. hughesii	Singh & Chandra, 1996.	Barakar Fm.	Middle Permian	Gopal Prasad Village, Talchir Coalfield, Angul District, Orissa
3.	*Neomariopteris khanii Maithy, 1977*	Maithy, 1977.	Kamthi Fm.	Late Permian	Hinjrida Ghati near Handapa Village, Angul District, Orissa
	N. khanii	Chandra & Rigby, 1983.	Kamthi Fm.	Late Permian	Hinjrida Ghati near Handapa Village, Angul District, Orissa
	Neomariopteris cf. N. khanii	Prasad, Shukla & Maithy, 1987.	Dubrajpur Fm.	Late Permian	Khatngi Hills, Pachwara Coalfield, Rajmahal Hills, Bihar
4.	*Neomariopteris lobifolia (Morris) Maithy, 1974*	Maithy, 1974.	Raniganj Fm.	Late Permian	Mahavir Colliery, East Raniganj Coalfield, West Bengal
	(Sphenopteris lobifolia)	Srivastava, 1955.	Raniganj Fm.	Late Permian	Raniganj Coalfield, West Bengal
	(S. lobifolia)	Maheshwari & Prakash, 1965.	Barakar Fm.	Middle Permian	Tattitola, Bansloi Valley, Rajmahal Hills, Bihar
	Neomariopteris cf. N. lobifolia	Bose, Banerji & Maithy, 1977.	Panchet Fm.	Early Triassic	Ledho Nala near Karamdiha Village, Ramkola – Tatapani Coalfield, Sarguja District, Madhya Pradesh
	N. lobifolia	Prasad, Shukla & Maithy, 1987.	Barakar Fm.	Middle Permian	Amjhari, Bansloi River, Pachwara Coalfield, Rajmahal Hills, Bihar
5.	*Neomariopteris polymorpha* (Feistmantel) Maithy, 1974	Maithy, 1974.	Raniganj Fm.	Late Permian	Raniganj Coalfield, West Bengal
	(Sphenopteris polymorpha)	Feistmantel, 1876.	Raniganj Fm.	Late Permian	Raniganj coalfield, West Bengal
	(S. polymorpha)	Feistmantel, 1879.	Karharbari Fm.	Early Permian	Lumki Hills, Giridih Coalfield, Bihar
	(S. polymorpha)	Feistmentel, 1880.	Raniganj Fm.	Late Permian	Sitarampur, Raniganj Coalfield, West Bengal
	(S. polymorpha)	Feistmantel, 1882.	Raniganj Fm.	Late Permian	Kurabar, Karkati and Malhadu, Shadol District, Madhya Pradesh
	(S. polymorpha)	Bandyopadhya, 1959.	Barakar Fm.	Middle Permian	Palasthali, Raniganj Coalfield, West Bengal
	(S. polymorpha)	Bhattacharyya, 1959.	Raniganj Fm.	Late Permian	Jagaldaga, Palamau District, Bihar

S.N.	Species	Author(s)	Formation	Age	Locality
	(S. polymorpha)	Mehta & Anadalwar, 1960.	Barakar Fm.	Middle Permian	East of Patrapali, Ib River Coalfield, Orissa
	(S. polymorpha)	Lele, 1962.	Pali Fm.	Late Permian	Salaia, Shadol District, M.P.
	(S. polymorpha)	Saksena, 1962.	Pali Fm.	Late Permian	Karkati, Shadol District, M.P.
	(S. Polymorpha)	Bhattacharyya, 1963.	Barakar Fm.	Middle Permian	Churulia fireclay pit, Auranga Coalfield, Bihar
	(S. polymorpha)	Sen-Gupta, 1965.	Raniganj Fm.	Late Permian	East Bokaro Coalfield, Bihar
	(S. polymorpha)	Biswas, 1966.	Raniganj Fm.	Late Permian	Churulia area, Raniganj coalfield, West Bengal
	(S. polymorpha)	Maheshwari, 1966.	Barakar Fm.	Middle Permian	Tattitola, Bansloi Valley, Rajmahal Hills, Bihar.
	(S. Polymorpha)	Roy & Bhattacharyy 1967.	Barakar Fm.	Middle Permian	Ekadel, Talchir coalfield, Orissa
	(S. polymorpha)	Vimal & Singh, 1968.	Pali Fm.	Late Permian	Karkati, Shadol District, M.P.
	(S. polymorpha)	Khan, 1969.	Kamthi	Late Permian	Hinjrida Ghati near Handapa Village, Angul District Orissa
	(S. pymorpha)	Kulkarni, 1970.	Barakar Fm.	Middle Permian	Kakkari incline, South Karanpura coalfield, Bihar
	Neomariopteris polymorpha	Chitnis & Vagyani, 1979.	Kamthi Fm.	Late Permian	Satnavari Querry, Nagpur District, Maharashtra
	(Damudopteris polymorpha)	Pant & Khare, 1974.	Raniganj Fm.	Late Permian	Raniganj Coalfield, West Bengal
	N. polymorpha	Srivastava & Chandra, 1982.	Raniganj Fm.	Late Permian	Searsole Colliery, Raniganj Coalfield, West Bengal
6	*Neomariopteris talchirensis Maithy, 1974*	Maithy, 1974.	Barakar Fm.	Middle Permian	Junction of Lobjee and Sadabaha, Daltonganj Coalfield, Bihar
	(Cyathea sp. cf. *C. tchihatcheffi)*	Feistmantel, 1881.	Barakar Fm.	Middle Permian	Talchir Coalfield, Orissa
	(Sphenopteris polymorpha)	Feistmantel, 1876.	Raniganj Fm.	Late Permian	Raniganj Coalfield, West Bengal
	(S. polymorpha)	Maithy, 1969.	Karharbari Fm.	Early Permian	Daltongaj Coalfield, Bihar

bling or prostrate fern, based on petrified material.

The combined evidences lead us to believe that amongst many fern types of the Gondwana some may have a small tree habit as is envisaged for *Neomariopteris hughesii* rather than usual prostrate type. The only other fern with small tree like habit reported is *Palaeosmunda* from Late Permian of Queensland, Australia (Gould, 1970).

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Occurrence of palynofossils from the Tirap River section (Disang Group), Tinsukia District, Assam

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ABSTRACT

Mandaokar BD 1999. Occurrence of palynofossils from the Tirap River section (Disang Group), Tinsukia District, Assam. Palaeobotanist 48(3) : 239-243.

Disang shale exposed on the Tirap River section yielded 23 genera and 24 species of palynomorphs. The palynoassemblage is dominated by pteridophytic spores and angiospermic pollen grains, whereas gymnospermic elements are rare . The presence of *Striatriletes, Polypodiisporites, Schizaeoisporites, Striacolporites, Lakiapollis, Tricolpopollenites, Phragmothyrites* and *Inapertisporites* suggests an Eocene age to the assemblage.

Key-words—Disang, Palynomorphs, Flysch, Eocene, Assam.

सारांश

असम के तिनसुकिया जनपद के तिराप नदी परिच्छेद (डिसांग समूह) में परागाणु पादपाश्मों की उपस्थिति

भगवानदास दोमाजी मण्डावकर

तिराप नदी परिच्छेद पर डिसांग शैलों के अनावरण से परागाणुसंरूप के 23 वंश तथा 24 जातियाँ प्राप्त हुईं। परागाणु समुच्चय में टेरिडोफाइटी बीजाणुओं तथा आवृतबीजी परागकणों की प्रधानता है, जबकि अनावृतबीजी तत्व प्रायः नगण्य हैं। *स्ट्रायट्रायलिटीज़, पॉलीपोडाइस्पोराइटीज़, शीज़ियोस्पोराइटीज़, स्ट्रायकोलपोराइटीज़, लेकियापॉलिस, ट्राइकोलपोपोलेनाटीज़, फ्रैग्मोथिराइटीज़* तथा *इनेपरटिस्पोराइटीज़* की उपस्थिति से समुच्चय का इओसीनयुगीन होना प्रस्तावित हुआ है।

INTRODUCTION

PALYNOLOGICAL studies on the Tertiary sediments of Assam and adjoining regions go back to almost half of the century. Such studies were linked to the oil exploration activity in the region. A large number of surface, subsurface and road cutting samples were studied by ONGC. Evans (1932, 1964), Mathur & Evans (1964), Dasgupta (1977), Raja Rao (1981) and Rao (1983) worked on the geology of Assam and adjacent regions. Sah and Dutta (1966, 1968) and Dutta and Sah (1970) also worked on this area. Kar (1990) reported palynotaxa from Silchar- Haflong road section. Kumar (1994) described marine palynofossils comprising dinoflagellate cysts, acritarchs and reworked palynomorphs from the same sections.

