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Plant megaflora from the Siwalik (Upper Miocene) of Darjeeling District, West Bengal, India and its palaeoclimatic and phytogeographic significance

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ABSTRACT

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Qualitative and quantitative analysis of fossil assemblage so far collected from the Middle Siwalik sediments of Darjeeling District, West Bengal revealed the occurrence of 35 new taxa belonging to 18 angiospermous families. On the basis of present data as well as already known data from there, the reconstruction of vegetation scenarios of Himalayan foothills during Siwalik time has been done. We also discussed problems related to plant diversity, endemism, and migratory pathways of mainly phytogeographically important taxa. The analysis of present day distribution of all the recovered taxa from the region shows that they are mostly known to occur in Northeast India, Bangladesh, Myanmar and the Malayan region where the climatic conditions are favourable. About 1/3 taxa of total assemblage are found to grow presently in the Himalayan foothills of the eastern region and the remaining 2/3 taxa are locally extinct. This indicates that the climatic changes must have taken place after Mio–Pliocene. The dominance of evergreen elements in present fossil assemblage indicates the prevalence of tropical warm humid climate with plenty of rainfall during the deposition of sediments. Foliar physiognomic approach for reconstruction of palaeoclimate further suggests that the Oodlabari area in the Himalayan foothills of West Bengal enjoyed a tropical climate (with MAT 28.9º C and MAP 448 mm) during the Miocene Period. This is, however, contrary to the present day climate of the area with reduced precipitation.

On the basis of the present fossil assemblage, the coexistence intervals of different climatic parameters, i.e. Mean Annual Temperature (MAT), Warmest Month Temperature (WMT), Coldest Month Temperature (CMT), and Mean Annual Precipitation (MAP) have been estimated as 22º C–26.5º C, 17.8º C–20º C, 25º C–30º C, and 2650–3200 mm, respectively. However, Leaf Margin Analysis (LMA) suggests the MAT value as 28.9º C for the area during Upper Miocene.

Key–words—Megaflora, Leaf impressions, Darjeeling District, West Bengal, Siwalik (Mio–Pliocene), Palaeoclimate, Phytogeography.

भारत में पश्चिम बंगाल के दार्जिलिंग जिले के शिवालिक (ऊपरी मध्यनूतन) से प्राप्त गुरू पादपजात तथा उनका पुराजलवायवी व पादप भौगोलिक महत्व

महेश प्रसाद, अंकित कुमार कन्नौजिया, आलोक एवं संजय कुमार सिंह

सारांश

पश्चिम बंगाल में दार्जिलिंग जिले के मध्य शिवालिक अवसादों से अब तक संगृहीत जीवाश्म समुच्चय के गुणात्मक व मात्रात्मक विश्लेषण से 18 आवृतबीजी कुलों की 35 नूतन वर्गकों की प्राप्ति का खुलासा हुआ है। मौजूदा ऑंकड़े एवं पहले से ही ज्ञात वहां के ऑंकड़ों के आधार पर शिवालिक काल के दौरान हिमालयी गिरिपादों के वनस्पति परिदृश्य की पुनर्सरचना की गई है। मुख्यतः पादप भौगोलिक रूप से महत्वपूर्ण वर्गकों की पादप विविधता, विशेष क्षेत्रिता एवं प्रवासी पथ संबंधी समस्याओं की भी चर्चा की गई है। क्षेत्र से मिले समस्त वर्गकों के वर्तमान–कालिक वितरण

के विश्लेषण दर्शाते हैं कि वे वर्तमान समय में अधिकतर उत्तर पूर्व भारत, बांग्ला देश, म्यांमार एवं मलायाँ क्षेत्र में पाये जाते हैं। कुल समुच्चय के तकरीबन 1/3 वर्गक पूर्वी क्षेत्र की हिमालयी गिरिपादों में फिलहाल आज भी मौजूद हैं और बाकी 2/3 वर्गक स्थानीय रूप से नदारद है। इससे संकेत मिलता है कि जलवायवी परिवर्तन मध्य–अतिनूतन कालों के उपरांत हुए होंगे। मौजूदा जीवाश्म समुच्चय में सदाहरित तत्वों की प्रभुत्वता अवसादों के निक्षेपण के दौरान प्रचुर वर्षा सहित उष्णकटिबंधीय आर्द्र जलवायु की व्यापकता इंगित करती है। पुराजलवायु की पुनर्संरचना हेतु पर्णी रूपात्मक पहल सुझाता है कि मध्यनूतन के दौरान पश्चिम बंगाल के हिमालयी गिरिपादों में ऊदलाबाड़ी क्षेत्र में उष्णकटिबंधीय जलवायु (एम ए टी 28.9° सेल्सियस व एम ए पी 448 मिमी) थी। यह, फिर भी, कम परिक्षेपण सहित क्षेत्र की मौजूदा जलवायु के प्रतिकूल है।

मौजूदा जीवाश्म समुच्चय के आधार पर विविध जलवायवी पैरामीटरों अर्थात माध्य वार्षिकी तापमान (एम ए टी), कोष्णतम माह तापमान (डब्ल्यु एम टी), शीतलतम माह तापमान (सी एम टी) और माध्य वार्षिकी परिक्षेपण (एम एपी) के सह अस्तित्व अंतराल क्रमशः 22° से 26.5° सेल्सियस, 17.8° से 20° सेल्सियस, 25° से 30° सेल्सियस और 2650–3200 मिमी के रूप में अनुमानित किए गए हैं। जबकि पर्ण उपांत विश्लेषण (एल एम ए) ऊपरी मध्यनूतन कालों में उपरोक्त क्षेत्र के लिए एम ए टी मान 28.9° सेल्सियस दर्शाता है।

सूचक शब्द—गुरू पादपजात, पर्णछाप, दार्जिलिंग जिला, पश्चिम बंगाल, शिवालिक (मध्य–अतिनूतन) पुराजलवायु, पादपभूगोल

INTRODUCTION

THE Himalayan foothills have resulted from the tectonic processes that have been taking place in the Himalayan orogeny since the Cenozoic era. The Siwalik Basin, a part of the Himalayan foothills, was formed as a fore deep in front of the newly risen Himalaya during Middle Miocene orogeny and was the site of deposition of the Siwalik sediments. The Siwalik System is 5–6 km thick and is composed mainly of sandstones, grits and conglomerates. The Siwalik sequence of West Bengal has been broadly subdivided into three units–1. Upper pebbly sandstones and conglomerate unit, 2. Middle sandstone unit, and 3. Lower clay stone unit (Acharya, 1972, 1975). The lower claystone unit is best exposed in Ramthi River, Ghish River, Tista River and on the Sevok Road and consists of claystone, siltstone and fine grained sandstone. The Middle sandstone unit is well exposed in Lish and Ghish River and also in some tributaries of Tista River (Fig. 1).

The problems associated with the Siwalik (Mio–Pliocene) floras are of regionalism, endemism and migration/extinction in response to physical and climatic factors which need to be worked out in detail to unravel the history of the modern flora of India. The flora of Siwalik Group of India has been subjected to numerous changes. Many genera which are recorded in India during Mio–Pliocene either migrated or faced extinction. Evolution of the Siwalik floras in the northern region has largely been influenced by the Himalayan orogeny. The Middle–Miocene orogeny of the Himalaya led to the proliferation of several gymnospermous groups and appearance of several subtropical angiospermic taxa. In view of this, Pathak (1969) studied a few fossil leaves from the Middle Siwalik sediments of Mahanadi Section in the foothills of Darjeeling District. These fossils are fragmentary and their generic and specific determinations are doubtful. Later on through continuous efforts, a good collection of well–preserved plant megafossils comprising carbonised fossil woods and impressions of leaves and fruits have been made from the Lower and Middle Siwalik sediments exposed near Oodlabari, Sevok, Tista Bridge, Kali Khola, Bagrakot and Dudhia Village in the Darjeeling District. These megafossils have been studied in detail and a variety of plant fossil assemblage recovered (Antal & Awasthi, 1993; Antal & Prasad, 1995, 1996a, b; Antal *et al.,* 1996; Antal & Prasad, 1997). Prasad (2008) recorded fabaceous fossil wood showing affinity with modern taxa *Cynometra ramiflora* L. from the Middle Siwalik sediments of Ramthi River Section in Darjeeling District West Bengal. Three well preserved leaf impressions were identified showing their close resemblance with the extant taxa, *Cananga odorata* Hook.f. & Th., *Pterospermum acerifolium* L. and *Paranephelium xestophyllum* Miq. (Prasad *et al.,* 2009). Prasad *et al.* (2013) studied fossil cuticle of *Dichapetalum siwalicum* and *Pterospermum mioacerifolium* from the Sevok Road section. One fossil fruit, *Dalbergia prelatifolia,* is recovered from the lower part of the Siwalik succession (Ghish Clay Formation of Sivok Group; Middle to Upper Miocene) (Khan & Bera, 2014b). Prasad *et al.* (2013) carried out palynological investigation on the Lower Siwalik sediments.

Presently, investigations have been carried out to explore and work out systematically the plant megafossils (leaf and fruit impressions) from the Middle Siwalik sediments exposed in Oodlabari area in the Himalayan foothills of Darjeeling District, West Bengal, India (Fig. 1). On the basis of recovered data the reconstruction of the palaeofloristics, palaeoclimate/palaeoecology and phytogeography of the area have been interpreted.

GEOLOGICAL SETUP OF THE STUDY AREA

Darjeeling District rocks were subdivided by Mallet (1875) into five groups; these are Darjeeling gneiss, The Daling series, Buxa series, Gondwanas, and the Tertiary system. The outcrop of these form a series of bands, more or less running parallel to the general trend of Himalayas and dipping one beneath other into the hills. The curious feature of the subdivision is the younger formation always appears as under lie the older. Thus, the Tertiary beds disappear under the Gondwanas, the Gondwanas under the Buxa and Daling series and later under gneiss. The order of superposition has been completely reversed by folding and faults.

Gneiss are varies from a foliated granitoid rock composed of quartz, feldspar and biotite to more or less pure mica schist and includes partly intrusive granite and partly metamorphosed beds of sedimentary origin. The Daling series covers a large part of the northern and eastern part of the district. It consists of phyllite, slate and quartzite with some hornblende–schist and very subordinate bands of dolomite and crystalline limestone. Copper ore is frequently found disseminated through the slates and schist. The Buxa series, which is largely developed in Western Duars, occurs only at extreme eastern end of Darjeeling District. It consists of quartz, dolomite and slates, predominance of the latter rock serve as a means of distinction from the Daling series. The Gondwana beds outcrop near the base of the hills and constitute a narrow band between Daling and the Tertiaries, running from Pankhbari to Dalingkot. Gondwana chiefly consists of sandstone, shale and coal, all of which have intensely crushed and faulted, and dip at high angles to the north–north–west; Gondwanas metamorphosed by pressure and their component rocks converted into quartzite, slates and graphitic schists in which case it is difficult to distinguish them from the Daling series. Tertiary beds fringe the older rocks

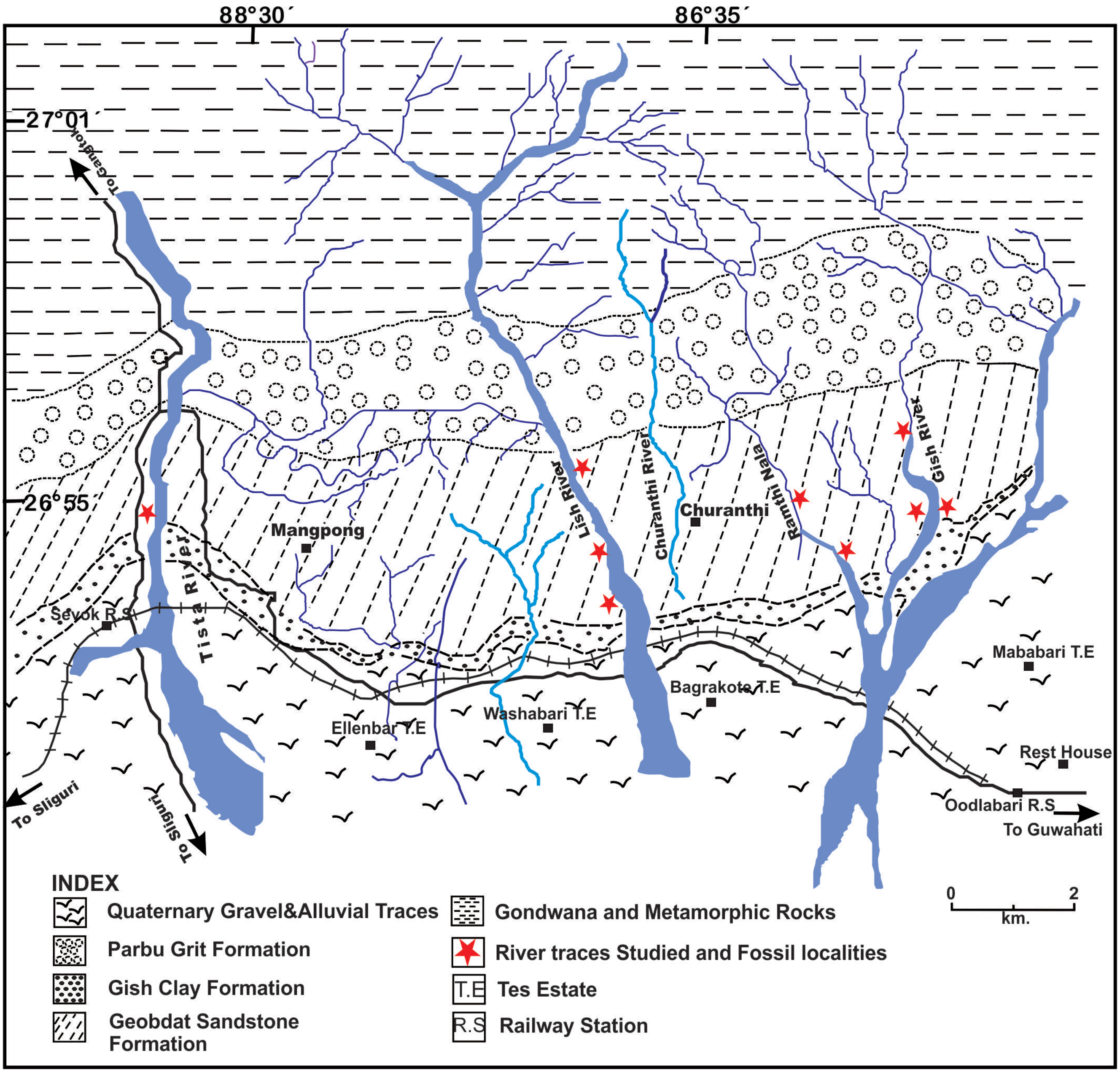

Fig. 1—Location of fossiliferous exposures in and around Oodlabari area, Darjeeling District, West Bengal.

continuously from close to the Mechi eastward nearly as far as Dalingkot. They are chiefly composed of soft, massive, "pepper and salt" sandstones, containing mica and feldspar, with crunchy grey micaceous and calcareous beds containing a few subordinate layers of limestone. The sandstone frequently contains lignite, which, however, has not been found in sufficient quantity to be of economic value.

A sedimentary pile of fluvial conglomerates, sandstones and mudstones has developed in the Himalayan foreland basins since the Middle Miocene, as a result of the uplift and concomitant erosion of the Himalayan orogenic belt (Nakayama & Ulak, 1999). These sedimentary successions, known as Siwalik Group in India and Pakistan and Churia Group in Nepal (Nakayama & Ulak, 1999), forms the foreland part of the Himalayan fold and thrust belt (Yin, 2006). In general terms, the upward coarsening Siwalik Group deposits can be subdivided lithostratigraphically into: (1) an upward coarsening mudstone–sandstone succession (Lower Siwalik Subgroup), (2) the sandstone–dominated Middle Siwalik Subgroup and (3) conglomerates, sandstones and mudstones of the Upper Siwalik Subgroup (Kumar *et al.,* 2003). In the Darjeeling District, the Upper Siwalik Subgroup is either not exposed or absent (Banerji & Banerji, 1982). Rocks of the tectonically deformed Lower Siwalik Subgroup exposed in the Tista River section around Kalijhora in the Darjeeling District, have been carried by the South Kalijhora Thrust (SKT) over the Middle Siwalik Subgroup (Basak & Mukul, 2000). The Middle Siwalik Subgroup is exposed in the footwall of the SKT and continues up to the mountain front over an aerial distance of ~ 4 km. This sedimentary succession is regarded as fluvial deposits (Acharya, 1973; Banerji & Banerji, 1982).

The sedimentary succession of the Middle Siwalik Subgroup, about 325 m thick consists of conglomerate beds, medium–to coarse–grained sandstone beds which are

Stratigraphy in the Darjeeling District (after Matin & Mukul, 2010)

Geologic Time	Group	Subgroup	Formation and Lithology
Late Miocene to Pliocene		Upper Siwalik	Murti Boulder bed (Crude immature conglomerate) Parbu Grit (pebbly sandstone and coarse to medium–sandstone)
	Siwalik Group	Middle Siwalik	Geabdat Sandstone (medium–to coarse–grained sandstone and shale, pebble beds and marl)
Early–Middle Miocene		Lower Siwalik	Chunabati Formation (Fine–to medium–grained sandstone, siltstone, mudstone, marl and conglomerate)
Upper Permian	Gondwana	Damuda	Sandstone, carbonaceous shale and coal
Lower Permian	Group	Rangit pebble–shale (Talchir?)	Diamictite, rythmite, quartzite marl
Precambrian	Daling Group		Buxa Formation Reyang Formation Daling Formation
	Paro Group		Parametamorphites with migmatitic and foliated granitic gneiss
	Darjeeling Gneiss		Two–mica migmatitic gneiss

often pebbly, medium grained sandstone beds, fine–grained sandstone beds, heterolithic units and mudstone beds. Neogene deposits of Siwalik Foreland Basin of Darjeeling Himalayas, exposed in road cuts and river sections along an east–west traverse between Sevok (Darjeeling District) in the west and Malbazar area (Jalpaiguri District) in the east.

The Upper Tertiary outcrops, forming the outer foothills, are not continuous throughout the area; they disappear in the area east of Lethi Nala and reappear, after a gap of about 10 miles, in the area between the Murti and the Jaldhaka with a greatly reduced width of outcrop. East of the Jaldhaka, there is another unusually long gap for about 40 miles, beyond which the Upper Tertiaries reappear in the Bhutan foothills and the Buxa Duar area of West Bengal. These gaps are occupied by enormous deposits of recent gravels.

A type section known as Sevok Group is exposed around Sevok in the Oodlabari area, Darjeeling District. Ghish Clay, which is the lowest formation of the Sevok Group, has been named after the Ghish forest rest house, in the vicinity of which it is well exposed in the Ghish Nala section. This formation typically consists of alternations of grey marly clay, nodular silt stone and soft, fine–grained standstone. The clay and siltstone beds vary in colour from grey to brownish grey, giving rise to mottled appearance at places; they are generally micaceous and are often somewhat indurated and calcareous. The calcareous matter is in places segregated into nodules and spheroids. The sandstones are grey and micaceous and often contain rounded pebbles of clay.

The thickness of this formation, as measured along the typical sections, is as follows:

Mahanadi	Tista	Lish	Ghish
700 feet	595 feet	236 feet	281 feet

The variation of thickness and the absence of this formation in the western sector of the area beyond the Mahanadi are largely due to erosion of the basal parts and subsequent overlaps by gravel terraces. The Ghish Clay is conformably overlain by the Geabdat Sand stone, the boundary having been drawn arbitrarily within a zone of gradation.

Geabdat Sandstone, occurring in the middle of the Sevok Group, has been named after the Geabdat peak (2682 feet) on the right bank of the Tista. Unlike the Ghish Clay, this formation comprises sediments of predominantly arenaceous nature. The most prominent type of sandstone is a rather soft, massive, medium to coarse–grained, poorly sorted, felspathic and micaceous rock of a pepper and salt colour. More indurated and bedded sandstones of brownish and dull grey colour are also seen. Current–bedding and large lenses of lignite are common in the sandstones. Gritty and pebbly beds are rare but a thin band of hard conglomerate, comprising pebbles of quartzite, schist and coaly shale embedded in an argillaceous matrix, was found to occur in the type section along the Sevok Road.

The Geabdat Sandstone is well represented in most of the exposed sections and constitutes the major part of the Sevok Group. Its thickness, as measured along the typical sections, is as follows:

Mahanadi	Tista	Lish	Ghish
3547 feet	4091 feet	2154 feet	2752 feet

The variation in the thickness of the formation is likely to be associated with an increased development of an arenaceous facies in the central part of the area around the Tista River. The Geabdat Sandstone is conformably overlain by the Parbu Grit and the passage between these two formations seems to be completely gradational.

MATERIALS AND METHODS

The fossil localities which have been visited are Ghish River, Ramthi River, Lish River, Sukha nala, Charanthi River and Sevok and nearby area and Sevok to Sikkim Road near Lion bridge, Mal bazaar to Jaigaon area, Chalsa to Pathjora Road Section Rangjung River section (Fig. 1). From these localities a variety of well preserved plant megafossils mainly leaf impressions and fossil woods have been collected.

The fossil localities lie in the foothills of Darjeeling District, West Bengal, India and are approachable by road to some extent and then by foot. The fossil woods have been collected mainly from Ghish and Ramthi River Section, Sevok–Sikkim Road Section and Lish River Section. However, the leaf impressions are plentiful in some of the localities (Fig. 2).

The plant megafossils for present study are collected from different localities which details are as given below:

Ghish River (26º55.758': 88º36.689')—This river lies on north–east of Oodlabari (26º51.920': 88º37.505') and the fossiliferous beds are exposed at 1.5, 2.0, and 3.00 km upward from its mouth. The beds are found on both side of the river cutting. A few leaf impressions and a number of carbonised and petrified woods were collected.

Ramthi River (26º53.684': 88º36.158')—This lies about one kilometer southeast of Ghish River and it is approachable by Jeep and then on foot from Ghish Basti. The sections are exposed on both banks of the river. A good fossiliferous bed is found on the right side upward which is less than one kilometer from its mouth. Few well preserved leaf impressions and some semi–carbonised woods were collected from this area. More than 20 carbonised woods were collected from this River Section. Palynological samples were also collected (Fig. 2c).

Lish River (26º53.604': 88º33.754')—This is situated near Bagrakote and easily approachable by jeep up to Sanik School. It is very near to the mouth of the river. A lot of well preserved leaf impressions were collected from two fossiliferous beds on left side of the river about 1.5 km from its mouth. Palynological samples have also been collected from this Section (Fig. 2a).

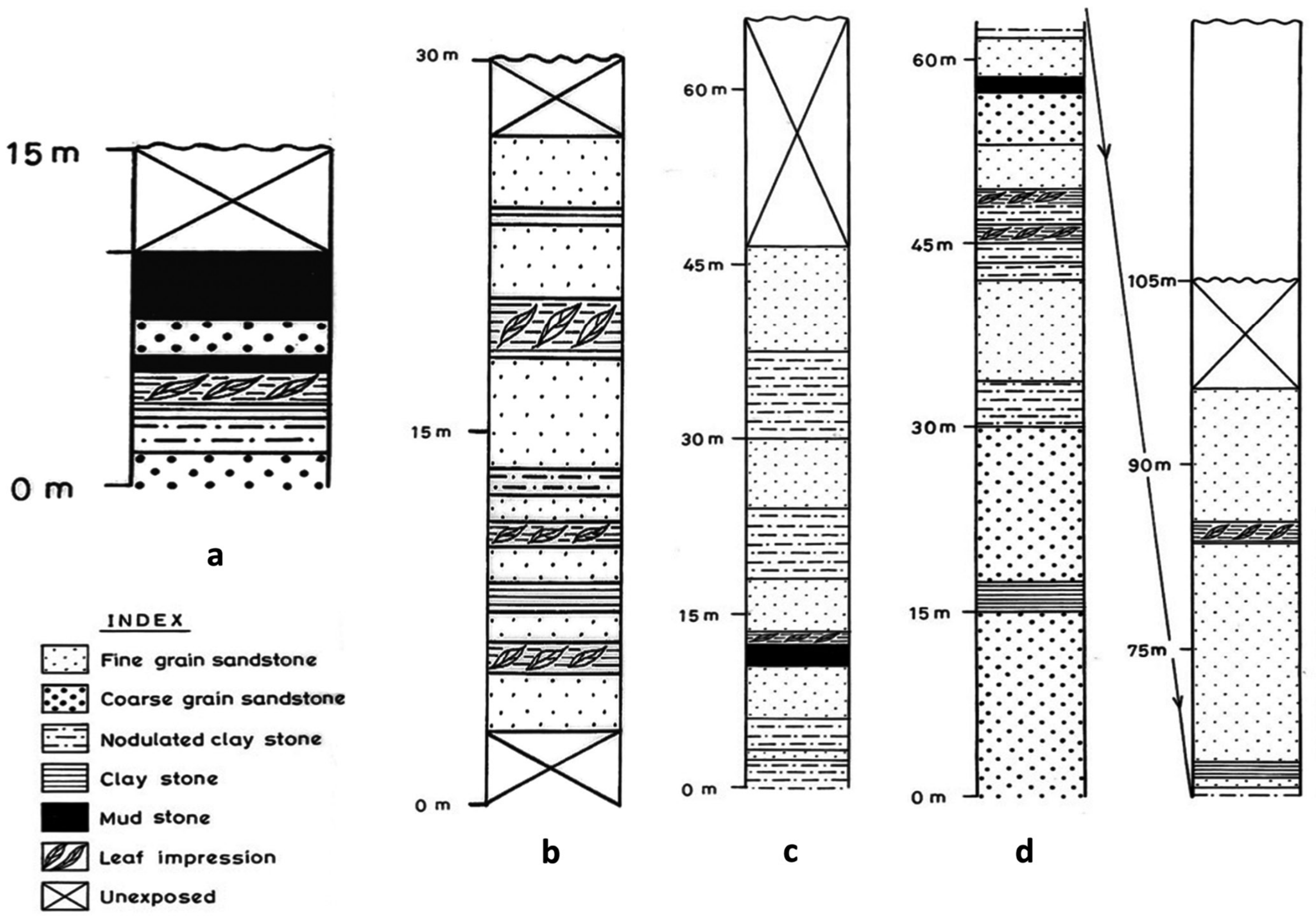

Fig. 2—Lithocolumns of exposed sections of a. Lish River, b. & d. Sevok Road, and c. Ramthi River from where fossils were collected.

Sevok and Sikkim Road (26º54.143': 88º28.3570') —A variety of leaf impressions were collected from a fossiliferous bed exposed near Lion bridge. Another fossiliferous bed is well exposed on left side of the road about two km from Lion bridge. The leaf impressions were collected from a well exposed section on Sikkim Road about 1.5 km from the bridge. The palynological samples were also collected from there (Fig. 2b).

Sevok and nearby area (26º54.196': 88º28.325')—It is easily approachable by jeep. The Lower and Middle Siwalik sections are exposed in this area. Leaf and fruit impressions are collected from two fossiliferous beds from near a bridge at Sevok–Oodlabari Road (Fig. 2d).

More than 1000 specimens of well preserved leaves and few fruit impressions were collected from fossiliferous beds exposed in the above localities situated in Oodlabari area, Darjeeling District, West Bengal. The leaf impressions are devoid of cuticle and found to be preserved on grey and purple shales and a few of them on fine grained sandstone. The leaf impressions have been studied morphologically with the help of either hand lens or low power microscope under reflected light.

A range of herbarium sheets of several extant families and genera was examined at the Central National Herbarium, Sibpur, Howrah, West Bengal in order to identify these leaf impressions. For description of leaf impressions the terminology given by Hickey (1973) and Dilcher (1974) has been followed. In naming the fossils, the International Code of Botanical Nomenclature (ICBN) has been followed and the fossil leaves have been named according to usual practice prevalent in the country and abroad. The living generic names have been retained. The families have been arranged according to Bentham and Hooker’s system of classification which was followed by Metcalfe and Chalk (1950). The abbreviations used for description of leaves are AO (Acute–Obtuse), RR (Right–Right), AR (Acute–Right), RO (Right–Obtuse).

SYSTEMATICS

Order—MAGNOLIALES

Family—ANONACEAE

Genus—ARTABOTRYS R.Br.

Artabotrys siwalicus n. sp.

(Pl. 1.1, 2; Pl. 3.1; Pl. 5.5; Pl. 21.6)

Material—Four specimens.

Description—Leaf simple, symmetrical; narrow elliptic; preserved size 14.5 x 6.3 cm, 9.0 x 5.1 cm, 11.1 x 6.1 cm, 3.6 x 4.5 cm; apex slightly broken seemingly wide acute; base attenuate, normal; margin entire; texture chartaceous; venation pinnate, eucamptodromous to brochidodromous; primary vein single, straight, stout, slightly curved; secondary veins 10 pairs visible, 0.9–3.0 cm apart, angle of divergence (60°–85°) basal secondary vein with greater angle moderately acute to right angle, usually alternate, unbranched, uniformly curved up and join to their superadjacent secondaries, sometime form loop at right angle; intersecondaries present; tertiary veins fine, angle of origin usually AO–RR, straight to sinuous, sometimes curved, branched, oblique to right angle in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40316.

Paratype—B.S.I.P. Museum No. 40317–40319.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of Siwalik formation to which fossils belong.

Affinity—The diagnostic features of the present fossil leaves are symmetrical, narrow elliptic shape, attenuate base, eucamptodromous to brochidodromous venation, basal secondary vein with greater angle, moderately acute to right angle, usually alternate, unbranched, uniformly curved up and join to their superadjacent secondaries sometime form loop at right angle, presence of intersecondaries, usually AO–RR, straight to sinuous sometimes curved, branched tertiary veins, oblique to right angle in relation to mid vein. The comparative study with modern leaves of all the available species of this genus suggests that the present fossil leaves show closest affinity with the leaves of *Artabotrys zeylanicus* Hook.f. & Thoms. (C.N.H. Herbarium Sheet No. 1457; Pl. 1.3) of the family Anonaceae.

Fossil records and comparison—So far only one fossil leaf is reported from Siwaliks of Nahan area described under the form species *Artabotrys nahanii* (Prasad, 2012). It differs from present fossil having more number of secondaries. Thus in being different, it has been described as a new species *Artabotrys siwalicus* n. sp.

The genus *Artabotrys* R.Br. consists of more than 100 species (Mabberley, 1997) distributed in old world tropics and subtropics; two species in Kerala *Artabotrys zeylanicus* Hook.f. & Thoms. are considered as a typical Indo–Sri Lankan linkage taxa, occurring in semievergreen and evergreen forests of peninsular India and Sri Lanka (Mathew & George, 2013).

Family—ANONACEAE

Genus—PSEUDUVARIA

Pseuduvaria mioreticulata n. sp.

(Pl. 1.4, 5; Pl. 2.1)

Material—Three specimens.

Description—Leaf simple; narrow elliptic; preserved size 20.0 x 4.5 cm, 9.0 x 5.1 cm and 20.5 x 6.2 cm; apex seemingly acute; base acute, normal; margin entire; texture thick chartaceous; petiole present, 1.5–2.0 cm long; venation pinnate, eucamptodromous; primary vein single, almost straight, prominent, stout; secondary veins 9 to 10 pairs visible, 0.8 to 1.7 cm apart usually alternate, unbranched, angle of divergence (50°–65°), moderately acute, lower secondary veins are less acute than upper one; intersecondaries are present, simple; tertiary veins fine, angle of origin usually RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40320.

Paratype—B.S.I.P. Museum No. 40321–22.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix ‘mio’ to the name of modern comparable species *P. mioreticulata.*

Affinity—The most characteristic features of the present fossil leaves such as slightly narrow elliptic shape, moderately acute secondary veins, lower secondary veins are less acute than upper one, presence of intersecondaries, RR, percurrent, straight to sinuous, branched, oblique tertiary veins are characteristic feature of present fossil leaves. On keeping in view these characters, consultation of the herbarium sheets of different genera and species of dicotyledonous families has been carried out and concluded that the present fossil resembles closely with the extant leaves of *Pseuduvaria reticulata* (Blume) Miq. (C.N.H. Herbarium Sheet No. 13265; Pl. 2.2) of the family Anonaceae.

Fossil records and comparison—There is no record of fossil leaf resembling the genus *Pseuduvaria* from the Tertiary sediment of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and hence it is being described as *Pseuduvaria mioreticulata* n. sp.

Pseuduvaria consists of 38 species (Mabberley, 1997) distributed from India to Australia. *Pseuduvaria reticulata* (Blume) Miq. is deciduous shrub or tree, widespread in Peninsular Malaysia, Sumatra, Java, Lesser Sunda islands and Borneo (Su & Saunders, 2009).

Family—ANONACEAE

Genus—MEIOGYNE Miq.

Meiogyne sevokensis n. sp.

(Pl. 3.6, 8)

Material—One specimen.

Description—Leaf simple, asymmetrical, narrow elliptic; preserved size 9.0 x 3.0 cm; apex attenuate; base obtuse; margin entire; texture chartaceous; petiole present 0.2 cm long, normal; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 5–7 pairs visible, 0.6 to 1.7 cm apart, alternate, unbranched, angle of divergence (about 50°) acute, uniformly curved up and joined to superadjacent secondary veins; intersecondary veins present, simple; tertiary veins fine, angle of origin usually RR, percurrent, straight to curved, branched, oblique to right angle in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40323.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of small town, Sevok on Siliguri to Sikkim Road.

Affinity—The characteristic features of the present fossils such as asymmetrical, narrow elliptic shape, attenuate apex, almost acute secondary veins, uniformly curved up; presence of intersecondary, usually RR, percurrent, branched tertiary veins suggest their affinity with the modern leaves of the genus *Meiogyne* Miq. of the family Anonaceae. The herbarium sheets of different species of this genus have been examined in order to find out its specific affinity and concluded that the leaves of *Meiogyne ramarowii* (Dunn.) Gandhi (C.N.H. Herbarium Sheet No. 2197; Pl. 3.7) show closest similarity with the fossil leaves in shape, size and venation pattern.

Fossil records and comparison—Prasad *et al.* (2014) described a fossil leaf resembling with *Meiogyne* under the form species *M. purniyagiriensis* from the Siwalik sediments of Tanakpur area, Uttarakhand which differ from present leaf in shape, size and venation pattern. *M. purniyagiriensis* possess small size (4.0 x 1.5 cm) with narrow ovate shape in comparison to large, narrow elliptic shape in the present fossil. Moreover the fossil leaf described from Tanakpur area possesses higher number of secondaries (10 pairs) instead of 5–6 pairs in the present fossil. In being different from the known species the present fossil leaf described as a new species, *Meiogyne sevokensis*.

Meiogyne Miq. consists of nine species distributed in the Indo–Malayan region (Mabberley, 1997). The modern comparable taxon, *M. ramarowii* (Dunn.) Gandhi is a understorey tree of wet evergreen forests at 300–1200 m. It is also distributed in the evergreen forests of Western Ghats and is more common in South and Central Sahydri.

Family—ANONACEAE

Genus—UVARIA Linn.

Uvaria siwalica Prasad, 1994c

(Pl. 3.2, 3, 4, 5)

Material—Three specimens.

Description—Leaf simple, symmetrical, ovate to oblanceolate; preserved size 8.9 x 6.02 cm, 8.5 x 4 cm and 8.4 x 5.4 cm; apex acute; base wide acute to obtuse; margin entire; texture thick chartaceous; petiole 0.5 to 1.0 cm long, normal; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 12 pairs visible, 0.2 to 1.2 cm apart, basal pair of secondary arises more closely, usually alternate to sub–opposite, unbranched, angle of divergence (about 60º), moderate acute, uniformly curved up; intersecondary veins present, simple; tertiary veins fine, angle of origin usually RR, percurrent, almost straight, branched, oblique in relation to mid vein, predominantly alternate and close.

Specimen—B.S.I.P. Museum No. 40324–40326,

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian)

Affinity—In being possessing an symmetrical, oblanceolate shape, acute apex, wide acute base, eucamptodromous venation, basal pair of secondary arises more closely, usually alternate to sub–opposite, unbranched, secondary veins, presence of simple intersecondary veins,

PLATE 1

(All figures are of natural size unless otherwise mentioned) ⟶

1. *Artabotrys siwalicus* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40316 (Holotype).
2. *Artabotrys siwalicus* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 1.5. BSIP Museum No. 40316 (Holotype).
3. *Artabotrys zeylanicus* Hook.f. & Th.–Modern leaf showing similar shape, size and venation pattern.
4. *Pseuduvaria mioreticulata* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40320 (Paratype).
5. *Pseuduvaria mioreticulata* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40320 (Paratype).

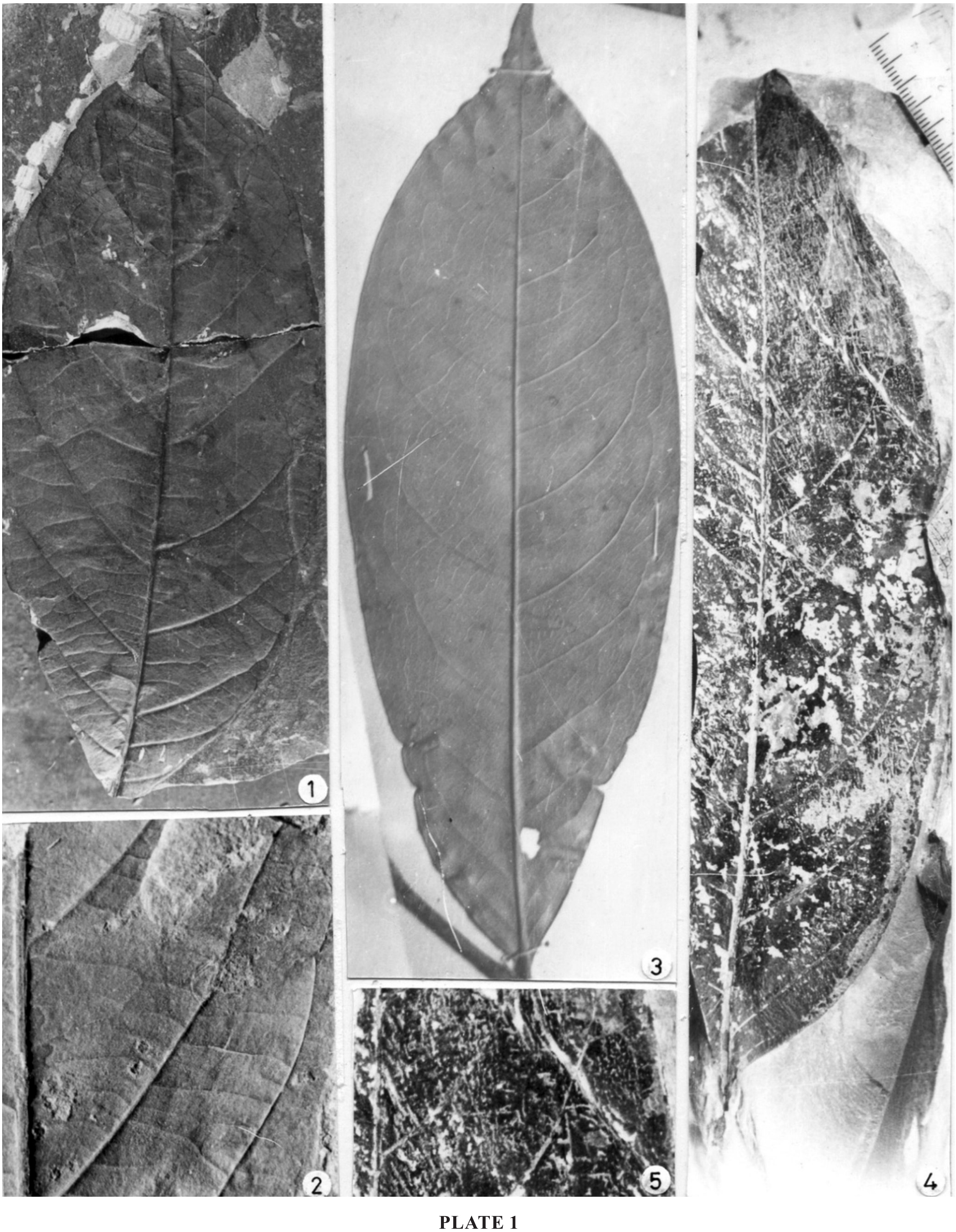

PLATE 1

usually RR, percurrent, branched tertiary, the fossil leaves resemble closely the modern leaves of *Uvaria hamiltonii* Hook.f. & Thoms. (C.N.H. Herbarium Sheet No. 9441) of the family Anonaceae.

