

Cuticle bearing fossil leaves from Mio-Pliocene period in the Sub Himalayan zone and its phytogeographical and environmental implications

Mahesh Prasad¹, E.G. Khare¹, A.K. Kannaujia^{2*} and Alok³

¹Birbal Sahni Institute of Palaeobotany, Lucknow-226 007, India

²Department of Botany, Lucknow University, Lucknow-226 007, India

³Department of Botany, Allahabad University, Allahabad-211 002, India

*Corresponding Author email : ankit_kannaujia24@yahoo.com

Publication Info

Paper received:
03 July 2012

Revised received:
31 December 2012

Accepted:
25 January 2013

Abstract

A variety of fossil leaves were collected from the Siwalik group of India and Nepal. Few of them possessing sufficient cuticle were identified on the basis of morphological and cuticular features (epidermal cells, stomatal density, stomatal index etc). They closely resembled with the extant taxa, *Pterospermum acerifolium* (Sterculiaceae), *Dichapetalum gelonioides* (Dichapetalaceae), *Paranephelium macrophyllum*, *P. xestophyllum* (Sapindaceae), *Gluta renghas* (Anacardiaceae) and *Mimusops elengi* (Sapotaceae). The habit, habitat and present day distribution of the above modern comparable taxa suggest the prevalence of tropical humid environment during deposition of Siwalik sediments in the Sub-Himalayan zone. The extinction of the above comparable taxa (except *Pterospermum acerifolium*) from the Sub-Himalayan zone indicates the environmental change after Mio- Pliocene time. The epidermal and stomatal features of the fossil leaves collectively suggest the existence of a broad leaved mesophytic forest at low altitude having comparatively high humidity all along the Himalayan foot hills during 8-12 million years ago.

Key words

Foliar epidermal architecture, Fossil leaves, Morphology, Phytogeography, Sub-Himalayan zone

Introduction

The Siwalik groups are developed in the Himalayan foreland basin all along the Sub-Himalayas and well exposed from west to east and conformably rest on the Murrees. They are broadly divided in to lower, middle and upper Siwalik ranging from Middle Miocene to Lower Pleistocene in age (20ma). The Siwaliks are about 5000 m thick and are believed to have been deposited in different environment viz. Piedmont, outwash plain channel and flood plain and lacustrine. The palaeobotanical investigation on the fossil leaves from sub- Himalayan zone (Mio-Pliocene) revealed a variety of floral assemblage belonging to both monocotyledon and dicotyledon families of angiosperms (Prasad, 2008).

The Siwalik sediments (shale, siltstone and fine grained sandstone) have yielded a good amount of fossil leaves having well preserved cuticular structure which have been studied systematically in order to infer the climatic condition during the Siwalik period. There is little effort on the cuticular study of fossil leaves from the Siwalik sediments. So far, Prasad and Khare (2004) studied the cuticles of two fossil leaves (*Diospyrus pretoposia* and *Sterculia kathgodamensis*) recovered from Middle Siwalik sediments of Arjun Khola area, Nepal. Mehrotra *et al.* (2003) studied the cuticles of fossil leave of *Terminalia catapa* Linn. collected from Upper Siwalik (Plio-Pleistocene) sediments of Arunachal Pradesh, India. Stomatal density and index of four fossil species of *Ginkgo* collected from Jurassic to early Cretaceous have been investigated which

provide evidence for CO₂ rich atmosphere in the Mesozoic (Li-Qun Chen *et al.*, 2001). The stomatal frequency of tree leaves is increasingly used as a proxy to calculate past atmospheric CO₂ mixing ratio on various geological time scales (Wagner *et al.*, 2004; Kouwenberg *et al.*, 2005). Stomatal frequency analysis of fossil leaves of Oak (*Quercus petrae*) from lignite deposits has been used to detect CO₂ changes on a million- year time scale (Vander Burgh *et al.*, 1993; Kurschner *et al.*, 1996). Besides, the epidermal and stomatal morphology of the genus *Cassia* Linn. was studied by Kotresha and Seetharam (1995) and Mishra and Srivastava (2011) in order to find out their importance in identification and taxonomic delimitation of closely related taxa as well as the effect of environmental factors on the stomatal frequency and index. Parveen and Pullaiah (2008) pointed out that the cuticular studies are taxonomically significant in determining phonetic relationship at even generic level.

In the present investigation, the foliar morphology and cuticular (epidermal and stomatal) features of six cuticle bearing fossil leaves collected from different fossil locality in the Himalayan foot hills have been studied and identified them with their modern equivalents. The nature and distribution of epidermal cells and stomata, stomata frequency and stomatal index of both the fossil and living leaves of the same taxon have also been studied for their comparison and the effect of environmental factors on them.

Materials and Methods

The fossil locality Oodhlabari (26° 52'N : 26° 56'E) is a small town on Siliguri – Guwahati road at the left bank of Ghish River in Darjeeling District, West Bengal, India. The Siwalik sediments in Darjeeling District, West Bengal are exposed all along the foot hills which vary considerably in their slope and do not occur continuously. Acharyya (1972) broadly divided the Siwalik sequence of this area into three units (i) Upper pebbly sandstone and conglomerate unit (ii) Middle sandstone unit and (iii) Lower claystone unit. The fossil leaves were found common in both lower and middle unit.

The others fossil localities (Koilabas and Arjun Khola) are situated in the sub-Himalayan zone of Nepal. In Nepal, the sediments of Siwalik group are known as Churia group after the Churia, a hill which is the extension of the Himalayan foot hills. The Churia hill represent clastic sediments of fresh water molasses that accumulated in long narrow foredeep formed to the South of rising Himalaya in the third episode of Himalayan uplift during middle Miocene. The Churia Group ranges in age from Middle Miocene to Middle Pliocene. The detail lithology and stratigraphy of Churia Group have been studied by Kumar and Gupta (1981), Chaudhuri (1983), Tokuoka *et al.* (1986), Corvinus

(1990) and Appel (1991). The Churia group has been classified into two formation Lower Churia Formation (sandstone facies) and Upper Churia Formation (Conglomerate facies). The Lower Churia Formation with an average thickness of about 1800 ft. is composed of fine grained calcareous well bedded sandstones and siltstones while upper Churia formation consists of mainly of boulder, pebbles and loose micaceous sandstones exposed south of the Lower Formation in the Dang area.