The Disang shale is about 4000 m thick and so far generated insufficient palynological data. The purpose of this study is to decipher the age of this thick clastic Tertiary section of eastern Assam by using reliable palynological fossils. The investigation is mainly concerned with Disang deposits which are spread in southern part of Makum Coalfield, Assam. Thirty-five samples of dark grey, black, splintery, greyish shales, siltstone, fine grained sandstone, brownish clay and tough grey sandstone were collected from Disang shale, a section ideally exposed on eastern bank of the Tirap River (Text-figure 1). The overlying and underlying sediments are made up of grey carbonaceous shale and total thickness of the exposure is about 35.5 m. These samples were chemically processed to isolate pollen-spores following usual maceration technique. The material is quite rich in palynofossils. The slides were prepared in polyvenyl alcohol and mounted in canada balsam. Identification, counting and photodocumentation of specimens were done with BH_2 Olympus Research Microscope.

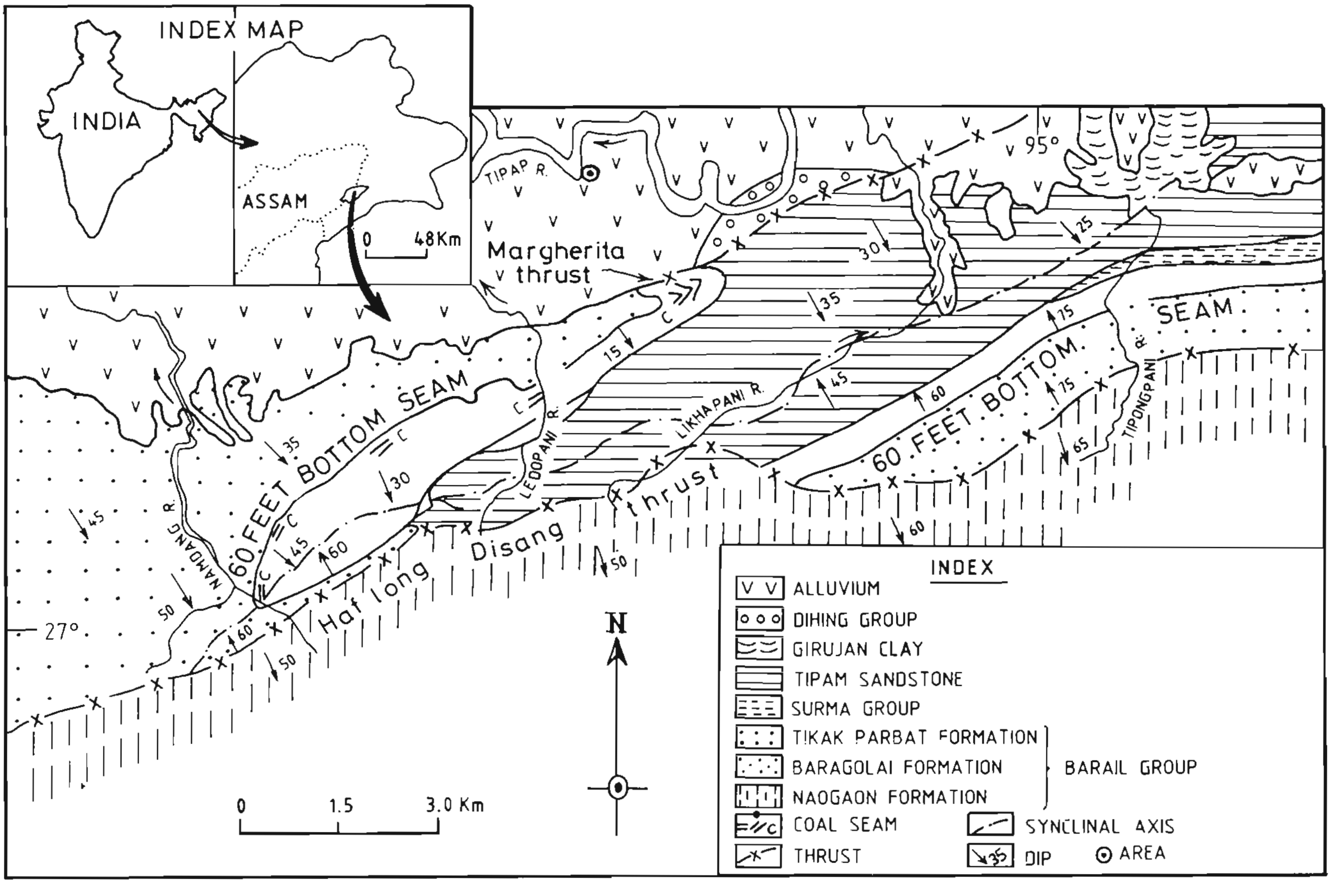
GEOLOGICAL SETTING

The members of this group are seen in the section of Khasi Hills, Meghalaya and Tirap River southern part of the Makum Coalfield, Assam (Text-figure 1). The uninterrupted Disang sediments were studied on the Tirap River section in an open cast quarry. This field lies between the latitudes 27° 17' and longitudes 95° 52'. It is along the outermost flank of the Patkoi ranges. The outcrop of the Tirap River section is a long narrow arm like extension over 160 km in length continuing south west ward along the foot hills of Barail range. The sediments comprises unfossiliferous, grey slaty sandstone and slaty arenaceous shales diping at about 45° and apparently cover by Barail Group. The slaty cleavage being almost invariably parallel to Patkoi range. One of the shale was observed to be carbonaceous and a few poorly preserved unidentifiable lamellibranches were found. The Disang sediments are described to be similar to those of Kopili Formation. The contact between Disang Group and overlying Barail Group is gradational. The regional framework of the Tertiary sediments as indicating by Raja Rao (1981) is tabulated below.

PALYNOASSEMBLAGE

Palynoassemblage recovered from Disang of the Tirap River section encompasses 24 identifiable species and 23 genera. A check list of 24 different species of pteridophytic, angiospermic, gymnospermic and fungal spores are listed in Table 2.

The genera restricted to Disang shales are usually found



Text-figure 1— Geological map of the Makum Coalfield, Assam.

Table 1—Showing sequence of Cenozoic rocks in Makum Coalfield, Assam (after Raja Rao, 1981)

Group	Formation	Thickness	Rock types
Recent/ Pliocene	Dihing	1800 m	Mostly pebbly sandstone with thin greyish clay beds.
	----------Unconformity----------		
Mio/ Pliocene	Namsang Formation	800 m	Fine to coarse grained sandstone with bands of clay.
	----------Unconformity----------		
	Tipam Group		
Miocene	ii) Girujan clay	1800 m	Mottled clay with greyish soft sandstone.
	i) Tipam Sandstone	2300 m	Ferruginous, fine to coarse grained micaceous to felspathic sand - stone.
	----------Unconformity----------		
	Barail Group		
Oligocene	iii) Tikak Parbat Formation	600 m	Greyish to yellowish white sandstone, sandy shales with coal seams.
	ii) Baragolai Formation	3500 m	Greyish to bluish grey yellowish red mudstone, shale, sandstone, carbonaceous shales and thin coal seams.
	i) Naogaon Formation	2200 m	Compact fine grained, dark grey sandstone with sands of splintery shales.
Eocene	Disang Group	4000 m	Grey to dark grey splintery shales, iron stained and sandy shale with thin partings of compact quartzitic sand-stones.