Fossil records and comparison—Prasad (1994c) has described a fossil leaf showing affinity with *Uvaria hamiltonii* Hook.f. & Thoms. under the form species, *Uvaria siwalica* from the Lower Siwalik sediments of Kathgodam, Nainital District, Uttarakhand. He further describe a fossil leaf of *Uvaria* of same affinity from Sub–Himalayan zone (Middle Miocene) of western Nepal, Prasad (2008). On comparison with Prasad's specimen it has been found that both the fossil leaves have similar venation pattern, specially the course and orientation of secondary and tertiary veins. The present fossil leaf is therefore reported under the same species, *Uvaria siwalica* Prasad.

Uvaria Linn. comprises 110 species distributed mainly in tropical Asia; a few species also occur in Africa. About 16 species are growing in the Indian region. *Uvaria hamiltonii* Hook.f. & Thoms. with which the fossil specimen shows closest resemblance is a large shrub, distributed in evergreen to Moist deciduous forests of the Sub–Himlayan tract, Sikkim, Chhota Nagpur, Bangladesh, Andaman Islands and Myanmar. (Hooker, 1872; Gamble, 1972).

Family—ANONACEAE

Genus—FISSISTIGMA Griff.

Fissistigma senii Lakhanpal, 1969

(Pl. 4.1, 3)

Material—Two specimens.

Description—Leaf simple, symmetrical, elliptic; preserved size 8.9 x 4.3 cm and 7.2 x 3.3 cm; apex acute; base acute, normal; margin entire; texture chartaceous; petiole preserved, 3 cm long, normal; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins more than 11–12 pairs visible, 0.4 to 1.1 cm apart, usually alternate, unbranched, angle of divergence (about 55º–70º), moderate to wide acute, uniformly curved up, curvature sharp near the margin; tertiary veins fine, angle of origin usually RR, percurrent, usually straight, rarely sinuous, branched, oblique in relation to midvein predominantly alternate and close.

Specimen—B.S.I.P. Museum No. 40327–40328.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—The diagnostic features of the present fossil leaves are symmetrical, elliptic; acute apex; eucamptodromous venation, moderate to wide acute secondary veins, uniformly curved up, curvature sharp near the margin; usually RR, percurrent, usually straight, rarely sinuous tertiary veins. During identification it has been observed that these features are found common in the modern leaves of the genus *Fissistigma* Griff. of the family Anonaceae. The comparative study with modern leaves of all the available species of this genus suggests that the present fossil leaves show closest affinity with the leaves of *Fissistigma bicolor* (Roxb.) Merr. (=*Melodorum bicolor* (Roxb.) Hook.f. & Thoms) (C.N.H. Herbarium Sheet No. 27611; Pl. 4.2) of the family Anonaceae.

Fossil records and comparison—So far, three fossil leaves resembling *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 reponed 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. & Thoms) Merill. In 1992, Lakhanpal and Awasthi reported another fossil leaf under the form species *Fissistigma siwalika* from the Siwalik sediments of Jawalamukhi, Himachal Pradesh, India. This fossil is larger in size (14.5 x 5.3 cm) having oblanceolate shape and rounded apex. The fossil leaf, *Fissistigma mioelegans,* Prasad *et al*., 1999 described from Siwalik sediments of Koilabas area, western Nepal, has less secondaries with distantly placed and arise less acutely in comparison to present fossil. On critical comparison it has been found that the fossil leaves *Fissistigma senii* Lakhanpal, 1969 has similar venation pattern, specially the course and orientation of secondary and tertiary veins. Thus, the present fossil leaf is described under the same species.

Fissistigma Griff. consists of about 60 species distributed in tropical Africa, China, northeast Australia and in Indo–Malayan region (Willis, 1973). *Fissistigma bicolor* (Roxb.) Merr. is small deciduous or evergreen, trees rarely woody vines distributed in Tropical Himalaya (Nepal, Sikkim), Assam and Myanmar.

Order—MALPIGHIALES

Family—FLACOURTIACEAE

Genus—GYNOCARDIA R.Br.

Gynocardia butwalensis Konomatsu & Awasthi, 1999

(Pl. 5.4, 6)

Material—One specimen.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 13.9 x 5.1 cm; apex acute; base acute, asymmetrical; margin entire; texture chartaceous; petiole broken; venation pinnate, eucamptodromous; primary vein

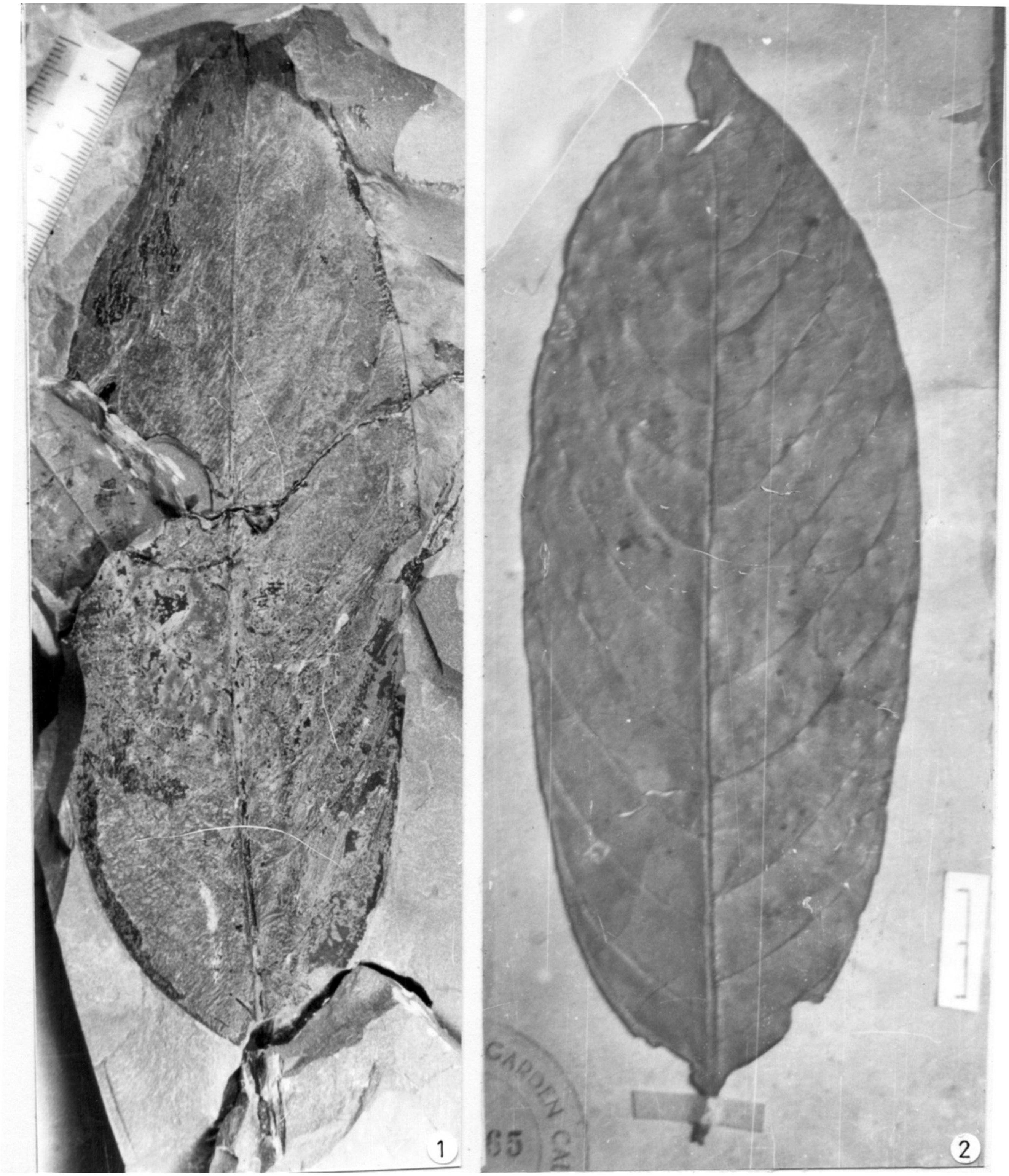

PLATE 2

(All figures are of natural size unless otherwise mentioned)

1. *Pseuduvaria mioreticulata* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40321 (Holotype).

2. *Pseuduvaria reticulata* (Blume) Miq.–Modern leaf showing similar shape, size and venation pattern.

single, almost straight, stout; secondary veins 5–6 pairs visible, 1.6 to 3.3 cm apart, basal secondaries are closely placed, alternate to sub–opposite, unbranched, angle of divergence vary irregularly (60°–80°), acute to nearly right angle, uniformly curved up and run upward for a long distance and joined to the superadjacent secondary; intersecondary veins present, simple; tertiary veins fine, angle of origin, RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close to distant.

Specimen—B.S.I.P. Museum No. 40329.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—Symmetrical, narrow elliptic shape; acute apex, eucamptodromous venation, acute to nearly right angle secondaries, closely placed basal secondaries, running of secondary veins for a long distance, presence of intersecondaries veins, RR, percurrent, straight to sinuous, branched tertiary veins suggest the fossil leaves resemble closely with the modern leaves of *Gynocardia odorata* R.Br. (=*Chaulmoogra odorata* Roxb.; C.N.H. Herbarium Sheet No. 33496; Pl. 5.5) of the family Flacourtiaceae.

Fossil records and comparison—So far the following three fossil leaves resembling the genus *Gynocardia* R.Br. have been reported from the Siwalik sediments of India and Nepal. *Gynocardia mioodorata* from Lower Siwalik sediments of Koilabas area of Nepal (Prasad *et al.*, 1999), *G. butwalensis* Konomatsu & Awasthi, 1999 from Lower Siwalik of Tinau Khola near Butwal, Nepal and from Siwalik sediments of Mandi District, Himachal Pradesh (Prasad *et al.,* 2013). All the above known fossils show similar features and are compared with the single extant species *Gynocardia odorata* R.Br. On comparison it has been seen that the present fossil leaves show closest similarity with *G. butwalensis* Konomatsu & Awasthi and are hence assigned to the same specific name.

The family Flacourtiaceae is well documented from Tertiary sediments of India. The earliest record (*Homalioxylon mandlaensis* Bande, 1974, *Hydnocarpoxylon indicum* Bande & Khatri, 1980 and *Flacourtioxylon mohgaonensis* Trivedi & Srivastava, 1986 goes back to Palaeocene–Eocene of Deccan Intertrappean beds of India.

Gynocardia R.Br. consists of single species, *Gynocardia odorata* R.Br. with which the fossil leaves show closest affinity. It is a large evergreen tree distributed in moist forests of mountain valley in South Asia, South Xizang and Yunnan in China, Bangladesh, Nepal and Myanmar. In India, it is commonly found in north–east India (Gamble, 1972). It also occurs in the sub–Himalayan tract, ascending to 1300 m from Sikkim eastward, Khasi Hills, Chittagong, Myanmar (Brandis, 1971).

Family—FLACOURTIACEAE

Genus—HYDNOCARPUS Gaertner

Hydnocarpus ghishiensis n. sp.

(Pl. 6.1, 2, 4)

Material—Three specimens.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 9.8 x 3.7 cm, 9.4 x 3.6 cm and 8.4 x 4.4 cm; apex broken seemingly acute; base wide acute, normal; margin entire; texture chartaceous; venation pinnate; eucamptodromous to brochidodromous; primary vein single, prominent, almost straight, stout; secondary veins 6–7 pairs visible, 1.4 to 2.6 cm apart, usually alternate, unbranched, angle of divergence (45º–50°), narrow acute, basal secondary veins with greater angle, uniformly curved up and joined to their superadjacent secondaries; intersecondary veins present, simple; tertiary veins fine, angle of origin usually RR, percurrent, straight to sometimes curved, branched, oblique to right angle in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40330.

Paratype—B.S.I.P. Museum No. 40331–40332.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the Ghish River Section from where fossils were collected.

Affinity—The characteristic features of the present fossil leaves are symmetrical, narrow elliptic shape, broken seemingly acute apex, eucamptodromous to brochidodromous venation pattern, unbranched, narrow acute secondary veins, basal secondary veins with greater angle, uniformly curved

PLATE 3

(All figures are of natural size unless otherwise mentioned) ⟶

1. *Artabotrys siwalicus* n. sp.–Another fossil leaf showing slight variation in shape, size and venation pattern. BSIP Museum No. 40317 (Paratype).

2., 3., 4. *Uvaria siwalica* Prasad–Fossil leaves showing variation in shape, size and venation pattern. BSIP Museum No. 40324, 40325, 40326.

5. *Uvaria siwalica* Prasad–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40326.

6. *Meiogyne sevokensis* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40323 (Holotype).

7. *Meiogyne ramarowii* (Dunn.) Gandhi.–Modern leaf showing similar shape, size and venation pattern.

8. *Meiogyne sevokensis* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40323.

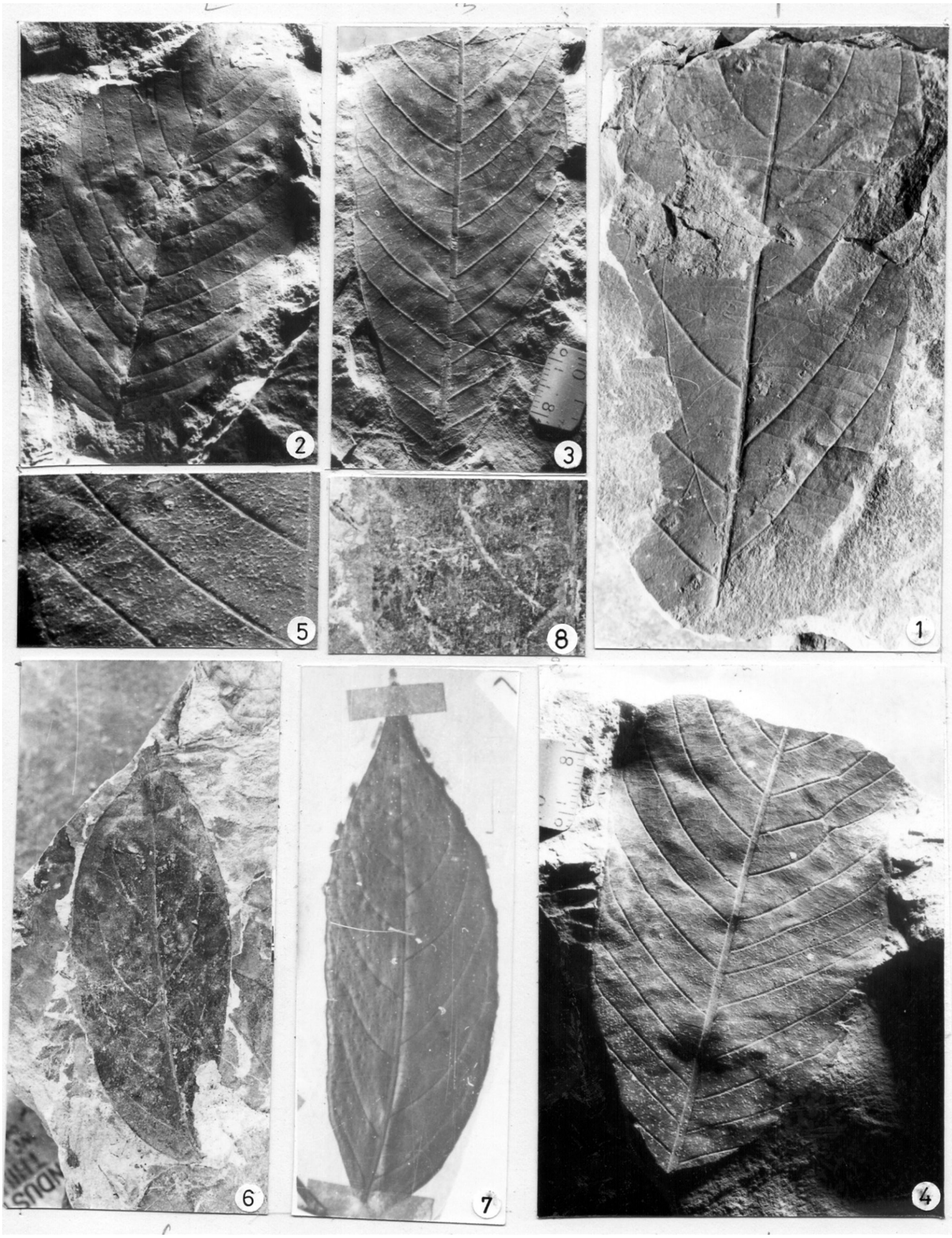

PLATE 3

up and joined to their superadjacent secondaries, presence of intersecondary veins, fine, angle of origin usually RR, percurrent, straight to sometime curved tertiary veins. These features are found commonly in the extant leaves of *Hydnocarpus* Gaertner of the family Flacourtiaceae. After comparative study of all the available species of *Hydnocarpus* Gaertner, it was observed that the fossil leaves show similarity with the leaves of *Hydnocarpus pertandra* (Buch.–Ham.) Oken (=*Hydnocarpus laurifolia* (Dennst.) Sleummer; C.N.H. Herbarium Sheet No. 16136; Pl. 6.3, 5).

Fossil records and comparison—Fossil leaves resembling the extant species *Hydnocarpus kurzii* are described as *Hydnocarpus palaeokurzii* from the Siwalik sediments of Oodlabari, West Bengal (Antal & Awasthi, 1993) and Kathgodam, Uttar Pradesh (Prasad, 1994c). Prasad and Awasthi, 1996 reported two fossil species of *Hydnocarpus* Gaertner, i.e. *Hydnocarpus chorkholaensis* & *Hydnocarpus siwalicus* from Siwalik sediments of Surai Khola Sequence, western Nepal. The present fossil leaves have been compared with all the above known species and found different in the nature and arrangement of secondary veins, the secondary veins are arise acutely and run parallel to the margin for a long distance. In being different with all the known species the present fossil leaves are described as *Hydnocarpus ghishiensis* n. sp.

Hydnocarpus Gaertner comprises 40 Indo–Malayan species (Mabberley, 1997). *Hydnocarpus pertandra* (Buch.–Ham.) Oken with which fossil resembles closely is a tall tree distributed in wet evergreen forests and along streams, generally up to 1000 m, sometimes extends up to 1700 m. Endemic to the Western Ghats, very common in South and Central Sahyadris.

Family—CLUSIACEAE

Genus—GARCINIA Linn.

Garcinia eocambogia Prasad, 1994c

(Pl. 4.4, 6; Pl. 5.1)

Material—Two specimens.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 9.0 x 3.0 cm and 11.0 x 3.6 cm; apex slightly broken appearing acute; base acute, normal; margin entire; texture thick chartaceous; petiole indistinct; venation pinnate, eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins more than 13 pairs visible, 0.6 to 1.1 cm apart, alternate to opposite sometime branched angle of divergence (about 50º), narrow acute, uniformly curved up; intersecondary veins present, simple, frequent, 2–3 veins present in between two secondaries; tertiary veins poorly preserved, angle of origin usually RR–AO, percurrent, straight to curved, sometime branched, oblique in relation to mid vein, alternate to opposite and close.

Specimen—B.S.I.P. Museum No. 40333–40334.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik), Upper Miocene (Sarmatian to Pontian).

Affinity—The characteristic features of the present fossil leaves are symmetrical, narrow elliptic shape, probably acute apex, eucamptodromous venation, narrow acute, uniformly curved up secondary veins, presence of simple, frequent, 2–3 intersecondary veins in between two secondaries, RR–AO, percurrent, straight to curved tertiary veins. These features are found commonly in the extant leaves of *Garcinia* Linn. of the family Clusiaceae. After comparative study of all the available species of *Garcinia* Linn. it was observed that the fossil leaf shows similarity with the leaves of extant *Garcinia cambogia* Roxb. (=*Gutta gamba)* (C.N.H. Herbarium Sheet No. 56908; Pl. 4.5; Pl. 5.2) of the family Clusiaceae.

Fossil records 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 and 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. On comparison, it has been seen that the present fossil leaves show closest similarity with the known fossil leaf, *G. eucambogia* Prasad from Siwalik sediments of Kathgodam Uttar Pradesh and hence assigned to the same species.

The leaf cuticles of *Garcinia* Linn. have also been recorded from lignite beds (Miocene) of Ratnagiri District, Maharashtra (Dalvi & Kulkarni, 1982; Kulkarni & Dalvi, 1981)

PLATE 4

(All figures are of natural size unless otherwise mentioned) →

1., 3. *Fissistigma senii* Lakhanpal–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40327, 40328.

2. *Fissistigma bicolor* (Roxb.) Merr.–Modern leaf showing similar shape, size and venation pattern.

4., 6. *Garcinia eocambogia* Prasad–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40333, 40334.

5. *Garcinia cambogia* Roxb.–Modern leaf showing similar shape, size and venation pattern.

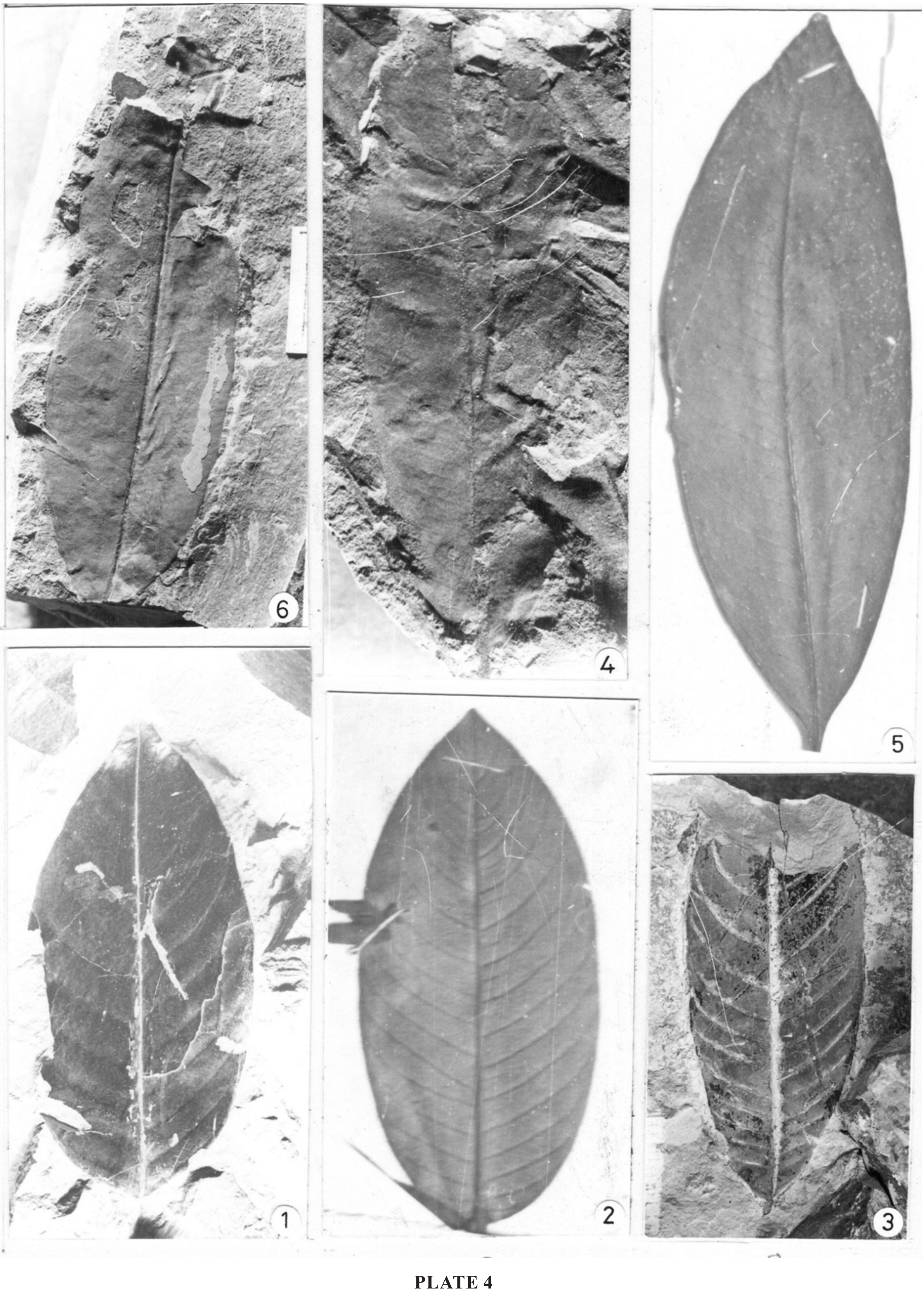

PLATE 4

and its fossil woods are known from Deccan Intertrappean beds of Shahpura, Madhya Pradesh, India (Bande & Khatri, 1980).

Garcinia Linn. consists of about 400 species of trees and shrubs distributed in the tropical regions of Asia and South Africa (Mabberley, 1977; Willis, 1973). Of which, 36 species are found in India. *Garcinia cambogia* Roxb. is small or medium sized tree found commonly in the evergreen forests of Western Ghats, from Konkan southwards to Travancore, and in the Shola forests of Nilgiris up to an altitude of 6,000 feet.

Order—MALVALES

Family—DIPTEROCARPACEAE

Genus—VATICA Linn.

Vatica siwalica n. sp.

(Pl. 7.7, 8)

Material—Two specimens.

Description—Leaf simple, symmetrical, elliptic; preserved size 6.0 x 3.5 cm and 6.9 x 3.5 cm; apex acute; base wide acute; margin entire; texture chartaceous; petiole small, 0.2 cm long, normal; venation pinnate, eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 6–7 pairs visible, 0.6 to 1.6 cm apart, alternate to sub–opposite, angle of divergence (45–65°), variation in angle of divergence, narrow to moderate acute, lower secondaries are more acute than upper secondaries; intersecondary veins present but not frequent; tertiary veins fine, angle of origin usually RR, percurrent, straight to sinuous, branched, oblique in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40335.

Paratype—B.S.I.P. Museum No. 40336.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of the formation (Siwalik) from where fossil specimen was collected.

Affinity—In being symmetrical, elliptic shape, acute apex, eucamptodromous venation, narrow to moderate acute secondary veins (lower secondaries are more acute than upper secondaries), presence of intersecondary veins, fine, RR, percurrent, straight to sinuous, branched tertiary veins; these fossil leaves show their nearest affinity with the extant taxon, *Vatica pachyphylla* Merr. (C.N.H. Herbarium Sheet No. 51060; Pl. 7.9) of the Family Dipterocarpaceae.

Fossil records and comparison—Only one fossil leaf showing close similarity with the genus *Vatica* L. has been described previously under the form species *Vatica nepalensis* from the Siwalik sediments of Surai Khola, Nepal (Prasad & Pandey, 2008). On comparison of the present fossil with the above known species, it has been observed that the present fossil leaves differ in being obovate shape and larger size (8.0 x 7.3 cm). Thus it has been described as a new species *Vatica siwalica.*

Vatica L. comprises about 25 extant species. These are small or moderate sized trees distributed in tropical Asia and Indian Archipelago (Hooker, 1872). *Vatica pachyphylla* Merr. is endemic to Phillipines.

Family—DIPTEROCARPACEAE

Genus—VATICA Linn.

Vatica prenitida n. sp.

(Pl. 7.3, 4, 6)

Material—Two specimens.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 5.1 x 1.5 cm and 5.7 x 1.6 cm; apex bluntly acute; base obtuse; margin entire; texture chartaceous; venation pinnate; eucamptodromous to brochidodromous; primary vein single, prominent, almost straight, stout; secondary veins 8 pairs visible, 0.4 to 1.0 cm apart, alternate to sub–opposite, unbranched, angle of divergence (60º–70°), wide acute, lower secondary veins with greater angle, usually alternate, uniformly curved up and secondary veins join to their superadjacent secondaries and forming a loop; intersecondary veins present, simple; tertiary veins fine, angle of origin usually RR, percurrent, straight to sometime curved,

PLATE 5

(All figures are of natural size unless otherwise mentioned) ⟶

1. *Garcinia eocambogia* Prasad–Part of fossil leaf magnified to show details of venation pattern. x 3. BSIP Museum No. 40333.
2. *Garcinia cambogia* Roxb.–Part of modern leaf magnified to show similar details of venation pattern. x 2.
3. *Fissistigma senii* Lakhanpal–Part of fossil leaf magnified to show details of venation pattern. x 3. BSIP Museum No. 40328.
4. *Gynocardia butwalensis* Konomatsu & Awasthi–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40329.
5. *Gynocardia odorata* R. Br.–Modern leaf showing similar shape, size and venation pattern.
6. *Gynocardia butwalensis* Konomatsu & Awasthi–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40329.
7. *Artabotrys siwalicus* n. sp.–Apex of fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40318 (Paratype).

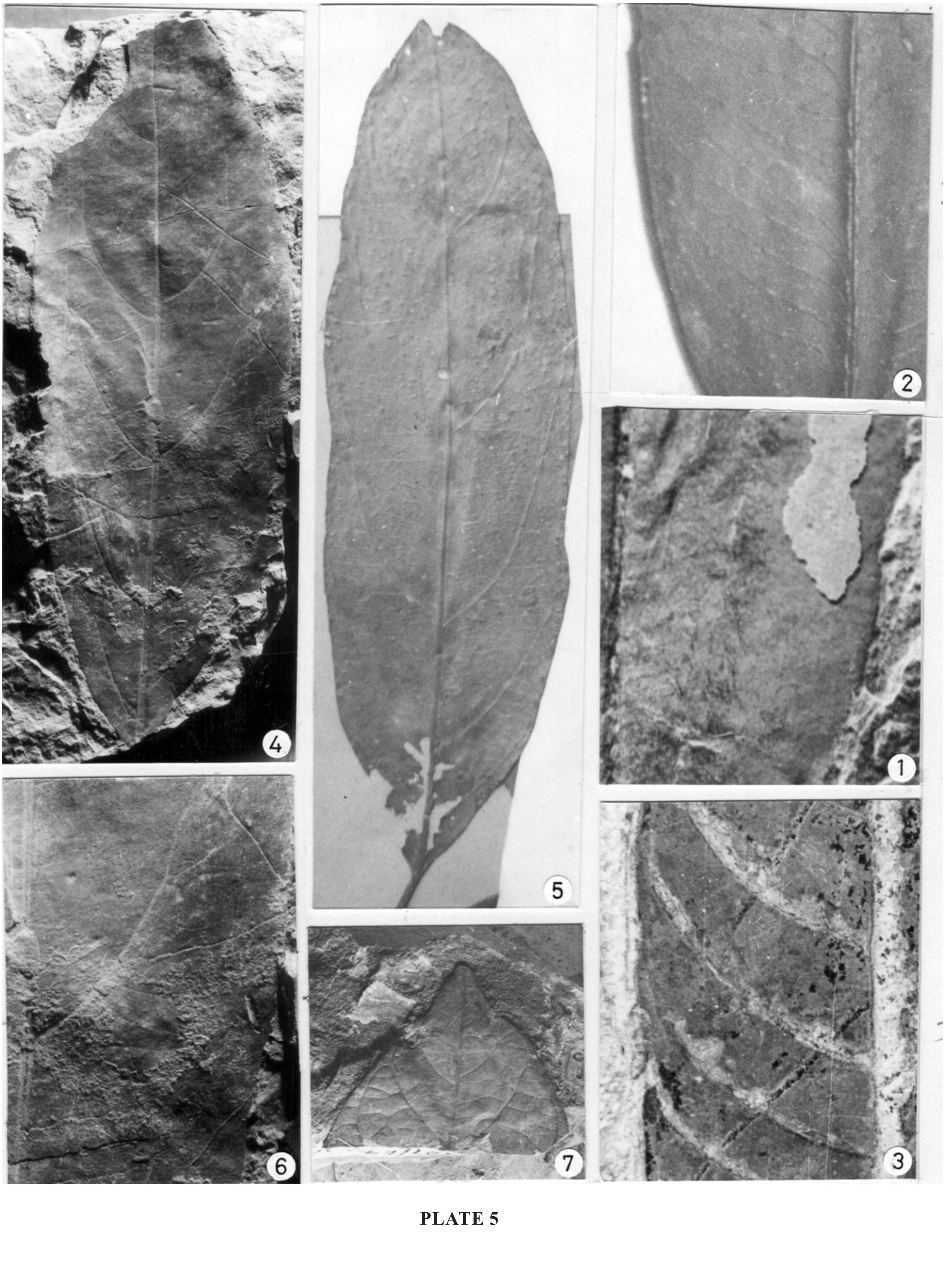

PLATE 5

branched, usually oblique in relation to mid vein rarely right angle towards the margin, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40337.

Paratype—B.S.I.P. Museum No. 40338.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix 'Pre' to the name of modern comparable species, *V. nitida*.

Affinity—The fossil leaf is characterized by symmetrical, narrow elliptic shape; bluntly acute apex; obtuse base; eucamptodromous to brochidodromous venation; unbranched, wide acute secondary veins, lower secondary veins with greater angle, usually alternate, uniformly curved up and join to their superadjacent secondaries and forming a loop, presence of intersecondary veins, simple RR, percurrent, straight to sometime curved, branched tertiary veins. These features undoubtedly indicate that the present fossil leaf closely resembles the extant leaf of *Vatica nitida* A. DC. (=*Stemonoporus nitidus*; C.N.H. Herbarium Sheet No. 52070; Pl. 7.6) of the family Dipterocarpaceae.

Fossil records and comparison—Two fossil leaves showing close similarity with those of extant *Vatica* L. have been described from the Siwalik of India. They are *Vatica nepalensis* from the Siwalik sediments of Surai Khola, Nepal and *V. siwalica* described in this text. On comparison of the present fossil with the above already known species, it has been observed that it does not resemble to any of them. The present fossil leaf differs from *V. nepalensis* Prasad & Pandey 2008 in being obovate shape and larger size (8.0 x 7.3 cm) However, *Vatica prenitida* differs from present fossil leaf in being elliptic shape and larger size (6.9 x 3.5 cm), This has, therefore, been described as a new species *Vatica prenitida.*

Vatica L. comprises about 25 species. These are small or moderate sized trees distributed in tropical Asia and Indian Archipelago (Hooker, 1872). *Vatica nitida* A. DC. (=*Stemonoporus nitidus*) is endemic to Sri Lanka.

Family—BOMBACACEAE

Genus—BOMBAX Linn.

Bombax palaeomalabaricum n. sp.

(Pl. 8.4, 5)

Material—One specimen.

Description—Leaf simple, symmetrical, elliptic; preserved size 11.8 x 5.4 cm; apex slightly broken seemingly acute; base wide acute; margin entire; texture thick chartaceous; venation pinnate; craspedodromous; primary vein single, prominent, straight, stout; secondary veins 12–13 pairs visible, 0.8 to 1.4 cm apart, usually alternate, unbranched, angle of divergence (about 65°), wide acute, uniformly curved up; intersecondary veins present, simple, frequent; tertiary veins fine, angle of origin usually AO, percurrent, straight to sinuous, branched, predominantly alternate, oblique to right angle in relation to mid vein and close.

Holotype—B.S.I.P. Museum No. 40339.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian);

Etymology—By adding prefix 'Palaeo' to the name of modern comparable species, *B. malabaricum.*

Affinity—The diagnostic features of the present fossil leaf such as symmetrical, elliptic shape, craspedodromous venation, usually alternate, unbranched, uniformly curved up, wide acute secondary veins, presence of intersecondary veins, simple, frequent, AO, percurrent, straight to sinuous, branched tertiary veins indicate that the present fossil shows resemblance with the modern leaves of the genus *Bombax* Linn. of the family Bombacaceae. In order to find out specific affinity, the herbarium sheets of all the available species of this genus were critically examined and it was concluded that the leaves of *Bombax malabaricum* DC. (= *Salmalia Malabarica* Schott.; C.N.H. Herbarium Sheet No. 57036) show closest affinity with the fossil leaf in shape, size and venation pattern.

Fossil records and comparison—There is no record of fossil leaf resembling *Bombax* Linn. from the Tertiary sediment of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and hence it is being described as *Bombax palaeomalabaricum* n. sp.

Bombax Linn. consists of 20 extant species distributed in old world tropic (Mabberley, 1997). *Bombax malabaricum* DC or semal is a tall deciduous tree. It is distributed throughout the hotter parts of the country up to 1500 m or more. It also distributed in southern China and Indo–Malayan region (Antil *et al*., 2013).

PLATE 6

(All figures are of natural size unless otherwise mentioned) →

1., 2. *Hydnocarpus ghishiensis* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40330 (Holotype), 40331(Paratype).

3. *Hydnocarpus pertandra* (Buch–Ham.) Oken–Modern leaf showing similar shape, size and venation pattern.

4. *Hydnocarpus ghishiensis* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 3. BSIP Museum No. 40330 (Holotype).

5. *Hydnocarpus pertandra* (Buch–Ham.) Oken–Part of modern leaf magnified to show similar details of venation pattern. x 2.

6. *Vatica siwalica* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40335 (Holotype).

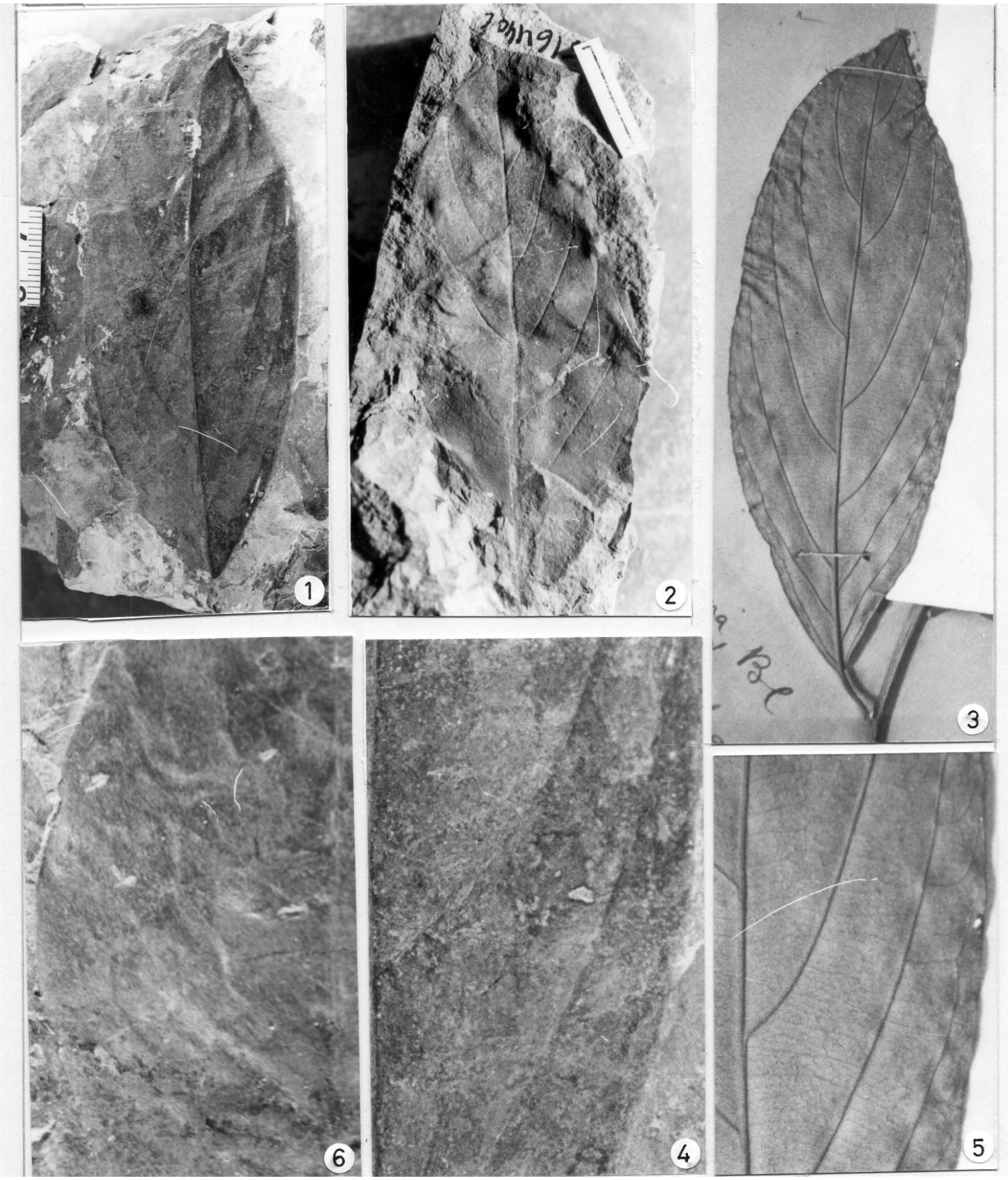

PLATE 6

Family—STERCULIACEAE

Genus—STERCULIA Linn.

