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First record of fossil leaves from Siwalik (Upper Miocene) sediments of Mandi District, Himachal Pradesh, India: palaeoclimatic and phytogeographical implications

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ABSTRACT

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Six fossil leaf impressions comparable with extant taxa, *Gynocardia odorata* R.Br. (Flacourtiaceae), *Millettia pachycarpa* Benth. and *Cynometra polyandra* Roxb. (Fabaceae), *Ventilago calyculata* Tul. (Rhamnaceae), *Terminalia tomentosa* (Roxb.) W. & A. (Combretaceae) and *Daemonorops calycarpus* Mart. (Arecaceae) have been reported for the first time from Siwalik sediments exposed near Sarkaghat in Mandi District of Himachal Pradesh. All species are presently distributed in the tropical evergreen to moist deciduous forests of north-east India and south-east Asia. Their occurrence in the Siwalik sediments suggests that tropical humid climate with high precipitation prevailed in the area during Upper Miocene. The occurrence of palm leaf in the area is of ecologically importance as it indicates a characteristic feature of tropical vegetation where the temperature and humidity remain high throughout the year.

Key–words—Fossil leaves, Angiosperm, Morphotaxonomy, Palaeoclimate, Phytogeography, Siwalik (Upper Miocene), Sarkaghat, Himachal Pradesh.

भारत में हिमाचल प्रदेश के मंडी जिले के शिवालिक (मध्य मध्यनूतन) अवसादों से प्राप्त जीवाश्म पत्तियों का पहला अभिलेख : पुराजलवायवी एवं पुराभौगोलिक निहितार्थ

महेश प्रसाद, ललित मोहन एवं संजय कुमार सिंह

सारांश

हिमाचल प्रदेश के मंडी जिले में सरकाघाट के समीप अनावरित शिवालिक अवसादों से मौजूदा टैक्सा *गायनोकार्डिया ओडोरेटा* आर.बी आर. (फ्लाकोर्टिएसी), *मिल्लेशिया पेचीकार्पा* बेन्थ एवं *सायनोमेट्रा पॉलीऐन्ड्रा* रॉक्स्ब. (फैबासी), *वेंटीलगो कैलीकुलेटा* तुल. (रमनासी), *टर्मिनेलिया टोमेन्टोसा* (रॉक्स्ब.) डब्ल्यू एवं ए. (कॉम्ब्रीटेसी) और *डैमोनोरॉप्स कैलीकार्पस* मार्ट (ऐरेकेसी) से तुल्य छह जीवाश्म पत्ती मुद्राश्म पहली बार मिली हैं। समस्त जातियां उत्तर-पूर्व भारत एवं दक्षिण-पूर्व एशिया के आर्द्र पतझड़ी वनों के उष्णकटिबंधीय सदाहरित में फिलहाल वितरित हैं। शिवालिक अवसादों में उनकी प्राप्ति सुझाती है कि मध्य मध्यनूतन के दौरान क्षेत्र में उच्च वर्षण के साथ उष्णकटिबंधीय आर्द्र जलवायु व्याप्त थी। क्षेत्र में ताड़ पत्ता की प्राप्ति पारिस्थितिकीय रूप से अहम है क्योंकि यह उष्णकटिबंधीय वनस्पति का अभिलक्षणिक लक्षण का संकेत देती है जहां साल भर तापमान एवं आर्द्रता उच्च रही।

संकेत-शब्द—जीवाश्म पत्तियां, आवृतबीजी, आकृतिवर्गीकरणविज्ञान, पुराजलवायु, पादप भ-ूविज्ञान, शिवालिक (मध्य मध्यनूतन), सरकाघाट, हिमाचल प्रदेश।

INTRODUCTION

THE Sub-himalayan zone of Indian subcontinent mainly consists of Neogene deposits which are known as the Siwalik Group. It extends from Potwar Plateau in the north-west to Brahmaputra in the north-east covering a distance of about 2400 km in length and 20-25 km in width. The Siwalik is considered to be the most significant in geological history of India because some major geological events took place during this period. The major upheaval of the Himalaya has been taken place during the Middle Miocene and continued until the close of Pleistocene which changed the physiography and provided ample opportunity for rapid spread and diversification of angiospermous plants in India.

The Siwalik sediments provide an excellent opportunity to study the plant megafossils comprising petrified and carbonized woods and leaf, fruit and seed impressions. The studies on plant megafossils of Siwalik were carried out by several workers (Awasthi, 1992; Prasad, 2008) to contribute significantly in understanding plant diversity and climate changes during Middle Miocene to Middle Pleistocene. Most of the palaeobotanical work has been done during the last two and half decades from the different localities mainly in the central sector of Siwalik (Prasad, 2008). However, in the western Siwalik sector (Himachal Pradesh) a little work has been done mainly in the Siwalik of the Nalagarh (Prakash, 1975, 1979; Yadav, 1989) Jawalamukhi and Ranital (Ghosh & Ghosh, 1958; Lakhanpal, 1967, 1968, 1969; Lakhanpal & Dayal, 1966; Lakhanpal & Awasthi, 1992) and Bilaspur (Prasad, 2006).

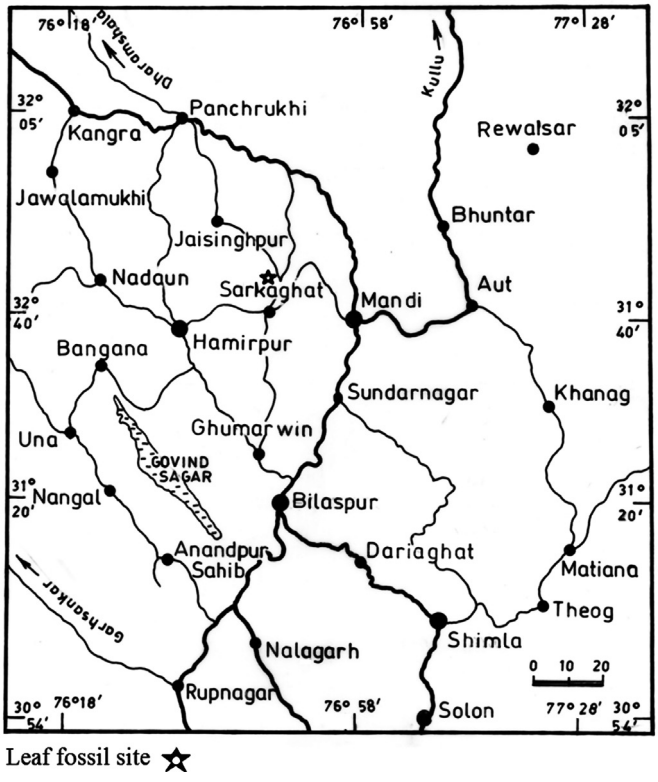

Fig. 1—Map showing fossil locality.