The fossil locality Koilabas is situated in Tribhuvan Nagar District (27° 42'N: 82° 20' E) of western Nepal. It is one of the richest fossiliferous localities in the Himalayan foot hills of Nepal. In this area, the Lower Churia Formation is well exposed all along the upstream of Koilabas nala up to Darwaja and consists of fine-grained sandstone, calcareous thin limestones and variegated clays. Beyond Darwaja up to Chorkholi and onwards the rocks are supposed to belong to Middle Churia Formation which is predominantly arenaceous in nature

Arjun khola (27° 52'N : 82° 50'E) falls in the Dang section of western Nepal and is situated about 3 km. north – west of well known small town, Lamhi in Deokhuri District of Nepal. Almost a complete and uninterrupted sequence of the Churia Group is well exposed all along the road from Arjun Khola Bridge to Ghorai of about 15 km. stretch. These sequences consist of molasses sediments of Lower and Middle Siwalik. The whole sequence is divided into 14 profiles. There are more than 30 fossiliferous beds of mainly shales, siltstones and some fine sandstone. Most of them have yielded a variety of well preserved leaves, fruit and seed impressions and some fossil wood.

Several fossil leaves were collected from Lower – Middle Siwalik (Mio-Pliocene) sediments exposed in the Sub- Himalayan zone. Only six specimens possessing cuticles were found preserved on grey and purple shale as well as fine grained sandstone. The fossil material presented here comes from Siwalik sediments of Oodhlabari (Lish River section, and Sevok Road section) in West Bengal, India, Koilabas (Koilabas Nala section) in Tribhuvan Nagar District, Western Nepal and Arjun Khola (Profile 3, Arjun Khola-Ghorai Road section), Nepal in the sub-Himalayan zone. These fossil leaves were cleared with the fine chisels and studied with the help of hand lens and low power microscope under reflected light. The photographs were taken on Digital Camera with zooming facility. The taxonomic assignments were made based upon the published literature and study of Herbarium sheets of several extant genera of dicotyledonous families at the Central National Herbarium (C.N.H.), Sibpur, Howrah, West Bengal in order to identify the fossil specimens. Morphological characters and venation patterns of the fossil leaves were described and compared with those of modern leaves by the application of method

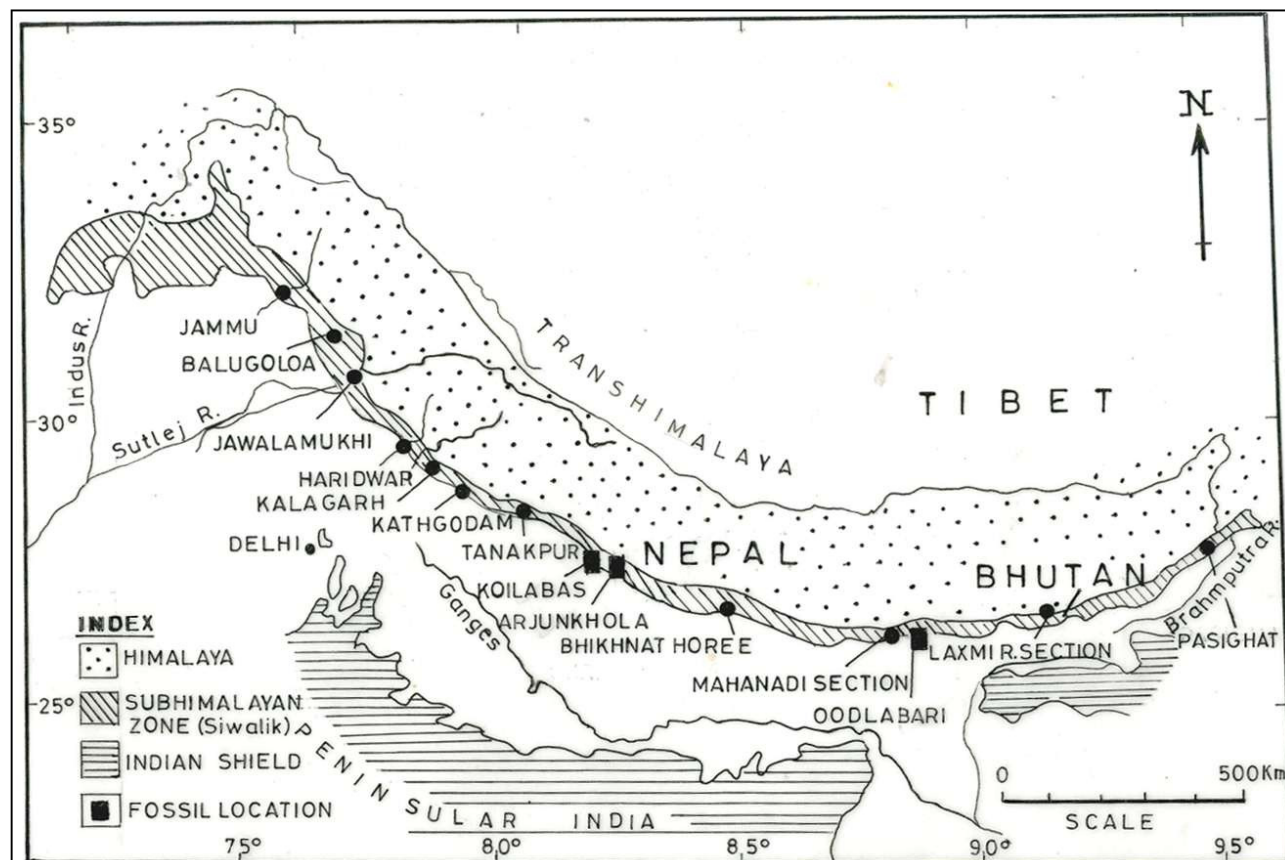


Fig. 1 : Map of study area in the Sub-Himalayan zone showing the location of fossil sampling sites

described by Hickey (1973) and Dilcher (1974) and the Leaf Architecture Working Group (Ash *et al.*, 1999).

The cuticles were removed from leaf impressions with help of organic chemicals and treated with acid followed by KOH, wash with water and dehydrated by ethanol. The slides were prepared in Canada balsam. The photographs were taken on digital camera attached to high power microscope. Epidermal cell frequency, epidermal cell size, stomatal architecture and their size, stomatal frequency, stomatal indices were observed under high power microscope. The stomatal index of different fossil leaves was calculated by the expression used by Salisbury (1928). Stomatal Index (SI) = $S / (E + S) \times 100$; S = Number of stomata in a unit area; E = Number of epidermal cells in the same unit area. All the fossil and living specimens in this study are deposited in the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow.

