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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

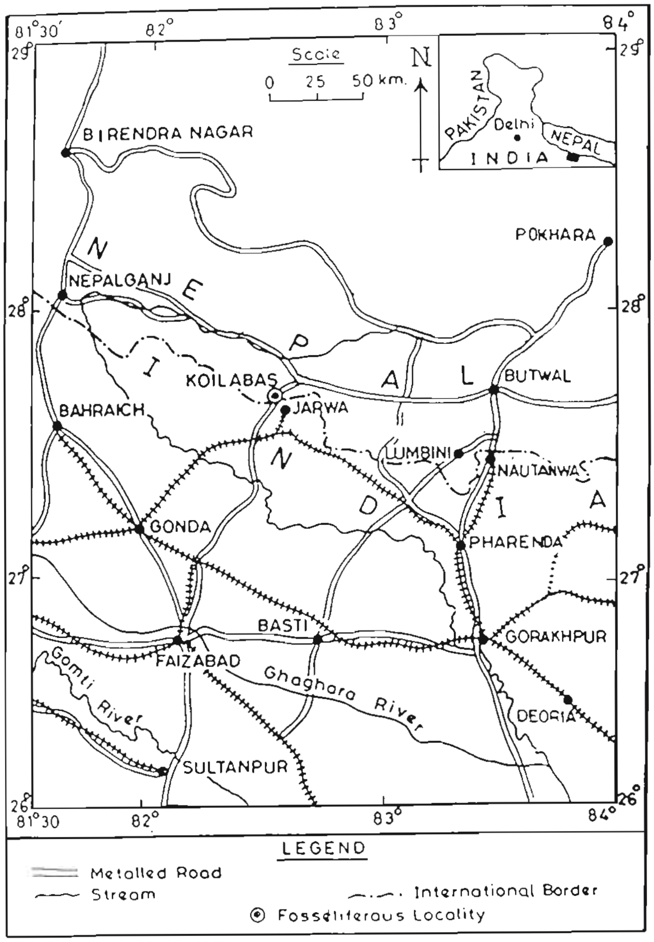
महेश प्रसाद, स्व. जसवंत सिंह अन्तल, पाटेश्वरी प्रसाद त्रिपाठी एवं विनय कुमार पाण्डेय

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

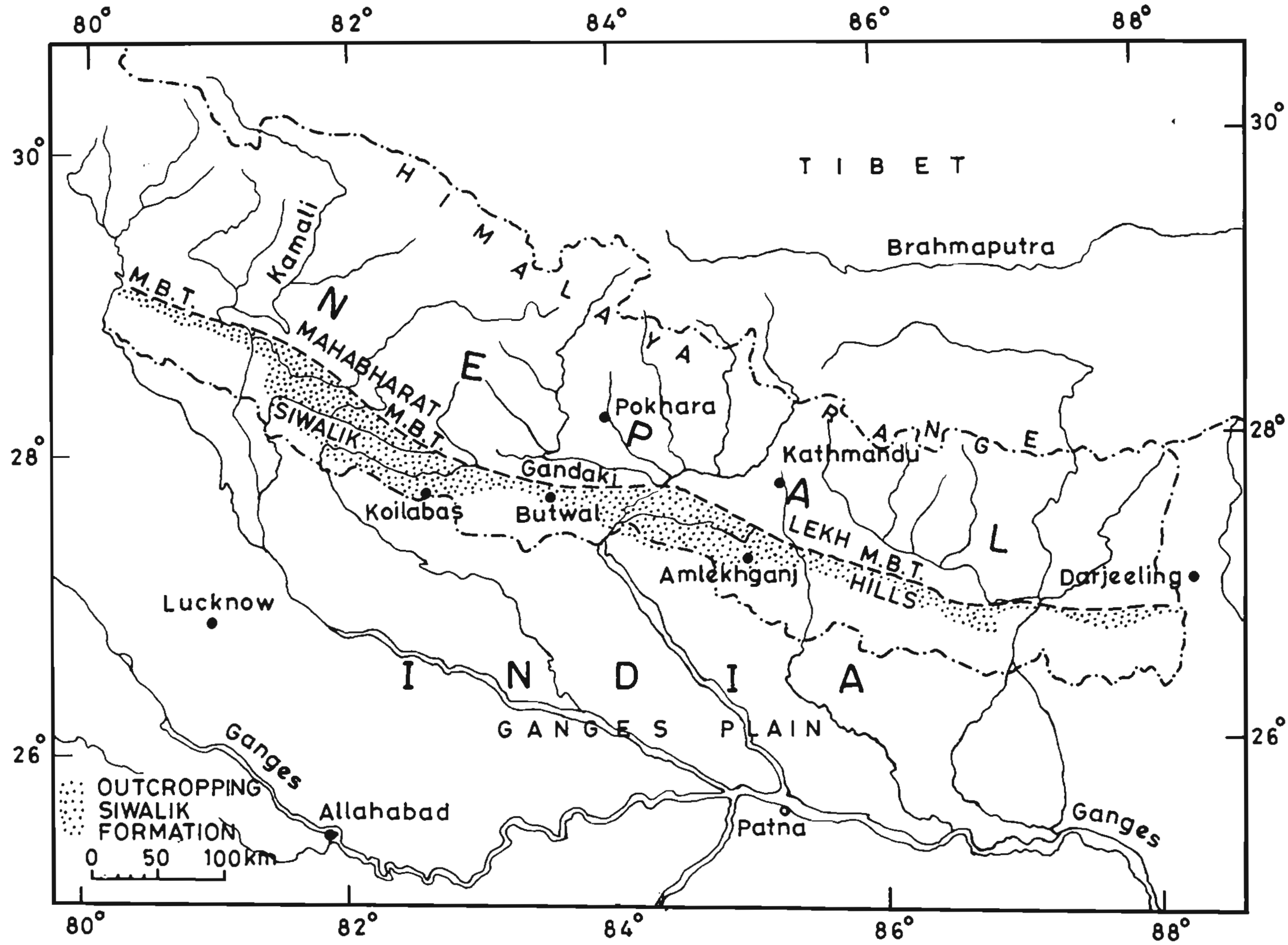
The Siwaliks represent clastic sediments of fresh water molasse which accumulated in a long narrow foredeep formed to the south of the rising Himalaya in the third episode of Himalayan uplift during Middle Miocene. These sediments accumulated under four different environments like, lacustrine, channel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