In view of the previous meagre palaeobotanical work on the Siwalik sediments of Himachal Pradesh, authors visited different fossil localities and collected large number of fossil leaf impressions for the first time from the Middle Siwalik sediments of Sarkaghat in Mandi District, Himachal Pradesh. Out of the whole collection only a few leaf impressions were identified with the extant species which have been described and discussed in the present communication.

GEOLOGICAL SETUP OF THE AREA

Cautley coined the word Siwalik in 1832 (Falconer, 1832; Medlicott, 1873) for the southern part of the Himalayan ranges between river Ganga and river Yamuna which yielded fossils for the first time near Haridwar. The Siwalik possesses uniqueness in the world of geology, because these freshwater deposits represent a continuous sedimentary and fossil record of the last ~18 million years (Ma). They form nearly a 6000 m of an extensive Neogene-Quaternary apron of freshwater sediments, which are exposed along the proximal margin of the Himalayan Foreland Basin, between Potwar Plateau in the west and Brahamputra Valley in the east. Pilgrim (1913) was the first to provide three fold classifications of Siwalik and suggested divisions of Lower, Middle and Upper Siwalik faunal zones as Kamlial, Chinji, Nagri, Dhok Pathan, Tatrot, Pinjor and Boulder Conglomerate (Fig. 2). It is interesting to note that these deposits represent one of the best continuous terrestrial Neogene fossil records, which are significant for the understanding of the Eurasian terrestrial environments and palaeoclimates.

The fossil locality, Sarkaghat (N 31°44'26" : E 76°43'33") lies along the National Highway 70 very near to Sarkaghat area of Mandi District, Himachal Pradesh (Fig. 1). The fossil leaf bearing bed is a part of Middle Siwalik Sarkaghat anticline. About 8 km from the leaf fossil site is the Nalad Khad section (lat 31°46'N: long 76°43'E) which has been magnetostratigraphically studied and dated by earlier workers, Brozovic and Burbank (2000). The Nalad Khad section is located on the western limb of the Sarkaghat anticline, and in the Jawalamukhi thrust sheet. It is characterized by mainly thick units of fine to coarse, dark grey indurate, multistoried sandstones with red, yellow and brown pedogenic mudstones (Figs 3, 4). They have also correlated the local magnetic polarity stratigraphy (MPS) to the global magnetic polarity stratigraphic time scale (MPTS), Cande and Kent (1992).

MATERIAL AND METHODS

More than 30 leaf impressions were collected from Middle Siwalik beds exposed in a road cutting section (31°44'15.70" N: 76°43'20.19" E) near a well known town, Sarkaghat which falls in Mandi District of Himachal Pradesh.

The fossil locality is situated on the left side of main road which leads to Dharampur and easily accessible through vehicle. The leaf impressions were devoid of cuticle and preserved on usually grey shales (Fig. 3). The 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, Shibpur, 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 Department of Geology, University of Panjab, Chandigarh, India.

SYSTEMATICS

Order—MALPIGHIALES

Family—FLACOURTIACEAE

Genus—GYNOCARDIA R.Br.

Gynocardia butwalensis Konomatsu & Awasthi, 1999

(Pl. 1.1, 3)

Material—One specimen with counter part.

Description—Leaves simple, almost symmetrical, elliptic; preserved size 11.0 x 4.5 cm; apex slightly broken; base wide acute; margin entire; texture thick chartaceous; petiole 0.3 cm long, normal; venation pinnate, eucamptodromous to nearly brochidodromous; primary vein (1º) single, prominent, stout, slightly curved; secondary veins (2º) seven pairs visible, 0.1-2.5 cm apart, uniformly curved up and join to their superadjacent secondaries, angle of divergence 60º-75º, wide acute, usually alternate, unbranched, intersecondary veins present, rare, simple; tertiary veins (3º) poorly preserved, still fine, angle of origin usually RR, percurrent, arising from midrib at right angle and join to their lower secondary veins at the same angle, sometimes branched, straight to sinuous, oblique to right angle in relation to midvein, predominantly alternate and close.

Specimen—GSI Chd. 301 (Figured specimen).

Type locality—Near Sarkaghat, Mandi District, Himachal Pradesh, India.

Type stratum—Middle Siwalik (Upper Miocene).

Affinity—The diagnostic features of the present fossil leaves such as elliptic shape, wide acute base, entire margin, eucamptodromous to brochidodromous venation, wide angle of divergence of secondary veins, RR, percurrent tertiaries with right angle in relation to midvein collectively suggest their resemblance with the genus *Gynocardia* R.Br. of the family Flacourtiaceae. A critical examination of the herbarium sheets of all the available species of this genus revealed that the leaves of *Gynocardia odorata* R.Br. show closest affinity with the present fossil leaves in almost all the morphological features (C.N.H. Herbarium Sheet No. 287, Pl. 1.2). The ge-

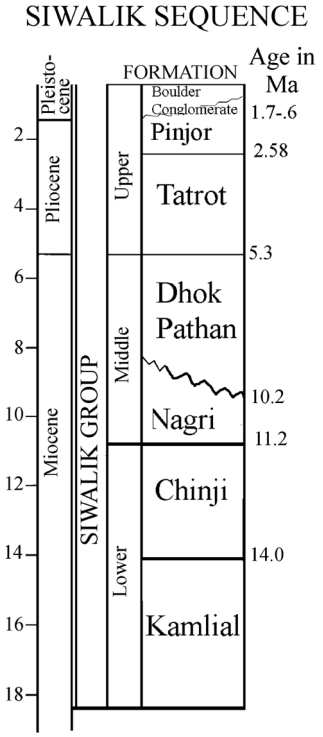

Fig. 2—General stratigraphic framework of the Siwalik sequence of the Indian sub continent (after Johnson *et al.,* 1985; Ranga Rao *et al*., 1988).

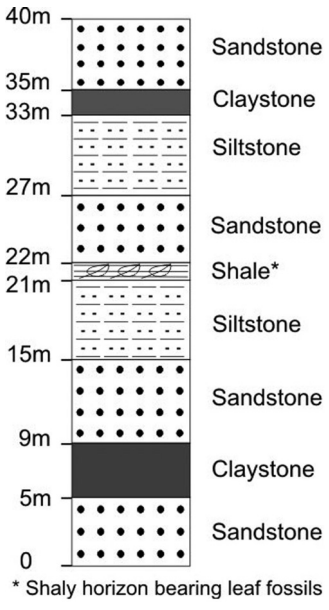

Fig. 3—Lithocolumn of the exposed section from where the leaf fossils were collected.

