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MIDDLE MIOCENE (SIWALIK) PLANT MEGAFOSSILS FROM THE SUB- HIMALAYAN ZONE OF UTTARAKHAND AND THEIR PALAEOCLIMATIC IMPLICATIONS

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ABSTRACT

Systematic study on the plant fossils (leaf and fruit impressions) collected from Lower Siwalik sediments of Sarda River section near Thuligad in the Sub-Himalayan hills, Uttarakhand revealed the occurrence of 12 new fossil taxa resembling the genera, *Gynocardia* (Flacourtiaceae), *Mesua* (Clusiaceae), *Dipterocarpus* (Dipterocarpaceae) *Grewia* (Tiliaceae), *Nephalium* (Sapindaceae) *Millettia, Albizia* and *Xylia* (Fabaceae) and *Machilus* (Lauraceae). The predominance of evergreen elements in the present Siwalik fossil assemblage indicates the prevalence of tropical, humid climate with plenty of rain fall during the deposition of Siwalik sediments.

The analysis of present-day distribution of all the 12 fossil species recovered from the Siwalik sediments of Tanakpur area shows that they are mostly known to occur in the North-east India, Bangladesh, Myanmar and Malaysia wherever favourable climatic conditions exist. Of these, two taxa *Dipterocarpus koilabasensis* Prasad *et al*. and *Dipterocarpus miogracilis* n. sp. belonging to the family Dipterocarpaceae are phytogeographically important as they are not growing nowadays in the Himalayan foot hills of Uttarakhand but migrated towards north eastward (North-east India, Malaya, Myanmar etc.) due to prevailing unfavorable climatic condition during the Siwalik period (Middle Miocene).

Coexistence approach (CoA) suggests that the Tanakpur area in the Himalayan foot-hills of Uttarakhand enjoyed a tropical climate with MAT 21^{0}C-27^{0}C and MAP 1900-3500mm during the Mio- Pliocene times. Thus it may suggest that fossil flora recovered from the Siwalik of Thuligad area coexist in such climatic ranges during Middle Miocene times.

Keywords: Plant megafossils (Leaf and fruit impressions), morphotaxonomy, palaeoclimate, Siwalik Group, Sub-Himalayan Hills, Uttarakhand

INTRODUCTION

The sediments of Siwalik were deposited continuously by various rivers in the Himalayan foreland since last 20 million years (Johnson *et al*., 1985). These sediments provide an excellent opportunity to study on the plant macrofossils including fossil wood, leaf, fruit and seed impression entombed in alluvial context. The Siwalik sediments comprise mudstone, sandstone and coarsely bedded conglomerates. The Siwalik beds in the fossil locality, Thuligad area, Champawat district, Uttarakhand are found running in the north east direction and are well exposed at the bank of Sharda river near Thuligad and Thuligad-Purniyagiri Road about 15 Km. from Tanakpur, Champawat district (Figs. 1,2). A little palaeobotanical work has been carried out from Tanakpur area. First of all a leaf impression resembling the genus *Persea* of the family Lauraceae was reported from there (Lakhanpal and Guleria, 1978). Later on, Shashi *et al*. (2006, 2008) described well preserved leaf fossils under 13 form species belonging to the families Anonaceae, Sterculiaceae, Fabaceae, Apocynaceae, and Lauraceae.

Recently more than hundred specimens of well preserved leaf and fruit impressions were collected from the fossiliferous beds of lower Siwalik claystone (Figs. 2,3) exposed all along Sharda River (Fig.3). Of these, only 12 well preserved fossil specimens including 11 fossil leaves and one fruit have been identified with their extant taxa. A systematic paleobotany of these taxa has been discussed in detail and based on available data the palaeoclimate of the area has interpreted in the present communication.

GEOLOGICAL SETTING

The Siwalik sediment in India, Nepal and Bhutan are exposed in the southern frontal area of the Himalaya in a WMW to ESE trending belt and is bounded by the Main Boundary Thrust (MBT) to the north and the Himalayan Frontal Thrust (HFT) to the south. The beds generally dip north or north eastward. On the basis of lithic nature and palaeontological data the Siwalik sediments have been subdivided into Lower, Middle and Upper Siwalik ranging in age from Middle Miocene to Upper Pleistocene (Pilgrim, 1913). The Siwalik deposits are one of the most comprehensively studied fluvial sequences in the world. They comprise mudstones, sandstones and coarsely bedded conglomerates laid down when the region was a vast basin during Middle Miocene to Upper Pleistocene times. The rocks become coarser grained upward through the Group being dominated by claystone, mudstone and siltstone in the lower part and terminating with conglomerate beds in the uppermost units. The sediments were deposited by rivers flowing southwards from the Greater Himalayas, resulting in extensive multi-ordered drainage systems. Following this deposition, the sediments were uplifted through intense tectonic regimes (commencing in Upper Miocene times), subsequently resulting in a unique topographical entity - the Siwalik Hills.

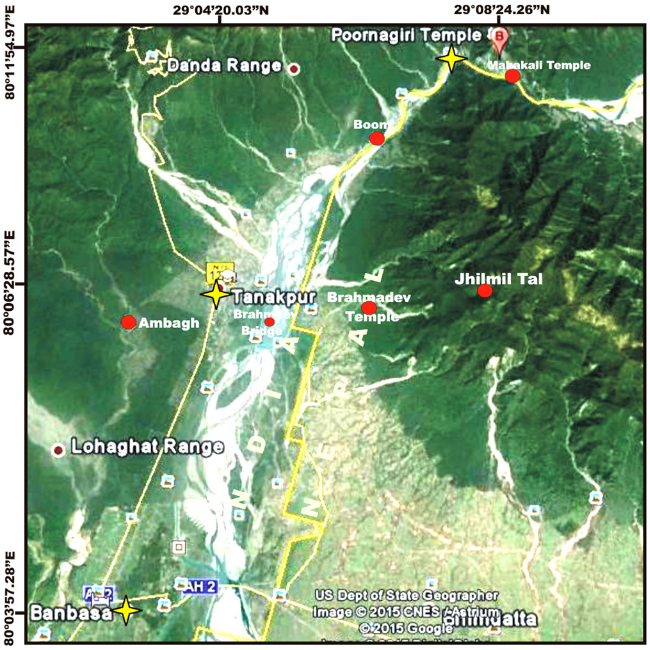


Fig. 1 Google snap showing the location of study area

The Siwalik deposit lies south of the Main Boundary Thrust. Its thickness varies due to development of valley in the region. The detailed lithology and stratigraphy of the Siwalik have been given by Sahni and Mathur (1964); Karunakaran and Ranga Rao (1979); Chaudhuri (1971); Kumar and Tandon, (1985); Mishra and Valdiya (1961); Ranga Rao *et al*., (1979); Tandon (1976); Shukla (1984).

The Siwalik beds in the Tanakpur area are found running in the north-east direction and are well exposed at the bank of Sharda River near Thuligad (Fig. 4) and on Thuligad-Purniyagiri road about 15 km from Tanakpur and Tanakpur- Pithoragarh Road and Karaurhi Nala near Bastia village. The sediments are coarsening upwards reflecting on increase in transport energy with time. The Lower and Middle Siwalik sediments consist of alternation of sandstone and mudstone beds while the Upper Siwalik sediments are characterized by alternation of conglomerate and mudstone beds with local lenses of sandstone.

MATERIAL AND METHODS

More than 100 leaf and fruit impressions were collected from the lower Siwalik sediments exposed at the bank of Sharda River ($29^0$08.212': 80^0 10.902') near Thuligad about 15 Km.

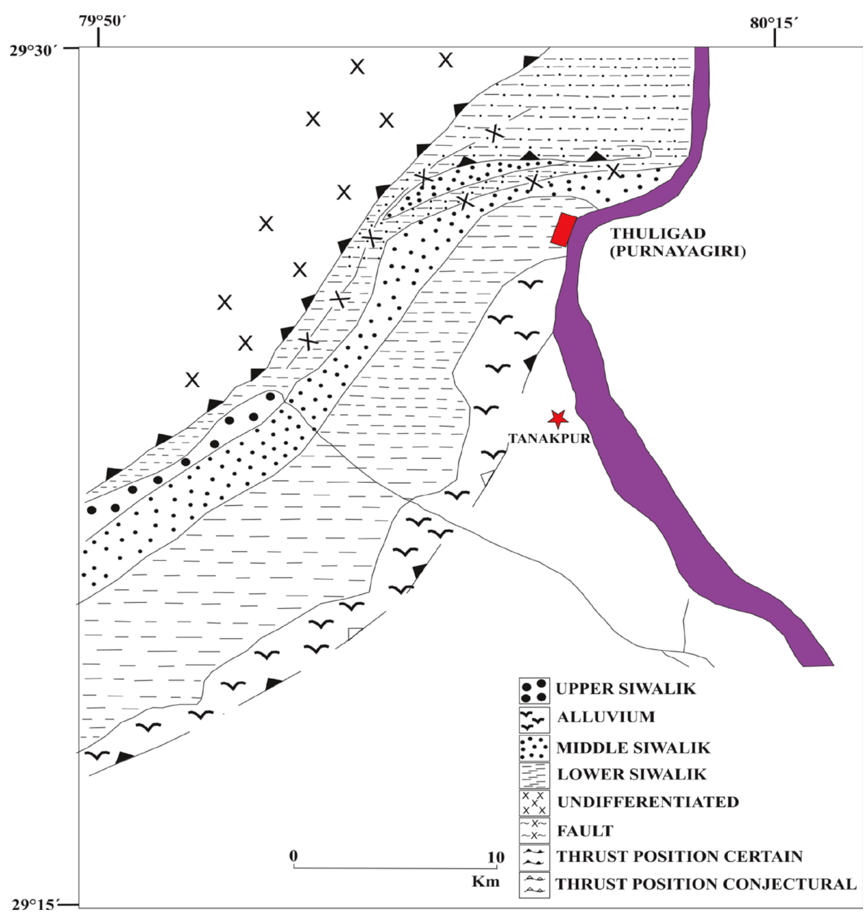
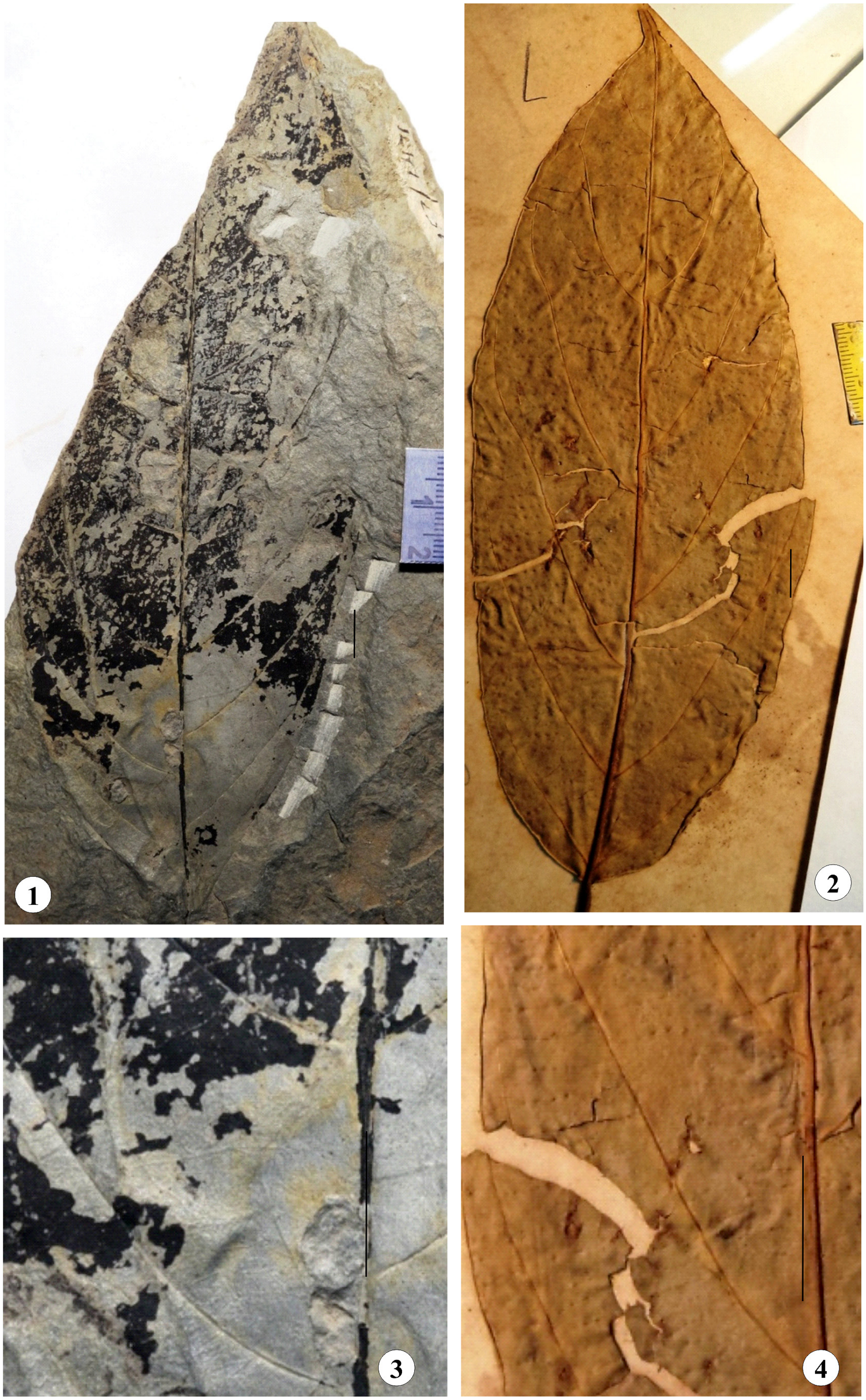


Fig.2. Geological map showing Lower Siwalik sedimentation around the fossil locality.