Sterculia miocolorata n. sp.

(Pl. 8.6, 7; Pl. 9.1)

Material—Two specimens.

Description—Leaf simple, symmetrical, rounded; preserved size 11.5 x 5.7 cm and 7.5 x 5.5 cm; apex indistinct; base rounded; margin non entire; texture chartaceous; petiole present, 2.5 cm long, thick; venation pinnate, divergent; primary vein about 8 pairs arising from the base and running to the each pinna, straight to slightly curved; secondary veins 5–6 pairs visible, 1.3 to 2.2 cm apart, angle of divergence (55°–65°), moderate acute to narrow acute, uniformly curved up, seemingly unbranched; tertiary veins still fine, angle of origin, RR, percurrent, straight to curved, branched, oblique in relation to midvein, predominantly alternate and distant.

Holotype—B.S.I.P. Museum No. 40340.

Paratype—B.S.I.P. Museum No. 40341.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix 'mio' to the name of modern comparable species *S. colorata*.

Affinity—The characteristic features of the present fossil leaves are symmetrical, rounded shape, non entire margin, presence of 2.5 cm long, thick petiole, pinnate and divergent venation, about 8 pairs primary vein arising from the base and running to the each pinna, moderate acute to narrow acute angle of secondary veins, RR, percurrent, straight to curved, branched tertiary veins. A detail study of the herbarium sheets of different genera and species, it was seen that the above features are found common in the modern leaves of *Sterculia colorata* Roxb. (=*Firmiana colorata* Roxb.) of the family Sterculiaceae (C.N.H. Herbarium Sheet No. 120).

Fossil records and comparison—From Siwalik sediments, there are six fossil records of *Sterculia* leaves. These are *Sterculia kathgodamensis* from the Lower Siwalik sediments of Kathgodam area in Nainital District of Uttar Pradesh (now Uttarakhand), *S. mioensifolia* and *S. premontana* from the Himalayan foothills of western Nepal (Prasad, 1994c; Prasad & Pandey, 2008). The others are *S. urens* Roxb., *S. villosa* Roxb. and *S. versicolor* Wall. from the Late Tertiary sediments of Mahuadanr Valley (Bande & Srivastava, 1990; Singh & Prasad, 2007, 2010). The present fossil leaf has been compared with the above known species and found that it differs in arrangement of primary vein, it having 8 primary veins as compare to only single prominent primary vein in already known species. Thus in being different, it has been described as a new species *Sterculia miocolorata.*

The genus *Sterculia* L. comprises about 60 species which are native of tropics of both hemispheres but especially abundant in tropical Asia. Anon (1966) recorded about 12 species of *Sterculia* in India. *Sterculia colorata* syn. *Firmiana colorata* (Roxb.) R.Br. commonly called 'Scarlet Sterculia' and common in the forests of the Western Ghats and the Deccan. Later, Krishnamurthy, 1993 reported that it occurs in Assam, Madhya Pradesh, south India and the Andaman Islands.

Family—STERCULIACEAE

Genus—STERCULIA Linn.

Sterculia siwalica n. sp.

(Pl. 8.1, 3)

Material—Two specimens.

Description—Leaf simple, symmetrical, narrow elliptic to lanceolate; preserved size 6.7 x 3.1 cm and 8.1 x 4.2 cm; apex acute; base slightly broken; margin entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 11–12 pairs visible, 0.4 to 0.9 cm apart, usually alternate, unbranched, angle of divergence (about 65º), moderate acute to wide acute, uniformly curved up and joined to that superadjacent secondary veins at obtuse angle; intersecondary veins present, simple; tertiary veins fine, angle of origin usually RR, percurrent, almost straight, sometime branched,

PLATE 7

(All figures are of natural size unless otherwise mentioned) →

1. *Sterculia mioparviflora* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40344 (Holotype).
2. *Sterculia parviflora* Roxb.–Modern leaf showing similar shape, size and venation pattern.
3., 4. *Vatica prenitida* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40337 (Holotype), 40338(Paratype).
5. *Vatica nitida* A. DC.–Modern leaf showing similar shape, size and venation pattern.
6. *Vatica prenitida* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 4. BSIP Museum No. 40338 (Paratype).
7., 8. *Vatica siwalica* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40335 (Holotype), 40336 (Paratype).
9. *Vatica versicolor* Wall.–Modern leaf showing similar shape, size and venation pattern.
10. *Vatica siwalica* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2.5. BSIP Museum No. 40335 (Holotype).
11. *Vatica versicolor* Wall.–Part of modern leaf magnified to show similar details of venation pattern. x 3.

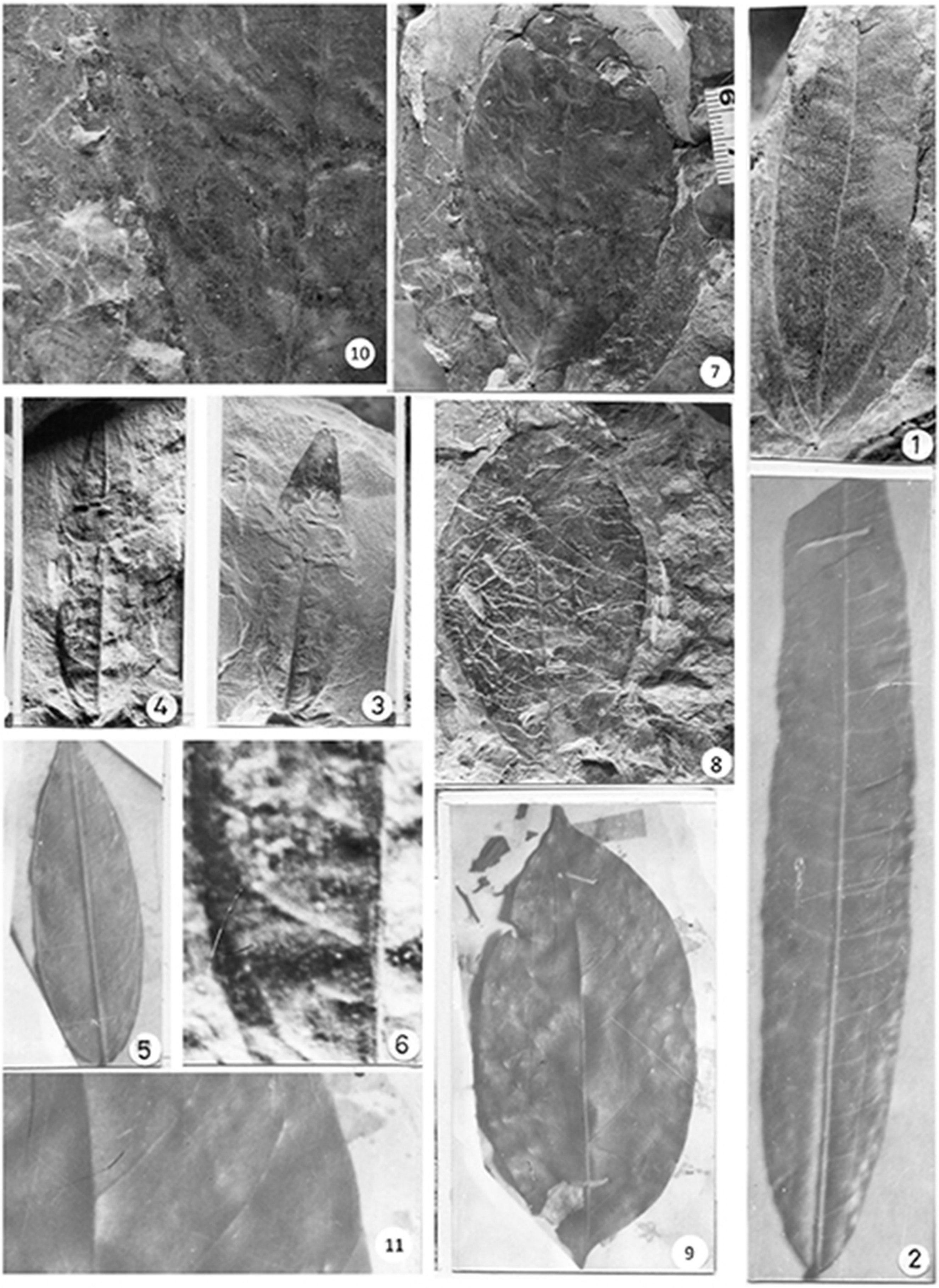

PLATE 7

Table 1—Species of *Sterculia* and their differentiatve characters from the present fossil.

Fossil taxa	Differentiative character
Sterculia kathgodamensis	Larger in size with narrow oblong shape
S. mioensifolia	Larger in size and having more number of secondaries (16 pairs)
S. premontana	Having lesser number of secondaries (7 pairs)
S. villosa Roxb.	Larger in size and ovate shape
S. urens Roxb.	Having five distinct primary veins
S. miocolorata	Large size, rounded, lesser number of secondaries (5–6 pairs) and 8 primary veins
S. siwalica	Moderate acute angle of divergence

oblique in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40342.

Paratype—B.S.I.P. Museum No. 40343.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

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

Affinity—The diagnostic features of the present fossil leaf such as symmetrical, narrow elliptic to lanceolate shape, acute apex, eucamptodromous venation, usually alternate, unbranched, moderate acute to wide acute, uniformly curved up secondary veins joining to that superadjacent secondary veins at obtuse angle, intersecondary veins presence of intersecondary veins, RR, percurrent, almost straight, sometimes branched tertiary veins indicate that the present fossil shows resemblance with the modern leaves of *Sterculia* Linn. of the family Sterculiaceae. In order to find out specific affinity, the herbarium sheets of all the available species of this genus were critically examined and it was concluded that the leaves of *Sterculia versicolor* Wall. (C.N.H. Herbarium Sheet No. 57449; Pl. 8.2) show close similarity with the fossil leaf in shape, size and venation pattern.

Fossil records and comparison—Six fossil leaves resembling the genus *Sterculia* Linn. have been known from the Tertiary sediments of India and Nepal. These are *S. kathgodamensis* Prasad (1994c) from the Siwalik sediments of Kathgodam, Uttarakhand, *S. mioensifolia* and *S. premontana* from Siwalik sediments of Suraikhola area, Nepal (Prasad & Pandey, 2008), *S. urens* Roxb., *S. villosa* Roxb. and *S. versicolor* Wall. from the Late Tertiary sediments of Mahuadanr Valley (Bande & Srivastava, 1990; Singh & Prasad, 2007, 2010), On comparison with above mentioned species it has been concluded that present fossil leaf is similar with that of *S. versicolor* reported by Singh and Prasad (2010) which is without assigning any specific epithet. Both have similar venetion pattern specially the course and orientation of secondary and tertiary veins. The present fossil leaf is therefore reported under a new form species *Sterculia siwalica* n. sp.

Sterculia L. comprises about 150 extant species which are native of tropics of both hemispheres but especially abundant in tropical Asia (Mabberley 1997). *Sterculia versicolor* Wall. is a tree found to grow in Myanmar on limestone rocks, on the bank of Irrawaddy near Segaen (Hooker, 1872).

Family—STERCULIACEAE

Genus—STERCULIA Linn.

Sterculia mioparviflora n. sp.

(Pl. 7.1)

Material—One specimen.

PLATE 8

(All figures are of natural size unless otherwise mentioned)

1. *Sterculia siwalica* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40342 (Holotype).
2. *Sterculia versicolor* Wall.–Modern leaf showing similar shape, size and venation pattern.
3. *Sterculia siwalica* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2.5. BSIP Museum No. 40342 (Holotype).
4. *Bombax palaeomalabaricum* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40339 (Holotype).
5. *Bombax palaeomalabaricum* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40339 (Holotype).
6. *Sterculia miocolorata* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40341 (Paratype).
7. *Sterculia miocolorata*–Part of fossil leaf magnified to show details of venation pattern. x 1.5. BSIP Museum No. 40340 (Holotype).

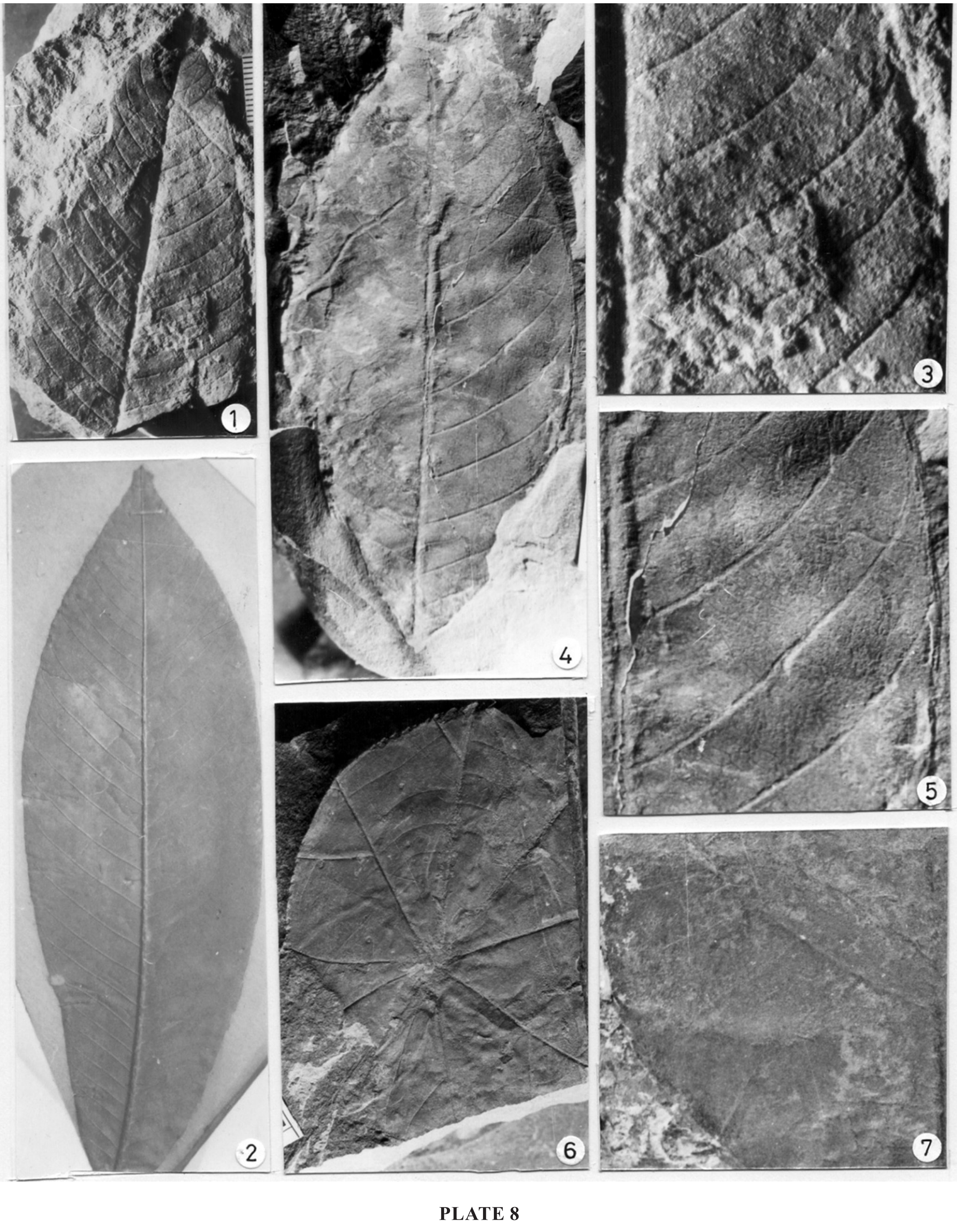

PLATE 8

Description—Leaf simple, symmetrical; narrow elliptic; preserved size 7.4 x 2.4 cm; apex broken; base acute; margin entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, straight, stout; secondary veins 10–11 pairs, 0.4–1.2 cm apart, angle of divergence (70°–80º), wide acute to nearly right angle, usually alternate, unbranched, uniformly curved up; intersecondaries present; tertiary veins fine, angle of origin, RR percurrent, oblique in relation to mid vein, alternate and close.

Holotype—B.S.I.P. Museum No. 40344.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix 'mio' to the name of modern comparable species *S. parviflora.*

Affinity—Symmetrical, narrow elliptic shape, eucamptodromous venation, wide acute to near right angle of divergence of secondaries, presence of intersecondaries and RR, percurrent tertiaries, collectively suggest its affinity with the modern leaves of *Sterculia parviflora* Roxb. of family Sterculiaceae (C.N.H. Herbarium Sheet No. 57697; Pl. 7.2).

Fossil records and comparison—There are seven records of fossil leaves of the genus *Sterculia* Linn. from Siwalik sediments. These are *Sterculia kathgodamensis* Prasad (1994c) from the Lower Siwalik sediments of Kathgodam area in Nainital District of Uttar Pradesh (now in Uttarakhand), *S. mioensifolia* and *S. premontana* Prasad & Pandey (2008) from the Himalayan foothills of western Nepal, *S. urens*, *S. villosa* and *S. versicolor* Wall. from the Late Tertiary sediments of Mahuadanr Valley (Bande & Srivastava, 1990; Singh & Prasad, 2007, 2010), *S. miocolorata*, and *S. siwalica* (described in this text) from the Siwalik sediments of Oodlabari District, West Bengal. The present fossil leaf has been compared with the above known species and found that it differs from already known fossil either in shape, size or number of secondary and primary veins (Table 1). Thus in being different, it has been described as a new species *Sterculia mioparviflora* n. sp.

Sterculia parviflora Roxb. with which fossil leaf shows closest resemblance is distributed in India, Indonesia, Malaya Peninsula, Myanmar, Thailand and Vietnam.

Family—RUTACEAE

Genus—TODDALIA Juss.

Toddalia miocenica n. sp.

(Pl. 9.6, 7)

Material—One specimen.

Description—Leaf simple, asymmetrical; preserved size 4.3 x 2.2 cm; elliptic, apex acute; base acute; margin entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, straight, stout; secondary veins 11–12 pairs, 0.2–0.5 cm apart, angle of divergence (60°–65°), wide acute, unbranched, uniformly curved up; intersecondaries present, usually 2–3 intersecondaries in between two secondaries; tertiary veins fine, angle of origin RR–AO, percurrent, branched, oblique in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40345.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the Miocene epoch to which the fossil locality belongs.

Affinity—The characteristic features of the present fossil leaf such as asymmetrical, elliptic shape, acute apex and base, eucamptodromous venation, wide acute, unbranched, uniformly curved up secondaries, presence of usually 2–3 intersecondaries in between two secondaries; RR–AO, percurrent and close tertiaries collectively suggest its closest affinity with the modern leaves of *Toddalia aculeata* Pers. Syn. *Toddalia asiatica* Linn .(Radlk.) of the family Rutaceae (C.N.H. Herbarium Sheet No. 74502; Pl. 18.6).

Fossil records and comparison—There is no record of fossil leaf resembling the genus *Toddalia* Juss. from the Tertiary sediment of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and hence it is being described as *Toddalia miocenica* n. sp.

Toddalia Juss. comprises only one species distributed throughout the old world tropics (Mabberley 1997). *Toddalia*

PLATE 9

(All figures are of natural size unless otherwise mentioned) ⟶

1. *Sterculia miocolorata* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40340 (Holotype).

2., 3. *Rhamnus siwalicus* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40446 (Holotype), 40447 (Paratype).

4. *Rhamnus erectus*–Modern leaf showing similar shape, size and venation pattern.

5. *Rhamnus siwalicus* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 3. BSIP Museum No. 40446 (Holotype).

6. *Toddalia miocenicus* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40345 (Holotype).

7. *Toddalia miocenicus* n. sp.–Part of fossil leaf magnified to show details of venation pattern x 3. BSIP Museum No. 40345 (Holotype).

8. *Rhamnus erectus*–Part of Modern leaf magnified to show similar details of venation pattern. x 3.

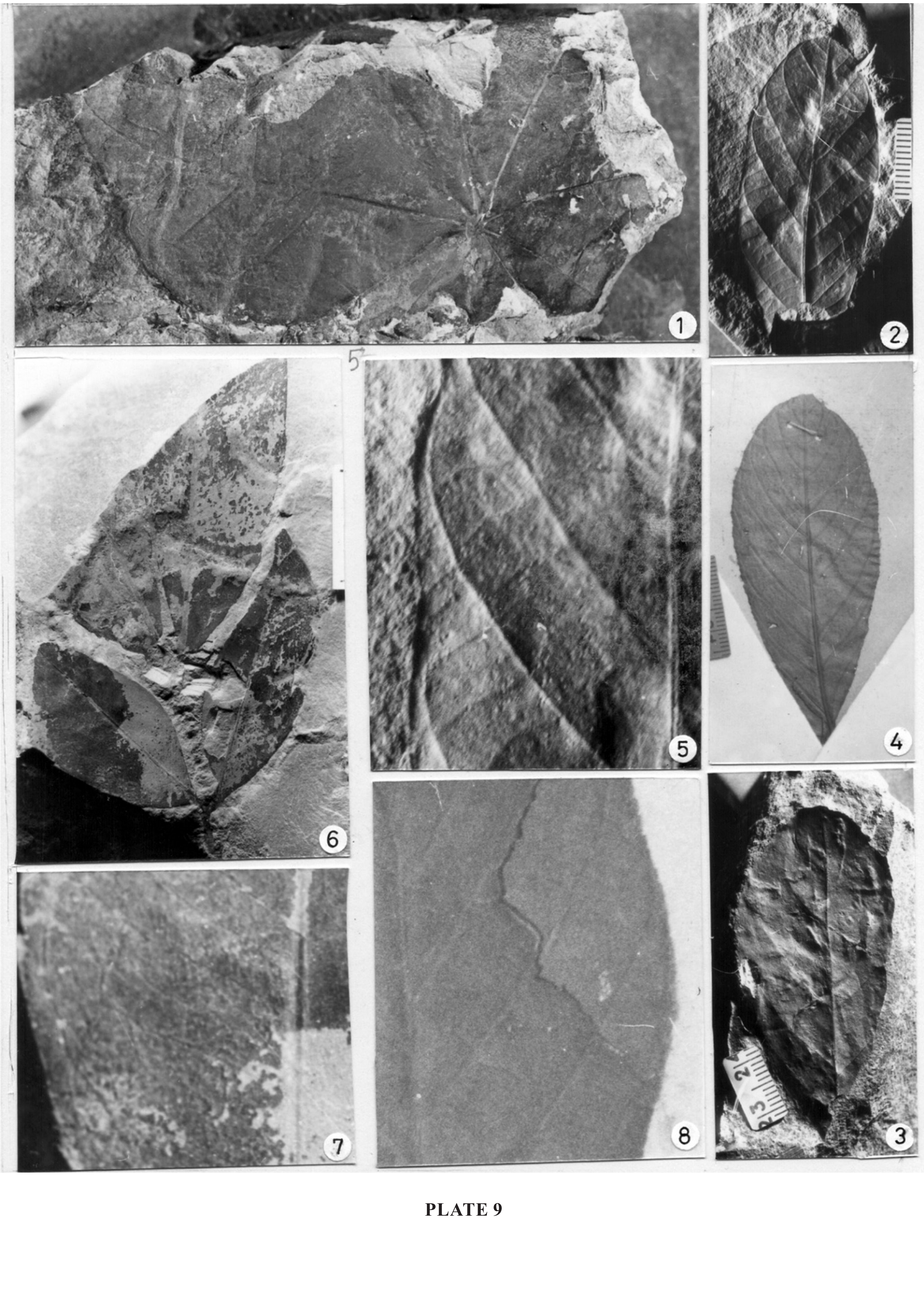

PLATE 9

aculeata Pers. Distributed from sub–tropical Himalaya extending from Kumaon to eastwards Bhutan and Assam (Khasia Hills) and in the peninsular India (Hooker, 1875). This taxon is also reported to occur in Orissa (Prain, 1903).

Order—ROSALES

Family—RHAMNACEAE

Genus—RHAMNUS Linn.

Rhamnus siwalicus n. sp.

(Pl. 9.2, 3. 5)

Material—Two specimens.

Description—Leaf simple, symmetrical, elliptic; preserved size 5.2 x 2.6 cm and 5.5 x 2.6 cm; apex obtuse; base acute; margin almost entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 8–9 pairs visible, 0.2 to 0.7 cm apart, alternate, unbranched, angle of divergence (40°–50°), narrow acute, curved up, curvature more pronounced and joined to their superadjacent secondary at obtuse angle; tertiary veins fine, angle of origin, usually RR, percurrent, straight to sometime sinuous, branched, oblique in relation to midvein, predominantly alternate and close to nearly distant; quaternary veins still fine with angle of origin nearly right angle, sometime branched and forming orthogonal to polygonal meshes.

Holotype—B.S.I.P. Museum No. 40346.

Paratype—B.S.I.P. Museum No. 40347.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of Siwalik Formation to which fossil belongs.

Affinity—The characteristic features of the present fossil leaf such as symmetrical, elliptic shape, obtuse apex, acute base, eucamptodromous venation, alternate, unbranched, narrow acute secondary veins, curved up, curvature more pronounced and joined to their superadjacent secondary at obtuse angle, RR, percurrent, straight to sometime sinuous, branched tertiary veins, fine with angle of origin nearly right angle, sometime branched quaternary veins and forming orthogonal to polygonal meshes undoubtedly indicate its resemblance with the extant leaves of *Rhamnus* Linn. especially *Rhamnus erectus* of the family Rhamnaceae (C.N.H. Herbarium Sheet No. 89054; Pl. 9.4, 8).

Fossil records and comparison—Only one fossil leaf resembling the genus *Rhamnus* Linn. has been known from the Tertiary sediments of India, i.e. *Rhamnus purpurea* Edgew. from Late Tertiary sediments of Mahuadanr Valley of Jharkhand. The present fossil leaf has been compared with the above known species and found that it differs in course of venation pattern and shape (oblong) in already known species. Thus in being different, it has been described as a new species *Rhamnus siwalicus* n. sp.

Rhamnus Linn. comprises 125 extant species of mainly tree deciduous and shrub distributed in North Hemisphere from Brazil to South Africa (Mabberley, 1997). *Rhamnus erectus* is distributed in Assam.

Order—VITALES

Family—VITACEAE

Genus—VITIS Linn.

Vitis siwalicus n. sp.

(Pl. 12.5, 6, 8)

Material—Two specimens.

Description—Leaf simple; narrow elliptic; preserved size 7.2 x 3.9 cm, 9.0 x 4.4 cm; apex broken; base acute, normal; margin serrate; texture thick chartaceous; petiole present, 1.2 cm long; normal, venation pinnate; eucamptodromous; primary vein single, almost straight, prominent, stout; secondary veins 9 to 10 pairs visible, 0.8 to 1.4 cm apart, usually alternate, unbranched, angle of divergence (65º–70º), wide acute, simple; tertiary veins fine, angle of origin usually RR, percurrent, straight to sinuous, branched, oblique in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40348.

Paratype—B.S.I.P. Museum No. 40349.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

PLATE 10

(All figures are of natural size unless otherwise mentioned)

→

1. *Paranephelium miocenica* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40350 (Holotype).
2. *Paranephelium macrophyllum* King–Modern leaf showing similar shape, size and venation pattern.
3., 4. *Filicium koilabasensis* Prasad–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40353, 40354.
5. *Filicium decipiens* (Wight & Arn.) Hook.f.–Modern leaf showing similar shape, size and venation pattern.
6. *Filicium koilabasensis* Prasad–Part of fossil leaf magnified to show details of venation pattern. x 4. BSIP Museum No. 40353.
7. *Filicium decipiens* (Wight & Arn.) Hook.f.–Part of modern leaf magnified to show similar details of venation pattern. x 2.5.

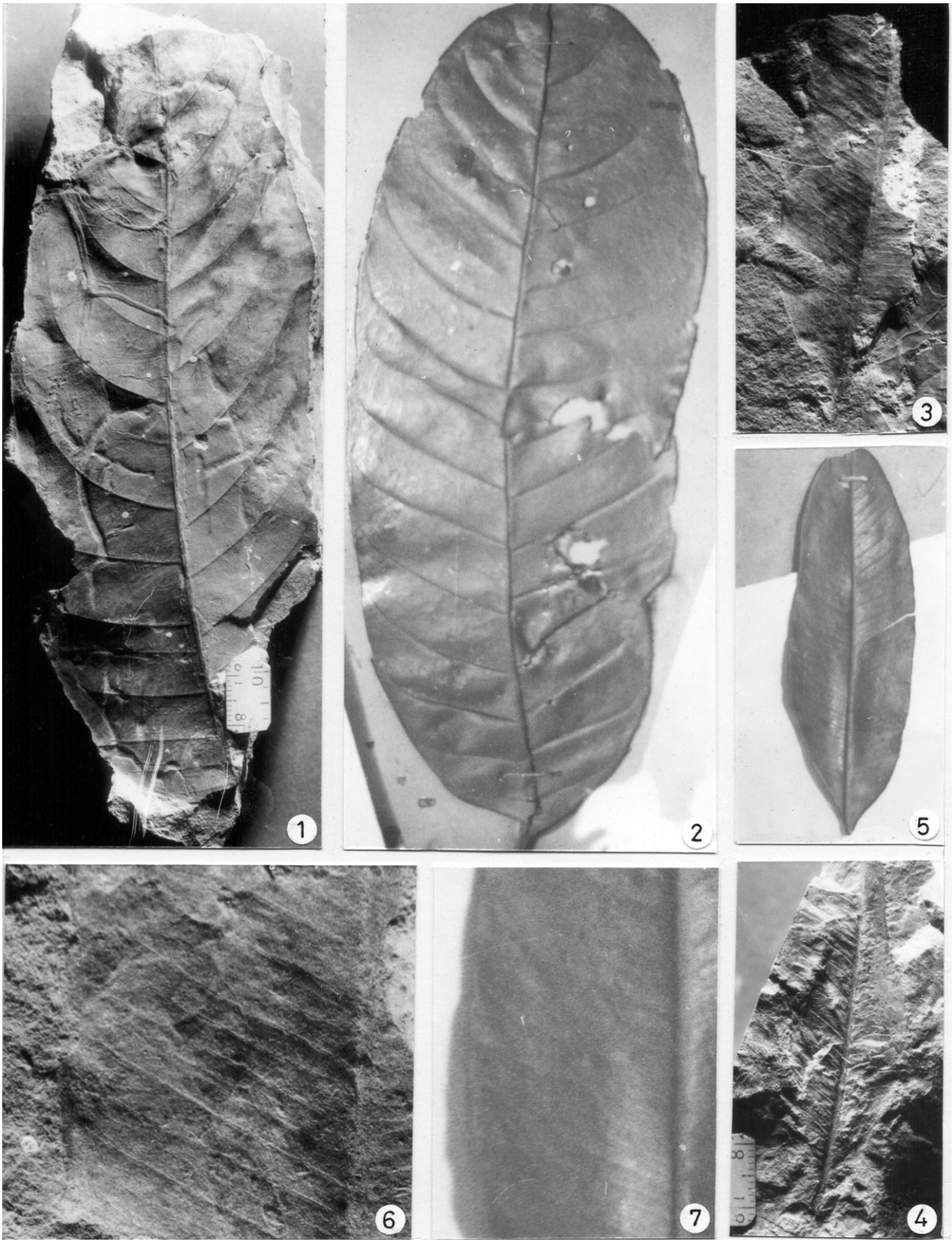

PLATE 10

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of Siwalik sediments from which fossil specimens were recovered.

Affinity—The morphological features such as narrow elliptic shape, acute base, serrate margin, eucamptodromous venation, wide acute secondary veins, RR, percurrent, straight to sinuous tertiaries, oblique in relation to mid vein are characteristic features of present fossil leaves. Keeping in view these characters, consultation of the herbarium sheets of different genera and species of dicotyledonous families has been carried out and concluded that the present fossil resembles closely with the extant leaves of *Vitis lanceolaria* (Roxb.) Wall. [=*Tetrastigma lanceolarium* (Roxb.) Planch.] (C.N.H. Herbarium Sheet No. 8; Pl. 12.7) of the family Vitaceae.

Fossil records and comparison—There is no record of fossil leaf resembling the genus *Vitis* Linn. from the Tertiary sediment of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and hence it is being described as *Vitis siwalica* n. sp.

Vitis L. consists of 65 species (Mabberley, 1997) distributed mainly in Northern Hemisphere. *Vitis lanceolaria* (Roxb.) Wall. is widespread in West Sumatra (Veldkamp, 2007).

Order—SAPINDALES

Family—SAPINDACEAE

Genus—PARANEPHELIUM Miq.

Paranephelium miocenica n. sp.

(Pl. 10.1; Pl. 11.1, 2)

Material—Two specimens.

Description—leaf simple, symmetrical, narrow elliptic; preserved size 14.0 x 5.12 cm and 11 x 5.5 cm; apex broken; base seemingly acute; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, slightly curved, stout; secondary veins 13–14 pairs visible 0.8 to 1.2 cm apart, usually alternate, unbranched, angle of divergence 60º–90°, moderate acute to right angle, lower secondary veins are with greater angle and secondary on one side of lamina are with more angle than other side of lamina, uniformly curved up and joined to their super adjacent at obtuse angle; intersecondaries present, simple; tertiary veins fine, angle of origin usually RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close to distant. Further details could not be seen.

Holotype—B.S.I.P. Museum No. 40350.

Paratype—B.S.I.P. Museum No. 40351.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik), Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix 'mio' to the extant species, *P. macrophyllum.*

Affinity—Symmetrical, narrow elliptic shape, eucamptodromous venation; usually alternate, unbranched, moderate acute to right angle of secondary veins, lower secondary veins are with greater angle and secondary on one side of lamina are with more angle than other side of lamina, uniformly curved up and joined to their super adjacent at obtuse angle; intersecondaries present, simple; RR, percurrent, straight to sinuous, branched tertiary veins. These features suggest that the fossil leaves belong to the extant genus *Paranephelium* Miq. of the family Sapindaceae. A critical examination of the herbarium sheets of a number of species of this genus indicates that the leaves of *Paranephelium macrophyllum* King (C.N.H. Herbarium Sheet No. 94835) shows closest resemblance with the present fossils in shape, size and venation pattern.

Fossil records and comparison—As concerned as the fossil record of *Paranephelium* there is two fossils known from Tertiary of India. Of there *Paranephelium seriaensis* Prasad and Dwivedi 2008, is known from the Middle Miocene sediments of western Nepal. It has acute apex and distance between two secondary veins is 0.7–1.2 cm and there is absence of intersecondary veins in contrast to the present fossil leaf where apex is attenuate and intersecondary veins are present. The other species, *Paranephelium makumensis* Srivastava and Mehrotra (2013) described from Makum Coalfield, Assam can be differentiated in being possessing more acute angle of secondary veins on one side of the midrib, more over the width of the Siwalik fossils is greater than *P. makumensis* Srivastava and Mehrotra. In view of this, the present fossils have been described under a new species *Paranephelium miocenica.*

Paranephelium Miq. is a small genus consisting of only four species distributed in south–east Asia and western Malaysia. It is small–to–medium sized tree of the lower canopy or higher understorey of the primary rain forest, mixed deciduous forest or dry evergreen forest, especially in the moist part near streams, sometimes in secondary forest, rarely in scrub; typical of lowlands and the lower hillside (Davids, 1984). The comparable species, *P. macrophyllum* King is presently distributed in the evergreen forest of South–east Asian region (Adema *et al.*, 1994).

Family—SAPINDACEAE

Genus—CUPANIA Linn.

Cupania oodlabariensis n. sp.

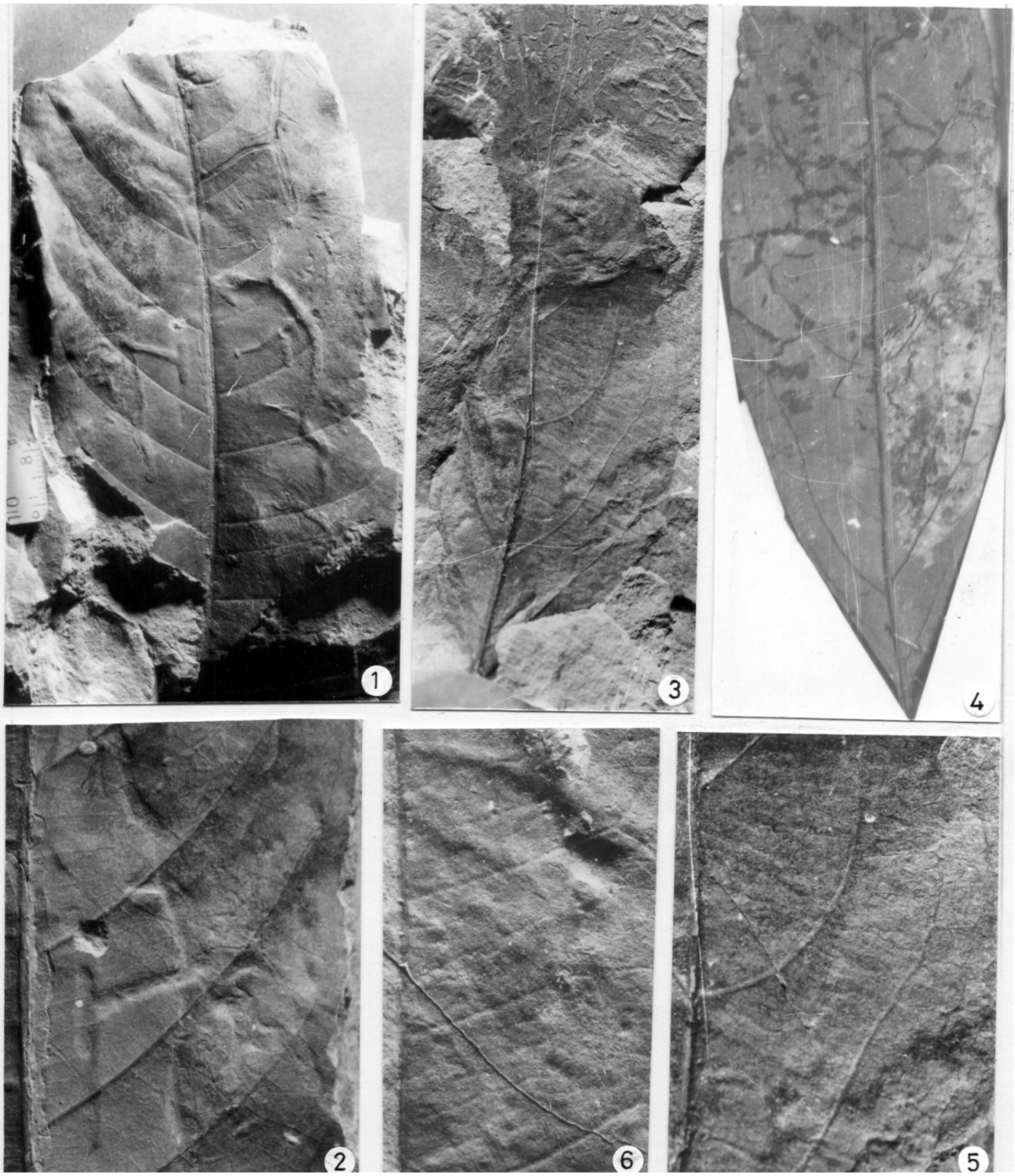

PLATE 11

(All figures are of natural size unless otherwise mentioned)

1. *Paranephelium miocenica* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40351 (Paratype).
2. *Paranephelium miocenica* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40350 (Holotype).
3. *Cupania oodlabariensis* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40352 (Holotype).
4. *Cupania pleuropteris* var. *apiculata* Hiern–Modern leaf showing similar shape, size and venation pattern.
5. *Cupania oodlabariensis* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2.
6. *Filicium koilabasensis* Prasad–A part of another fossil leaf magnified to show details of venation pattern. x 4. BSIP Museum No. 40354.

(Pl. 11.3, 5)

Material—One specimen.

Description—Leaf simple, elliptic; preserved size 10.3 x 4.2 cm; apex broken; base narrow acute; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 5–6 pairs visible, 1.4 to 2.3 cm apart, alternate to opposite, seemingly unbranched, angle of divergence (40°–75°), narrow acute to right angle, curved up with marked curvature and joined with superadjacent secondaries at right angle; tertiary veins fine, angle of origin, RR, percurrent, straight to sinuous, branched, acute to right angle in relation to midvein, alternate to opposite and close; quaternary veins still fine, angle of origin usually RR, branched forming usually orthogonal to polygonal meshes.