Species	Locality/Period	Reference
Terminalia balugoloensis	Siwalik of Balugoloa, H.P.	Lakhanpal & Awasthi, 1992
T. chebula	Late Tertiary of Mahuadanr, Jharkhand	Singh & Prasad, 2007
Terminalia cf. *T. catappa*	Tertiary of Czechoslovakia	Nemejc, 1975
Terminalia claibornensis Berry	Eocene of Texas	Ball, 1931
T. elegans Heer	-	Schimper, 1874
T. estamina	Middle Eocene of Central Sierra, Nevada, USA	MacGinitie, 1941
T. europaea	Tertiary of Germany	Weyland, 1943
T. fenzliana Unger	Tertiary of Czechoslovakia	Nemejc, 1975
T. gypsorum Saporta	-	Schimper, 1874
T. hilgardiana Berry	Eocene of Texas	Ball, 1931
T. indicola Berry	Eocene of Texas	Ball, 1931
T. italica	-	Berry, 1919
T. kachchhensis	Tertiary of Kachchh	Lakhanpal & Guleria, 1981
T. koilabasensis	Siwalik of Koilabas, Nepal	Prasad, 1990
T. lauriana	Tertiary of Brazil	Krasser, 1903
T. lesleyana	Eocene of southestern N. America	Berry, 1916
T. maxima	Tertiary of Brazil	Principi, 1915
T. miobelerica	Siwalik of Kathgodam, Uttaranchal Siwalik of West Bengal	Prasad, 1994a, Antal & Prasad, 1998
"	Miocene of Neyveli Lignite, South India	Agarwal, 2002
T. miocenica	Tertiary of Germany	Weyland, 1943
T. mulleri	Siwalik of Ranibagh, Uttaranchal	Trivedi & Srivastava, 1985
T. neyvelensis	Miocene of Neyveli Lignite, South India	Agarwal, 2002
T. obovata	Oligocene of Makum Coalfield, Assam	Awasthi & Mehrotra, 1995
T. palaeocatappa	Oligocene of Makum Coalfield, Assam	Awasthi & Mehrotra, 1995
	Tura Formation, Meghalaya	Mehrotra, 2000
	Miocene of Neyveli Lignite, South India	Agarwal, 2002
	Upper Siwalik of Arunachal Pradesh	Jhoshi *et al.,* 2003
T. palaeochebula	Siwalik of Suraikhola, Nepal	Awasthi & Prasad, 1990
"	Miocene of Neyveli Lignite, South India	Agarwal, 2002
T. panandhroensis	Tertiary of Kachchh, India, Siwalik of Koilabas, Nepal	Lakhanpal & Guleria, 1981; Prasad, 1994b
T. palaeopaniculata	Miocene of Neyveli Lignite, South India	Agarwal, 2002
T. panonica	Tertiary of South Gustine	Unger, 1867
T. phaeocarpoides	Eocene of South Carolina, USA	Berry, 1916
T. radobojana	Tertiary of Kumi, Euboea	Unger, 1867
T. rottensis	Tertiary of Germany	Weyland, 1943
T. siwalica	Siwalik of Koilabas, Nepal	Prasad, 1990
Terminalia sp.	Tertiary of Alaska	Hollick, 1936
Terminalia sp.	Palaeogene of Japan	Matsuo, 1970
Terminalia sp.	Siwalik of Koilabas, Nepal	Tripathi & Tiwari, 1983

T. tallyana Ett.	-	Schimper, 1874
T. trinitense Berry	Cenozoic of North America	LaMotte, 1952
T. tomentosa	Late Tertiary of Mahuadanr, Jharkhand	Bande & Srivastava, 1990
T. ungeri Ett.	Tertiary of Czechoslovakia	Nemejc, 1975
Terminaliphyllum rectinervis	Upper Cretaceous of Bohemia	Velenovsky, 1884, 1889
Terminaliophyllum faggei	Post Eocene of Nigeria	Puri, 1966
T. keayi	Post Eocene of Nigeria	Puri, 1966
Terminaliophyllum sp.	Eocene of Borneo	Geyler, 1887

Table 1—Fossil leaves of the genus *Terminalia* Linn. recorded from India and abroad.

nus *Gynocardia* R.Br. consists of single species, *Gynocardia odorata* R.Br. with which the fossil leaves show closest affinity. It is a large evergreen tree distributed in moist forests of mountain valley in South Asia, South Yixang and Yunnan in China, Bangladesh, Nepal and Myanmar. In India it is commonly found in north-east India (Gamble, 1972).

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

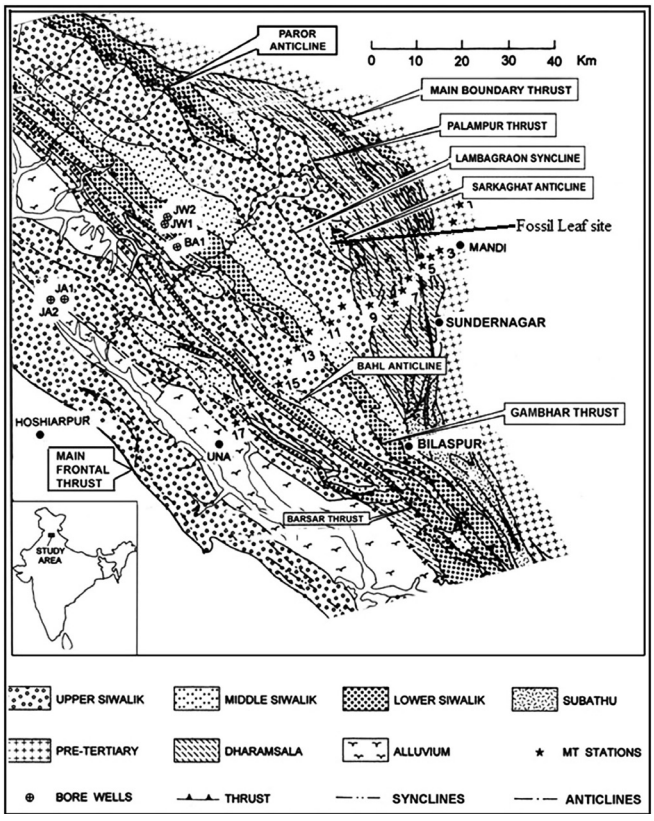

Fig. 4—Geological map showing the Middle Siwalik outcrop around fossil locality (after Ranga Rao *et al*., 1979).

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

Order—FABALES

Family—FABACEAE

Genus—MILLETTIA W. & A.

Millettia bilaspurensis Prasad, 2006

(Pl. 1.4, 5, 6, 8)

Material—Three specimens (one with counter part).

Description—Leaflet, slightly asymmetrical at the base, narrow oblong; preserved size 11.2 x 2.7 cm, 10.5 x 3.0 cm and 10.2 x 3.2 cm; apex narrow acute; base acute; texture chartaceous; petiole indistinct; venation pinnate, eucamptodromous; primary vein (1º) single, prominent, stout, almost straight to curved; secondary veins (2º) 16-17 pairs visible, 0.3-0.9 cm apart, arise straight and curved near the margin, alternate to sub opposite, unbranched, angle of divergence about 45º, narrow acute, almost uniform; inter secondary veins not seen; tertiary veins (3º) fine, angle of origin RR, percurrent, usually straight, sometimes sinuous, branched, oblique in relation to midvein, opposite to alternate and close.