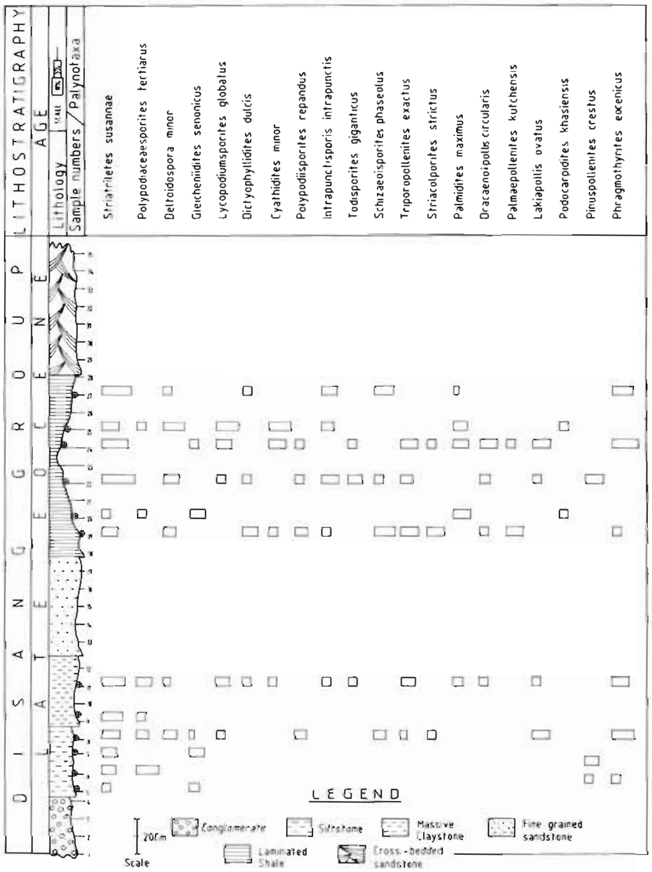
Table 2 — Spores and pollen taxa recovered in the (Disang) Tirap River section Assam

Fossil taxa
Striatriletes susannae van der Hammen emend. Kar, 1979
Palypodiaceaesporites tertiarus Sah & Dutta, 1968
Polypodiaceaesporites chatterjii Kar, 1979
Deltoidospora minor Miner, 1935
Gleicheniidites senonicus Saxena, 1978
Lycopodiumsporites globatus Kar, 1985
Dictyophyllidites dulcis Kar, 1985
Cyathidites minor Couper, 1953
Polypodiisporites repandus Takahashi, 1964
Intrapunctisporis intrapunctis Krutzsch, 1959
Todisporites giganticus Mandaokar, 1987
Schizaeoisporites phaseolus Delcourt & Sprumont, 1955
Triporopollenites exactus Salujha, Kindra & Rehman, 1972
Striacolporites striatus Sah & Kar, 1970
Palmidites maximus Couper, 1953
Dracaenoipollis circularis Sah & Kar, 1970
Palmaepollenites kutchensis Venkatachala & Kar, 1969
Magnamonocolpites plicatus Kar, 1985
Lakiapollis ovatus Venkatachala & Kar, 1969
Podocarpidites khasiensis Dutta & Sah, 1970
Piceapollenites excellensus Kar, 1985
Pinuspollenites crestus Kar, 1985
Phragmothyrites eocaenicus Kar & Saxena, 1981
Inapertisporites kedvesii Elsik, 1968

associated with the Eocene assemblages (Sah & Kar, 1970; Sah & Dutta, 1966; Dutta & Sah, 1970; Kar, 1985). Kar (1990), studing the outcrop from Haflong-Silchar road of North Cachar Hill, Assam suggested an Eocene age. *Striatriletes* van der Hammen emend. Kar (1979) reported from the various Tertiary sediments. The oldest record of this taxon is from Middle-Late Eocene of Kutch by Kar & Saxena (1981). Venkatachala *et al.* (1989) reported the distribution of different Palaeocene - Eocene marker palynotaxa in India and Africa. According to them the genus *Lakiapollis* having an affinity to modern pollen of *Durio* is found in Palaeocene - Eocene strata from Kerala, Kutch and Meghalaya. Fossil spores showing affinity to lycopodium are generally accommodated in *Lycopodiumsporites* Thiergart ex Delcourt & Sprumont (1955). This genus is one of the most common elements in Palaeocene-Eocene of north-east India and is known to occur since Palaeozoic. The polypodiaceous spores from the Indian Tertiary sediments are mostly known as *Palypodiaceaesporites* Thiergart (1940), *Polypodiisporites* (Potonie', 1934). These genera are encountered in Palaeocene-Eocene in good percentage. The palynological assemblage and ratio of the basic groups of pteridophytic, angiospermic, and gymnospermic pollen indicate a Late Eocene age. The majority of the taxa are known from Late Eocene although some of them are known from Palaeocene to Miocene. The presence of *Striatriletes, Polypodiisporites, Gleicheniidites, Lakiapollis, Polypodiaceaesporites, Lycopodiumsporites, Striacolporites, Intrapunctisporis* together with palm pollen strengthen this assumption.

PALYNOFLORAL COMPARISON

Kar (1990) reported a rich palynoflora consisting of 26 genera and 28 identifiable species from the Silchar-Haflong



Text-figure 2 — Showing spore-pollen frequency tied to litholog of Tirap River section.

road, Assam. The palynotaxa common to Silchar-Haflong road and the present Tirap River section (Disang assemblage) are *Striatriletes, Polypodiaceaesporites, Polypodiisporites, Podocarpidites, Pinuspollenites, Piceapollenites* and *Phragmothyrites*. The palynotaxa present in the Silchar-Haflong but absent from the present palynoassemblage are *Lygodiumsporites, Psiloschizosporis, Klausipollenites, Taeniasporites, Hamiapollenites, Neocouperipollis, Margocolporites, Pellicieroipollis, Palaeomalvaceaepollis, Parmathyrites, Notothyrites, Diporisporites* and? *Sumatradinium* sp. The palynotaxa present in the Tirap River section, Disang shale Assam but absent from the Silchar-Haflong road section are; *Deltoidospora, Gleicheniidites, Schizaeoisporites, Striacolporites* and *Magnamonocolpites*. A comparative study reveals that the Silchar-Haflong road section and the present Tirap River section are mostly comparable qualitatively.

The fragmentary vegetal matter comprising thin lenses of coal are occasionally found in carbonaceous shale and gritty greywacke sandstone of Baratang Formation, Andaman. Chatterjee (1967) divided the terrigenous flysch sediments of main Andaman Island into Baratang and Port Blair formations. The occurrence of palynofossils from Cretaceous to Early Cenozoic foraminifera, nannofossils and coccoliths are known from the same sediments. Banerjee (1966, 1967), Mathur & Mathur (1980), Mandal *et al.* (1994, 1996) recorded very few palynofossils from these sediments. Only palynotaxa common to the Baratang Formation, Andaman and the Tirap River section are; *Polypodiisporites, Cyathidites, Dictyophyllidites* and *Gleicheniidites*. A comparative account shows that the Andaman and the present assemblage is not comparable qualitatively and quantitatively, but closely comparable on the basis of lithology as the present outcrop consists of turbidite sequence with dark grey shale, greywacke sandstone and some thin limestone deposited under deep sea water environment.

DISCUSSION

Interpretation on depositional environment is broadly based on the available lithological and palynological information mainly obtained from the Tirap River section. The Disang Group consists of 4000 m thick sequence of greywacke sandstone and shale showing the features of turbidites. Evans (1964) suggested that the provenance of flysch type of sediments might be a land mass lying to the east of longitude 89° 30' in the eastern Himalayas. Raju (1968) however, suggested that part of detritus derived from the geanticline as well as from peripheral shield area. During this phase of geosynclinal development in the Naga- Lushai belt, submergence of the platform area is a part of Shillong Plateau and Upper Assam gave rise to shelf deposits of the Sylhet Limestone. The palynofloral distribution is intimately linked with lithofacies. The observation pertaining to their palaeoecology are of considerable use but present sediments are not related to the shelf carbonate clastic deposits of Khasi and Jaintia hills.

The Disang Group consists of lenticular bodies of cross bedded sandstones, local lenses of conglomerate and laminated red shale and mudstone exhibiting fining upward cycles. In Priabonian palynoflora predominated by Palm pollen mainly belonging to a riparian communities. These deposits are interpreted to have been laid down in a coastal environment. Rich fern association, viz., *Striatriletes, Polypodiaceaesporites, Dictyophyllidites, Gleicheniidites, Intrapunctisporis* are present namely in inland basin. There is very little information from the Disang shale. The rocks are almost barren, only dinoflagellate cysts, acritarch and few pollen grains were recovered (Arun Kumar, 1994). Most likely these sediments were deposited in the inner shelf marine environment close to the shore. To the end of Priabonian, the development of conifers like *Piceapollenites, Podocarpidites* and *Pinuspollenites* are striking. Thus the change of climate is not only testified by a higher share of conifer but also by their taxonomic composition. These pollen were recorded in

Upper Priabonian/Lower Oligocene sequence in Carpathian Palaeogene (Snopkova, 1980). These taxa imply colder climatic oscillation and the beginning of a gradually cooling trends. The overlying Disang sediments is mainly composed of coarsening upward succession of carbonaceous shales, including thin stringes of coal, interbedded siltstone, shale and white reddish cross bedded sandstone, interpreted to the deposits of delta distributary channel in the proximity of shore line. The overall sequencial trend to be transgressive through time and space.