Holotype—B.S.I.P. Museum No. 40352.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of small town, Oodlabari near the fossil locality.

Affinity—Elliptic shape, eucamptodromous venation, alternate to opposite, seemingly unbranched secondary veins with narrow acute to right angle of divergence and with marked curvature and joining with superadjacent secondaries at right angle, RR, percurrent, straight to sinuous, branched tertiary veins, acute to right angle in relation to midvein and orthogonal to polygonal meshes formed by quaternary veins collectively suggest its closest affinity with the modern leaves of *Cupania pleuropteris* var. *apiculata* Hiern [=*Guioa pleuropteris* (Blume) Radlk.] of the family Sapindaceae (C.N.H. Herbarium Sheet No. 94604; Pl. 11.4).

Fossil records and comparison—Only one fossil leaf is reported from Siwalik near Kathgodam, Uttarakhand under *Cupania miocenica* (Prasad *et al.,* 2004). It differs from present fossil having small size (5.6 x 9.5 cm) and the secondary veins are more and closely placed, moreover intersecondaries are also present. Thus in being different, it has been described as a new species *Cupania oodlabariensis* n. sp.

Cupania Linn. comprises 45 extant species and some of them are distributed in the warm America (Mabberley 1997). *Cupania pleuropteris* var. *apiculata* Hiern [=*Guioa pleuropteris* (Blume) Radlk.] is an understory tree disturbed in forests or open sites in undisturbed mixed dipterocarps, coastal and sub–montane forests in Myanmar, Indo–China, Thailand, Peninsular Malaysia, Sumatra, Borneo and Philippines.

Family—SAPINDACEAE

Genus—FILICIUM Thw.

Filicium koilabasensis Prasad 1994e

(Pl. 10.3, 4, 6)

Material—Four specimens.

Description—Leaflet almost symmetrical; narrow elliptic; preserved size 7.0 x 2.5 cm, 7.5 x 2.2 cm, 7.5 x 2.1 cm and 8.0 x 2.1 cm; apex acute to attenuate; base acute, normal sometime slightly oblique; margin entire; texture chartaceous; petiole present 0.5 to 0.7 cm long; venation pinnate, eucamptodromous; primary vein single, prominent, stout, straight to somewhat curved; secondary veins 24 pairs visible 0.2 to 0.4 cm apart, closely placed, angle of divergence (about 60°), acute, opposite rarely branched; 1–2 intersecondaries arise in between two secondaries; tertiary veins fine with angle of origin AR–RO, percurrent, almost straight, branched, oblique in relation to mid vein, predominantly alternate and close.

Specimens—B.S.I.P. Museum No. 40353–40356.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—The characteristic features of the present fossil leaves are symmetrical, narrow elliptic shape, acute to attenuate apex, acute base, normal sometime slightly oblique, 0.5 to 0.7 cm long petiole, eucamptodromous venation, closely placed and acute secondaries, abundance of intersecondaries, AR–RO, percurrent tertiary veins. Such features are found common in the modern leaves/leaflets of *Toddalia lanceolata* Lam. of the family Rutaceae and *Filicium decipiens* (Wight & Arn.) Hook.f. of the family Sapindaceae. *Toddalia lanceolata* slightly differs from present fossil in the nature of secondary veins which do not join each other near the margin as found in the fossil. Thus, the extant leaves of *Filicium decipiens* (Wight & Arn.) Hook.f. (C.N.H. Herbarium Sheet Nos. 78732,

PLATE 12

(All figures are of natural size unless otherwise mentioned)

→

1., 3. *Sabia eopaniculata* Prasad–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40357, 40358.

2. *Sabia lanceolata* Colebr.–Modern leaf showing similar shape, size and venation pattern.

4. *Sabia eopaniculata* Prasad–Part of fossil leaf magnified to show details of venation pattern. x 3. BSIP Museum No. 40357.

5., 6. *Vitis siwalicus* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40348 (Holotype), 40349 (Paratype).

7. *Vitis lanceolaria*–Modern leaf showing similar shape, size and venation pattern.

8. *Vitis siwalicus* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2.5. BSIP Museum No. 40348 (Holotype).

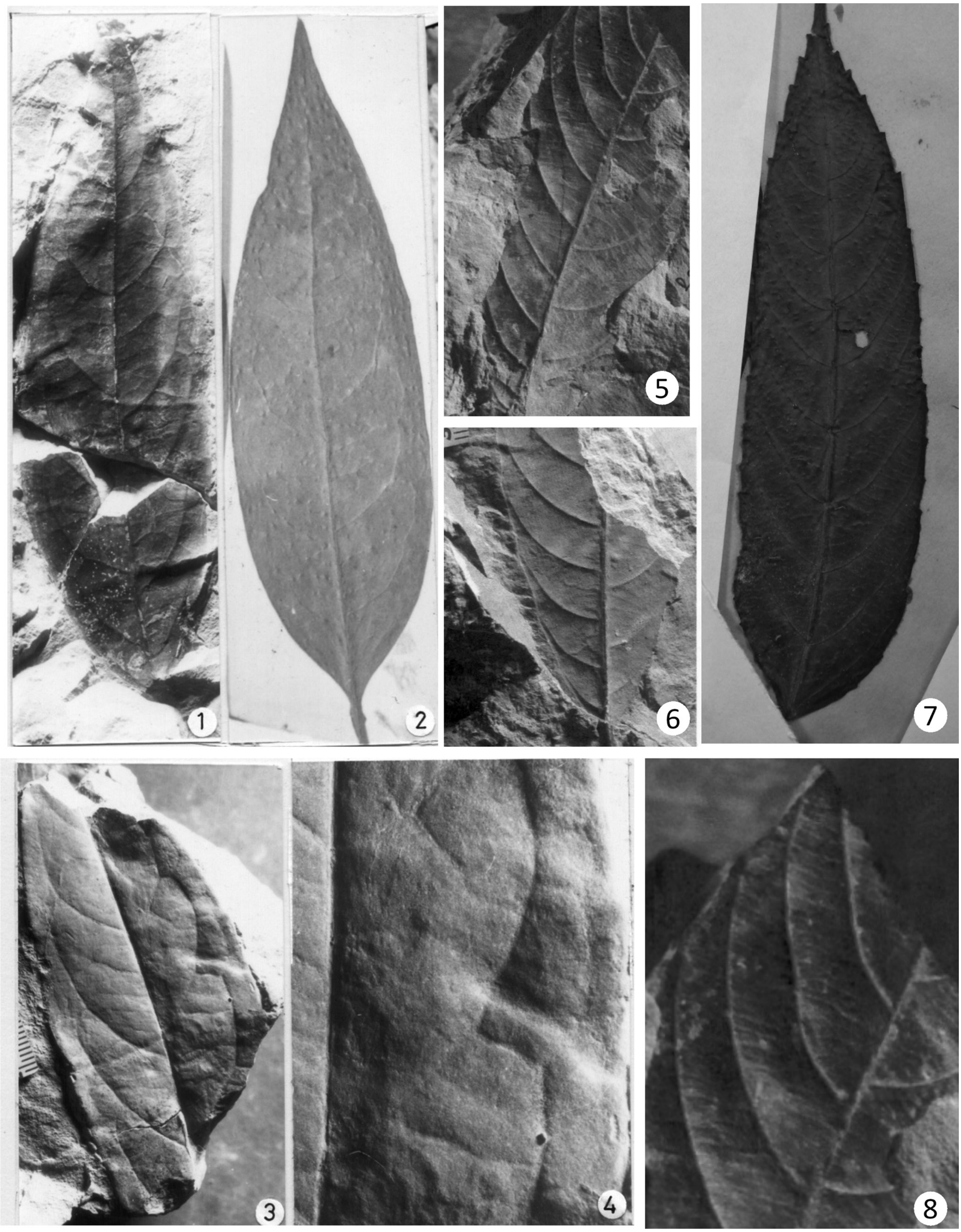

PLATE 12

65968; Pl. 10.6, 7) show closest similarity with the fossils in all the morphological features.

Fossil records and comparison—Prasad (1994e) has described a fossil leaf showing affinity with *Filicium decipiens* Thw. under the form species, *Filicium koilabasensis* from the Lower Siwalik sediments of Koilabas, Nepal. On comparison with Prasad's specimen it has been found that both the fossil leaves have similar venation pattern, specially the course and orientation of secondary and tertiary veins. The present fossil leaf is therefore described under the same as *Filicium koilabasensis* Prasad.

Filicium Thw. ex Hook.f. comprises three species presently distributed in the tropical region of old world (Mabberley 1997). *Filicium decipiens* (Wight & Arn.) Hook.f. with which fossils resemble closely is a medium sized, evergreen tree occurring in the forests of Western Ghats, from the Nilgiris southwards. It also found in Sri Lanka and tropical Africa (Brandis, 1971).

Family—SABIACEAE

Genus—SABIA Colebr.

Sabia eopaniculata Prasad, 1994e

(Pl. 12.1, 3, 4)

Material—Two specimens.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 12.4 x 3.6 cm and 8.4 x 4.1 cm; apex narrow acute; base acute, normal; margin entire; texture chartaceous; venation pinnate; brochidodromous; primary vein single, almost straight, prominent, stout; secondary veins 6–7 pairs visible, 1.3 to 2.4 cm apart, alternate, seemingly unbranched, angle of divergence (50°–65º), vary moderate to wide acute, uniformly curved up and joined to that superadjacent secondary before the margin at nearly right to obtuse angle; intersecondary veins present, frequent, simple; tertiary veins fine, angle of origin usually RR, percurrent, straight, sometime curved and sinuous, oblique in relation to mid vein, predominantly alternate and close.

Specimens—B.S.I.P. Museum No. 40357–40358.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—The distinguishing characters of the present fossil leaf such as symmetrical, narrow elliptic shape, narrow acute apex, acute base, brochidodromous venation, alternate, seemingly unbranched, moderate to wide acute uniformly curved up secondary veins joining to the superadjacent secondary before the margin at nearly right to obtuse angle, presence of intersecondary veins, frequent, simple, RR, percurrent, straight, sometime curved and sinuous tertiary veins suggest that the present fossil leaves belong to the genus *Sabia* Colebr. of the family Sabiaceae. A critical examination of herbarium sheets of all the available species of this genus shows that the leaves of *Sabia lanceolata* Colebr. of the family Sabiaceae have closest affinity with the present fossil leaf (C.N.H. Herbarium Sheet No. 1900, 16301; Pl. 12.2).

Fossil records and comparison—Only one fossil leaf showing close similarity with the genus *Sabia* Colebr.*,* has been described under form species *Sabia eopaniculata* form Siwalik sediments of Koilabas area, Nepal (Prasad, 1994e). On comparison with above mentioned fossil it has been found that present fossil leaves are very similar to the fossil leaf reported by Prasad *et al.,* 1994e from Siwalik of Nepal in venation pattern, especially the course and orientation of secondary and tertiary veins. The present fossil leaf is therefore attributed to the same species, *Sabia eopaniculata* Prasad.

Sabia Colebr. consists of about twenty–five extant species. It is distributed in S. E. Asia and Malaysian region. *Sabia lanceolata* Colebr. is an evergreen woody climber or scandent shrub and distributed in Bangladesh, Bhutan, India, Myanmar and China (Yun–Fei & Li–Xiu, 2007).

Family—ANACARDIACEAE

Genus—BUCHANANIA Spreng.

Buchanania palaeosessilifolia n. sp.

(Pl. 13.1, 2, 3, 5)

Material—Four specimens.

Description—Leaf simple, asymmetrical, elliptic to narrow elliptic; preserved size 10.9 x 4.0 cm, 8.0 x 4.5 cm, 8.0 x 4.3 cm and 7.5 x 4.5 cm; apex broken; base acute; margin entire; texture chartaceous; venation pinnate, craspedodromous to eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 15 to 16

PLATE 13

(All figures are of natural size unless otherwise mentioned)

⟶

1., 2., 3. *Buchanania palaeosessilifolia* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40359 (Holotype), 40360, 40361 (Paratype).

4. *Buchanania sessilifolia* Blume–Modern leaf showing similar shape, size and venation pattern.

5. *Buchanania palaeosessilifolia* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2.5. BSIP Museum No. 40362 (Paratype).

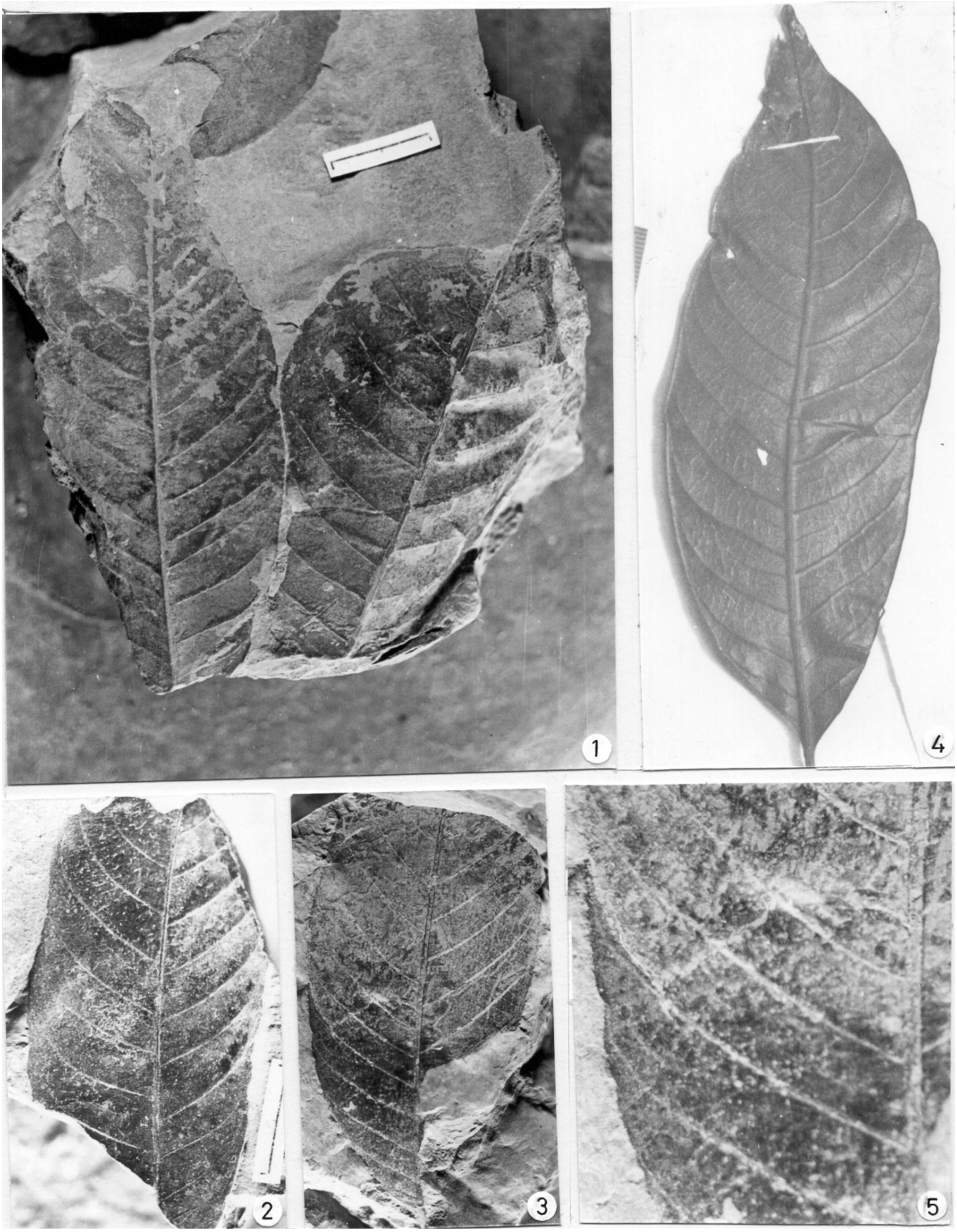

PLATE 13

pairs visible, 0.5 to 1.1 cm apart, alternate to sub–opposite, unbranched, angle of divergence (60°–70°), moderate acute, uniformly curved up, curvature more pronounced near the margin; tertiary veins fine, angle of origin, RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close to nearly distant.

Holotype—B.S.I.P. Museum No. 40359.

Paratype—B.S.I.P. Museum No. 40362.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding the prefix 'palaeo' to the name of modern comparable species, *B. sessilifolia.*

Affinity—The characteristic features of the present fossil leaves such as symmetrical, shape elliptic to narrow elliptic shape, craspedodromous to eucamptodromous venation, moderately acute secondary veins, pronounced curvature near the margin, RR, percurrent, straight to sinuous, branched tertiary veins collectively suggest its closest affinity with the modern leaves of *Buchanania sessilifolia* Blume of the family Anacardiaceae (C.N.H. Herbarium Sheet No. 846; Pl. 13.4). It should be mentioned that the fossil also shows close resemblance with extant leaves of *Nothopegia* in the same family but differs in possessing more acute secondaries.

Fossil records and comparison—There is no prior record of fossil leaf resembling the genus *Buchanania* Spreng. from the Tertiary sediments of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and hence it is being described as *Buchanania palaeosessilifolia* n. sp.

Buchanania Spreng. comprises 25 species distributed in Indo–Malayan region and west Pacific (Mabberley, 1997). *Buchanania sessilifolia* Blume distributed in Indo-China, Thailand, Malaya Peninsula, Sumatra, Borneo, Philippines and the Moluccas.

Order—FABALES

Family—FABACEAE

Genus—MILLETTIA Wight & Arn.

Millettia mioserícea n. sp.

(Pl. 15.3, 5)

Material—One specimen.

Description—Leaf simple, symmetrical, elliptic; preserved size 7.8 x 3.2 cm, apex acuminate; base acute; margin entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 10 to 11 pairs visible, 0.4 to 1.0 cm apart, alternate to sub–opposite, unbranched, angle of divergence (40°–60º), narrow to wide acute, uniformly curved up; tertiary veins fine, angle of origin usually RR, percurrent, straight to sinuous, branched, oblique in relation to mid vein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40363.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix 'mio' to the name of modern comparable species *Millettia sericea.*

Affinity—The characteristic features of the present fossil leaves such as elliptic shape, acuminate apex, eucamptodromous venation, narrow to wide acute secondary vein, uniformly curved up, RR, percurrent, straight to sinuous, branched tertiary veins indicate that the present fossil leaves show close resemblance with the modern leaves of *Millettia sericea* (Vent.) W. & A. (C.N.H. Herbarium Sheet No. 12090; Pl. 15.4, 6) of the family Fabaceae show closest resemblance with the fossil leaflet in shape, size and venation pattern.

About 32 fossil leaves resembling the genus *Millettia* W. & A. have been reported from the Tertiary sediments of India and abroad. They are listed herewith along with their differentiative characters (Table 2):

After a detailed comparative study of all the above species it is observed that many of them differ from present fossil either in shape, size or in nature and course of secondary veins. In view of this the present fossil leaf is being described under a new species *M. mioserícea.*

About 90 extant species of *Millettia* W. & A. are distributed in the tropic of old world (Mabberley, 1997). *Millettia sericea* (Vent.) W. & A with which the

PLATE 14

(All figures are of natural size unless otherwise mentioned) →

1., 3. *Millettia purniyagiriensis* Shashi *et al.*–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40365, 40366, 40367.

2. *Millettia rubiginosa* Wight & Arn.–Modern leaf showing similar shape, size and venation pattern.

4. *Millettia prakashii* Shashi *et al.* Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40364.

5. *Millettia atropurpurea* Benth.–Modern leaves showing similar shape, size and venation pattern.

6. *Millettia prakashii* Shashi *et al.*–Part of fossil leaf magnified to show details of venation pattern. x 2.5. BSIP Museum No. 40364.

7. *Millettia atropurpurea* Benth.–Part of modern leaf magnified to show details of venation pattern. x 2.

8., 9. *Cynometra palaeoiripa* Prasad *et al.*–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40373, 40374.

10. *Cynometra palaeoiripa* Prasad *et al.*–Part of fossil leaf magnified to show details of venation pattern. x 6. BSIP Museum No. 40373.

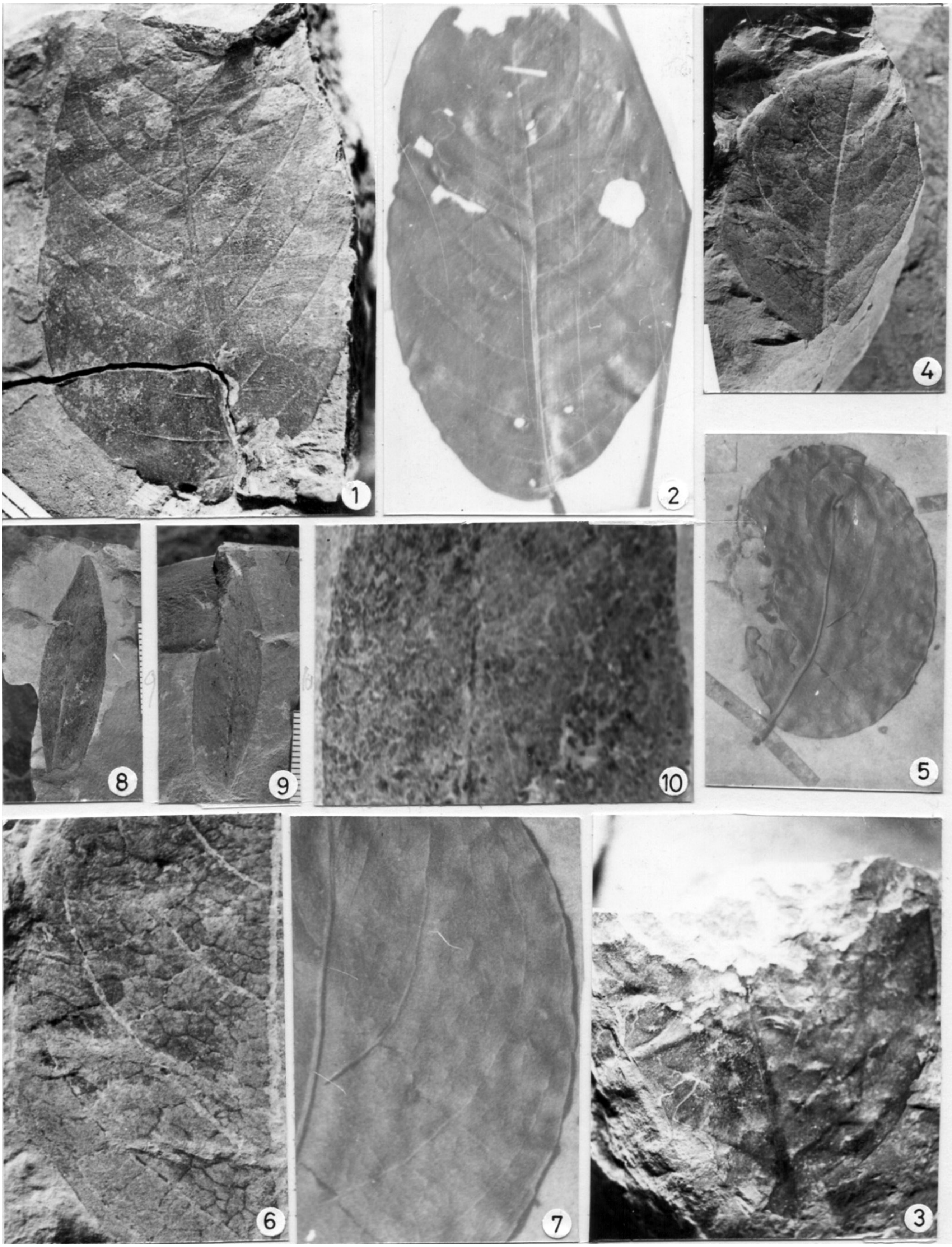

PLATE 14

Table 2—Fossil species of *Millettia* from Tertiary sediments with their differentiative characters.

Species	Fossil Locality/ Period	Differentiative Characters
M. auriculata Bande & Srivastava, 1990	Late Cenozoic of Mahuadanr, Jharkhand	Ovate shape, secondaries upturn and gradually diminishing inside the margin connected to superadjacent secondaries by series of cross–veins
M. asymmetrica Lakhanpal & Guleria, 1982	Miocene of Kachchh, W. India	Small size (3.9 x 2.7 cm) and ovate shape
M. bilaspurensis Prasad, 2006.	Siwalik of Bilaspur, H.P., India	Large size (13.6 x 2.7 cm), narrow oblong shape, 18 pairs of closely placed, secondaries with narrow acute angle of divergence
M. churiensis Prasad & Awasthi, 1996; Agarwal, 2002	Siwalik of Suraikhola, Nepal, Miocene of Neyveli lignite, south India	Small size (4.2 x 1.2 cm), lanceolate shape, acuminate apex, few number of secondaries (about 8 pairs)
M. imlibasensis Prasad *et al.,* 1999	Siwalik of Koilabas, Nepal	Small size (4.3 x 1.6 cm) base obtuse, intersecondaries present
Millettia impressa Menzel, 1920	Tertiary of West Africa	Unaccompanied by description and photograph
M. kathgodamensis Prasad *et al*., 2004	Siwalik of Kathgodam, Uttarakhand, India	Texture coriaceous, few number of secondaries (about 7 pairs), angle of origin usually RR, forming orthogonal meshes.
M. koilabasensis Prasad, 1990b; Prasad & Tripathi, 2000; Prasad & Pandey, 2008	Siwalik of Koilabas, Nepal; Siwalik of Bhutan; Siwalik of Suraikhola, Nepal	Narrow obovate shape, few number of secondaries (8 pairs), AR–RO angle of origin of tertiary veins
M. miocenica Lakhanpal & Guleria, 1982	Miocene of Kachchh, western India	Small size (5.6 x 3.2 cm) and oblong shape
M. miobrandisiana Prasad, 1994e	Siwalik of Koilabas, Nepal	Small size (2.3 x 1.1 cm) and wide ovate shape, brochidodromous venation, angle of divergence of secondaries is acute to right angle
Millettia mioinermis Prasad *et al*., 2014 (in Press)	Siwalik of Tanakpur, Uttarakhand, India	Obovate shape, base attenuate, texture coriceous, angle of origin of tertiaries is AO
M. notoensis Ishida, 1970	Middle Miocene of central Japan	Ovate shape with only 4–5 secondaries
M. oodlabariensis Antal & Prasad, 1996a	Siwalik of Darjeeling of West Bengal, India	Large size (14.3 x 3.5 cm), texture coriaceous, rarely brochidodromous venation
M. ovatus Tripathi *et al.,* 2002	Siwalik of Koilabas, Nepal	Small size (3.5 x 2.5 cm), ovate shape, few number of secondaries (4–5 pairs), AO–RR angle of origin of tertiary veins
M. palaeocubithi Awasthi & Prasad, 1990	Siwalik of Suraikhola, Nepal	Oblanceolate shape, few number of secondaries (4 pairs)
M. palaeopachycarpa Agarwal, 2002	Miocene of Neyveli lignite, south India	Small size (5.0 x 2.1 cm), lanceolate shape, few number of secondaries (about 6 pairs)
M. palaeomanii Dwivedi *et al.*, 2006b	Siwalik of Koilabas, Nepal	Small size (3.2 x 1.5 cm), wide ovate shape, texture coriaceous
M. palaeoracemosa Awasthi & Prasad 1990; Prasad, 1994c	Siwalik of Suraikhola, Nepal, Siwalik of Kathgodam, Uttarakhand	Wide obovate shape, texture coriaceous, fewer secondaries (6 pairs) distantly placed, rarely AO angle of origin of tertiary veins

M. purniyagiriensis Shashi *et al*., 2006	Siwalik of Tanakpur, Uttarakhand, India	Few number of secondaries (7 pairs), angle of secondary veins in one side of lamina greater than the secondaries of other side, angle of origin of tertiaries is AR–RR
M. prakashii Shashi *et al*., 2007	Siwalik of Tanakpur, Uttarakhand, India	Large size, texture coriaceous, few number of secondaries (7–8 pairs), lower pair more acute than above, joined superadjacent at right angle, angle of origin of tertiaries are usually AR
M. singhii Mathur *et al.,* 1996	Kasauli Formation, H.P., India	Small size (4.0 x 1.5 cm), wide elliptic shape, few number of secondaries (about 7 pairs)
M. siwalica Prasad, 1990a, Prasad 1994d, Prasad *et al*., 2014 (in Press)	Siwalik of Koilabas, Nepal, Siwalik of Kathgodam, Uttarakhand, India	Small size (3.1 x 2.0 cm), texture coriaceous, AO angle of origin of tertiary veins
Millettia sp. Mathur *et al.,* 1996	Kasauli Formation, H.P., India	Small size (2.2 x 0.8 cm), few number of secondaries (about 6 pairs)
Millettia sp. Huzioka & Takahasi, 1970	Eocene of SW Honshu, Japan	Lanceolate shape with inequilateral obtuse base

present fossil resembles is growing in the Himalayan foothills commonly in Myanmar, Thailand, Vietnam Indonesia, Java, Kalimantan, Sumatra, Malaysia (Malaya).

Family—FABACEAE

Genus—MILLETTIA Wight & Arn.

Millettia prakashii Shashi *et al.,* 2007

(Pl. 14.4, 6)

Material—One specimen.

Description—Leaf simple, asymmetrical, elliptic; preserved size 5.7 x 3.5 cm; apex slightly broken; base wide acute; margin entire; texture chartaceous; petiole broken; venation pinnate, eucamptodromous; primary vein single, almost straight, stout; secondary veins 5–6 pairs visible, 0.6 to 1.5 cm apart, alternate to sub–opposite, unbranched, angle of divergence (50°–65°), moderate to acute, uniformly curved up and joining to their superadjacent secondaries at obtuse angle; intersecondaries veins present, simple; tertiary veins fine, angle of origin, RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close to nearly distant.

Specimen—B.S.I.P. Museum No. 40364.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—The most important features of the present fossil leaflet are elliptic shape, eucamptodromous venation, moderate to acute and uniformly curved up secondary veins joining to their superadjacent secondaries at obtuse angle, presence of simple intersecondaries veins, RR, percurrent, straight to sinuous, branched tertiary veins. On critical study of the herbarium sheets of different extant taxa it has been concluded that the leaflets of *Millettia atropurpurea* Dunn. (C.N.H. Herbarium Sheet No. 112827; Pl. 14.5, 7) of the family Fabaceae show closest resemblance with the present fossil leaflet in shape, size and venation pattern.

Fossil records and comparison—So far, about 32 fossil leaves resembling *Millettia* W. & A. have been recorded from the Tertiary sediments of India and abroad (listed earlier in this text). After a detailed comparative study of all the above species it is observed that many of them differ in nature and course of secondary veins. Moreover, most of them are either narrow or smaller in size than the present fossil but *Millettia prakashii* Shashi *et al.* 2007 described from the Siwalik sediments of Tanakpur, Uttarakhand is almost identical to the present fossil leaf and hence it has been described under the same species.

Millettia Wight & Arnott comprises about 90 species (Mabberley, 1997, p. 457) of trees, shrubs and climbers which are distributed in the tropical regions of Africa, Asia and Australia (Willis, 1973). About 30 species distributed in Indian region. *Millettia atropurpurea* Benth. with which the fossil resembles is a large tree which occurs in the evergreen forests of south eastern part of the Pegu Hills between the Thaungyin and Hlaingbwe rivers and elsewhere in Martaban and Tennasserim and Myanmar (Brandis, 1971; Gamble, 1972).

Family—FABACEAE

Genus—MILLETTIA Wight & Arn.

Millettia purniyagiriensis Shashi *et al*., 2006

(Pl. 14.1, 3)

Material—Three specimens.

Description—Leaf asymmetrical, wide elliptic; preserved size 8.7 x 5.9 cm, 10.0 x 6.5 cm and 6.5 x 6.5 cm; apex broken; base obtuse in equal; petiole present, small, thick; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent almost straight, stout; secondary veins 6–7 pairs visible, 0.9 to 1.7 cm apart, alternate to opposite, unbranched, uniformly curved up and run for a short distance and joined to superadjacent secondary usually at obtuse angle, angle of divergence usually 45º–60°, vary irregularly, acute to right angle, basal pairs of secondary arise nearly right angle; tertiary veins moderate sometime branched, angle of origin AO to rarely RR, percurrent, straight to sinuous, oblique in relation to midvein, alternate to opposite and close; quaternary veins fine with angle of origin usually AO sometimes branched forming rectangular to rarely polygonal meshes.

Specimens—B.S.I.P. Museum No. 40365–40367.

Type locality—Ramthi River, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—The diagnostic features of the present fossils are asymmetrical, wide elliptic shape; obtuse base; petiole present entire margin; eucamptodromous venation; acute to right angle, unbranched, uniformly curved up secondary veins which run for a short distance and joined to superadjacent secondary usually at obtuse angle, basal pairs of secondary arise nearly at right angle, AO to rarely RR, percurrent, tertiary veins, usually AO sometimes branched quaternary veins forming rectangular to rarely polygonal meshes. A critical study of the herbarium sheets of different extant taxa it has been concluded that the leaflet of *Milletia rubiginosa* Wight & Arn. (C.N.H. Herbarium Sheet No. 70120; Pl. 15.2) of the family Fabaceae show closest resemblance with the fossil leaflet in size, shape and venation pattern.

Fossil records and comparison—So far, about 32 fossil leaves resembling *Millettia* W. & A. have been recorded from the Tertiary sediments of India and abroad (listed earlier in this text). After a detailed comparative study of all the above species, it is observed that many of them differ in nature and course of secondary veins, but *Millettia purniyagiriensis* Shashi *et al.* shows closest similarity with the present fossil, so it is assigned to the same species *Millettia purniyagiriensis* Shashi *et al.,* 2006.

Millettia W. & A. comprises about 90 species (Mabberley, 1997, p. 457) of trees, shrubs and climbers which are distributed in the tropical regions of Africa, Asia and Australia (Willis, 1973). About 30 species distributed in Indian region. *Milletia rubiginosa* Wight & Arn. is a large woody climber distributed in Western Ghats, Kerala (District–Palakkad, Idukki, Thiruvananthapuram, Kollam, Thissur), Tamil Nadu (District–Tirunelveli).

Family—FABACEAE

Genus—MILLETTIA Wight & Arn.

Millettia sevokensis n. sp.

(Pl. 16.1, 2, 4)

Material—Four specimens.

Description—Leaf simple, asymmetrical, narrow elliptic; preserved size 12.3 x 5.4 cm, 6.0 x 5.4 cm, 7.0 x 3.5 cm and 5.5 x 3.5 cm; apex acute; base acute; margin entire; texture thick chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 12 to 13 pairs visible, 0.6 to 1.7 cm apart, alternate, unbranched, angle of divergence (60°–70°), moderate to wide acute, lower secondary veins are more acute than upper, uniformly curved up; intersecondary veins are present, simple, tertiary veins fine, angle of origin, RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close to distant.

Holotype—B.S.I.P. Museum No. 40368.

Paratype—B.S.I.P. Museum No. 40369–40371.

PLATE 15

(All figures are of natural size unless otherwise mentioned)

⟶

1. *Spatholobus siwalicus* n. sp. Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40372 (Holotype).
2. *Spatholobus parviflorus* (DC.) Kuntze–Modern leaf showing similar shape, size and venation pattern.
3. *Millettia miosericea* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40363 (Holotype).
4. *Millettia sericea* (Vent.) W. & A.–Modern leaves showing similar shape, size and venation pattern.
5. *Millettia miosericea* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2.5. BSIP Museum No. 40363 (Holotype).
6. *Millettia sericea* (Vent.) W. & A.–Part of modern leaf magnified to show similar details of venation pattern. x 2.5.

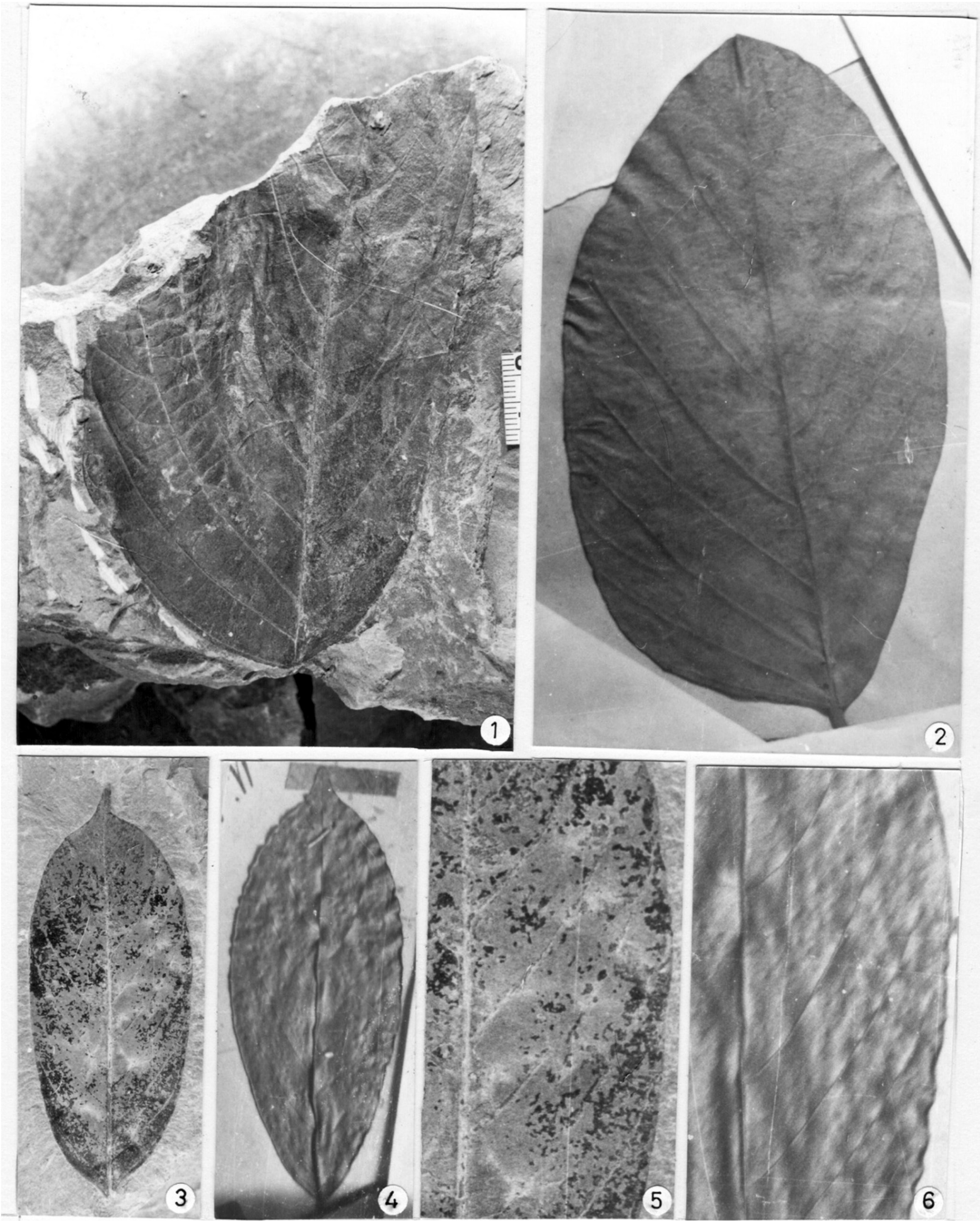

PLATE 15

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of fossil locality, Sevok on Silliguri–Guwahati Road, Darjeeling District.

Affinity—The characteristic features of the present fossil leaves are asymmetrical, narrow elliptic shape, acute apex, acute base, eucamptodromous venation, unbranched, moderate to wide acute, lower secondary veins are more acute than upper one, uniformly curved up, presence of intersecondaries, RR, percurrent, straight to sinuous, branched tertiary veins. A critical study of the herbarium sheets of different extant taxa it has been concluded that the leaflet of *Milletia brachycarpa* Merr. (C.N.H. Herbarium Sheet No. 112668; Pl. 16.3) of the family Fabaceae show closest resemblance with the fossil leaves in shape, size and venation pattern.

