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Plant macrofossils from the sedimentary sequence of Churia Group, Nepal : their phytogeographic and palaeoclimatic significance

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ABSTRACT

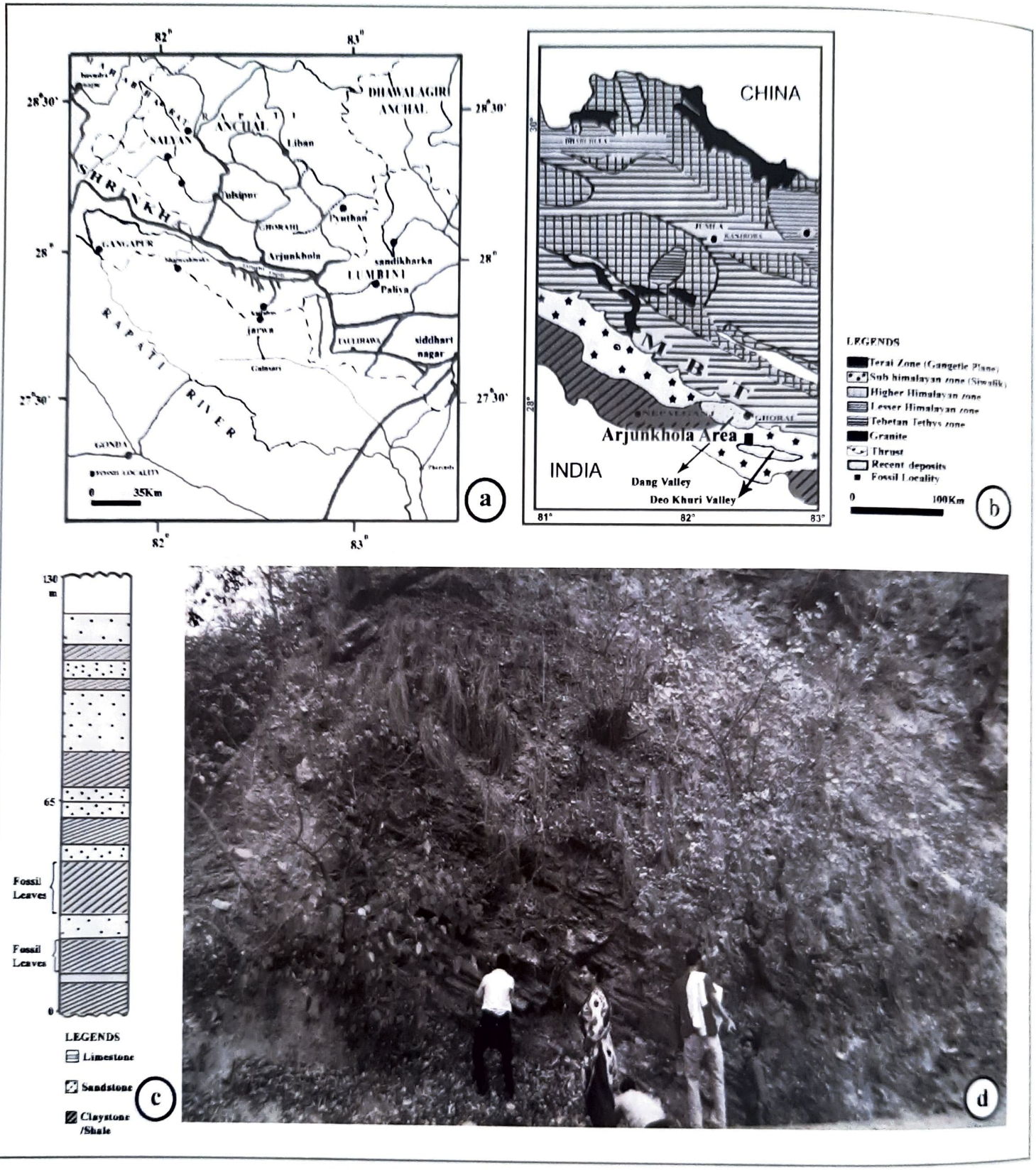
In the present investigation, taxonomic studies were carried out on recently discovered plant macrofossils from the Churia Group (Miocene) of sediments exposed in the Arjun Khola area, Nepal. The present study has revealed occurrence of sixteen fossil species belonging to twelve tropical dicotyledonous families. Of these, eleven species are recorded for the first time from the Miocene of Nepal. As the nearest living relatives of the macroflora reported here, are restricted to the northeast part of India and southeastern Asia, it is plausible that tropical forests and moist conditions were prevalent during the Miocene times in this region. The above inferences have been corroborated using the Coexistence Approach (CoA) analysis for palaeoclimate estimation. It also indicates prevalence of tropical climatic conditions during the Miocene in the Arjun Khola area, with Mean Annual Temperature (MAT) of about 20°-28.5°C, Warm Month Temperature (WMT) of about 29°-34°C, Cold Month Temperature (CMT) of about 15°- 22°C and Mean Annual Precipitation (MAP) of about 1800 mm-3200 mm.

Key-words: Arjun Khola, Churia Group, Dicotyledonous plant macrofossils, Miocene, Nepal, Palaeoclimate, Phytogeography.

INTRODUCTION

Numerous plant macrofossils comprising of angiosperm leaves, fruit and seed impressions have been reported previously from the Churia Group (Prasad & Awasthi 1996, Prasad & Pradhan 1998, Prasad et al. 1999, Konomatsu & Awasthi 1999, Prasad & Khare 2004, Prasad 2007, Prasad & Dwivedi 2008). These fossils are known from numerous localities of Nepal viz., Koilabas, Surai Khola, Butwal, Tinau Khola, Binai Khola, Arjun Khola and Surkhet. In view of the meager work done on this aspect from the Arjun Khola area of Nepal exposing Churia Group of sediments, the present investigation has been carried out to study the plant macrofossils from this locality.

The study area (27° 53' 42.8"N: 82° 30' 31.4"E) lies in the Deukhuri District of Rapti Anchal, western Nepal and is easily approachable by metalled road originating from Mahendra Highway situated about 3 km west of Lamhi (27° 52' 24.9"N : 82° 32' 22.4"E), a famous town of Deukhuri Valley (Text-fig. 1a). A well-developed sequence of Churia Group is exposed in the Arjun Khola area all along the Arjun River and the road leading to Ghorai covering a distance of 15 km. The sediments consist of clays, shales, sandstones and siltstones. The plant macrofossils reported in the present study were recovered from the thinly bedded splintery shales.



Text Figure 1a-d. a) Location of study area, Arjun Khola, Nepal **b)** Geological map of the study area, **c)** Lithocolumn of Profile-5A showing fossiliferous levels, **d)** Field photograph of the studied section, Arjun Khola, Nepal.

GEOLOGICAL SETTING

The Churia Group sedimentary sequence is delimited by the Main Frontal Thrust (MFT) in the south and by the Main Boundary Thrust (MBT) in the north. The sedimentary sequence of Churia Group consists of Neogene fluvial deposits ranging in age from Miocene (~15 Ma) to the Pliocene (~3 Ma) (Tokuoka 1994). Almost a complete and uninterrupted sequence of Churia Group is well exposed all along the road from Arjun Khola to Ghorai (Text figs. 1a, b, c and d). The

lithology and stratigraphy of the Churia Group has been discussed in detail, by Gleinnie & Ziegler (1964), Sharma (1980), Kumar & Gupta (1981), Chaudhuri (1983), Tokuoka et al. (1986), Corvinus (1990) and Appel et al. (1991). Gleinnie & Ziegler (1964) classified the Churia Group into two formations: Lower Churia Formation (Sandstone facies) and Upper Churia Formation (Conglomerate facies). The sandstone facies often contains plant fossils associated with paleosols. Later, Chaudhuri (1983) divided the Churia Group into three successive formations viz., Lower Churia, Middle Churia and Upper Churia, based on lithostratigraphic evidences. The Lower Churia Formation has an average thickness of about 1800 m and is composed of well-bedded indurated sandstones and siltstones. The Middle Churia Formation is about 2000 m thick and comprises dominantly of arenaceous rocks with clay intercalations, while the Upper Churia Formation consists of up to 2500 m thick succession, characterized by fine grained, poorly indurated sandy clays in the lower part and conglomerates in the upper part. The sedimentary sequence at Arjun Khola (study area) is divided into 14 profiles on the basis of their lithological characters and consists of an alternate sequence of sandstones and shales, with predominance of impressions of plant macrofossils within the shales.

MATERIAL AND METHODS

The fossil leaves were collected from the sedimentary sequence of Churia Group (Miocene) exposed along the Arjun Khola - Ghorai Road in Deukhuri District, Nepal. These were collected mainly from profile 5A (27° 54' 50.6"N: 82° 31' 00.4"E) of Churia Group of sediments in the Arjun Khola area (Text figs. 1a, b, c and d). Plant macrofossils were also recorded from profiles 2, 3 and 10. The leaf impressions preserved in the purple to gray shales were studied in detail with the help of hand lens and low power microscope under reflected light. The identification of leaves has been carried out at Central National Herbarium, Howrah, West Bengal. We followed the terminologies provided by Hickey 1973, Dilcher 1974 and Ash et al. 1999 for the description of fossil leaves in the present study. For co-existence analysis on the studied plant macrofossils, we followed Mosbrugger and Utescher (1997) and Utescher et al. (2014). All the fossil specimens, photographs and negatives have been deposited in the Museum of Birbal Sahni Institute of Palaeosciences, Lucknow.

SYSTEMATIC PALAEOBOTANY

Order: Magnoliales

Family: Annonaceae

Genus: *Melodorum* Lour.

***Melodorum arjunkholaensis* n. sp.**

(Pl. 4, figs. 1, 3)

Diagnosis: Leaves simple, symmetrical, elliptic; 9.5 cm x 4.0 cm to 10.3 cm x 4.3 cm; apex seemingly acute; base wide obtuse; petiole normal; margin entire, texture chartaceous; venation pinnate; eucamptodromous; primary vein single, straight; secondary veins 0.5 - 1.5 cm apart, unbranched, uniformly curvature pronounced near the margin, upper secondaries more acute than lower secondaries; tertiary veins fine, angle of origin AO-RR type, percurrent, oblique in relation to mid vein.

Description: Leaves simple, symmetrical, elliptic; preserved size 9.5 cm x 4.0 cm and 10.3 cm x 4.3 cm; base wide acute; margin entire; petiole size 0.7 cm; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, straight, prominent, stout; secondary veins 11-12 pairs visible, 0.6 - 1.0 cm apart, opposite to alternate, angle of divergence 50°-60°, narrow to moderately acute, unbranched; tertiary veins poorly preserved, angle of origin AO-RR, percurrent, almost straight to branched, oblique in relation to mid vein, predominantly alternate and close.

Holotype: B.S. I. P. Museum no. 40977.

Type Locality: Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The species name is after the Arjun Khola locality, from where the fossil was recovered.

Affinity: The characteristic features of the present fossil leaves such as symmetrical, elliptic shape; seemingly acute, wide acute base, eucamptodromous venation, moderately acute angle of divergence of

secondary veins, curving upward near the margin, upper secondaries more acute than lower secondaries, usually AO-RR angle of origin, percurrent tertiaries with oblique in relation to midvein undoubtedly indicate its affinity with the modern leaves of *Melodorum fulgens* Hook. f. & Thoms. (Syn. *Fissistigma fulgens*) of family Annonaceae. (C.N.H. Herbarium sheet no.13797, 17798; Pl. 4, figs 2,4). Fossil leaves also show close resemblance with the modern leaves of *Michilus macrantha* Nees. (C.N.H. Herbarium sheet no. 75594) of family Lauraceae and *Melodorum polyanthum* Hook. f. & Th. of family Annonaceae. However, these differ in having additional number of secondary veins, as compared to the fossil specimens.

Fossil record and comparison: Fossil leaf resembling the genus *Melodorum* Lour. has been reported as the form species, *Melodorum jarwaensis* from Siwalik Group of Koilabas Village near Jarva, Uttar Pradesh (Tripathi et al., 2002). Compared to previously reported fossil leaves (*M. jarwaensis*, Tripathi et al., 2002) the present fossil differs in having a wide elliptic shape and additional secondaries (17 pairs). Hence, it has been described as a new species *Melodorum arjunkholaensis* n. sp.

The genus *Melodorum* Lour. comprises of about 35 species distributed in tropical Asia (Malaysia, Singapore, Borneo, Philippines) and Africa. *Melodorum fulgens* Hook. f. & Thoms. is a moderate sized climber distributed in Malaya Islands (Ridley 1967).

Genus: *Mitrephora* Blume

Mitrephora siwalika Antal and Awasthi, 1993

(Pl. 1, figs. 8, 10)

Description: Leaf simple, symmetrical, narrow elliptic; preserved size 9.8 cm x 3.6 cm; apex slightly broken; base wide acute; margin entire; petiole 0.3 cm, normal; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, straight, prominent, stout; secondary veins 8 pairs visible, 1.2 to 1.5 cm apart, alternate to opposite, unbranched; angle of divergence 50°-60°, moderate acute, uniformly curved upwards and sometimes join to super adjacent secondaries; intersecondary veins present, simple; tertiary veins fine, angle of origin RR type, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close.

Specimen: B.S. I. P. Museum no. 40978.

Locality: Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Affinity: The diagnostic features of the present fossil leaf are symmetrical, narrow elliptic shape, wide acute base, moderately thick and normal petiole, eucamptodromous venation, uniformly upward curvature of secondary veins with moderate angle of divergence, usually RR angle of origin, percurrent, straight to sinuous, and oblique in relation to midvein of tertiary veins. During the process of identification it has been observed that these features are found common in the modern leaves of the genus *Mitrephora* Blume of family Annonaceae. The comparative study with modern leaves of all the available species of this genus namely, *Mitrephora ferrugenea, M. fragras, M. grandiflora, M. heynenana, M. maingayi, M. multifolia, M. obtuse, M. reflexa, M. reticulate, M. rugosa, M. thorelii, M. tomentosa, M. viridifolia* and *M. williansii* suggests that the fossil leaf from Arjun Khola has closest affinity with *Mitrephora maingayi* Hook. f. & Thomson. (C.N.H. Herbarium sheet no. 13256; Pl.1, figs 9, 11).