CONCLUSION

1) On the basis of palynological assemblage the sequence assigned to Late Eocene age.
2) A correlation of the Silchar-Haflong road section was made with the present one situated 240 km south-west ward on the basis of palynofossils.
3) Rich fern association is present namely in inland basin. The palynoflora suggests a humid and tropical climate with plenty of rainfall during the deposition of these sediments.
4) The terrestrial elements are mainly represented by saccate gymnosperm of Pinaceae and spores of Gleicheniaceae. Angiosperm pollen are mostly corroded .

It seems that these pollen were carried by water currents to a long distance and finally deposited in a deep brackish water (flysch) sediments.

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Investigations on a fossil agavaceous axis from Neyveli Lignite, Tamil Nadu, India

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ABSTRACT

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Further anatomical observations on a fossil agavaceous axis from Neyveli lignite Mine-1, Neyveli, Tamil Nadu show the presence of anomalous secondary growth with amphivasal vascular bundles as well as other cell inclusions such as raphides. Simple perforation in the fossil vessel end plates suggests an advanced character of the plant. Association of monosulcate reticulate pollen (cf. *Liliacidites*) in the same axis further supports its affinities with Liliaceae.

Key-words—Fossil axis, Anomalous secondary growth, Raphide, Agavaceae, Neyveli Lignite, India.

सारांश

भारत के तमिलनाडु प्रान्त के नयवेली लगुडांगार (लिग्नाइट) से प्राप्त एगेवेशियस पादपाश्म अक्ष पर अनुसन्धान

कृष्ण अम्बवानी

तमिलनाडु के नयवेली लगुडांगार (लिग्नाइट) खदान-1 से प्राप्त एक एगेवेशियस पादपाश्म अक्ष के पुनः शरीर रचनात्मक प्रेक्षण करने पर फ्लोएमकेन्द्री संवहनी बण्डलों के साथ असंगत द्वितीयक वृद्धि की उपस्थिति प्रदर्शित हुई है, साथ ही अन्य कोशिकीय समावेशन, जैसे रैफाइड की उपस्थिति भी प्रदर्शित हुई है। पादपाश्म वाहिका छोर प्लेट में सरल छिद्रों का होना पौधों के अग्रगामी अभिलक्षण को सूचित करता है। एक ही अक्ष में एकखांची जालिकारूपी परागकणों (तुलनात्मक रूप-लिलिएसिडाइटिस) का साहचर्य इसकी लिलिएसी के साथ सजातीयता को पुनः समर्थित करता है।

INTRODUCTION

THE family Liliaceae is one of the largest families of Monocotyledonae distributed widely in warm tropical regions. Some taxa of this family also grow in temperate climate. Bentham and Hooker (1883) established family Agavaceae in their classification system and merged Dracenae with Liliaceae. Engler (1892) included the family Liliaceae under the order Liliflorae and treated Agavaceae as a subfamily. However, Wettstein (1901) preferred to classify Agavaceae as a separate family in Liliflorae. Hutchinson (1959) maintained Agavales as a separate group under which he accommodated Agavaceae and Xanthorrhoeaceae. Chmura (1956) preferred to merge Agavaceae under the order Liliales and Cronquist (1968) treated Agavaceae under subclass Lilidae. Dhalgren and Clifford (1982) in their revised classification for monocotyledons created Liliflorae as a super order which included family Liliaceae under the order Liliales. According to them, the family Agavaceae is further subdivided into two subfamilies, viz., Agavoideae and Yuccoideae.

The Agavoideae contained the genera *Agave, Beschorneria, Bravoa, Furcraea, Littaea, Manfendra, Polianthes* and *Pseudobravoa*, whereas Yuccoideae includes *Clistoyucca, Hesperaloe, Hesperocallis, Hesperoyucca, Samulea* and *Yucca*. Nevertheless, family Agavaceae needs more attention to resolve its evolutionary status in the plant kingdom. The agavaceous fossils (pollen and wood) are known as early as Late Maastrichtian to Pliocene (Chmura, 1973; Suc, 1974; Van Campo & Sivak, 1976; Ambwani, 1982).

MATERIAL AND METHOD

The agavaceous fossil axis was collected by the author from the Neyveli lignite Mine-I, Neyveli, Tamil Nadu and preliminary observations were published (Ambwani, 1982). In the present paper detail anatomy has been carried out under SEM and some more significant observations have been studied.

For SEM observations transverse and longitudinal sections of the axis were prepared, and dried under controlled temperature between 30°-50°C. Then the sections were mounted on the metallic stub and conducted by applying silver paint. The specimens were then coated by evaporating gold/Palladium alloy and studied under scanning electron microscope (Phillps 505). The accelerating voltage for image analysis varied from 15 KV to 20 KV.

The fossil axis is dark brown in colour, measures about 4.5 cm long and 2-3 cm thick, cylinderical and surrounded by spirally arranged scars. These scars probably represent both leaf bases and flower pedicels indicating its being an apical part of the plant (possibly a part of inflorescence). The central conducting zone is also visible as a solid core in the axis (Pl. 1, fig. 1).

ANATOMY

Cortex—The cortical zone is well preserved and extends up to 2-3 mm in thickness. The cells of this zone are slightly thick-walled usually filled with some organic material, which are globular in shape and variable size ranging from 1-4 μm. At some places the parenchymatous cells also contain different cell inclusions of complex morphology of unknown nature (Pl. 2, figs 5, 6). The cortical zone bears radially running vascular strands (Pl. 1, fig. 2).

Cambium—A layer below the cortical zone probably belongs to cambium and does not extend more than 10-15 μm comprising elongated cells. This layer is responsible for the demarcation of primary tissue meristem (PTM) and the development of secondary tissue meristem (STM) in the stem. The STM generally helps to add the secondary vascular tissue in growing stems (Pl. 1, fig. 3).

Primary vascular bundle zone—Primary vascular zone consists of primary vascular bundles which are amphivasal in nature. They are irregularly scattered in the central ground parenchyma (Pl. 1, figs 2, 4). These bundles usually have peripherally arranged long overlapping tracheids and vessels surrounding the central phloem strand (Pl. 1, fig. 5). The xylem includes short parenchymatous cells.

The phloem cells are thin-walled and angular in shape. Each vascular bundle is surrounded by parenchymatous cells (Pl. 1, fig. 5). The size of the vascular bundles varies from 30-150 μm while the length of the tracheids may extend up to 70 μm or more and 10 μm wide. The vessel perforation measures 5 μm and the bordered pits 1-2 μm in diameter (Pl. 2, figs 2, 3). The ground parenchyma cells of this zone are thin-walled, but sometimes thick-walled cells may be observed, they invariably bear pits on the walls (Pl. 2, fig. 7).

Secondary vascular bundle zone—The secondary vascular bundles are more or less similar to that of primary vascular bundles which are responsible for growth in thickness in the stem. They are centripetally arranged and provide woody appearance to the axis. Thus more than 2/3 of the stem comprises secondary vascular system. The vascular bundles are amphivasal where xylem surrounds phloem (Pl. 1, fig. 6). The xylem tracheids are well preserved and show spiral, scalariform and reticulate thickenings (Pl. 2, fig. 1). However, vessels with simple perforation end plates are also present (Pl. 2, fig. 3), walls of the vessels have pitted thickenings, the pits on the outer side are simple but on the inner surface are slightly raised or bear thickening around them (Pl. 2, figs 2, 3). These pits are usually arranged in alternate fashion. Phloem in this zone is well preserved and seen in the central part of vascular bundles (Pl. 1, figs 5, 6).

Fibrous bundles—The fibrous bundles are present generally in the cortical zone measuring 6-8 μm and comprise 10-20 individual cells (Pl. 1, fig. 8).

Crystals—Needle-like crystals, probably calcium oxalate

PLATE 1

⟶

1. Fossil agavaceous axis showing leaf scars.
2. Cross section of the axis under low power (a part shows the arrangement of primary and secondary vascular bundles) x 25, x 50 respectively (Pv - Primary vascular bundles, Sv - Secondary vascular bundles, Lt - Leaf traces).
3. Part of the cortex showing cambium (cmb) cells (x 500).
4. Primary vascular bundles scattered in the central part of axis (x 300).
5. Vascular bundle in oblique section showing phloem cells (x 1000).
6. Single amphivasal vascular bundle showing phloem in the centre (x 1000).
7. Part of the vascular bundle enlarged to show vessels and xylem parenchyma (x 1200).
8. A part with fibre bundle in the cortex (x 750).