Fossil records and comparison—So far, about 33 fossil leaves resembling *Millettia* Wight & Arnott have been recorded from the Tertiary sediments of India and abroad (listed in Table 3). After a detailed comparative study of all the above species, it has been observed that many of them differ in nature and course of secondary veins. Moreover, most of them are either narrow or smaller in size than the present fossil (Table 3).

Thus in being different, the present fossil leaves are described under the new species *Millettia sevokensis* n. sp.

Millettia Wight & Arnott comprises about 90 extant species (Mabberley, 1997, p. 457) of trees, shrubs and climbers which are distributed in the tropical regions of Africa, Asia and Australia (Willis, 1973). About 30 species distributed in Indian region. *Milletia brachycarpa* Merr. with which the fossil resembles closely is a tree which occurs in the evergreen forests of Philippines (IUCN red data list species).

Family—FABACEAE

Genus—SPATHOLOBUS Hassk.

Spatholobus siwalicus n. sp.

(Pl. 15.1)

Material—One specimen.

Description—Leaf simple, asymmetrical, wide elliptic; preserved size 12.7 x 7.2 cm; apex broken; base obtuse, inequal; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 10–11 pairs visible, 0.9 to 1.9 cm apart, alternate to sub–opposite, unbranched, angle of divergence (40°–60°), narrow to moderately acute, uniformly curved up running for a long distance and joining to their superadjacent secondaries at right angle; intersecondary veins not visible; tertiary veins thick, angle of origin, RR, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close to distant; quaternary veins with angle of origin usually RR, percurrent sometime branched forming usually orthogonal to polygonal meshes.

Holotype—B.S.I.P. Museum No. 40372.

Table 3—List of fossil leaves of *Millettia* and their distinguishing characters.

Species	Fossil Locality/ Period	Differentiative Characters
M. auriculata Bande & Srivastava, 1990	Late Cenozoic of Mahuadanr, Jharkhand, India	Small size (5.0 x 6.3 cm), ovate, secondaries upturn and gradually diminishing inside the margin connected to superadjacent secondaries by series of cross–veins shape
M. asymmetrica Lakhanpal & Guleria,1982	Miocene of Kachchh, W. India	Small size (3.9 x 2.7 cm) and ovate shape
M. bilaspurensis Prasad, 2006	Siwalik of Bilaspur, H.P., India	Narrow oblong shape, higher number of secondaries (18 pairs) closely placed with narrow acute angle of divergence.
M. churiensis Prasad & Awasthi 1996; Agarwal, 2002	Siwalik of Suraikhola, Nepal, Miocene of Neyveli lignite, south India	Small size (4.0 x 1.2 cm), lanceolate shape, obtuse base, fewer secondaries (8–9 pairs)
M. imlibasensis Prasad *et al.,* 1999	Siwalik of Koilabas, Nepal	Small size (4.3 x 1.6 cm) base obtuse
Millettia impressa Menzel, 1920	Tertiary of the West Africa	Unaccompanied by description and photograph

M. kathgodamensis Prasad *et al.*, 2004	Siwalik of Kathgodam, Uttarakhand, India	Small size (9.3 x 2.5 cm), texture coriaceous, fewer secondaries (about 7 pairs)
M. koilabasensis Prasad 1990b; Prasad & Tripathi 2000; Prasad & Pandey, 2008	Siwalik of Koilabas, Nepal; Siwalik of Bhutan; Siwalik of Suraikhola, Nepal	Small size (8.0 x 3.5 cm), narrow obovate shape, fewer secondaries (8 pairs), AR–RO angle of origin of tertiary veins
M. miocenica Lakhanpal & Guleria, 1982	Miocene of Kachchh, W. India	Small size (5.6 x 3.2 cm) and seemingly oblong shape
M. miobrandisiana Prasad, 1994e	Siwalik of Koilabas, Nepal	Small size (2.3 x 1.1 cm) and wide ovate shape, brochidodromous venation, fewer secondaries (7 pairs), distantly placed
Millettia mioinermis Prasad *et al.,* 2014 (in Press)	Siwalik of Tanakpur, Uttarakhand, India	Small size, obovate shape, base attenuate, texture coriceous, fewer secondaries, angle of origin of tertiaries is AO
M. notoensis Ishida, 1970	Middle Miocene of central Japan	Ovate shape with 4–5 secondaries
M. oodlabariensis Antal & Prasad, 1996a	Siwalik of Darjeeling of West Bengal, India	Texture coriaceous, sometimes brochidodromous venation
M. ovatus Tripathi *et al*., 2002	Siwalik of Koilabas, Nepal	Small size (3.5 x 2.5 cm), ovate shape, fewer secondaries (4–5 pairs) AO–RR angle of origin of tertiary veins
M. palaeocubithi Awasthi & Prasad, 1990	Siwalik of Suraikhola, Nepal	Small size (6.0 x 2.5 cm), oblanceolate shape, fewer secondaries (4 pairs), angle of divergence of secondaries is acute
M. palaeomanii Dwivedi *et al.*, 2006a	Siwalik of Koilabas, Nepal	Small size (3.2 x 1.5 cm), wide ovate shape, texture coriaceous, fewer secondaries (about 8 pairs)
M. palaeopachycarpa Agarwal, 2002	Miocene of Neyveli lignite, south India	Fewer secondaries (about 6 pairs)
M. palaeoracemosa Awasthi & Prasad 1990; Prasad 1994c	Siwalik of Suraikhola, Nepal, Siwalik of Kathgodam, Uttarakhand, India	Small size (4.7 x 3.0 cm) and wide obovate shape, texture coriaceous, fewer secondaries (6 pairs) distantly placed
M. prakashii Shashi *et al.*, 2007	Siwalik of Tanakpur, Uttarakhand, India	Texture coriaceous, fewer secondaries (7–8 pairs), lower pair more acute than above, angle of origin of tertiaries are usually AR
M. purniyagiriensis Shashi *et al.*, 2006	Siwalik of Tanakpur, Uttarakhand, India	Small size, fewer secondaries (7 pairs), angle of secondary veins in one side of lamina greater than the secondaries of other side, angle of origin of tertiaries is AR–RR
M. singhii Mathur *et al.,* 1996	Kasauli Formation, H.P., India	Small size (4.0 x 1.5 cm), wide elliptic shape, fewer secondaries (about 7 pairs)
M. siwalica Prasad, 1990a, 1994d; Prasad *et al*., 2014 (in Press)	Siwalik of Koilabas, Nepal, Siwalik of Kathgodam, Uttarakhand, India	Small size (3.1 x 2.0 cm), texture coriceous, fewer secondaries (9 pairs), angle of origin of tertiaries is AO
Millettia sp. (Mathur *et al.,* 1996)	Kasauli Formation, H.P., India	Small size (2.2 x 0.8 cm), fewer secondaries (about 6 pairs)
Millettia sp. (Huzioka & Takahasi, 1970)	Eocene of SW Honshu, Japan	Lanceolate shape with inequilateral obtuse base

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

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

Affinity—The distinguishing morphological features of the fossil leaves such as asymmetrical, wide elliptic shape, large size, obtuse inequal base; entire margin, chartaceous texture, eucamptodromous venation, alternate to sub–opposite and unbranched secondaries with angle of divergence (40°–60°), running for along distance before joining to their superadjacent secondaries at right angle, RR, percurrent tertiary veins collectively suggest that these fossil leaves belong to the genus *Spatholobus* Hassk. of the family Fabaceae. After detail comparison with the modern leaves of different species of this genus it has been found that the present fossil leaves show closest affinity with the extant leaves of *Spatholobus parviflorus* (DC.) Kuntze (=*Butea parviflora* DC.) in shape, size and venation pattern (C.N.H. Herbarium Sheet No. 281; Pl. 15.2).

Fossil records and comparison—There is no record of fossil leaf resembling the genus *Spatholobus parviflorus* from the Tertiary sediments of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and hence it is being described as *Spatholobus siwalica* n. sp.

Spatholobus Hassk. comprises about 29 extant species distributed in the South–East Asia to Central Malayan region (Mabberley, 1997). The modern comparable species *Spatholobus parviflorus* (DC.) Kuntze has a wide geographic range from India, Bangladesh, Nepal, Bhutan and China (Yunnan), and South–East Asia (IUCN Red Data List).

Family—FABACEAE

Genus—CYNOMETRA Linn.

Cynometra palaeoiripa Prasad *et al*,. 1999

(Pl. 14.8, 9, 10)

Material—Two specimens.

Description—Leaf simple, asymmetrical, small, narrow elliptic; preserved size 4.0 x 1.3 cm and 4.1 x 1.3 cm; apex acute; base wide acute; margin entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins 7–8 pairs visible, less than 0.4 to 1.0 cm apart, usually alternate, seemingly unbranched, angle of divergence (about 45º–55°), narrow acute, uniformly curved up and joined to their supera adjacent secondaries; intersecondary veins present, simple; tertiary veins fine, poorly preserved with angle of origin usually RR, percurrent, almost straight, sometime branched, oblique in relation to midvein, predominantly alternate and close.

Specimens—B.S.I.P. Museum No. 40373–40374.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—The diagnostic features of the present fossil leaves are asymmetrical, small lamina, narrow elliptic shape, acute apex, wide acute base, eucamptodromous venation, usually alternate, narrow acute, uniformly curved up, presence of intersecondaries, RR, percurrent, almost straight, sometime branched tertiary veins. Such features are common in the modern leaves of *Cynometra* Linn. of the family Fabaceae. A critical examination of the herbarium sheets of all the available species of this genus suggests that the extant leaves of *Cynometra iripa* Kotel. show closest affinity with the present fossil leaf in all the morphological features (C.N.H. Herbarium Sheet No. 13874).

Fossil records and comparison—Fossil leaves resembling the genus *Cynometra* Linn. have been described under three specific names from Siwalik sediments of India and Nepal. These are *Cynometra siwalika* from Middle Siwalik sediments of Suraikhola, Nepal (Awasthi & Prasad, 1990), *Cynometra tertiara* from Lower–Middle Siwalik of Oodlabari, Darjeeling District, West Bengal, India (Antal & Awasthi, 1993) and *C. palaeoiripa* from Siwalik sediments of Koilabas area, western Nepal (Prasad *et al.*, 1999), Lower Siwalik sediments of Kathgodam, Uttarakhand (Prasad *et al.*, 2004) and Siwalik sediments of Tanakpur area, Uttarakhand, India (Prasad *et al.*, 2014). A comparative study shows that *C. palaeoiripa* Prasad *et al*. 1999 has the nearest affinity with the present fossil in being possessing asymmetrical, elliptic shape with similar course of secondary and tertiary veins. In view of this, the present fossils have been assigned to the same species, *C. palaeoiripa* Prasad *et al.* 1999.

Cynometra Linn. comprises about 70 tropical species, of which five are found in India. The modern comparable species *C. iripa* Kotel. is presently distributed in Indo–Malayan region.

PLATE 16

(All figures are of natural size unless otherwise mentioned)

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1., 2. *Millettia sevokensis* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40368 (Holotype), 40369 (Paratype).

3. *Millettia brachycarpa* Merr.–Modern leaf showing similar shape, size and venation pattern.

4. *Millettia sevokensis* n. sp.–Part of modern leaf magnified to show details of venation pattern. x 1.5. BSIP Museum No. 40369 (Paratype).

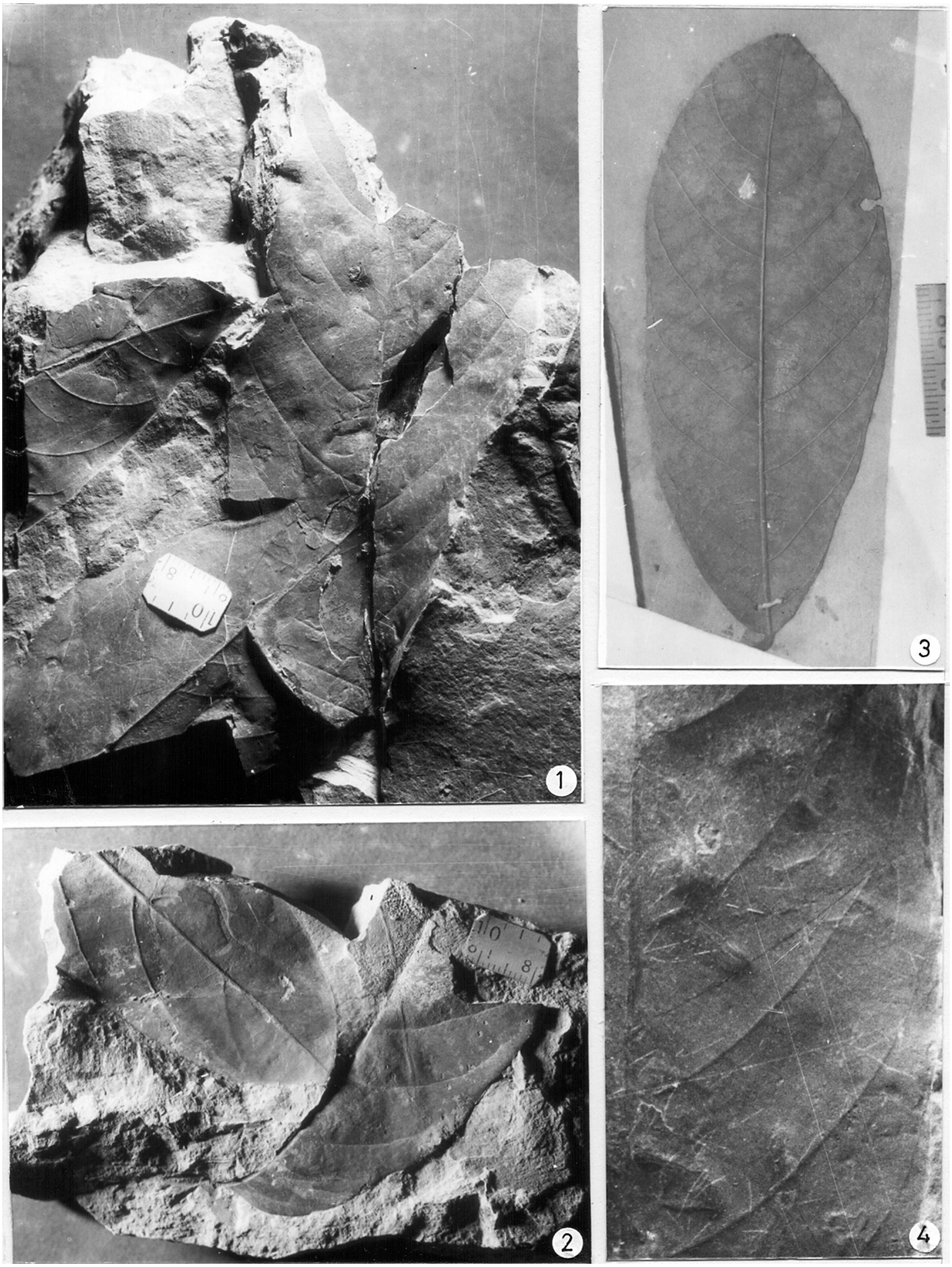

PLATE 16

Order—GENTIANALES

Family—RUBIACEAE

Genus—RANDIA Linn.

Randia lishensis n. sp.

(Pl. 21.1, 3, 5)

Material—One specimen.

Description—Leaf simple, symmetrical, narrow elliptic; preserved size 13.8 x 4.9 cm; apex broken; base acute; margin entire; texture chartaceous; venation pinnate, craspedodromous, sometimes eucamptodromous; primary vein single, prominent, straight, stout; secondary veins 9–10 pairs visible 0.9 to 2.1 cm apart, alternate to opposite, unbranched, angle of divergence 40º–60°, narrow to moderate acute, curved up and run straightly, sometime joined with supraadjacent; intersecondaries present, simple; tertiary veins fine, angle of origin RR, percurrent, straight to sinuous sometime branched, oblique in relation to midvein, predominantly alternate and nearly distant.

Holotype—B.S.I.P. Museum No. 40375.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the name of Lish River Section from where the fossils were collected.

Affinity—The diagnostic features of the present fossil leaf such as symmetrical, narrow elliptic shape, acute base; entire margin, craspedodromous to eucamptodromous venation, narrow to moderate acute angle of secondary veins, curved up and run straightly, sometime joined with their supradjacent, presence of intersecondaries, RR, percurrent tertiary veins collectively suggest its affinity with the modern leaves of *Randia densiflora* Wall. (Benth.) [= *Aidia densiflora* (Wall.) Masam] of the family Rubiaceae (C.N.H. Herbarium Sheet No. 205770; Pl. 21.2, 4) in shape, size and venation pattern.

Fossil records and comparison—So far, eight fossil species of the genus *Randia* Linn. have been reported from India and abroad. Of these four species are described from the Siwalik sediments of India and Nepal. These are *Randia miowallichii* Prasad (1990a) from Siwalik sediments of Koilabas, western Nepal and from Oodlabari, Darjeeling District, West Bengal, India (Antal & Awasthi, 1993), *R. siwalica* and *R. palaeofasciculata* from Siwalik sediments of Suraikhola, western Nepal (Prasad & Awasthi, 1996) and *R. miouncaria* Prasad and Dwivedi (2007) from the Siwalik sediments of Seria Naka, Koilabas area, western Nepal and *R. tanakpurensis* Prasad *et al.* (2014) from the Siwalik sediments of Tanakpur area Uttarakhand.

On comparison, it has been observed that none of these known species show similarity with the present fossil leaves. They differ mostly either in shape, size or in the nature and course of secondary and tertiary veins. *R. miowallichii* Prasad differs in having small size and oblanceolate shape as compared to large size and narrow elliptic shape in present fossils. *R. palaeofasciculata* Prasad & Awasthi can be differentiated in being smaller size (3.4 x 1.4 cm) as compared to large size (13.8 x 4.9 cm) of the present fossils. Similarily, the fossil leaf, *R. siwalica* Prasad & Awasthi differs in being its larger size (18.5 x 5.8 cm) with eucamptodromous venation. *R. miouncaria* Prasad & Dwivedi differs in having oblanceolate shape and eucamptodromous venation as compared to narrow elliptic shape and craspedodromous venation in present fossil. *R. tanakpurensis* Prasad *et al*. also differs from present fossil in being oblanceolate shape and smaller size (7.6 x 3.0 cm). In being different from already known species the present fossil leaves have been assigned to a new specific name, *Randia lishensis* n. sp.

Randia Linn. consists of 300 species (including *Basanantha* Hook.f.) distributed throughout the tropical to subtropical regions of the world. *Randia densiflora* Wall. Benth. [= *Aidia densiflora* (Wall.) Masam] is distributed in India, Andaman Islands, Myanmar, Thailand, Peninsular Malaysia, Sumatra and Borneo (Sarwak, West, South–East Kalimanthan).

Family—RUBIACEAE

Genus—GARDENIA J. Ellis

Gardenia precoronaria n. sp.

(Pl. 20.3)

Material—One specimen.

PLATE 17

(All figures are of natural size unless otherwise mentioned)

1., 2. *Cerbera miocenica* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40382 (Holotype), 40383 (Paratype).

3. *Cerbera odallum* Gaertn.–Modern leaf showing similar shape, size and venation pattern.

4. *Cerbera miocenica* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2.5. BSIP Museum No. 40382 (Holotype).

5. *Cerbera odallum* Gaertn.–Part of modern leaf magnified to show similar details of venation pattern. x 2.

6. *Cerbera miocenica* n. sp. Part of fossil leaf magnified to show the variation in angle of divergence of secondary veins. x 2.5. BSIP Museum No. 40383 (paratype).

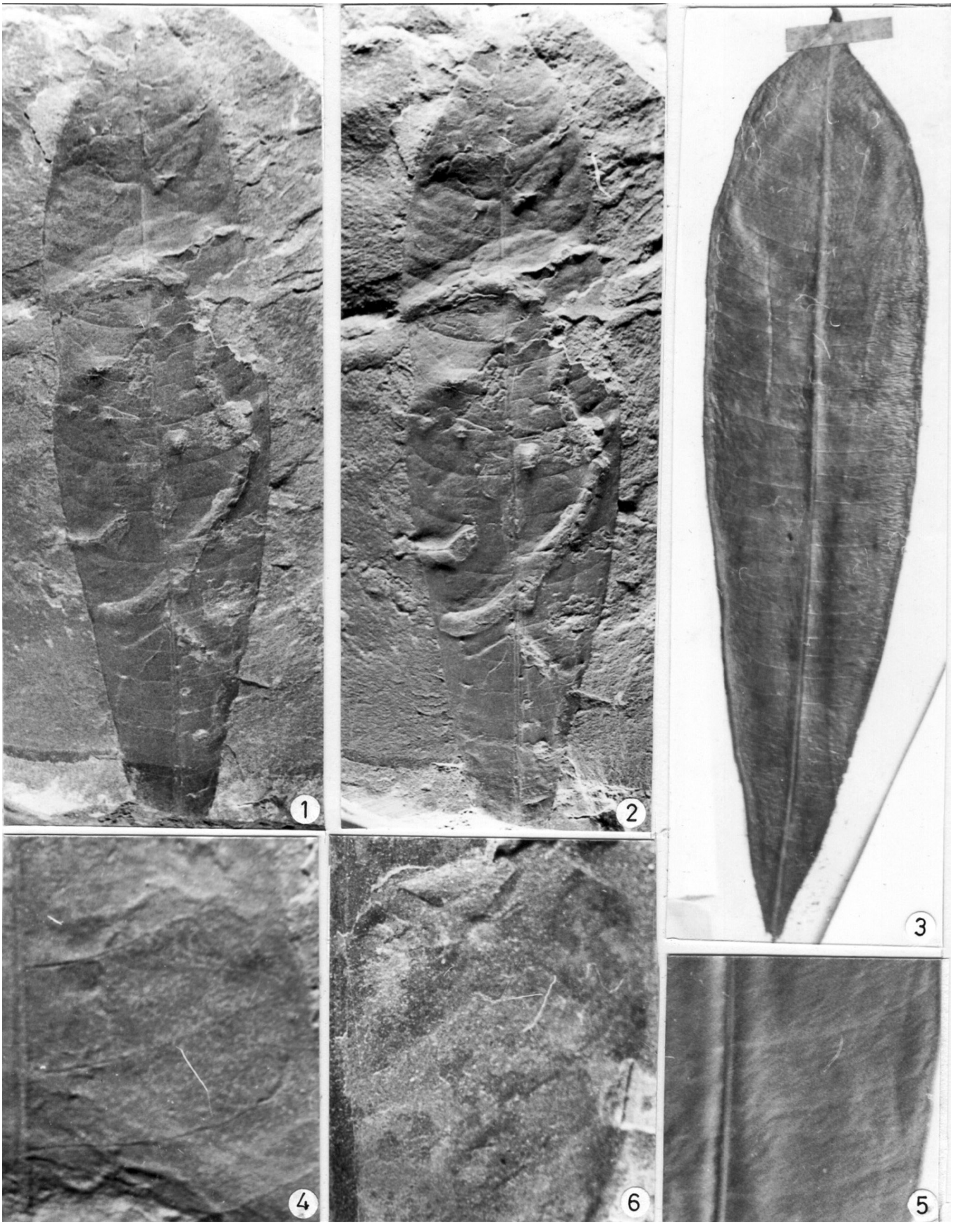

PLATE 17

Description—Leaf simple, symmetrical and wide elliptic; size 9.6 x 6.7 cm; apex broken; base indistinct; margin entire; texture chartaceous; venation pinnate, simple craspedodromous to eucamptodromous; primary vein single, prominent, stout, almost straight; secondary veins about 10–11 pairs visible, angle of divergence about 80º, moderate to right angle; apical secondary of one side of midrib are with more angle and curved uniformly upwards while other secondary veins run straight upwards and curved slightly near the margin, unbranched; tertiary veins fine, angle of origin RR, percurrent, almost straight, rarely branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40377.

Type locality—Lish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix 'pre' to the modern comparable species *G. coronaria.*

Affinity—The distinguished morphological features of the fossil leaves such as symmetrical, wide elliptic shape, craspedodromous to eucamptodromous venation, moderate to right angle of secondary veins and apical secondary of one side of midrib are with more angle, RR, percurrent, almost straight, rarely branched tertiary veins suggest that the fossil leaves belong to the genus *Gardenia* J. Ellis of the family Rubiaceae. After critical observation of the modern leaves of different species of this genus it has been found that the present fossil leaves show closest affinity with the extant leaves of *Gardenia coronaria* Buch.–Ham. in shape, size and venation pattern (C.N.H. Herbarium Sheet No. 314; Pl. 20.4).

Fossil records and comparison—So far, three fossil leaf taxa showing affinities with *Gardenia* J. Ellis have been reported from India. These are G. *palaeoturgida* Lakhanpal and Awasthi from the Upper Siwaliks (Lakhanpal & Awasthi, 1984), *G. nainitalensis* Prasad, 1994c from the Lower Siwaliks and *Gardenia vagadkholia* from the Vagadkhol Formation (Singh *et al.,* 2011). Of these, *G. palaeoturgida* differs from the present fossil leaf in its smaller size (70 × 30 mm), brochidodromous venation, and obovate shape, *G. nainitalensis* differs in being smaller (44 × 26 mm) and brochidodromous venation whereas *Gardenia vagadkholia* differs in greater number of secondaries (11 pairs) and narrower angle of divergence (50º–60º). Thus in being different from all the known fossil leaves the present fossil has been described as *Gardenia precoronaria* n. sp.

Gardenia J. Ellis. comprises about 60 species distributed in tropical & warm old world (Mabberley, 1997). *Gardenia coronaria* Buch.–Ham. is a small sized but tall deciduous tree distributed in the forests of Chittagong, Chittagong Hill Tracts, Cox's Bazar, Sylhet and Moulvi Bazar, Bangladesh.

Order—ERICALES

Family—EBENACEAE

Genus—DIOSPYROS Linn.

Diospyros palaeoargentea n. sp.

(Pl. 18.1, 2, 4)

Material—Two specimens.

Description—Leaf simple, symmetrical, large, narrow oblanceolate; preserved size 16.2 x 4.6 cm and 15.1 x 4.1 cm; apex and base slightly broken; margin entire; texture coriaceous; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins more than 22 pairs visible, 0.5 to 1.2 cm apart, usually alternate to opposite, unbranched, angle of divergence (about 45°–60º), narrow acute to moderate acute, uniformly curved up and joined to their superadjacent secondaries; intersecondary veins present, simple, frequent, 3–4 intersecondaries veins of almost same thickness between two secondaries; tertiary veins fine, poorly preserved with angle of origin usually RR, percurrent, almost straight to sometimes curved, branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40378.

Paratype—B.S.I.P. Museum No. 40379.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—By adding prefix 'palaeo' to the modern comparable species *D. argentea*.

Affinity—Symmetrical, large, narrow oblanceolate shape, eucamptodromous venation, usually alternate to opposite, unbranched, narrow acute to moderately acute secondary veins, presence of intersecondary veins, frequent, 3–4 intersecondaries veins of almost same thickness between two secondaries, fine with angle of origin usually RR, percurrent, almost straight to sometime curved, branched tertiary veins

PLATE 18

(All figures are of natural size unless otherwise mentioned) ⟶

1., 2. *Diospyros palaeoargentea* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40378 (Holotype), 40379 (Paratype).

3. *Diospyros argentea* Griff.–Modern leaves showing shape, size and venation pattern.

4. *Diospyros palaeoargentea* n. sp. Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40378 (Holotype).

5. *Diospyros argentea* Griff.–Part of modern leaf magnified to show similar details of venation pattern. x 2.

6. *Toddalia aculeata*–Modern leaf showing similar shape, size and venation pattern as fossil leaf (Pl. 9.6).

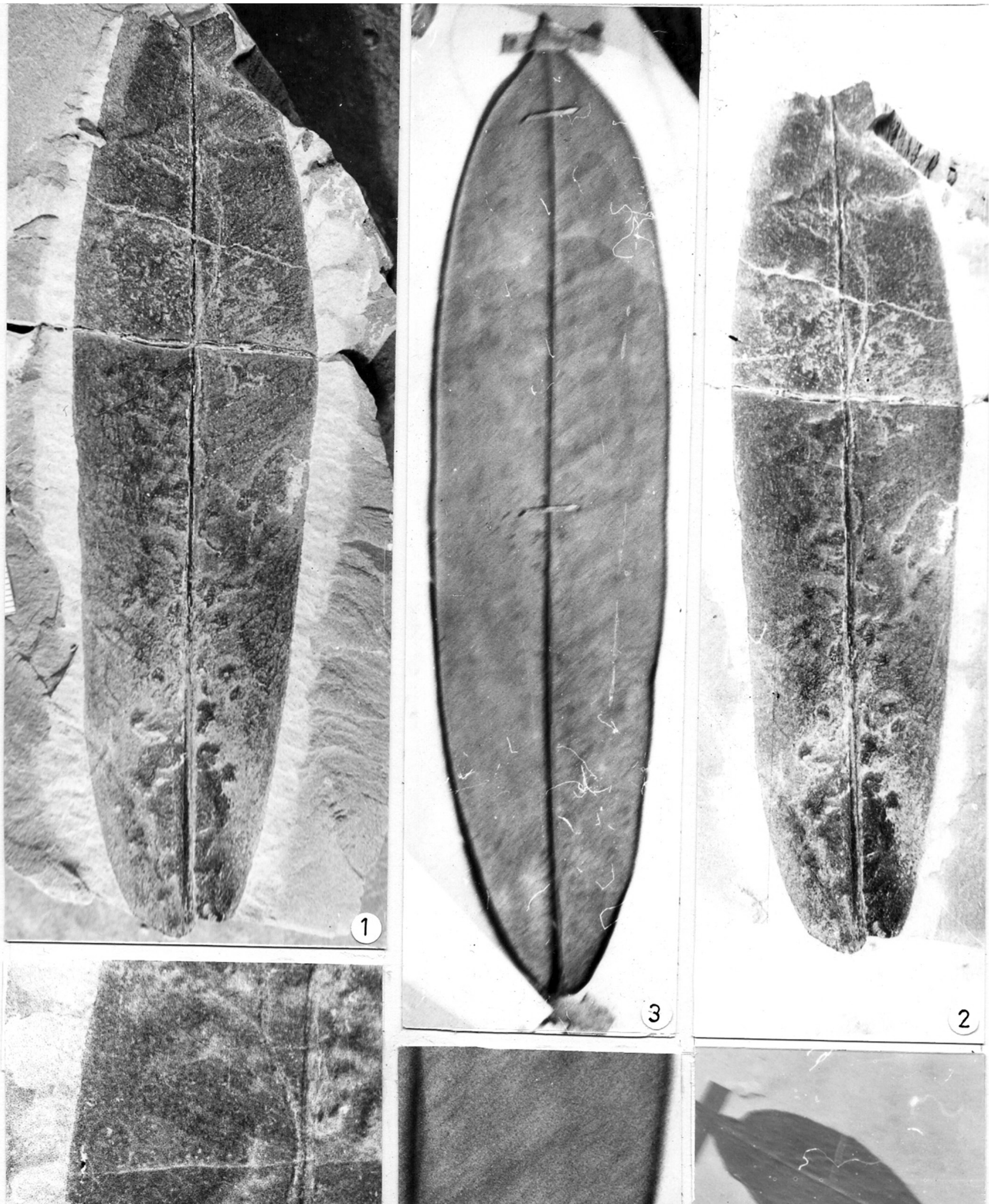

PLATE 18

Table 4—Differentiative characters of the known fossil species of *Diospyros* Linn. from Indian subcontinent.

Fossil species	Differentiative characters
Diospyros embryopterisites	Small in size (8.0 x 3.5 cm), no. of secondaries are less (about 8 pairs) distantly placed, only few intersecondary veins present.
D. miocenicus	Small in size (7.0 x 2.2 cm), narrow oblong shape, no. of secondaries are less (13 pairs) having greater angle of divergence, only few intersecondary veins present.
D. miokaki	Small in size (8.0 x 5.1 cm), elliptic shape, no. of secondaries are less (6–7 pairs) distantly placed, only few intersecondary veins present.
D. kathgodamensis	Small in size (6.0 x 2.0 cm), narrow elliptic shape, no. of secondaries are less (10 pairs) distantly placed.
D. palaeoebenium	Small in size (7.7 x 4.0 cm), narrow ovate shape, no. of secondaries are less (about 8 pairs) distantly placed, greater angle of divergence, only few intersecondary veins present.
D. tulsipurensis	Small in size (8.4 x 3.8 cm), elliptic shape, no. of secondaries are less (about 9 pairs), angle of divergence is acute to right angle, only few intersecondary veins present.
D. koilabasensis	Small in size (3.5 x 5.0 cm), no. of secondaries are less (about 6 pairs), intersecondaries absent.
D. pretoposia	Elliptic shape, no. of secondaries are less (about 12 pairs), distantly placed, one side of secondaries run along the margin for a long distance.
D. darwajaensis	No. of secondaries are less (7–8 pairs), distantly placed, intersecondary veins rarely seen.
D. nainitalensis	Small in size (4.3 x 2.2 cm), narrow oblong shape, fewer number of secondaries (5 pairs), distantly placed, few intersecondaries present.
D. palaeoeriantha	Small in size (4.9 x 1.5 cm), narrow elliptic shape, fewer number of secondaries (5 pairs) distantly placed, few intersecondaries present.
D. purniyagiriensis	Narrow elliptic shape, fewer secondaries, lower pairs more acute than above distantly placed, joined superadjacent secondary at acute angle.

collectively suggest its affinity with the modern leaves of *Diospyros argentea* Griff. of the family Ebenaceae (C.N.H. Herbarium Sheet No. 282786; Pl. 18.3, 5) in shape, size and venation pattern.

Fossil records and comparison—Fossil leaves resembling the genus *Diospyros* have been described under two generic names, i.e. *Diospyros* Linn. and *Diospyrophyllum* Velenovsky. The later consist 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 world. Eleven species have been reported from the Tertiary sediments of Indian sub–continents. These are *Diospyros embryopterisites* Varma, 1968 from the Middle Siwalik of Hardwar, Uttarakhand, *D. miocenicus* Prasad and Awasthi, 1996, *D. miokaki* Awasthi and 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 sediments of Kathgodam. The later species has also been reported from the Lower–Middle Siwalik of Darjeeling District, West Bengal. *D. tulsipurensis* Prasad *et al.,* 1997 from the Lower Siwaliks of Seria Naka at Indo–Nepal border

PLATE 19

(All figures are of natural size unless otherwise mentioned)

→

1., 2. *Chionanthus siwalicus* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40380 (Holotype), 40381 (Paratype).

3. *Chionanthus intermedia* (Wight) F. Muell.–Modern leaf showing similar shape, size and venation pattern.

4., 7. *Ficus precunea* Lakhanpal–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40384, 40385.

5. *Chionanthus siwalicus* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40381 (Paratype).

6. *Ficus precunea* Lakhanpal–Part of fossil leaf (Fig. 4) magnified to show details of venation pattern. x 2. BSIP Museum No. 40384.

8. *Ficus precunea* Lakhanpal–Part of fossil leaf (Fig. 7) magnified to show details of venation pattern. x 2. BSIP Museum No. 40385 (Holotype).

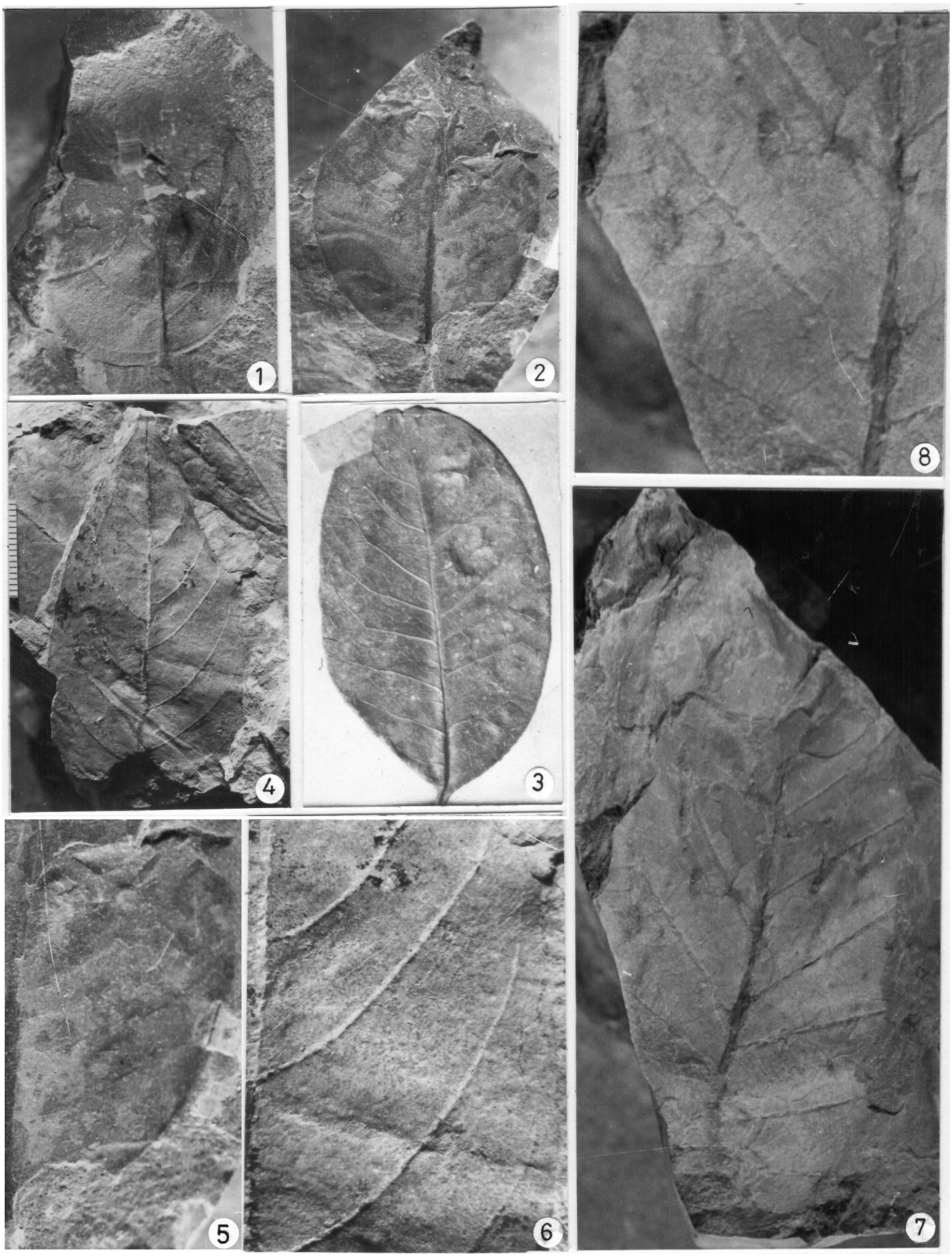

PLATE 19

in Gonda District of Uttar Pradesh, *D. koilabasensis* Prasad, 1990a and *D. pretoposia* Prasad, 1990a, *D. darwajaensis* Prasad *et al*., 1999 from the Siwalik sediments of Koilabas W. Nepal and *D. miocenicus* Prasad and Awasthi, and *D. pretoposia* Prasad from Miocene of Neyveli lignite deposit of Tamil Nadu (Agarwal, 2002), *D. nainitalensis* and *D. palaeoeriantha* Prasad *et al*., 2004 from Siwalik sediments of Gola River near Jamrani, Kathgodam, Uttarakhand. *D. purniyagiriensis* and *D. palaeoebenum* Prasad are described from Siwalik sediments of Tanakpur area, Uttarakhand (Shashi *et al*., 2007).

After a detailed comparative study of all the above species it is observed that many of them differ in nature and course of secondary veins. Moreover, most of them are either narrow or smaller in size than the present fossil (Table 4) so it assigned as new species *Diospyros palaeoargentea*.

Diospyros consists of 450 extant species (Mabberley, 1997) distributed in America, Madagascar, Australia and Africa. *Diospyros argentea* Griff. is a tree common in primary lowland and hill forests, commonly distributed in Malaysia (Peninsular Malaysia, Sarawak) and Singapore.

Order—LAMIALES

Family—OLEACEAE

Genus—CHIONANTHUS Linn.

Chionanthus siwalicus n. sp.

(Pl. 19.1, 2, 5)

Material—Two specimens.

Description—Leaf simple, asymmetrical, wide ovate; preserved size 4.3 x 4.1 cm and 5.5 x 3.5 cm; apex broken, base obtuse; margin entire; texture thick chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, slightly curved, weak; secondary veins 4–5 pairs visible, 0.6 to 1.3 cm apart, alternate, seemingly unbranched, angle of divergence (about 60°–75º), wide acute to nearly right angle, basal secondaries arise nearly at right angle, uniformly curved up and joined to their superadjacent secondaries; intersecondary veins present, simple; tertiary veins fine, poorly preserved with angle of origin usually RR, percurrent, almost straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40380.