Results and Discussion

Fossil leaf type - 1

Family-Sterculiaceae, Genus -*Pterospermum* Schreber, *Pterospermum mioacerifolium* Prasad *et al.*, 2010

Leaflet broken, lamina length 5 cm, maximum width 4 cm; apex broken; base broken; normal; margin not observe; texture coriaceous; petiole not preserved; venation pinnate; primary vein (1°) not observed; secondary veins (2°) incomplete preserved; tertiary vein (3°) present, angle of origin Right-Right, percurrent, straight to curved, sometimes sinuous, branched, oblique to right angle in relation to primary veins, alternate to opposite and distant. Cuticle thickness thin, epidermal cells are usually polygonal with usually straight walls, average size of cell $14.76 \times 8.86 \mu\text{m}$, epidermal cell frequency 2844 per sq. mm. Stomata were observed in the lower foliar surface, distributed randomly, polycytic, anomocytic, size $18.38 \times 16.39 \mu\text{m}$, subsidiary cells were irregular in shape, $18 \mu\text{m}$ in length, $15 \mu\text{m}$ in width, stomatal frequency 120 per sq. mm and stomatal index 4.04 (Figs 2 E, G)

The diagnostic features of the present fossil leaf such as presence of inter secondary veins, RR and close tertiaries and type of stomatal structure and nature of stomata, presence of trichome or air chambers in epidermal cells indicate that the present fossil leaf showed close affinity with the extant leaves of *Pterospermum acerifolium* Willd. of the family Sterculiaceae (C.N.H. Herbarium sheet

no. 5930; Figs. 2F, H). It was a tall tree growing in Myanmar, Sub-Himalaya zone, West Bengal, Chittagong, hills of Assam, Kanara and scattered in Bihar and Orissa and central provinces and Andamans.

Both the fossil woods and leaves of the genus, *Pterospermum* Schreb. are known from Tertiary sediments of India. The fossil wood *Pterospermoxylon kutchensis* (Awasthi and Lakhanpal, 1980) is reported from western India and *P. bengalensis* (Roy and Mukhopadhyay, 2005) from West Bengal. So far, three fossil leaves showing affinity with the genus *Pterospermum* Schreb. have been reported from the Siwalik sediments of Darjeeling District, West Bengal. *P. palaeohyeanum* (Antal and Awasthi, 1993) from Gish River section and *P. siwalicum* (Antal and Prasad, 1996) from Ramthi River section near Oodlabari, and *Pterospermum acerifolium* Willd. has also been described from the sub-Himalayan zone (Siwalik) of West Bengal (Prasad et al., 2010). In possessing similar morphological characters as *P. mioacerifolium* and having affinity with the same extant species (*P. acerifolium* Willd.), the present fossil leaf has been described herewith under the same form species, *Pterospermum mioacerifolium* (Prasad et al., 2010).

Sterculiaceae is the most important family of Malvales as it provides chocolate and cocoa. It includes more than 1500 species belonging to 70 phytogeographically significant genera distributed in the tropics and subtropics of both hemispheres. *Pterospermum* represented by both fossil woods and leaves are recorded from Mio-Pliocene sediments of India. The occurrence of fossil species *Pterospermum mioacerifolium* in the present assemblage suggests the existence of Sterculiaceae from late Cretaceous onwards. The evolutionary radiation of core malvacean families including the Sterculiaceae appears to have been a latest Cretaceous to early Tertiary phenomenon (Manchester, 1992).

Holotype: BSIP Museum No. 39794, *Locality:* Oodlabari (Sevok Road section), Darjeeling District, West Bengal, *Horizon and Age:* Middle Siwalik Formation; Upper Miocene.

Fossil leaf type -2

Family: Dichapetalaceae, Genus: *Dichapetalum* Roxb., *Dichapetalum siwalicum* sp. nov.

Leaf almost symmetrical, narrow elliptic; lamina length 10.5 cm, maximum width 2.5 cm; apex broken; base narrow acute, normal; margin entire; texture coriaceous; petiole 0.3 cm long, normal; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, massive, almost straight, slightly curve at apex; secondary veins (2°) only six pairs visible. 1.2 cm apart; angle of divergence acute (about 45°);

moderate, curved up and run parallel to the margin for a long distance, alternate, unbranched; intersecondary veins not observed; tertiary vein (3°) poorly preserved, angle of origin Right-Right, percurrent, straight to sinuous, unbranched. Cuticles thin, epidermal cells were usually polygonal with straight walls, average cell size 24.35x14.15 µm, epidermal cell frequency 2185 per sq mm, stomata were observed in the lower foliar surface, distributed randomly, polycytic, 14.15x14.66 µm, subsidiary cells were irregular in shape, 35 µm in length and 15 µm in width, stomatal frequency 210 per sq mm and stomatal index 8.76 (Fig. 2A, C).

The diagnostic features of the present fossil leaf such as symmetrical, narrow elliptic shape, narrow acute base, entire margin, coriaceous texture, eucamptodromous venation, characteristic secondary veins running parallel to the margin, type and nature of stomata and epidermal cells indicate the present fossil leaf shows close affinity with the extant leaves of *Dichapetalum gelonioides* Eng. of the family Dichapetalaceae (C.N.H. Herbarium sheet no. 76629; Figs 2 B,D). The comparable taxa, *D. gelonioides* Eng. is an Indo-Malayan large shrub or small tree. In India it is distributed in the evergreen forests of Western Ghats and South and Central Sahyadris.

Fossil leaf of the genus, *Dichapetalum* Roxb. is not yet known from the Tertiary sediments of Indian subcontinents. It forms its first report from the Siwalik Upper Middle Miocene of West Bengal and described here as a new species, *D. siwalicum*. The specific epithet denotes its occurrence in the Siwalik sediments. *Diachapetalum* Thouars is a large genus of the family Diachapetalaceae represented by 124 species of trees, shrubs and Lianas and distributed mainly in tropical Africa and Madagascar and Indo-Malayan regions. Based on fossil record, it is concluded that the centre of origin of this family may be Africa (Punt, 1975).

Holotype: BSIP Museum No. 39795, *Locality:* Oodlabari (Sevok Road section), Darjeeling District, West Bengal, *Horizon and Age:* Middle Siwalik Formation; Upper Miocene, *Etymology:* The specific epithet is derived from Siwalik Group of rocks containing the fossil specimen.

Fossil leaf type -3

Family: Sapindaceae, Genus: *Paranephelium* Miq., *Paranephelium seriaensis* Prasad and Dwivedi, 2008

Leaflet almost symmetrical, oblong; lamina length 8.0 cm., maximum width 3.0 cm; apex broken; base acute, normal; margin entire; texture coriaceous; petiole not observed; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, massive, almost straight, slightly curved toward apex; secondary veins (2°) only six pairs