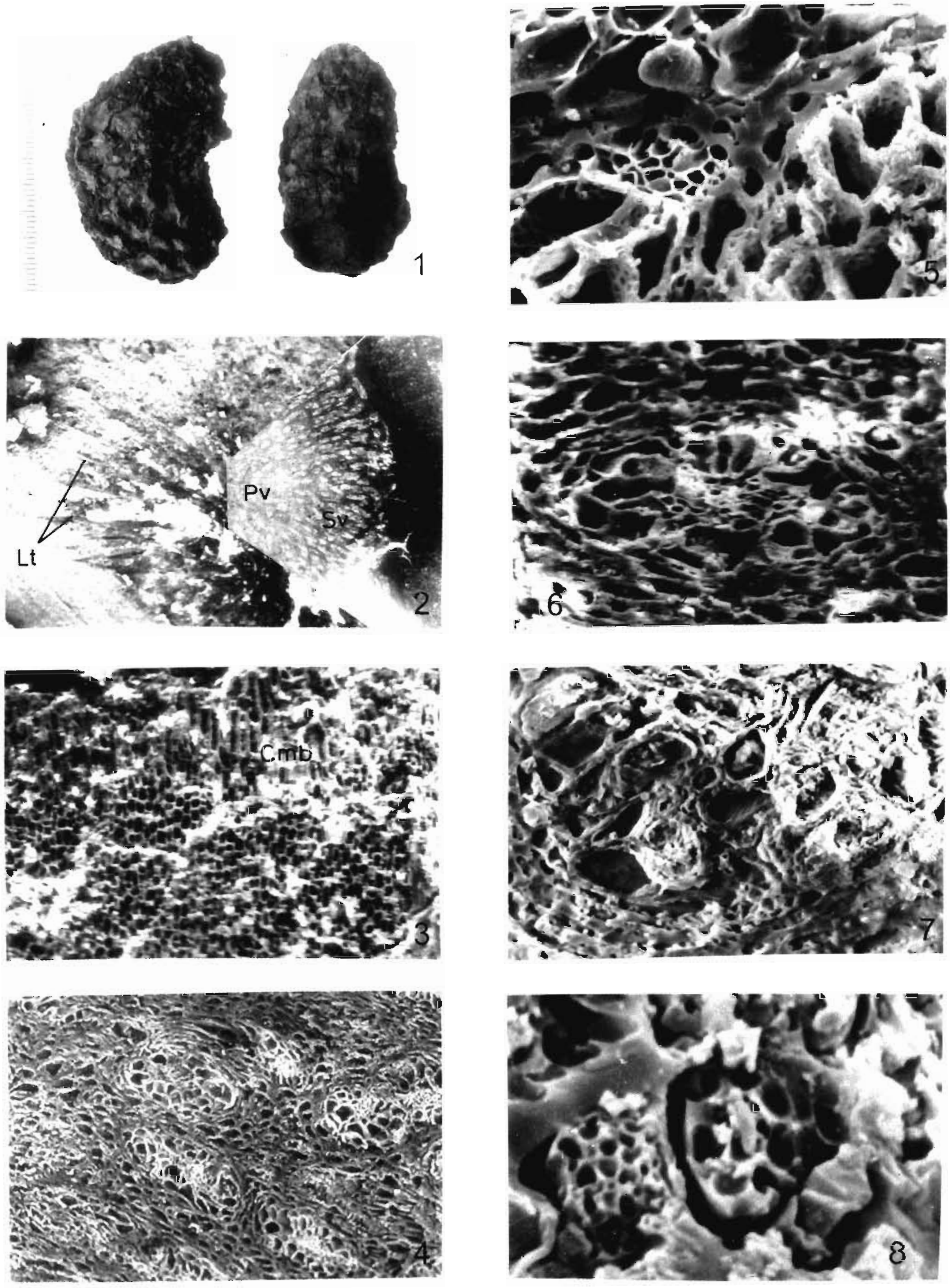

PLATE 1

in nature, are seen generally seated in parenchyma cells. However, they are profusely present in the suberised cells of the cortical zone. These calcium oxalate crystals are referred as pseudo-raphides. They may be branched or single. The thickness of crystals varies from 0.5-5.0 µm. The thicker crystals are broader at the base and become finer towards apex (Pl. 2, figs 8, 9).

Other cell inclusions—In the parenchymatous cells of cortical zone, primary vascular zone as well as secondary vascular zone of the axis different cell inclusions have been observed. They vary from round to elongated bodies. A large number of sinuate bodies are also seen in the ground parenchymatous cells (Pl. 2, fig. 5). The size of these bodies varies from 1-5 µm (circular type), up to 10 µm (elongated type) and 10-20 µm (sinuate type). However, the exact nature of these bodies could not be ascertained.

DISCUSSION

Agavaceous plants are found usually as sub-shrub to shrubs sometimes large shrubs (e.g., *Dracena* and *Yucca*). In their herbaceous habitat the aerial stems develop from the underground rhizomatous stems and for this habitat they lost the cambial activity in their secondary vascular system as seen in most of the dicotyledonous plants. Such stems probably had adapted the atectostelic characteristic having two or more whorls of vascular strands. They probably had primitive vessels both in stem as well as root. These primitive vessels had generally oblique walls with scalariform perforation plates which, later, in more evolved taxa included vessels with simple perforation plates.

According to De Mason (1979) a number of monocotyledonous plants produce secondary growth by means of a special kind of cambium known by various names but Clowes (1961) termed it as secondary thickening meristem (STM). It is a characteristic of Agavaceae (Rudall, 1995), occurring in all the genera of the family (e.g., *Agave, Furcraea, Beucarnea, Dasylirion*). The secondary tissue meristem (STM) differentiates from mature primary tissue. Anatomically the primary vascular bundles are colateral while the secondary ones are amphivasal in nature (see Tomlinson & Zimmermann, 1969). In the present fossil axis though collateral bundles could not be observed but the continuity of primary and secondary bundles is noticed (Pl. 1, fig. 2). Zimmermann and Tomlinson (1970) concluded that in *Dracaena fragrans* and *Yucca brevifolia* the primary vascular bundles are differentiated only when the shoot elongation is complete.

According to Cheadle and Kosakai (1971), the specialisation of tracheary elements in Agavaceae as a whole is at a relatively low level. Vessels of any kind seem to be absent in bulbs, rhizomes, inflorescence axes and leaves. The vessels identified by them in aerial stem are of only primitive nature. According to Ayensu (1972), Cheadle (1943) and Wagner (1977), the most primitive vessel types are considered with long, narrow and oblique wall perforations with scalariform perforation plates. Whilst the most advanced ones are short and broad with a single large circular perforation plate. However, vessels in the present specimen are comparatively short, scalariform and pitted with simple perforation plates. It therefore seems that the plant had already acquired an advanced anatomical character. It is also observed that the continuity with the primary vascular system is by means of short bridges which link with leaf traces; similar pattern in Agavaceae has been observed by Parthasarathy and Tomlinson (1967).

The monosulcate pollen recovered from the same specimen confirm that the axis is a part of an inflorescence and the sulcate nature indicates less advanced character (Pl. 2, fig. 10). Calcium oxalate accumulated in several types of cells in plants may be simple, short, crystals or needle-like ones (pseudo-raphides). They may also be druce type bundles or sometimes branched needles (Pl. 2, figs 8, 9). According to Dahlgren and Clifford (1982) and Gulliver (1864) the raphides are more common in monocotyledons than in dicotyledons which are of high taxonomic importance.

It can be presumed that monocotyledons have a close connection with particular group of dicotyledons and it is very likely that their ancestors far back were in common with the ancestors of dicotyledons. It is also evident from the primitive characters which are regarded as ancestral ones. The similarities are found between certain Liliales and Magnoliales of mono- and dicotyledonous groups respectively. However, Agavaceae exhibits a more stabilised organisation of typical characters in the stem, though has not been able to form a true wood.

Records of agavaceous fossils from the Maastrichtian lead to presume their origin in the Upper Cretaceous time. The present find of plant remain along with monosulcate pollen (cf. *Liliacidites*) (Pl. 2, fig. 10) further indicates that these plants were quite established in the Neyveli Formation as also reported by Ramanujam and Reddy (1984), Siddhanta (1986), Saxena (1992) and Thanikaimoni *et al.* (1984).

PLATE 2

⟶

1. Tracheids showing scalariform thickenings (x 2500).
2, 3. Section showing vascular pits and end perforation (x 4000).
4. Longitudinal section of vessel wall showing bordered pit with membrane (x 5000).
5, 6. Parenchymatous cells with cell inclusions (x 4000).
7. Parenchymatous cells showing pits on wall (with round bodies x 4500).
8, 9. Rhaphide crystals in the cortical zone (x 2000).
10. Monosulcate pollen (cf. *Liliacidites* sp.) (x 1200).