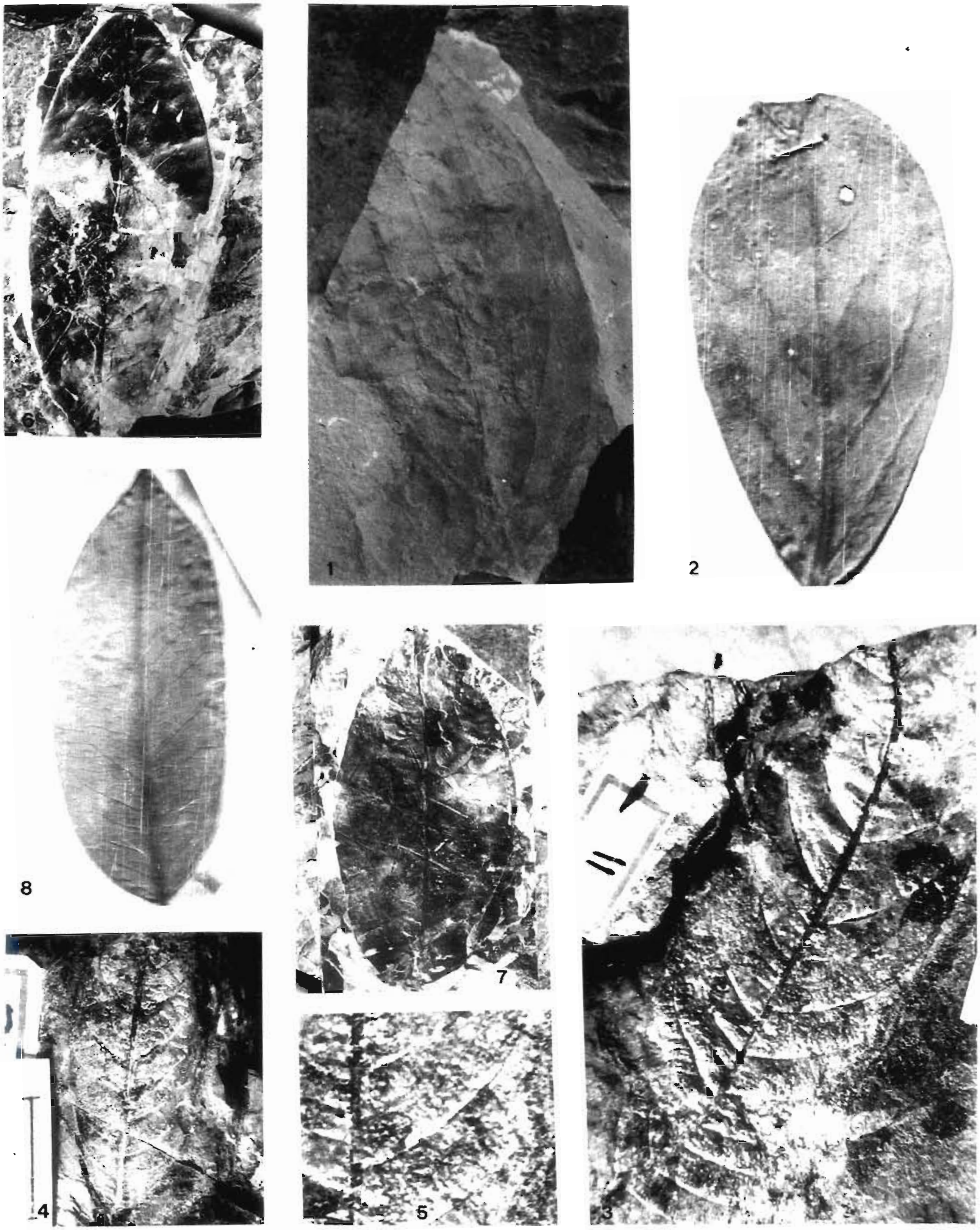


PLATE 1

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

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.