EXPLANATION OF PLATE I

1. ***Gynocardia mioodorata*** Prasad - Fossil leaf showing shape, size and venation pattern. 2. ***Gynocardia odorata*** R. Br. - Modern leaf showing similar shape, size and venation pattern. 3. ***Gynocardia mioodorata*** Prasad - Part of fossil leaf magnified to show details of venation. 4. ***Gynocardia odorata*** R. Br.- Part of modern leaf magnified to show similar details of venation.

Plate I



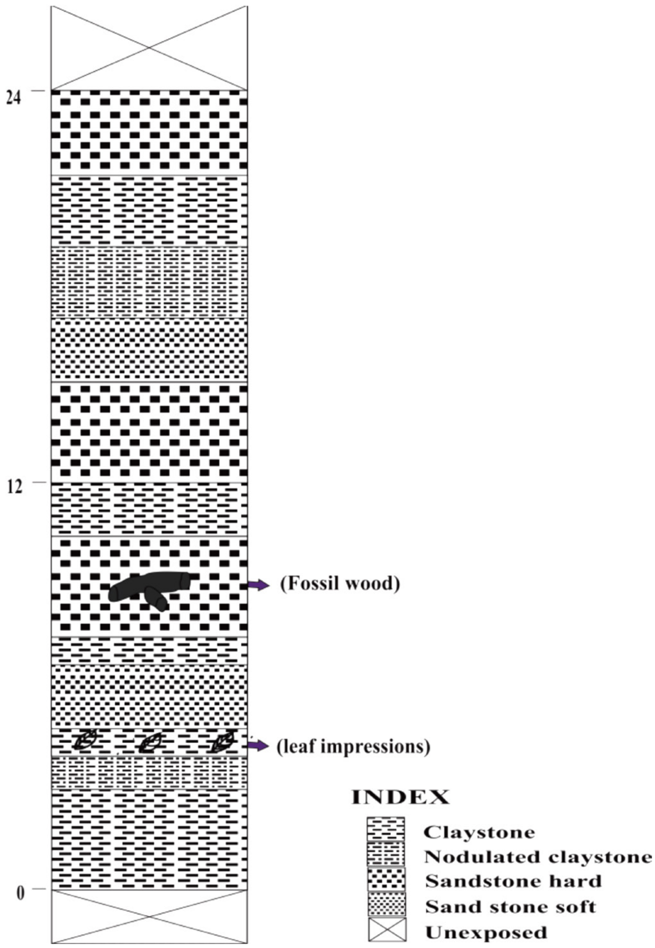


Fig.3. Lithocolumn of a part of Sarda River setion in Thuligad area, Champawat district indicating the bed from where fossil material were collected

from Tanakpur, Champawat district, Uttarakhand (Figs1,4). The leaf impressions were devoid of cuticle and preserved on usually grey shales (Fig.3). These fossils have been studied morphologically with the help of either hand lens or low power microscope under reflected light. The herbarium sheets of several extant families and genera were examined at Central National Herbarium, Sibpur, Howrah, West Bengal in order to identify these leaf impressions. For the description of leaf impressions, the terminology given by Hickey (1973) and Dilcher (1974) has been followed. The photographs of the leaves of the modern comparable taxa have been provided to show similarity with the fossil leaves. All the figured specimens have been deposited at Museum, BSIP, Lucknow.

SYSTEMATIC PALAEOBOTANY

Magnoliopsida
Family **Flacourtiaceae** de Candolle, 1824
Genus ***Gynocardia*** R. Br.

Gynocardia mioodorata Prasad *et al*., 1999
(Pl. I, figs.1,3)

Material: This species is represented by a single well preserved leaf impression without its apical part.

Description: Leaf simple, symmetrical, elliptic, preserved size 16.5 x 6.0 cm; broken toward apex, base obtuse; margin entire; texture chartaceous; petiole preserved; venation pinnate, eucamptodromous; primary vein single, prominent, stout, almost straight; secondary veins 7-8 pairs visible, 0.7-2.0 cm apart, uniformly curved up and joined to their supraadjacent secondary vein, sometimes form a loop in apical portion, angle of divergence about 65°, alternate to sub-opposite, unbranched; tertiary veins fine, angle of origin AR to AO, sometime branched, percurrent, more or less straight to sinuous, alternate to opposite, oblique to right angle in relation to mid vein and close.

Specimen: BSIP Museum no. 40818.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Affinity: Symmetrical, elliptic shape; eucamptodromous venation, spacely arranged middle secondaries and closely placed basal secondaries, running of secondary veins for a long distance, AR-AO, percurrent, straight to sinuous, branched tertiary vein suggest that the fossil leaves resemble closely with the modern leaves of *Gynocardia odorata* R. Br. (=*Chaulmoogra odorata* Roxb.; C.N.H. Herbarium Sheet no. 33496; Pl. I, fig.2,4) of the family Flacourtiaceae.

So far, the following three fossil leaves resembling the genus *Gynocardia* R. Br. have been reported from the Siwalik sediments of India and Nepal. *Gynocardia mioodorata* Prasad from Lower Siwalik sediments of Koilabas area, Nepal (Prasad *et al*., 1999) and from Siwalik of Arunanchal Pradesh. (Khan *et a*l., 2011) *G. butwalensis* from Lower Siwalik of Tinau Khola near Butwal, Nepal (Konomatsu and Awasthi, 1999) and from Siwalik sediments of Mandi District, Himachal Pradesh (Prasad *et al*., 2013). All the above known fossils show similar features and are compared with the single extant species *Gynocardia odorata* R. Br. On comparison it has been seen that the present fossil leaves show closest similarity with the known fossil leaf, *Gynocardia mioodorata* (Prasad *et al.,* 1999) and hence assigned to the same specific name.

The family Flacourtiaceae is well documented from Tertiary sediments of India. The earliest record *Homalioxylan mandlaensis* Bande, 1974, *Hydnocarpoxylon indicum* Bande

EXPLANATION OF PLATE II

1. ***Grewia tanakpurensis*** n. sp.- Fossil leaf showing shape, size and venation pattern. 2. ***Grewia salviifolia*** Linn. f.- Modern leaf showing similar shape, size and venation pattern. 3. ***Grewia tanakpurensis*** n. sp.- Part of fossil leaf magnified to show details of venation. 4. ***Grewia salviifolia*** Linn. f. - Part of modern leaf magnified to show similar details of venation. 5. ***Mesua tertiara*** Lakhanpal- Fossil leaf showing shape, size and venation pattern. 6. ***Mesua ferrea*** Linn.- Modern leaf showing similar shape, size and venation pattern. 7. ***Mesua tertiara*** Lakhanpal- Part of fossil leaf magnified to show details of venation. 8. ***Mesua ferrea*** Linn. -Part of modern leaf magnified to show similar details of venation. 9. ***Grewia mallootophylla*** Konomatsu & Awasthi- Fossil leaf showing shape, size and venation pattern. 10. ***Grewia laevigata*** Vahl.- Modern leaf showing shape, size and venation pattern. 11. ***Grewia mallootophylla*** Konomatsu & Awasthi- Part of fossil leaf magnified to show details of venation. 12. ***Grewia laevigata*** Vahl.- Part of modern leaf magnified to show similar details of venation.

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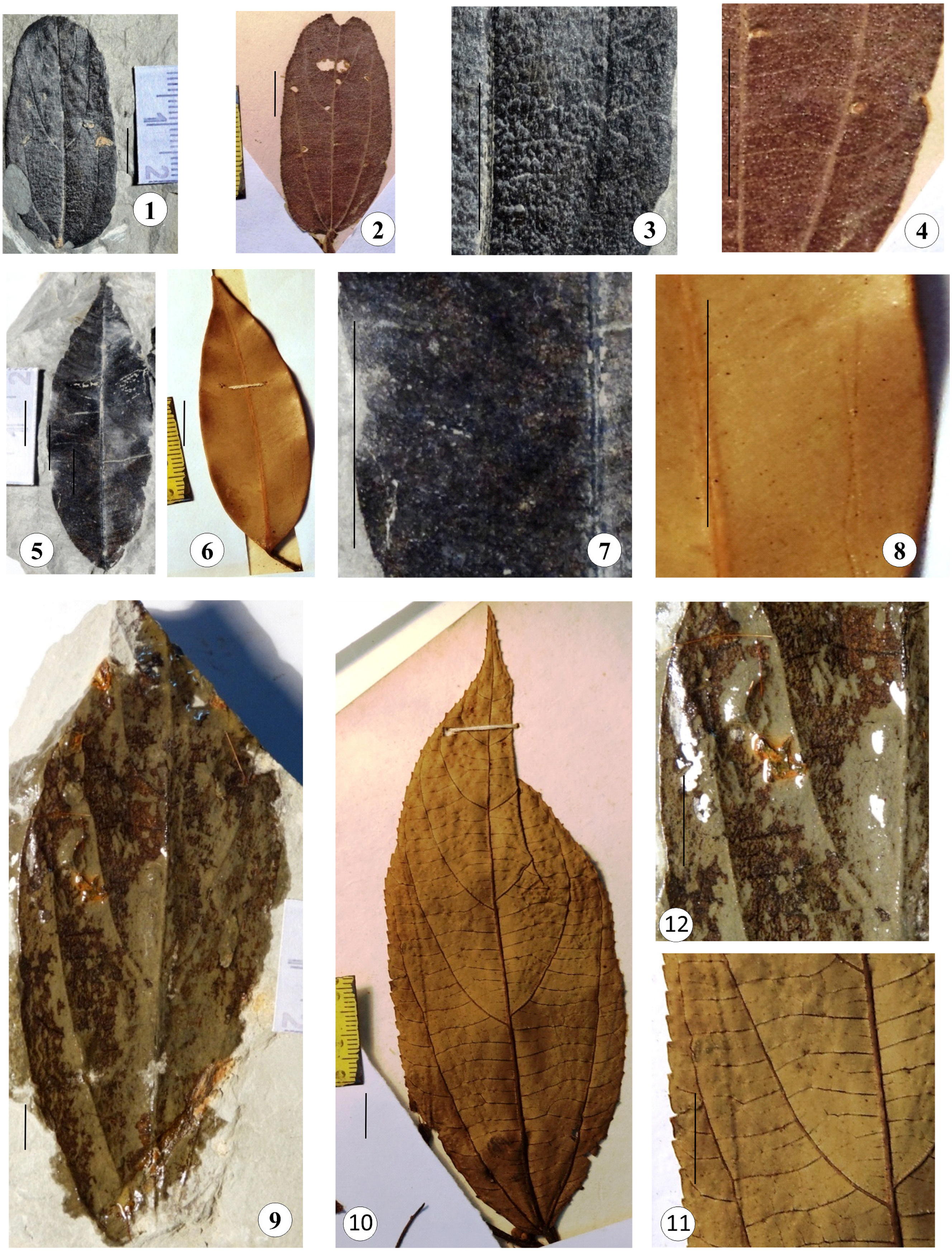
Plate II



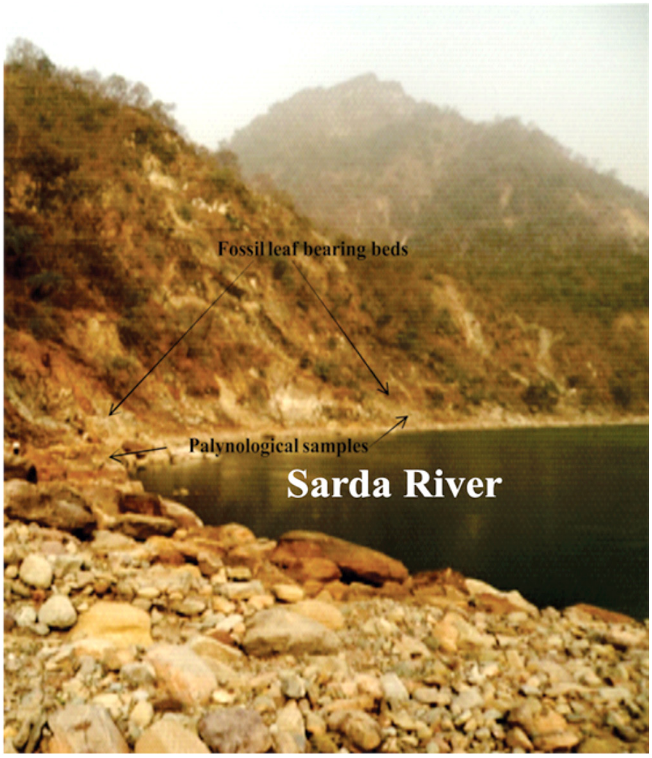


Fig. 4. Showing Sharda River section exposed near Thuligad from where fossil specimens were collected

and Khatri, 1980 and *Flacourtioxylon mohgaonensis* Trivedi & Srivastava, 1986 goes back to Palaeocene-Eocene of the Deccan Intertrappean beds of India.