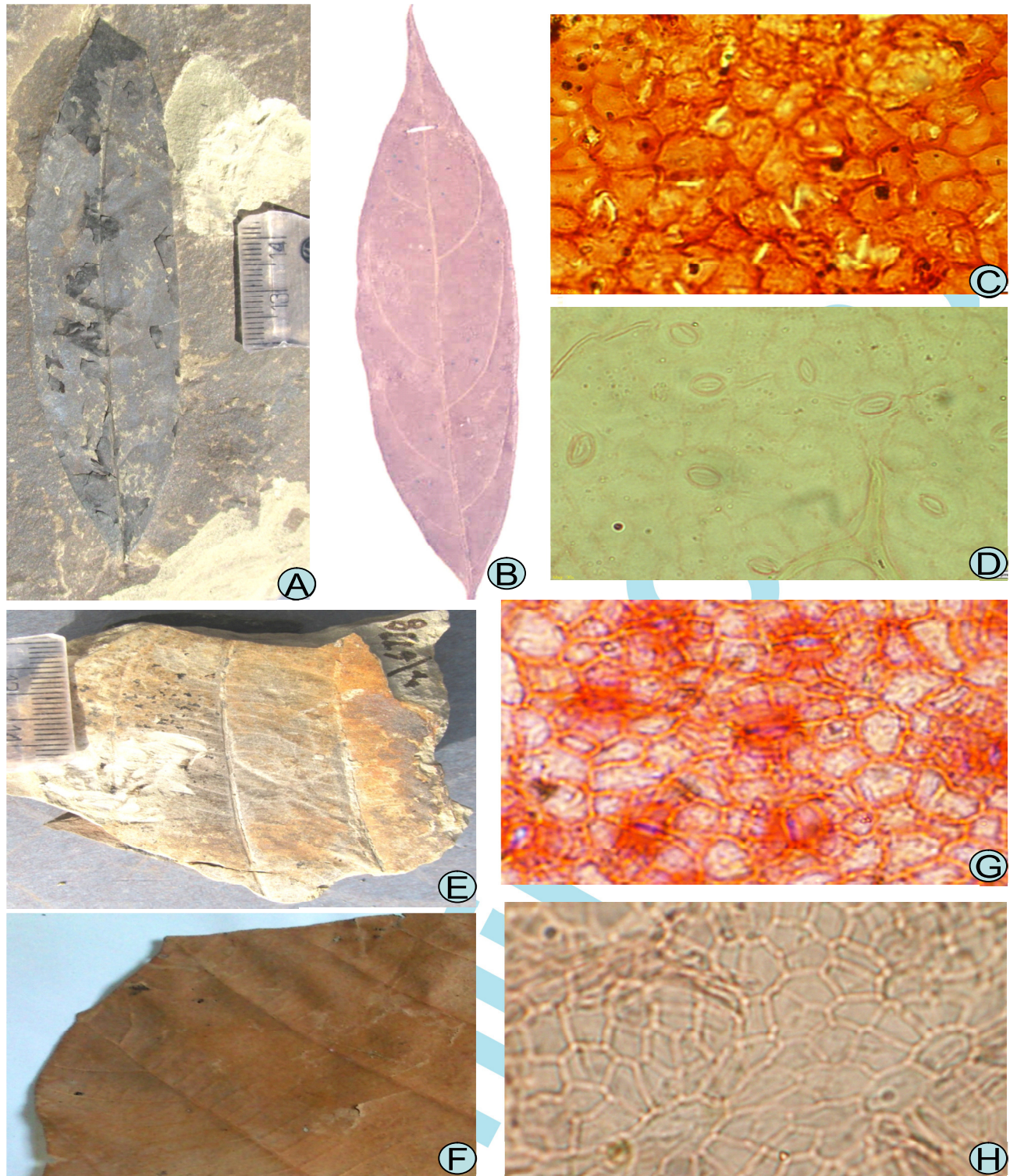


Fig. 2 : A: Fossil leaf, *Dichapetalum siwalicum* sp. nov. with cuticles in natural size showing shape, size and venation pattern; B: Modern leaf, *Dichapetalum gelonioides* in natural size showing similar shape, size and venation pattern; C: A part of cuticle of fossil leaf, *Dichapetalum siwalicum* sp. nov. showing cellular and stomatal structure; D: A part of fossil cuticle of *Dichapetalum gelonioides* showing similar cellular and stomatal structure; E: A part of fossil leaf, *Pterospermum mioacerifolium* Prasad *et al.* with cuticles in natural size showing shape, size and venation pattern; F: A part of modern leaf *Pterospermum acerifolium* showing similar shape, size and venation pattern; G: A part of cuticle of fossil leaf, *Pterospermum mioacerifolium* Prasad *et al* showing cellular and stomatal structure; H: A part of cuticle of modern leaf, *Pterospermum acerifolium* showing similar cellular and stomatal structure and distribution of stomata