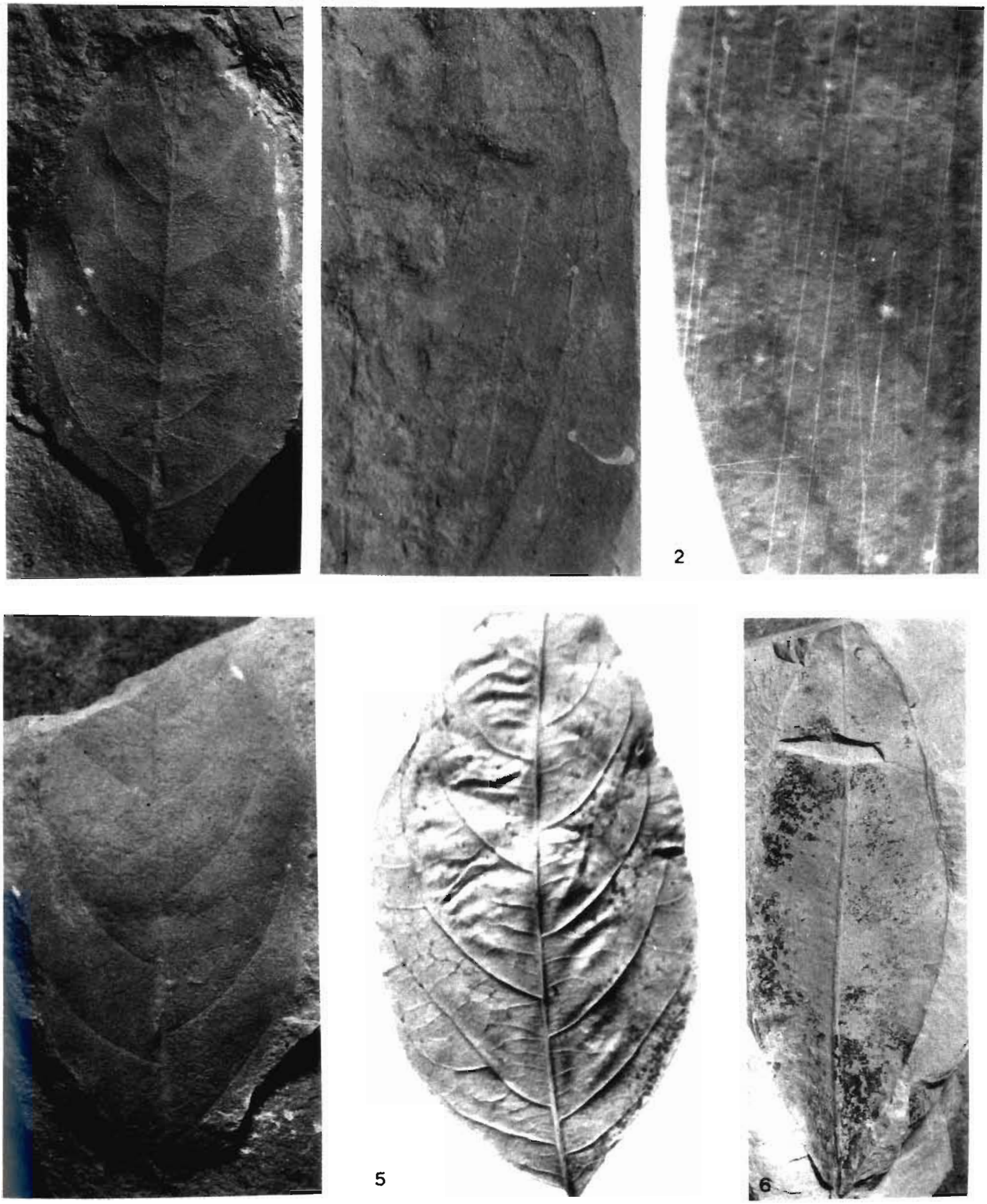


PLATE 2

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)