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

Family **Calophyllaceae** Lindley, 1836
Genus ***Mesua*** Linneus, 1785

Mesua tertiara Lakhanpal, 1964
(Pl. II, figs.5,7)

Material: This species is based on a single well preserved fossil leaf.

Description: Leaf simple, symmetrical, elliptic; preserved size 1.7 × 4.7 cm; apex attenuate; base acute; petiole not preserved; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, prominent, stout, straight to slightly curved; secondary veins very fine, closely placed, more than 30 pairs visible, about 0.2 cm apart, alternate to opposite, angle of divergence 45^0, moderate, sometimes basal secondaries arises at lesser angles, uniformly, curved up; tertiary veins fine with angle of origin both AO and RR, percurrent, straight to sinuous, oblique in relation to mid vein, predominantly alternate and close.

Specimen: BSIP Museum specimen no. 40819.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Affinities: The shape, size, and venation pattern of the fossil leaves suggest its close resemblance with the modern leaf of *Mesua ferrea* Linn. of the family Calophyllaceae (C.N.H. Herbarium sheet No.48256; Pl. II, figs.6,8).

Fossil leaf resembling *Mesua ferrea* L. has already been reported under the name *Mesua tertiara* from the Earth beds of Kapurdi, Western Rajasthan (Lakhanpal, 1964); the Siwalik sediments of Koilabas Nepal, (Prasad, 1990a); the Siwalik sediments of Kathgodam, India, (Prasad, 1994a); the Neyveli Lignite deposits, Tamilnadu, India (Agarwal, 2002) and the Siwalik of Surai Khola, Western Nepal (Prasad & Pandey, 2008). After comparing the present fossil to all know fossil leaves it has been found that the this fossil leaf shows close resemblance with the leaves described from Surai Khola, Western Nepal. Thus in having similar features the present fossil leaves are described here under the same species *Mesua tertiara.*

The modern comparable taxa *Mesua ferrea* Linn. is a medium to large sized tree. It is native to wet tropical parts of Sri Lanka, India, southern Nepal, Burma, Thailand, Indochina, the Philippines, Malaysia and Sumatra, where it grows in evergreen forests, especially in river valleys. In the eastern Himalayas and Western Ghats in India it grows up to altitudes of 1500 meters, while in Sri Lanka up to 1000 meters. It thrives well in a locality with heavy rainfall and humid atmosphere (Hooker, 1872; Brandis, 1971).

Family **Dipterocarpaceae** Blume, 1825
Genus ***Dipterocarpus*** Gaertn., 1805

Dipterocarpus koilabasensis Prasad *et al*., 1999
(Pl. III, figs.1-3)

Material: Single, well preserved and incomplete leaf impression.

Description: Leaf simple, elliptic, in shape; preserved size 20 ×6.5; apex broken; base obtuse; margin entire to undulated; texture coriaceous; petiole absent; venation pinnate, eucamtodromous; primary vein single, prominent, stout, almost straight; 19 pairs of secondary veins visible, 1.2 to 1.5 cm apart, curved up, almost straight, sharply curved before joining the margin or their superadjacent secondaries, angle of divergence 40^0 - 55^0, acute, moderate, unbranched; tertiary veins fine, angle of origin usually RR type, percurrent, straight to sinuous, oblique in relation to midvein, predominantly alternate and close.

Holotype: BSIP Museum specimen no. 40820.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

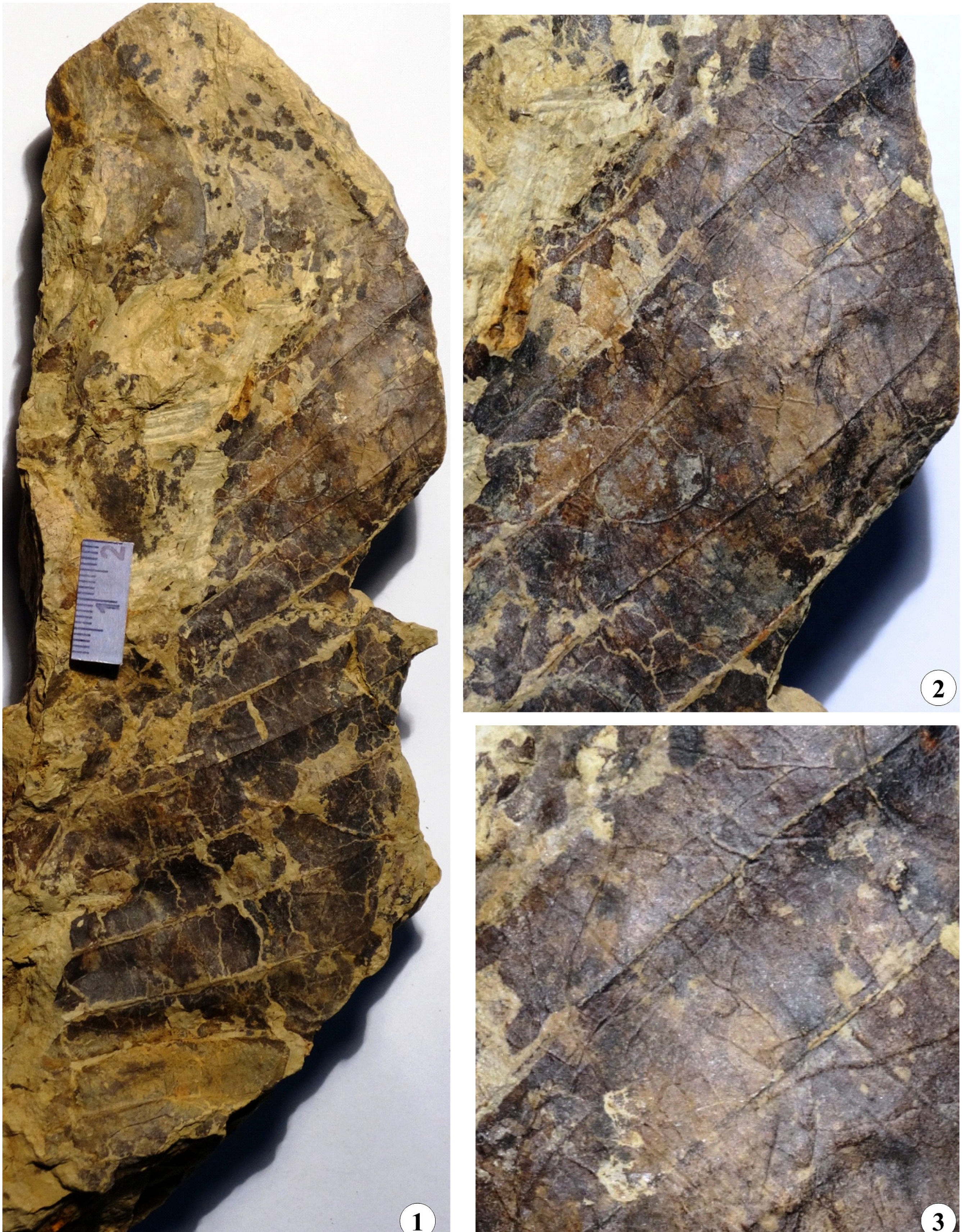
Horizon and Age: Siwalik Formation; Middle Miocene.

Affinity: Elliptic shape, obtuse base, entire to undulated margin, coriaceous texture, eucamptodromous venation, moderate angle of divergence of secondary veins with sharp curvature near the margin and percurrent, straight to sinuous

EXPLANATION OF PLATE III

1. ***Dipterocarpus koilabasensis*** Prasad - Fossil leaf showing shape, size and venation pattern. 2. ***Dipterocarpus koilabasensis*** Prasad - Part of fossil leaf magnified to show details of venation. 3. ***Dipterocarpus koilabasensis*** Prasad - Part of fossil leaf highly magnified to show sinuous nature of tertiary vein.

Plate III



tertiary veins altogether indicate its resemblance with extant leaves of the genus *Dipterocarpus* F. Gaertn. of the family Dipterocarpaceae. A detailed examination of the herbarium sheets of all the available species of this genus has been carried out in order to find out its nearest specific affinity. After detailed comparison it has been concluded that the extant leaves of *Dipterocapus turbinatus* Gaertn. (C.N.H. Herbarium sheet no. 50741,) shows closest affinity with the present fossil leaf.

Several fossil leaves showing affinity with the genus *Dipterocarpus* F. Gaertn. have been reported from the tertiary sediments of both India and abroad. They are *Dipterocarpus antiquus* and *Dipterocarpus atavinus* from the Tertiary of Sumatra (Heer, 1883); *D. tabuanus* and *D. nordenskioldi,* from Pliocene of Java (Geyler, 1887); *D. siwalicus* from the Siwalik sediments of Jwalamukhi (Lakhanpal and Guleria, 1987), Koilabas (Prasad, 1990a), Suraikhola (Awasthi and Prasad, 1990), Kathgodam (Prasad, 1994a), Surkhet valley (Prasad & Pradhan, 1998), Bhutan (Prasad & Tripathi, 2000), West Bengal (Antal & Prasad, 1996b) and Kasauli Formation (Guleria *et al*., 2000). *D. koilabasensis* Prasad *et al*., 1999 from Siwalik of Koilabas, Western Nepal; *Dipterocarpus suraikholaensis* Prasad & Pandey, 2008 from Siwalik of Surai khola, Western Nepal, and from Kimin Formation of Arunanchal Pradesh (Khan *et al*., 2011). A critical comparison of the present fossil leaf with the above known fossil species indicates that this shows similarity with the known fossil species, *Dipterocarpus suraikholaensis* Prasad.

The genus *Dipterocarpus* F. Gaertn. consists of about 78 species distributed in India and Western Malaysia (Willis, 1973), out of which 17 species are Indian and 5 are endemic in Sri Lanka. Two are found in southern India and the others in eastern Bengal, Myanmar and Andaman Islands. The extant species *Dipterocarpus turbinatus* Gaertn. with which the fossil shows closest affinity is a large evergreen tree occurring in the forest of Bangladesh, Tenasserrim, Andaman and Chittagong hills. It is also common in the tropical forest throughout Myanmar (Gamble, 1972; Hooker, 1872).

Family **Dipterocarpaceae** Blume, 1825
Genus ***Dipterocarpus*** Gaertn., 1805

Dipterocarpus miogracilis n. sp.
(Pl. IV, figs.1,3)

Material: This species is based on a single, well preserved and incomplete leaf impression.

Description: Leaf simple, elliptic in shape; preserved size 18 ×8; apex broken; base obtuse, broken; margin entire to undulated; texture coriaceous; petiole absent; venation pinnate, craspedodromous to eucamtodromous; primary vein single, prominent, stout, straight; 14 pairs of secondary veins visible, 1.0 to 1.2 cm apart, opposite-alternate, almost uniform spacing between veins curved up, almost straight before joining the margin or their superadjacent secondaries, angle of divergence 45^0 - 50^0, acute , moderate, unbranched; tertiary veins fine, angle of origin usually RR type, percurrent, straight to sinuous, oblique in relation to midvein, predominantly alternate and close.

Holotype: BSIP Museum specimen no. 40821.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Derivation of name: By adding prefixed 'mio' to the modern comparable extant taxa, *D. gracilis*

Affinity: The large size of the leaf having wide elliptic shape, obtuse base, entire to undulated margin, coriaceous texture, eucamptodromous venation, course of secondary veins which runs straightly upward with moderate acute angle of divergence and percurrent, straight to sinuous tertiary veins altogether indicate its resemblance with modern leaves of the genus *Dipterocarpus* F. Gaertn. of the family Dipterocarpaceae. A detailed examination of herbarium sheets of several species of this genus has been carried out in order to find out nearest specific affinity of the fossil leaf. After detailed comparison it has been found that among the available species *Dipterocarpus gracilis* Blume (C.N.H. Herbarium sheet no. 50611, Pl. IV, figs.2,4) shows closest affinity with the present fossil leaf.

On comparing the present fossil leaf with the already known species of the genus *Dipterocarpus*, it has been observed that it does not show similarity with any of them. The present fossil leaf differs from most of them in being large size and such arrangement of secondaries is also not present in any of the known species. This has, therefore, been described as a new species *Dipterocarpus miogracilis.*

The extant species *Dipterocarpus gracilis* with which fossil leaf shows close affinity is critically endangered species in the family Dipterocarpaceae, native to South Asia and Southeast Asia. This large tree is found in lowland semi-evergreen and evergreen dipterocarp forests. *D. gracilis* found in Bangladesh, India (Andaman and Nicobar Islands, Arunachal Pradesh, Assam and Tripura, Indonesia Java, Kalimantan, Sumatra, Peninsular Malaysia, Myanmar, Thailand and the Philippines.

Family **Tiliaceae** de Jussieu, 1789
Genus ***Grewia*** Linneus, 1735

Grewia mallotophylla Konomatsu and Awasthi 1999
(Pl. II, figs.9,12)

Material: This species is based on a single specimen.