Fossil record and comparison: Two fossil leaves resembling the modern leaves of the genus *Mitrephora* Blume have been reported from Siwalik sediments of India and Nepal. *Mitrephora siwalika* Antal & Awasthi described from Lower to Middle Siwalik of Darjeeling district of West Bengal shows resemblance with *M. maingayi* Hook. f. & Thomson (Antal & Awasthi 1993). Forms having similar affinity have also been reported from the Middle Siwalik of Surai Khola area of western Nepal (Prasad & Awasthi 1996), Lower Siwalik sediments of Bhutan (Prasad & Tripathi 2000) and Uttarakhand, India (Shashi et. al. 2006). Another fossil species of the genus that is *Mitrephora miocenica* (Prasad et al. 1997) described from Lower Siwalik sediments of Serianaka near Jarwa, Gonda District, Uttar Pradesh shows closest affinity with the extant species, *M. macrophylla* Oliver. From

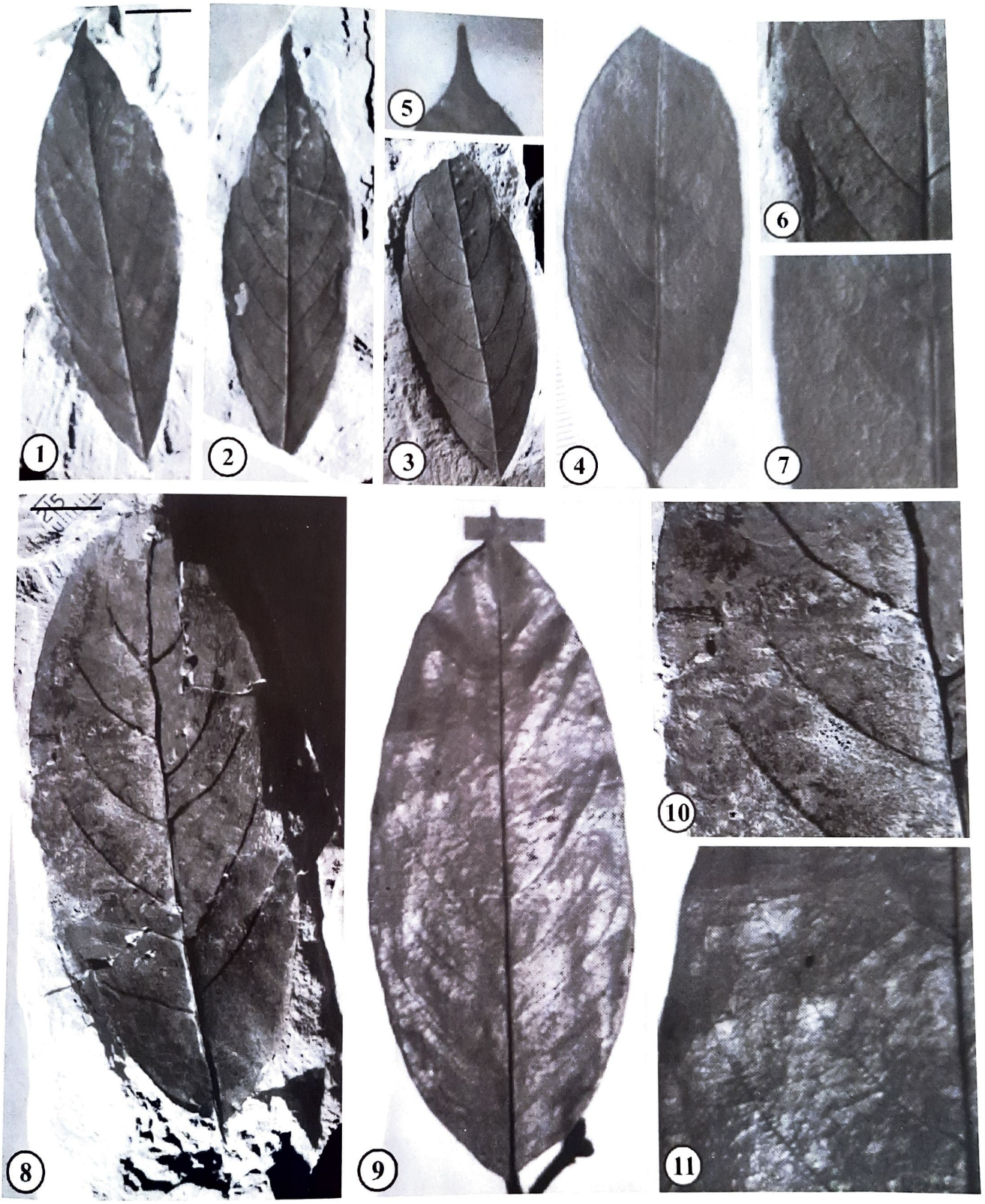


Plate 1

1-3. *Uvaria nepalensis* n. sp. - Fossil leaves showing shape, size and venation pattern. BSIP Museum no. 40979 (Holotype) 40980 and 40981 (Paratype). 4. *Uvaria calamistrata* Hance.- Modern leaf showing similar shape, size and venation pattern. 5. *Uvaria calamistrata* Hance.- Apical part of modern leaf showing acuminate type of apex as the fossil. 6. *Uvaria nepalensis* n. sp. – A part of fossil leaf magnified to show details of venation. BSIP Museum no. 40979. 7. *Uvaria calamistrata* Hance.- A part of modern leaf showing similar details of venation. 8. *Mitrephora siwalika* Antal & Awasthi - Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40978. 9. *Mitrephora maingayi* Hook. F. & Thomson - Modern leaf showing similar shape, size and venation pattern. 10. *Mitrephora siwalika* Antal & Awasthi - A part of fossil leaf magnified to show details of venation pattern. BSIP Museum no. 40978. 11. *Mitrephora maingayi* Hook. F. & Thomson - A part of modern leaf magnified to show similar details of venation pattern. (Scale bar = 1 cm).

comparative study of the above known fossils it has been found that the fossil leaf *Mitrephora siwalika* Antal & Awasthi shows closest similarity with the present fossil leaf in shape, size and venation pattern and thus, the present fossil leaf has been described as *M. siwalika* Antal & Awasthi.

The genus *Mitrephora* Blume comprises about 40 species distributed in Assam, Malaya Peninsula, Tenasserim (Myanmar), Java, Sri Lanka and Chittagong (Bangladesh). *Mitrephora maingayi* Hook. f. & Thomson with which fossil resembles closely, occurs in evergreen forest of Assam, Chittagong (Bangladesh), Martaban Hills (Myanmar), Malaya Peninsula, Java & Sri Lanka (Brandis 1971, Gamble 1972).

Genus: *Uvaria* Linn.

***Uvaria nepalensis* n. sp.**

(Pl. 1, figs. 1- 3, 6)

Diagnosis: Leaves simple, symmetrical, narrow elliptic; 5.7-7.1 cm x 2.0-2.5 cm; apex acute to attenuate; base acute; margin entire; venation pinnate; eucamptodromous; secondary veins 0.6 to 0.8 cm apart, sub-opposite to alternate, unbranched; narrow to moderately acute angle of divergence; tertiary veins fine, angle of origin RR type, percurrent, branched, close to nearly distant.

Description: Leaves simple, symmetrical, narrow elliptic; preserved size 5.7 cm x 2.5 cm, 5.9 cm x 2.0cm and 7.1 cm x 2.2cm; apex acute to attenuate; base acute; margin entire; petiole not preserved; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, straight, prominent, stout; secondary veins 6-7 pairs visible, 0.6 to 0.8 cm apart, sub-opposite to alternate, unbranched, angle of divergence 40°-60°, narrow to moderately acute, uniformly curved upwards; tertiary veins fine, angle of origin RR type, percurrent, straight to sinuous, branched, oblique in relation to mid vein, predominantly alternate, close to nearly distant.

Holotype: B.S.I.P. Museum no. 40979.

Paratype: B.S.I.P. Museum no. 4098, 40981.

Type Locality: Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The specific name is after the country, Nepal.

Affinity: The characteristic features of the present fossil leaves viz., acute to attenuate apex, acute base, eucamptodromous venation, acute angle and sub-opposite to alternate arrangement of secondaries, RR, percurrent and straight to sinuous arrangement of tertiaries undoubtedly indicate its closest affinity with the modern leaves of *Uvaria calamistrata* Hance. of the family Annonaceae (C.N.H. Herbarium sheet nos. 10873,112299, 112355; Pl.1; figs 4.7). Moreover, the leaves of *Vatica perakensisi* King of the family Dipterocarpaceae resemble in the shape and nature of base and apex but differ in their size and number of secondary veins, which are greater than the present specimens. This fossil leaf also shows similarity with the extant leaves of *Annona mucosa* (Jacq.) Wild. of family Annonaceae in their nature of apex and base, however, the shape is slightly lanceolate. It differs from present fossil leaves in having comparatively narrow lamina with more number of secondary veins.

Fossil record and comparison: Prasad (1994c) has described a fossil leaf showing affinity with *Uvaria hamiltonii* Hook. f. & Thoms. under the form species *Uvaria siwalika* from the Lower Siwalik of Kathgodam, Nainital district, Uttarakhand. Another fossil species, *Uvaria ghishia* Antal & Prasad has been decribed from Lower Siwalik sediments of Ghish River, Darjeeling district, West Bengal (Antal & Prasad 1998). Prasad & Dwivedi (2008) also described a fossil leaf of *Uvaria* under *Uvaria siwalika* Prasad from the Middle Miocene of western Nepal. Recently, Shukla & Mehrotra (2014) described a fossil leaf showing affinity with *Uvaria zeylanica* Deless ex DC. under a form species *U. palaeozeylanica*. A comparison with the already known fossil specimens reveals that *Uvaria siwalika* Prasad and *Uvaria ghishia* Antal & Prasad have almost similar venation pattern, but differs in having larger size (11.0 cm x 4.4 cm) and oblanceolate shape. Similarly, *Uvaria ghishia* Antal & Prasad also differs in having wide elliptic shape (9.5 x 5.6cm) and bearing 2-3 intersecondary veins in between secondaries. *U. palaeozeylanica* Shukla & Mehrotra can be easily

differentiated in possessing brochidodromous type of venation pattern and different nature of secondary veins. The present fossil leaf is therefore, described here as a new species *Uvaria nepalensis*.

The genus *Uvaria* Linn. consists of about 110 tropical species (Mabberley 1997). About 16 species of the genus are growing in the Indian region. *Uvaria calamistrata* Hance. with which the fossils leaves resemble is a climbing shrub and distributed in China, East Asia and Vietnam (Wu et al. 2011).

Order: Malpighiales

Family: Flacourtiaceae

Genus: *Hydnocarpus* Garertn. Fruct.

***Hydnocarcpus lamhiensis* n. sp**

(Pl. 2, fig. 1)

Diagnosis: Leaf simple, symmetrical, narrow elliptic; lamina size 13.0 cm x 5.5 cm; base wide acute, slightly inequilateral; margin entire; venation pinnate; eucamptodromous; secondary veins 5-6 pairs, opposite to alternate, 0.9 to 2.5 cm apart; unbranched; narrow to moderately acute angle of divergence; tertiary veins fine, angle of origin RR type, percurrent, nearly close to distant.

Description: Leaf simple, symmetrical, narrow elliptic; preserved size 13.1 cm x 5.9 cm ; apex broken; base wide acute; margin entire; petiole preserved, 1.0 cm long, normal; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, straight, prominent, stout; secondary veins 5 pairs visible, 2.0 to 4.4 cm apart, opposite to alternate, unbranched, angle of divergence 45°- 65°, narrow to moderate acute, uniformly curved upwards and run for a long distance and join to their super adjacent secondary at obtuse angle; intersecodary veins not visible; tertiary veins fine, angle of origin RR type, percurrent, almost straight, sometimes branched, oblique to right angle in relation to mid vein, predominantly alternate, close to nearly distant.

Holotype: B.S.I.P. Museum no. 40982.

Type Locality: Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The species name is after a famous town, "Lamhi", near the fossil locality.

Affinity: The morphological features exhibited by the present fossil leaf-like, narrow elliptic shape, wide acute base; eucamptodromous venation; acute angle of divergence of secondary veins, uniformly curving upward and run for a long distance to join their super adjacent secondary at obtuse angle, RR, percurrent, almost straight tertiary with oblique to right angle in relation mid vein are collectively indicative of its close affinity with the modern leaves of *Hydnocarpus macrocarpa* Bedd. of the family Flacortiaceae (C.N.H Herbarium sheet no.33753; Pl.2 fig. 2).

Fossil record and comparison: Fossil leaves resembling the extant species *Hydnocarpus kurzii* have been described as *Hydnocarpus palaeokurzii* from the Lower - Middle Siwalik sediments of Oodlabari, West Bengal (Antal and Awasthi 1993) and Lower Siwalik of Kathgodam, Uttarakhand (Prasad 1994c). Later on, Prasad and Awasthi (1996) reported two fossil species of *Hydnocarpus* Gaertner, i.e., *Hydnocarpus chorkholaensis* and *Hydnocarpus siwalicus* from Middle Siwalik sediments of Surai Khola area, western Nepal. Recently, another fossil leaf showing affinity with *Hydnocarpus pertandra* (Buch-Ham.) Oken has been described under a form species *Hydnocarpus ghishiinsis* Prasad et al. (2015) from the Middle Siwalik of Ghish River Section, Darjeeling District, West Bengal. The present fossil leaf has been compared with all the above known species and it has been observed that it is different in having larger size with inequilateral base and in the nature and arrangement of secondary veins, as the secondary veins arise acutely with sharp curvature and run parallel to the margin for a long distance. As the presently described species differs from all the known species, a new species i.e., *Hydnocarpus lamhiensis* has been instituted.

The genus *Hydnocarpus* Garertner consists of about 40 species distributed in Indo-Malaya and tropical Asia. *Hydnocarpus macrocarpa* Bedd. is a large tree distributed in Travancore area of the Western Ghats, India and Myanmar (Brandis 1971).

Plate 2

1. *Hydnocarpus lamhiensis* n. sp. - Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40982. (Holotype). 2. *Hydnocarpus macrocarpa* Bedd. - Modern leaf showing similar shape, size and venation pattern. 3. *Calophyllum suraikholaensis* Awasthi & Prasad - A part of fossil leaf magnified to show details of venation pattern. BSIP Museum no. 40983. 4. *Calophyllum polyanthum* Wallich ex Choisy - A part of modern leaf magnified to show similar details of venation pattern. (Scale bar = 1 cm).

Family: Calophyllaceae

Genus: *Calophyllum* Linn.

***Calophyllum suraikholaensis* Awasthi and Prasad 1990**

(Pl. 2, fig. 3; Pl. 3, figs. 7, 9,)

Description: Leaves simple, symmetrical, narrow elliptic; preserved size 6.5 cm x 4.0 cm to 10.7 cm x 4.0 cm; apex acute; base acute; margin entire; petiole preserved 1.5 cm long, normal; texture coriaceous; venation pinnate, craspedodromous; primary vein single, straight, prominent, stout; secondary veins numerous, less than 0.1 - 0.2 cm apart, closely placed, uniformly curved toward the margin, angle of divergence 85°-90°, right angle, running parallel to each other, unbranched; tertiary veins (3°) not seen.

Specimen: B.S.I.P. Museum no. 40983, 40984.

Locality: Rehar, Tatapani near Arjun Khola and Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Affinity: The diagnostic characters of the present fossil leaves are elliptic in shape, acute apex, acute base, craspedodromous leaf venation, uniformly upward curving of secondary veins running parallel to each other and right angle of divergence of secondaries. It shows closest affinity with the modern leaves of *Calophyllum polyanthum* Wallich ex Choisy of the family Clusiaceae (C.N.H. Herbarium sheet no. 47407; Pl. 3, figs. 8, 10).

Fossil record and comparison: Five fossil species of the genus *Calophyllum* Linn. have been reported so far from India and abroad. These are *Calophyllum pliocenicum* Krasser (1903) from the Tertiary of Ouricanga Brazil, *C. nathorstii* (Geyler) Krausel and *Calophyllum* sp. Krausel (1929) from the Tertiary of Sumatra, *Calophyllum masensis* Pons (1978) from the Tertiary of Colombia and *C. suraikholaensis* from the Lower Siwalik sediments of Surai Khola, Nepal (Awasthi & Prasad 1990), Lower - Middle Siwalik of Oodlabari, West Bengal (Antal & Awasthi 1993), Lower Siwalik of Kathgodam, Uttarakhand (Prasad1994c), Upper Siwalik of Papumpare, Arunachal Pradesh (Khan et al. 2011), Miocene of Warkalli Formation, Kerala coast (Awasthi & Srivastava 1992), Palaeocene of Cherapunji (Ambwani 1991), Oligocene of Makum Coalfield, Assam (Awasthi & Mehrotra 1995). A comparative study of the above known fossil leaves indicate that the fossil leaf, *Calophyllum suraikholaensis* Awasthi & Prasad described from the Lower Siwalik sediments of Kathogdam, Uttarakhand is almost identical to the present fossil leaf.

The genus *Calophyllum* Linn. comprises about 187 species of trees distributed in both the hemispheres. *C. polyanthum* Wall. Ex Choisy with which the fossil leaf closely resembles is presently growing in the evergreen forests of Tenasserim (Myanmar), Andaman and Nicobar Islands, Malaya peninsula and Sri Lanka (Brandis 1971).

Order: Malvales

Family: Dipterocarpaceae

Genus: *Hopea* Roxb.

***Hopea masotkholaensis* n. sp.**

(Pl. 7, figs. 1, 3)

Diagnosis: Leaf simple, symmetrical, elliptic; lamina size 9.1 cm x 4.2 cm; base acute; margin entire, texture chartaceous; venation pinnate; eucamptodromous; primary vein single, straight, stout; secondary veins 0.4 to 0.9 cm apart, angle of divergence moderate acute; tertiary veins RR type angle of origin, percurrent, oblique in relation to mid vein and close.

Description: Leaf simple, symmetrical, narrow elliptic; preserved size 9.1 cm x 4.2 cm; apex broken; base acute; slightly asymmetrical, margin entire; petiole not preserved; texture chartaceous; venation pinnate, craspedodromous (basal region), eucamptodromous (apical region); primary vein single, straight, prominent, stout; secondary veins 14 pairs visible, usually alternate, slightly curved upwards, sometimes branched, angle of divergence about 50°-60°, moderate acute, 0.4 to 0.6 cm apart; tertiary veins fine, angle of origin usually RR type, sometimes branched, straight, percurrent, oblique in relation to mid vein, predominantly alternate and close.

Holotype: B.S.I.P. Museum no. 40996.

Type Locality: Profile 5A (27° 54' 50.6" N: 82°

31' 00.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Western Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The species name has been drived from the name of a small place "Masot Khola", near the fossil locality.