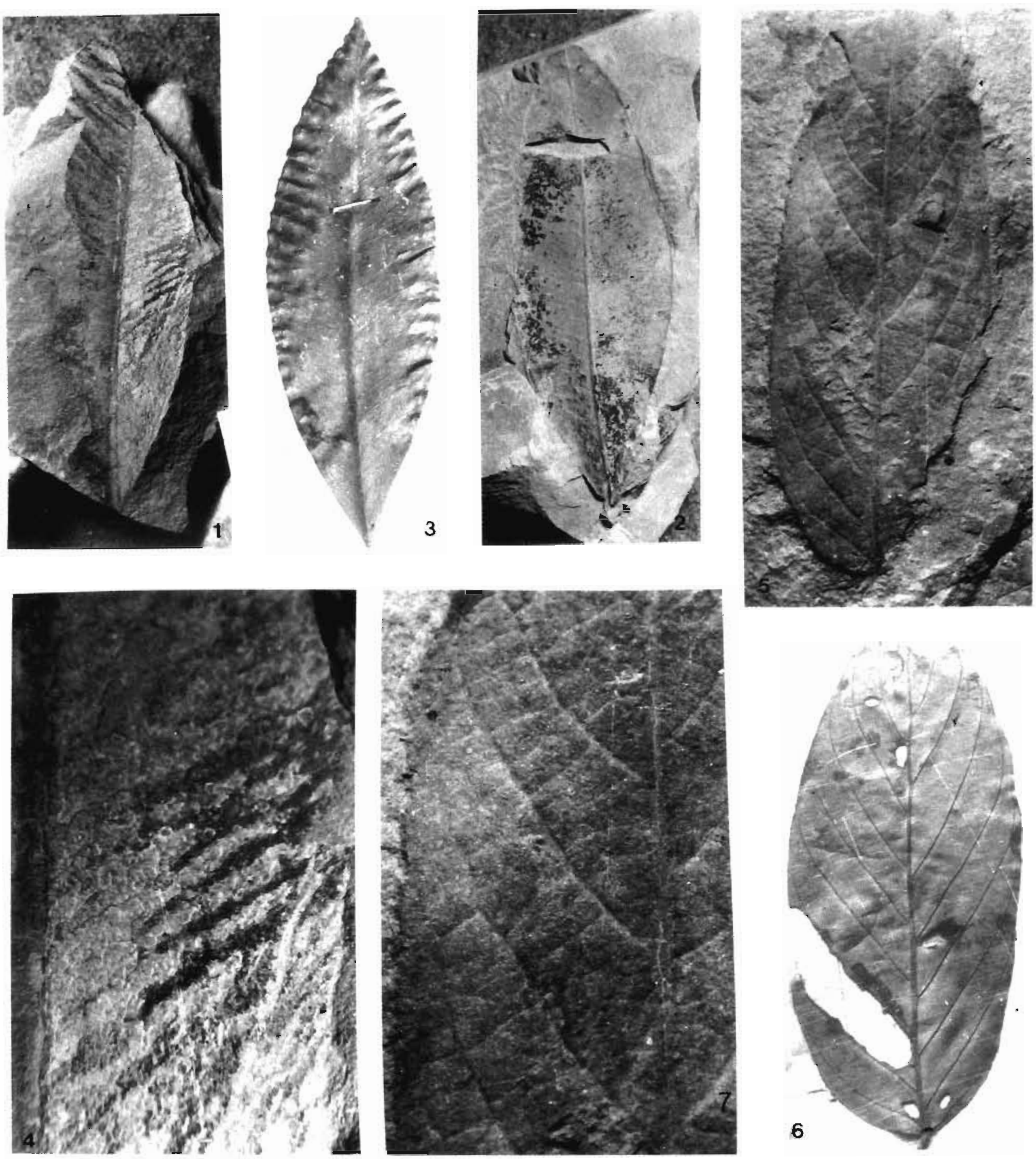


PLATE 3

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(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 borneonsis* 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-