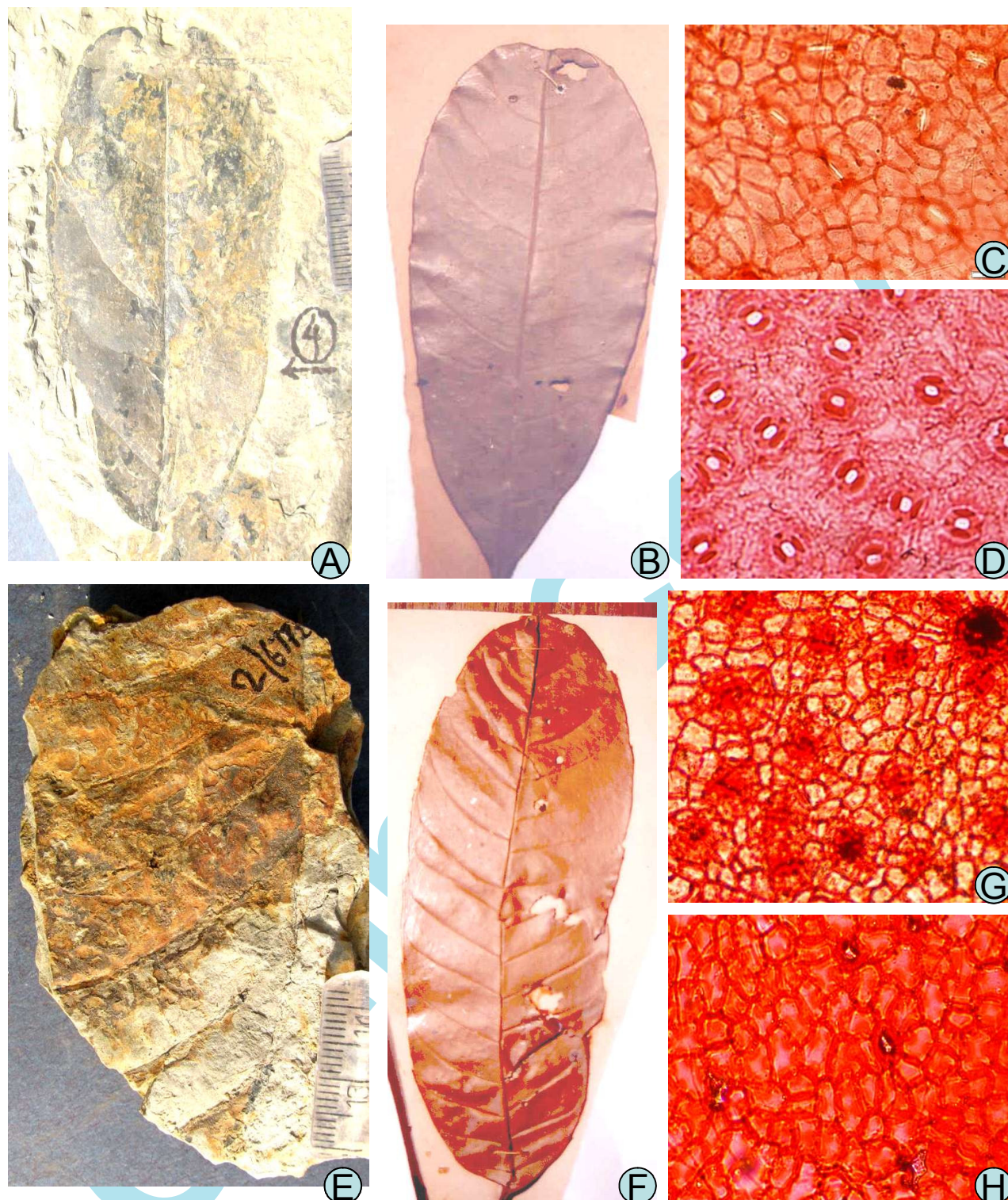


Fig. 3 : A: Fossil leaf, *Paranephelium seriaensis* Prasad and Dwivedi with cuticles in natural size showing shape, size and venation pattern; B: Modern leaf, *Paranephelium xestophyllum* in natural size showing similar shape, size and venation pattern; C: A part of cuticle of fossil leaf, *Paranephelium seriaensis* Prasad and Dwivedi showing cellular and stomatal structure; D: A part of cuticle of modern leaf *Paranephelium xestophyllum* showing similar cellular and stomatal structure; E: Fossil leaf, *Paranephelium miocenicum* sp. nov. with cuticles in natural size showing shape, size and venation pattern; F: Modern leaf, *Paranephelium macrophyllum* showing similar shape, size and venation pattern; G: A part of cuticle of fossil leaf, *Paranephelium miocenicum* sp. nov. showing cellular and stomatal structure; H: A part of cuticle of modern leaf, *Paranephelium macrophyllum* showing similar cellular and stomatal structure

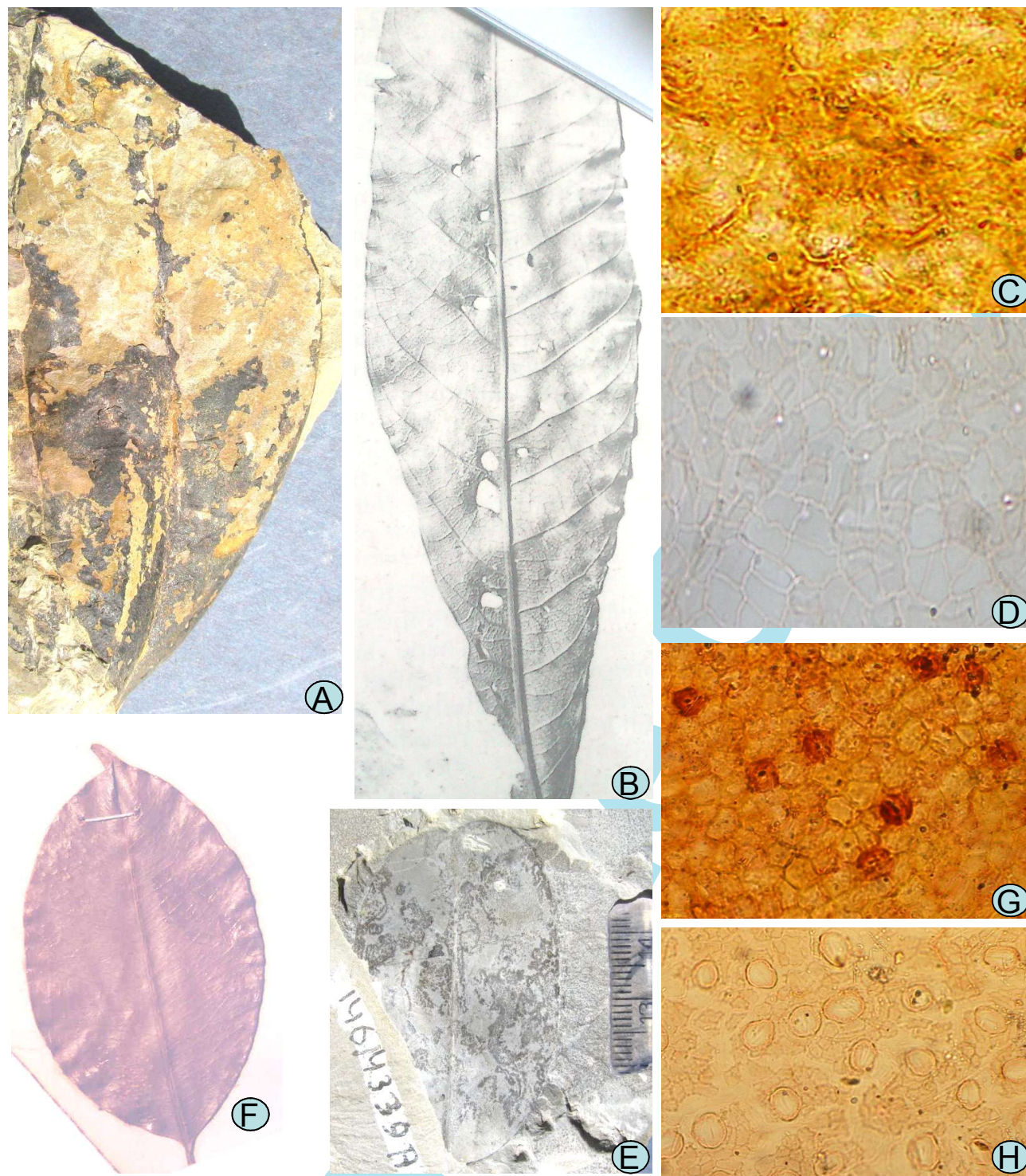


Fig. 4: A: Fossil leaf, *Gluta siwalika* Awasthi and Prasad with cuticles in natural size showing shape, size and venation pattern; B: Modern leaf, *Gluta renghas* in natural size showing similar shape, size and venation pattern; C: A part of cuticle of fossil leaf, *Gluta siwalika* Awasthi and Prasad showing cellular and stomatal structure; D: A part of cuticle of modern leaf, *Gluta renghas* showing similar cellular and stomatal structure; E: Fossil leaf, *Mimusops mioelengi* sp. nov. with cuticles in natural size showing shape, size and venation pattern; F: Modern leaf, *Mimusops elengi* in natural size showing similar shape, size and venation pattern; G: A part of cuticle of fossil leaf, *Mimusops mioelengi* sp. nov. showing cellular and stomatal structure; H: A part of cuticle of modern leaf, *Mimusops mioelengi* showing similar cellular and stomatal structure

visible; length between two secondary 1-1.5 cm, angle of divergence acute (about 50°), moderate, curved up and run parallel to margin, attachment at secondary alternate, unbranched; intersecondary veins not observed; tertiary veins (3°) not observed, angle of origin Right-Right, percurrent, straight, branched, predominantly alternate, oblique in relation to mid vein and close. Cuticle thin, epidermal cells are usually polygonal with straight walls, average size 24.09 x 12.90 µm, epidermal cell frequency 2072 per sq. mm, stomata are observed in the lower foliar surface, distributed randomly, polycytic, anomocytic, average size 14.3 x 9.04 µm subsidiary cells were irregular in shape, 20 µm in length and 15 µm in width, stomatal frequency 74 per sq. mm and stomatal index 3.44 (Figs 3A,C).