Description: Leaf simple, incomplete, apical part on one side of midrib broken, symmetrical, seemingly ovate to elliptic, preserved size 9.0 x 6.0 cm; apex indistinct, base probably obtuse, margin entire to slightly serrate; texture chartaceous, petiole not preserved; venation pinnate, acrodromous; primary vein prominent, stout, almost straight; two strongly developed secondary veins arising from a single point at the base, secondary veins arising from midrib at acute angle, about 45°-50°, only 3 pairs present in the available specimen; tertiary veins arising almost at right angles from midvein as well as from secondary veins, convex, percurrent, forked, perpendicular in relation to midvein; quaternary veins fine, orthogonal.

Specimen: BSIP Museum specimen no. 40823.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Affinity: The distinguishing features of the fossil leaves are: wide elliptic shape, obtuse base, entire to slightly non-entire

EXPLANATION OF PLATE IV

1. ***Dipterocarpus miogracilis*** n. sp.- Fossil leaf showing shape, size and venation pattern. 2. ***Dipterocarpus gracilis*** Blume- Modern leaf showing similar shape, size and venation pattern. 3. ***Dipterocarpus miogracilis*** n. sp.- Part of modern leaf magnified to show details of venation. 4. ***Dipterocarpus gracilis*** Blume- Part of modern leaf magnified to show similar details of venation.

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Plate IV

margin, moderate acute, angle of divergence of secondary veins, basal pair of secondary veins running upwards up to more than half of the lamina, unbranched and RR, percurrent, tertiary veins nearly right angle in relation to midvein. These characters suggest the affinity of the fossil leaves with those of the genus *Grewia* Linn. of the family Tiliaceae.

A critical examination of the herbarium sheets of extant leaves of about 15 species of this genus has been carried out and we found that the leaves of *Grewia laevigata* Vahl. shows closest similarity with the present fossil leaves (C.N.H. Herbarium sheet nos 803; Pl. II, figs.10,11).

Fossil leaves resembling the genus *Grewia* Linn. are already known from Tertiary sediments of India and Nepal. Of these, *Grewia ghishia* Antal and Awasthi, 1993 and *Grewia tistaensis* Antal & Prasad, 1998 are from Siwalik sediments of Darjeeling district, West Bengal showing close resemblance with the extant species *G. umbellifera* Bedd., *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. respectively. Konomatsu and Awasthi (1999) described a leaf impression from Siwalik sediments of Arunkhola, W. Nepal under form species *Grewia mallotophylla* showing resemblance with the genus *Grewia and Mallotus* of the family Tiliaceae and Euphorbiaceae. Later shows specific affinity with *Grewia laevigata*, *G. tiliaefolia*, *G. microcos* and *G. umbellate* and *Mollotus philippineense.* Recently, Prasad *et al.* (2004) described a leaf impression from Kathgodam, Uttarakhand under *Grewia kothgodamensis* showing resemblance with *Grewia laurifolia*. Two more fossil leaves have been described from Tura Formation of Meghalaya under form species, *G. sahni* and *G. garoensis* (Mehrotra, 2000). After comparison with the above listed fossil leaves it has been observed that present fossil leaf shows close resemblance with *Grewia mallotophylla.* Therefore, the present fossil leaf has been kept under the same species, *Grewia mallatophyllum* Konomatsu & Awasthi.

The genus *Grewia* Linn. consists of more than 100 species found in tropical to sub-tropical regions. The *Grewia laevigata* with which the fossil leaf resembles is generally small trees, distributed in the semi evergreen to evergreen forests of South India and Southeast Asia. In India normally it is present in Kerala, District Idukki, Thrissur and Thiruvananthapuram (Brandis, 1971).

Family **Tiliaceae** de Jussieu, 1789
Genus ***Grewia*** Linneus, 1735

Grewia tanakpurensis n. sp.
(Pl. II, figs.1,3)

Material: This consists of only one well preserved complete specimen and devoid of cuticle.

Description: Leaf simple, small, symmetrical, narrow oblong, preserved length 4.2 cm and maximum width 1.8 cm; apex obtuse; base nearly obtuse; margin entire; texture chartaceous; petiole not preserved; venation pinnate, simple craspedodromous; primary vein prominent, stout, straight; secondary veins 3 pairs visible, 1.0 to 1.5 cm apart with angle of divergence acute, narrow 45°, divergence angle nearly uniform, moderate, uniformly curving upward, opposite to alternate, first pair of basal secondaries arising at more acute angle and extending high up to middle part of lamina, branching laterally into curved veins reaching towards margin; tertiary veins with angle of origin mostly percurrent, straight to sinuous, sometimes branched, oblique to right angle in relation to midvein, predominantly opposite, close; quaternary veins not visible.

Holotype: BSIP Museum specimen no. 40822.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Derivation of name: After the name of a famous town, Tanakpur nearest to the fossil locality.

Affinity: Symmetrical, small, narrow oblong shape, obtuse apex, obtuse base, entire margin, secondary veins with angle of divergence acute, narrow, basal secondaries reaching upwards almost up to about half of lamina and laterally branching into convexly curved veins are the characteristic features of the fossil leaf which collectively indicate its affinities with the leaves of the genus *Grewia* Linn. of family Tiliaceae.

The present fossil leaf was compared with 28 modern species of *Grewia* Linn. and found closely resembling *G. salvifolia* L. f (C.N.H. Herbarium sheet no.61067; Pl. II, figs.2,4).

In few characters the leaves of *G. multiflora* Juss. and *G. obtusa* Wall. also show affinity with the fossil leaf, but on the whole it differs. In *G. obtusa*, the first pair of secondaries extends very long towards apex as compared to the fossil specimen. The leaves of *G. multiflora* are smaller in size and therefore differ from the present fossil leaf.

So far, eight fossil leaves showing close resemblance with the genus *Grewia* Linn. are known from Tertiary sediments of Indian subcontinents (Listed earlier in this text). All the known fossil leaves have been compared with our present fossil leaf and found that none of them shows closest similarity as they are comparatively bigger in size and the secondary veins are more in number than the Siwalik fossil. One of the fossil leaf described from late Tertiary sediments of Mahuadanr, Jharkhand has been compared with extant species, *G. salvifolia* as the present fossil leaf and has not been given any fossil name. In view of this the present fossil has been reported as *Grewia tanakpurensis* n. sp. The fossil woods resembling *Grewia* have also been described as *Grewioxylon* sp. (Lakhanpal *et al*., 1978) from Intertrappean beds of Mandla District, Madhya Pradesh and *Grewioxylon mahurzariense* Prakash & Dayal, 1965 from the Deccan Intertrappean beds of Mahurzari, Madhya Pradesh are known. These records obviously support the occurrence of the genus *Grewia* Linn. during Tertiary period.

The extant genus *Grewia* Linn. consists of 150 species growing specifically in the tropical region of Asia, Africa and Australia (Willis, 1973, p. 499). *Grewia* is confined to the tropical and subtropical regions of the Old World, i.e. Africa, Madagascar, Arabia, India, Burma, Ceylon, Andaman-Nicobar,

EXPLANATION OF PLATE V

1. ***Nephalium palaeoglabrum*** Prasad- Fossil leaf showing shape, size and venation pattern. 2 ***Nephalium glabrum*** Noronh.- Modern leaf showing similar shape, size and venation pattern. 3. ***Nephalium palaeoglabrum*** Prasad- Fossil leaf (lower part of the leaf) showing asymmetrical basal part. 4. ***Nephalium glabrum*** Prasad- Modern leaf (lower part of the leaf) showing similar asymmetrical basal part. 5. ***Nephalium palaeoglabrum*** Prasad- Another fossil leaf showing variation in shape, size. 6. ***Nephalium palaeoglabrum*** Prasad- Part of fossil leaf showing details of venation. 7. ***Nephalium glabrum*** Noronh. Part of modern leaf magnified to show similar details of venation.