PLATE 4 ⟶

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

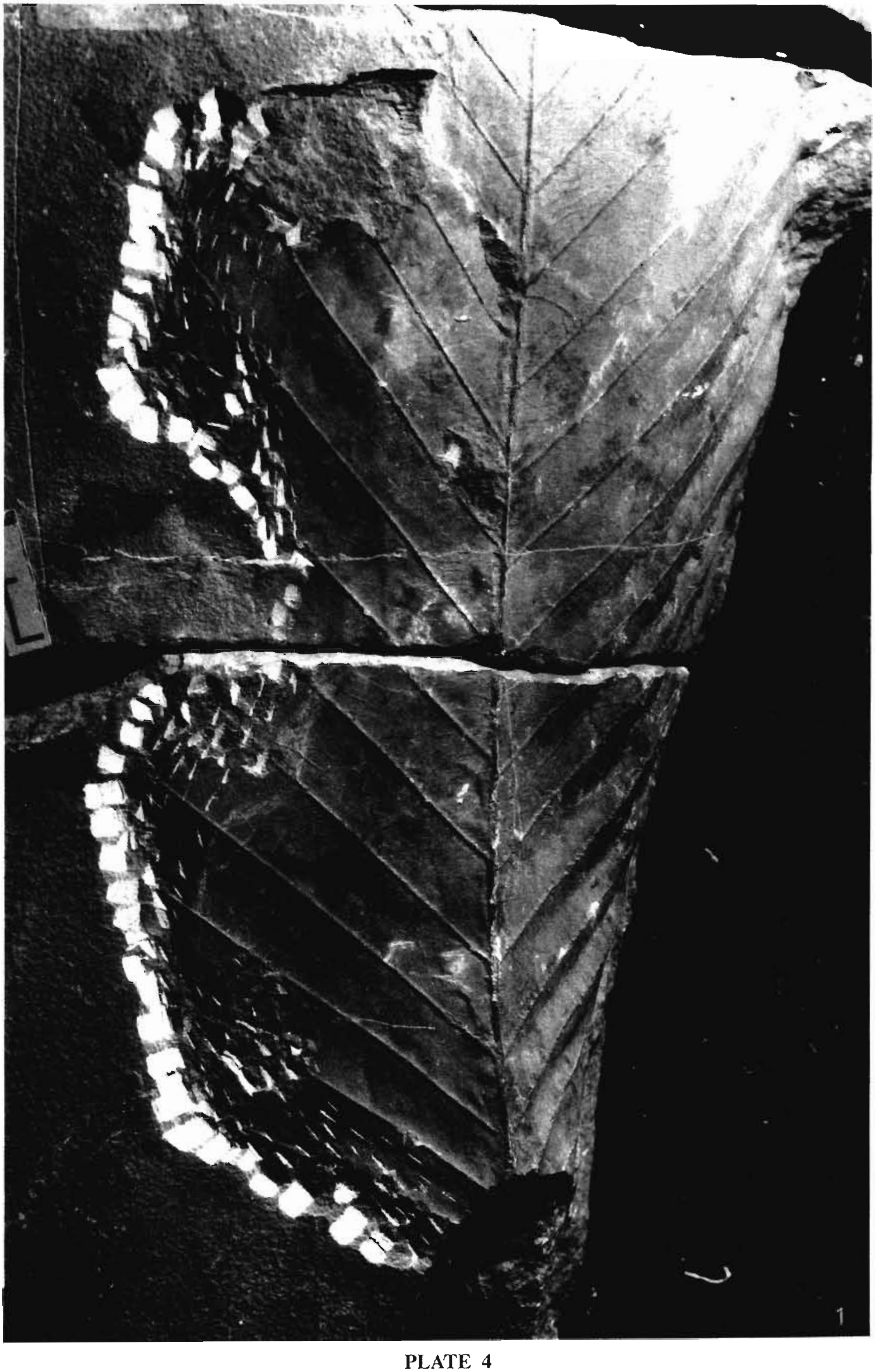

PLATE 4

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

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

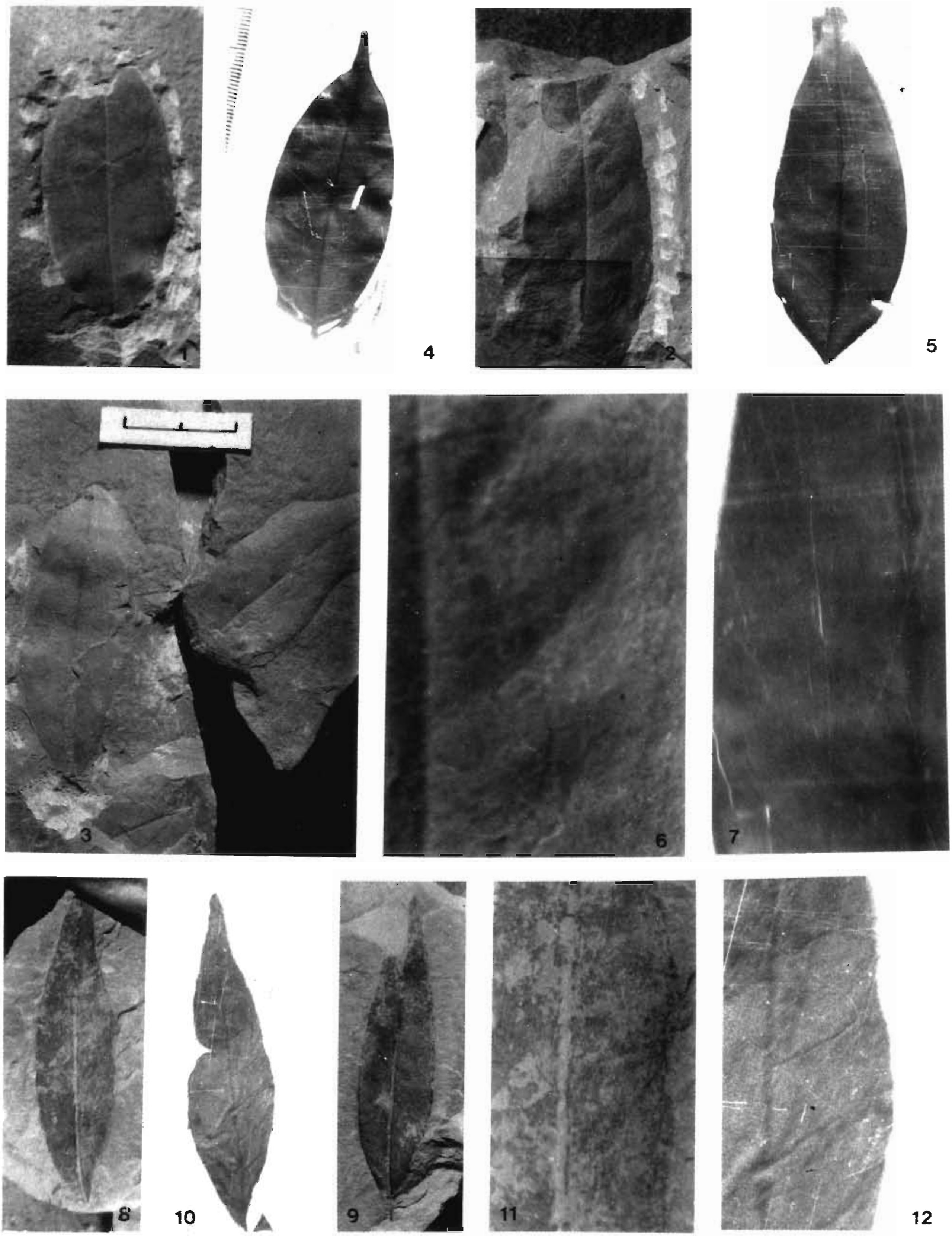

PLATE 5

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 ⟶

(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.