Specimens—GSI Chd. 302-304 (Figured specimens).

Type locality—Near Sarkaghat, Mandi District, Himachal Pradesh, India.

Type stratum—Middle Siwalik (Upper Miocene).

Affinity—The characteristic features of the present fossil leaves such as narrow oblong shape, narrow acute apex and acute base, entire margin, eucamptodromous venation, acute angle of divergence of secondary and its nature of curvature, RR, percurrent, straight to sinuous tertiary veins indicate their affinity with the leaves of extant genus *Millettia* W. & A. of the family Fabaceae. In order to identify up to specific level the extant leaves of available species of this genus have been studied and concluded that the modern leaves of *Millettia pachycarpa* Benth. (C.N.H. Herbarium Sheet No. 12288, 12287, 12276, Pl. 1.7) show closest affinity with the present fossil in almost all the morphological features. The genus *Millettia* W. & A. comprises 90 species distributed in the tropical region of old world (Mabberley, 1997). The modern comparable taxa, *Millettia pachycarpa* Benth. (syn. *Millettia taiwaniana* Hayata) is a perennial climbing shrub. It is endemic to south-east Asian region and mostly distributed in north-east Himalaya extending through Assam and Bangladesh and Myanmar. It is also common in Malacca, China, Thailand and Vietnam (Hooker, 1879; Gamble, 1972; Perry, 1980).

About 24 fossil leaves resembling the genus *Millettia* W. & A. have been recorded from Tertiary sediments of India and abroad. These fossil leaves have been studied critically and found that the fossil leaf *Millettia bilaspurensis* Prasad (2006) described from Siwalik of Bilaspur, Himachal Pradesh (about 95 km south-east of fossil locality) shows closest affinity with the present fossils and hence they have been kept under the same species. *Millettia bilaspurensis* Prasad.

Genus—CYNOMETRA Linn.

Cynometra siwalika Awasthi & Prasad 1990

(Pl. 2.1)

Material—One specimen.

Description—Leaflet asymmetrical, preserved size 7.5 x 2.5 cm, narrow elliptic; apex slightly broken; base acute; texture coriaceous; venation pinnate, brochidodromous; primary vein (1º) single, prominent, moderate, almost straight; secondary veins (2º) poorly preserved, 9-10 pairs visible, alternate to sub-opposite, angle of divergence 55º-70º, acute, moderate, uniformly curved up and join to superadjacent secondaries; intersecondary veins present, simple; tertiary vein (3º) fine, angle of origin usually RR, percurrent, orthogonal reticulate, oblique in relation to midvein, predominantly alternate and close.

Specimen—GSI Chd. 305 (Figured specimen).

Type locality—Near Sarkaghat, Mandi District, Himachal Pradesh, India.

Type stratum—Middle Siwalik (Upper Miocene).

Affinity—The characteristic features of the present fossil leaflet such as asymmetrical, narrow elliptic shape, acute base, brochidodromous venation, alternate to sub-opposite, closely placed secondary veins having variation in angle of divergence, presence of intersecondary veins and percurrent tertiaries indicate its affinity with the extant leaves of *Cynometra polyandra* Roxb. of the family Fabaceae (C.N.H. Herbarium Sheet No. 138770: Pl. 2.2). The genus *Cynometra* Linn. consists of about 70 species (Mabberley, 1997) distributed in the tropical regions of the world. Only five species are found in Indian region. The extant taxa *C. polyandra* Roxb. is a tall evergreen tree distributed in the forests of Khasia and Cachar Hills and Malaya peninsula (Brandis, 1971).

So far, four fossil leaflets resembling the genus *Cynometra* Linn. were known from the Siwalik sediments of India and Nepal. They are *Cynometra siwalika* Awasthi & Prasad (1990) from Surai Khola, western Nepal and Tanakpur area, Uttarakhand, India (Shashi *et al*., 2006), *C. tertiara* Antal & Awasthi (1993) from Oodlabari, West Bengal and *C. palaeoiripa* from Koilabas area, western Nepal (Prasad *et al*., 1999) and Suraikhola western Nepal (Prasad & Pandey, 2008). The present fossil leaflet shows closest affinity with *Cynometra siwalika* Awasthi & Prasad in shape, size and venation pattern hence placed in the same species.

Order—ROSALES

Family—RHAMNACEAE

Genus—VENTILAGO Gaertn.

Ventilago ovatus Konomatsu & Awasthi, 1999

(Pl. 2.4)

Material—one specimen.

PLATE 1

(All figures are of natural size unless otherwise mentioned)

1. *Gynocardia mioodorata* Prasad *et al.*, 1999-Fossil leaf in natural size showing shape, size and venation pattern.
2. *Gynocardia odorata* R.Br.-Modern leaf in natural size showing similar shape size and venation pattern.
3. *Gynocardia mioodorata* Prasad *et al.*, 1999 – A part of fossil leaf magnified to show details of venation. x 1.5.
4. 5. 6. *Millettia bilaspurensis* Prasad 2006-Fossil leaves in natural size showing shape, size and venation pattern.
7. *Millettia pachycarpa* Benth.-Modern leaf showing similar shape, size and venation pattern.
8. *Millettia bilaspurensis* Prasad 2006-Apart of fossil leaf magnified to show details of venation. x 2.