Affinity: The diagnostic features of the present fossil leaf such as symmetrical, narrow elliptic shape, acute base, eucamptodromous venations, usually alternate with sometimes slightly curved upward and moderately acute angle of divergence of secondary veins, usually RR, straight, percurrent with oblique in relation to mid vein, alternate and close tertiary veins show its nearest resemblance with modern leaves of the genus, *Hopea* Roxb. of the family Dipterocarpaceae. In order to find out its specific affinity, the herbarium sheets of available species of this genus were critically examined and it has been found that the leaves of *Hopea balangeran* Korth. of family Dipterocarpaceae resemble very closely the fossil leaf (C.N.H. Herbarium sheet no. 2096; Pl.7, figs 2, 4).

Fossil record and comparison: So far, four records of the fossil leaves of the genus *Hopea* are known from the Siwalik sediments. These are *Hopea siwalica* Antal & Awasthi (1993) from the Lower Siwalik sediments of Darjeeling district, West Bengal, India; *H. mioglabra* Prasad (1994e) from the Lower Siwalik sediments of Koilabas, Nepal; *H. kathgodamensis* Prasad (1994c) from the Lower Siwalik sediments of Kathgodam, India and *H. mioparviflora* Prasad & Pradhan (1998) from the Middle Siwalik sediments of Surkhet area, Nepal. A comparison with the present fossil leaves with all the above known fossils revealed that *H. mioglabra* Prasad is the only fossil leaf having almost similar shape, size but differs in possessing less secondary veins (8 pairs) as compared to 15 pairs in the present fossil leaves. Other species are also entirely different in being smaller in size and having comparatively closely placed secondary veins. Thus, the present fossil leaf has been described as a new species i.e., *Hopea masotkholaensis*.

The genus *Hopea* Roxb. comprises about 102 species distributed in Indo-Malaya region, South India, Myanmar, Ceylon and New Guinea (Mabberley 1997). *Hopea balangeran* Korth., with which the present fossil leaf shows resemblance is an evergreen tree distributed in Borneo and Malaysia (Brandis 1971, Gamble 1972).

Family: Malvaceae

Genus: *Grewia* Linn.

***Grewia miopaniculata* n. sp.**

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

Diagnosis: Leaf simple, symmetrical, narrow ovate; size 6.3 cm x 2.1 cm; apex acute; base obtuse; margin entire; texture chartaceous, venation pinnate, acrodromous, imperfect; five primary vein (one mid vein and 4 laterals); secondary veins arising from mid primary; tertiary veins fine, angle of origin RR type, percurrent, branched and straight to sinuous, oblique to right angle in relation to mid vein.

Description: Leaf simple, symmetrical, narrow ovate; preserved size 6.3 cm x 2.1cm; apex acute; base obtuse; margin entire; texture chartaceous; venation acrodromous, imperfect; primary veins five (one mid vein and four laterals) arise from the base, two basal veins are running near the base towards the margin while other two lateral veins run upward for a long distance and gives off veins towards margin at acute to right angle looking like tertiary veins; secondary veins 4 to 5 pairs visible, arising from mid primary vein, alternate with angle of divergence 50°, acute, moderate, unbranched, uniformly curved upwards; intersecondary veins not seen; tertiary veins fine, angle of origin RR, percurrent, straight to sinuous, branched, oblique to right angle in relation to mid vein, predominantly alternate and nearly distant.

Holotype: B.S.I.P. Museum no. 40985.

Type Locality: Profile 2 (27° 54' 10.8" N: 82° 30' 55.2" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The specific name is after the comparable extant species of the genus i.e., *G. paniculata*.

Affinity: The characteristic morphological features of the present fossil are symmetrical, narrow ovate

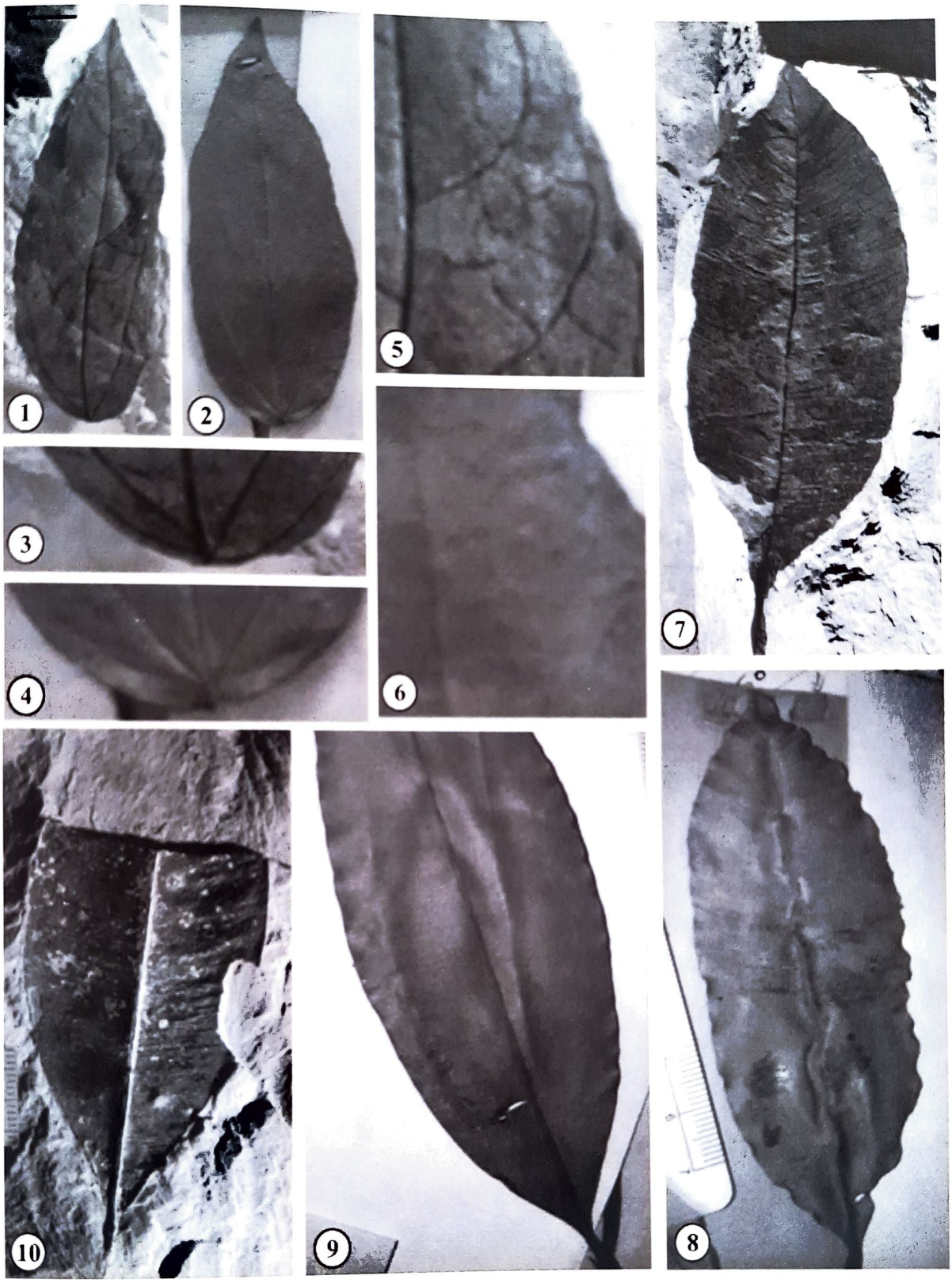


Plate 3

1. *Grewia miopaniculata* n. sp - Fossil leaf showing shape, size, nature of apex and venation pattern. BSIP Museum no. 40985 (Holotype). 2. *Grewia paniculata* Roxb. Modern leaf showing similar shape, size, nature of apex and venation pattern. 3. *Grewia miopaniculata* n. sp - Basal part of the fossil leaf showing nature of base and closely placed two pairs of primary veins. BSIP Museum no. 40985. 4. *Grewia paniculata* Roxb. - Basal part of modern leaf showing similar nature of base and primary veins. 5. *Grewia miopaniculata* n. sp - A part of fossil leaf magnified to show details of venation pattern. BSIP Museum no. 40985. 6. *Grewia paniculata* Roxb. A part of modern leaf magnified to show details of venation pattern. 7. *Calophyllum suraikholaensis* Awasthi & Prasad - Fossil leaf showing shape, size, nature of apex and base and venation pattern. BSIP Museum no. 40983. 8. *Calophyllum polyanthum* Wallich ex Choisy - Modern leaf showing shape, size, nature of apex and base and venation pattern. 9. *Calophyllum suraikholaensis* Awasthi & Prasad - A fossil leaf showing nature of base and venation pattern. BSIP Museum no. 40984. 10. *Calophyllum polyanthum* Wallich ex Choisy - A Modern leaf showing similar shape size, nature of base and venation pattern. (Scale bar = 1 cm).

shape, acute apex, obtuse base, acrodromous, imperfect venation, five primary veins (two basal primaries running towards the margin, while other two lateral primaries run upward for a long distance and give off veins towards the margin at acute to right angle (looking like tertiary veins) and usually RR, oblique to right angle in relation to mid vein, percurrent, straight to sinuous and strongly branched tertiary veins. All these features indicate its affinity with the modern leaves of the genus, *Grewia* Linn. of family Malvaceae. A critical examination of the herbarium sheets of extant leaves of about 16 species of this genus has been carried out and found that the leaves of *Grewia paniculata* Roxb (C.N.H Herbarium no. 61996; Pl.3, figs 2,4,6) show closest similarity with the present fossil leaf.

Fossil record and comparison: Fossil leaf resembling the genus *Grewia* Linn. are already known from Tertiary sediments of India and Nepal. Of these, *Grewia ghishia* Antal & Awasthi (1993) and *Grewia tistaensis* Antal & Prasad (1998) are from the Lower Siwalik sediments of Darjeeling district, West Bengal showing close resemblance with the extant species *G. umbellifera* Bedd. and *G. tiliaefolia* Vahl. respectively. Two fossil leaves are known from the late Cenozoic sediments of Mahuadanr, Palamau district, Bihar (Srivastava et al. 1992, Singh & Prasad 2010). These specimens have been compared with extant species *G. tiliaefolia* Vahl. and *G. Salvifolia* Heyen. Konomatsu and Awasthi (1999) described a leaf impression from Middle Siwalik of Arjun Khola, Nepal under the form species *Grewia mallotophylla* showing resemblance with the genus *Grewia* and *Mallotus* of the families Tiliaceae and Euphorbiaceae respectively. Prasad et al. (2004) described a leaf impression from Lower Siwalik of Kathgodam, Uttarakhand under *Grewia kathgodamensis.* It shows resemblance with extant taxa *Grewia laurifolia.* Two more fossil leaves have been described from Tura Formation of Meghalaya under the form species, *G. sahni* and *G. garoensis* (Mehrotra 2000a). A comparison with the present fossil leaf to the above listed fossil leaves indicate that none of them shows resemblance with the present fossil leaf. The Arjun Khola fossil leaf can be easily differentiated from already known fossil species in having presence of five veins at the base of lamina. In view of this, the present fossil leaf has been described under a new species, *Grewia miopaniculata.*

The extant genus *Grewia* Linn. consists of 150 species growing specifically in the tropical region of Asia, Africa and Australia (Willis 1973). *Grewia* is confined to the tropical and subtropical regions viz., Africa, Madagascar, Arabia, India, Burma, Ceylon, Malaya Peninsula, East Indies, China, North Australia. The genus is fairly represented in India with about 34 species are found in the Indian subcontinent. *Grewia paniculata* Roxb. is a bushy tree distributed in India, China and Malaysia (Mabberley 1997).

Order: Rutales

Family: Rutaceae

Genus: *Zanthoxylum* Linn.

***Zanthoxylum siwalicum* Prasad and Awasthi 1996**

(Pl. 6, figs. 6, 8)

Description: Leaf simple, symmetrical, elliptic; preserved size 6.2 cm x 3.0 cm; apex retuse; base acute; margin entire; texture coriaceous; venation pinnate; brochidodromous; primary vein single, straight, prominent, moderately thin; secondary veins 5-6 pairs visible, 1.9 to 1.1 cm apart, alternate to opposite, unbranched; angle of divergence about 70°, wide acute, intersecondary veins present, simple, abundant; tertiary veins poorly preserved with angle of origin RR type, percurrent, sometimes branched, oblique to parallel in relation to mid vein, alternate to opposite, close to nearly distant.

Specimen: B.S.I.P. Museum no. 40986.

Locality: Profile 3 (27° 54' 27.7" N: 82° 30' 54.6" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Affinity: The diagnostic features of the present fossil leaf like symmetrical, elliptic shape, obtuse apex, acute base, brochidodromous venation, alternate to opposite secondary veins with wide acute angle of divergence, frequent intersecondary veins are found common in modern leaves of *Zanthoxylum hamiltonium* Wall. of the Family Rutaceae (C.N.H. Herbarium sheet no. 2226; Pl. 6, figs 7, 9).

Fossil record and comparison: A fossil leaf resembling the genus *Zanthoxylum* Linn. has been reported from the Middle Siwalik sediments of Surai Khola area, western Nepal (Prasad & Awasthi 1996). Comparative analysis indicates that the fossil leaf *Zanthoxylum siwalicum* Prasad & Awasthi has similar shape, size and venation pattern.

The genus *Zanthoxylum* L. consist of about 80 species distributed in India, Myanmar, America, Africa and Australia. The modern taxon, *Zanthoxylum hamiltonium* Wall. is a climbing thorny shrub used to grow in evergreen to moist deciduous forests of NE India (Sikkim and Assam) and Myanmar (Brandis 1971).

Order: Sapindales

Family: Sapindaceae

Genus: *Otonephelium* Radlk.

***Otonephelium nepalensis* n. sp.**

(Pl. 5, fig. 6)

Diagnosis: Leaf simple, symmetrical, elliptic; lamina size 10.3 x 5.0 cm; apex slightly broken; base acute; margin entire; venation pinnate; eucamptodromous; primary vein single, straight; secondary veins 9 pairs, alternate to opposite, unbranched, uniformly curved up, angle of divergence 45°- 65°, narrow to moderate acute, forming loop near the apex; angle of origin of tertiary veins RR, percurrent, oblique in relation to mid vein.

Description: Leaf simple, symmetrical, elliptic; preserved size 10.3 x 5.0 cm; apex broken; base acute; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, straight, stout; secondary veins 9 pairs visible, 0.9-1.4 cm apart, alternate to opposite (opposite in the middle), sub-opposite (near apex and base), angle of divergence 45°-65°, narrow to moderately acute, uniformly curved, curvature is more pronounced near the margin, forming loop near the apex; intersecondary veins invisible; tertiary veins moderate, angle of origin RR, branched, straight to sinuous, percurrent, oblique in relation to mid-vein, opposite to alternate, close to nearly distant.

Holotype: B.S.I.P. Museum no. 40987.

Type Locality: Rehar, Tatapani near Arjun Khola area (27° 53' 42.8" N: 82° 30' 31.4" E), Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The species name is after the name of country, Nepal.

Affinity: The characteristic features of the present fossil leaf such as symmetrical, elliptic shape, eucamptodromous venation; formation of loop near the margin; usually RR, close to nearly distant tertiaries indicate its closest affinity with the modern leaves of *Otonephelium stipulaceum* Radlk. of the family Sapindaceae (C.N.H. Herbarium sheet no. 502; Pl.5, fig.7).

Fossil record and comparison: So far, there is no record of fossil leaf resembling the genus *Otonephelium* Radlk. The occurrence of this fossil leaf in the Siwalik sediments of Arjun Khola area, Nepal represents its first record and hence described as *Otonephelium nepalensis* n. sp.

The genus *Otonephelium* Radlk. consists of one species distributed in India. *Otonephelium stipulaceum* Radlk. is a tree distributed in moist forests of Western Ghats (South and Central Sahyadris), Malabar and Andamans (Mabberey1997, Brandis 1971).

Genus: *Sapindus* Linn.

***Sapindus arjunkholaensis* n. sp.**

(Pl. 7, figs. 5, 7, 9)

Diagnosis: Leaf simple, symmetrical, narrow elliptic; 6.2 x 3.3cm; apex seemingly obtuse; margin entire; venation pinnate; brochidodromous; primary vein single, straight, moderately thin; secondary veins 8 to 9 pairs, curved upward and joined to super adjacent secondary before the margin and turning into loop at acute angle, opposite to alternate; tertiary veins fine, angle of origin RR to nearly AO, oblique in relation to mid vein.