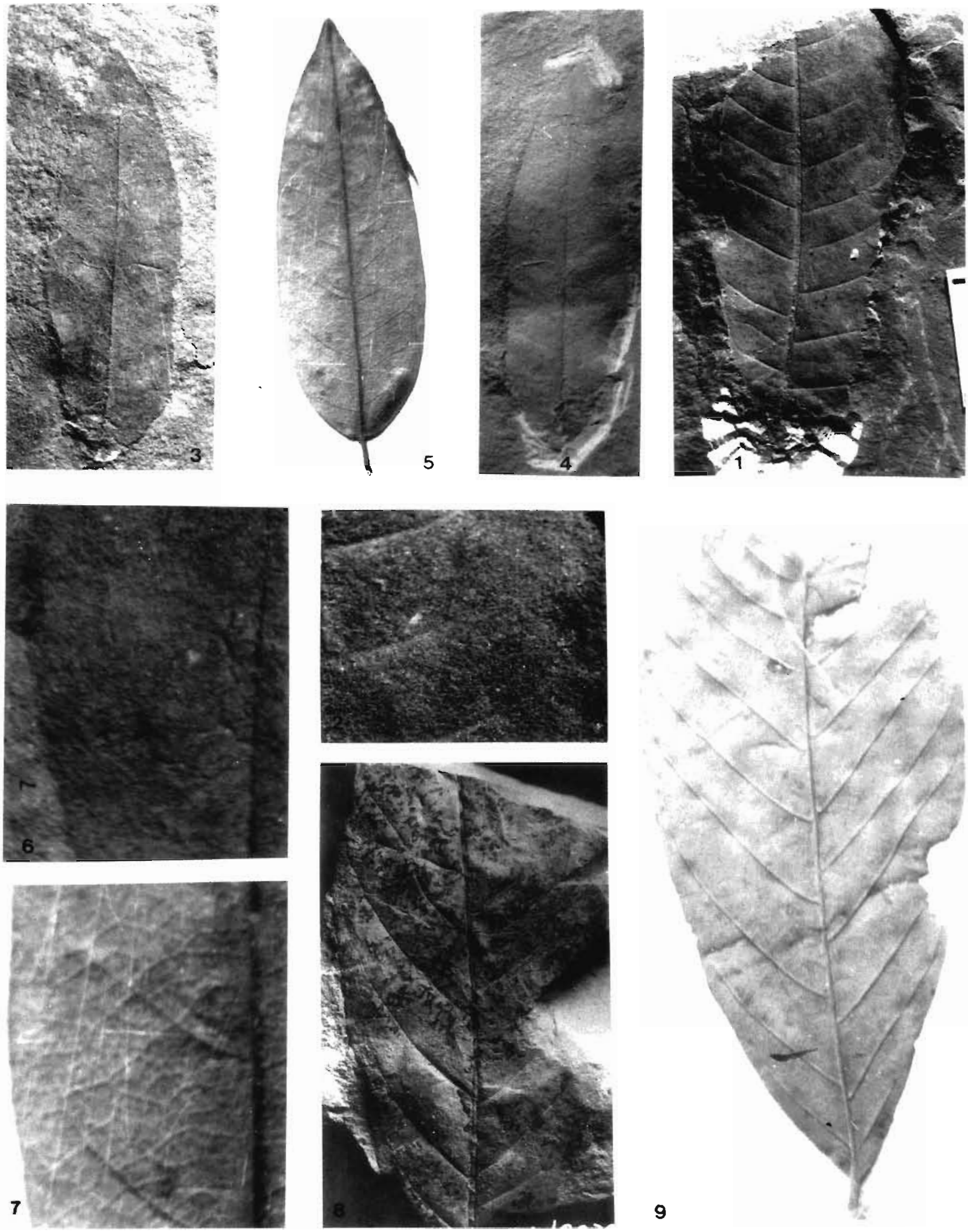

PLATE 6

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 ⟶

(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.

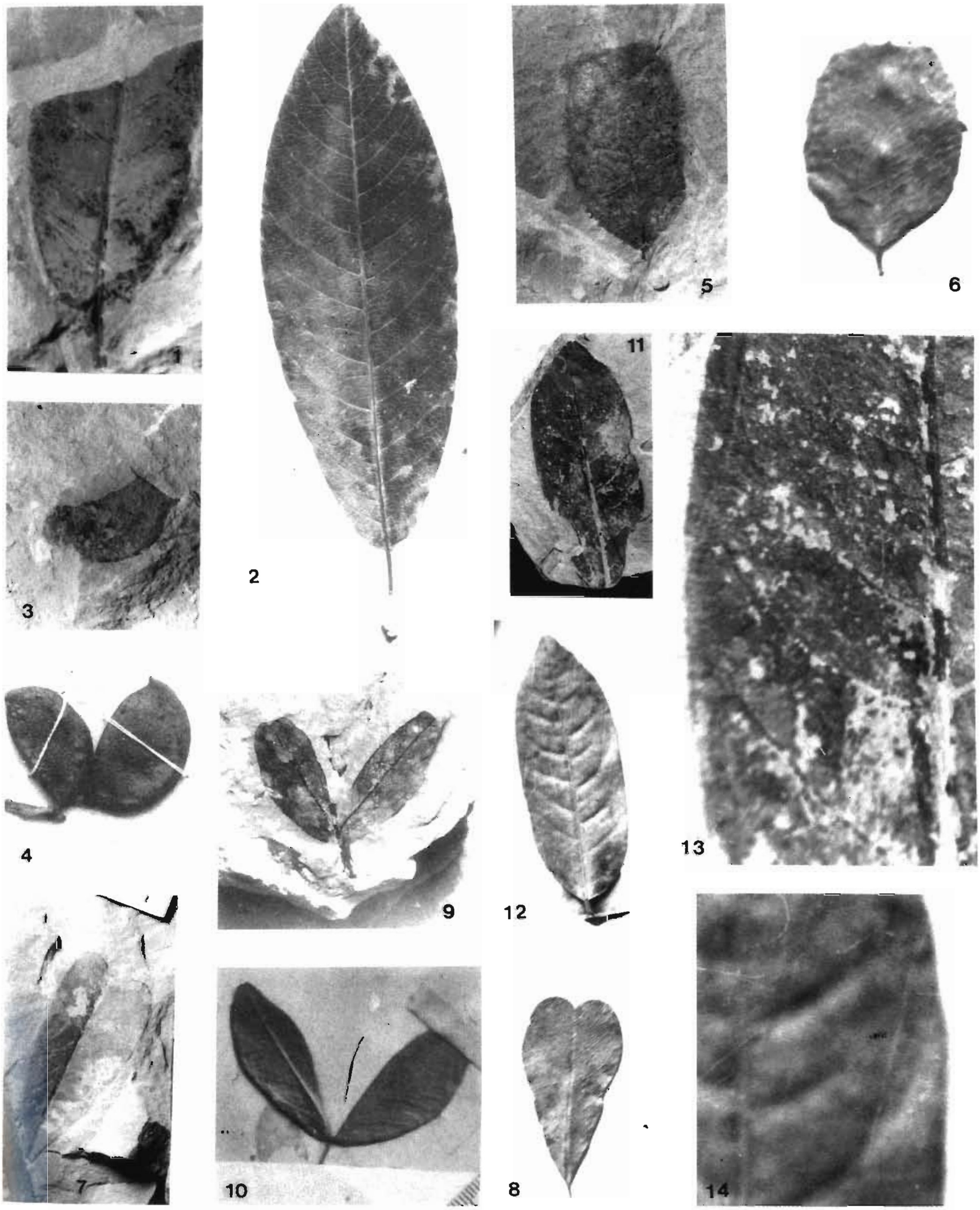

PLATE 7

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,

PLATE 8 ⟶

(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.