Paratype—B.S.I.P. Museum No. 40381.

Type locality—Ramthi River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After Siwalik Formation to which the fossil locality belongs.

Affinity—The diagnostic features such as asymmetrical, wide ovate shape, obtuse base, eucamptodromous venation, alternate, seemingly unbranched, wide acute to nearly right angle secondaries, basal secondaries arise nearly at right angle, uniformly curved up and joined to their superadjacent secondaries; presence of intersecondary veins, RR, percurrent, almost straight to sinuous, branched tertiary veins collectively indicate that the present fossil leaf resembles closely with the extant leaves of *Chionanthus intermedia* (=*Chionanthus ramiflorus* Roxb.) (Wight) F. Muell. (C.N.H. Herbarium Sheet No. 287107; Pl. 19.3) of the family Oleaceae.

Fossil records and comparison—There is no record of fossil leaves resembling the genus *Chionanthus* Linn. from the Tertiary sediments of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal, India and hence it is being described as *Chionanthus siwalicus* n. sp.

Chionanthus Linn. is a tree or shrub usually evergreen and consists of about 80 species (Mabberley, 1997) *Chionanthus intermedius* (Wight) F. Muell. is distributed in Asia and tropical region of Indian sub–continent.

Family—APOCYNACEAE

Genus—CERBERA Linn.

Cerbera miocenica n. sp.

(Pl. 17.1, 2, 4, 6)

Material—Two specimens.

Description—Leaf simple, symmetrical, large, narrow elliptic; preserved size 14.8 x 3.9 cm and 14.8 x 3.8 cm; apex attenuate; base slightly broken seemingly attenuate; margin entire; texture coriaceous; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins more than 20 pairs visible, less than 1.0 cm apart, closely placed, alternate to opposite, seemingly unbranched, angle of divergence (about 65º–85º), wide acute to right angle, lower half secondaries are with

PLATE 20

(All figures are of natural size unless otherwise mentioned) →

1. *Chonemorpha miocenica.* Prasad & Awasthi–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40376.
2. *Chonemorpha macrophylla* D. Don–Modern leaf showing similar shape, size and venation pattern.
3. *Gardenia precoronaria* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40377 (Holotype).
4. *Gardenia coronaria* Buch–Ham.–Modern leaf showing similar shape, size and venation pattern.

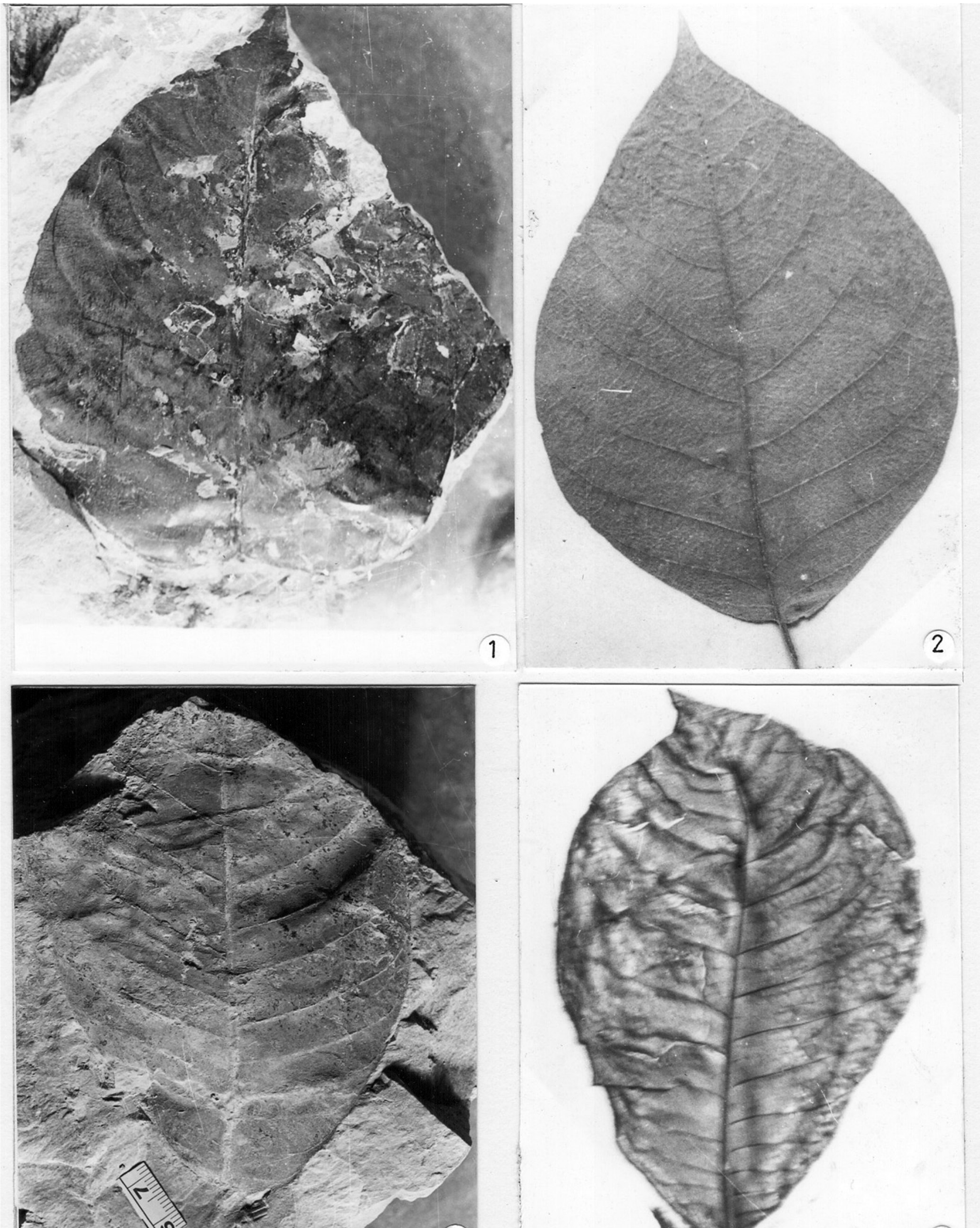

PLATE 20

greater angle, uniformly curved up and joined to their superadjacent secondaries; intersecondary veins present, frequent, simple, 2–3 veins present between two secondaries; tertiary veins fine, poorly preserved with angle of origin usually AO, percurrent, straight to sinuous, sometime branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum No. 40382.

Paratype—B.S.I.P. Museum No. 40383.

Type locality—Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology—After the age 'Miocene' of the sediments from where fossils were recovered.

Affinity—The diagnostic features of the present fossil leaves are symmetrical, large, narrow elliptic shape; attenuate apex; eucamptodromous venation; closely placed, alternate to opposite, seemingly unbranched, wide acute to right angle of secondary veins, greater angle of lower half secondaries, presence of frequent, simple, 2–3 intersecondary veins, AO, percurrent, straight to sinuous, sometime branched tertiary veins. Such features are found common in the modern leaves/ leaflets of *Ardisia colorata* Roxb. of the family Primulaceae, *Alstonia scholaris* of the family Apocynaceae and *Cerbera odallum* Gaertner (=*Cerbera lactaria* Buch.–Ham. ex. Spreng.) of family Apocynaceae. *Ardisia colorata* Roxb. differs from the present fossil in the nature of secondary veins which do not join each other near the margin; they join before the margin and *Alstonia scholaris* differs from present fossil in the nature of intersecondaries which is composite type usually only one in between two secondary veins. Thus the characters exhibited by present fossils collectively suggest its affinity with the modern leaves of *Cerbera odallum* Gaertner (= *Cerbera lactaria* Buch.–Ham. ex. Spreng.) of family Apocynaceae (C.N.H. Herbarium Sheet No. 289368; Pl. 19.3, 5) in shape, size and venation pattern.

Fossil records and comparison—There is no record of fossil leaf resembling the genus *Cerbera* Linn. from the Tertiary sediments of India. This fossil leaf represents its first occurrence in the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and hence, it is being described as *Cerbera miocenica* n. sp.

Cerbera Linn. comprises 3–4 extant species distributed in tropical coasts of India and west pacific oceans (Mabberley, 1997). The trees of *Cerbera odallum* Gaertner grows in coastal salt swamps and creeks in south India (particularly abundantly near the canals and backwaters of Kerala) and along riverbanks in southern and central Vietnam, Cambodia, Sri Lanka and Myanmar (Gaillard *et al*. 2004).

Family—APOCYNACEAE

Genus—CHONEMORPHA G. Don.

Chonemorpha miocenica Prasad & Awasthi, 1996

(Pl. 20.1)

Material—One specimen.

Description—Leaf simple, symmetrical, very wide ovate; preserved size 10.0 x 8.0 cm; apex accuminate; base obtuse; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, straight, stout; secondary veins 9–10 pairs visible 0.6 to 1.5 cm apart, alternate, branched near the margin, angle of divergence 45º–90°, narrow acute to right angle, lower secondary veins are with greater angle than upper ones, uniformly curved up but it is very sharp near the margin and joined to the supradjacent secondary at right angle; tertiary veins fine, angle of origin predominantly RR, percurrent, straight to sinuous, usually oblique in relation to midvein, nearly right angle near the margin, predominantly alternate and close; quaternary veins still fine arise at nearly right angle and forming orthogonal to polygonal meshes.

Specimen—B.S.I.P. Museum No. 40376.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik), Upper Miocene (Sarmatian to Pontian).

Affinity—The diagnostic features of the present fossil leaf such as symmetrical, very wide ovate shape, obtuse base, eucamptodromous venation, alternate, branched near the margin and narrow acute to right angle secondary veins, lower secondary veins are with greater angle than upper one, uniformly curved up but it is very sharp near the margin and joined to the superadjacent secondary at right angle, RR, percurrent, straight to sinuous tertiary veins collectively indicate that the present fossil leaf resembles closely with the extant leaves of *Chonemorpha macrophylla* G. Don. (C.N.H. Herbarium Sheet No. 52534; Pl. 20.2) of the family Apocynaceae.

PLATE 21

(All figures are of natural size unless otherwise mentioned) ⟶

1., 5. *Randia lishensis* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum No. 40375 (Holotype), 40376 (Paratype).

2. *Randia densifolia* (Wall.) Benth.–Modern leaf showing similar shape, size and venation pattern.

3. *Randia lishensis* n. sp.–Part of fossil leaf magnified to show details of venation pattern. x 2. BSIP Museum No. 40375 (Holotype).

4. *Randia densifolia* (Wall.) Benth.–Part of modern leaf magnified to show similar details of venation pattern. x 2.

6. *Artabotrys zeylanicus* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum No. 40319 (Paratype).

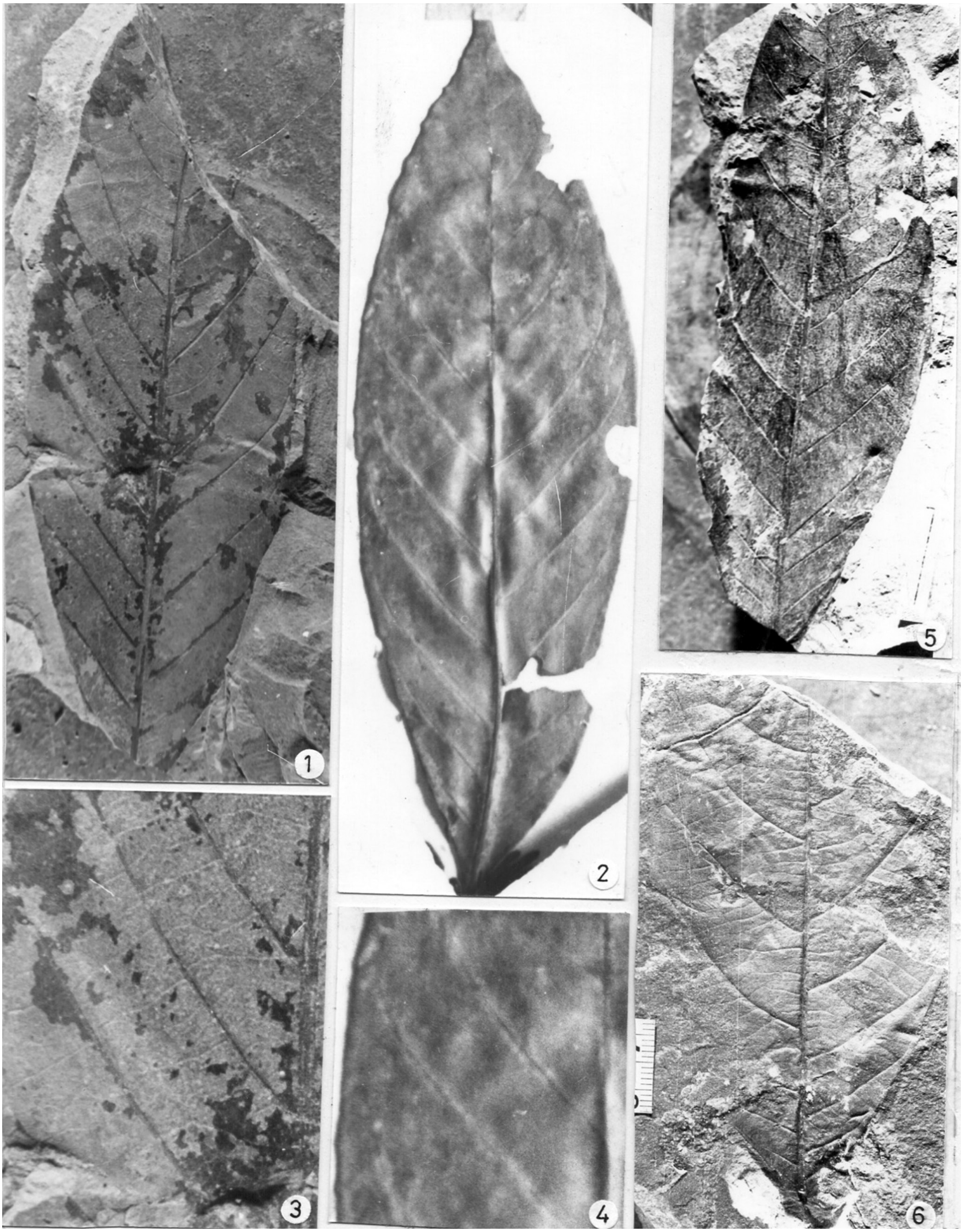

PLATE 21

Fossil records and comparison—So far, only one fossil species resembling the genus *Chonemorpha* G. Don., i.e. *Chonemorpha miocenica* Prasad and Awasthi, 1996 reported from Siwalik sediments of Surai Khola, western Nepal and Arunachal Pradesh, India (Khan *et al.,* 2010). On comparative study it has been observed that the present fossil leaves exhibit similar morphological features as the above known species *Chonemorpha miocenica,* hence this fossil has been described under the same species.

Chonemorpha G. Don. comprises about 13 species distributed in Indo–Malayan region (Mabberley, 1997). *Chonemorpha macrophylla* G. Don. is a large climbing shrub of moist forest in the greater part of India, from Kumaon and Sikkim in the Himalaya to Travancore and Sri Lanka and Andaman Islands (Gamble, 1972).

Family—MORACEAE

Genus—FICUS Linn.

Ficus precunea Lakhanpal, 1968

(Pl. 19.4, 6, 7, 8)

Material—Two specimens.

Description—Leaf simple, asymmetrical; elliptic; preserved size 10.5 x 5.6 cm; apex slightly broken; base cordate; normal, margin entire to nonentire; texture chartaceous; petiole indistinct; venation pinnate, eucamptodromous; primary vein single, straight, stout; secondary veins 5–6 pairs visible, 0.9–1.6 cm apart, angle of divergence (55°) moderately acute, running upward for a short distance; intersecondaries not distinct; tertiary veins fine, angle of origin usually RR, percurrent, branched oblique to mainly right angle in relation to mid vein, predominantly alternate and close.

Specimens—B.S.I.P. Museum No. 40384–40385.

Type locality—Ghish River Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age—Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Affinity—The morphological features exhibited by the present fossil leaf like elliptic shape, cordate base, entire to non-entire margin, eucamptodromous venation, secondaries running upward for a short distance, RR, percurrent, close to distant tertiaries collectively suggest its affinity with the extant leaves of *Ficus cunea* Ham. (Syn. *F. semicordata* Buch–Ham, C.N.H. Herbarium Sheet No. 1472; Pl. 19.6) of the family Moraceae.

Fossil records and comparison—About 32 fossil leaves resembling the genus *Ficus* Linn. have been described from Cenozoic sediments of India (Table 5). Out of them, three fossil leaves resembling the same taxon, *Ficus cunea* Buch–Ham. have been described under the form species, *Ficus precunea* Lakhanpal from Siwalik sediments of Balugoloa H.P. (Lakhanpal, 1968), from Koilabas, Nepal (Prasad, 1990a) and Kathgodam, Uttarakhand, India (Prasad *et al*., 2004) and also show closest similarity with the present fossil leaf. Hence, this fossil leaf has been described under the same species *Ficus precunea* Lakhanpal.

Ficus Linn. comprises 750 extant species of trees, shrubs or root clinging lianas, widely distributed throughout the tropics of both Hemispheres especially Indo–Malaya to Australia. The modern comparable species, *Ficus cunea* Buch–Ham. is a small tree distributed in the Sub–Himalayan tract, Assam and Myanmar (Brandis, 1971).

DISCUSSION AND CONCLUSION

This is the most comprehensive work and systematic study on plant mega fossils comprising well preserved leaf impressions from the Middle Siwalik sediments exposed in Oodlabari and nearby area, Darjeeling District, West Bengal. The floral assemblage recovered from these sediments is constituted by 35 species belonging to 28 genera and 18 dicotyledonous families of Angiosperms. This study added 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 Miocene in the Himalayan foothills have been deduced. Palaeoclimate estimation has also been discussed on the basis of coexistence and physiognomic approach.

FLORAL ASSEMBLAGE AND PLANT DIVERSITY

Study on the leaf–impressions from the Middle Siwalik sediments of Oodlabari area, Darjeeling District enhanced our knowledge of the fossil angiospermous flora during Siwalik period. This study deals with a variety of fossil assemblages consisting of mostly woody plants of dicotyledonous families. These are as follows:

Anonaceae
Artabotrys siwalicus n. sp.
Pseuduvaria mioreticulata n. sp.
Meiogyne sevokensis n. sp.
Uvaria siwalica Prasad, 1994c
Fissistigma senii Lakhanpal, 1969
Flacourtiaceae
Gynocardia butwalensis Konomatsu & Awasthi, 1999
Hydnocarpus ghishiensis n. sp.
Clusiaceae
Garcinia eocambogia Prasad, 1994c
Dipterocarpaceae
Vatica siwalica n. sp.
Vatica prenitida n. sp.
Bombacaceae
Bombax palaeomalabaricum n. sp.
Sterculiaceae
Sterculia miocolorata n. sp.

Table 5—List of *Ficus* species recorded from different fossil localities and horizons.

Fossil	Species horizon/ locality	References
Ficus arnottiana	Quaternary beds, Maharashtra	Mahajan & Mahabale, 1973
F. caricites	Mewar State	Trivedi, 1980
F. champerensis	Siwalik beds, Bhikhnathoree	Lakhanpal & Awasthi, 1984
F. cherrapunjiensis	Palaeocene	Ambwani, 1991
F. cunia	Karewa beds, Kashmir Dharamsala beds, Himachal Pradesh	Puri, 1947; Gupta & Jiwan, 1972
F. banogensis	Dagshai Formation and Dharamsala Formation, Himachal Pradesh	Mathur *et al.,* 1996
F. foveolata	Late Tertiary deposits of Palamau District, Bihar	Bande & Srivastava, 1990
F. glaberrima	Late Tertiary deposits of Palamau District, Bihar	Bande & Srivastava, 1990
F. kachchhensis	Eocene of Kachcch	Lakhanpal and Guleria, 1981
F. khariensis	Miocene of Kachchh	Lakhanpal & Guleria, 1982
F. miocenica	Siwalik sediments, western Nepal	Konomatsu & Awasthi, 1999
F. nemoralis	Karewa beds, Kashmir	Puri, 1948
F. glomerata	Quaternary beds, Maharashtra	Mahajan & Mahabale, 1973
F. religiosities	Mewar State	Trivedi, 1980
F. nepalensis	Siwalik sediments, Koilabas, western Nepal	Prasad, 1990a
F. oodlabariensis	Siwalik sediments, West Bengal	Antal & Awasthi, 1993
F. precunia	Siwalik beds, Jawalamukhi, Himachal Pradesh, Siwalik sediments, Koilabas, western Nepal	Lakhanpal, 1968; Prasad, 1990a
F. raptiensis	Siwalik sediments, Suraikhola, western Nepal	Prasad & Awasthi, 1996
F. microcarpa	Late Tertiary beds of Mahuadanr Valley, Jharkhand	Singh & Prasad, 2008
F. retusoides	Siwalik sediments, Koilabas, western Nepal, Siwalik sediments, West Bengal, Neyveli Lignite, south India	Prasad, 1990a; Antal & Awasthi, 1993; Agarwal, 2002
F. tomentosa	Late Tertiary deposits of Palamau District, Bihar	Bande & Srivastava, 1990
F. benjamina	Quaternary beds of Sirmur District, Himachal Pradesh; Siwalik sediments of Himachal Pradesh	Prasad *et al*., 2002; Prasad, 2006
F. curticeps	Late Tertiary beds of Mahuadanr Valley, Jharkhand	Singh & Prasad, 2008
F. eumysorensis	Siwalik sediments near Jarwa, Uttar Pradesh	Tripathi *et al*., 2002
F. barogensis	Kasauli Formation, Barog, Himachal Pradesh	Mathur *et al*., 1996
F. kasaulica	Kasauli Formation, Barog, Himachal Pradesh	Mathur *et al*., 1996
F kumarhattiensis	Dagshai Formation, Himachal Pradesh	Mathur *et al.,* 1996
F. precurticeps	Neyveli Lignite, south India	Agarwal, 2002
F. prereligiosa	Mar Formation (Neogene), Bikaner District, Rajasthan	Mathur & Mathur, 1998
Ficus sp.	Mar Formation (Neogene), Bikaner District, Rajasthan	Mathur & Mathur, 1998
Ficus sp. A–C	Dagshai Formation, Solan District, Himachal Pradesh	Mathur *et al.,* 1996
Ficus sp. cf *F. tomentosa* Roxb.	Dagshai Formation, Himachal Pradesh	Mishra & Mathur, 1992
F. palaeoracemosa	Kasauli Formation, Himachal Pradesh	Srivastava *et al.,* 2011

Sterculia siwalica n. sp.
Sterculia mioparviflora n. sp
Rutaceae
Toddalia miocenica n. sp.
Rhamnaceae
Rhamnus siwalicus n. sp.
Vitaceae
Vitis siwalica n. sp.
Sapindaceae
Paranephelium miocenica n. sp.
Cupania oodlabariensis n. sp.
Filicium koilabasensis Prasad 1994e
Sabiaceae
Sabia eopaniculata Prasad 1994e
Anacardiaceae
Buchanania palaeosessilifolia n. sp.
Fabaceae
Millettia prakashii Shashi *et al.,* 2007
Millettia miosericea n. sp.
Millettia purniyagiriensis Shashi *et al*., 2006
Millettia sevokensis n. sp.
Spatholobus siwalicus n. sp.
Cynometra palaeoiripa Prasad *et al.,* 1999
Rubiaceae
Randia lishensis n. sp.
Gardenia precoronaria n. sp.
Ebenaceae
Diospyros palaeoargentea n. sp.
Oleaceae
Chionanthus siwalicus n. sp.
Apocynaceae
Cerbera miocenica n. sp.
Chonemorpha miocenica Prasad & Awasthi, 1996
Moraceae
Ficus precunea Lakhanpal, 1968

With the addition of 35 new species described in the text, the floral assemblage of the Siwalik Group of Oodlabari area now consists of 91 species belonging to 68 genera of 31 angiospermous families (Table 6; Fig. 3). They are based on mainly leaf impressions. The assemblage is predominated by woody plants/trees (45 species). The remaining species are small trees and shrubs (27 species), shrub (16 species) and climbers (3 species). Herbs are totally absent (Table 6; Fig. 4). The fabaceous taxa are dominating the assemblage consisting of 11 species (Fig. 3). The earlier fossil records also show their abundance from other localities in the Siwalik foothills of India and Nepal during Mio–Pliocene (Prakash & Tripathi, 1992; Prasad, 1993, 1994a–d, 2008, 2012; Prasad *et al.,* 1997, 1999, 2004, 2013; Antal & Awasthi, 1993; Prasad & Awasthi, 1996; Prasad & Pandey, 2008; Antal & Prasad, 1995, 1996a–c, 1997, 1998; Antal *et al.,* 1996; Bera & Khan, 2009; Khan & Bera, 2014a, b; Table 6). These fabaceous taxa have been rarely recorded from the Oligocene of Palaeogene sub–period of India (Mehrotra, 2000a, b). This indicates that they might have entered later in the Indian sub–continent during Oligocene, after the establishment of land connections from where they were flourishing. It is believed that during the Neogene legumes became a major component of Indian tropical forest and distributed widely with other evergreen members. In the Siwalik sediments of Oodlabari area in the Darjeeling foothills the Fabaceae is well known by the occurrence of its fossil woods, leaves and fruits (Antal *et al*., 1996; Mitra & Banerjee, 2004; Prasad, 2008; Khan & Bera, 2014b; Table 6).

The study on the plant megafossils recovered from Oodlabari and nearby area revealed the occurrence of exclusively tropical elements during the Siwalik times. The important tropical subdominant families are Dipterocarpaceae, Lythraceae, Sapindaceae, Sapotaceae, Combretaceae and Ebenaceae. They are mainly distributed in India, Nepal and Southeast Asian regions. The present day distribution of the modern equivalents of the fossil taxa known from Oodlabari area indicates their wider distribution in different geographical regions all over India and other places (Fig. 7; Table 6). In India, they are distributed mostly in north–east and south–east regions as there still exists favourable climatic conditions. The fossil assemblage comprises more than 43% those taxa with modern relatives that are found to grow both in India and Malaya Peninsula. They are *Mitrephora siwalika* Antal and Awasthi, 1993, *Alsodeia palaeoechinocarpa* Antal and Prasad, 1998, *Gynocardia butwalensis* Konomatsu and Awasthi, *Calophyllum suraikholaensis* Awasthi and Prasad, Antal and Awasthi, 1993, *Shorea bengalensis* Antal and Awasthi, 1993, *Dipterocarpus siwalicus* Lakhanpal and Guleria, Antal and Prasad, 1996b, *Bombax palaeomalabaricum* n. sp., *Sterculia mioparviflora* n. sp., *Pterospermum mioacerifolium* Prasad *et al.,* 2009, *Xanthophyllum mioflavescens* Antal and Prasad, 1996a, *Bursera preserrata* Antal and Awasthi, 1993, *Ventilago tistaensis* Antal and Prasad, 1997, *Sabia eopaniculata* Prasad,1994e, *Cupania oodlabariensis* n. sp., *Bouea premacrophylla* Antal and Awasthi, 1993, *Buchanania palaeosessilifolia* n. sp., *Swintonia miocenica* Antal and Prasad, 1996a, *Albizia palaeolebbek* Antal and Awasthi, 1993, *Millettia prakashii* Shashi *et al.*, 2007, *Spatholobus siwalicus* n. sp., *Cynometra palaeoiripa* Prasad *et al.*, *Pongamia siwalika* Antal and Awasthi, 1993, *Terminalia miobelerica* Antal & Prasad*,* 1998, *Syzygium palaeocuminii* Prasad and Awasthi, Antal and Prasad, 1997, *Randia miowallichii* Prasad 1990a*, Randia lishensis* n. sp., *Diospyros koilabasensis* Prasad, 1990a, *Alstonia mioscholaris* Antal and Awasthi, 1993, *Cerbera miocenica* n. sp., *Callicarpa siwalika* Antal and Awasthi, 1993, *Cinnamomum* sp. Antal and Awasthi, 1993, *Actinodaphne palaeoangustifolia* Antal and Awasthi, 1993, *Mallotus kalimpongensis* Antal and Awasthi, 1993, *Glochidion* (*Phyllanthus*) *palaeohirsutum* Antal and Prasad, 1996a, *Homonoia mioriparia* Antal and Prasad, 1997, *Ficus* *retusoides* Prasad, 1990a, *F. Oodlabariensis* Antal & Awasthi, *Ficus precunea* Lakhanpal, *Vitis siwalica* n. sp

A number of taxa have their extant relatives restricted to the Malayan region including *Cananga tertiara* Prasad, 1994c, *Pseuduvaria mioreticulata* n. sp, *Uvaria ghishia* Antal and Prasad, 1998, *Flacourtia tertiara* Prasad and Awasthi, Antal and Prasad, 1997, *Hydnocarpus palaeokurzii* Antal and Awasthi, 1993, *Shorea miocenica* Antal and Prasad, 1996b, *Hopea siwalica* Antal and Awasthi, 1993, *Hopea kathgodamensis* Antal & Prasad, 1998, *Vatica siwalica* n. sp., *Pterospermum siwalicum* Antal and Prasad, 1996a, *Sterculia siwalica* n. sp., *Paranephelium seriaensis* Prasad and Dwivedi, 2008, *Cynometra tertiara* Antal and Awasthi, 1993, *Millettia oodlabariensis* Antal and Prasad, 1996a, *Millettia miosericea* n. sp., *Millettia sevokensis* n. sp. and *Diospyros palaeoargentea* n. sp.

The extant relatives of the fossil taxa, *Bambusa* sp. Antal and Awasthi, 1993, *Paranephelium miocenica* n. sp., *Lagerstroemia patelii* Lakhanpal and Guleria, 1981, *Chonemorpha miocenica* Prasad and Awasthi, *Vernonia palaeoarborea* Antal and Awasthi, 1993 and *Chionanthus siwalicus* are cosmopolitan. *Vatica prenitida* n. sp. is related to extant species that grow in the tropical regions of Sri Lanka.

Besides, the floral assemblage consists of some fossil related to species that are now considered as south Indian taxa like, *Artabotrys siwalicus* n. sp., *Meiogyne sevokensis* n. sp., *Alsodeia palaeozeylanicum* Antal and Awasthi, 1993, *Hydnocarpus ghishiensis* n. sp., *Garcinia eocombogia* Prasad, 1994d, *Pterospermum palaeoheynianum* Antal and Awasthi, 1993, *Sterculia miocolorata* n. sp., *Grewia ghishia* Antal and Awasthi, 1993, *Beddomia palaeoindica* Antal and Prasad, 1998, *Filicium koilabasensis* Prasad 1994e, *Nothopegia eutravancorica* Antal and Awasthi, 1993, *Millettia purniyagiriensis* Shashi *et al*., 2006 and *Macaranga siwalika* Antal and Awasthi, 1993.

The remaining taxa like, *Clinogyne ovatus* Awasthi and Prasad; Antal and Prasad, 1995, *Dillenia palaeoindica* Prasad and Prakash, *Fissistigma senii* Lakhanpal, 1969, *Polyalthia palaeosiamiarum* Awasthi and Prasad, Antal and Prasad 1996c, *Uvaria siwalica* Prasad, *Casearia pretomentosa* Antal and Awasthi, 1993, *A. palaeoracemosa* Antal and Prasad, 1997, *Shorea siwalika* Antal and Awasthi, 1993, *Toddalia miocenica* n. sp., *G. tistaensis,* Antal and Prasad, 1998, *Ziziphus palaeoapetala* Antal and Prasad, 1997, *Rhamnus siwalicus* n. sp., *Bauhinia ramthiensis* Antal and Awasthi, 1993, *Combretum sahnii* Antal and Awasthi, 1993, *Gardenia precoronaria* n. sp. have closest relatives distributed in North east Indian region.

The present floral assemblage consists of 4 major types of elements: (1) Evergreen, (2) Evergreen and Moist deciduous, (3) Moist deciduous and (4) Mixed deciduous. In the floral assemblage so far recorded from Siwalik of Oodlabari area, 52% taxa are evergreen, 22% evergreen to Moist deciduous, 17% Moist deciduous and 9% mixed deciduous. Thus the

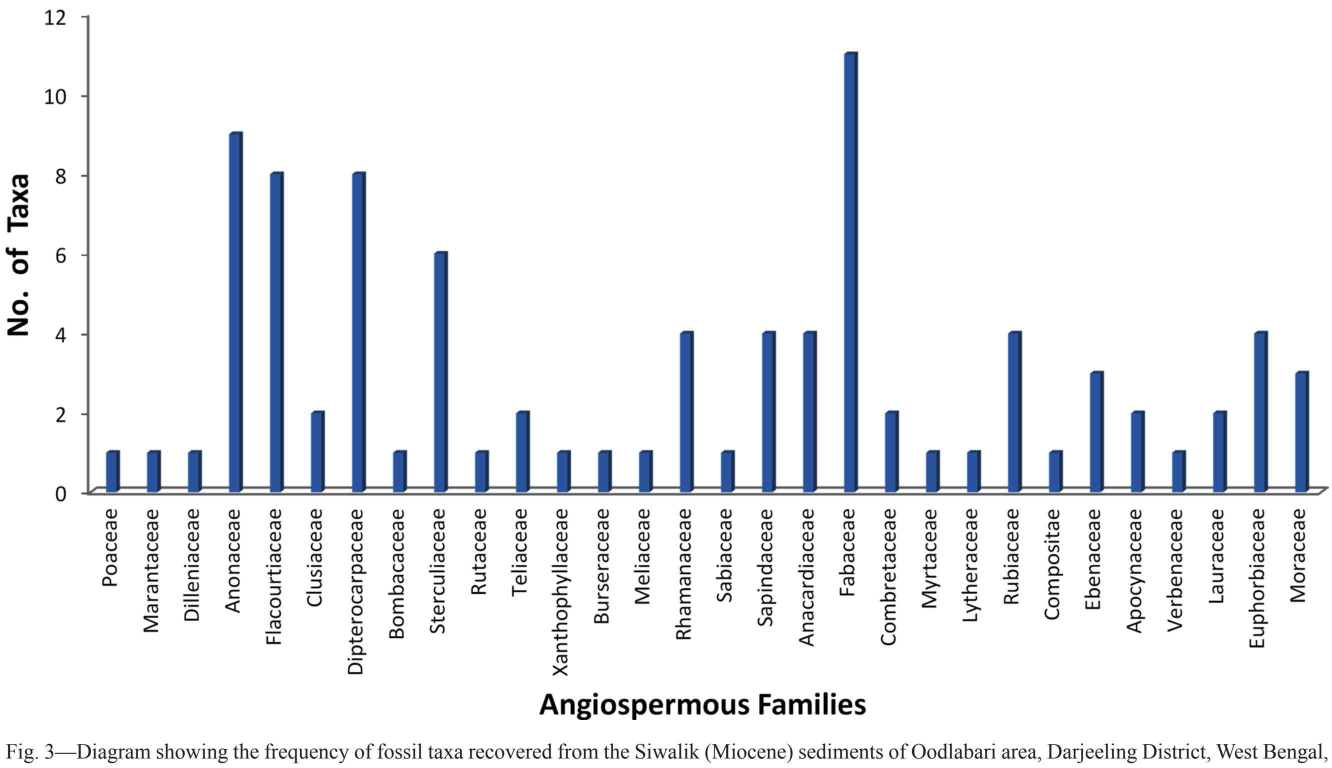

Fig. 3—Diagram showing the frequency of fossil taxa recovered from the Siwalik (Miocene) sediments of Oodlabari area, Darjeeling District, West Bengal, India.

Table 6—Present day distribution and forest types of modern comparable species of the fossil Oodlabari Assemblage, West Bengal, India.