Plate V

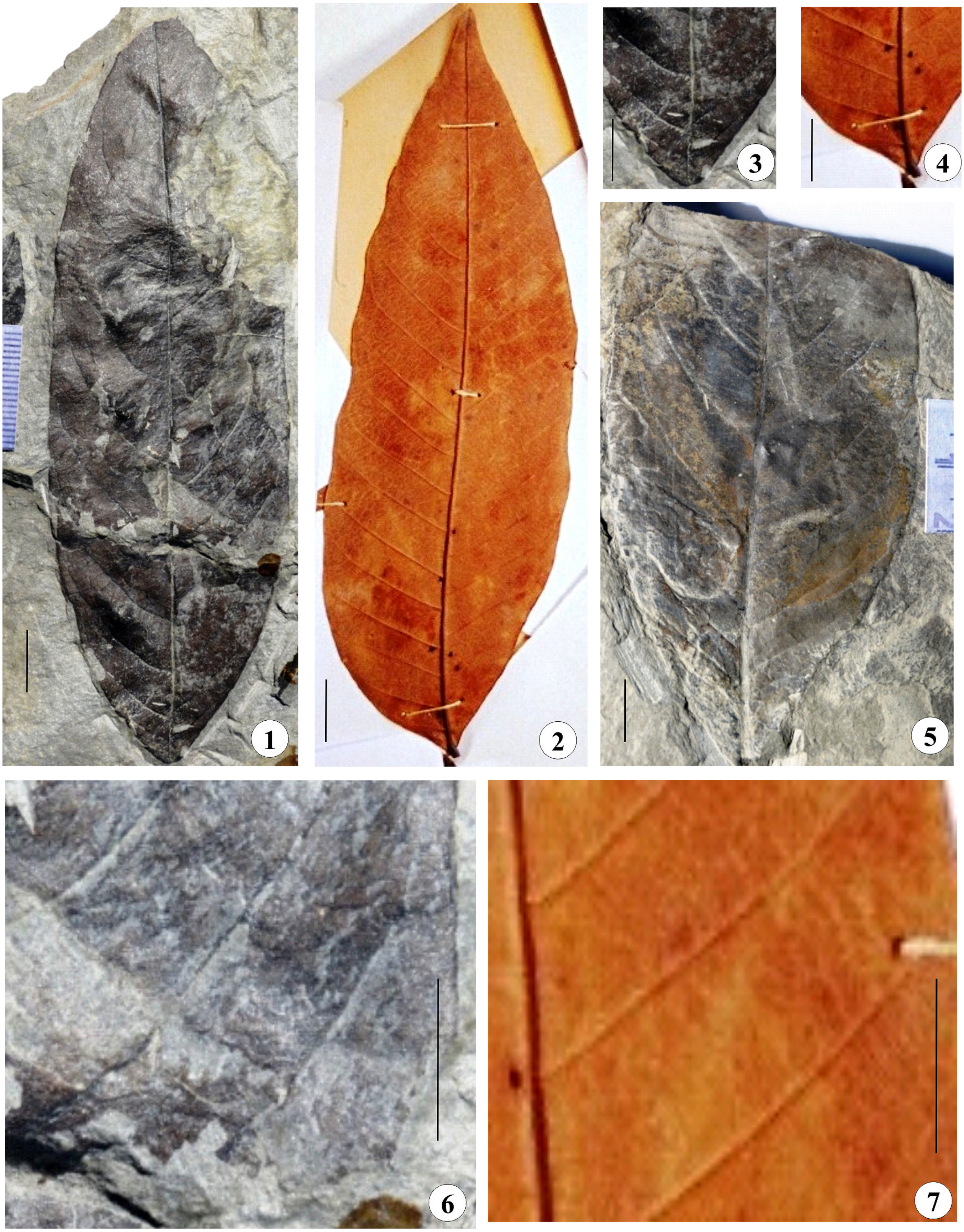


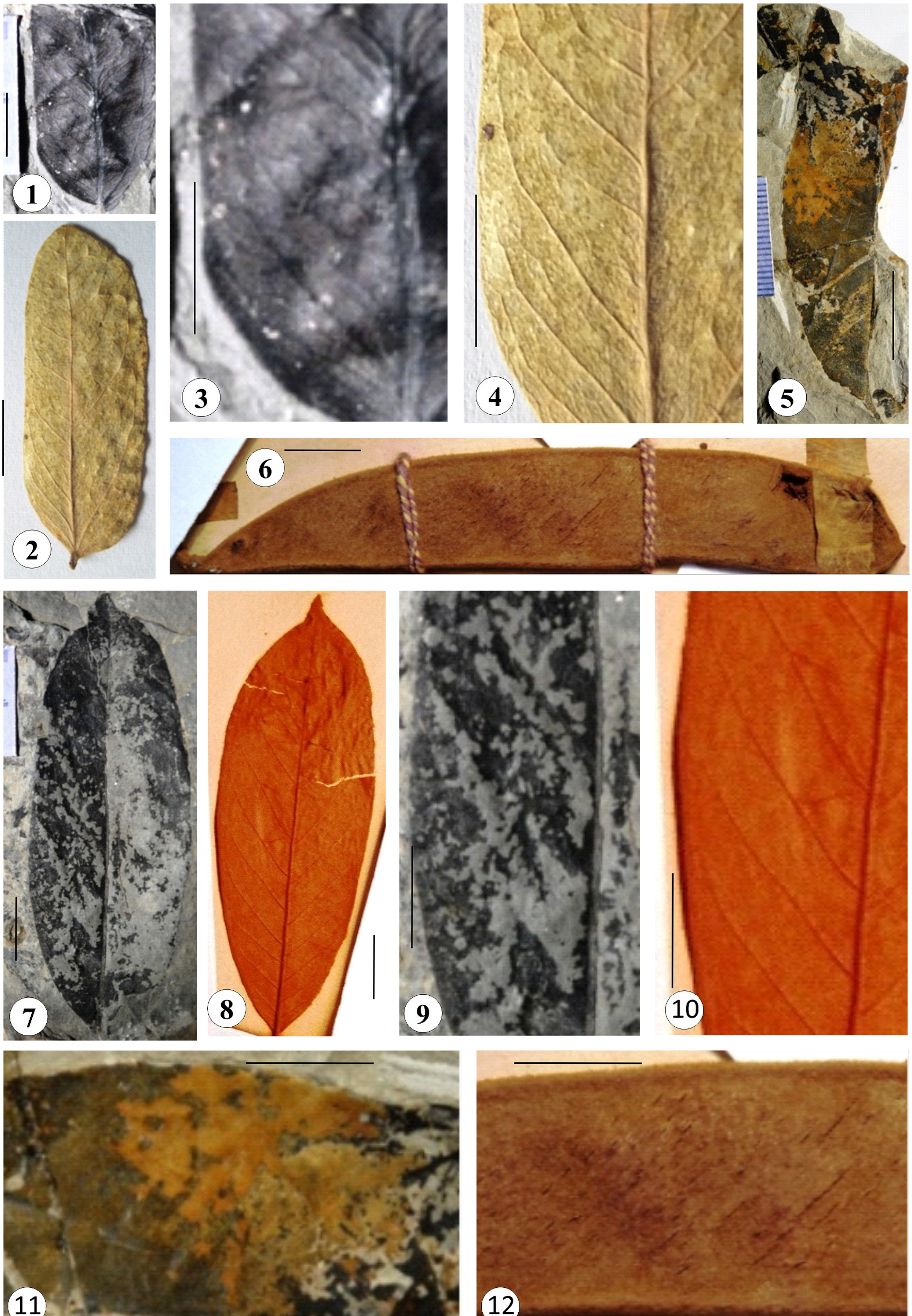
Table 1. Showing fossil species of *Millettia* from Tertiary sediments with their differentiate characters.

Species	Fossil Locality/ Period	Differentiative Characters
M. auriculata Bande & Srivastava, 1990	Late Cenozoic of Mahuadanr, Jharkhand	Ovate shape, secondaries upturn and gradually diminishing inside the margin, connected to superadjacent secondaries by series of cross-veins shape.
M. asymmetrica Lakhanpal & Guleria,1982	Miocene of Kachchh, W. India	Small size (3.9 x 2.7 cm) and ovate shape
M. bilaspurensis Prasad, 2006.	Siwalik of Bilaspur, H.P., India	Large size (13.6 x 2.7 cm), narrow oblong shape, more number of secondaries (18 pairs), closely placed, narrow acute angle of divergence in secondaries.
M. churiensis Prasad & Awasthi, 1996; Agarwal, 2002	Siwalik of Suraikhola, Nepal, Miocene of Neyveli lignite, South India	Small size (4.2 x 1.2 cm), lanceolate shape, acuminate apex, lesser number of secondaries (about 8 pairs)
M. imlibasensis Prasad et al., 1999	Siwalik of Koilabas, Nepal	Small size (4.3 x 1.6 cm), base obtuse, intersecondaries present.
Millettia impressa Menzel, 1920	Tertiary of the West Africa	Unaccompanied by description and photograph
M. kathgodamensis Prasad et al., 2004	Siwalik of Kathgodam, Uttarakhand, India	Texture coriaceous, lesser number of secondaries (about 7 pairs), angle of origin usually RR, forming orthogonal meshes.
M. koilabasensis Prasad, 1990b; Prasad & Tripathi, 2000; Prasad & Pandey, 2008	Siwalik of Koilabas, Nepal; Siwalik of Bhutan; Siwalik of Suraikhola, Nepal	Narrow obovate shape, lesser number of secndaries (8 pairs), AR-RO angle of origin of tertiary veins
M. miocenica Lakhanpal & Guleria, 1982	Miocene of Kachchh, Western India	Small size (5.6 x 3.2 cm) and oblong shape
M. miobrandisiana Prasad, 1994c	Siwalik of Koilabas, Nepal	Small size (2.3 x 1.1 cm) and wide ovate shape, brochidodromous venation, angle of divergence of secondaries is acute to right angle
Millettia mioinermis Prasad *et al*., 2014 (In Press)	Siwalik of Tanakpur, Uttarakhand, India	Obovate shape, base attenuate, texture coriaceous, angle of origin of tertiaries is AO
M. notoensis Ishida, 1970	Middle Miocene of Central Japan	Ovate shape with only 4-5 secondaries
M. oodlabariensis Antal & Prasad, 1996a	Siwalik of Darjeeling, 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	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 pair)
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 Suraikhola, Nepal, Siwalik of Kathgodam, Uttarakhand	Wide obovate shape, texture coriaceous, lesser number of secondaries (6 pairs), distantly placed, rarely AO angle of origin of tertiary vein.
M. purniyagiriensis Shashi *et al.,* 2006	Siwalik of Tanakpur, Uttaranchal, India	Lesser 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, Uttaranchal, India	Large size, texture coriaceous, lesser number of secondaries (7-8 pairs), lower pair more acute than above, joined superadjacent at right angle, angle of origin of tertiaries are usually AR
M. singhii Mathur *et al.,* 1996	Kasauli Formation, H.P., India	Small size (4.0 x 1.5 cm), wide elliptic shape, lesser number of secondaries (about 7 pairs)
M. siwalica Prasad, 1990a; Prasad, 1994a	Siwalik of Koilabas, Nepal, Siwalik of Kathgodam, Uttarakhand, India	Small size (3.1 x 2.0 cm), texture coriaceous, AO angle of origin of
Millettia sp. Mathur *et al*., 1996	Kasauli Formation, H.P., India	Small size (2.2 x 0.8 cm), lesser number of secondaries (about 6 pairs)
Millettia sp. Huzioka & Takahasi, 1970	Eocene of SW Honshu, Japan	Lanceolate shape with inequilateral, obtuse base

EXPLANATION OF PLATE VI

1. ***Albizia palaeolebbeck*** Antal & Awasthi- Fossil leaf showing shape, size and venation pattern. 2. ***Albizia lebbeck*** (Linn.) Benth.- Modern leaf showing similar shape, size and venation pattern. 3. ***Albizia palaeolebbeck*** Antal & Awasthi- Part of fossil leaf magnified to show details of venation. 4. ***Albizia lebbeck*** (Linn.) Benth.- Part of modern leaf magnified to show similar details of venation. 5. ***Leguminocapon siwalicum*** n. sp. - Fossil fruit showing shape, size and nature of base. 6. ***Millettia auriculata*** Backer- Modern fruit showing similar shape, size and base. 7. ***Millettia bilaspurensis*** Prasad- Fossil leaf showing shape, size and venation pattern. 8. ***Millettia pachycarpa*** Benth.- Modern leaf showing similar shape, size and venation pattern. 9. ***Millettia bilaspurensis*** Prasad- Part of fossil leaf showing shape, size and venation pattern 10. ***Millettia pachycarpa*** Benth.- Part of modern leaf magnified to show details of venation. 11. ***Leguminocarpon siwalicum*** n. sp.- Part of fossil fruit magnified to show details of the striation on the surface. 12. ***Millettia auriculata*** Backer- Part of modern fruit magnified to show similar details of striations on the surface.

Plate VI



Malay Peninsula, East Indies, Indo-China, extending to North Australia. The genus is fairly represented in India. About 34 species are found in the Indian subcontinent. *G. tiliaefolia* is distributed in east Tropical Africa and India. In India it occurs in arid regions of Bengal, Bihar, central and southern India. *G. tiliaefolia* is found in Assam, Upper Gangetic Plain, central and southern India. Both *G. tiliaefolia* and its variety *argentia* are moderate-sized tropical trees occurring in arid regions. It is generally believed by the plant taxonomists that most probably the original home of *Grewia* was Equatorial Africa from where its line of distribution extended eastwards to India, Burma, Siam and Indo-China (Narayanaswami and Rao, 1950). If this statement is correct, the eastward march of *Grewia* must have begun quite early because on the evidence of *G. foxii* which was present in the Assam region in Eocene times. Moreover, the fossil record shows that *Grewia* had a very wide distribution in the early Tertiary. In fact, it seems to have had a wider distribution in the past than at present. The present abundance of the genus in Africa may be due to the suitable environment which the plant got in that continent and may not be an indication of its origin there.

Family **Sapindaceae** de Jussieu, 1789
Genus ***Nephelium*** Linneus 1767

Nephelium palaeoglabrum Prasad *et al*., 1997
(Pl. V, figs.1,3,5,6)

Material: This species is based on the two specimens of well preserved leaf impression.

Description: Leaf simple, asymmetrical, narrow elliptic; preserved size 8.7 x 5.0 cm, 11.5 x 3.5 cm; apex acute; base acute; inequilateral; margin entire; texture chartaceous; petiole not preserved; venation pinnate, craspedodromous to eucamptodromous; primary vein single, prominent, stout, almost straight; secondary veins 7-11 pairs visible, less than 0.5 to 1.0 cm apart, angle of divergence 50^0-$60^{0,}$ acute, moderate, uniformly curved up and become finer before joining the superadjacent vein, unbranched, usually alternate, rarely subopposite; intersecondary veins absent; tertiary veins fine with angle of origin usually RR, branched, percurrent, straight to sinuous, oblique in relation to midvein, predominantly alternate, close; quaternary veins poorly preserved, angle of origin RR, branched forming orthogonal to polygonal meshes.

Specimen: BSIP Museum specimen no. 40824, 40825.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Afftnity: Slightly asymmetrical, narrow elliptic shape, acute apex and base, entire margin, craspedodromous to eucamptodromous venation, moderate angle of divergence of secondary veins and percurrent tertiaries which are oblique to nearly right angle in relation to midvein are the diagnostic features of the present fossil leaves. Besides, the fossil leaf is also characterised by uniform curvature of secondaries which become finer before joining the superadjacent veins. These features collectively indicate that the present fossil leaves show closest resemblance with the modern leaves of *Nephelium glabrum* Noronh. of the family Sapindaceae (CNH Herbarium Sheet no. 66827; (Pl. V, figs.2,4,7,)

So far, four fossil leaves resembling the genus *Nephelium* Linn. have been described from the Tertiary sediments of India and abroad. They are *Nephelium jovis* Unger, 1867 from the Tertiary of Europe*, N. verbeerkianum* Geyler, 1875 from Tertiary of Borneo, N. *oligocenicum* Awasthi & Mehrotra, 1995 from the Oligocene of Makum Coalfield, Assam, India and *Nephelium palaeoglabrum* Prasad *et al.,* 1997 from Seria Naka, Uttar Pradesh.

On comparative study of these known fossil leaves with that of the present fossil it has been found that the present fossil leaves shows close similarity with the *N. palaeoglabrum* Prasad *et al.* in shape, size and in venation pattern. In view of this, the present fossil has been assigned to the same species *N. palaeoglabrum* Prasad *et al*.

Nephelium is a genus of about 30 species which are either trees or shrubs distributed in Indian Archipelago, S. China and Australia. The modern comparable species, *Nephelium glabrum* Noronh. with which fossil shows closest affinity, is an evergreen tree found to grow in Malayan Archipelago (Hooker, 1872). It is also found in west side of the Peninsula, in evergreen forests from the Konkan southwards, Khasi Hills and Myanmar (Brandis, 1971).

Family **Fabaceae** Lindley, 1836
Genus ***Millettia*** Wight and Arn., 1834

Millettia bilaspurensis Prasad, 2006
(Pl. VI, figs.7,9)

Material: This species is based on a fairly preserved leaf impression.

Description: Leaf almost symmetrical, narrow elliptic; preserved size 8.0 x 2.6 cm; apex acuminate; base nearly wide acute; margin entire; texture chartaceous; petiole not preserved; venation pinnate; eucamptodromous; primary vein single, prominent, almost straight, stout; secondary veins, 13 pairs visible, 0.4 to 0.6 cm apart, alternate to sub-opposite, unbranched, angle of divergence (40°- 60º), narrow to wide acute, uniformly curved up; tertiary veins fine, angle of origin usually RR, percurrent, straight to sinuous, branched, oblique in relation to mid vein, predominantly alternate and close; quaternary veins not preserved.

Holotype: BSIP Museum specimen no. 40826.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Affinity: The characteristic features of the present fossil leaf such as narrow elliptic shape, acuminate apex, eucamptodromous venation, narrow to wide acute angle of secondary veins with uniform curvature, RR, percurrent, straight to sinuous, branched tertiary veins suggest its affinity with the leaves of extant genus, *Millettia* W.&A. of the family Fabaceae. A comparative study of a variety of herbarium sheets of a number of species (17 species) of this genus has been carried out and concluded that the modern

EXPLANATION OF PLATE VII

1. ***Machilus miovillosus*** n. sp –Fossil leaf showing shape, size and venation pattern. 2. ***Machilus villosus*** Hook. f.– Modern leaf showing similar shape, size and venation pattern. 3. ***Machilus miovillosus*** n. sp – Part of fossil leaf magnified to show details of venation. 4. ***Machilus villosus*** Hook. f. – Part of modern leaf magnified to show details of venation. 5. ***Xylia siwalika*** n. sp. – Fossil leaf showing shape, size and venation pattern. 6. ***Xylia xylocarpa*** (Roxb.) Taub.- Modern leaf showing similar shape, size and venation pattern. 7. ***Xylia siwalika*** n. sp. – Part of fossil leaf magnified to show details of venation. 8. ***Xylia xylocarpa*** (Roxb.) Taub.- Part of modern leaf magnified to show similar details of venation.