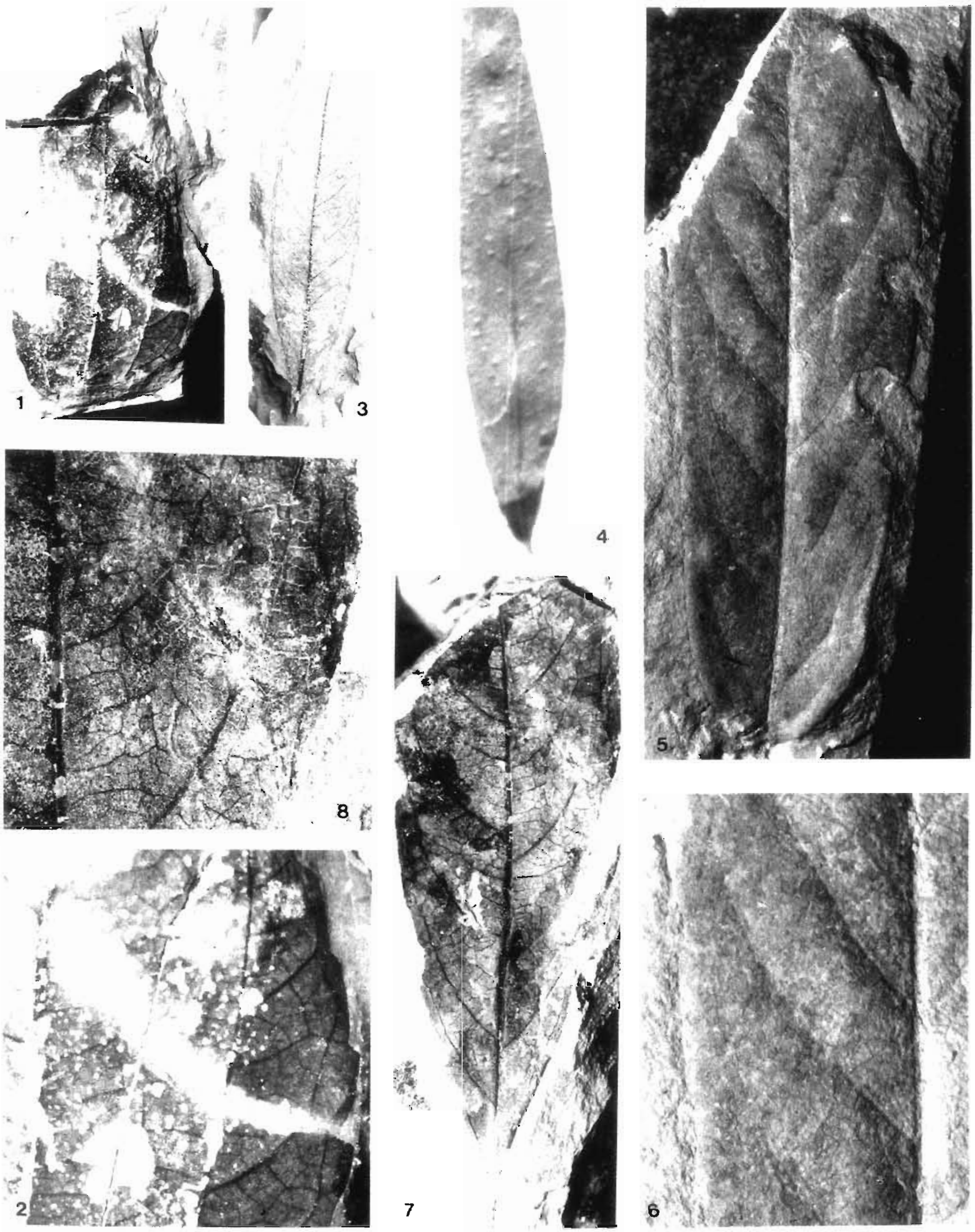

PLATE 8

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-

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.