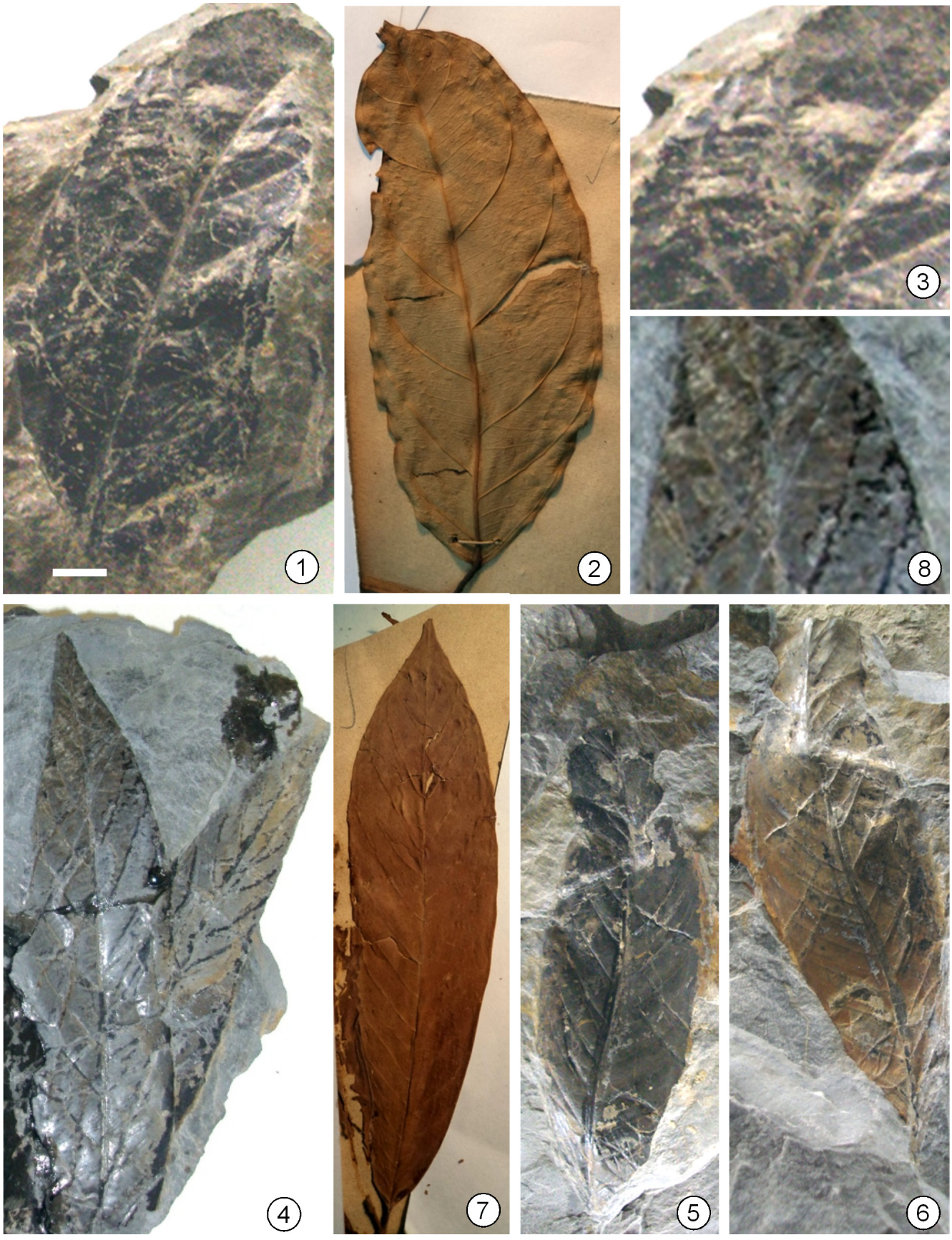

PLATE 1

Description—Leaf simple, asymmetrical, ovate; preserved size 8.0 x 4.0 cm; apex acute to mucronate; base slightly broken, unequal; margin entire; texture thick chartaceous; petiole broken; venation pinnate, eucamptodromous; primary vein (1º) single, prominent, moderate, almost straight; secondary veins (2º) 6 pairs, 1.0-2.0 cm apart, alternate, angle of divergence 50º -65º, acute, moderate uniformly curved up and running upward for a little distance and then join to their superadjacent secondaries, unbranched; tertiary veins (3º) fine, angle of origin usually RR, percurrent, almost straight, sometimes branched, usually right angle in relation to midvein, alternate to opposite and close.

Specimen—GSI Chd. 306 (Figured specimen).

Type locality—Near Sarkaghat, Mandi District, Himachal Pradesh, India.

Type stratum—Middle Siwalik Formation (Upper Miocene).

Affinity—The important features of present fossil leaf such as narrow ovate shape, acute to mucronate apex, unequal base, entire margin, eucamptodromous venation, characteristic curvature of secondary veins, RR, percurrent tertiary veins having right angle relation with midrib collectively indicate its affinity with the leaves of the genus *Ventilago* Gaertn. of the family Rhamnaceae. After critical examination of all the available species of this genus it has been concluded that the extant leaves of *Ventilago calyculata* Tul. (syn. *V. madrasputana* Gaertn.) show closest affinity with the present fossil (C.N.H. Herbarium Sheet No. 999; Pl. 2.5). It is worth mentioning that the basal secondary veins vary in specimen to specimen C.N.H. Herbarium Sheet No. 22052). It has been seen that the angle of divergence of secondaries increases as the width of basal part of leaf increases. The genus *Ventilago* Gaertn. consists of 35 species, presently distributed in the old world (Tropical Africa and Madagascar). The modern comparable taxon, *V. calyculata* Tul. is a small tree found in the evergreen to moist deciduous forests of Sub-himalayan tract from Jammu eastwards up to Assam and Myanmar (Brandis, 1971).

Two leaf fossils resembling the genus *Ventilago* Gaertn. have been known from the Siwalik sediments. First of all, Antal and Prasad (1997) reported a fossil leaf under the form species *Ventilago tistaensis* from the Lower Siwalik sediments of Darjeeling District, West Bengal. Later on Konomatsu & Awasthi (1999) described another fossil leaf *V. ovatus* from the Middle Siwalik sediments of Dumkibas, western Nepal. The present fossil leaf has been compared with both the known fossils and observed that it shows similarity with *V. ovatus* Konomatsu & Awasthi described from Siwalik of Nepal and thus kept under the same species.

Order—MYRTALES

Family—COMBRETACEAE

Genus—TERMINALIA Linn.

Terminalia himachalensis sp. nov.

(Pl. 2.6)

Material—Two specimens.

Description—Leaf simple, almost symmetrical, narrow oblong; preserved size 12.6 x 4.5 cm; apex and base slightly broken; margin entire; texture chartaceous; venation pinnate: eucamptodromous; primary vein (1º) single, prominent, stout, slightly curved; secondary veins (2º) 12-13 pairs visible, 0.8-1.4 cm apart, alternate to opposite, seemingly unbranched, angle of divergence about 60º-70º, acute, moderate, uniformly curved up and join to their superadjacent secondary veins; tertiary veins (3º) still fine, well preserved in the upper part, angle of origin RR, rarely AO, percurrent, straight to sinuous, branched, oblique in relation to midvein, nearly right angle near the margin, alternate to opposite and close.

Specimen—GSI Chd. 307 (Holotype).

Type locality—Near Sarkaghat, Mandi District, Himachal Pradesh, India.

Type stratum—Middle Siwalik (Upper Miocene).

Etymology—After the name of state, Himachal Pradesh to which fossil locality belongs.