Plate VII

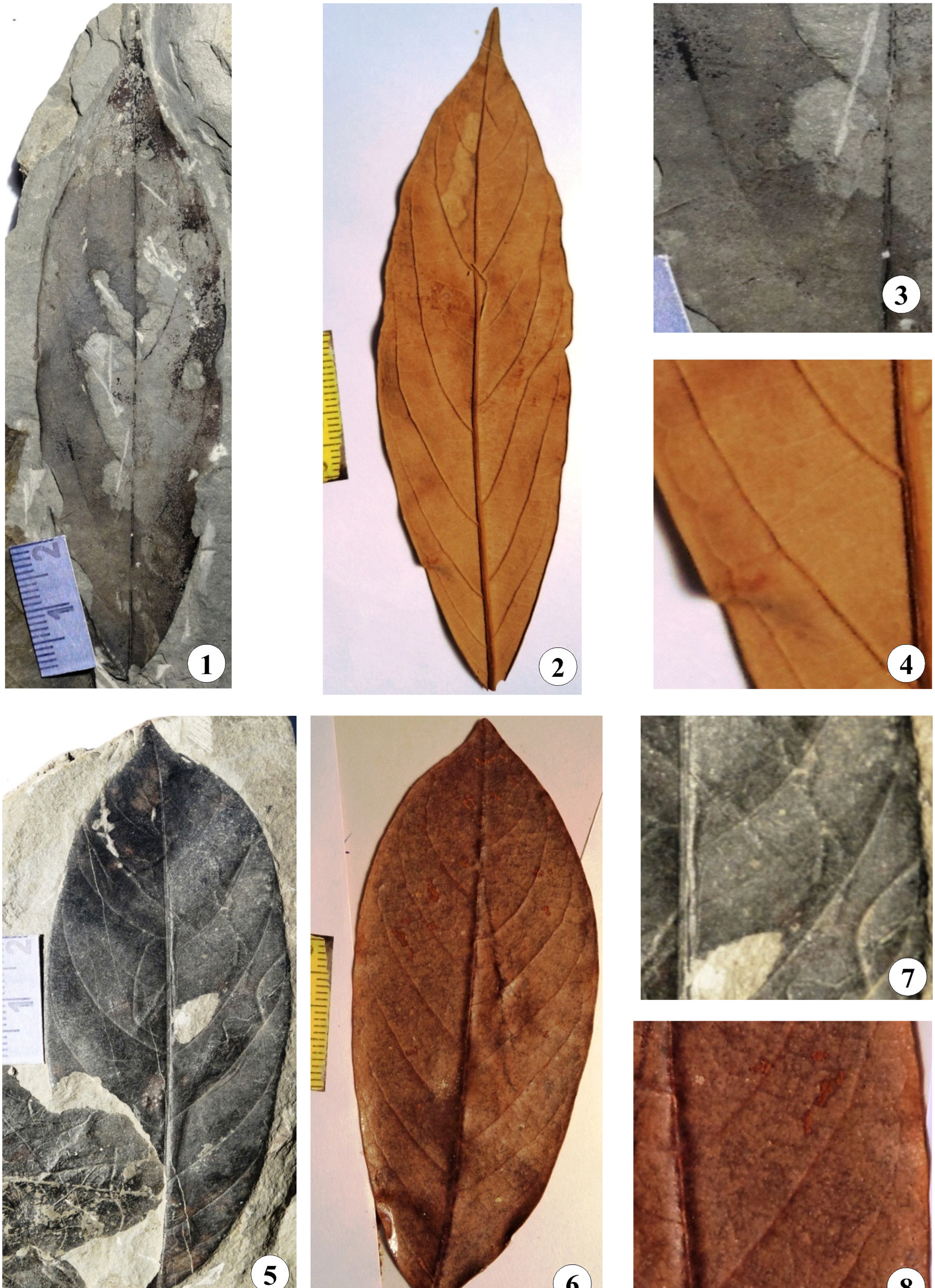


Table 2. Showing records of fabaceous fossil fruit species from Tertiary sediments of India and their differentiate characters.

Fossil taxa	Locality/Horizon/Age	Differentiate characters
Pongamia kathgodamensis Prasad, 1994b	Siwalik of Kathgodam, Uttrakhand; Koilabas W. Nepal; Suraikhola, W. Nepal; Chandan Nagar, Arunachal Pradesh	Fruit narrow oblong, small size (1.9-2.0 cm x 0.4-0.6cm), No striations on surface
Derris prakashii Prasad *et al*., 2004	Siwalik of Kathgodam, Uttarakhand	Fruit small size (3.4-4cmx1.6-1,8cm), Oblong shape with decurved ends, Margin thick
Derrisocarpon miocenicum Mitra and Banerjee, 2004	Siwalik of Darjeeling District, West Bengal	Fruit obliquely orbicular, small, 2.9mm in diameter, one seeded, Beak like projection at apical end present
Dalbergia sissoo Lakhanpal and Dayal,1966	Siwalik of Jawalamukhi, Himachal Pradesh	Winged fruit and one seeded
Entada palaeoscandens Awasthi and Prasad, 1990	Siwalik of Suraikhola, W. Nepal; Siwalik of Koilabas, W. Nepal; Oligocene of Makum Coal field, Assam; Siwalik of Darjeeling District, West Bengal	Seed 3.2-5.9cm long, rounded, shallow depression on one end, presence of pronounced sinus at the hilum
Fossil fruit cf *Caesalpinia* sp. Prasad *et al*., 2007	Oligocene of Baragolai, Assam	Small in size, wide elliptic, dorsal side sharply curved terminating into pointed end
Buteocarpon oligocenica Srivastava and Mehrotra, 2010	Oligocene of Makum Coalfield, Assam	Fruit larger in size (3.3-11.03x2.7-3.64cm), apex attenuate, dorsal margin concave
Buteocarpon awasthii Srivastava and Mehrotra, 2010	Oligocene of Makum Coalfield, Assam	Larger in size (10.1x3.29cm), dorsal and ventral margin thick, acute apex, veinlets (striations) oriented towards apex
Leguminocarpon dalbergiodes Awasthi and Mehrotra, 1995	Oligocene of Makum Coalfield, Assam	Fruit oval to strap shape, smaller in size (4.0x1.0cm), 2-seeded, reticulate striations at places
Leguminocarpon cassioides Mehrotra and Mandaokar, 2002	Lower Miocene of Aizawl, Mizoram	Fruit cylindrical in shape, larger in size (32x2.9-3.3cm), apex and base rounded, chambered
Leguminocarpon mizoramensis Tewari and Mehrotra, 2002	Oligocene of Champhai, Mizoram	Fruit with sub-parallel margin and rounded end
Leguminocarpon kainai Guleria et al. 2005	Eocene of Manipur	Fruit strap shape with thick margin, No striations on the surface
Leguminocarpon desmodioides Bhattacharyya, 1985	Palaeocene of Garo Hills, Assam	Fruit oblong, smaller in size (2.3x0.7cm), distal end rounded with mucronate tip, chambered
Leguminocarpon derrisoides Bhattacharyya, 1985	Palaeocene of Garo Hills, Assam	Fruit semi-elliptic to semi-circular, smaller in size (2.3-3.1cm x 1.3-1.6cm), undulate margin, broadly winged
Leguminocarpon mellettioides Bhattacharyya, 1985	Palaeocene of Garo Hills, Assam	Fruit complete, ovate to oval in shape, smaller in size (2.7-3.5cm x 1.6-2.0cm), wide,.18-7.9 stalk attached to a broadly rounded end
Leguminocarpon pongamioides Bhattacharyya, 1985	Palaeocene of Garo Hills, Assam	Fruit almost complete, smaller in size (3.3cm x 2.1cm, oblong to oval in shape, margin curved, protuberances present at the ends
Leguminocarpon albizioides Bhattacharyya, 1985	Palaeocene of Garo Hills, Assam	Fruit complete, oblong in shape, margin straight on one other moderately wavy, 3-4 chambers, surface with oblique striations
Lguminocarpon khariensis Lakhanpal and Guleria, 1982	Miocene of Kachachh, Gujrat	Fruit small and wide, size (1.6-7.0-1.4-2,5cm),margin termination into pointed apex, wavy, chambered, one seeded
Leguminocarpon baragolaiensis Srivastava and Mehrotra, 2010	Oligocene of Makum Coal field, Assam	Fruit oblong, dorsal and ventral margin thick, striation horizontal to oblique
Leguminocarpon barailensis Srivastava and Mehrotra, 2010	Oligocene of Makum Coal field, Assam	Fruit flat, wide (6.18-7.9x3.2cm), dorsal and ventral margin thick, construction in middle portion, striation absent
Leguminocarpon makumensis Srivastava and Mehrotra, 2010	Oligocene of Makum Coal field, Assam	Fruit oblong, wide, 7.6 x 3.0cm, presence of 4 chambers
Leguminocarpon lakhanpaii Srivastava and Mehrotra, 2010	Oligocene of Makum Coal field, Assam	Fruit elliptical, small,1.8x.47cm, apex and base acute, septa present
Leguminocarpon tirapensis Srivastava and Mehrotra, 2010	Oligocene of Makum Coal field, Assam	Fruit small and narrow,4.7x0.9cm, septa present, apex tapering for a long distance
Leguminocarpon dilcheri Srivastava and Mehrotra, 2010	Oligocene of Makum Coal field, Assam	Fruit oblong, larger in size, 13.4x2.8cm, margin thick, beak like structure at both the end, constriction present
Leguminocarpon sp. Srivastava and Mehrotra, 2010	Oligocene of Makum Coal field, Assam	Fruit small, wide,3.4x3.9, acute
Dalbergia prelatifolia Khan and Bera, 2014	Siwalik of Darjeeling District, West Bengal	Fruit oblong in shape, winged, margin thick, apex and base rounded, 3-seeded
Fossil fruit cf *Dalbergia* Lakhanpal and Dayal,1966	Siwalik of Jwalamukhi, H.P.	Fruit small,winged, narrow elliptic, one lateral side more rounded, apex rounded, base cuneate
Mastertia neoassamica Khan and Bera, 2014	Siwalik of Darjeeling District, West Bengal	Fruit elliptic, curved, dorsal and ventral margin thick, septa present, 2- chambered
Acacia miocatechuoides Khan and Bera, 2014	Siwalik of Darjeeling District, West Bengal	Fruit elliptic, small, 2.4x0.5 cm, apex acute, striation absent, septa present, 3- seeded

leaves of *Millettia pachycarpa* Benth. (C.N.H. Herbarium sheet no.112287; (Pl. VI, figs.8,10) show closest affinity with the present fossil leaf.

About 32 fossil leaves resembling the genus *Millettia* W. & A. have been reported from the Tertiary sediments of India and abroad. They are listed herewith along with their differentiate characters (Table 1).

After a detailed comparative study of all the above species it is observed that present fossil leaf shows similarity with *Millettia bilaspurensis* Prasad in shape, size and in nature and course of secondary veins. In view of this the present fossil leaf is being described under same species *M. bilaspurensis* Prasad.

The genus *Millettia* Wight & Arnott comprises about 90 species (Mabberley, 1997, p. 457) of trees, shrubs and climbers which are distributed in the tropical regions of Africa, Asia and Australia (Willis, 1973). About 30 species distributed in Indian region. *Millettia pachycarpa* Benth. with which the fossil resembles closely is a tree which occurs in the evergreen forests of Himalayan foothill, Myanmar, Thailand, Vietnam Indonesia, Java, Kalimantan, Sumatra, Malaya and Singapore.

Family **Fabaceae** Lindley, 1836

Genus ***Leguminocarpon*** Goeppert, 1885

Leguminocarpon siwalicum n. sp.
(Pl. VI, figs.5,11)

Material: It consists of a single fairly preserved fruit impression.

Description: Fruit legume, flattened, very narrow elliptic in shape, thick chartaceous in texture, almost straight and symmetrical, preserved size 7.0 x 1.7 cm, dorsal and ventral margin thin and parallel, apical end broken, basal end uniformly narrowing into stalk, stalk 0.5 cm long, thin, normal, dorsal margin slightly convex and ventral margin almost straight. Striations are seen on the fruit surface in between dorsal and ventral margin.

Holotype: BSIP Museum specimen no. 40827.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon & Age: Siwalik Formation; Middle Miocene.

Derivation of name: After the name of Siwalik Formation.

Affinity: The morphological features of the present fossil fruit such as flattened, narrow elliptic legume which is almost straight with convex dorsal margin and concave ventral margin and presence of stalk undoubtedly suggest its affinity among the family Fabaceae. In order to find out nearest affinity with genera and species a number of herbarium sheets containing fruits of fabaceous taxa like *Acacia, Millettia, Dalbergia, Caesalpinia, Albizia, Butea, Cassia, Pterocarpus* etc. have been examined and concluded that the fruits of *Millettia auriculata* Backer show closest similarity with the present fossil fruit (C.N.H. Herbarium sheet no. 15560,15553; Pl. VI, figs.6,12).