Description: Leaf simple, symmetrical, narrow elliptic; preserved size 6.2 cm x 3.3cm; apex seemingly obtuse; margin entire; texture chartaceous; venation pinnate; brochidodromous; primary vein single, prominent, stout; secondary veins 8 to 9 pairs visible, 0.8 to 1.5 cm apart, alternate to opposite, unbranched,

curving upward and joined to super adjacent secondary before the margin, turning into loop at acute angle, angle of divergence about 50°- 60°, moderately acute, intersecondary veins present, simple; tertiary veins fine, angle of origin RR - AO, percurrent, straight to sometimes curved, branched, oblique in relation to mid-vein, predominantly alternate and close.

Holotype: B.S.I.P. Museum no. 40988.

Type Locality: Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola - Ghorai road section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The species name is after the name of fossil locality, Arjun Khola.

Affinity: In having symmetrical and narrow elliptic shape of the leaf, entire margin, brochidodromous venation, curving upward and joining with super adjacent secondary veins before the margin at acute angle, presence of intersecondary veins, RR - AO, percurrent, straight to sometimes curved tertiaries veins, show closest affinity with the modern leaves of *Sapindus* Linn. of the family Sapindaceae. After critical study of the modern leaves of different species of the genus it has been found that the present fossil leaves show closest affinity with the extant leaves of *Sapindus emarginatus* Vahl. in shape, size and venation pattern (C.N.H. Herbarium sheet no. 14164; Pl. 7, figs. 6,8,10).

Fossil record and comparison: The fossil leaves resembling the genus *Sapindus* Linn. have been described as leaf type D and leaf Type E from the Eocene of Barmer Rajasthan, India (Deshmukh & Sharma 1978). These fossils show their resemblance with extant leaves of *Sapindus bilinicus* and *S. falcifolius* respectively. Comparative study of the above known fossil leaves indicates that these are almost identical and differ from the present fossil leaves in having larger size (10-16 cm x 3.5-4.5 cm) with more number of secondary veins, which arise comparatively at narrow acute angle of divergence. Recently, Srivastava and Mehrotra (2013) reported another fossil species *Sapindus palaeoemerginatus* from the Oigocene of Assam which possesses suborbiculate elliptic shape with different pattern of secondary veins. Being different from the already known fossil leaves mentioned above, the present fossil has been given a new specific name i.e., *Sapindus arjunkholaensis*.

The genus *Sapindus* Linn. consists of about 40 species, native to warm temperate to tropical regions. It includes both deciduous and evergreen species. The extant taxon, *Sapindus emarginatus* Vahl. is a large tree distributed in forests of dry region, common throughout India, Myanmar, Aravali Hills and western Peninsula (Brandis 1971).

Order: Fabales

Family: Fabaceae

Genus: *Millettia* Wight & Arn.

***Milletia miocinerea* n. sp.**

(Pl. 5, figs. 8, 10)

Diagnosis: Leaf simple, symmetrical, elliptic; lamina size 7.2 cm x 3.2 cm; apex acute; base acute; margin entire; venation pinnate; eucamptodromous; secondary veins 7 pairs, alternate, uniformly curved upward, moderately acute angle of divergence; tertiary veins fine, RR type of angle of origin, percurrent, oblique in relation to mid vein.

Description: Leaf simple, symmetrical, elliptic; preserved size 7.2 x 3.2 cm; apex slightly broken, seemingly acute; base acute; margin entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, almost straight, prominent, stout; secondary veins 7 pairs visible, 1.1 to 2.0 cm apart, uniformly curved upwards, alternate, unbranched; angle of divergence about 50°-55°, moderately acute, intersecondary veins present, simple; tertiary veins poorly preserved, fine, angle of origin RR, percurrent, straight to sinuous, oblique in relation to mid vein, predominantly alternate, close to nearly distant.

Holotype: B.S.I.P. Museum no. 40989.

Type Locality: Profile 12 (27° 57' 06.1" N: 82° 29' 32.2" E), Arjun Khola – Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The species name is after the modern comparable species of the genus i.e., *M. cinerea*

Affinity: The characteristic features of the present fossil are symmetrical, elliptic shape, seemingly acute

apex, acute base, eucamptodromous venation, moderately acute angle of divergence of secondary veins and uniformly curved upwards, presence of intersecondary veins; usually RR, percurrent, straight to sinuous, predominantly alternate, close to nearly distant tertiary veins. These features resemble the modern leaves of *Millettia cinerea* Benth. of the family Fabaceae (C.N.H. Herbarium sheet no. 112355; Pl. 5, figs 9, 11). The present fossil leaf is also comparable to the modern leaves of *Uvaria calamistrata* Hance. of family Annonaceae but differ in the arrangements of secondary veins.

Fossil record and comparison: About 34 fossil leaves resembling the genus *Millettia* W. & A. have been reported from the Tertiary sediments of India and Nepal. They are listed herewith along with their characteristic features (Table-1).

A comparative analysis of all the above species indicates that the present fossil leaf is entirely different from all the earlier recorded species of *Millettia*. In view of this, a new species *Millettia miocinerea* has been instituted.

Genus *Millettia* Wight & Arn. consists of about 150 species and are distributed in the tropical and subtropical regions of the world. *Millettia cinerea* Benth. is a climber usually growing in NE Himalaya (Assam and Sikkim), eastern Bengal, Myanmar and China (Gamble 1972, Brandis 1971).

Order: Myrtales

Family: Combretaceae

Genus: *Combretum* Linn.

***Combretum sahnii* Antal and Awasthi 1993**

(Pl. 4, figs. 5, 7)

Description: Leaves simple, symmetrical, elliptic; preserved size 10.5 cm x 4.5 cm to 10.5 cm x 4.1 cm; apex broken; base broken; margin entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein single, slightly curved, prominent, stout; secondary veins 7 pairs, 0.8 to 2.0 cm apart, usually alternate, rarely opposite, unbranched; angle of divergence 50°-75°, acute to wide acute, some basal pairs of secondary veins arise at greater angle, curved upward and run for a long distance; tertiary veins fine, angle of origin RR type, percurrent, straight to sinuous, branched, oblique to right angle in relation to mid vein, predominantly alternate and close.

Specimen: B.S.I.P. Museum no. 40990.

Locality: Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Affinity: The diagnostic features of the present fossil leaves such as symmetrical, elliptic shape, entire margin, eucamptodromous venation, secondary veins with alternate pattern, greater angle of some basal pair of secondaries, almost all the secondary veins curved upwards and run for a long distance; RR angle of origin, percurrent, tertiary veins with oblique to right angle in relation to mid vein show its affinity with the modern leaves of *Combretum decandrum* Jacq. of the family Combretaceae (C.N.H. Herbarium sheet no. 107; Pl. 4, figs 6, 8).

Fossil record and comparison: So far, there are five fossil records of *Combretum* Linn. leaves from the Tertiary of India and abroad. These are *C. europium* Web. from the Oligocene of Chivon e Salcedo (Principi 1926), *C. sarothrosatachyoides* Mass. from the Pliocene of Saromaziana (Principi 1926), *Combretum decandrum* Jacq. from the late Tertiary of Mahuadanr, Jharkhand, *C. sahnii* from Lower-Middle Siwalik of Darjeeling district, West Bengal (Antal & Awasthi 1993), Kasauli Formation, Himachal Pradesh (Mathur et al. 1996), Lower Siwalik of Koilabas area, Nepal (Prasad 1994a), Eocene sediments of Vastan Lignite, western India (Singh et al. 2015), Siwalik of Papumpare district, Arunachal Pradesh (Khan et al. 2011) and *C. miocenicum* from Lower Siwalik of Bhutan (Prasad & Tripathi 2000). Comparison of the present fossil leaf with all the above known fossils indicates only *C. sahnii* Antal & Awasthi shows closest resemblance in shape, size and venation pattern.

The genus *Combretum* Linn. consists of about 260 species distributed in tropical and sub-tropical region of the old world. *Combretum decandrum* Jacq. is a large climbing shrub, found to grow in NE India (Sikkim, Assam), Bihar, Central Provinces, Northern Circars, northern Deccan, Chittagong (Bangladesh) and

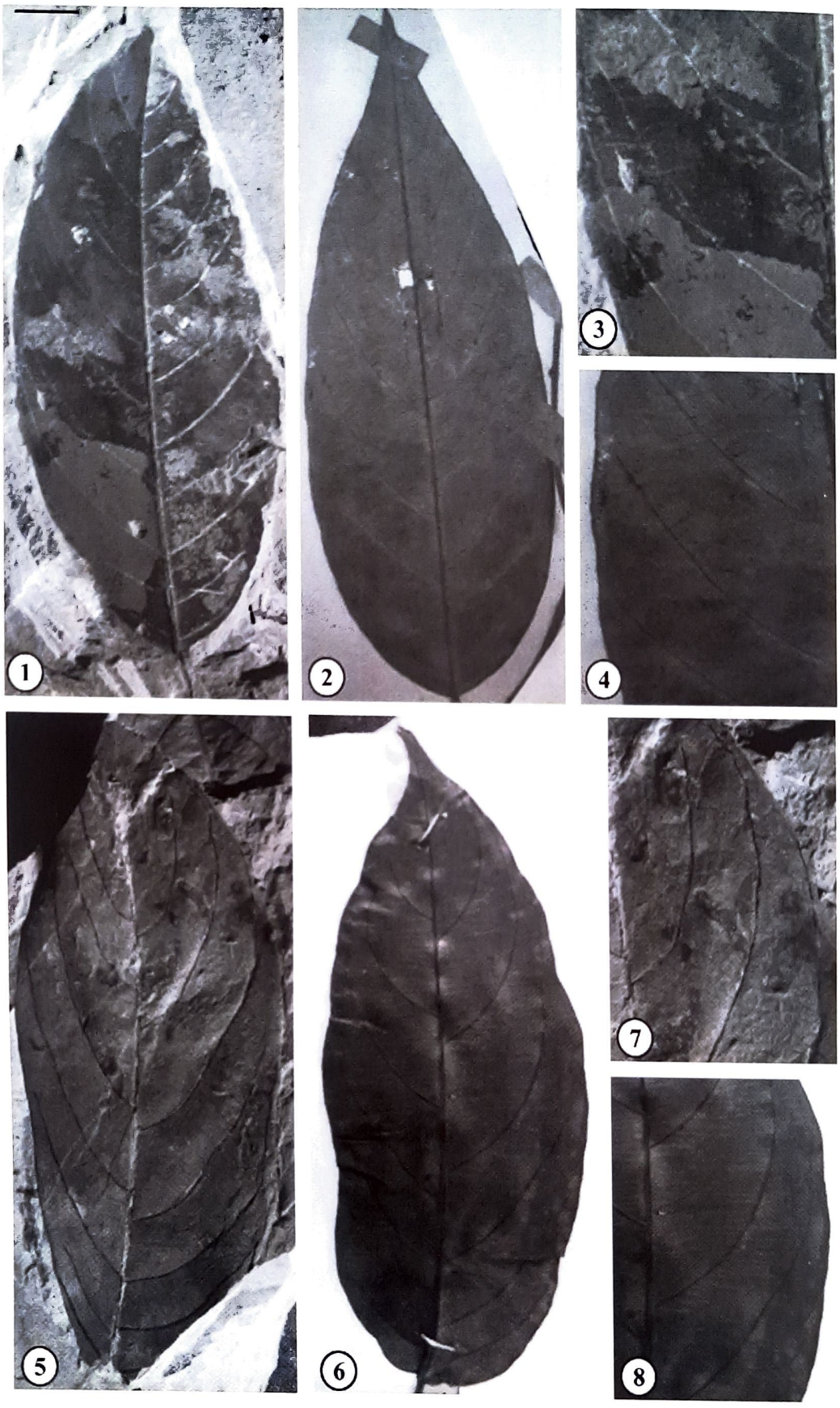


Plate 4

1. *Melodorum arjunkholaensis* n. sp. - Fossil leaf showing shape, size, nature of apex and venation pattern. BSIP Museum no. 40977 (Holotype). 2. *Melodorum fulgens* Hook. F. & Thoms - Modern leaf showing similar shape, size nature of apex and venation pattern. 3. *Melodorum arjunkholaensis* n. sp. - A part of fossil leaf magnified to show details of venation pattern. 4. *Melodorum fulgens* Hook. F. & Thoms- A part of modern leaf magnified to show details of venation pattern. 5. *Combretum sahnii* Antal & Awasthi- Fossil leaf showing shape, size, nature of apex and venation pattern. BSIP Museum no. 40990. 6. *Combretum decandrum* Jacq. - Modern leaf showing similar shape, size, nature of apex and venation pattern. 7. *Combretum sahnii* Antal & Awasthi. – A part of fossil leaf magnified to show details of venation pattern. 8. *Combretum decandrum* Jacq. A part of modern leaf magnified to show similar details of venation pattern. (Scale bar = 1 cm).

Table 1. Showing the characteristic features of fossil species of *Millettia* known from the Tertiary sediments of India and Nepal.

Species	Age and Locality	Characteristic features
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, India	Small size (3.9 x 2.7 cm) and ovate shape.
M. bilaspurensis Prasad 2006	Siwalik of Bilaspur, Himachal Pradesh, India	Large size (13.6 x 2.7 cm), narrow oblong shape, more number of secondaries (18 pairs) closely placed.
M. churiensis Prasad & Awasthi 1996, Agarwal 2002	Siwalik of Suraikhola, Nepal, Miocene of Neyveli lignite, India	Small size (4.2 x 1.2 cm), lanceolate shape, acuminate apex, almost same 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.
M. kathgodamensis Prasad et al. 2004, Prasad et al. 2016	Siwalik of Kathgodam, Uttarakhand, India	Texture coriaceous, base oblique, close forming orthogonal meshes. Oblique to right angle in relation to midvein.
M. koilabasensis Prasad 1990b, Prasad & Tripathi 2000, Prasad & Pandey 2008	Siwalik of Koilabas, Nepal; Siwalik of Bhutan; Siwalik of Suraikhola, Nepal	Narrow obovate shape, same number of secndaries (8 pairs), AR-RO angle of origin of tertiary veins.
M. miocenica Lakhanpal & Guleria 1982	Miocene of Kachchh, India	Small size (5.6 x 3.2 cm) and oblong shape.
M. miobrandisiana Prasad 1994a	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. 2016 (In Press)	Siwalik of Tanakpur, Uttarakhand, India	Obovate shape, base attenuate, texture coriaceous, angle of origin of tertiaries is AO.
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, near Jarwa, Nepal	Small size (3.5 x 2.5 cm), ovate shape, lesser number of secondaries (4-5 pairs), AO- RR angle of origin of tertiary veins.
M. palaeocubithii Awasthi & Prasad 1990	Siwalik of Suraikhola, Nepal	Oblanceolate shape, lesser 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, lesser number of secondaries (about 6 pairs).
M. palaeomanii Dwivedi et al. 2006	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 Surai Khola, Nepal and Siwalik of Kathgodam, Uttarakhand, India	Wide obovate shape, texture coriaceous, lesser number of secondaries (6 pairs), rarely AO angle of origin of tertiary vein.
M. purniyagiriensis Shashi et al. 2006	Siwalik of Tanakpur, Uttarakhand, India	Same 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. 2008	Siwalik of Tanakpur, Uttarakhand, India	Large size, texture coriaceous, same 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, Himachal Pradesh, India	Small size (4.0 x 1.5 cm), wide elliptic shape, same number of secondaries (about 7 pairs).
M. siwalica Prasad 1990, 1994a, Prasad et al. 2016 (In Press)	Siwalik of Koilabas, Nepal and Siwalik of Kathgodam, Uttarakhand, India	Small size (3.1 x 2.0 cm), texture coriaceous, AO angle of origin of tertiary vein.

Myanmar (Brandis 1971).

Order: Myrtales

Family: Myrtaceae

Genus: *Eugenia* Gaertner

***Eugenia lamhiensis* n. sp**

(Pl. 6, figs. 1, 2, 4)

Diagnosis: Leaf simple, symmetrical, narrow elliptic; 9.4 cm x 3.4 cm; apex attenuate; base acute; margin entire; venation pinnate; eucamptodromous; secondary veins many, opposite, unbranched; narrow acute angle of divergence, intersecondary and intramarginal veins present; tertiary veins AO-RR type, percurrent, oblique in relation to mid vein.