Fossil Taxa	Modern Comparable Species	Forest Types	Distributions
MONOCOTYLEDONS			
Poaceae			
Bambusa sp. Antal & Awasthi, 1993	*Bambusa* sp.	Mixed deciduous	Sub-Himalayan tract and Cosmopolitan
Marantaceae			
Clinogyne ovatus Awasthi & Prasad; Antal & Prasad, 1995	*C. grandis* Benth. & Hook.	Moist deciduous	Sub-Himalayan tract
Dilleniaceae			
Dillenia palaeoindica Prasad & Prakash, Antal & Awasthi, 1993	*Dillenia indica* Linn.	Evergreen to Moist deciduous	Sub-Himalayan tract, Myanmar South east Asia, south India
Anonaceae			
Artabotrys siwalicus n. sp.	*Artabotrys zeylanicus* Hook.f. & Th.	Evergreen	Peninsular India and Sri Lanka.
Cananga tertiara Prasad, 1994c	*C. odorata* Hook.f. & Th.	Evergreen	Martaban, Tennasserin, Malaya peninsula
Pseuduvaria mioreticulata n. sp.	*Pseuduvaria reticulata* (Blume) Miq.	Evergreen to Moist deciduous	Malaysia, Sumatra, Java and Borneo
Mitrephora siwalica Antal & Awasthi, 1993	*Mitrephora maingayi* Hook.f. & Th.	Evergreen	North east India Myanmar, Bangladesh, Malaya Peninsula
Fissistigma senii Lakhanpal, 1969	*Fissistigma bicolor* (Roxb.) Merr.	Evergreen to deciduous	Tropical Himalaya (Nepal, Sikkim), Assam, Burma
Polyalthia palaeosiamiarum Awasthi & Prasad; Antal & Prasad, 1996	*Polyalthia siamiarum* Bl.	Evergreen	North east India, Bangladesh, Myanmar, Andaman
Uvaria ghishia Antal & Prasad, 1998	*Uvaria hirsuta* Jack.	Evergreen	Myanmar, Malaya
Uvaria siwalica Prasad, 1994c	*Uvaria hamiltonii* Hook.f. & Th.	Evergreen to Moist deciduous	Sub-Himalayan tract, Sikkim, Chhota Nagpur, Bangladesh, Andaman Islands and Myanmar
Meiogyne sevokensis n. sp.	*Meiogyne ramarowii* (Dunn.) Gandhi	Wet Evergreen	Endemic to the Western Ghats- South and Central Sahyadris
Flacourtiaceae			
Casearia pretomentosa Antal & Awasthi, 1993	*Casearia tomentosa* Roxb.	Mixed deciduous	Sub Himalayan tract, Nepal, central and south India, Bangladesh
Alsodeia palaeozeylanicum Antal & Awasthi, 1993	*Alsodeia zeylanicum* Thw.	Evergreen	Malabar Hills, south India, Sri Lanka
A. Palaeoracemosa Antal & Prasad, 1997	*A. racemosa* H.F. & Th.	Evergreen to Moist deciduous	North east India, south India
A. palaeoechinocarpa Antal & Prasad, 1998	*Alsodeia echinocarpa* Korth.	Evergreen	Sumatra, Cochinchina
Flacourtia tertiara Prasad & Awasthi, Antal & Prasad 1997	*Flacourtia inermis* Roxb.	Evergreen	Malayan Archipelago

Hydnocarpus ghishiensis n. sp.	*Hydnocarpus pertandra* (Buch.-Ham.)	Wet Evergreen	Endemic to Western Ghats, very common in South and Central Sahyadris
Hydnocarpus palaeokurzii Antal & Awasthi, 1993	*Hydnocarpus kurzii* (King) Warb.	Evergreen	Myanmar, Martaban Hills
Gynocardia butwalensis Konomatsu & Awasthi, 1999	*Gynocardia odorata* R.Br.	Evergreen	Northern and eastern Bengal, Assam, Chittagong, Myanmar
Clusiaceae			
Calophyllum suraikholaensis Awasthi & Prasad, Antal & Awasthi, 1993	*Calophyllum polyanthum* Wall.	Evergreen	Andaman, Malaya, south India, Sri Lanka
Garcinia eocambogia Prasad, 1994c	*Garcinia cambogia* Roxb.	Evergreen	Western Ghats, from Konkan southwards to Travancore, and in the Shola forests of Nilgiris
Dipterocarpaceae			
Shorea siwalika Antal & Awasthi, 1993	*Shorea assamica* Dyer.	Evergreen	North east India
S. miocenica Antal & Prasad, 1996b	*Shorea buchananii* C.E.C. Fischer	Evergreen	Myanmar
S. bengalensis Antal & Prasad, 1997	*S. roxburghii* (*S. talura* Roxb.)	Evergreen	Malaya, south India
Dipterocarpus siwalicus Lakhanpal & Guleria, Antal & Prasad, 1996b	*Dipterocarpus tuberculatus* Roxb.	Evergreen to Moist deciduous	Myanmar, Cochinchina, Thailand
Hopea siwalika Antal & Awasthi, 1993	*H. wightiana* Wall.	Evergreen	Indo-Malayan region
Hopea kathgodamensis Prasad, Antal & Prasad, 1998	*H. micrantha* Hook.f.	Evergreen	Myanmar, Moluccas, Borneo
Vatica siwalica n. sp.	*Vatica pachyphylla* Merr.	Evergreen	Philippines
Vatica prenitida n. sp.	*Vatica nitida* A. DC.	Evergreen to Moist deciduous	Sri Lanka
Bombacaceae			
Bombax palaeomalabaricum n. sp.	*Bombax malabaricum* DC.	Moist deciduous	Southern China and Indo-Malayan region.
Sterculiaceae			
Pterospermum palaeoheynianum Antal & Awasthi, 1993	*Pterospermum heynianum* Wall.	Mixed deciduous	South and central India
P. siwalicum Antal & Prasad, 1996a	*P. semi-sagitatum* Buch.-Ham. ex. Roxb.	Moist deciduous	Myanmar, Bangladesh
Sterculia miocolorata n. sp.	*Sterculia colorata* Roxb.	Moist deciduous	Eastern Ghats, Assam, Madhya Pradesh, south India, Andaman Islands
Sterculia siwalica n. sp.	*Sterculia versicolor* Wall.	Evergreen to Moist deciduous	Myanmar on limestone rocks, bank of Irrawaddy
Sterculia mioparviflora n. sp.	*Sterculia parviflora* Roxb.	Evergreen to Moist deciduous	India, Indonesia, Malaya Peninsula, Myanmar, Thailand and Vietnam

Pterospermum mioacerifolium Prasad *et al.* 2009	*Pterospermum acerifolium* (L.) Willd.	Evergreen to Moist deciduous	Sub-Himalayan tract, Bengal, Chittagong and Myanmar, North Kanara, Andaman
Rutaceae			
Toddalia miocenica n. sp.	*Toddalia aculeate* Pers.	Evergreen to Moist deciduous	Kumaon to eastwards Bhutan and Assam (Khasi Hills), Orissa
Tiliaceae			
Grewia ghishia Antal & Awasthi, 1993	*Grewia umbellifera* Bedd.	Evergreen to Moist deciduous	Western Ghats, south India
G. tistaensis, Antal & Prasad, 1998	*G. tilaefolia* Vahl.	Moist deciduous	Sub Himalayan tract, south and central India
Xanthophyllaceae			
Xanthophyllum mioflavescens Antal & Prasad, 1996a	*Xanthophyllum flavescens* Roxb.	Evergreen	Indo-Malaya
Burseraceae			
Bursera preserrata Antal & Awasthi, 1993	*Bursera serrata* Colebr.	Evergreen	North east India, central India, Myanmar
Meliaceae			
Beddomia palaeoindica Antal & Prasad, 1998	*Beddomia indica* Hook.f.	Evergreen	south India
Rhamnaceae			
Ziziphus palaeoapetala Antal & Prasad, 1997	*Ziziphus apetala* Hook.f. & Th.	Mixed deciduous	Sikkim
Ventilago tistaensis Antal & Prasad, 1997	*Ventilago calyculata* Thw.	Mixed deciduous	India, Myanmar and Sri Lanka
Rhamnus siwalicus n. sp.	*Rhamnus erectus*	Evergreen	Assam
Vitis siwalica n. sp.	*Vitis lanceolaria* (Roxb.) Wall.	Evergreen	Assam, Tripura, Arunachal Pradesh, West Sumatra
Sabiaceae			
Sabia eopaniculata Prasad	*Sabia lanceolata* Colebr.	Evergreen	Bangladesh, Bhutan, India, Myanmar and China
Sapindaceae			
Paranephelium seriaensis Prasad & Dwivedi, 2008	*Paranephelium xestophyllum* Miq.	Evergreen	Tennasserim
Paranephelium miocenica n. sp.	*Paranephelium macrophyllum* King	Evergreen	South east Asian region
Cupania oodlabariensis n. sp.	*Cupania pleuropteris* var. *apiculata* Hiern	Evergreen to Moist deciduous	Burma, Indo-China, Thailand, Malaysia, Sumatra, Borneo, Philippines
Filicium koilabasensis Prasad 1994e	*Filicium decipiens* (Wight & Arn.) Hook.f.	Evergreen	Western Ghats, Sri Lanka and tropical Africa
Anacardiaceae			
Nothopegia eutravancorica Antal & Awasthi, 1993	*Nothopegia travancorica* Bedd.	Evergreen	south India
Bouea premacrophylla Antal & Awasthi, 1993	*Bouea macrophylla* Grifth.	Evergreen	Andaman, Sunderban, Myanmar, Malaya

Buchanania palaeosessilifolia n. sp.	*Buchanania sessilifolia* Blume.	Moist deciduous	Indochina, Thailand, Malaya Peninsula, Sumatra, Borneo, Philippines, Moluccas
Swintonia miocenica Antal & Prasad, 1996a	*Swintonia floribunda* Griffth.	Evergreen	Myanmar, Bangladesh, south India
Fabaceae			
Bauhinia ramthiensis Antal & Awasthi, 1993	*Bauhinia acuminata* Linn.	Moist deciduous	Sub Himalayan tract, Myanmar, Andaman, Malaya
Cynometra tertiara Antal & Awasthi, 1993	*Cynometra cauliflora* Linn.	Evergreen	Moluccas, Sri Lanka, Malaya Peninsula
Albizia palaeolebbek Antal & Awasthi, 1993	*Albizia lebbek* Benth.	Moist deciduous	Sub Himalayan tract, central & south India, Myanmar Andaman
Millettia oodlabariensis Antal & Prasad, 1996a	*Millettia albiflora* Prain.	Evergreen	Myanmar, Malaya
Millettia prakashii Shashi *et al.*, 2007	*M. atropurpurea* Benth.	Evergreen	Myanmar, Martaban Hills and south India
Millettia miosericea n. sp.	*Millettia sericea* (Vent.) W. & A	Evergreen	Myanmar, Thailand, Vietnam, Indonesia, Java, Malaya
Millettia purniyagiriensis Shashi *et al*., 2006	*Millettia rubiginosa* Wight & Arn.	Evergreen to Moist deciduous	Western Ghats, Kerala, Tamil Nadu
Millettia sevokensis n. sp.	*Millettia brachycarpa* Merr.	Evergreen	Endemic to Philippines
Spatholobus siwalicus n. sp.	*Spatholobus parviflorus* (DC.) Kuntze.	Evergreen to Moist deciduous	Indo-Malaya, Kerala
Cynometra palaeoiripa Prasad *et al.,*1999	*Cynometra iripa* Kotel.	Mixed deciduous	India, Bangladesh, Myanmar, Thailand, Northeast Australia, New Guinea, Philippines
Pongamia siwalika Antal & Awasthi, 1993	*Pongamia pinnata* Vent.	Evergreen	India, Sri Lanka, Myanmar
Combretaceae			
Combretum sahnii Antal & Awasthi, 1993	*Combretum deccandrum* Roxb.	Mixed deciduous	Sub-Himalaya tract, south & central India
Terminalia miobelerica Prasad, Antal & Prasad, 1998	*Terminalia belerica* Roxb.	Evergreen to Moist deciduous	Sub Himalayan tract Myanmar, Malaya
Myrtaceae			
Syzygium palaeocumini Prasad & Awasthi, Antal & Prasad, 1997	*Syzygium cumini* (Linn.) Skeels	Evergreen to Moist deciduous	India, Myanmar, Sri Lanka
Lythraceae			
Lagerstroemia patelii Lakhanpal & Guleria, 1981	*Lagerstroemia speciosa* Pers.	Moist deciduous	North east India, central & south India, Myanmar
Rubiaceae			
Randia miowallichii Prasad, Antal & Awasthi, 1993	*Randia wallichii* Hook.f.	Evergreen to Moist deciduous	North east India, Myanmar, Andaman, Malaya
Randia lishensis n. sp.	*Randia densifolia* (Wall.) Benth.	Evergreen to Moist deciduous	India, Andaman, Myanmar, Thailand, Malaysia, Sumatra, Borneo

Gardenia precoronaria n. sp.	*Gardenia coronaria* Buch.-Ham.	Moist deciduous	Chittagong, Chittagong Hill Tracts, Bangladesh
Compositae			
Vernonia palaeoarborea Antal & Awasthi, 1993	*Vernonia arborea* Ham.	Evergreen	North east India, Myanmar, south India, Andaman
Ebenaceae			
Diospyros koilabasensis Prasad, Antal & Awasthi, 1993	*Diospyros montana* (Var. *cordifolia)* Hyne ex. A. DC.	Moist deciduous	India, Myanmar
Diospyros palaeoargentea n. sp.	*Diospyros argentea* Griff.	Evergreen to Moist deciduous	Malaysia, Singapore
Oleaceae			
Chionanthus siwalicus n. sp.	*Chionanthus intermedia* (Wight) F. Muell.	Evergreen	Tropical regions of Indian subcontinent
Apocynaceae			
Alstonia mioscholaris Antal & Awasthi, 1993	*Alstonia scholaris* R. Br.	Evergreen	India & Myanmar
Cerbera miocenica n. sp.	*Cerbera odallum* Gaertner	Evergreen to Semi-deciduous	south India, Vietnam, Cambodia, Sri Lanka, Myanmar
Chonemorpha miocenica Prasad & Awasthi 1996	*Chonemorpha macrophylla* G. Don	Moist deciduous	North east India, Western Ghats and Malaya
Verbenaceae			
Callicarpa siwalika Antal & Awasthi, 1993	*Callicarpa arborea* Roxb.	Moist deciduous	Sub Himalayan tract, central India, Myanmar
Lauraceae			
Cinnamomum sp. Antal & Awasthi, 1993	*Cinnamomum* sp.	Evergreen	South east Asia and Indo-Malayan region
Actinodaphne palaeoangustifolia Antal & Awasthi, 1993	*Actinodaphne angustifolia* Nees.	Evergreen	North east India, Bangladesh, Myanmar
Euphorbiaceae			
Mallotus kalimpongensis Antal & Awasthi 1993	*Mallotus philippinensis* Muell. Arg.	Mixed deciduous	Throughout India and Myanmar
Macaranga siwalika Antal & Awasthi, 1993	*Macaranga peltata* Muell. Arg.	Evergreen	South and central India, Sri Lanka
Glochidion (*Phyllanthus*) *palaeohirsutum* Antal & Prasad, 1996a	*Glochidion hirsutum* Muell.	Evergreen	North east India, Myanmar Malaya, Bangladesh, Andaman
Homonoia mioriparia Antal & Prasad, 1997	*Homonoia riparia* Lour.	Evergreen	India, Myanmar, Malaya, China
Moraceae			
Ficus retusoides Prasad, Antal & Awasthi, 1993	*Ficus retusa* Linn.	Evergreen	Sub Himalayan tract, Myanmar, Andaman, Sri Lanka
F. oodlabariensis Antal & Awasthi	*F. benjamina* Linn.	Evergreen to Moist deciduous	North east India, central India, Myanmar, Java
Ficus precunea Lakhanpal, 1968	*Ficus cunea* Ham.	Evergreen to Moist deciduous	Sub-Himalayan tract, Assam, Myanmar

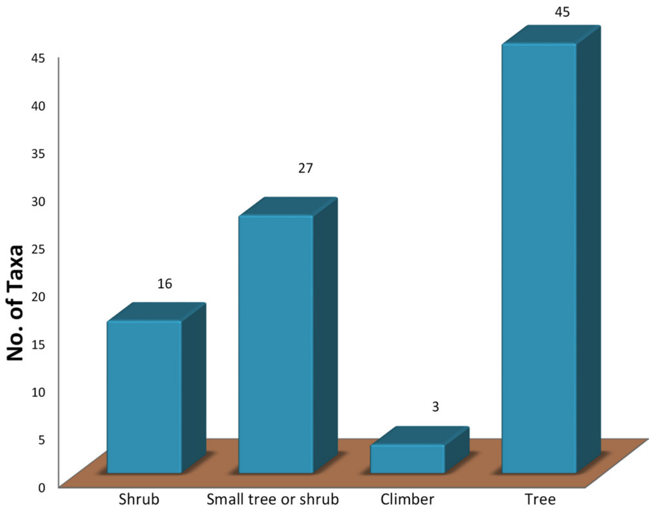

Fig. 4—Diagrammatic representation of forest elements (Tree, Shrub and Climber) in the floral assemblage recovered from Siwaik group of Oodlabari area, Darjeeling District, West Bengal.

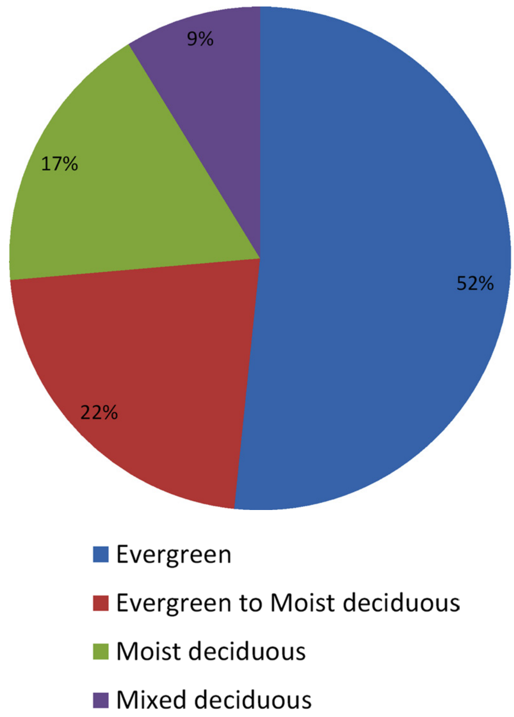

Fig. 5—Diagrammatic representation of forest elements of the fossil assemblage recovered from Siwalik Group of Oodlabari area, Darjeeling District, West Bengal.

evergreen elements dominate the flora of Oodlabari area (Fig. 5; Tables 6, 7) during Siwalik period in contrast to mixed deciduous vegetation occurring today in the area (Kanjilal, 1950).

PALAEOCLIMATE RECONSTRUCTION

Palaeoclimate reconstruction from fossil plants is one of the most important contributions of palaeobotanical studies. The principal basis to any study of the past is the principle of 'Uniformity in the order of nature'. This principle, the present is the key to the past, implies that the physical and biological processes that operate in today's environment as well as vegetation must were functioning the same way in the past. Likewise, the type of weather variation and climatic conditions observed today must also have occured in the past. 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 that 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 identified with 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 Miocene sediments and the modern equivalents of these fossil forms still exist in the forests of different phytogeographical regions, it has, therefore become easier to deduce the palaeoclimate and palaeoecology of the Oodlabari area in the Himalayan foothills of West Bengal during Siwalik period.

The other parameter for reconstruction of palaeoclimate is the physiognomic characters of plant fossils. The presence of fossil leaves in any fossil assemblage plays a deciphering role in interpreting the palaeoclimate. Further, this is an independent systematic relationship of the species and therefore, it is likely that the error in interpretation is minimum.

Thus, on the basis of plant megafossils especially leaf–impressions, the interpretation regarding palaeoclimate can be drawn by two approaches:

Coexistence approach i.e. from comparison of the leaf–impression with the extant taxa.

Foliar physiognomic approach i.e. from study of the structural features of leaf–impressions.

Coexistence approach

The coexistence approach is utilized as a method for terrestrial palaeoclimate reconstructions in Tertiary Period (Mosbrugger & Utescher, 1997; Bohme *et al.*, 2007). It is based on the assumption that Tertiary plant taxa have similar climatic requirements as their nearest living relatives (NLR).

Thus, it deals with the interpretation of past climate by using the climatic preferences of modern plants. The palaeolimate reconstruction using fossil floral assemblage requires three types of information: (1) a living relative for each fossil species (2) the autoecology of the living relatives of each fossil species and (3) a modern association of species similar to the fossil flora. In the real sense, the modern analogue community should be similar to the fossil assemblage in both species composition and relative abundance of taxa. The plant fossils collected from Oodlabari area have been compared with their modern equivalents and mainly coexist in other geographical regions. It has also been observed that a few of them still live today in the study area. Therefore, it is easier to infer the palaeoclimate of the region during the past.

The basic idea of the coexistence approach is very simple and follows nearest living relatives' philosophy. It based on the assumption that the climatic requirements of a fossil taxa are very similar to living relatives (Modern equivalents) because it is assumed that the modern equivalent taxa require similar climatic parameters as the fossil taxa. For example, there are two fossil taxa, i.e. *Ficus cunea* and *Cerbera miocenica* in the present fossil assemblage with their living relatives, *Ficus cunea* and *Cerbera odallum* respectively. The MAT coexistence interval of *Ficus cunea* is 19.4ºC–25.3ºC and *Cerbera odallum* is 21.5ºC–26.5ºC (Fig. 18a). Thus, it is obvious that modern taxa *Ficus cunea* and *Cerbera odallum* require the Mean Annual Temperature between 19.4ºC–25.3ºC and 21.5ºC–26.5ºC respectively and suggesting that there is a mean annual temperature interval between 21.5ºC and 25.3ºC in which both the taxa coexist. Similarly, the MAT, coexistence intervals of all the 35 Nearest Living Relative taxa (Modern taxa) of Oodlabari fossil flora have been obtained from published literature (Champion & Seth, 1968) and Climatological table of observation in India (1931–1960) as well as through internet and on its application it has been found that the MAT Coexistence interval for fossil assemblage is 22ºC–26.5ºC under which all the fossil taxa once lived. In the similar way the estimates (coexistence intervals) have been obtained for other parameters such as temperature of warmest month (WMT), and coldest month (CMT) as well as mean annual precipitation. Thus the following reconstructed climatic estimates (Coexistence intervals) for different climatic parameter, i.e. MAT, WMT, CMT and MAP are obtained (Fig. 6a–d).

MAT (Mean Annual Temperature) 22ºC–26.5ºC

CMT (Mean Annual Temperature of Coldest Month) 17.8ºC–20ºC

WMT (Mean Annual Temperature of Warmest Month) 25ºC–30ºC

MAP (Mean Annual Precipitation) 2650–3200 mm

The floral assemblage recovered so far from the Siwalik sediments of the Oodlabari area comprise 91 fossil taxa and mostly all of them were compared with their modern equivalents (Table 6). The present habit and habitat of these taxa show that they mostly occur in the tropical evergreen and Moist deciduous forests of north eastern India, Bangladesh, Myanmar and Southeast Asian regions (Malaya, Philippines, Java, Borneo, etc.) enjoying almost the same climatic condition (Gamble, 1972; Hooker, 1872, 1882, 1884; Champion & Seth, 1968; Desch, 1957; Table, 6). Thus, it may be surmised that a warm and humid climate prevailed in Oodlabari area in the Himalayan foothills during Miocene in contrast to the present relatively dry climate there. The predominance of evergreen elements in the assemblage (Tables 6, 7; Fig. 5) further indicates the prevalence of tropical (warm humid) climate with plenty of rainfall. Most of the taxa in the fossil assemblage do not occur in the vicinity of Oodlabari area or all along the whole Himalayan foothills of both India and Nepal (Table 6). This obviously indicates that changes in the climate must have taken place after the deposition of Siwalik sediments in this region.

The change in climate after the Middle Miocene period can also be explained by a general global cooling and by the events within the region, particularly the Himalayan uplift and swallowing 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 physiognomic approach

The morphological features of the leaves reflect some functional and physiological process of the plant. For example, thick, waxy, succulent leaves indicate arid environment in which plant must conserve water. Leaf physiognomy is used to reconstruct the palaeoclimate either by CLAMP (Wolfe, 1993; Spicer *et al.,* 2009) or by Leaf Margin Analysis Method (Wilf, 1997; Su *et al*., 2010). This is particularly useful for deducing temperature and precipitation pattern because the leaf is instrumented in maintaining plant water and temperature balance.

Physiognomic features of the fossil angiospermous leaves such as shape, size, venation, density, texture, margin, tip, etc. have a great relationship with climate and thus provide more reliable results (Table 8). 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 Coexistence approach. The detailed physiognomic study of the fossil leaves recovered from the Siwalik sediments of Oodlabari area in the Himalayan foothills of West Bengal provides some significant data for the reconstruction of palaeoclimate prevailing in the foothills during Siwalik period.

Wolfe (1995) has studied the physiognomic features of modern angiospermous leaves and correlated them with climate in hundreds of communities throughout the world. He took a multivariate approach which compares many combinations of leaf characters using computer programme which is knows as CLAMP Method (Climate Leaf Analysis Multivariate Programme Method). In original CLAMP Method he used 29 leaf characters related to leaf margin, size, apex, base and shape. Later on Spicer *et al*., (1996) used Wolfe's CLAMP data base with an additional leaf size characters to estimate palaeotemperature and palaeoprecipitation for four fossil assemblages. Kovach and Spicer (1996) also used Wolfe's data for the estimation of palaeotemperature and found that the CLAMP Method worked well for MAT (Mean Annual Temperature) in the range of 10º–20ºC but above or below this range could not be accurately estimated. Thus keeping in view the above fact the application of CLAMP to the present fossil flora for the estimation of palaeoclimate would not be useful. However, Spicer *et al*., (2009, 2011) modified the programme used in the CLAMP Method and made it suitable for better estimation of palaeoclimate. The other physiognomic features such as margin, size, drip tips, petiole, texture, apex and base, leaf organization and venation density of the angiospermous fossil leaves of Siwalik sediments of Oodlabari area have been analyzed here for reconstruction of the palaeoclimate (Table 8).

One of the best indicators of climate appears to be the leaf margin, viz. entire versus non–entire. The approach, Leaf Margin Analysis (LMA) for the reconstruction of climate is based on the work of Baily and Sinnott (1916), who had found a direct relation between the margin and climate. According to him the typical entire margined leaves of woody families, like Anonaceae, Lauraceae, Ebenaceae, Clusiaceae, Sapotaceae, Dipterocarpaceae, 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 possess both entire and non–entire margin. According to Baily 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.

Analysis of the fossil leaf assemblage recovered from Oodlabari area, shows that only nine taxa, i.e. *Dillenia palaeoindica, Alsodeia palaeoechinocarpa, Flacourtia tertiara, Pterospermum mioacerifolium, Grewia ghishia, G. tistaensis, Macaranga siwalica, Ficus precunia* and *Vitis siwalica* have nonentire margin while the rest (82) are with entire margin indicating a warm tropical climate (Table 8). Wolfe (1979) presented some models for the comparison of Mean Annual Temperature (MAT) and percentage of species with entire margined leaves. Some models were also derived from the plot of MAT and percentage of entire margined species. These are as follows:

MAT = 1.4 + 0.306 X (% entire) (by Wolfe, 1979; Wing & Greenwood, 1993)

In this equation (% entire) is the percentage of leaf species in the assemblage that have entire margins.

An application of this equation to the present floral assemblage yields that the MAT value estimates of 28.9ºC. This suggests that the MAT (Mean Annual Temperature) during Middle Siwalik time all along the Himalayan foothills was 28.9ºC. It is 4.52ºC higher than present day value. The present day MAT of the Himalayan foothill zone is 24.40ºC (data for 20 years interval) obtained from India Meteorological Department (Champion & Seth, 1968).

The estimated MAT of 28.9ºC is very significant as it corresponds to the present day MAT value of North east India (29.04ºC) where maximum (more than 38.46%) comparable taxa of the fossils assemblage of Oodlabari area are distributed presently (Table 6, Fig. 7). Similarly, more than 14% comparable taxa of the fossil assemblages are growing nowadays in the South Indian region where MAT value varies from 25º to 27ºC and is responsible for the existence of evergreen forest (Champion & Seth, 1968).

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 helps to retard the growth of epiphytes. Deciduous leaves generally lack drip tip, because of their short life span. In the present fossil assemblage about 16 taxa possess conspicuous drip tips (Table 8). Thus it also shows the possibility of tropical humid climate around Oodlabari area in the Himalayan foothills of Darjeeling District, West Bengal during the deposition of Siwalik sediments.

Additional physiognomic features like leaf size are also considered to be reliable indicators of terrestrial palaeoclimate. It has been observed that leaf size distribution in any forest type is correlated with available moisture and it is found that bigger leaves occur in the understory elements of evergreen forests and decreases with low temperature or precipitation. Raunkiear (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, less in the subtropics and least in the warm temperate forests. 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) (Raunkiear, 1934; Webb, 1959). According to this classification the fossil leaves recovered from Siwalik of Oodlabari area are mainly mesophyll type which indicates that a tropical humid climate was prevailed in the area during Middle Miocene.

Similarly, there is a strong relation between the Mean Annual Precipitation (MAP) and average leaf area. Wilf *et al.* (1998) has formulated an equation to estimate the MAP by using the proportion of large size leaves in the assemblage of any region. This equation is as follows:

MAP = 47.5 + 6.18 X (% Large leaves)

(% Large leaves) is the percentage of leaves in an assemblage of mesophyll size or larger in area mesophyll or larger ($\geq 33\ cm^2$).

In order to estimate the Mean Annual Precipitation (MAP) of Himalayan foothills in Oodlabari area during Miocene time the above equation is applied to the fossil leaf assemblages of Oodlabari area and observed that the MAP value is 448 mm. When this MAP value has been compared with the present MAP value of fossil localities (Siliguri 279 mm, nearest station) in the Himalayan foothills and it has been seen that their average MAP value is reduced by 169 mm. This difference in MAP value of the present and past is much higher which can affect the climatic condition as well as the flora of the region.

The MAP value estimated from the fossil leaf assemblages of Oodlabari area has also been compared with the present MAP value of those regions (North east India and south India) where nowadays, most of the comparable species of the fossils are growing luxuriantly and also found that its value is greater than their MAP value, as the MAP value of North east India (i.e. Assam 274 mm, Kuchagaon 335 mm,) and south India (Kerala 278 mm and Karnataka 281 mm.)

Thus, from the foregoing discussion it may be concluded that Oodlabari and nearby area in Himalayan foothills of West Bengal enjoyed a tropical climate (with MAT 28.9ºC and MAP 448 mm) along with plenty of rainfall during the Miocene times. This is, however, contrary to the present day climate of the area with reduced precipitation.

PHYTOGEOGRAPHY

Phytogeography deals with the study of the geographic distribution of plant with the affect of climatic parameters (especially temperature and precipitation). When we going on high mountain we quickly become aware of the impact of cooling temperature and higher precipitation on local vegetation types. That is why, there is a clear relationship between mean annual temperature and distribution of flora. On the basis of this phenomenon various latitudinal zone/ classification schemes have been developed to reflect site–specific condition of climate and vegetation in both mountain as well as low land areas. Thus, the 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 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 through Myanmar. 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 even Fabaceae which were present before the Palaeogene in South–east Asia appeared in the Neogene on the Indian subcontinent.

The present day distribution of modern equivalents of all 91 species recovered from the Siwalik of Oodabari area shows that they are presently known to grow in different geographical regions all over India, Nepal and other places mostly South east Asian region (Table 6; Fig. 7). In India, they are distributed mainly in north east and southern regions wherever favourable climatic conditions are available. In this assemblage, there are about 43% those taxa which are found to grow both in India and Malaya peninsula 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.

About 19% taxa in the present assemblage have their modern relatives with a restricted distribution in the South–east Asian region suggesting that these taxa migrated from South east Asia to India during Neogene and flourished around Oodlabari area at the time of deposition of Siwalik sediments. Later on, they disappeared from the area probably due to change in climatic conditions.

Similarly, 16% taxa in the present assemblage have their modern relatives distributed presently in north–east India, Bangladesh and Myanmar (Table 6, Fig. 7). This suggests that these taxa were present during Miocene in the foothills near Oodlabari area but do not grow nowadays there and thus they have migrated toward east in Assam, Bengal, Sikkim, Meghalaya, Bangladesh and Myanmar because of better favourable conditions.

The floral assemblage also indicates that there are few taxa which are found to grow still at different altitudes in the foothills around Oodlabari and adjoining areas (Table 6) which suggest that they have susceptibility to adopt in the new climatic conditions prevailing after Mio–Pliocene mainly due to further rise of Himalaya.

On the basis of present day distribution of modern equivalents of the fossil assemblage recovered from Oodlabari area the whole fossil floral taxa can be classified into three types:

(i) Extant taxa: Those taxa which have their living counterparts growing in or near the fossil locality.

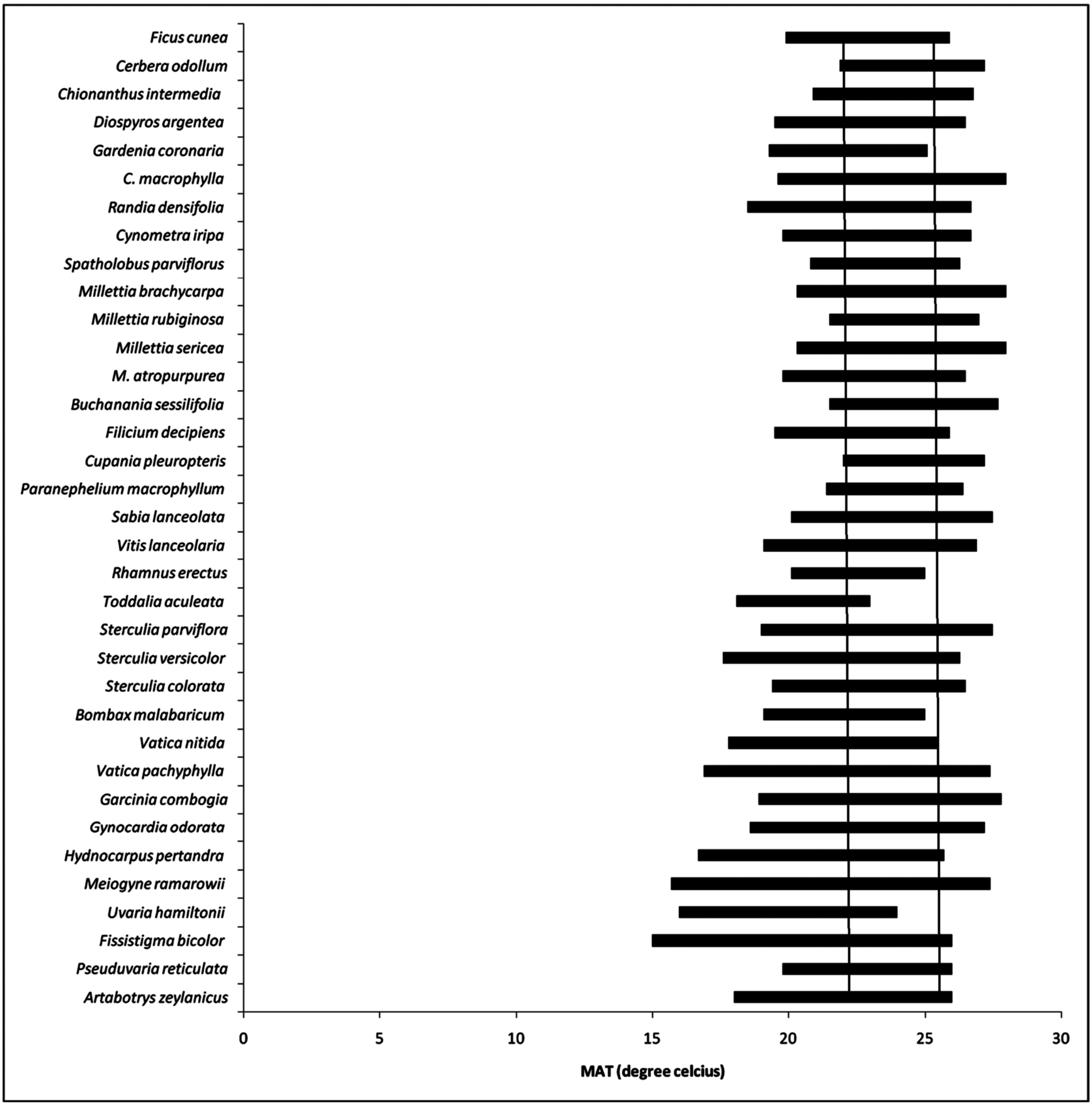

Fig. 6a—Showing the coexistence intervals of climatic parameter, Mean Annual Temperature (MAT) of modern relatives of all the 35 taxa recorded from Oodlabari area, Darjeeling District, West Bengal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of MAT.

(ii) Exotic taxa: Those taxa which grow in other parts of India.

(iii) Extirpated taxa: Those taxa which have disappeared from Indian regions and now grow in other parts of the world.

These patterns of plant distributional indicate that there may be two possible explanations for these distribution patterns. 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 foothills in the study area by dispersal from other subcontinents, most probably at the time of former land connections or from other areas of India, but subsequently became extinct.

The Siwalik fossil assemblage is mainly represented by the members of the tropical families Anonaceae, Flacourtiaceae Fabaceae, Dipterocarpaceae and Anacardiaceae

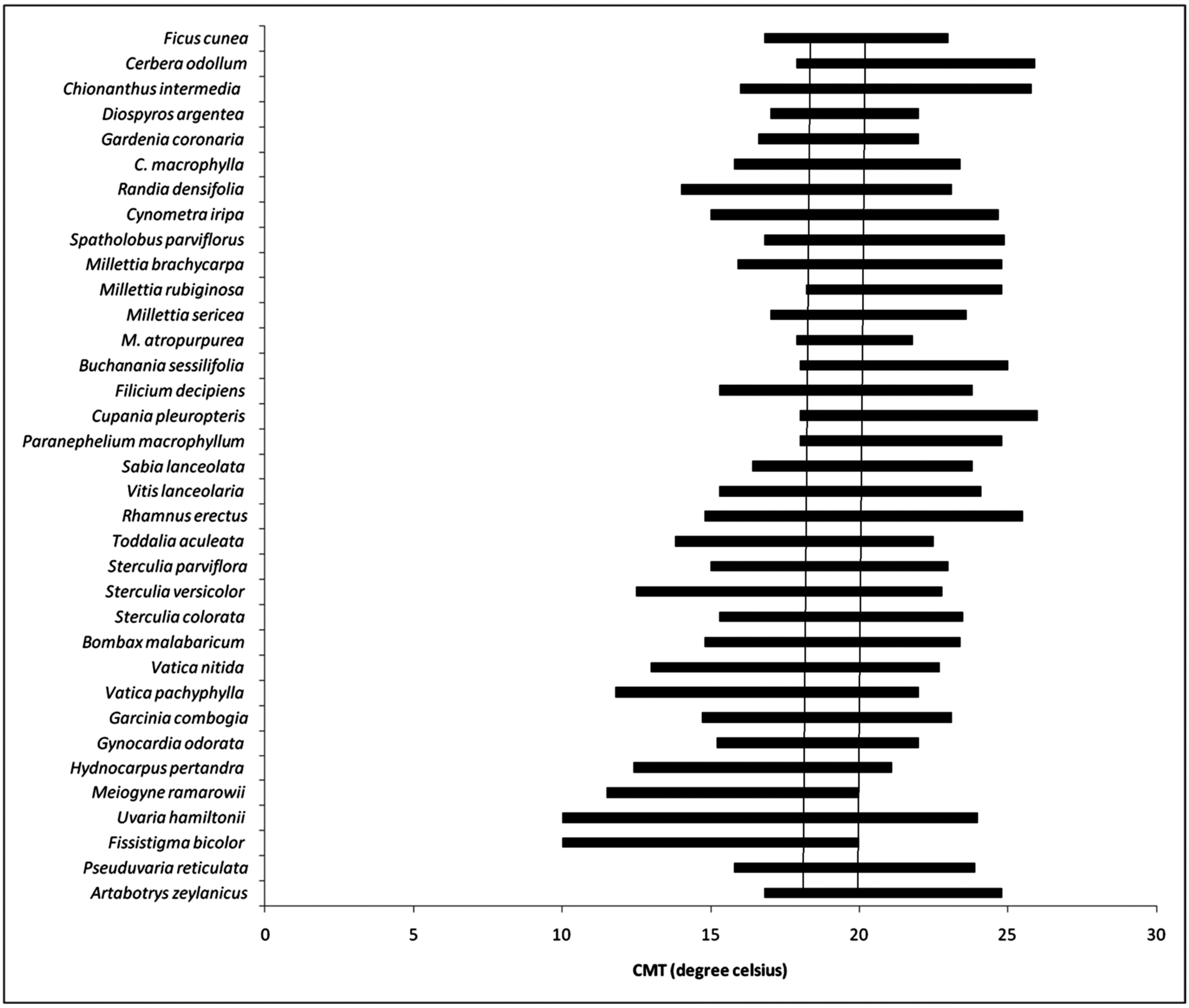

Fig. 6b—Showing the coexistence intervals climatic parameter, Mean Temperature of Coldest Month (CMT) of modern relatives of all the 35 taxa recorded from Oodlabari area, Darjeeling District, West Bengal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of CMT.

(Table 6, Fig. 3). The fossil record of these families shows that they were abundant in other parts of India and Nepal in the Neogene Period (Bande & Prakash, 1986; Prasad, 2008,) 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 those land area where they were flourishing in the Palaeogene Period.

From phytogeographical point of view, Dipterocarpaceae may be regarded as an important family. The present and past distribution of the family indicates that it is pantropical and specially belongs to tropical Asia except for two genera *Marquesa* and *Monotes* which are distributed in the Africa. 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 eastward to Philippines and northward through Myanmar to India. The possible time of the southwest migration was Early Miocene when the land connections between Malaya, Myanmar and eastern India were established. The abundance of dipterocarps such as *Dipterocarpus, Anisoptera, Isoptera, Shorea, 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 foothills where they are still flourishing. The

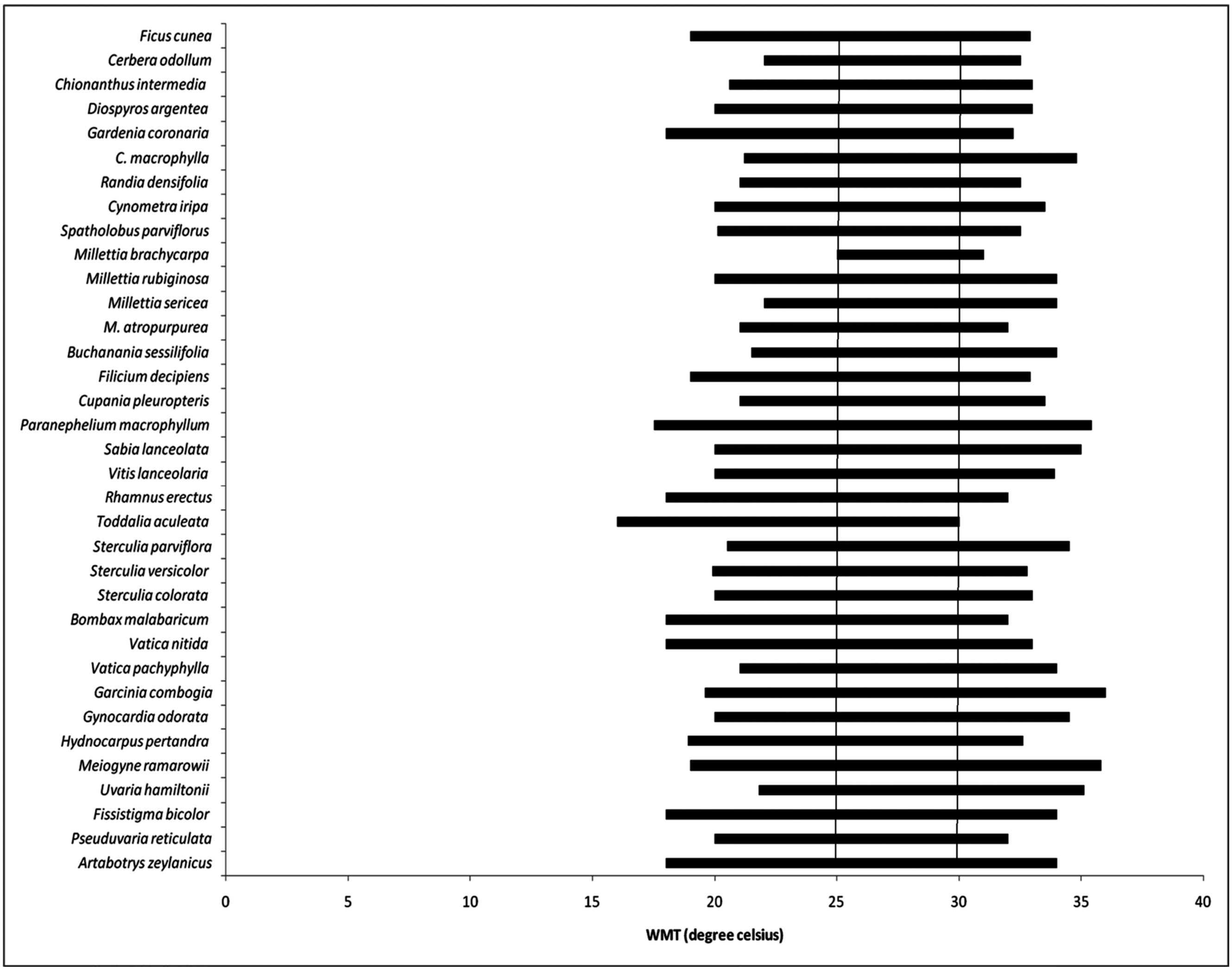

Fig. 6c—Showing the coexistence intervals of climatic parameter, Mean Temperature of Warmest Month (WMT) of modern relatives of all the 35 taxa recorded from Oodlabari area, Darjeeling District, West Bengal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of WMT.

occurrence of dipterocarpaceous remains (fossil woods, leaves, fruits impressions) in the Himalayan foothills (Prasad, 2008; Table 6) and the Tertiary beds of Africa (Bancroft, 1933; Chiarugi, 1933) suggest that from eastern India the dipterocarps also spread westward into Africa most probably via Arabia (Lakhanpal, 1970; Seward, 1935).