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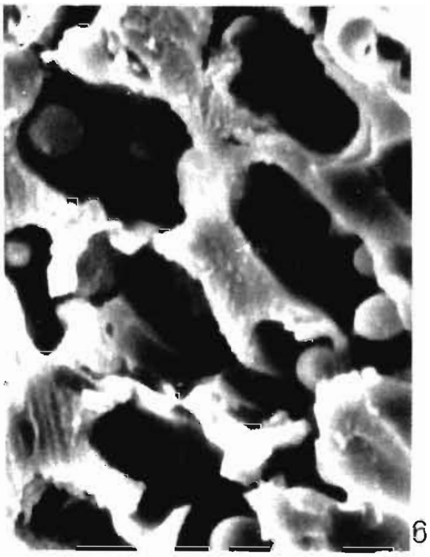
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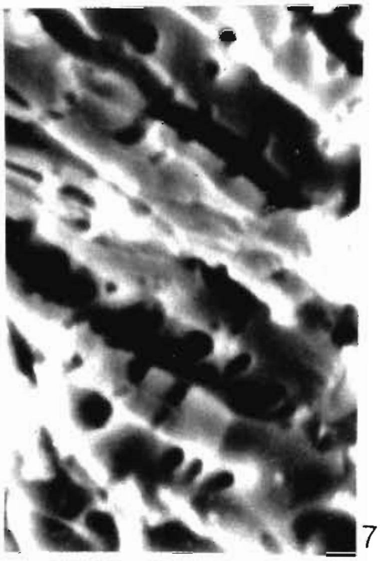
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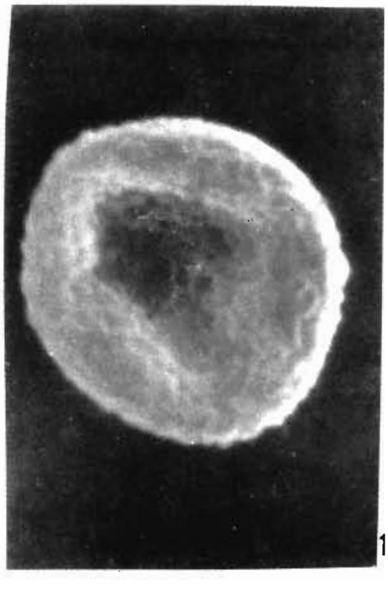
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PLATE 2

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Cocos nucifera like petrified fruit from the Tertiary of Amarkantak, M.P., India

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ABSTRACT

Tripathi RP, Mishra SN & Sharma BD 1999. *Cocos nucifera* like petrified fruit from the Tertiary of Amarkantak, M.P., India. Palaeobotanist 48(3) : 251-255.

Description is given of a petrified coconut like fruit measuring 13 x 10 x 6 cm collected from the Tertiary sediments of Amarkantak (M.P.), India. The fruit wall is thick differentiated into a narrow epicarp, a wide fibrous mesocarp and a sclerosed thick endocarp. Seed coat is 3-4 cells thick, adhered to or free from the endocarp. The pulp or endosperm of the seed is made of loosely arranged thin walled parenchyma. This is the first report of a *C. nucifera* like petrified fruit from India.

Key-words—Petrified, Coconut, Fruit, Tertiary, India.

सारांश

भारत के मध्य प्रदेश राज्य के अमरकंटक नामक स्थान से प्राप्त टर्शियरीयुगीन *कोकस न्यूसीफेरा* की भाँति के अश्मित फल

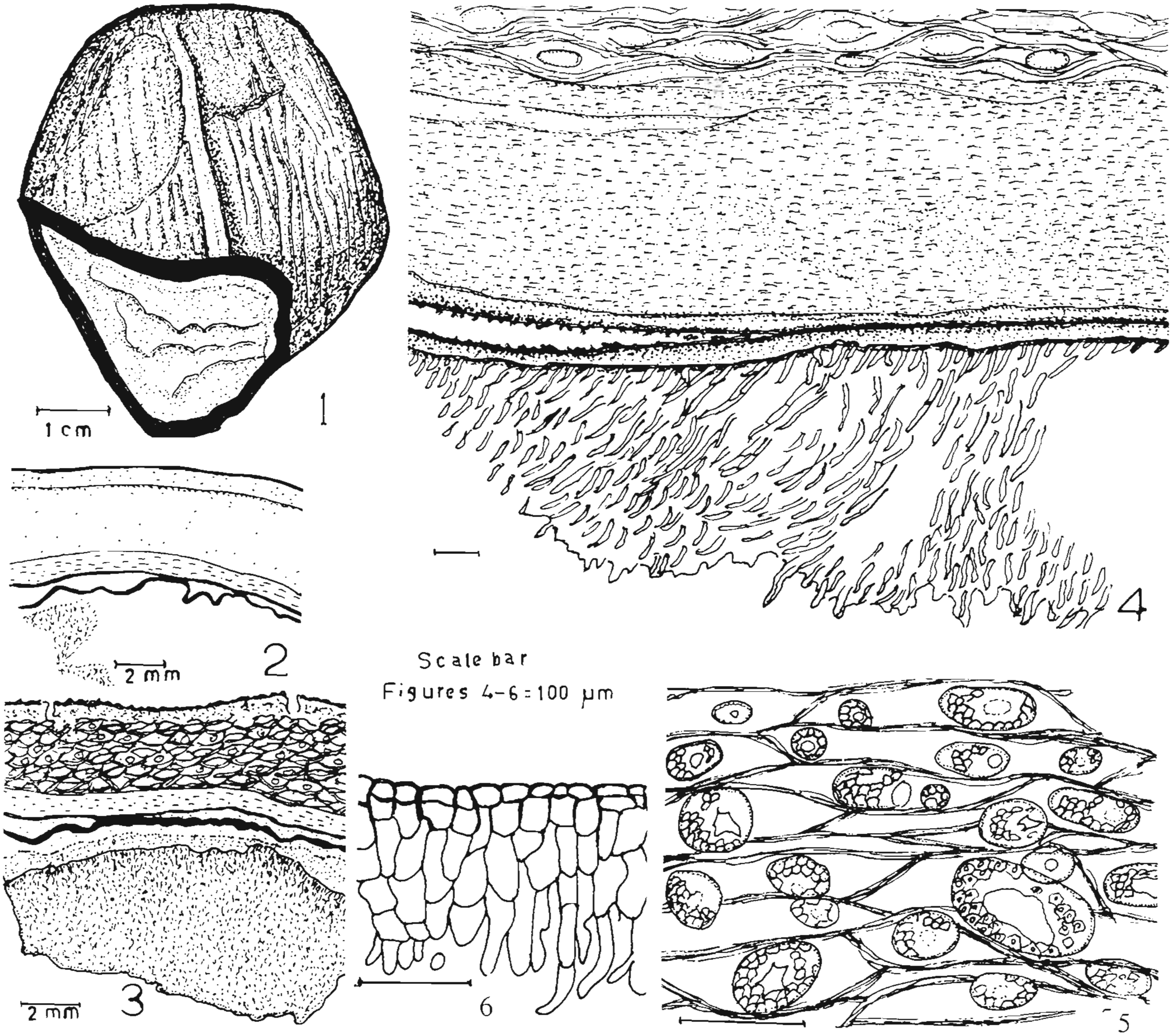
आर.पी. त्रिपाठी, एस.एन. मिश्र एवं बी.डी. शर्मा

अमरकंटक के टर्शियरीयुगीन अवसादों से प्राप्त 13 x 10 x 6 सेमी. आमाप के नारियल की भांति के एक अश्मित फल का विवरण इस शोध पत्र में प्रस्तुत किया गया है। इस फल की फलभित्ति एक संकरी बाह्यफलभित्ति में स्थूलतः विभेदित हैं। इसमें एक चौड़ी तन्तुमय मध्यफलभित्ति है तथा एक दृढ़ स्थूल अन्तःफलभित्ति है। बीज आवरण 3-4 कोशिकाओं से युक्त तथा स्थूल है तथा यह अन्तःफलभित्ति से आसंजित अथवा मुक्त है। बीज का गूदा अथवा भ्रूणपोष शिथिलतः संयोजित पतले भित्तिमय मृदूतकों से निर्मित है। भारत में *कोकॅस न्यूसीफेरा* की भांति का यह अश्मित फल पहली बार अंकित किया गया है।

INTRODUCTION

SAHNI (1946) described a palm trunk *Palmoxylon sundaram* from the Tertiary of Deccan Intertrappean beds which has the anatomy of a stem of *Cocos nucifera*. But, no petrified fruit of this taxon could be collected so far from India. Otherwise, also there are not many records of occurrence of fossil fruits of *Cocos* from India (Mahabale, 1978). Kaul (1951) reported *C. sahnii* preserved in Fuller's earth from the Eocene of Kapurdi, Barmer (Rajasthan). Patil and Upadhye (1984) described a petrified fruit of *C. intertrappea* from the Tertiary of Mohgaonkalan, Madhya Pradesh. The present material closely resembles *C. nucifera* in shape, size, anatomy of wall layers and endosperm, and is the first record of a *Cocos nucifera* like petrified fruit from India.