Description: Leaf simple, symmetrical, narrow elliptic; preserved size 9.4 cm x 3.4 cm to 6.6 cm x 3.0 cm; apex attenuate; base acute; petiole not preserved, margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, almost straight, prominent, stout; secondary veins more than 22 pairs visible with angle of divergence about 60°, moderately acute, closely placed, 0.3 to 0.5 cm apart, opposite; intersecondary veins present, simple, frequent, 1-2 veins in between two secondary veins, intramarginal vein present; tertiary veins angle of origin AO- RR type, percurrent, sometime ramified, almost straight, branched, alternate to opposite , oblique in relation to mid vein and close.

Holotype: B.S.I.P. Museum no. 40991.

Paratype: B.S.I.P. Museum no. 40992.

Type Locality: Profile 5A (27° 54' 50.6" N: 82° 31' 00.4" E), Arjun Khola-Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The new species is named after the well known small town, Lamhi near the fossil locality.

Affinity: The characteristic features of the present fossil leaves such as symmetrical, narrow elliptic shape, attenuate apex, acute base; eucamptodromous venation; opposite, acute angle of divergence of secondaries; presence of frequent intersecondary veins; AO-RR, sometimes ramified, almost straight and branched tertiaries and presence of intramarginal veins on both the margin suggest its closest affinity with the modern leaves of *Eugenia jambolana* Lam. (*Syzygium cuminii* (Linn.) Skeel of the family Myrtaceae (C.N.H. Herbarium no. 169403; Pl. 6, figs 3, 5).

Fossil record and comparison: There is no prior record of the fossil leaves resembling the genus *Eugenia* Linn. from the Siwalik sediments of India. However, there are six species showing affinity with the genus *Syzygium* Gaertn. from India and abroad (Prasad & Awasthi 1996). One of them, *Syzygium palaeocuminii* Awasthi & Prasad 1996 described from the Middle Siwalik sediments of Surai Khola area also shows affinity with *Syzygium cuminii* (Synonym: *Eugenia jambolana*). However, the present fossil specimens differ in the pattern of secondary veins, which are arising with less acute angle and running for a greater length towards the apex. As the genus *Syzygium* has been merged with the genus *Eugenia* and entirely different from already known fossil species, the new specific name has been designated as *Eugenia lamhiensis* n. sp.

Genus *Eugenia* Linn. comprises about 550 species distributed in America, Africa, Australia, Guinea and southeast Asia. Modern comparable taxa, *Eugenia jambolana* Lam. is an evergreen tropical tree native to the Indian subcontinent and adjoining regions of southeast Asia (Mabberley 1997). The species occurs in India, Bangladesh, Pakistan, Nepal, Sri Lanka, Malaysia, Philippines and Indonesia.

Order: Ericales

Family: Ebenaceae

Genus: *Diospyros* Linn.

***Diospyros masotkholaensis* n. sp.**

(Pl.8, figs.5, 7)

Diagnosis: Leaf simple, symmetrical, lanceolate to oblong; lamina size 17.0 cm x 4.2 cm; apex attenuate; base acute; margin entire; venation pinnate, eucamptodromous; primary vein single, prominent, stout; secondary veins alternate to opposite, unbranched, moderately acute angle of divergence; intersecondary veins present, tertiary veins fine, RR, percurrent with oblique to right angle in relation to mid vein.

Description: Leaf simple, symmetrical, lanceolate to oblong; preserved size 16.8 cm x 4.0 cm; apex attenuate; base acute; margin entire; texture coriaceous, petiole not preserved; venation pinnate, seemingly eucamptodromous; primary vein (1°) single, slightly curved, prominent, stout; secondary veins, 16 pairs, alternate to opposite, angle of divergence 55°- 60°, moderate acute, curved upwards and joined to superadjacent secondary vein; intersecondary veins present, simple; tertiary veins poorly preserved with angle of origin usually RR, percurrent, straight to sinuous, alternate to opposite, oblique to right angle in relation to mid vein.

Holotype: B.S.I.P. Museum no. 40993.

Type Locality: Profile 10 (27° 55' 50.9" N: 82° 29' 48.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The new species name has been proposed after the name of a small place "Masot Khola", near the fossil locality.

Affinity: The significant features of the present fossil leaf such as symmetrical, lanceolate to oblong shape, attenuate apex, acute base, eucamptodromous venation, alternate to opposite, curved upward, straight, unbranched, moderately acute angle of divergence of secondary veins and presence of intersecondary veins resemble the modern leaves of *Diospyros oleifolia* Wall. Ex. Kurz. of family Ebenaceae (C.N.H. Herbarium sheet no. 282697; Pl. 8, figs. 6, 8).

Fossil record and comparison: Fossil leaves resembling the genus *Diospyros* have been described under two generic names i.e., *Diospyros* Linn. and *Diospyrophyllum* Velenovsky. *Diospyrophyllum* consists of only one species, *Diospyrophyllum provectum* described from the Upper Cretaceous of Bohemia (Velenovsky 1889). The genus *Diospyros* Linn. contains about 70 species reported from different parts of world. The species reported from the Tertiary sediments of India and Nepal are represented in Table 2.

A detailed comparative study of all the (Table 2) reveals that these species differ mainly in the nature and course of secondary veins. Moreover, most of them are smaller in size than the present fossil (Table 2). Therefore, a new species *Diospyros masotkholaensis* has been instituted.

The genus *Diospyros* Linn. consists of about 186 species distributed in tropics and rarely sub-temperate regions. The extant taxa, *Diospyros oleifolia* Wall. is a medium sized evergreen tree distributed in tropical forests of Martaban, Tennasserim, Myanmar and Java (Ridley 1967).

Order: Laurales

Family: Lauraceae

Genus: *Cinnamomum* Schaeffer

***Cinnamomum corvinusianum* n. sp.**

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

Diagnosis: Leaf simple, symmetrical, narrow oblong; lamina size 11.8 cm x 2.6 cm; base acute; margin entire; venation supra-basal, acrodromous, perfect; primary veins three, one mid primary and two lateral primaries; tertiary veins arising from both mid and lateral primaries, angle of origin RR, percurrent, right angle in relation to mid vein, alternate to opposite and close.

Description: Leaf simple, symmetrical, narrow oblong; preserved size 11.8 cm x 2.6 cm; apex broken; base acute; margin entire; texture chartaceous; petiole not preserved; venation acrodromous, supra basal, perfect; primary veins three, arising at above the base, one mid primary and two lateral primaries, lateral primary curved toward the apex, moderately thick, prominent, stout, unbranched, tertiary veins poorly preserved, angle of origin RR, arising from both mid and lateral primaries, percurrent, almost straight, right angle in relation to mid vein, alternate to opposite and close.

Holotype: B.S.I.P. Museum no. 40994.

Type Locality: Rehar, Tatapani near Arjun Khola area (27° 53' 42.8" N: 82° 30' 31.4" E), Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The species name is after the name of Late Dr. G. Corvinus, an eminent Geoscientist who discovered the fossil locality.

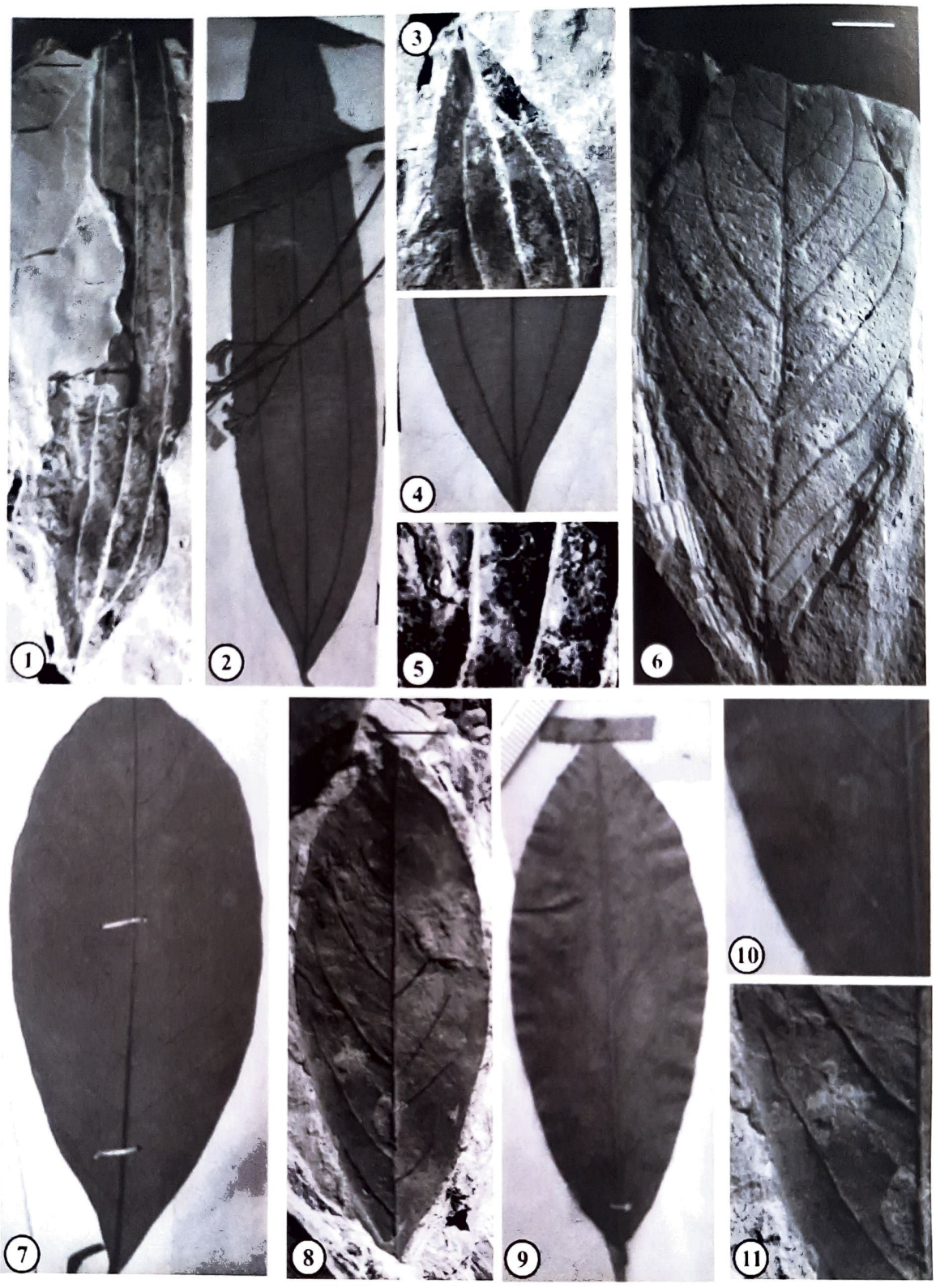


Plate 5

1. *Cinnamomum corvinusianum* n. sp. - Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40994 (Holotype). 2. *Cinnamomum culitlawn* Linn. - Modern leaf showing similar shape, size and venation pattern. 3. *Cinnamomum corvinusianum* n. sp. - Basal part of fossil leaf showing nature of base and supra basal primary veins. BSIP Museum no. 40994. 4. *Cinnamomum culitlawn* Linn. Basal part of modern leaf showing similar nature of base and supra basal primary veins. 5. *Cinnamomum corvinusianum* n. sp. – A part of fossil leaf magnified to show details of tertiaries arrangements in between primaries. 6. *Otonephelium nepalensis* n. sp. - Fossil leaf showing shape, size nature of base and details of venation. BSIP Museum no. 40987 (Holotype). 7. *Otonephelium stipulaceum* Radlk. - Modern leaf showing similar shape, size nature of apex and venation pattern. 8. *Millettia miocinerea* n. sp. - Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40989 (Holotype). 9. *Millettia cinerea* Benth. Modern leaf showing similar shape, size and venation pattern. 10. *Millettia miocinerea* - A part of fossil leaf magnified to show details of venation pattern. BSIP Museum no. 40989 (Holotype). 11. *Millettia cinerea* Benth. - A part of modern leaf magnified to show similar details of venation pattern. (Scale bar = 1 cm).

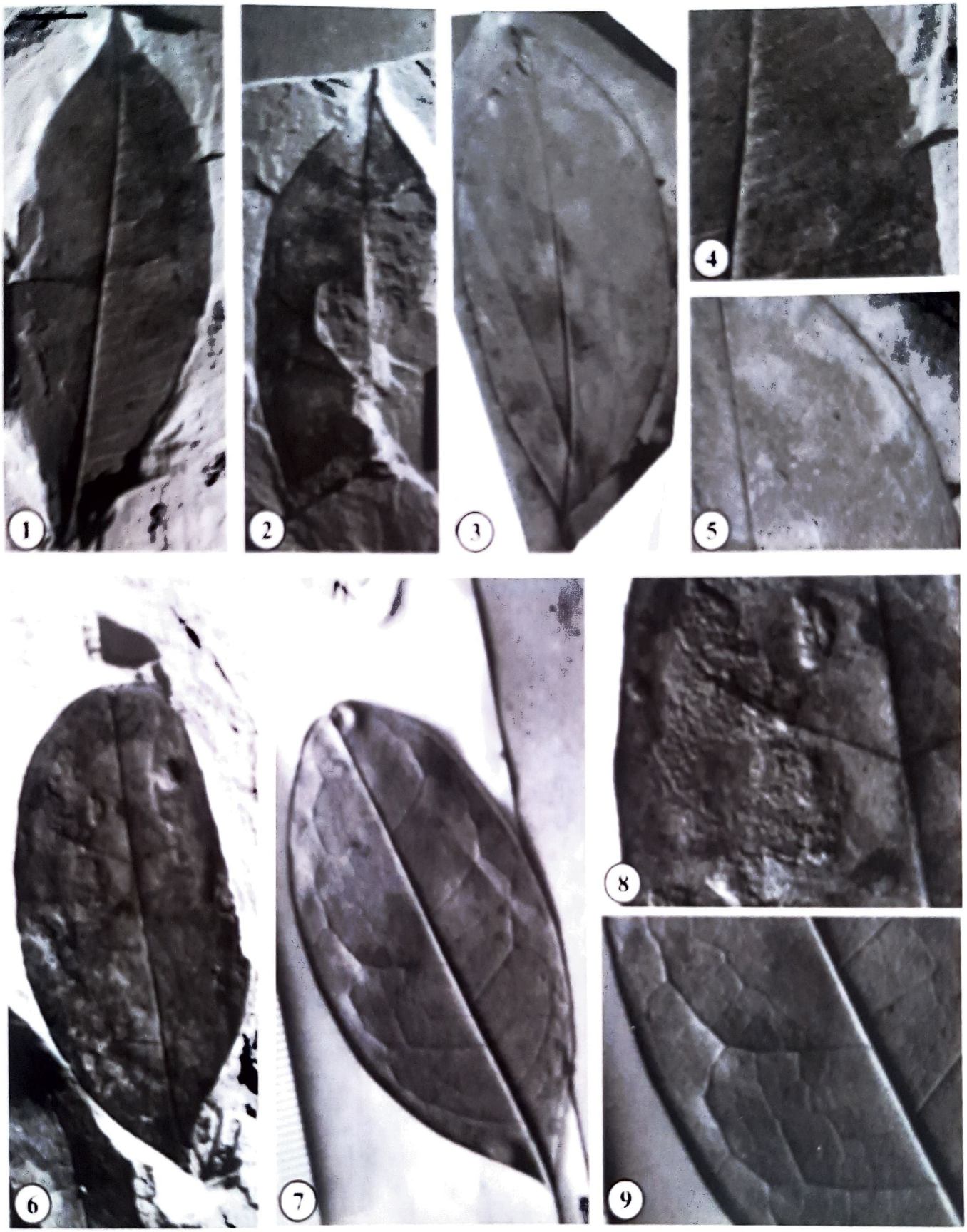


Plate 6

1, 2. *Eugenia lamhiensis* n. sp. - Fossil leaves showing shape, size and venation pattern. BSIP Museum no. 40991 (Holotype), 40991 (Paratype). 3. *Eugenia jambolana* DC. - Modern leaf showing similar shape, size and venation pattern. 4. *Eugenia lamhiensis* n. sp. – A part of fossil leaf magnified to show details of venation. BSIP Museum no. 40991. 5. *Eugenia jambolana* DC. - Part of Modern leaf magnified to show similar details of venation. 6. *Zanthoxylum siwalicum* Prasad & Awasthi. - Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40986. 7. *Zanthoxylum hamiltonium* Wall. - Modern leaf showing similar shape, size and venation pattern. 8. *Zanthoxylum siwalicum* Prasad & Awasthi. - A part of fossil leaf magnified to show details of venation. 9. *Zanthoxylum hamiltonium* Wall. - A part of modern leaf magnified to show similar details of venation. (Scale bar = 1 cm)