Affinity—The most important features of the present fossil leaves are almost symmetrical, narrow oblong shape, entire margin, number and nature of secondary veins, eucamptodromous venation, RR-AO, percurrent, straight to sinuous tertiary veins. A comparative study of herbarium sheets of different families and genera shows that these features are

PLATE 2

(All figures are of natural size unless otherwise mentioned)

1. *Cynometra siwalika* Awasthi & Prasad 1990-Fossil leaf in natural size showing shape, size and venation pattern.
2. *Cynometra polyandra* Roxb.-Modern leaf showing similar shape, size and venation pattern.
3. *Cynometra siwalika* Awasthi & Prasad 1990-A part of fossil leaf magnified to show details of venation. x 2.2.
4. *Ventilago miocalyculata* Prasad– Fossil leaf showing shape, size and venation pattern.
5. *Ventilago calyculata* Tul.-Modern leaf showing similarity in shape, size and venation pattern.
6. *Terminalia himachalensis* sp. nov.-Fossil leaf in natural size showing shape, size and venation pattern.
7. *Terminalia tomentosa* (Roxb.) W. & A.-Modern leaf showing similar shape, size and venation pattern.
8, 9. *Amesoneuron miocenica* sp. nov. – Fossil leaf in natural size showing shape, size and venation pattern.
10. *Daemonorops calycarpus* Mart. – Modern leaf showing similar shape, size and venation pattern.

PLATE 2

Name of Taxa	Characteristic features of fossil leaves						
	Shape and Size	**Apex**	**Base**	**Venation pattern**	**Secondary veins**	**Inter-secondary veins**	**Tertiary veins**
Terminalia panandhroensis Lakhanpal & Guleria,1981	Symmetrical, elliptic, 16.0 x 10.5 cm	-	-	Eucamptodromous	10 pairs, angle of divergence 75º-90º	+	Angle of origin AR-RO, forked, almost straight, oblique in relation to midvein, close
T. palaeochebula Awasthi & Prasad, 1990	Symmetrical, elliptic, 12.0 x 6.5 cm	-	Obtuse	Eucamptodromous	8-9 pairs, angle of divergence 60º	-	Angle of origin RR, oblique in relation to midvein, close
T. koilabasensis Prasad, 1990	Symmetrical, narrow elliptic, 7.0 x 6.0 cm	Acute	Acute cuneate	Eucamptodromous	11 pairs, 0.6-1 cm apart, angle of divergence 65º-70º, more acute on one side, unbranched	-	Angle of origin AR-RR, branched straight, oblique in relation to midvein, close
T. siwalica Prasad, 1990	Asymmetrical narrow obovate, 8.9 x 4.0 cm	Acute	Acute, asymmetrical	Eucamptodromous	7-8 pairs, angle of divergence 50º, 0.8-1.2 cm apart, unbranched	-	Angle of origin AO, almost straight, nearly right angle in relation to midvein, close
T. miobelerica Prasad, 1994a	Asymmetrical elliptic, 12.0 x 6.5 -7.5 cm	-	-	Eucamptodromous	6 pairs, 1.3-3.2 cm apart, angle of divergence 65º, unbranched	+	RR-AO, straight, branched, oblique in relation to midvein, close
T. balugoloensis Lakhanpal & Awasthi, 1992	symmetrical, narrow elliptic, 18.5 x 5.0 cm	Acumi-nate	Obtuse	Eucamptodromous	16 pairs, 0.8-1.4 cm apart, angle of divergence 60º-80º, unbranched	+	Usually RR, straight to sinuous, branched, oblique to nearly right angle near the margin, close
Terminaliophyllum keayi Puri, 1966	not clear, fragment 6.0 x 4.8 cm	-	-	Eucamptodromous	4-5 pairs visible, 1.3-2.0 cm apart, angle of divergence 70º-85º	+	RR-AO, branched, oblique in relation to midvein, almost straight, close
T. faggei Puri, 1966	elliptic, 8.0 x 2.03 cm 8.0 X 6.0 cm	-	-	Eucamptodromous	5-6 pairs visible, 1-2.0 cm apart, angle of divergence 55º-60º	+	Usually RR, straight to sinuous, branched, oblique in relation to midvein, close
T. indicola Berry	symmetrical, lanceolate, 20.0 x 6.0 cm	Acute	Cuneate	Camptodromous	12-14 pairs, angle of divergence 70º-85º upper, secondary 30º-40º, unbranched	-	RR, straight to sinuous, branched, oblique to nearly right angle in relation to midvein, close
T. lesleyana Berry, 1916	Symmetrical, obovate, 15 x 8 cm	Bluntly Acute	-	Camptodromous	Numerous, closely placed, angle of divergence 45º(60º-70º)	-	-
T. hilgardiana Berry (Ball, 1931)	Symmetrical, oblong-oval, up to 25 x 10 cm	-	Obtuse	Camptodromous	About 20 pairs, angle of divergence 40-70º	-	-

T. phaeocarpoides Berry, 1916 (Ball, 1931)	Obovate, 16.0 x 8.0 cm	Acute (Pointed)	Cuneate	Camptodromous	8 pairs, angle of divergence 50º	-	Angle of origin AO, almost straight, right angle in relation to midvein, close
T. claibornensis Berry (Ball, 1931)	Symmetrical, narrow elliptic, 10.5 x 3.0 cm	Seemingly Acute	Cuneate	Eucamptodromous	Numerous, closely placed, fine, angle of divergence about 60º	-	Very fine, usually RR, straight, oblique in relation to midvein, close
T. mulleri Trivedi & Srivastava, 1985	Symmetrical, elliptic, 3.0 x 1.6 cm	Obtuse	Obtuse	Camptodromous	About 10 pairs, closely placed, angle of divergence 45º-65º , unbranched	-	Angle of origin RR, AO, straight to sinuous, oblique in relation to midvein, close
T. chebula Retz. Singh & Prasad, 2007	Symmetrical elliptic, 21 x 10.7 cm	Acute	Rounded	Eucamptodromous to Brochidodromous	17-18 pairs, angle of divergence about 70º, unbranched	-	AO, straight to sinuous, branched, oblique in relation to midvein, close
T. kachchhensis Lakhanpal & Guleria, 1981	Appearing symmetrical, elliptic-oblong, 8.0 x 6.0 cm	-	Rounded	Eucamptodromous	10 pairs visible, angle of divergence 55º-80º, unbranched		Angle of origin RR-RA, branched, oblique in relation to midvein, close
T. obovata Awasthi & Mehrotra, 1995	Symmetrical, narrow obovate, 9.5 x 4.5 cm	Rounded	-	Eucamptodromous	9 pairs, 0.9-1.2 cm apart, angle of divergence 45º-65º	-	Angle of origin AR, recurved, oblique in relation to midvein, close
T. palaeocatappa Awasthi & Mehrotra, 1995	Symmetrical, narrow obovate, 13 x 8.5 cm	Obtuse to Rounded	Obtuse	Eucamptodromous	12 pairs visible, 0.7-1.7 cm apart, angle of divergence 70º-80º, bifurcated	-	Percurrent
Terminalia sp. Matsuo, 1970	Symmetrical, elliptic-ovate, 6.5 x 3.3 cm	Wide Acute	-	Camptodromous	9 pairs, 0.4-0.8 cm apart, angle of divergence 35º-70º	-	Fine, usually AO, straight, oblique in relation to midvein, close
T. estimina MacGinitie, 1941	Symmetrical, ovate-obovate, 11.0 x 5.0 cm	Obtuse-Acuminate	Cuneate	Eucamptodromous to Brochidodromous	6-9 pairs, 0.4-1.4 cm apart, angle of divergence 40º-50º, loop formation, branched	-	Fine, straight to sinuous, oblique to nearly right angle in relation to midvein, close
T. panonica Unger, 1867	Symmetrical, elliptic-ovate, 9.8 x 3.2 cm	Acuminate	Acute	Eucamptodromous	5 pairs, 0.5-2.5 cm apart, angle of divergence about 60º	+	Usually RR, straight to sinuous, oblique to right angle in relation to midvein, branched, close to nearly distant.
T. europaea (Web.) Weyland, 1943	Almost symmetrical, obovate- elliptic, 6.0-9.0 x 2.1-2.8 cm	Acute	Cuneate	Camptodromous	About 10 pairs, 0.5-1.4 cm apart, angle of divergence 50º-55º	-	Angle of origin RR, straight, oblique to nearly right angle, close
T. rottensis Weyland, 1943	Symmetrical, obovate, 6.7 x 3.5 cm	Obtuse	Cuneate	Camptodromous	10 pairs, 0.4-1.2 cm, angle of divergence about 60º	+	Angle of origin RR, straight to sinuous, oblique in relation to midvein
T. miocenica (Unger, 1867) Weyland, 1943	Ovate	Cuneate	Obtuse	-	-	-	-