Fossil fruits belonging to the family Fabaceae reported from both Palaeogene and Neogene sediments of India. Besides, a doubtful legume fruit, *Sonajoricarpon rajmahalensis* resembling the modern fruit of genus *Butea* has been reported from the early Cretaceous sediments of the Rajmahal Hills (Banerji, 2000; Srivastava and Krassilov, 2012). A total of twenty nine fossil fruit species of Fabaceae are known from Tertiary sediments of different parts of India (listed herewith). Most of the fossil species have been identified with extant genera *Albizia, Derris, Desmodium, Millettia, Pongamia, Entada, Dalbergia, Delonix, Caesalpinia, Butea, Derris* and *Cassia* etc. of the family Fabaceae.

The present fossil being a legume is placed under the form genus *Leguminocarpon* Goeppert, 1885. As the fossil bears narrow elliptic shape with tapering base into a small stalk, thin margin, absence of septa, nature of striations it can be differentiated from already known species (Table-2). Though our fossil shows near resemblance with *Leguminocarpon mellettioides* Bhattacharyya described from Palaeocene of Garo Hills, Assam which also shows modern affinity with the genus *Millettia.* However, after critical examination it has been found that our fossil is different from *L. millettioides* in being larger size with narrow elliptic shape and there is absence of acutely pointed tips as found in the known fossil. In view of this, the present fossil is being described as a new species, *Leguminocarpon siwalicum.*

The extant species *Millettia auriculata* Backer (=*M. Macrophylla* Kurz) with which present fossil fruit resembles is growing in the Himalayan foot hills. It is common in the Sal forest from Sutlej eastward, Bihar, Central India and south of the Godavari (Brandis, 1971).

Family **Fabaceae** Lindley, 1836

Genus ***Albizia*** Durraz, 1772

Albizia palaeolebbek Antal and Awasthi, 1993
(Pl. VI, figs.1,3)

Material: It is represented by well preserved incomplete leaf.

Description: Leaflets asymmetrical, oblong, preserved lamina length 2.7 cm, maximum width 1.6 cm; apex broken; base obtuse, oblique; margin entire; texture chartaceous; petiole preserved, small; venation pinnate, eucamptodromous; primary vein prominent, moderate, almost straight; secondary veins 10-12 pairs, up to 0.5 cm apart, with angle of divergence narrow acute (about 45^0), basal secondary arising at more acute angle, uniformly curving upwards and joining supradjacent veins, usually alternate, branched near margin; intersecondary veins present, frequent; tertiary veins fine, angle of origin RR- AO, percurrent, branched, straight to sinuous, oblique in relation to midvein, predominantly alternate and close.

Specimen: BSIP Museum specimen no. 40828.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Affinity: The distinguishing features of the fossil such as asymmetrical leaflets, oblong shape, oblique base, eucamptodromous venation basal secondary of one side of midvein arising at more acute angle and running upwards for a long distance, presence of intersecondary veins indicate that the fossil leaflet shows closest affinity with the genus *Albizia* Durraz of the family Fabaceae.

The leaves of about 14 modern species of *Albizia* Durraz were studied in order to find out the specific affinity. The fossil specimen shows close similarity with *Albizia lebbek* Benth, and in some characters with *A. odoratissima* Benth. But the leaves in *A. odoratissima* are larger in size as compared to the fossil leaflets. However, all morphological details of the specimens match closely with *A. lebbek* Benth. (C.N.H. Herbarium sheet no 25649; Pl. VI, figs.2,4).

There are five records of the fossil leaflets of *Albizia,* viz. *A miokalkara* (Hu & Chaney) Ishida, 1970 from Miocene of Japan, *Leguminosites* Geyler, 1875 from the Tertiary of Borneo, *A.*

siwalica Prasad, 1990b from the Siwalik sediments of Koilabas, Nepal, *A. palaeolebbek* Antal & Awasthi, 1993 from Siwalik of oodlabari area, Darjeeling, West Bengal and *A. microfolia* Prasad & Awasthi, 1996 Siwaik of Surai Khola, Nepal. After a comparative study of the known fossil leaves it has been found that *A. palaeolebbek* Antal & Awasthi, 1993 reported from Siwalik of West Bengal shows closest similarity with the present fossil leaflet. Since present fossil leaflet shows hardly any difference from *A. palaeolebbek*, it is placed under the same form species. It is worth to mention that the fossil woods closely resembling *Albizia lebbek* have also been reported from the Siwalik sediments of Himachal Pradesh (Prakash, 1975), Tertiary of West Bengal (Ghosh and Roy, 1981), Dupitila Series, Assam (Lakhanpal *et al*., 1981) and from the Tertiary of Kutch Basin (Guleria, 1983) This, obviously, indicates its abundant occurrence during the Tertiary period in the Indian subcontinent.

The genus *Albizia* Durraz. is represented by about 50 species distributed in tropical and subtropical regions (Willis, 1973) of all over the world. However, 14 species have been reported from India. *A. lebbek* Benth. with which the fossil specimen resemble, is a large deciduous tree presently growing in Sub-Himalayan tracts from Indus eastwards ascending to about 5,000 ft, Bengal, central and south India, Myanmar, Andaman and dry regions of Sri Lanka (Gamble, 1972, p. 303).

Family **Fabaceae** Lindley, 1836
Genus ***Xylia*** Benth., 1842

Xylia siwalika n. sp.
(Pl. VII, figs.5,7)

Material: The species is represented by a single well preserved, almost complete leaf impression.

Description: Leaf simple, symmetrical, wide oblong, preserved size 9.0×3.9 cm; apex acuminate; base obtuse; margin entire; texture chartaceous; petiole 0.1 mm visible in specimen; venation pinnate, eucamptodromous, primary vein single, prominent, stout, almost straight; secondaries 8 pairs visilble, alternate to opposite, 0.6 to1.0 cm apart, angle of divergence 45^0-55^0, moderate acute, uniformely curved upward, unbranched; tertiary veins fine, angle of origin RR, oblique in relation to midvein, predominantly alternate and close, further detail could not be seen.

Holotype: BSIP Museum specimen no. 40829.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon & Age: Siwalik Formation; Middle Miocene.

Derivation of name: After the name of Horizon 'Siwalik' to which fossil locality belong.

Affinity: The important characters of the fossil leaf like oblong shape, acuminate apex, obtuse base, entire margin,

Table 3. Present day distribution and forest type of comparable taxa recovered from the Siwalik sediments of Sharda River section, Thuligad area Champawat District, Uttarakhand.

Fossil taxa	Modern Equivalent taxa	Forest types	Distribution
Flacourtiaceae			
Gynocardia mioodorata Prasad *et al*., 1999	*Gynocardia odorata* R. Br.	Evergreen-moist deciduous	Sikkim, Khasi Hills, Myanmar, Nepal, Bangladesh
Clusiaceae			
Mesua tertiara (Lakhanpal) Prasad and Pandey, 2008	*Mesua ferrea* L.	Evergreen	S. E. India, South India, Myanmar, Malaysia, Andaman Islands, Sri Lanka
Dipterocarpaceae			
Dipterocarpus koilabasensis Prasad *et al.*,1999	*Dipterocarpus turbinatus* Gaertn.	Evergreen	N. E. India, Bangladesh & Myanmar
Dipterocarpus miogracilis n. sp.	*Dipterocarpus gracilis* Blume	Evergreen-moist deciduous	N. E. India, Andaman- Nicobar island, Bangladesh, Myanmar, Malaysia, Thailand
Tiliaceae			
Grewia tanakpurensis n. sp.	*Grewia salvifolia* L.f.	Evergreen to Moist deciduous	India, Africa, Sri Lanka, China, Vietnam, Thailand India, South east Asia
Grewia mallootophylla Konomatsu and Awasthi, 1999	*Grewia laevigata* Vahl.	Tropical Evergreen	Malaya
Sapindaceae			
Nephelium palaeoglabrum Prasad *et al.*,1997	*Nephelium glabrum* Noronh.	Evergreen	N. E. India, Myanmar, Malaya
Fabaceae			
Millettia bilaspurensis Prasad, 2006	*Millettia pachycarpa* Benth.	Evergreen	Sub Himalayan region, Myanmar, Malaya
Leguminocarpon siwalicum n. sp.	*Millettia auriculata* Backer.	Evergreen-moist deciduous	Sub Himalayan tract, Central & South India, Myanmar
Albizia palaeolebbeck Antal and Awasthi, 1993	*Albizia lebbeck* (L.) Benth.	Moist deciduous	Andaman, New Guinea, Northern Australia
Xylia siwalika n. sp.	*Xylia xylocarpa* (Roxb.) Taub.	Tropical moist deciduous	India, Myanmar, Thialand, Combodia, Vietnam & South –central part of Laos
Lauraceae			
Machilus miovillosus n. sp.	*Machilus villosus* Hook. f.	Evergreen to Moist deciduous	Outer Himalayan ranges from Indus eastward, Sikkim, Khasi Hills, Martaban & Myanmar

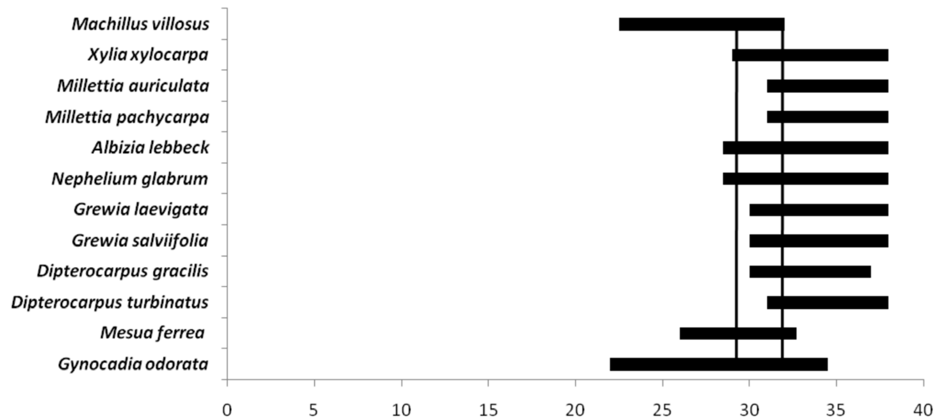


Fig. 5a WMT (degree celsius)

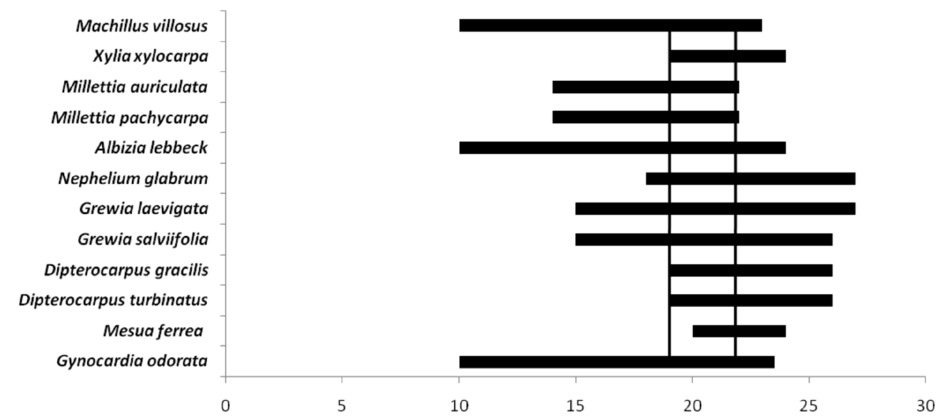


Fig. 5b CMT (degree celsius)

Fig. 5a - Showing the coexistence intervals of climatic parameter, Mean Temperature of Warmest month (WMT) of modern relatives of all the taxa recorded from Sharda River Section, Uttarakhand, (indicate the intervals of coexistence) and vertical line indicating the common range of WMT. Fig. 5b- Showing the coexistence intervals climatic parameter, Mean Temperature of coldest month (CMT) of modern relatives of all the taxa recorded from Sharda River Section, Uttarakhand (indicate the intervals of coexistence) and vertical line indicating the common range of CMT.

eucamptodromous venation, moderate angle of divergence of the secondaries collectively indicate its close resemblance with extant taxa, *Xylia xylocarpa* (Roxb.) Taub. (C.N.H. Herbarium sheet no. 70083: Pl. VI, figs.6,8 of the family Fabaceae.

As far as authors are aware, there is no fossil record of the genus *Xylia* from India and abroad. Obviously it is the first record of the fossil leaf of *Xylia* from the Siwalik beds of Uttarakhand and hence it is described here as *Xylia siwalika* n. sp.

The genus, *Xylia* Benth. now consists of 13 species (Willis, 1973).They are large trees and largely distributed in south and southeast Asia (Burma, Vietnam, Combodia, Thiland). In India, it is normally found to grow along with *Pterocarpus marsupium*, *Anogeissus latifolia*, *Grewia tiliaefolia*, *Terminalia* spp., *Careya arborea*, *Calycopteris floribunda*, *Strychnos nux-vomica*, *Diospyros montana* in peninsular region and extended upto south Bengal.