There are two competing hypotheses for the explanation of origin and phytogeography of the Asian dipterocarps (Merril, 1923; Ashton, 1982). One hypothesis says that the dipterocarps originated on the Eurasian Plate possibly in the Malaysian region and migrated westward and towards South Asia/ India and Africa. These originated there in the Late Mesozoic and migrated into India during Late Cenozoic Era (Lakhanpal, 1970; Sasaki, 2006). The other hypothesis suggested that the dipterocarps originated in Gondwana (Croizat, 1952; Ashton, 1982) and reached Asia by rafting on the Indian Plate (Dayanandan *et al.,* 1999; Decousso *et al.,* 2004). Moreover, the fossil resin chemistry and palynological data from 50 Ma old sediments suggest that the Asian dipterocarps migrated from India into Asia as the land connection between the Indian and the Asian Plates was established at ca. 50 Myrs ago (Scotese, *et al*, 1988; Rowley 1996; Dutta *et al*., 2011). This view is strongly supported by the earliest record of fossil dipterocarps from Oligocene sediments (34–24 Ma) of Borneo, a centre of presently high diversity of dipterocarps with more than 280 species (Muller, 1981). According to Morley (2000) the dipterocarps originated within the Late Cretaceous rain forest of Africa or South America before they split. Like the rain forest, the family Dipterocarpaceae probably also experienced widespread expansion under the climatic optimum from the Palaeocene to the Middle Eocene. The diversification of the dipterocarps in Africa and South America are rarely documented in the fossil record (Ashton, 1982) perhaps due to the unfavourable

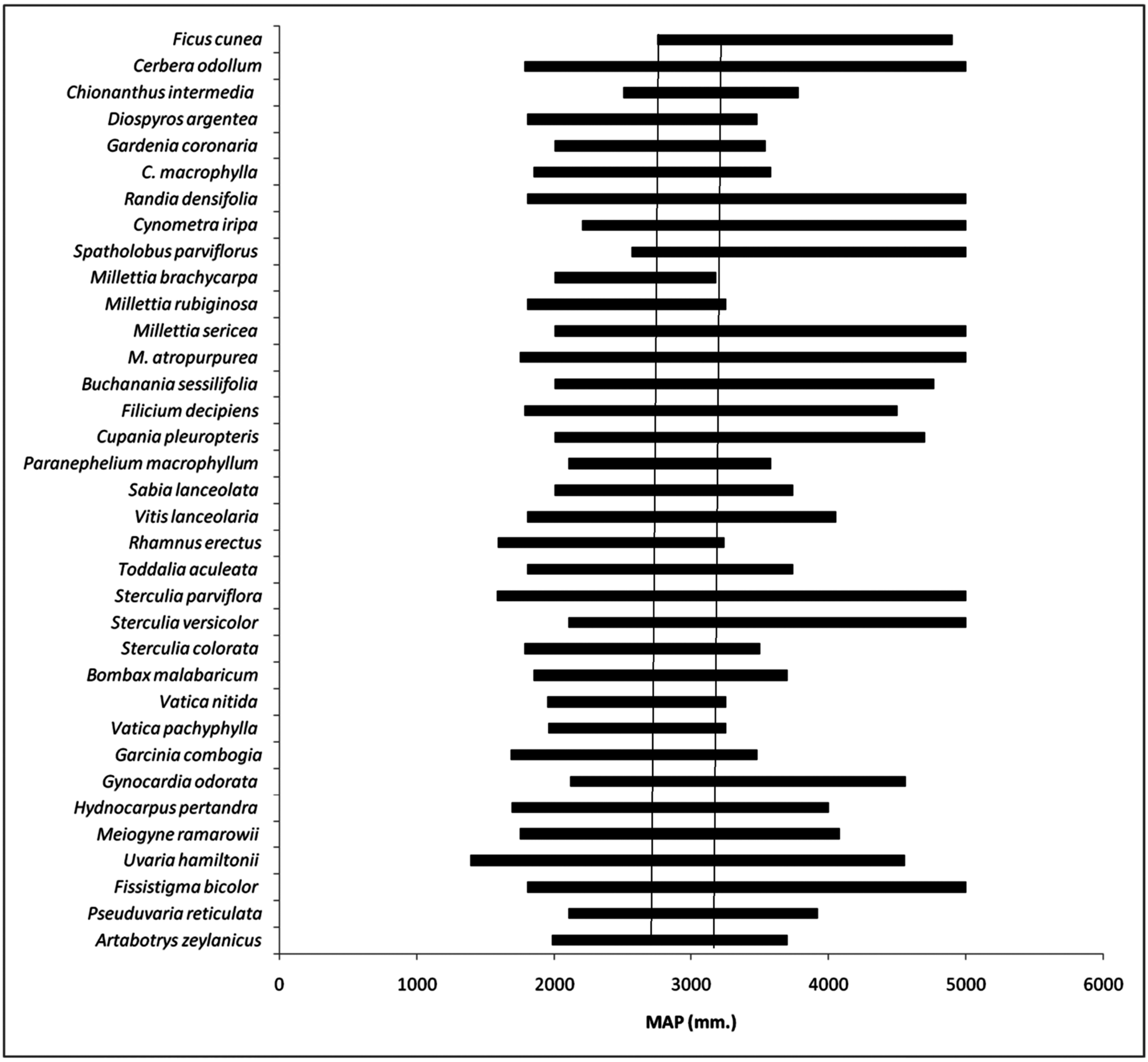

Fig. 6d—Showing the coexistence intervals of climatic parameter, Mean Annual Precipitation (MAP) of modern relatives of all the 35 taxa recorded from Oodlabari area, Darjeeling District, West Bengal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of MAP.

depositional environment. The earliest fossil record of this family based on resin and pollen grain from early Eocene of western India. (Dutta *et al*., 2011) indicates the wide spread existence of the Asian sub family Dipterocarpoideae in the early Eocene extremely equatorial climate of the Indian Plate prior to the early Eocene collision of India with Asia (Morley 2000; Copley *et al*., 2010). Due to climatic change during the Late Eocene and Oligocene the diversification of dipterocarps decreases across the Indian sub continent (Morley 2000). The occurrence of fossil leaves of *Dipterocarpus* in the early Miocene sediments of north west India (Guleria *et al*., 2000) indicates the continuity of this family from Oligocene. In the Middle Miocene climate became warmer and moister due to uplift of the Himalaya (Morley, 2000) and made suitable for a drastic increase in their species diversity and became a dominant group in the forests of the Indian sub continent as evidenced by geological distribution and diversification during Miocene Period (Prasad, 2008; Guleria, 1992). On increasing aridity and seasonality after Late Miocene and Pliocene the climatic conditions became unsuitable for the growth of dipterocarps and thus started towards their gradual disappearance alongwith the other moist loving species of

Table 7—Showing distribution of modern comparable taxa of fossil assemblage recovered from Siwalik of Oodlabari, Darjeeling District, West Bengal in different types of tropical forest.

Fossil taxa	**Allied modern comparable species**	**Wet evergreen forests**	**Semi-evergreen forests**	**Moist deciduous forests**	**Littoral and swamp forests**	**Dry deciduous forests**	**Thorn deciduous forests**	**Dry evergreen forests**
Bambusa sp. Antal & Awasthi, 1993	*Bambusa* sp.			+				
Dillenia palaeoindica Prasad & Prakash, Antal & Awasthi, 1993	*Dillenia indica* Linn.	+	+		+			
Clinogyne ovatus Awasthi & Prasad; Antal & Prasad, 1995	*Clinogyne grandis* Benth. & Hook.			+				
Mitrephora siwalika Antal & Awasthi, 1993	*Mitrephora maingayi* Hook.f. & Th.	+						
Artabotrys siwalicus n. sp.	*Artabotrys zeylanicus* Hook.f. & Th.	+						
Cananga tertiara Prasad, 1994c	*Cananga odorata* Hook.f. & Th.	+						
Pseuduvaria mioreticulata n. sp.	*Pseuduvaria reticulata* (Blume) Miq.			+				
Fissistigma senii Lakhanpal, 1969	*Fissistigma bicolor* (Roxb.) Merr.	+	+	+				
Polyalthia palaeosiamiarum Awasthi & Prasad, Antal & Prasad, 1996	*Polyalthia siamiarum* Bl.	+						
Uvaria ghishia Antal & Prasad, 1998	*Uvaria hirsuta* Jack.	+						
Uvaria siwalica Prasad,1994c	*Uvaria hamiltonii* Hook.f. Thoms.	+	+	+				
Meiogyne sevokensis n. sp.	*Meiogyne ramarowii* (Dunn.) Gandhi	+						
Casearia pretomentosa Antal & Awasthi, 1993	*Casearia tomentosa* Roxb.		+	+				
Alsodeia palaeozeylanicum Antal & Awasthi, 1993	*Alsodeia zeylanicum* Thw.	+						
A. palaeoracemosa Antal & Prasad, 1997	*Alsodeia racemosa* H.f. & Th.	+	+	+				
A. palaeoechinocarpa Antal & Prasad, 1998	*Alsodeia echinocarpa* Korth.	+						
Flacourtia tertiara Prasad & Awasthi, Antal & Prasad, 1997	*Flacourtia inermis* Roxb.	+						
Hydnocarpus siwalicus Prasad & Awasthi, 1996	*Hydnocapus glaucescens* Blume	+						
Hydnocarpus ghishiensis n. sp.	*Hydnocarpus pertandra* Buch.-Ham.	+						
Hydnocarpus palaeokurzii Antal & Awasthi, 1993	*Hydnocarpus kurzii* (King) Warb.	+	+					
Gynocardia butwalensis Konomatsu & Awasthi, 1999	*Gynocardia odorata* R. Br.	+						
Calophyllum suraikholaensis Awasthi & Prasad, Antal & Awasthi, 1993	*Calophyllum polyanthum* Wall.	+						
Garcinia eocambogia Prasad, 1994c	*Garcinia cambogia* Roxb.	+						
Shorea siwalika Antal & Awasthi, 1993	*Shorea assamica* Dyer	+	+					
S. miocenica Antal & Prasad, 1996	*Shorea buchananii* C.E.C. Fischer	+						
S. bengalensis Antal & Awasthi, 1997	*S. roxburghii* (*S. talura* Roxb.)	+						

Dipterocarpus siwalicus Lakhanpal & Guleria, Antal & Prasad, 1996b	*Dipterocarpus tuberculatus* Roxb.	+	+	+				
Hopea siwalika Antal & Awasthi, 1993	*Hopea wightiana* Wall.	+						
Hopea kathgodamensis Prasad, Antal & Prasad, 1998	*Hopea micrantha* Hook.f.	+						
Vatica siwalica n. sp.	*Vatica pachyphylla* Merr.	+						
Vatica prenitida n. sp.	*Vatica nitida* A. DC.	+		+				
Bombax palaeomalabaricum n. sp.	*Bombax malabaricum* DC.			+				
Pterospermum palaeoheyneanum Antal & Awasthi, 1993	*Pterospermum heyneanum* Wall.			+				
Sterculia miocolorata n. sp.	*Sterculia colorata* Roxb.		+	+				
Sterculia siwalica n. sp.	*Sterculia versicolor* Wall.	+	+	+				
Sterculia mioparviflora n. sp.	*Sterculia parviflora* Roxb.	+	+	+				
Pterospermum mioacerifolium Prasad *et al.*, 2009	*Pterospermum acerifolium* (L.) Willd.	+	+	+				
Toddalia miocenica n. sp.	*Toddalia aculeata* Pers.	+	+	+				
Grewia ghishia Antal & Awasthi, 1993	*Grewia umbellifera* Bedd.	+						
G. tistaensis Antal & Prasad, 1998	*Grewia tilaefolia* Vahl.			+				
Xanthophyllum mioflavescens Antal & Prasad, 1996a	*Xanthophyllum flavescens* Roxb.	+						
Bursera preserrata Antal & Awasthi, 1993	*Bursera serrata* Colebr.	+	+					
Beddomia palaeoindica Antal & Prasad, 1998	*Beddomia indica* Hook.f.	+						
Ziziphus palaeoapetala Antal & Prasad, 1997	*Ziziphus apetala* Hook.f. Th.			+		+		
Ventilago tistaensis Antal & Prasad, 1997	*Ventilago calyculata* Thw.			+		+		
Rhamnus siwalicus n. sp.	*Rhamnus erectus*	+	+	+				
Vitis siwalica n. sp.	*Vitis lanceolaria* (Roxb.) Wall.	+						
Sabia eopaniculata Prasad, 1994e	*Sabia lanceolata* Colebr.	+						
Paranephelium seriaensis Prasad & Dwivedi, 2008	*Paranephelium xestophyllum* Miq.	+						
Paranephelium miocenica Prasad *et al.*, 2009	*Paranephelium macrophyllum* King	+						
Cupania oodlabariensis n. sp.	*Cupania pleuropteris* var. *apiculata* Hiern	+	+	+				
Euphorea longanoides	*Euphorea longana* (Lour.) Steud	+						
Filicium koilabasensis Prasad, 1994e	*Filicium decipiens* (Wight & Arn.) Hook.f.	+						
Nothopegia eutravancorica Antal & Awasthi, 1993	*Nothopegia travancorica* Bedd.	+						
Bouea premacrophylla Antal & Awasthi, 1993	*Bouea macrophylla* Grifth.	+						
Buchanania palaeosessilifolia n. sp.	*Buchanania sessilifolia* Blume			+				
Swintonia miocenica Antal & Prasad, 1996a	*Swintonia floribunda* Grifth.	+						
Bauhinia ramthiensis Antal & Awasthi, 1993	*Bauhinia acuminata* Linn.			+				
Cynometra tertiara Antal & Awasthi, 1993	*Cynometra cauliflora* Linn.	+						
Cynometra palaeoiripa Prasad *et al.,* 1999	*Cynometra iripa* Kotel.			+		+		
Albizia palaeolebbek Antal & Awasthi, 1993	*Albizia lebbek* Benth.		+	+				

Millettia oodlabariensis Antal & Prasad, 1996a	*Millettia albiflora* Prain.	+						
Millettia prakashii Shashi *et al.*, 2007	*Millettia atropurpurea* Benth.	+						
Millettia miosericea n. sp.	*Millettia sericea* (Vent.) W. & A.	+						
Millettia purniyagiriensis Shashi *et al.*, 2006	*Millettia rubiginosa* Wight & Arn.	+	+	+				
Millettia sevokensis n. sp.	*Millettia brachycarpa* Merr.	+						
Spatholobus siwalicus n. sp.	*Spatholobus parviflorus* (DC.) Kuntz.	+	+	+				
Pongamia siwalika Antal & Awasthi, 1993	*Pongamia pinnata* Vent.				+	+		
Dalbergia prelatifolia Khan & Bera, 2014b	*Dalbergia latifolia* Roxb.	+	+	+				
Combretum sahnii Antal & Awasthi, 1993	*Combretum deccandrum* Roxb.		+					
Terminalia miobelerica Prasad, Antal & Prasad, 1998	*Terminalia belerica* Roxb.	+	+	+				
Syzygium palaeocumini Prasad & Awasthi, Antal & Prasad, 1997	*Syzygium cumini* (Linn.) Skeels	+	+	+				
Lagerstroemia patelii Lakhanpal & Guleria, 1981	*Lagerstroemia speciosa* Pers.			+	+			
Randia miowallichii Prasad, Antal & Awasthi, 1993	*Randia wallichii* Hook.f.		+					
Randia lishensis n. sp.	*Randia densifolia* (Wall.) Benth.	+	+	+				
Chonemorpha miocenica Prasad & Awasthi, 1996	*Chonemorpha macrophylla* G. Don			+				
Gardenia precoronaria n. sp.	*Gardenia coronaria* Buch- Ham			+				
Vernonia palaeoarborea Antal & Awasthi, 1993	*Vernonia arborea* Ham.	+	+					
Diospyros koilabasensis Prasad, Antal & Awasthi, 1993	*Diospyros montana* (Var. *cordifolia)* Hyne ex. A. DC.	+						
Diospyros palaeoargentea n. sp.	*Diospyros argentea* Griff.	+	+	+				
Chionanthus siwalika n. sp.	*Chionanthus intermedia* (Wight) F. Muell.							
Alstonia mioscholaris Antal & Awasthi, 1993	*Alstonia scholaris* R.Br.	+						
Cerbera miocenica n. sp.	*Cerbera odallum* Gaertner	+	+	+				
Callicarpa siwalika Antal & Awasthi, 1993	*Callicarpa arborea* Roxb.	+	+	+				
Cinnamomum sp. Antal & Awasthi, 1993	*Cinnamomum* sp.	+	+					
Actinodaphne palaeoangustifolia Antal & Awasthi, 1993	*Actinodaphne angustifolia* Nees.	+		+				
Mallotus kalimpongensis Antal & Awasthi, 1993	*Mallotus philippinensis* Muell. Arg.		+	+				
Macaranga siwalika Antal & Awasthi, 1993	*Macaranga peltata* Muell. Arg.		+	+				
Glochidion (*Phyllanthus*) *palaeohirsutum* Antal & Prasad, 1996a	*Glochidion hirsutum* Muell.	+						
Homonoia mioriparia Antal & Prasad, 1997	*Homonoia riparia* Lour.	+						
Ficus retusoides Prasad, Antal & Awasthi, 1993	*Ficus retusa* Linn.	+	+					
Ficus precunea Lakhanpal, 1968	*Ficus cunea* Ham.	+		+				
F. oodlabariensis Antal & Awasthi, 1993	*F. benjamina* Linn.	+	+					

Angiosperms from the most parts of India (except south and north east India) (Morley, 2000; Prasad, 2008). The record of the most of the species in our findings also supports this view.

The plant fossils recovered from Siwalik sediments of Oodlabari area, Darjeeling District, West Bengal have been categorized into four types of forest taxa, i.e. Evergreen taxa, Evergreen to Moist deciduous taxa, Moist deciduous taxa and Mixed deciduous taxa (Table 6, Fig, 5). These are as follows:

(i) ***Evergreen taxa***: *Artabotrys siwalicus* n. sp., *Cananga tertiara* Prasad, 1994c, *Mitrephora siwalika* Antal & Awasthi, 1993, *Polyalthia palaeosiamiarum* Awasthi & Prasad, Antal & Prasad, 1996c, *Uvaria ghishia* Antal & Prasad, 1998, *Meiogyne sevokensis* n. sp., *Alsodeia palaeozeylanicum* Antal & Awasthi, 1993, *A. palaeoechinocarpa* Antal & Awasthi, 1998, *Flacourtia tertiara* Prasad & Awasthi, Antal & Prasad, 1997, *Hydnocarpus ghishiensis* n. sp., *Hydnocarpus palaeokurzii* Antal & Awasthi, 1993, *Gynocardia butwalensis* Konomatsu & Awasthi, 1999, *Calophyllum suraikholaensis* Awasthi & Prasad, Antal & Awasthi, 1993, *Garcinia eocombogia* Prasad, 1994d, *Shorea siwalika* Antal & Awasthi, 1993, *S. bengalensis* Antal & Awasthi, 1997, *S. miocenica* Antal & Prasad, 1996b, *Hopea siwalika* Antal & Awasthi, 1993, *Hopea kathgodamensis* Prasad, Antal & Prasad, 1998, *Vatica siwalica* n. sp., *Xanthophyllum mioflavescens* Antal & Prasad, 1996a, *Bursera preserrata* Antal & Awasthi, 1993, *Beddomia palaeoindica* Antal & Prasad, 1998, *Rhamnus siwalicus* n. sp., *Sabia eopaniculata* Prasad, 1994e, *Paranephelium seriaensis* Prasad & Dwivedi, 2008, *Filicium koilabasensis* Prasad, 1994e, *Nothopegia eutravancorica* Antal & Awasthi, 1993, *Bouea premacrophylla* Antal & Awasthi, 1993, *Swintonia miocenica* Antal & Prasad, 1996a, *Cynometra tertiara* Antal & Awasthi, 1993, *Millettia oodlabariensis* Antal & Prasad, 1996a, *Millettia prakashii* Shashi *et al.*, 2007, *Millettia miosericea* n. sp., *Millettia sevokensis* n. sp., *Pongamia siwalika* Antal & Awasthi, 1993, *Vernonia palaeoarborea* Antal & Awasthi, 1993, *Chionanthus siwalicus*, *Alstonia mioscholaris* Antal & Awasthi, 1993, *Cinnamomum* sp. Antal & Awasthi, 1993, *Actinodaphne palaeoangustifolia* Antal & Awasthi, 1993, *Macaranga siwalika* Antal & Awasthi, 1993, *Glochidion* (*Phyllanthus*) *palaeohirsutum* Antal & Prasad,

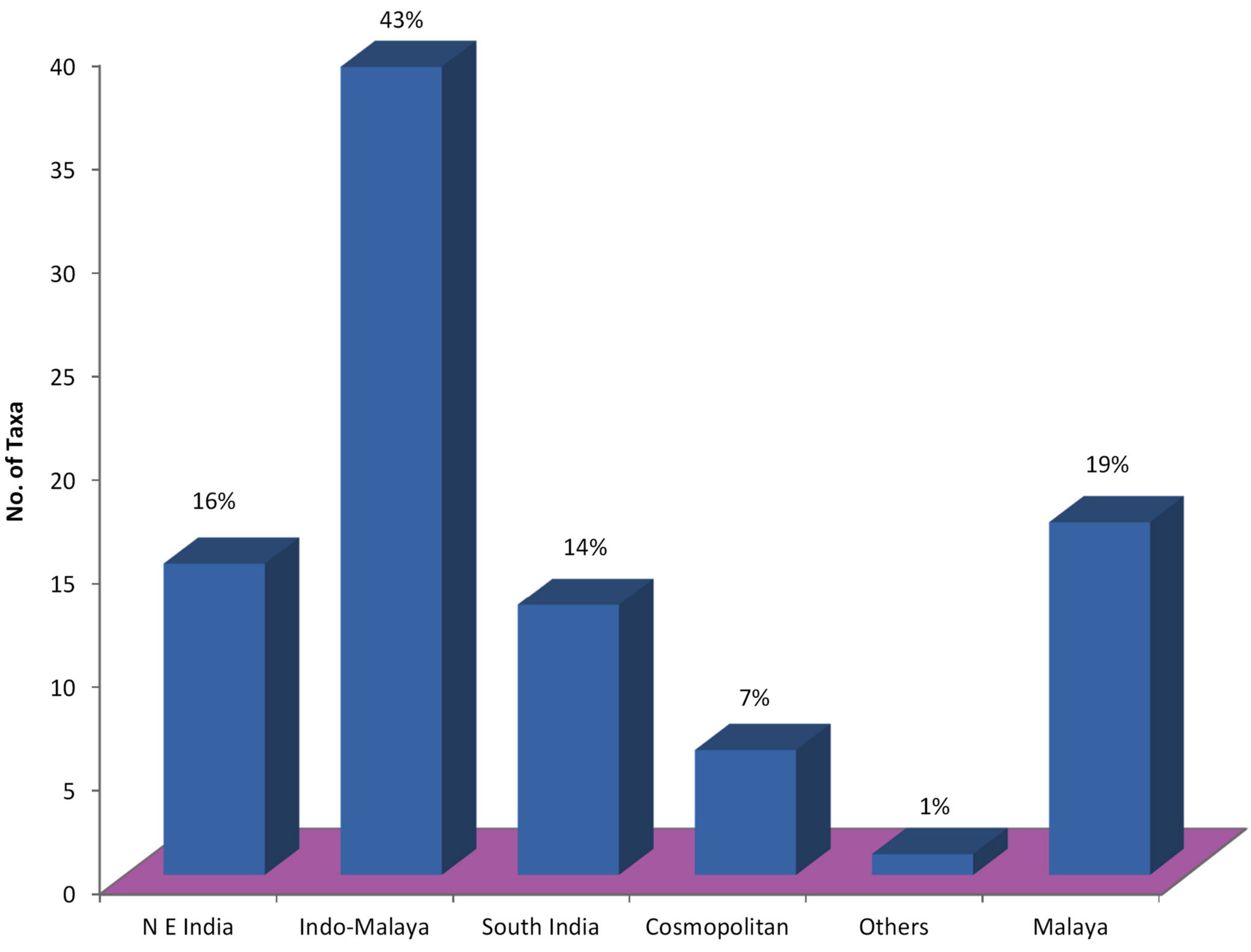

Fig. 7—Showing the distribution of modern comparable taxa of the fossil assemblage recovered from Siwalik Group of Oodlabari area, Darjeeling District, West Bengal in different geographical region.

Table 8—Physiognomic characters of the fossil leaves recorded from Siwalik sediments of Oodlabari area, Darjeeling District, West Bengal.

PHYSIOGNOMIC CHARACTERS							
Fossil Taxa	**Average leaf size sq. cm.**	**Leaf margin Entire (E) Non-entire (N)**	**Drip trips Present (P) Absent (-)**	**Leaf Texture Charta-ceous (CH) Coria-ceous (CO)**	**Leaf Base Acute (A) Obtuse (O) Cuneate (C) Cordate (CR) Attenuate (AT) Indistinct (-)**	**Leaf Organi-sation Compou-nd (C) Simple (S)**	**Venation Pattern Close (C) Distant (D)**
1	2	3	4	5	6	7	8
Bambusa sp.	38.0	E	P	CH	-	S	C
Clinogyne ovatus	79.8	E	-	CH	O	S	C
Dillenia palaeoindica	36.5	N	-	CH	A	S	C
Mitrephora siwalika	41.6	E	-	CH	O	S	C
Artabotrys siwalicus	86.9	E	P	CH	A	S	D
Cananga tertiara	58.85	E	-	CO	O	S	C
Fissistigma senii	38.27	E	P	CH	A	S	C
Polyalthia palaeosiamiarum	30.4	E	-	CH	A,O	S	C
Uvaria ghishia	54.9	E	-	CO	-	S	C
Uvaria siwalica	53.5	E	-	CH	A	S	C
Pseuduvaria mioreticulata	90.0	E	-	CH	A	S	C
Meiogyne sevokensis	27.0	E	P	CH	AT	S	C
Casearia pretomentosa	54.6	E	-	CO	O	S	C
Alsodeia palaeozeylanicum	5.25	E	-	CH	A	S	C
A. palaeoracemosa	37.5	E	P	CH	A	S	C
A. palaeoechinocarpa	91.0	N	-	CH	A	S	C
Flacourtia tertiara	34.2	N	-	CH	A	S	C
Hydnocarpus ghishiensis	36.26	E	-	CH	-	S	C
Hydnocarpus palaeokurzii	29.7	E	-	CH	A	S	C
G. butwalensis	66.81	E	-	CH	A	S	C
Calophyllum suraikholaensis	36.7	E	-	CH	C	S	C
Garcinia eocombogia	39.6	E	-	CH	-	S	C
Shorea siwalika	50.5	E	-	CH	O	S	C
S. miocenica	83.6	E	-	CO	-	S	C
Vatica siwalica	24.15	E	-	CH	A	S	C
Vatica prenitida	9.12	E	A	CH	A	S	C
S. bengalensis	66.0	E	P	CO	CR	S	C
Dipterocarpus siwalicus	85.2	E	-	CO	A, O	S	C
Hopea siwalika	15.3	E	-	CH	O	S	C
H. kathgodamensis	25.2	E	-	CH	O	S	C

Bombax palaeomalabaricum	63.72	E	-	CH	-	S	C
Xanthophyllum mioflavescens	21.0	E	-	CH	A	S	C
Pterospermum palaeoheynianum	16.4	E	-	CH	O	S	C
Pterospermum mioacerifolium	110.4	N	-	CH	-	S	D
P. siwalicum	52.8	E	-	CO	-	S	D
Sterculia miocolorata	65.5	E	-	CH	-	S	D
Sterculia siwalica	34.02	E	-	CH	A	S	C
Sterculia mioparviflora	17.76	E	-	CH	-	S	C
Toddalia miocenica	9.46	E	-	CH	A	S	C
Grewia ghishia	19.0	N	P	CH	O	S	C
G. tistaensis	65.5	N	-	CH	-	S	C
Beddomia palaeoindica	37.0	E	-	CO	O	S	C
Bursera preserrata	9.7	E	P	CH	A	S	C
Zizyphus palaeoapetata	44.0	E	-	CH	A	S	C
Rhamnus siwalicus	14.3	E	-	CH	O	S	C
Ventilago tistaensis	44.1	E	-	CH	A	S	C
Vitis siwalica	39.6	N	-	CH	A	S	C
Sabia eopaniculata	50.84	E	-	CH	A	S	C
Cupania oodlabariensis	43.26	E	-	CH	-	S	C
Paranephelium miocenica	77	E	-	CH	-	S	C
Paranephelium seriaensis	50.4	E	-	CH	A	S	C
Filicium koilabasensis	20	E	-	CH	-	S	C
Nothopegia eutravancorica	51.0	E	-	CO	A	S	C
Buchanania palaeosessilifolia	45	E	-	CH	-	S	C
Bouea premacrophylla	140.0	E	-	CO	O	S	C
Swintonia miocenica	89.1	E	P	CH	A	S	C
Bauhinia ramthiensis	38.7	E	-	CH	CR	C	C
Cynometra tertiara	19.2	E	-	CH	A	C	C
Cynometra palaeoiripa	5.33	E	P	CH	A	C	C
Albizia palaeolebbek	1.98	E	-	CH	O	C	C
Millettia oodlabariensis	50.0	E	P	CO	A	C	C
Millettia prakashii	19.95	E	-	CH	-	C	C
Millettia miosericea	24.96	E	P	CH	A	C	C
Millettia sevokensis	66.96	E	-	CH	-	C	C
Millettia purniyagiriensis	65	E	-	CH	-	C	C
Spatholobus siwalicus	91.44	E	-	CH	O	C	C
Pongamia siwalica	33.7	E	-	CH	O	S	D
Combretum sahnii	40.0	E	P	CO	A	C	C
Terminalia miobellerica	10.8	E	P	CH	-	C	C
Syzygium palaeocumini	15.8	E	P	CH	A	S	C
Lagerstroemia patelii	71.2	E	P	CO	A	S	C
Gardenia precoronaria	64.3	E	-	CH	-	S	C
Randia miowallichi	30.4	E	-	CO	A	S	C

Randia lishensis	67.62	E	-	CH	-	S	C
Cerbera miocenica	57.72	E	-	CO	AT	S	C
Alstonia mioscholaris	14.3	E	-	CO	C	S	C
Vernonia palaeoarborea	57.2	E	-	CH	A	S	C
Diospyros koilabasensis	8.3	E	-	CH	CR	S	C
Diospyros palaeoargentea	74.52	E	-	CO	-	S	C
Chonemorpha miocenica	80	E	-	CH	-	S	C
Chionanthus siwalicus	23.65	E	-	CH	O	S	C
Callicarpa siwalika	87.5	E	-	CH	O	S	C
Cinnamomum sp.	50.0	E	-	CO	O	S	C
Actinodaphne palaeoangustifolia	7.5	E	-	CH	A	S	C
Mallotus kalimpongensis	27.5	E	-	CH	A	S	C
Macaranga siwalika	36.4	N	-	CO	Peltate	S	C
Glochidion (Phyllanthus) palaeohirsutum	34.2	E	-	CH	-	S	C
Homonoia mioriparia	16.8	E	-	CH	A	S	C
Ficus retusoides	18	E	-	CO	-	S	C
Ficus precunea	58.8	N, E	-	CH	CR	S	C
F. oodlabariensis	30.8	E	-	CO	O	S	C

1996a, *Homonoia mioriparia* Antal & Prasad, 1997, *Ficus retusoides* Prasad, Antal & Awasthi 1993, *Vitis siwalica* n. sp

(ii) ***Evergreen and Moist deciduous taxa:*** *Dillenia palaeoindica* Prasad & Prakash, Antal & Awasthi, 1993, *Pseuduvaria mioreticulata* n. sp., *Fissistigma senii* Lakhanpal, 1969, *Uvaria siwalica* Prasad, 1994c, *A. palaeoracemosa* Antal & Prasad, 1997, *Dipterocarpus siwalicus* Lakhanpal & Guleria, 1982, Antal & Prasad, 1996b, *Vatica prenitida* n. sp., *Sterculia siwalica* n. sp., *Sterculia mioparviflora* n. sp., *Pterospermum mioacerifolium* Prasad *et al.,* 2009, *Toddalia miocenica* n. sp., *Paranephelium miocenica* n. sp., *Cupania oodlabariensis* n. sp., *Millettia purniyagiriensis* Shashi *et al*., 2006, *Spatholobus siwalicus* n. sp., *Terminalia miobelerica* Prasad, Antal & Prasad, 1998, *Syzygium palaeocuminii* Prasad & Awasthi, Antal & Prasad, 1997, *Randia miowallichii* Prasad, Antal & Awasthi, 1993, *Randia lishensis* n. sp., *Cerbera miocenica* n. sp., *Ficus precunea* Lakhanpal.

(ii) ***Moist deciduous:*** *Clinogyne ovatus* Awasthi & Prasad; Antal & Prasad, 1995, *Bombax palaeomalabaricum* n. sp., *P. siwalicum* Antal & Prasad, 1996a, *Sterculia miocolorata* n. sp., *Grewia ghishia* Antal & Awasthi, 1993, *G. tistaensis,* Antal & Prasad, 1998, *Buchanania palaeosessilifolia* n. sp., *Bauhinia ramthiensis* Antal & Awasthi, 1993, *Albizia palaeolebbek* Antal & Awasthi, 1993, *Lagerstroemia patelii* Lakhanpal & Guleria, 1981, *Chonemorpha miocenica* Prasad & Awasthi, *Gardenia precoronaria* n. sp., *Diospyros koilabasensis* Prasad, Antal & Awasthi, 1993, *Diospyros palaeoargentea* n. sp., *Callicarpa siwalika* Antal & Awasthi, 1993, *F. oodlabariensis* Antal & Awasthi.

(iv) ***Mixed deciduous:*** *Bambusa* sp. Antal & Awasthi, 1993, *Casearia pretomentosa* Antal & Awasthi, 1993, *Pterospermum palaeoheynianum* Antal & Awasthi, 1993, *Ziziphus palaeoapetala* Antal & Prasad, 1997, *Ventilago tistaensis* Antal & Prasad, 1997, *Cynometra palaeoiripa* Prasad *et al.,* 1999, *Combretum sahnii* Antal & Awasthi, 1993, *Mallotus kalimpongensis* Antal & Awasthi 1993.

The evergreen taxa dominate the assemblage. This obviously indicates that tropical evergreen forests were growing around Oodlabri area during 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 fossil locality have got migrated to other phytogeographical regions due to unfavourable climatic conditions that prevailed after Mio–Pliocene Period most probably due to the uplift of Himalaya.

CONCLUSIONS

The present systematic study on plant megafossils added significant data to the Tertiary Palaeobotany. On the basis of present assemblage as well as already known data from the area, the palaeoclimate and phytogeography of the area during Miocene in the Himalayan foothills of West Bengal have been deduced. The palaeoclimate reconstruction has also been made by using both Coexistence and physiognomic approach.

Systematic description, identification, Fossil records and comparison as well as present day distribution of all the 35 fossil species have been individually discussed in details.

The morphotaxonomical study on the fossil plant assemblage (leaf impressions) collected from Middle Siwalik sediments of Oodlabari area, West Bengal has been carried out which revealed the occurrence of 35 species of 18 angiospermous families. Of these, 24 species have been recorded new to the fossil flora of Siwalik Group. These are *Artabotrys siwalicus, Meiogyne sevokensis, Pseuduvaria mioreticulata, Hydnocarpus ghishiensis, Vatica siwalica, V. prenitida, Bombax palaeomalabaricum, Sterculia siwalica, S. mioparviflora, S. miocolorata, Toddalia miocenica, Rhamnus siwalicus, Vitis siwalica, Paranephelium miocenica, Cupania oodlabariensis, Buchanania palaeosessilifolia, Millettia miosericea, M. sevokensis, Spatholobus siwalicus, Randia lishensis, Gardenia precoronaria, Diospyros palaeoargentea, Chionanthus siwalicus* and *Cerbera miocenica*.

The assemblage is predominated by large woody plants/ trees (45 species). The remaining species are small trees and woody shrubs (27 species), shrubs (16 species) and climbers (3 species). The herbs are totally absent.

The family Fabaceae (Legume family) represented by 11 species is the most dominant family in this Siwalik fossil assemblage followed by Anonaceae (9 species), Flacourtiaceae (8 species), Dipterocarpaceae (7 species), Sterculiaceae (6 species) and Sapindaceae, Anacardiaceae and Euphorbiaceae (4 species). The family Fabaceae which appeared in Upper Palaeocene became a major component of the evergreen forest during Mio–Pliocene times all along the Himalayan foothills.

The evergreen elements (52%) dominate the fossil flora of Siwalik in Oodlabari area in the foothills of West Bengal during Miocene in contrast to mixed deciduous elements at present. The predominance of evergreen elements such as *Mitrephora maingai, Meiogyne ramarowii, Hydnocarpus pertandra, Garcinia cambogia, Calophyllum polyanthum, Shorea assamica, S. roxburgii, S. buchananii, Dipterocarpus* spp., *Hopea wightiana, H. micrantha, Bursera serrata, Vitis lanceolata, Nothopegia travancorica, Bouea macrophylla, Swintonia floribunda, Millettia* spp., *Vernonia arborea, Actinodaphne angustifolia* and *Ficus retusa* in the Siwalik fossil assemblage indicates the prevalence of tropical warm humid climate with plenty of rainfall during the deposition of Siwalik sediments.

The analysis of present day distribution of fossil analogue all the species recovered from the area they are mostly known to occur in Indo–Malayan regions, Northeast India, Bangladesh, Myanmar and Malaysia wherever favourable climatic conditions exist. Only about 26% taxa of the total assemblage are found to grow presently in the Himalayan foothills and the remaining 74% taxa are locally extinct, suggesting changes in the climatic condition.

On the basis of present fossil assemblage, the coexistence intervals of different climatic parameters like Mean annual temperature (MAT), temperature of warmest month (WMT), and coldest month (CMT), as well as Mean annual precipitation (MAP) have been obtained as follows:

MAT (Mean Annual Temperature) 22ºC–26.5ºC

CMT (Mean Annual Temperature of Coldest Month) 17.8ºC–20ºC

WMT (Mean Annual Temperature of Warmest Month) 25ºC–30ºC

MAP (Mean Annual Precipitation) 2650–3200 mm

Foliar physiognomic approach for reconstruction of palaeoclimate suggests that the Oodlabari area in the Himalayan foothills of West Bengal enjoyed a tropical climate (with MAT 28.9ºC and MAP 448 mm) along with plenty of rainfall during the Miocene Period. This is, however, contrary to the present day climate of the area with reduced precipitation.

The dominance of entire margined species (82 species) in the fossil leaf assemblage, suggests that a warm tropical climate was prevailed during the Middle Siwalik period in the vicinity of Darjeeling foothills.

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