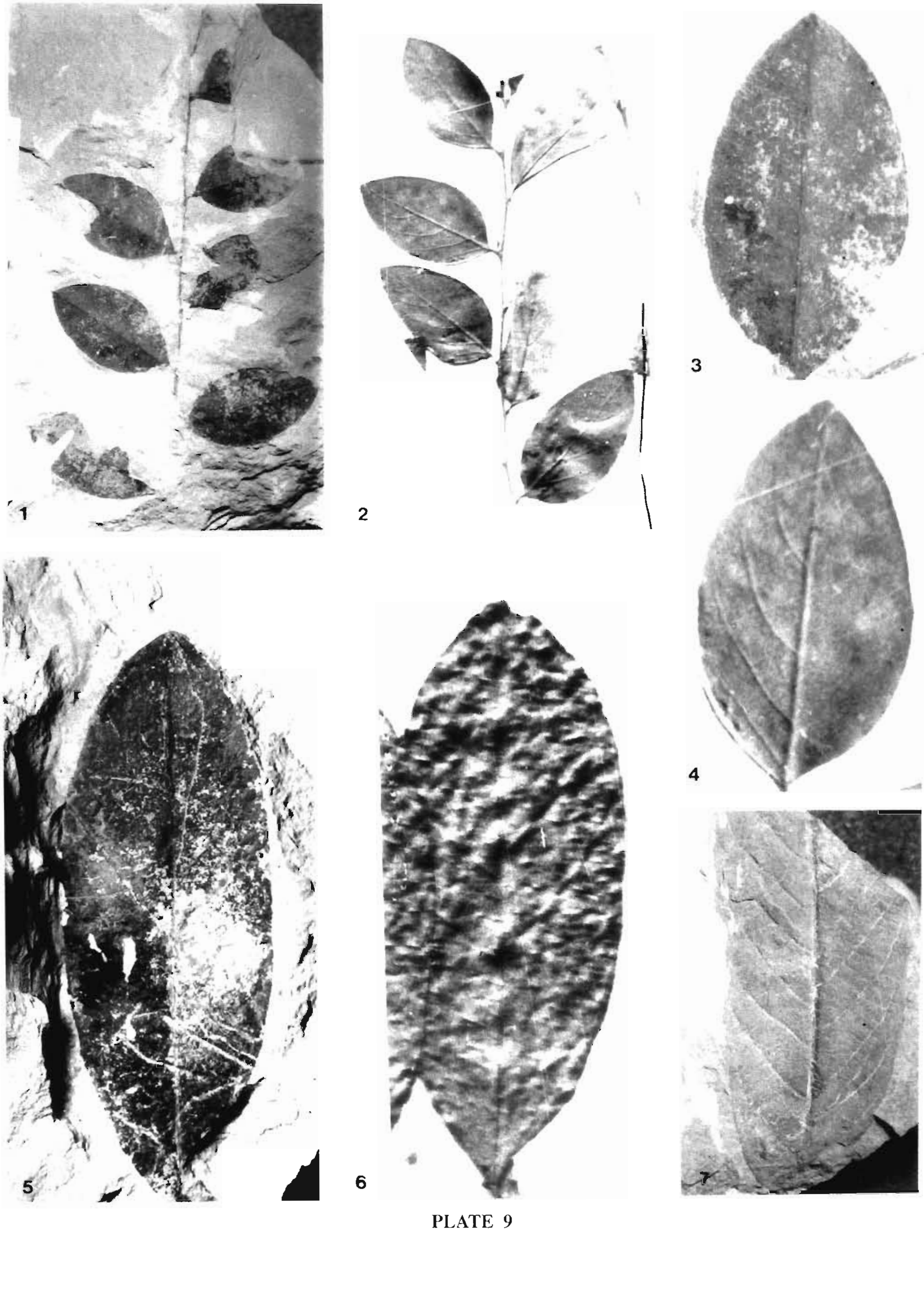

PLATE 9

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

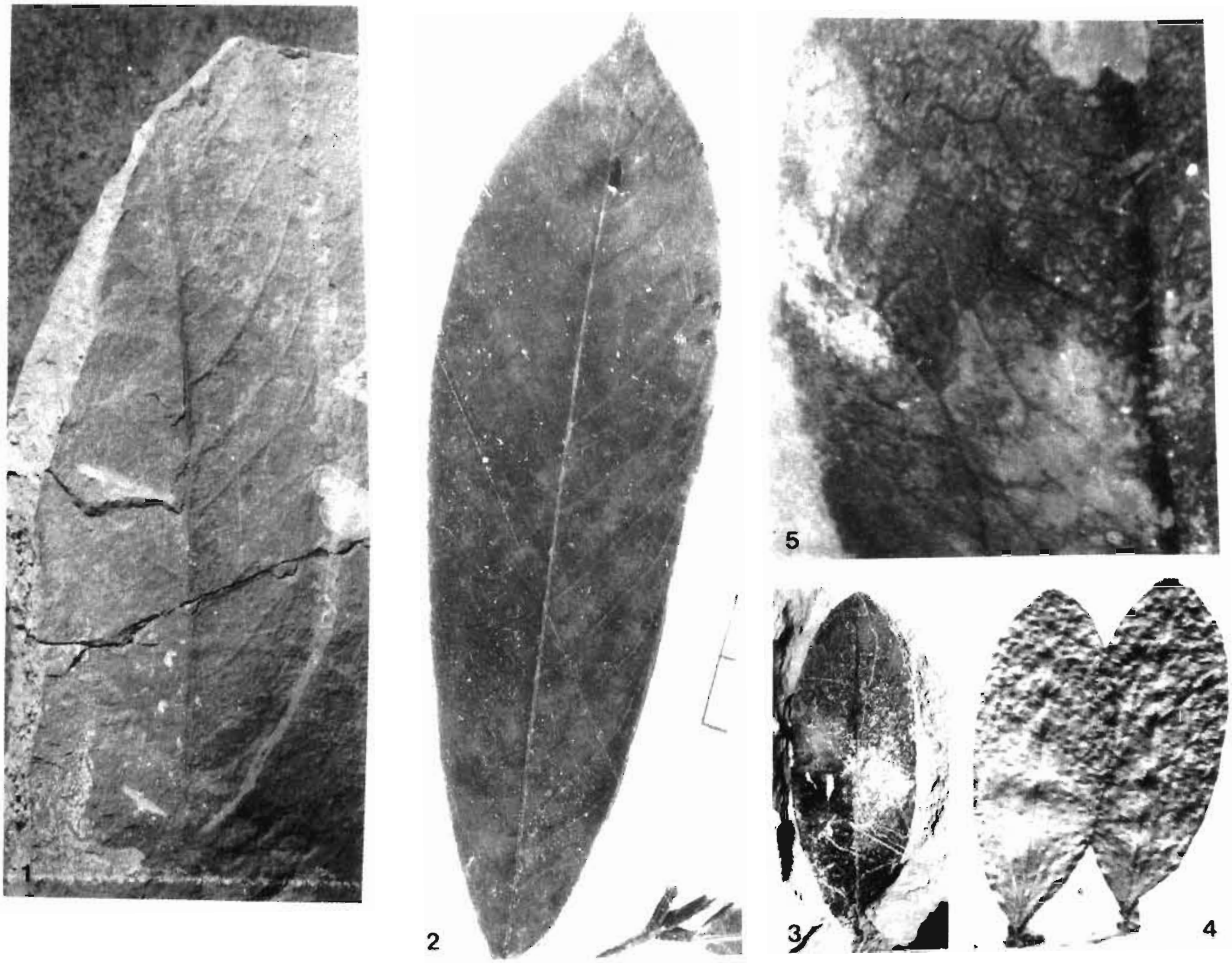

PLATE 10

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 salmii 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
Milletia siwalica Prasad, 1990a	*M. ovalifolia* Kurz.	Sub-Himalayan region, Myanmar	Moist deciduous
M. imlibasensis 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 *Cinnomonum* 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 Organi-zation Comp-ound VS Simple	Venation pattern Close(C) Distant(D)
1	2	3	4	5	6	7	8	9
Anona koilabasensis	13.8	E	-	-	CH	O	S	C
	49.5							
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. encultrata	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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