Family **Lauraceae** de Jussieu, 1789
Genus ***Machilus*** Nees., 1831

Machilus miovillosus n. sp.
(Pl. VI, figs.1,3)

Material: This species is represented by a single well preserved almost complete leaf impression.

Description: Leaf simple, symmetrical, oblanceolate; lamina length 10.5 cm, width 1.5 cm; apex attenuate; base acute; margin entire; texture thick chartaceous; petiole broken; venation pinnate, eucamptodromous; primary vein, single, prominent, straight, curved up; secondary veins about 6 pairs visible, 0.6-1.3 cm apart, alternate to nearly opposite, angle of divergence acute 55^0-60^0, moderate, uniformly curved up, seemingly unbranched; tertiary veins poorly preserved, fine, with angle of origin usually RR, alternate, percurrent, straight to sinuous, oblique to right angle in relation to midvein, predominantly alternate and close.

Holotype: BSIP Museum specimen no. 40830.

Locality: Sharda River Section, Thuligad area, Champawat District, Uttarakhand.

Horizon and Age: Siwalik Formation; Middle Miocene.

Derivation of name: By adding the prefixed 'Mio' to the modern comparable species, *M. villosus.*

Affinity: The distinguishing features of present fossil leaf like symmetrical, oblanceolate shape, acute base, entire margin, chartaceous texture, eucamptodromous venation and fine and closely placed tertiaries suggest that the fossil leaf shows closest resemblance with the genus, *Machilus* Nees specifically extant taxa *M. villosus* of the family Lauraceae. (C.N.H. Herberium sheet no.384628; Pl. VI, figs.2,4).

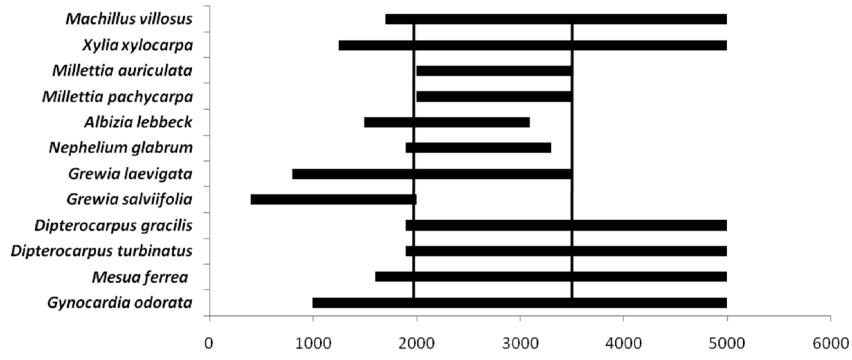


Fig. 5c

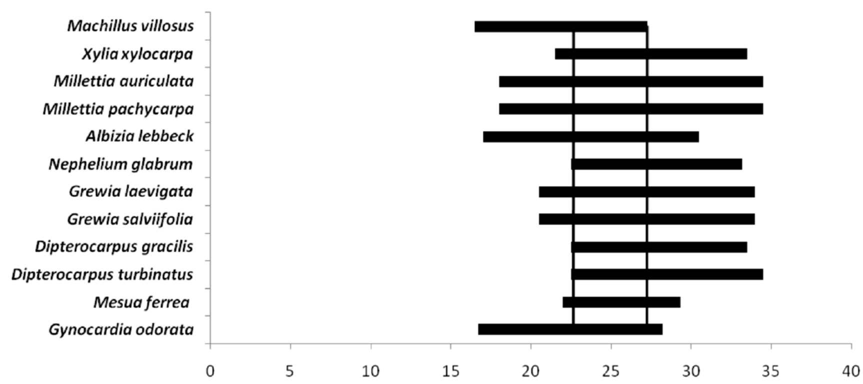


Fig. 5d

Fig. 5c = Showing the coexistence intervals of climatic parameter, Mean Annual Precipitation (MAP) of modern relatives of all the 35 taxa recorded from Sharda River Section, Uttarakhand (▬ indicate the intervals of coexistence) and vertical line indicating the common range of MAP. Fig. 5 d- Showing the coexistence intervals of climatic parameter, Mean Annual Temperature (MAT) of modern relatives of all the taxa recorded from Sharda River Section, Uttarakhand (▬ indicate the intervals of coexistence) and vertical line indicating the common range of MAT.

So far, only five fossil leaves resembling the genus *Machilus* Nees have been recorded from the Tertiary of India and overseas. These are *Machilus* sp. from the foot-hills of Darjeeling, West Bengal (Pathak, 1969), *M. americana* Brown and *M. asiminoides* Brown from the Miocene of Latah, Washington, USA (Brown, 1937), *Machilus miocenica* from Siwalik sediments of Kathgodam, Uttarakhand (Prasad, 1994b) and *M. neyveliensis* from Neyveli Lignite Mine, Tamil Nadu, S. India (Agarwal, 2002). All the above fossil leaves have been compared with the present fossil and concluded that the present fossil leaf is different from them either in the shape, size or arrangement of secondary and tertiary veins. As the present fossil leaf is distinct from already known fossil leaf, this has been described under a new specific name, *Machilus miovillosus*.

The extant taxon, *Machilus villosus* Hook. f. with which the fossil shows affinity is a moderate sized tree found growing in outer Himalayan ranges from Indus eastward, Khasi Hills, Martaban and Upper Myanmar. It is also distributed in the Sikkim, Himalaya at altitude of 7000 ft. (Brandis, 1971).

The genus *Machilus* comprises 89 species of evergreen trees and shrubs occurring in subtropical and tropical forest of China, Korea, Japan, Taiwan, Vietnam, Laos, Cambodia, Indonesia, Borneo, and the Philippines. It is sometimes included in the genus *Persea* (Hooker, 1885; Brandis, 1971). The family Lauraceae was part of the land flora of Gondwana. Fossil evidences indicate that the genus originated in West Africa during the Palaeocene, and spread to Asia to South America, and to Europe and, thence, to North America. It is thought that the gradual drying of Africa, west Asia and the Mediterranean from the Oligocene to the Pleistocene, and the glaciations of Europe during the Pleistocene caused the extinction of the genus across these regions.

FLORISTIC COMPOSITION AND ANALYSIS

The study on plant megafossil (leaf and fruit impressions) collected from the Middle Miocene of Sharda River section near Thuligad, Champawat district, Uttarakhand revealed the occurrence of 12 fossil taxa showing the close resemblance with the extant taxa viz., *Gynocardia odorata* R. Br., *Mesua ferrea* L., *Dipterocarpus turbinatus* Gaertn, *Dipterocarpus gracilis* Blume, *Grewia salvifolia* L. f., *Grewia laevigata* Vahl., *Nephelium glabrum* Noronh., *Millettia pachycarpa* Benth., *Millettia auriculata* Backer, *Albizia lebbeck* (L.) Benth., *Xylia xylocarpa* (Roxb.) Taub., *Machilus villosus* Hook. f. (Table-3). Five fossil taxa viz., *Dipterocarpus miogracilis* (Dipterocarpaceae), *Grewia tanakpurensis* (Tiliaceae), *Millettia tanakpurensis* (Fabaceae), *Xylia siwalika* (Fabaceae) and *Machilus miovillosus*

(Lauraceae) are proposed as new species and reported for the first time from the Lower Siwalik sediments of Thuligad area, Champawat district, Uttarakhand. The remaining fossil taxa are already reported from the different parts of Siwalik foreland basin of India and Nepal (Prasad, 2008).

The assemblage is overall dominated by woody plants only a few of them are shrubs, and the herbs are totally absent. Out of 12 recovered fossil taxa, four belonging to the family Fabaceae and thus dominated the whole flora. The earlier record also shows their abundance in the Siwalik foot hills (Prasad, 2008). All the comparable taxa are tropical in nature and distributed mostly in tropical evergreen forest of North-east India and south-east Asian regions (Table-3). Thus it suggests that during Siwalik (Middle Miocene), the Himalayan foot hills near Thuligad area, Champawat district, Uttarakhand accompanied with tropical evergreen forest instead of mixed deciduous forest at present.

In the fossil assemblage, the two taxa, *Dipterocarpus koilabasensis* Prasad *et al*., 1999 and *Dipterocarpus miogracilis* n. sp. belonging to the family Dipterocarpaceae has phytogeographical importance as they are not growing now a days in the Himalayan foot hills of Uttarakhand but migrated towards northeastward (North-east India, Malaya, Mayanmar etc.) due to prevailing unfavourable climatic condition during Siwalik period (Middle Miocene). The fossil record suggests that Dipterocarpaceae originated during the early Middle Oligocene (Merril, 1923; Muller, 1970). Lakhanpal (1974) further envisaged that the family originated in western Malaysia, where about two third of all dipterocarps species occur today (Desch, 1957). This region is also quite rich in the fossil record (Lakhanpal, 1974; Bande & Prakash, 1986). From western Malaysia dipterocarps spread east ward to Philippines and northward through Myanmar to India. The possible time of the southwest migration was Early Miocene when the land connections between Malaya, Myanmar and eastern India were established. The abundance of dipterocarps such as *Dipterocarpus, Anisoptera, Isoptera, Shorea, Hopea, Dryobalanops* in eastern India as well as in southern India during Miocene-Pliocene times indicates that they spread from eastern India to south west to Sri Lanka via Himalayan foot-hills where they are still flourishing. The occurrence of dipterocarpaceous remains (fossil woods, leaves and fruits, impressions) in the Himalayan foot-hills (Prasad, 2008) and the Tertiary beds of Africa (Bancroft, 1933; Chiarugi, 1933) suggest that from eastern India the dipterocarps also spread westward into Africa most probably via Arabia (Lakhanpal, 1970; Seward, 1935).

Palaeoclimatic interpretation

Palaeoclimate interpretation from fossil plants is one of the most important contributions of palaeobotanical researches. This principle, the present is the key to the past, implies that the physical and biological processes that operate in today's environment as well as vegetation must were functioning the same way in the past. The best approach to the study of palaeoclimate of a particular area is to compare the fossil floras with the modern vegetation and to know the existing climatic conditions. The study becomes more accurate as we go from Palaeocene upward until the Pleistocene as the modern equivalents of the fossil forms still exist in the present day vegetation and obviously the fossils could satisfactorily be compared and identified with the modern taxa.

As the plant fossils for the present study have been collected from the Middle Miocene sediments and the modern equivalents of these fossil forms still exist in the forests of different phytogeographical regions (Table-3), it has, therefore, become easier to deduce the palaeoclimate of the Thuligad area in the Himalayan foot-hills of Uttarakhand.

The coexistence approach is utilized as a method for terrestrial palaeoclimate reconstructions in the Tertiary period (Mosbrugger & Utescher, 1997; Bohme *et al.,* 2007). The basic idea of the coexistence approach is very simple and follows nearest living relatives philosophy. It is based on the assumption that the climatic requirements of fossil taxa are very similar to living relatives (Modern equivalents) because it is assumed that the modern equivalent taxa require similar climatic parameter as the fossil taxa. For example, there are two fossil taxa ie. *Michilus miovillosa* and *Xylia siwalika* in the present fossil assemblage with their living relatives, *Michilus villosa* and *Xylia xylocarpa* respectively. The MAT coexistence interval of *Michilus vilosa* is 18.0^{0}C-28.0^{0}C and *Xylia xylocarpa* is 23.^{0}C-35^{0}C (Fig. 5d). Thus, it is obvious that the modern taxa *Michilus vilosa* and *Xylia xylocarpa* require the Mean Annual Temperature between 18.0^{0}C-28.0^{0}C and 23.^{0}C-35^{0}C respectively and suggesting that there is a mean annual temperature interval between 18.0^{0}C and 35.0^{0}C in which both the taxa coexist. Similarly, the MAT, coexistence intervals of all the 12 Nearest Living Relative taxa (Modern taxa) of Thuligad fossil flora have been obtained from published literature (Champion & Seth, 1968) and Climatological table of observation in India (1931-1960) as well as through internet and after its application it has been found that the MAT Coexistence interval for fossil assemblage is 21^{0}C-27.5^{0}C under which all the fossil taxa once lived. In the similar way the estimates (coexistence intervals) have been obtained for other parameters such as temperature of warmest month (WMT), and coldest month (CMT) as well as mean annual precipitation. Thus the following reconstructed climatic estimates (Coexistence intervals) for different climatic parameter ie. MAT, WMT, CMT and MAP are obtained as 21^{0}C-27.5^{0}C, 28^{0}C-32^{0}C, 20^{0}C-22.5^{0}C and 1900mm-3500mm respectively (Fig. 5 a-d).

The floral assemblage recovered so far from the Siwalik sediments of the Thuligad area comprises 12 fossil taxa and mostly all of them were compared with their modern equivalents (Table -3). The present habit and habitat of these taxa show that they mostly occur in the tropical evergreen and moist deciduous forests of north eastern India, Bangladesh, Myanmar and Southeast Asian regions (Malaya, Philippines, Java, Borneo, etc.) enjoying almost the same climatic condition (Gamble, 1972; Hooker, 1872, 1882, 1884; Champion & Seth, 1968; Desch, 1957). Thus, it may be surmised that a warm and humid climate prevailed in Thuligad area in the Himalayan foot hills during Middle Miocene in contrast to the present relatively dry climate there. The dominance of evergreen elements in the assemblage (Table -3) further indicates the prevalence of tropical (warm humid) climate with plenty of rainfall.

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