The diagnostic features of the present fossil leaf such as symmetrical, oblong shape, acute apex, entire margin, coriaceous texture, eucamptodromous venation, alternate secondary veins, type and nature of stomata and epidermal cell indicate that the present fossil leaf shows close affinity with extant leaves of *Paranephelium xestophyllum* (Miq.) King of the family Sapindaceae (C.N.H. Herbarium sheet no. 1981; Figs 3B,D). *P. xestophyllum* (Miq.) King is a small evergreen tree distributed mainly in Sumatra, Upper Myanmar and Thailand.

A fossil leaf referred to the genus *Paranephelium* Miq. is known from the Siwalik of Seria Naka, Western Nepal under the form species, *Paranephelium seriaensis* (Prasad and Dwivedi, 2008). The present fossil leaf shows close similarity with those of *P. seriaensis* (Prasad and Dwivedi, 2008) in shape size and venation pattern and hence described here under the same species.

Specimen: BSIP Museum No. 39796, **Locality:** Koilabas Nala section, Koilabas, Tribhuvan Nagar, Western Nepal, **Horizon and Age:** Lower Siwalik Formation; Middle Miocene.

Fossil leaf Type 4

Family- Sapindaceae, Genus- *Paranephelium*, Miq., *Paranephelium miocenicum* sp. nov.

Leaflet broken, lamina length 7cm., apex broken; base broken; margin entire; texture coriaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, stout, almost straight; secondary veins (2°) preserved only on one side of midrib, 6 veins visible, 1-1.5 cm apart, angle of divergence nearly right; uniformly curved up, unbranched; tertiary veins (3°) moderate, angle of origin Right-Right, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate, close to nearly distant. Cuticle thin, epidermal cells are usually polygonal, straight, sometimes

undulated, average cells size 25.92 x 15.85 µm, epidermal cell frequency 1600 per sq. mm; stomata were observed in the lower foliar surface, distributed randomly, polycytic, anomocytic, size 32.33 x 27.34 µm, subsidiary cells were irregular in shape, 25 µm in the length and 20 µm in the width, frequency 110 per sq. mm and stomatal index 6.43 (Fig. 3E,G).

The diagnostic features of the present fossil leaf such as entire margin, coriaceous texture, eucamptodromous venation, characteristic secondary veins, type and nature of stomata and epidermal cells indicate the present fossil leaf shows close affinity with extant leaves of *Paranephelium macrophyllum* King of the family Sapindaceae (C.N.H. Herbarium sheet no. 94835, 94837; Figs F,H). The comparable species, *P. macrophyllum* King is presently distributed in the evergreen forest of South east Asian region (Adema et al., 1994).

The earlier recorded fossil leaf *Paranephelium seriaensis* (Prasad and Dwivedi, 2008) differed from the present fossil leaf in being smaller size with less number of secondary veins. Therefore, it has been reported under new species, *Paranephelium miocenicum* sp. nov.

Family Sapindaceae represented by two species of the genus *Paranephelium* in the present assemblage is distributed in tropical or subtropical with their main center of diversity in the south - east Asian region, though some forms extend into the temperate regions of Asia and North America (Klassen, 1999). The oldest records of Sapindaceae are from the Late Cretaceous and Paleocene of North America. However, In India, the oldest Sapindaceous remains are represented mostly by fossil woods from the Late Cretaceous of Deccan Intertrappean beds (Dayal, 1965; Mehrotra, 1987). The record of abundant fossil leaves of a number of sapindaceous genera like, *Euphorea*, *Cupania*, *Filicium*, *Otophora*, *Nephelium*, *Paranephelium*, *Arytera*, *Harpullea* and *Xerospermum* from different Siwalik localities suggests a high diversity all along the foot hill of Himalaya during the Mio-Pliocene time (Prasad, 2008). The phytogeographical distribution of the comparable taxa of the fossils recovered from Mio-Pliocene of sub-Himalayan zone indicates that most of them are not found there at present but migrated towards south - east Asian region where they found favorable condition for their growth. Thus it is suggested that the climatic changes must have taken place after Mio-Pliocene time.

Holotype: BSIP Museum No. 39797, **Paratype:** BSIP Museum No. 39798, **Locality:** Lish River section, Oodlalabari, Darjeeling District, West Bengal, **Horizon:** Lower Siwalik Formation; Middle Miocene, **Etymology:** The specific epithet is after Miocene age of the rocks.

Fossil leaf type - 5

Family- Anacardiaceae, Genus- *Gluta*, Linn., *Gluta siwalika* Awasthi and Prasad, 1990

Leaflet almost symmetrical, narrow elliptic to oblanceolate; lamina length 13 cm., width 5cm; apex broken; base acute, normal, margin entire; texture coriaceous; venation pinnate, eucamptodromous; petiole not observed; primary vein (1°) single, prominent; massive, curved; secondary veins (2°) 9 pairs visible, 0.5-1 cm, apart, angle of divergence acute (about 65°), uniformly curved toward the margin, alternate, unbranched; intersecondary veins poorly preserved, tertiary veins (3°) poorly preserved, angle of origin Right-Right, percurrent, straight to wavy, branched, oblique in relation to midvein, predominantly alternate and close. Cuticle thin, epidermal cells are usually rectangular to polygonal with almost straight walls, cell size 17.29x11.89µm, epidermal cell frequency 2334 per sq. mm; stomata were observed in the lower foliar surface, distributed randomly, polycytic, anomocytic, size 14.62x14.47 µm, stomatal frequency 98 per sq mm, stomatal index 4.02 (Figs 4 A,C).

The characteristic features of the present fossil leaf such as entire margin, coriaceous texture, eucamptodromous

venation, wide angle of secondary veins, type and nature of stomata and epidermal cells indicated that the present fossil leaf shows close affinity with the extant leaves of *Gluta renghas* Linn. of the family Anacardiaceae (C.N.H. Herbarium sheet no. 99076; Figs 4B,D). *Gluta renghas* Linn. is a evergreen tree distributed in Madagascar, India, Myanmar, Thailand, Indochina and throughout Malaysia.