T. tallyana Ett. Schimper, 1874	Obovate to lanceolate, 10 x 3 cm	-	-	Camptodromous	Angle of divergence 40º-50º	-	-
T. ungeri Ett. Nemejc, 1975	Oblong-lanceolate	-	-	Brochidodromous	-	-	-
T. tomentosa W. & A. Bande & Srivastava, 1990	4.4 x 4.5 cm fragment	Acumi-nate	-	Camptodromous to Eucamptodromous	Only 3-4 pairs visible, sharply curved near the margin, unbranched	-	Angle of origin AR, retroflexed, oblique to right angle in relation to midvein, close
T. radobojana Unger, 1867	Symmetrical, ovate, 8.0 x 3.9 cm	Acute	Acute	Eucamptodromous	10 pairs, 0.3-0.9 cm apart, angle of divergence 60º-70º, unbranched	-	Angle of origin AO-RR, straight, oblique in relation to midvein, close
Terminaliphyllum rectinervis Velenovsky, 1889	Almost symmetrical, narrow elliptic, 6.0 x 2.5 cm	Acute	Acute	Craspedodromous to Eucamptodromous	7 pairs, closely placed, 0.4-0.9 cm apart	-	-
Terminalia cf. *T. catappa* Nemejc, 1975	Symmetrical, narrow obovate, 12.0 x 3.3 cm	Obtuse	Cuneate	Craspedodromous to Eucamptodromous	13 pairs, 0.8-1.3 cm apart, angle of divergence 60º-80º, branched near the margin	-	Usually RR, almost straight, oblique in relation to midvein, close
Terminalia sp. Tripathi & Tiwari, 1983	Symmetrical, elliptic 7.4 x 3.5 cm	-	Acute	Eucamptodromous	6-7 pairs, 0.4-1.2 cm apart, unbranched	-	Angle of origin RR, almost straight, oblique in relation to midvein, close
T. palaeopaniculata Agarwal, 2002	Symmetrical, narrow elliptic, 6.8 x 5.0 cm	-	Obtuse	Eucamptodromous	6-9 pairs, 0.3-0.6 cm apart, angle of divergence 60º-75º, unbranched	-	Angle of origin RR, almost straight, oblique in relation to midvein, close
T. neyvelensis Agarwal, 2002	Symmetrical, elliptic, 6.0 x 2.5 cm	-	Obtuse	Eucamptodromous	5-6 pairs, 0.7-0.8 cm apart, angle of divergence 50º-60º, branched	-	Angle of origin RR-AR, straight, unbranched, oblique in relation to midvein, close
T. elegans Heer Schimper, 1874	Oblong	Obtuse	-	Camptodromous	Sub- opposite, closely placed	-	-
T. fenzliana Unger Nemejc, 1975	Unequal, obovate with serrate margin	Obtuse	Attenuate (Cuneate)	-	-	-	-
Terminalia sp. Hollick, 1936	Only basal portion of the lamina, 6.0 x 5.8 cm, wide elliptic	-	Seemingly acute	Eucamptodromous	8-9 pairs visible, 0.5-1.3 cm apart, angle of divergence 60º-70º	+	Angle of origin AO to rarely RR, straight, oblique in relation to midvein, close to distant
Terminalia himachalensis sp. nov.	Almost symmetrical, narrow oblong, 12.6 x 4.5 cm	-	-	Eucamptodromous	11-12 pairs visible, 0.8-1.4 cm apart, unbranched, angle of divergence 60º-70º	-	Angle of origin RR rarely AO, straight to sinuous, branched, oblique in relation to midvein in the most of the part, nearly right angle near the margin, close

Table 2—Showing differentiative characters of the fossil leaves of known species of the genus *Terminalia* from India and abroad.

found commonly in the modern leaves of the genus *Terminalia* Linn. of the family Combretaceae. On critical examination of the extant leaves of all the available species of this genus it has been concluded that the present fossil leaves show their close affinity with the leaves of *Terminalia elliptica* Willd. (syn. *T. alata* Heyne ex Roth; *T. tomentosa* (Roxb.) Wight & Arn.; C.N.H. Herbarium Sheet No. 1846, Pl. 2.7). The genus *Terminalia* Linn. consists of 150 species of large trees widely distributed in the tropics of the world (Mabberley, 1997). *Terminalia elliptica* Willd. (syn. *T. alata* Heyne ex Roth, *T. tomentosa* (Roxb.) Wight & Arn.) is native to southern and south east Asia, Bangladesh, Myanmar, Thailand, Laos, Combodia and Vietnam. It is found as a common plant in the prominent parts of southern India.

Fossil leaves resembling the genus *Terminalia* Linn. have been reported under three generic names, viz. *Terminalia* Linn., *Terminaliphyllum* Velenovsky and *Terminaliophyllum* Geyler from Tertiary-Cretaceous sediments of India and abroad. These are as listed in (Table 1) indicating their locality and horizon.

The present fossil leaves have been compared with all the known available fossil species and found that it does not match any of them. These differ mainly in the course and arrangement of secondary and tertiary veins (Table 2). In view of this the present fossil leaf has been assigned to new species *Terminalia himachalensis*. The Combretaceous taxa are mainly distributed throughout the tropics of South America, Africa, Australia, China and South East Asia. There are a global record of Combretaceous fossils represented by woods, leaves, flowers, fruits and pollen from Middle Cretaceous onwards. The genus *Terminalia* has a cosmopolitan distribution and show maximum diversity in South-East Asia. The earliest record of *Terminalia* (*Terminaliophyllum rectinervis* Velenovsky, 1884, 1889) goes back to Upper Cretaceous of Bohemia. From the fossil record (Table 1) it is obvious that *Terminalia* has continued from the Late Cretaceous to the present and was more widely spread during the Tertiary Period than now.