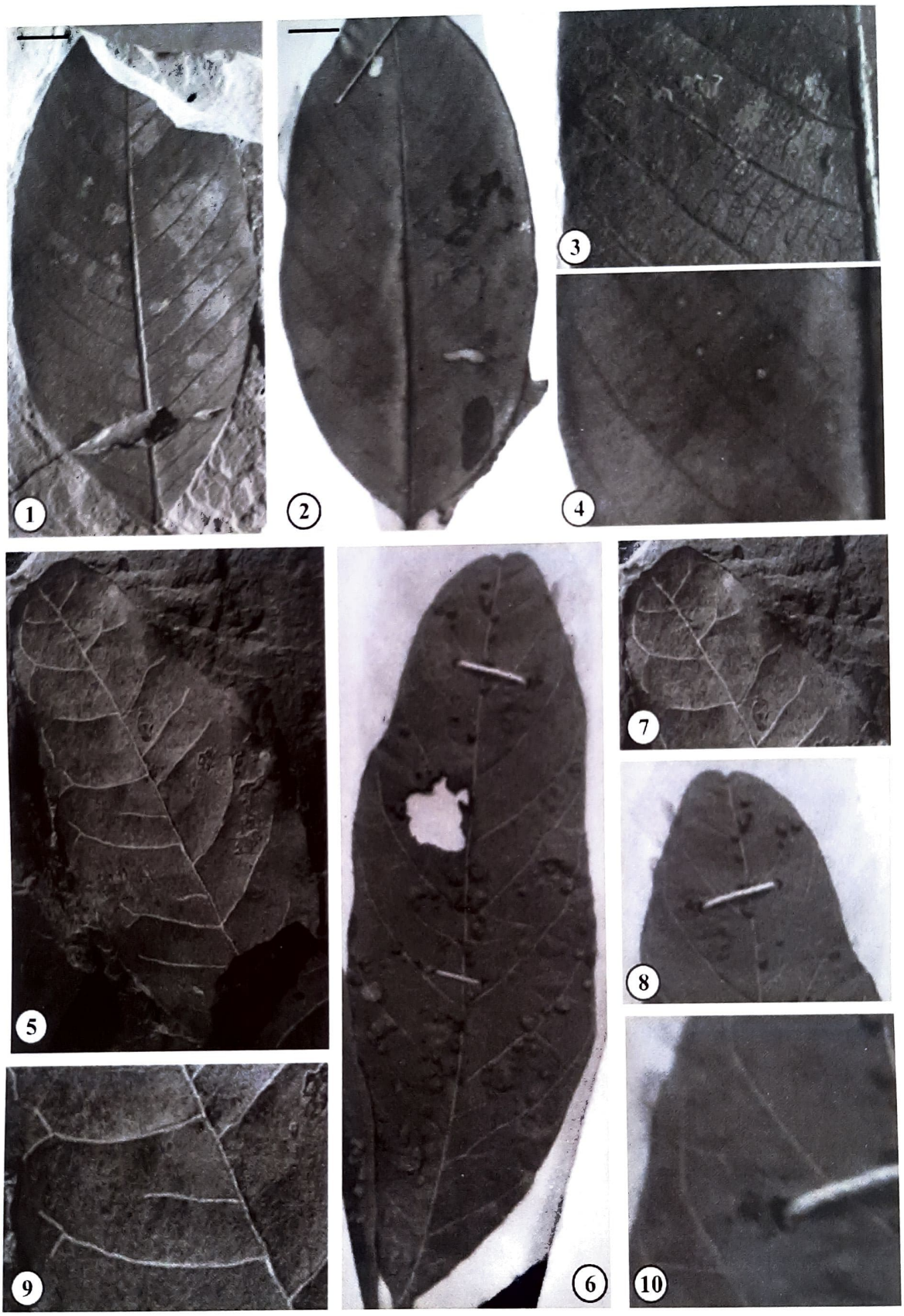


Plate 7

1. *Hopea masotkholaensis* n. sp. Fossil leaves showing shape, size and venation pattern. BSIP Museum no. 40996 (Holotype). 2. *Hopea balangeran* Korth. - Modern leaf showing similar shape, size and venation pattern. 3. *Hopea masotkholaensis* n. sp. A part of fossil leaf magnified to show details of venation. 4. *Hopea balangeran* Korth. - A part of modern leaf magnified to show similar details of venation. 5. *Sapindus arjunkholaensis* n. sp. Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40988 (Holotype). 6. *Sapindus emerginatus* Vahl. Modern leaf showing similar shape, size and venation pattern. 7. *Sapindus arjunkholaensis* n. sp. Apical part of fossil leaf showing nature of apex. 8. *Sapindus emerginatus* Vahl. Apical part of modern leaf showing similar nature of apex. 9. *Sapindus arjunkholaensis* n. sp. A part of fossil leaf magnified to show details of venation. (Scale bar = 1 cm)

Table 2. Showing characteristic features of the known fossil species of *Diospyros* Linn. recorded from India and Nepal.

Fossil species	Characteristic features
Diospyros embryopterisites Varma 1968	Small in size (8.0 x 3.5 cm), no. of secondaries is less (about 8 pairs) distantly placed, only few intersecondary veins present.
D. miocenicus Prasad & Awasthi 1996	Small in size (7.0 x 2.2 cm), narrow oblong shape, no. of secondaries is less (13 pairs) having greater angle of divergence, only few intersecondary veins present, tertiaries oblique in relation to mid vein.
D. miokaki Awasthi & Prasad 1990	Small in size (8.0 x 5.1 cm), elliptic shape, no. of secondaries is less (6-7 pairs) distantly placed, only few intersecondary veins present.
D. kathgodamensis Prasad 1994c	Small in size (6.0 x 2.0 cm), narrow elliptic shape, no. of secondaries is less (10 pairs) distantly placed.
D. palaeoebenum Prasad 1994b	Small in size (7.7 x 4.0 cm), narrow ovate shape, secondaries are less (about 8 pairs) distantly placed, greater angle of divergence, only few intersecondary veins present.
D. tulsipurensis Prasad et al. 1997	Small in size (8.4 x 3.8 cm), elliptic shape, secondaries are less (about 9 pairs), angle of divergence is acute to right angle, only few intersecondary veins present.
D. koilabasensis Prasad 1990a	Small in size (3.5 x 5.0 cm), secondaries are less (About 6 pairs), intersecondaries absent.
D. pretoposia Prasad 1990a	Elliptic shape, secondaries are less (about 12 pairs), distantly placed, one side of secondaries run along the margin for a long distance.
D. darwajaensis Prasad et al. 1999	Secondaries are less (7-8 pairs), distantly placed, intersecondary veins rarely seen.
D. nainitalensis Prasad et al. 2004	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 Prasad et al. 2004	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 Prasad; Shashi et al. 2008	Narrow elliptic shape, fewer no. of secondaries, lower pairs more acute than above, distantly placed, joined super adjacent secondary at acute angle.
D. barogensis Mathur et al. 1996	Narrow ovate shape, small size (3.3x1.6cm), obtuse base, lesser secondary veins (6 pairs).
Diospyros palaeoargentia Prasad et al. 2015	Almost similar in shape and size, abundant (22) and closely placed secondary.

Affinity: The important characteristic features of the present fossil leaf such as symmetrical, narrow oblong shape, acute base, acrodromous, supra-basal, perfect venation, three primaries (one mid, and two laterals), RR, percurrent, almost straight tertiaries having right angle in relation to mid vein resemble the modern leaves of *Cinnamomum culitlawn* Linn. of the family Lauraceae (C.N.H. Herbarium sheet no. 384142; Pl. 5, figs. 2, 4).

Fossil record and comparison: A number of fossil leaves resembling the genus *Cinnamomum* Shaeffer have been reported from India and aboard under four generic names, i.e. *Cinnamomum* Shaeffer, *Cinnamomiphyllum* Nathorst, *Cinnamomoides* Seward and *Cinnamomophyllum* Krausel & Weyland. So far, six fossil leaves have been reported from the Siwalik sediments of India and Nepal and one leaf from Eocene of Kachchh, western India. Pathak (1969) reported for the first time a fossil leaf resembling *Cinnamomum tamala* from the Middle Siwalik of Mahanadi River Section, West Bengal, India. *Cinnamomum* sp. has been described from the Lower-Middle Siwalik of Oodlabari area, West Bengal, India (Antal & Awasthi 1993), *C. mioinuctum* Prasad (1990a) and *C. nepalensis* (Prasad & Pandey 2008) has been described from the Siwalik sediments of Koilabas and Surai Khola localities of Nepal. *C. palaeotamala* has been described from the Upper Siwalik sediments of Bhikhnathoree, Bihar, India (Lakhanpal & Awasthi 1984). *C. miotavoyanum*

(Shashi et al. 2008) has been reported from the Lower Siwalik sediments of Tanakpur area, Uttarakhand and *C. eokachchhensis* (Lakhanpal & Guleria 1981) has been described from the Eocene of Kachchh, western India. A comparative study of the present fossil with all the above known fossils suggests that this species differs in having its narrow size and supra-basal, perfect acrodromous venation. As a matter of fact, the present fossil has been described here as a new species *Cinnamomum corvinusianum* n. sp.

The genus *Cinnamomum* Schaeffer consists of 350 species (including *Phoebe*). These are evergreen trees and shrubs distributed mainly in tropical and sub-tropical regions of east and southeast Asia and also in Australia. About 24 species of this genus occur in the Indian region (Gamble 1972). *Cinnamomum culitlawn* Linn with which fossil shows affinity is a moderate sized, evergreen tree occurring in China and Malayan region (Mabberley 1997).

Genus: *Persea* Miller

***Persea siwalika* n. sp.**

(Pl.8, figs.1, 3)

Diagnosis: Leaf simple, symmetrical, narrow elliptic; 9.7 cm x 3.0 cm; apex acute; base acute; margin entire; venation pinnate, eucamptodromous; secondary veins alternate to opposite, 1.2 cm to 2.9 cm apart, angle of divergence moderately acute; tertiary veins with angle of origin RR, percurrent, straight to sinuous, right angle in relation to mid vein.

Description: Leaf simple, symmetrical, narrow elliptic; preserved size 9.7 cm x 3.0 cm; apex acute; base acute; margin entire; texture chartaceous, petiole not preserved; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, stout, almost straight; secondary veins (2°) 7 to 8 pairs, alternate to opposite, 1.2 to 1.5 cm apart, run upward for a short distant, angle of divergence 45°-60°, narrow to moderately acute, unbranched; tertiary veins with angle of origin RR type, percurrent, straight to slightly sinuous, branched, predominantly alternate, usually right angle in relation to mid vein, close to nearly distant.

Holotype: B.S.I.P. Museum no. 40995.

Type Locality: Profile 10 (27° 55' 50.9" N: 82° 29' 48.4" E), Arjun Khola - Ghorai Road Section, Arjun Khola area, Deukhuri district, Rapti Anchal, Nepal.

Horizon & Age: Churia Group, Miocene.

Etymology: The specific name is after the Siwalik Group that is equivalent to Churia Group.

Affinity: In having symmetrical, narrow elliptic shape of the leaf with acute apex, acute base, eucamptodromous venation, alternate to opposite, unbranched, upward curving and moderately acute angle of divergence of secondary veins, RR, percurrent, sinuous to straight tertiary veins with right angle in relation to mid vein, the present fossil leaf is very closely comparable to the modern leaves of *Persea glaucescens* (Wight) N.P. of family Lauraceae (C.N.H. Herbarium sheet no. 384634; Pl. 8, figs.2, 4).

Fossil record and comparison: So far, three fossil leaves resembling the genus *Persea* Miller are known from the Miocene of India. These are *Persea* spp. from the Siwalik sediments of Tanakpur area, Uttarakhand (Lakhanpal & Guleria (1978), *Persea sibdasi* Mathur et al. (1996) from the Kasauli Formation, Himachal Pradesh and *Persea lakhanpalii* Mathur et al. (1996) from Dagshai Formation, Himachal Pradesh. Amongst these, the present one can be differentiated from *P. sibdasi* Mathur et al. in possessing asymmetrical shape and smaller in size (3.1 cm x 1.0 cm) with obtuse base. *P. lakhanpalii* Mathur et al. differs from the present fossil leaf in having smaller size (3.5cm x 1.2 cm) and brochidodromous type of venation. *Persea* spp. Lakhanpal & Guleria also differs owing to obovate to elliptic shape with inequilateral base. Furthermore, there are 10 pairs of secondary veins as compared to 7-8 pairs in the present fossil leaf. In view of this, the present fossil has been described as a new species i.e., *Persea siwalika* n. sp.

The genus *Persea* Schaeffer consists of about 200 species distributed in tropical Australia and America. *Persea glaucescens* (Wight) N.P. is a medium to large sized tree, distributed in mountain valleys or slops, open or dense forest of Bangladesh, Bhutan, India, Myanmar and Nepal.

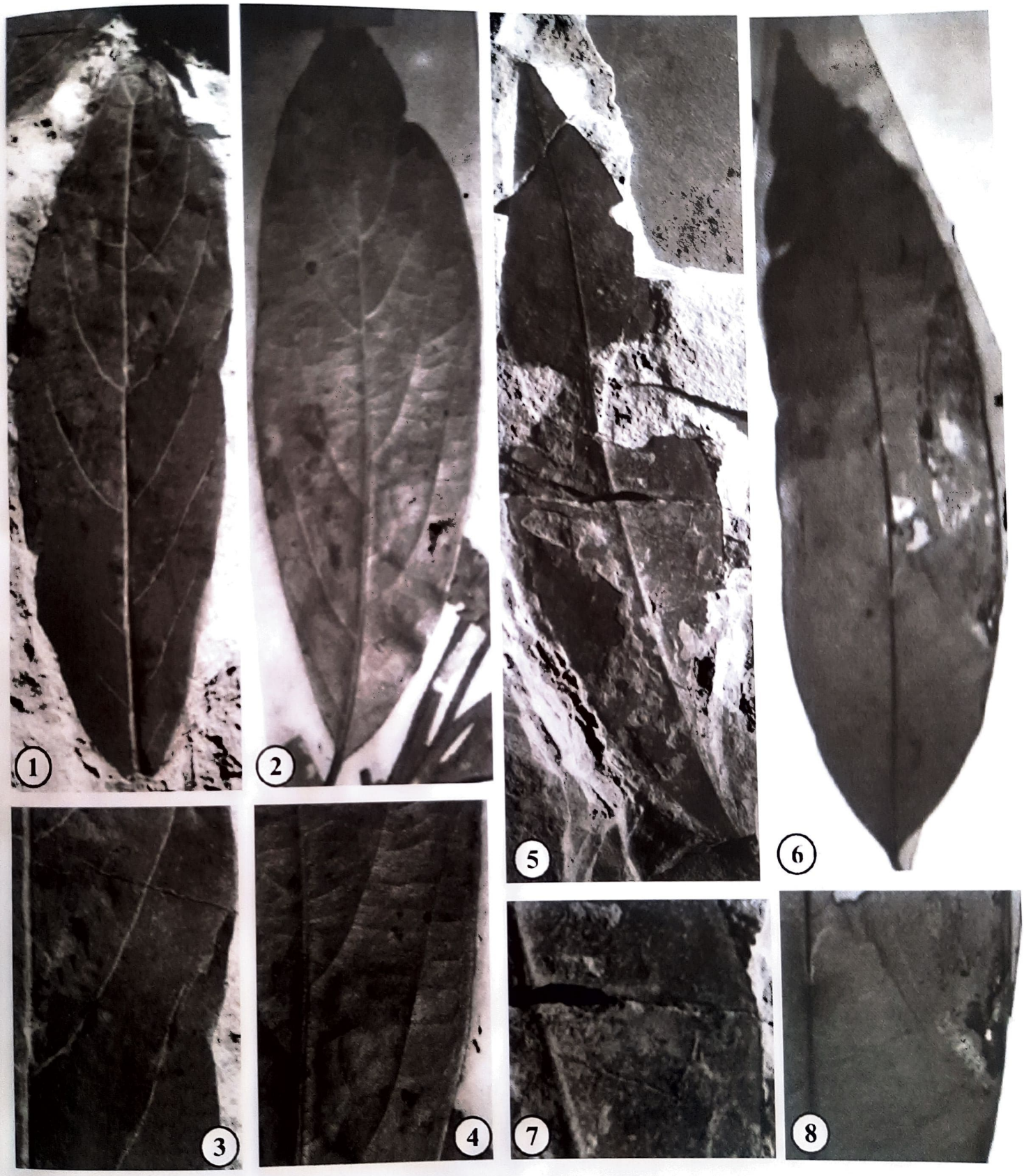


Plate 8

1. *Persea siwalika* n. sp. - Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40995 (Holotype). 2. *Persea glaucescens* Wight- Modern leaf showing similar shape, size and venation pattern. 3. *Persea siwalika* n. sp. -A part of fossil leaf magnified to show detail of venation. 4. *Persea glaucescens* Wight- A part of modern leaf magnified to show similar details of venation 5. *Diospyros masotkholaensis* n. sp. - Fossil leaf showing shape, size and venation pattern. BSIP Museum no. 40993 (Holotype). 6. *Diospyros oleifolia* Wight- Modern leaf showing similar shape, size and venation pattern. 7. *Diospyros masotkholaensis* n. sp. - A part of fossil leaf magnified to show details of venation. 8. *Diospyros oleifolia* Wight- A part of modern leaf magnified to show similar details of venation (Scale bar = 1 cm).