The genus *Gluta* Linn. is well known from Tertiary of India and abroad through the presence of its both fossil woods and leaf impression. The fossil woods have been recorded from several Neogene sediments of India including Sub-Himalayan zone, Myanmar and Southeast India (Roy and Ghosh, 1979; Awasthi, 1984; Kramer, 1974). However, its fossil leaf has been recorded only from Sub- Himalayan zone (Middle – Miocene) of Nepal (Awasthi and Prasad, 1990). This fossil leaf has also been compared with same extant species *G. renghas* Linn. and resembles closely with the present fossil leaf and hence it described under the same form species, *G. siwalika* Awasthi and Prasad.

Anacardiaceae has a pantropical distribution and found to grow in the deciduous and evergreen forest of mainly tropical regions, few species are found in warm temperate region or even in the north temperate areas of

Table 1 : Epidermal and stomatal features of the cuticles of extant and fossil leaves recovered from (Siwalik) Sub- Himalayan zone.

Taxa	Epidermal cell features			Stomatal features			
	Type of epidermal cell	Average length and width(µm)	Frequency	Type of stomata	Stomatal length and width(µm)	Stomatal frequency	Stomatal index
<i>Pterospermum mioacerifolium</i> Prasad et al. (fossil)	polygonal, straight	L-14.76 W-8.86	2844	Polycytic (anomocytic)	L-18.38 W-16.39	120	4.04
<i>Pterospermum acerifolium</i> (modern)	polygonal, straight	L-21.09 W-17.23	2160	Polycytic (anomocytic)	L-29.45 W-29.51	116	5.09
<i>Dichapetalum siwalicum</i> sp. nov.(fossil)	polygonal, straight	L-24.35 W-14.15	2185	Polycytic (anomocytic)	L-14.15 W-14.66	210	8.76
<i>Dichapetalum gelonioides</i> (modern)	polygonal, straight	L-29.56 W-17.35	1934	Polycytic (anomocytic)	L-24.22 W-18.65	180	8.51
<i>Paranephelium seriaensis</i> Prasad et al. (fossil)	polygonal, straight	L-24.09 W-12.90	2072	Polycytic (anomocytic)	L-14.34 W-9.04	74	3.44
<i>Paranephelium xestophyllum</i> (modern)	polygonal, straight	L-20.72 W-12.42	2334	Polycytic (anomocytic)	L-36.26 W-35.71	82	3.39
<i>Paranephelium miocenicum</i> sp.nov.(fossil)	polygonal, straight, sometimes undulated	L-25.92 W-15.85	1600	Polycytic (anomocytic)	L-32.33 W-27.34	110	6.43
<i>Paranephelium macrophyllum</i> (modern)	polygonal, straight, sometimes undulated	L-24.11 W-14.46	1720	Polycytic (anomocytic)	L-19.75 W-17.60	92	5.05
<i>Gluta siwalika</i> Awasthi and Prasad (fossil)	Rectangular to polygonal, straight	L-17.29 W-11.89	2334	Polycytic (anomocytic)	L-14.62 W-14.47	98	4.02
<i>Gluta renghas</i> (modern)	Rectangular to polygonal, straight	L-20.76 W-16.24	1974	Polycytic (anomocytic)	L-14.34 W-17.60	84	4.10
<i>Mimusops mioelengi</i> sp. nov.	polygonal, straight	L-25.96 W-9.12	2162	Polycytic (anomocytic)	L-33.56 W-28.19	130	5.67
<i>Mimusops elengi</i> (modern)	polygonal, straight	L-22.34 W-15.28	2334	Polycytic (anomocytic)	L-15.13 W-12.56	126	5.12

Eurasia (Takhtajan, 1997). It is well documented in fossil record with the several species of fossil woods, leaves, fruits and pollen from Tertiary sediments of both India and abroad (Mehrotra *et al.*, 1998; Prasad, 2008). Based upon the palaeobotanical data the emergence of the Anacardiaceae is suggested to the Cretaceous of Argentina (Raven and Axelrod, 1974, Martinez- Cabrera and Cevallos-Ferriz, 2004). Fossil remains of anacardiaceous taxa from Mexico and Oregon suggested that Mexico and some area of South America are supposed as an important center of diversification due to their high diversity and high level of endemism (Ramirez and Cevallos-Ferriz, 2002). The occurrence of a fossil wood, *Anacardioxylon mahurazari* of the family Anacardiaceae in the Deccan Intertrappean beds (Maestrichtian – Danian) in the present assemblage forms its oldest fossil record from India. Besides Sub-Himalayan zone, the genus *Gluta* is well documented in the tertiary sediments of North East India, North India and South India which indicates a wide spread distribution in the geological past. From its present day distribution, it is evident that this genus became extinct later on most probably due to climatic change after the rise of Himalaya and presently confined to South east regions.

Specimen: BSIP Museum No. 39799, *Locality:* Arjunkhola sequence, Profile-2, Deokhuri District, Western Nepal, *Horizon and Age:* Lower Siwalik Formation; Middle Miocene.

Fossil leaf type - 6

Family: Sapotaceae, Genus: *Mimusops* Linn., *Mimusops mioelengi* sp. nov.

Leaflet almost symmetrical, elliptic; lamina length 6

cm, maximum width 3.3 cm to 3.5 cm; apex slightly broken; base broken, normal; margin entire; texture coriaceous; venation pinnate, simple craspedodromous; petiole not observed; primary veins (1°) single, prominent, almost straight; secondary veins (2°) only 5 pairs visible, 1.5 cm, angle of divergence acute (about 40°), moderate, uniformly curved up, alternate to opposite, unbranched; intersecondary vein present, 4-5 intersecondary veins in between two secondary veins; tertiary veins (3°) with angle of origin Acute- Obtuse, percurrent, almost straight, branched, oblique in relation to mid vein and close. Cuticle thin, epidermal cells were usually polygonal, cell were usually thick with straight wall, cell size 25.96x9,12 µm, epidermal cell frequency 2162 per sq. mm; stomata were observed in the lower foliar surface, distributed evenly, randomly oriented, polycytic, anomocytic, subsidiary cells are irregular in shape, 20-30 µm in the length and 10-20 µm width, stomatal frequency 130 per sq. mm, Stomatal index 5.67 (Figs 4E,G).

The diagnostic features of present fossil leaf such as symmetrical, elliptic shape, entire margin, coriaceous texture, simple craspedodromous venation, characteristic curvature of secondary veins which arise at acute angle, presence of abundant intersecondary veins and type and nature of stomata and epidermal cells altogether suggest that the present fossil leaf shows close affinity with the extant leaves of *Mimusops elengi* Linn. of the family Sapotaceae (C.N.H. herbarium sheet no. 481; Figs 4F,H).