While discussing the origin of coconut, Mahabale (1978) described the anatomy of three wall layers of the fruit of *Co-*



Text-figures 1-6— **1**—*Cocos nucifera* like fruit. Specimen no. SNM/AMR-2. **2**— Three wall layers of fruit with seed coat free and adhered. **3**— Same. Enlarged. **4**—Same Enlarged. Note heterogeneous nature of endocarp, free and adhered positions of seed coat with endocarp. **5**—Fibres and fibrovascular bundles of mesocarp. **6**— Outer portion of seed coat with a distinct outer layer of cells.

cos sp., i.e., epicarp, mesocarp and endocarp and differentiated species of *Cocos* on this character, e.g., *C. nucifera, C. coronata (Syagrus coronata), C. schizophylla (Arycuriroba schizophylla), C. plumosa (Arecastrum ramanzoffianum)* and *C. yatay (Butia yatay)*. Except *C. nucifera* all others are small fruits and found in South America.

PLATE 1

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1. *Cocos nucifera* like fruit. Specimen no. SNM/AMR-2. Note external morphology of the fruit. x ca 1/2.
2. Cross section of the fruit showing three wall layers and the central cavity. x ca 1/2.
3. Cross section of pericarp showing epicarp (outerside) with alternating smaller and larger bundles (cavities) and wide mesocarp with scattered bundles and fibres. x 60.
4. Mesocarp with scattered bundles (cavities) and pseudo network of fibres. x 60.
5. A portion of mesocarp and distinct endocarp made up of closely packed sclerenchyma. Free seed coat is also seen. x 60.
6. Endosperm or pulp in peripheral portion is made of elongated cells. x 300.
7. Endosperm central portion made up of loosely packed parenchyma. x 400.
8. Same, Enlarged. x 800.

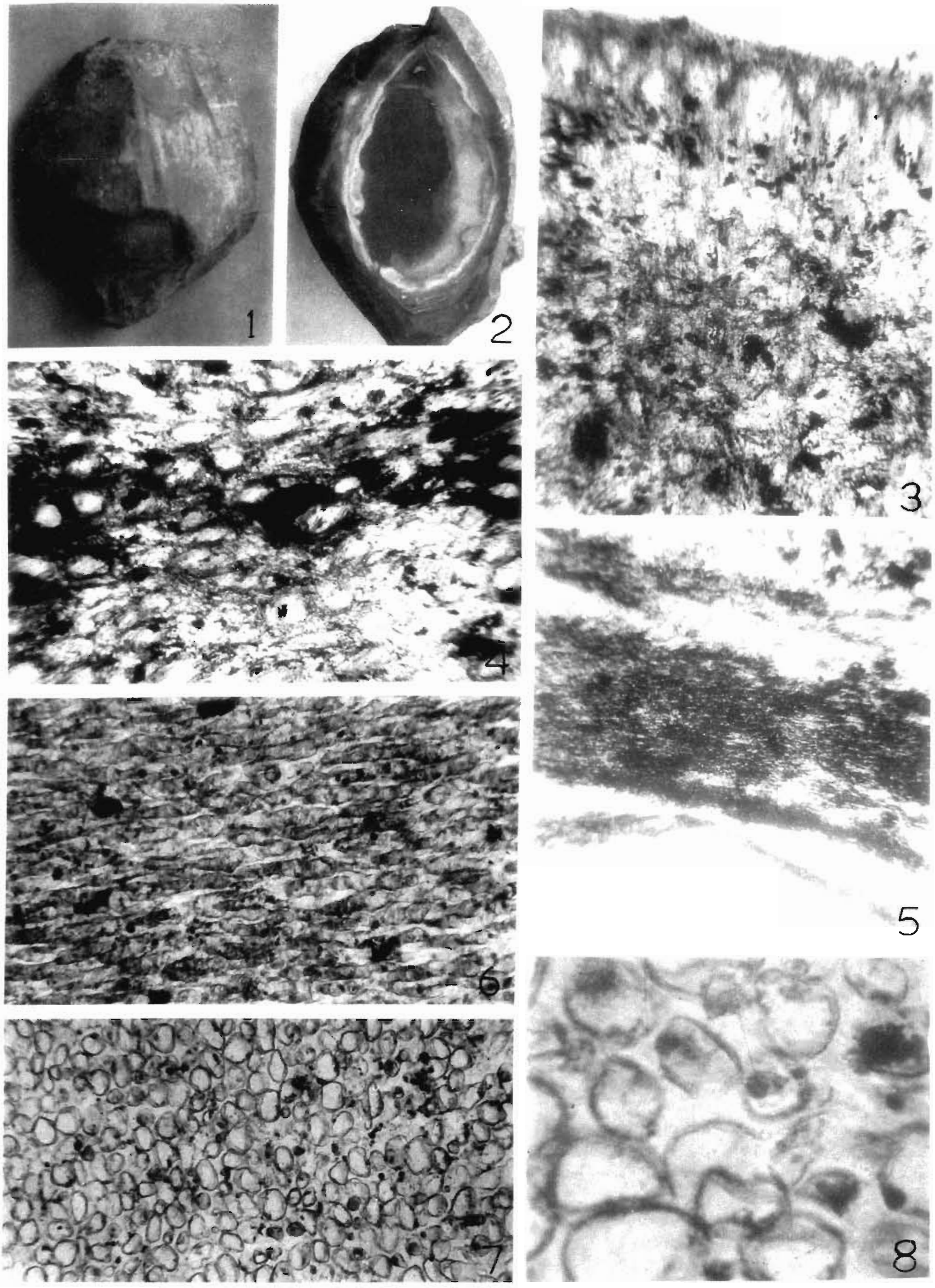
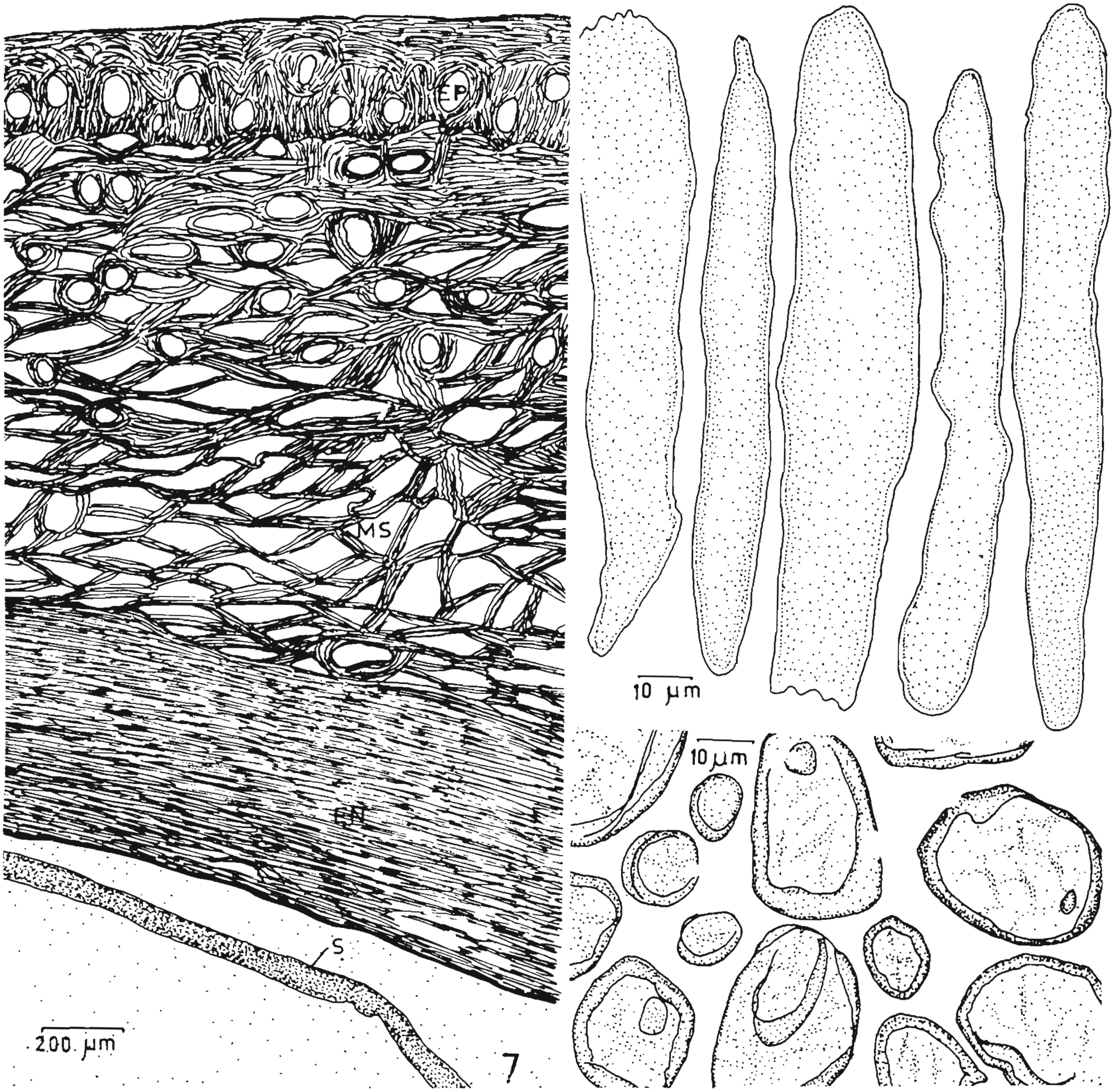