Table 3. Present day distribution and forest types of modern comparable species of the fossil taxa recovered in the present study from Arjun Khola area, Nepal

Fossil Taxa	Modern Comparable taxa	Forest type	Distribution
Melodorum arjun-kholaensis n. sp.	*Melodorum fulgens* Hook. f. & Thoms.	Evergreen	Tropical Asia and Africa, South East Asia, Australia, Malaya
Mitrephora siwalika Antal & Awasthi 1993	*Mitrephora reticulata* Hook.f. & Thoms	Evergreen	India, Tennasserim, Malaya, Peninsula, Java, Myanmar, Tropical Asia
Uvaria nepalensis n. sp.	*Uvaria calamistrata* Hance.	Evergreen	China
Hydnocarcpus lamhiensis n. sp	*Hydnocarpus macrocarpa* Bedd.	Evergreen	Indo-Malaya, Sri Lanka, Tropical Asia, Travancore Ghats
Calophyllum suraikholaensis Awasthi & Prasad 1990	*Calophyllum polyanthum* Wall. ex Choisy.	Tropical wet & dry Evergreen	NE India, Bangladesh, Myanmar, Malaya, Andamans, South India, Sri Lanka
Grewia miopaniculata n. sp.	*Grewia paniculata* Roxb. ex DC.	Moist Deciduous	India, China.
Hopea masotkholaensis n. sp.	*Hopea balangeran* Korth.	Evergreen	Indo-Malaya, South India, New Guinea, Myanmar
Zanthoxylum siwalicum Prasad & Awasthi 1996	*Zanthoxylum hamiltonium* Wall.	Evergreen to Moist deciduous forest	Sikkim, Assam, Myanmar
Otonephelium nepalensis n. sp.	*Otonephelium stipulaceum* Radlk.	Evergreen	India, Malabar
Sapindus arjun- kholaensis n. sp.	*Sapindus emarginatus* Gaertner	Moist Deciduous	India to Central Japan, West Himalaya, Assam
Milletia miocinerea n. sp.	*Millettia cinerea* Benth.	Evergreen	Borneo, Sumatra, Thailand, Peninsular Malaysia
Combretum sahnii Antal & Awasthi 1993	*Combretum decandrum* Roxb.	Mixed deciduous forest	Sub-Himalayan region, Bangladesh and Central India, South India
Eugenia lamhiensis n. sp	*Eugenia jambolana* DC.	Evergreen	India, Myanmar, Sri Lanka, Sub-Himalayan Tract
Diospyros masotkholaensis n. sp.	*Diospyros oleifolia* Wall. ex Kurz.	Evergreen	Tenasserim, Martaban, Myanmar, Java
Cinnamomum corvinusianum n. sp.	*Cinnamomum culitlawn* Linn.	Evergreen	China, Malaysia
Persea siwalika n. sp.	*Persea glaucescens* (Wight) N.P.	Evergreen	India, Malayasia, Myanmar, Bhutan, Nepal, Bangladesh

DISCUSSION AND CONCLUSIONS

The present study, in the Miocene sedimentary sequence of Churia Group exposed in the Arjun Khola area of Nepal, has revealed occurrence of sixteen fossil species of plants having affinity with extant flora namely: *Melodorum fulgens* Hook. f. & Thoms., *Mitrephora reticulata* Hook. f. & Thoms., *Uvaria calamistrata* Hance., *Hydnocarpus macrocarpa* Bedd., *Calophyllum polyanthum* Wall. ex Choisy., *Grewia paniculata* Roxb. ex DC., *Hopea balangeran* Korth., *Zanthoxylum hamiltonium* Wall., *Otonephelium stipulaceum* Radlk., *Sapindus emerginatus* Gaertner, *Millettia cinerea* Benth., *Combretum decandrum* Roxb., *Eugenia jambolana* DC., *Diospyros oleifolia* Wall. ex Kurz, *Cinnamomum culitlawn* Linn. *Persea glaucescens* (Wight) NP. Out of the sixteen macrofloral species, twelve are represented by tropical dicotyledonous families. Of these, eleven species are recorded for the first time from the Miocene interval of Nepal. In addition, Coexistance analysis was conducted for reconstructing palaeoclimate in the region during the Miocene. Moreover, taxomonic comparisions along with present-day distribution of extant flora has helped to a certain extent to decipher the phyto-

geographic scenario(s).

Palaeoclimate estimation through Coexistence Approach (CoA)

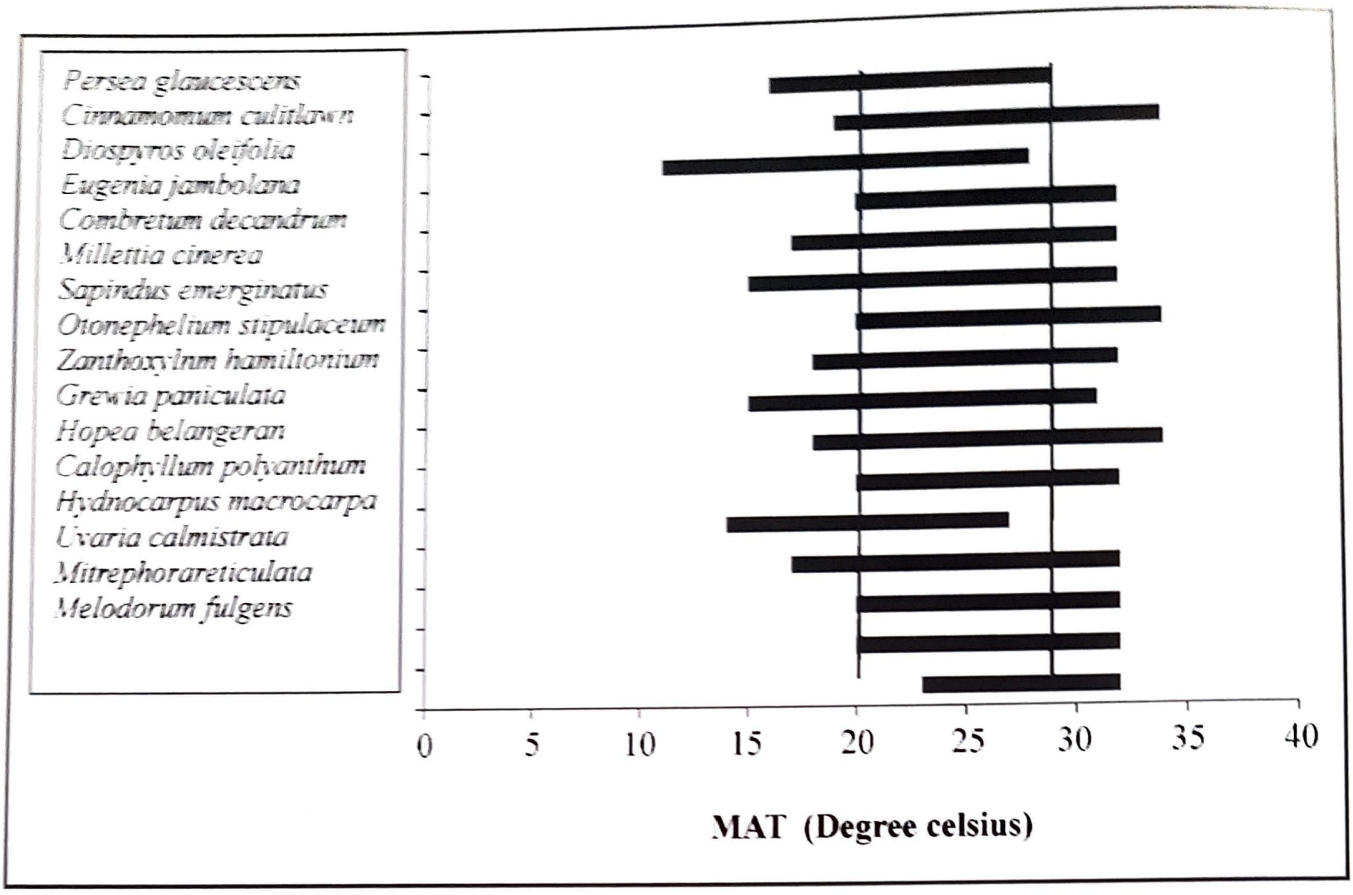
We here followed Coexistence Approach (CoA) developed by Mosbrugger and Utescher (1997) and subsequently enhanced by Utescher et al. (2014), that are based on the concept that fossil plant taxa (particularly of tertiary flora) should have similar climatic requirements as their Nearest Living Relatives (NLR). The analysis consists of three broad steps: 1) the nearest living relative (NLR) is determined for individual fossil taxon, 2) the modern distribution area is compiled for individual NLR, 3) range of climate parameters (MAT, MAP) are determined for the distribution area(s) and lastly, 4) for each climate parameter analysed, the climatic ranges under which maximum number of NLRs of individual fossil flora can co-exist (Coexistence Interval), is determined. In view of this, the macrofloral assemblage for all the plant fossils studied from the Arjun Khola area, Nepal have been compared with their modern equivalents. The MAT and Coexistence Intervals of the present-day modern taxa of Arjun Khola macrofloral assembalge were obtained from various sources (Champion & Seth 1968) from the Climatological table of observation in India (1931-1960); and from various websites (viz., *https//: weather-and- climate.com;* www.en.*climate-data.org; www.sdwebx.worldbank.org; www.-weatherspark.org*). This has led us to infer that the MAT for the Arjun Khola plant fossil assemblage is about 20.0^{0}C-28.5.^{0}C. Similarly, climatic estimates (Coexistence Intervals) for different climatic parameter i.e., WMT about 29°C-34°C), CMT about 15°C-22°C and MAP about 1800 mm-3200 mm were inferred (Text figs. 2 a-d). Thus, it is suggested that the Arjun Khola area in Nepal enjoyed a tropical climate along with plenty of rainfall during Miocene.

Phytogeographical interpretation

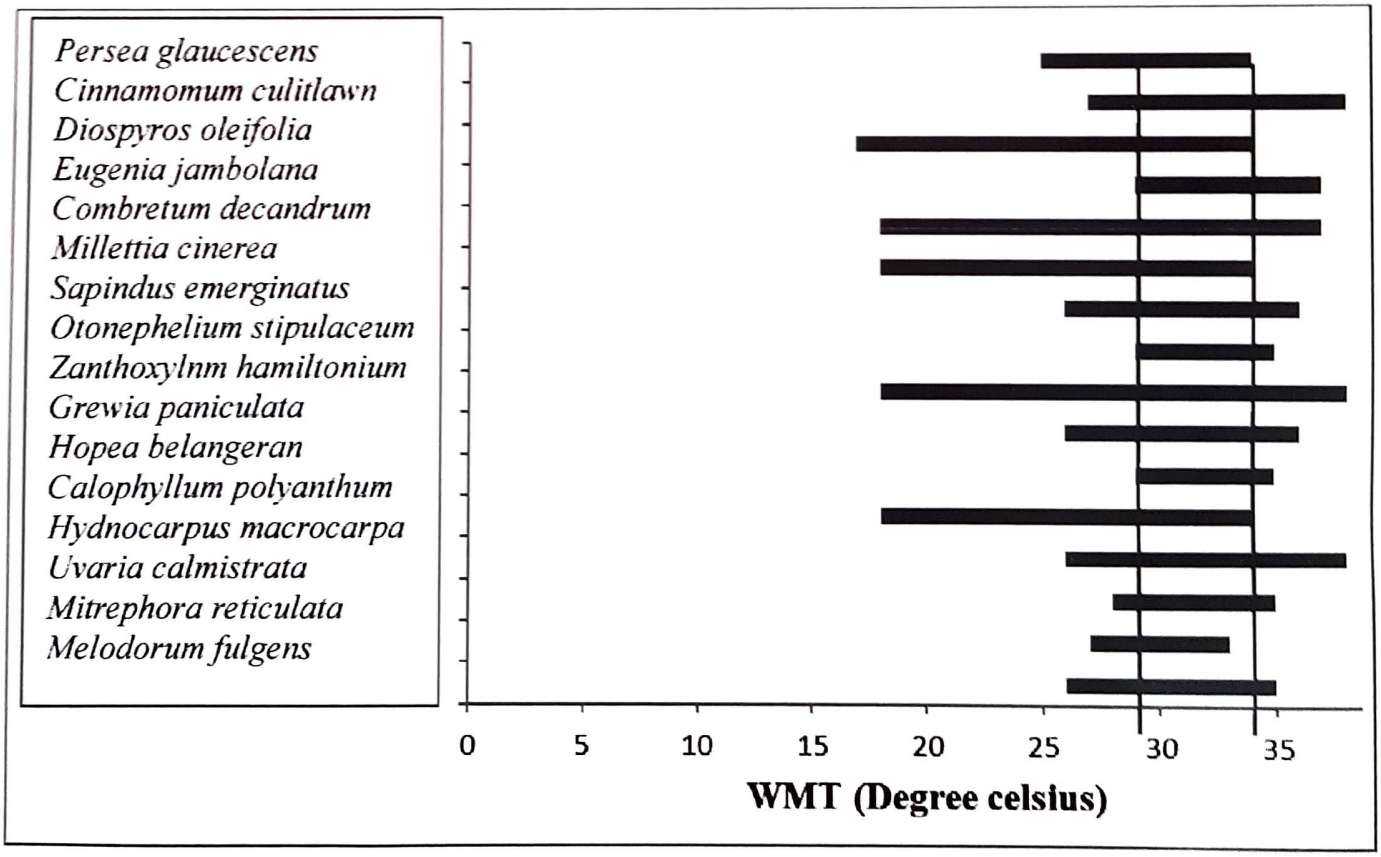
Out of the twelve families represented in the macroflora, Annonaceae comprises of three taxa namely *Melodorum fulgens*, *Mitrephora reticulata* and *Uvaria calamistrata*. Annonaceae is a pan-tropical family that occurs mainly in rainforests, with few occurances in the temperate regions (Richardson et al. 2004). The fossil record of Annonaceae from the neo-tropics is quite rich as compared to that from the Indo-Malayan region (Burnham & Johnson 2004). However, the oldest known fossils of Annonaceae comprising of seeds and pollen are from the Maastrichtian of Nigeria and Colombia, respectively, suggests a west Gondwanan origin for the family (Chesters 1955, Sole de Porta 1971). It is important to note here that Annonaceae fossil woods having affinity with *Polyalthia* (*P. simiarum*) have been reported from the late Cretaceous - ?Paleocene of Deccan Intertrappean beds and from the Paleocene-Eocene of western India (Guleria and Mehrotra 1999, Singh et al. 2011).

The family Rutaceae is represented by a single taxon, *Zanthoxylum hamiltonium* distributed in Sikkim, Assam, and Myanmar. Rutaceaeous genera are most abundant in tropical areas and particularly diverse in Asia, Oceania, Africa and Madagascar (Pan 2010). Based on abundant early records from Europe, Asia and North America, Rutaceae are generally considered to be of Laurasian origin (Morley 2000, 2003, Morley and Dick 2003). However, Africa also has a reasonably good record of Rutaceae, (Dupéron-Laudoueneix and Dupéron 1995, Pan 2010). Based on the molecular phylogeny of its sister clades Muellner et al. (2006) indicated that Rutaceae probably had a more generalized Tethyan origin, rather than an exclusively Laurasian origin. In India, the oldest fossils of Rutaceae include woods from the late Cretaceous Intertrappean beds of Peninsular India (Chitaley 1962, Chitaley & Khubalkar, 1974) and leaf fossils from the Paleocene-Eocene sedimentary deposits of western India (Singh et al. 2011).