Order—ARECALES

Family—ARECACEAE

Genus—AMESONEURON (Goeppert) Read & Hickey

Amesoneuron miocenica sp. nov.

(Pl. 2.8, 9)

Material—Two fragmentary specimens.

Diagnosis—leaves pinnately compound, preserved size 4.0 x 6.5 cm and 7.5 x 5.0 cm, preserved length of single pinna 5.0 cm, width about 1.0 cm, 9-10 pinnae visible, narrow oblong in shape, base not clear, apex acute, sometimes seemingly fused, texture chartaceous; midvein distinct, running more are less straight, midvein as well as side primaries veins are faint and poorly preserved, about six side primaries visible and run parallel on either side of midvein, no spines or teeth are seen either on midvein or on margin. Further details could not be seen.

Specimen—GSI Chd. 308 (Holotype), GSI Chd. 309 (Paratype).

Type locality—Near Sarkaghat, Mandi District, Himachal Pradesh, India.

Type stratum—Middle Siwalik Formation (Upper Miocene).

Etymology—Named after the Miocene age of rock samples.

Affinity—Nature of the materials, features of the pinna like, presence of midvein and typical parallel venation suggest the affinity of the fossils with the palm leaves. Of the three

Fossil Taxa	Comparable Extant Taxa	Forest Types	Present Day Distribution
Gynocardia butwalensis Konomatsu & Awasthi	*Gynocardia odorata* R.Br.	Evergreen	North-East India, Nepal, Bangladesh, Myanmar and China.
Millettia bilaspurensis Prasad	*Millettia pachycarpa* Berth	Evergreen	North-East India, Myanmar and South-East costal region.
Cynometra siwalika Awasthi & Prasad	*Cynometra polyandra* Roxb.	Evergreen	North-East India and Malaya peninsulas.
Ventilago ovatus Konomatsu & Awasthi	*Ventilago calyculata* Tul.	Evergreen to moist deciduous	Sub-himalayan tract, North-East India and Myanmar.
Terminalia himachalensis sp. nov.	*Terminalia tomentosa* (Roxb.) W. & A.	Moist deciduous	South India, Bangladesh and Myanmar
Amesoneuron miocenica sp. nov.	*Daemonorops calycarpus* Mart.	Evergreen to moist deciduous	Malaya, Malacca and Griffith.

Table 3— Present day distribution and forest types of the comparable taxa of fossils known from Siwalik sediments of Mandi District, Himachal Pradesh.

main types of lamina (Palmate, Costa palmate and Pinnate) the specimens are collectively belong to pinnate leaved palm. Taking into consideration some characteristic features like, narrow oblong pinnae with faint venation, less number of side parallel primaries, acute apex, etc. a critical survey of herbarium sheets of a large number of palm genera and species have been carried out and concluded that the leaves of the genus *Daemonorops calycarpus* Mart. of the family Arecaceae (C.N.H. Herbarium Sheet No. 494517; Pl. 2.10) show closest affinity with the present fossils. The genus *Daemonorops* Blume consists of about 114 species distributed in the Indo-Malayan region especially in Western Malaysia (Mabberley, 1997). *Daemonorops calycarpus* Mart. with which fossil shows closest resemblance is distributed in Malacca, Malaya, Griffith and Perak (Hooker, 1894).

More than 20 fossils palm and palms like leaves have been reported from Tertiary sediments of India under a variety of genera or simply as palm leaves. Read and Hickey (1972) recognised 9 genera with their diagnostic features to accommodate the fossil palm leaves. These are *Amesoneuron* Goeppert, *Bactrites* Berry, *Sablites* Saporta *Palmacites* Brongniart, *Phoenicites* Brongniart, *Phoenix* Linnaeus, *Sanmiguella* Brown, *Paloreodoxites* Knowlton and *Propalmophyllum* Lignier. According to their diagnostic features the present fossils belong to the genus *Amesoneuron* (Goeppert) Read & Hickey which was created specially to accommodate fragmentary remains of palm leaves lacking clear-cut evidence of original leaf form.

So far six fossil palm leaves have been described under this genus. They are *Amesoneuron borassoides* Bonde (1986) and *A. deccanensis* Guleria & Mehrotra, (1998) from Deccan Intertrappean beds of Madhya Pradesh and Tura Formation (Upper Palaeocene) of Garo Hills, Meghalaya, *A. lakhanpalii* Mehrotra (2000) from Tura Formation, Garo Hills, Meghalaya, *A. manipurensis* Guleria *et al.* (2005) from the Late Eocene of Imphal, Manipur, *A. sahnii* Guleria *et al.* (2000) from Lower Miocene of Kasauli Formation, Himachal Pradesh and *A siwalica* Prasad (2006) from Siwalik sediments of Ranital, Himachal Pradesh. A comparative study of present fossils with those above mentioned palm fossil leaves has been carried out and concluded that none of them show similarity with the present Siwalik fossils. In being different with earlier known fossils, the present specimens have been described as *Amesoneuron miocenica* sp. nov.

DISCUSSION AND CONCLUSION

The plant fossils recovered for the first time from the Siwalik sediments near Sarkaghat, Himachal Pradesh have been studied and identified with modern ones. They have been assigned to six fossil taxa viz., *Gynocardia butwalensis* Konomatsu & Awasthi, *Millettia bilaspurensis* Prasad, C*ynometra siwalika* Awasthi & Prasad, *Ventilago ovatus*. Konomatsu & Awasthi, *Terminalia himachalensis* and *Amesoneuron miocenica.* The present day distribution of the recorded taxa shows that they mostly occur in the tropical evergreen and moist deciduous forests of north-east India, Myanmar, Malaya and adjoining area (Table 3) receiving higher rain fall (Hooker, 1879, 1894; Champian & Seth, 1968; Gamble, 1972). Thus it may be concluded that a warm and humid climate with reduced precipitation prevailed in and around the fossil locality at the time of deposition in contrast to present day relatively dry climate. Almost all the taxa represented by the fossils do not occur in the area as well as in the whole Himalayan foot hills of Himachal Pradesh, thus indicating climate change after deposition of Siwalik sediments. This change in the climate since the Middle Miocene can also be explained by a general global cooling and by the geological events within the region like the Himalayan uplifts and swallowing of the Tethys Sea. These climatic and physiographic changes made the environment hostile for the endemic flora which was gradually replaced by the mixed deciduous forest all along the foot hills of Himalaya in the region. The presence of fossil palms in the Siwalik sediment (Middle Miocene) of Himachal Pradesh and Uttarakhand, India (Prasad, 1987, 2006) suggests its continuity from its origin (about 110 Ma) to the present.

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