PLATE 1



Text-figures 7-9— 7—*Cocos nucifera* like fruit. C.S. pericarp showing narrow epicarp with alternating two rows of bundles (cavities), wide mesocarp with bundles and reticulum of fibres and distinct endocarp made up of closely packed sclerosed parenchyma. Seed coat is free from pericarp (EP=Epicarp, MS= Mesocarp, EN=Endocarp, S=Seed coat). 8—Elongated cells in peripheral portion of endosperm. 9—Loosely placed cells in central portion of endosperm. Note nucleus like structure in some of the cells.

Rigby (1995) described a fruit of *C. nucifera* from the Pliocene of Queensland (Australia) but without internal details. The present material preserves all anatomical structures of the wall layers and of endosperm. These are compared with those of *C. intertrappea* Patil & Upadhye (1984) and *C. nucifera* (Kulkarni, 1965-unpublished; Murray, 1973; Robertson, 1977; Kulkarni & Pandey, 1984; Kulkarni & Mulla, 1997).

DESCRIPTION

Specimen no. SNM/AMR-2 (Text-figure 1) measures 13 x 10 x 6 cm, oval in shape with an ill-defined third ridge on a lateral side (Pl. 1, fig. 1). The surface has fine longitudinal striations of fibres of the epicarp (Text-figure 1). The distal end of the fruit is blunt while the proximal end is obtuse. A cross section of the fruit shows a multilayered wall surrounding a large, central cavity measuring 6 x 4 cm in size (Pl. 1, fig. 2.) The shape of the fruit in cross section looks more or less biconvex due to pressure exerted during the process of fossilization, otherwise, it should have been trilobed to circular in outline.

The wall of the nut is 6-15 mm thick and is differentiated into three distinct layers, i.e., outer epicarp, middle mesocarp and inner endocarp (Text-figure 2). Epicarp is narrow, 0.5 to 2 mm wide, consists of fibres and two alternate rows of vascular bundles (Pl. 1, fig. 3; Text-figures 3, 7). The outer row has smaller bundles than those of the inner row. Details of bundles remain unclear for want of good preservation of tissues of epicarp.

Mesocarp is wide, 2 to 5 mm thick and consists of fibres and fibrovascular bundles (Pl. 1, figs. 3, 4; Text-figures 5, 7). The fibres are oriented longitudinally or in little oblique directions giving a false network like appearance (Pl. 1, fig. 4; Text-figures 4, 7). Details of fibrovascular bundles could be seen only in a few peels/slides (Text-figure 5). The bundles are of various shapes and sizes (Pl. 1, fig. 4; Text-figure 5).

The third innermost layer of the fruit wall is hard, well developed, sclerosed layer known as endocarp (Pl. 1, fig. 5; Text-figures 4, 7). It is heterogeneous, 0.4 to 1.5 mm thick and consists of closely packed, tangentially oriented thick walled sclerosed parenchyma cells. The inner layer is narrower and has different types of cells, probably fibrovascular bundles (not clear) (Text-figure 4).

Inside the endocarp, there is a distinct seed coat which either adheres or is free from the endocarp (Pl. 1, fig. 5; Text-figures 2, 3, 4, 7). The seed coat is 40 to 85 µm thick and is made up of squarish parenchyma arranged in 2-3 rows without intercellular spaces (Text-figure 6). The pulp or endosperm is made up of loosely arranged elongated parenchyma (Pl. 1, fig. 6; Text-figures 4, 8) which measure 75 x 12 to 180 x 24 µm in size. Adjacent to the seed coat these cells are oriented radially and give filament like appearance and are packed little closely, whereas, in the central portion the cells are vertical to irregular and are placed loosely (Pl. 1, fig. 7). In cross section the cells are seen circular to irregular in shape with thick or thin walls. In some of these cells doubtful nuclei like bodies are also seen (Pl. 1, figs 7, 8; Text-figure 9).

The present *C. nucifera* like fruit differs from all other known species of *Cocos* including *C. intertrappea* of Patil and Upadhye (1984) in its bigger size and anatomy of pericarp (Mahabale, 1978). Epicarp is thin, mesocarp is fibrous and wide, and endocarp is well developed, hard, heterogeneous made up of sclerosed parenchyma and fibrovascular bundles. In external morphology the present material resembles Queensland specimens described by Rigby (1995) from the Pliocene horizon.

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An obituary

Academician Aleksandr Leonidovich YANSHIN
(28th March 1911-9th October 1999)

Academician A.L.Yanshin was born in Smolensk (Russia) on 28th March 1911. He obtained his master degree in 1932 from Moscow Geological - Exploration Institute. Subsequently after qualifying for his Ph.D. in 1937 he was awarded D.Sc. in 1953. In 1958 USSR Academy of Sciences elected him the full Academician - the highest Academic position in Russian Academic Society. During early days of career in prospecting and exploration of mineral deposits he switched over to regional - tectonic work and came out with brilliant publications on the principal problems of tectonics of Asia. In 1966 he headed a group of active tectonists and came out with the classical Tectonic Map of Eurasia on 1:50,00,000 scale. This is an unparallel compilation of data and geological reference work of Eurasian region and is still relevant. He worked at different capacities in well known institutions of Russian Academy of Sciences. During 1956-58 he headed the Regional Tectonic Laboratory of the Geological Institute, Moscow. During 1958-1982 he worked as Deputy Director of Institute of Geology and Geophysics, Siberian Branch of Academy of Sciences of USSR, Novosibirsk. From 1982-1988 he was the chief of Earth Science Sector or Vice-President of USSR Academy of Sciences at Moscow. During his tenure he organised the 27th International Geological Congress at 1984 in Moscow. He was also the Director of the newly formed Institute of Lithosphere, Moscow at this time. Since 1988 till his death he continued to work as Adviser to Russian Academy of Sciences Headquarter at Moscow. At the same time since 1993 he continued to be the President of Russian Ecological Academy and chaired the Professor's post in Ecological Faculty of Russian Friendship University, Moscow. He received many awards in Russia as well as other countries.

Academician Yanshin was the architect of Indo-Russian Cooperation in Earth Sciences under the Long Term Indo-Russian Projects and remained active Coordinator of DST, Government of India and Indian National Science Academy (INSA) New-Delhi projects. He was the Principal investigator in the projects involving Indian and Russian scientists dealing with the Comparative Geology and Tectonic Frame-work of Himalaya-Ural-Caucasus and Altai mountains. His last effort was to guide in formulation of Long Term Indo-Russian projects with Russian Academy of Sciences, Moscow and Birbal Sahni Institute of Palaeobotany, Lucknow (Under Department of Science and Technology, Government of India). Just before his death he fondly invited the Director, Birbal Sahni Institute of Palaeobotany, Lucknow, to visit Moscow and give a final shape to the collaborative project. The fate turned to be too cruel. Instead the Director BSIP attended his official funeral on 14th October, 1999 at Russian Academy of Sciences Main Building at 14, Lininsky Prospect, Moscow. In his death geological world lost a great scientist, we lost a great Indophile and I lost a teacher, personal friend and visionary of Indo-Russian collaborative projects.

The great humanist, as he was, in the later part of his career was much more concerned for protection of environment on our good Earth for human survival and worked for this noble cause till he breathed his last.

He is survived by wife Mrs. Fidan Yanshina and son Alexei.

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