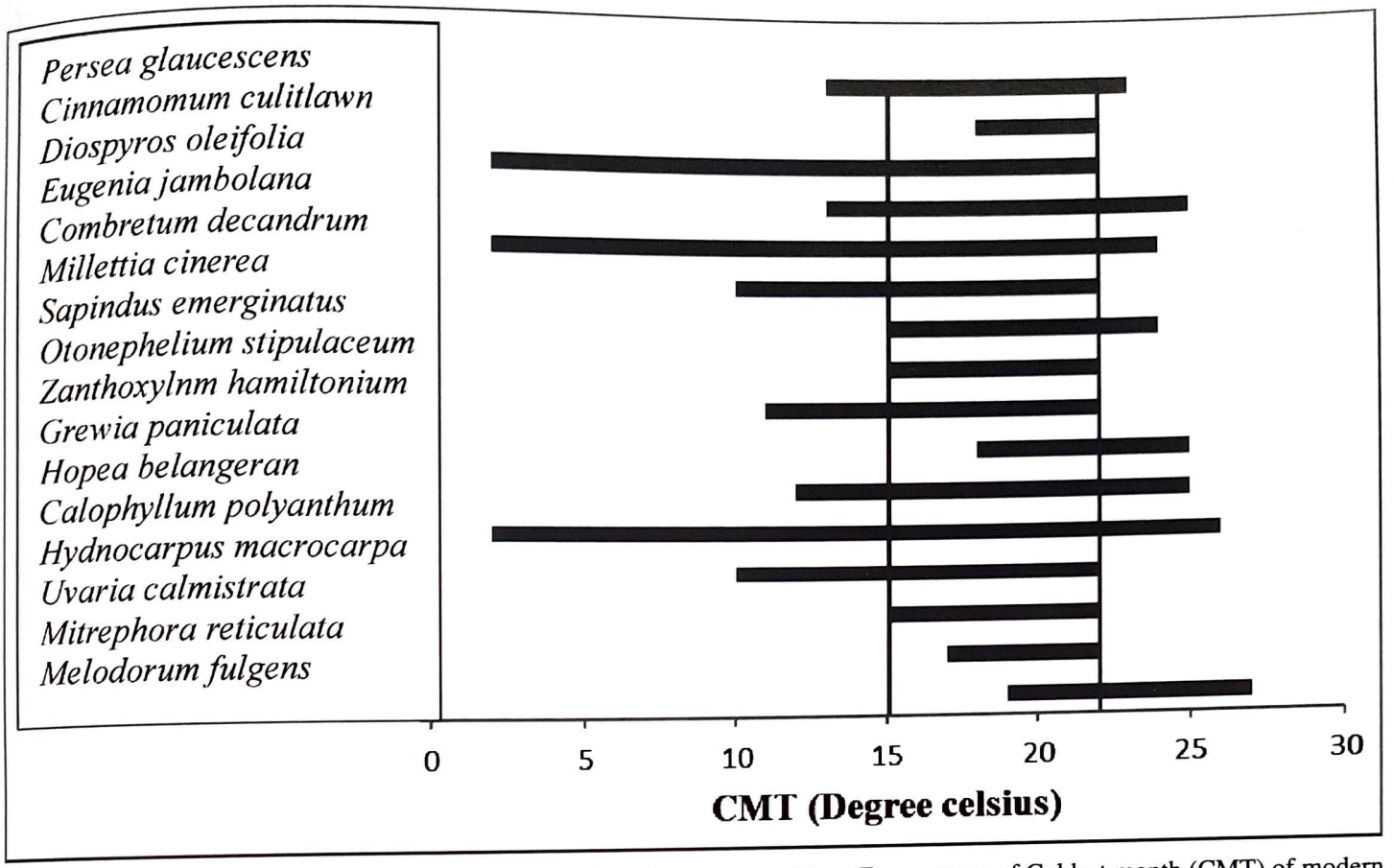
Combretum Linn. is the most common genus belonging to family Combretaceae. This family occurs throughout the tropical and subtropical regions with limited spread into warm temperate zones. The family is particularly more diverse along tropical sea coasts, in African savannas and in the Asian tropical deciduous forests (monsoon forests). The oldest confirmed remains of Combretaceae (*Terminalia*) are from the late Cretaceous of Portugal (Friis 1992, Stace 2007).



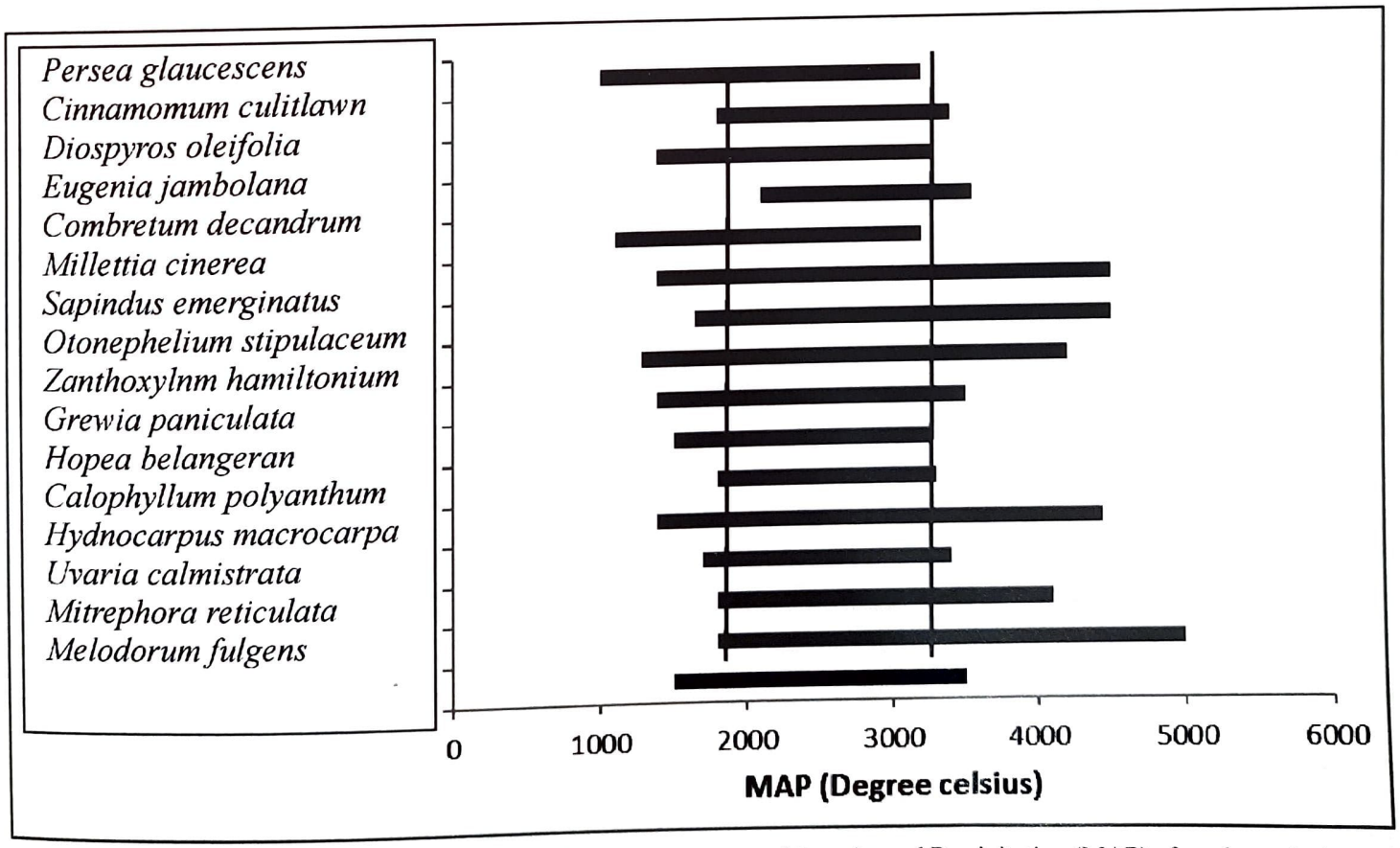
Text Figure 2a. Showing the coexistence intervals of climatic parameter, Mean Annual Temperature (MAT) of modern relatives of all the 16 taxa recorded from Arjunkhola area, western Nepal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of MAT.



Text Figure 2b. Showing the coexistence intervals of climatic parameter, Mean Temperature of Warmest month (WMT) of modern relatives of all the 16 taxa recorded from Arjunkhola area, western Nepal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of WMT.



Text Figure 2c. Showing the coexistence intervals of climatic parameter, Mean Temperature of Coldest month (CMT) of modern relatives of all the 16 taxa recorded from Arjunkhola area, western Nepal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of CMT.



Text Figure 2d. Showing the coexistence intervals of climatic parameter, Mean Annual Precipitation (MAP) of modern relatives of all the 16 taxa recorded from Arjunkhola area, western Nepal (▬ indicate the intervals of coexistence) and vertical line indicating the common range of MAP.

In India, fossils of Combretaceae have been reported from the late Cretaceous and Paleocene to Eocene deposits of western India (Mahabale & Deshpande 1965, Prakash & Dayal 1968, Singh et al. 2010, 2011, Mehrotra 2000, Sahni et al. 2006).

In the present macrofloral assemblage the Family Sapindaceae is represented by two genera: *Otonephelium* Radlk and *Sapindus* Linn. These are primarily tropical or subtropical in distribution with their main center of diversity in the south Asian region, though some forms extend into the temperate regions of Asia and North America (Klassen 1999). The family is also widespread in Australian rainforest (Harrington 2008). The oldest records of Sapindaceae are from the late Cretaceous and Paleocene of North America. However, Harrington (2008) in a recent evaluation of evolutionary history of Sapindaceae opined that Sapindaceae originated during the Pliocene–Miocene, rather than in the Paleocene. In India, the oldest records of Sapindaceae are represented mostly by fossil woods from the late Cretaceous of Deccan Intertrappean beds (Dayal 1965, Mehrotra 1987) and woods and leaves from the Miocene of India and Nepal (Prasad 1993, Prasad 2008).

The phytogeographically important taxon *Millettia cinerea* Benth. belonging to the family Fabaceae is a Malayan species and distributed in evergreen forests of Borneo, Sumatra, Thailand, and Peninsular Malaysia. According to Schrine (2005) the family Fabaceae originally evolved in tropical regions along the Tethys seaway during Palaeogene period. Studies on the plant macrofossils from Indian Subcontinent indicates that the genera of Family Fabaceae are most common in the Tertiary sediments (Prakash & Tripathi 1992, Prasad 2008). The fabaceous genera including *Millettia* have not been authentically reported from the Palaeogene period of Indian subcontinent, which suggests their later entry in the Indian subcontinents after the establishment of land connections with southeast Asian region by the end of Oligocene or early Miocene (Smith and Briden 1979, Smith et al. 1994). Perhaps, it was the appropriate time for entering into the southeast Asian elements into the Indian Subcontinent through its northeast corner during early Miocene (Agarwal et al. 2006). Later on, these taxa became abundant and were growing luxuriantly during the Neogene throughout India (Guleria 1992, Prasad 2008).

Cinnamoum and *Persea* are well known genera of the family Lauraceae which are commonly distributed in the Southeast Asian region (Indo-Malaya, Bangladesh, Myanmar, Nepal and Bhutan). The family Lauraceae comprises more than 50 genera and 2500 – 3000 species, mostly with an arboreal habit and are distributed throughout tropical and warm temperate regions. Indo-Malaya and tropical South America are the two major areas of their distribution (Mabberley 1997). The diverse fossil record of Lauraceae has been documented from the Cretaceous that includes flowers, fruits, leaves and woods. Lauraceous fossils including *Cinnamomum* are common in the Cretaceous and Tertiary sediments of both the Northern and Southern Hemispheres (Herendeen et al. 1999). Several fossil woods showing resemblance with the family Lauraceae are known from the Tertiary (Neogene) sediments of India. They have been generally reported under the form genus *Laurioxylon* Felix (Lakhanpal et al. 1981, Awasthi and Jafar 1990, Prasad 1990c, and Tiwari and Mehrotra 2000). However, the fossil leaves resembling the genera, *Machilus* (Prasad 1994, Prasad and Pandey 2008), *Actinodaphne* (Antal and Awasthi 1993, Prasad and Pandey 2008), *Cinamomum* (Lakhanpal and Guleria 1981,1982, Lakhanpal and Awasthi 1984, Prasad 1990, Antal and Awasthi 1993, Prasad 2008, Shashi et al. 2008, Konomatsu and Awasthi 1999), *Persea* (Lakhanpal and Guleria 1978), *Phoebe* (Bhattacharya 1983, Awasthi and Lakhanpal 1990) and *Litsea* (Awasthi and Lakhanpal 1984) have been recorded from both the Neogene and Paleogene sediments of the Indian Subcontinent.

The family Calophyllaceae is represented by a medicinally important genus *Calophyllum*. Most of the genera in this family were previously placed in the tribe Calophylleae of the family Clusiaceae. Some clusiaceous taxa (e.g., *Garcinia* and *Clusia*) reported in the Turonian flora from Sayreville, New Jersey, represent the earliest fossil evidence of the family (Crepet & Nixon 1998). Genera like *Calophyllum*, *Kayea* and *Mesua* belonging to the family Calophyllaceae are well

documented from the Tertiary sequences of India (Singh et al. 2015, Prasad 2008). The oldest fossil record of Calophyllaceae from India is represented by *Calophyllum dharmendrae* from the late Cretceous - ?Paleocene intertrappean deposits of Central India (Bande and Prakash 1980).

Diospyros is one of the most common genera of the family Ebenaceae. It is represented by 470 species of evergreen trees and shrubs and is native to the tropical and subtropical regions. It has a pantropical distribution with the greatest diversity of species in the Indo-Malayan region. Based on megafossils (woods and leaves), a number of fossil taxa resembling the genus *Diospyros* have been reported from different parts of the world (Prasad et al. 1999). The earliest record of *Diospyros* is from the Late Cretaceous (Kaiser 1890).

The genus *Grewia* Linn. of Family Malvaceae comprising of 150 species is well distributed in Africa, Europe, Asia and Australia. The comparable extant taxon *G paniculata* Roxb. ex. DC. is an Indo-Malayan species. The genus *Grewia* Linn has been recorded widely from the Cenozoic of India (Mehrotra 2000a, Mathur and Mathur 1998, Srivastava et al. 1992, Antal and Prasad 1999, Sivastava and Guleria 2000). However, its oldest record *Grewia mohagaonensis* is represented by a fruit (Paradkar and Dixit 1984) and a wood *Grewioxylon mahurzariense* (Prakash and Bande 1980), known from the late Cretaceous - ?Paleocene Deccan Intertrappean beds (Bande and Prakash 1980). The occurrence of two fossil species, i.e., *Pterospermoxylon sahnii* and *P. kutchensis* from the Eocene sediments are the earliest records from the Deccan Intertrappean beds (Bande and Prakash 1980).

The genus *Hopea* Roxb. is one of the significant representatives of the Family Dipterocarpaceae which may be regarded as an important family from a phytogeographical point of view. The present and past distribution of the family indicates that it is pantropical and specially belongs to tropical Asia except for the two genera *Marquesa* and *Monotes* which are distributed in Africa.

The Family Flacourticeae is represented by the genus *Hydnocarpus* in the present macrofloral assemblage. *Hydnocarpus* is an Indo-Malaysian genus with 40 species (Mabberley 1997). It mostly occurs in deciduous to evergreen forests and is distributed from sea level up to 2000 m. The fossil record suggests that it was common in India during the Mio-Pliocene times (Prasad 2008). The earliest record of this genus is represented by a fossil wood, *Hydnocarpoxylon indicum* from the Late Cretaceous-?Paleocene Deccan Intertrappean beds of Central India (Bande and Khatri 1980). The extant comparable species, *Hydnocarpus macrocarpa* Bedd. is a large tree distributed in Kerala, Tranvancore Ghats, India and in the Malayan region.

A perusal of the foregoing account reveals that tropical forests under moist conditions were prevalent during the Miocene times in the Arjun Khola region of Nepal that is presently occupied by mixed deciduous forests. The Coexistence analysis also corroborates these findings.

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