Mimusops L. is a genus of mainly tree in the family Sapotaceae consisting of about 43 species distributed in the tropical Africa, Madagascar Seychelles Myanmar and Indo- Malayan region. The comparable taxa *M. elengi* Linn. is a large evergreen tree, distributed in the forest of

Table 2 : Phytogeographical distribution and forest types of the modern comparable taxa of the fossils recovered from the (Siwalik) Sub-himalayan zone

Fossil Taxa	Modern comparable taxa	Forest type	Climate	Habitat	Distribution
<i>Pterospermum mioacerifolium</i> Prasad <i>et al.</i> ,	<i>Pterospermum acerifolium</i> Willd.	Most Deciduous to Evergreen	Tropical	Tall tree	North east India, Central provinces and South India, Bangladesh
<i>Dichapetalum siwalicum</i> sp. nov.	<i>Dichapetalum gelonioides</i> Engl.	Evergreen	Tropical	Large shrub to small tree	Indo-Malayan region
<i>Paranephelium seriaensis</i> Prasad <i>et al.</i> ,	<i>Paranephelium xestophyllum</i> (Miq.) King	Evergreen	Tropical	Small tree	South east Asia
<i>Paranephelium miocenicum</i> sp. nov.	<i>Paranephelium macrophyllum</i> King	Evergreen	Tropical	Tree	South east Asia
<i>Gluta siwalika</i> Awasthi and Prasad	<i>Gluta reinghas</i> Linn.	Evergreen	Tropical	Tree	South east Asia
<i>Mimusops mioelengi</i> sp. nov.	<i>Mimusops elengi</i> Linn.	Evergreen	Tropical	Medium sized tree	South Asia, South east Asia and Northern Australia

South India from northern Circars on the east and the Kokan on the west. It is also found in Shan hills, Myanmar, Andaman Island, and Sri Lanka. The family Sapotaceae is frequently documented in the fossil record from both India and abroad. In India it is represented by *Madhuca* and *Manilkara* (Awasthi and Mehrotra, 1993; Prakash and Tripathi, 1977), *Sideroxylon* (Prakash and Awasthi, 1970) *Payena-Plaquium* Awasthi and Srivastava, 1990, *Mimusops*/ *Bassia* (Navale, 1973), *Chrysophyllum* (Prasad, 2007) and *Madhuca* (Awasthi and Mehrotra, 1993). There is also an abundant record of sapotaceous taxa from the Tertiary sediments of other countries like, Congo, Ethiopia, Central and South America, Cuba, Venezuela, Mexico, New Zealand, Sumatra, Czechoslovakia, Egypt etc. (Campbell, 2002; Morley, 2000; Wheeler, 2007; Lemoigne *et al.*, 1974; Jacobs *et al.*, 2005; Kedeves, 1971). The earliest recorded sapotaceous fossil is *Sapotaceoidapollenites robustus* pollen from the Cretaceous (Senonian) / Paleocene of Borneo (Muller, 1968). However, Raven and Axelrod (1974) postulated a West Gondwana origin for this family before the end of the Cretaceous. By the Eocene, sapotaceous fossils were relatively abundant in northern hemisphere along with some equatorial region. The pattern of fossil distribution remains similar throughout the Oligocene). Thereafter, in the Miocene this appears to have spread southwards and it began to appear in India, Indonesia, New Guinea, and New Zealand and more extensively in Ethiopia and Congo.

Holotype: BSIP Museum No. 39800, *Locality:* Koilabas Nala section, Koilabas, Tribhuvan Nagar, Western Nepal, *Horizon and Age:* Lower Siwalik Formation; Middle Miocene, *Etymology:* The specific epithet is named by adding prefix 'Mio' to the modern comparable species.

The systematic study on fossil leaves containing well preserved cuticles from Siwalik group exposed in the Sub- Himalayan zone of India and Nepal revealed the occurrence of six fossil taxa showing their affinity with the extant taxa, *Pterospermum acerifolium* (Sterculiaceae), *Dichapetalum gelonioides* (Dichapetalaceae), *Paranephelium macrophyllum* and *P. xestophyllum* (Sapindaceae), *Gluta renghas* (Anacardiaceae) and *Mimusops elengi* (Sapotaceae). They are distributed presently in the evergreen forest of terrestrial low land area of mainly north east India and Myanmar. The habit and present day distribution of the modern equivalent taxa of the recorded fossils (Table 2) indicate the prevalence of warm humid climate in the areas during sedimentation. All the modern comparable taxa except *Pterospermum acerifolium* of the family Sterculiaceae does not grow now a day in the sub- Himalayan zone which suggests that these taxa became extinct from there due to unfavorable

condition prevailed after Mio-Pliocene period most probably due to uplift of Himalaya.

The micromorphological features of cuticles of these fossils are useful in interpreting palaeoecology/ palaeoenvironment of the region. Morphological variability of the epidermal characteristics mainly stomatal complex, number, form and arrangement of subsidiary cells have provided evidences of environmental changes during the past. The undulated anticlinal wall has been observed on the surface of both the fossil and modern species of *Paranephelium* which may be related to the development of stresses in environmental conditions prevailing during the growth period. It is also apparent that the amplitude of the undulation increases with the increased shade and humidity (Watson, 1962). All the taxa recovered from the Siwalik (Sub-Himalayan zone) possess polycytic stomatal apparatus with various gradations towards anomocytic (Table 1). The paracytic and its gradation indicate the mesomorphic and xero-mesomorphic nature of the taxa (Carr *et al.*, 1986). The stomatal frequency varies from 74-210 per sq. mm in the fossil leaves and 82-180 per sq. mm in their modern equivalent leaves. The highest frequency (210 per sq. mm) was found in the fossil leaves of *Dichapetalum siwalicum* which is a shrub or small tree (Table 2). According to Salisbury (1928) the highest stomatal frequency was found in the leaves of trees and shrubs governed by the environmental conditions prevailing there. Moreover, the humidity tends to reduce the proportion of stomatal frequency. The taxa (except *Dichapetalum*) of the present assemblage have almost constant frequency and are comparatively low in number which indicate the prevalence of high humidity in the Sub-Himalayan zone during the Mio-Pliocene times.

The stomatal index was constant in the leaves of all the taxa (except *Dichapetalum*) and did not vary much (3.44-6.43). The earlier study also showed that the stomatal index remained constant for a plant species in different ecological condition however, the stomatal frequency tends to decrease or increase with high or low humidity respectively. Thus the stomatal frequency is supposed to be a best indicator of environmental humidity while stomatal index may be a taxonomical indicator for a particular plant species.

Acknowledgments

We express our sincere gratitude to Dr. N.C. Mehrotra, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for constant encouragement and taking keen interest during the progress of this work. Thanks are also due to Dr. M. S. Mandal, Deputy Director, Central National Herbarium, Howrah for his kind help during the consultation of herbarium.

References

- Acharrya, S.K.: Geology of Darjeeling coalfield with reference to its intrusive *Rec. Geol. Surv. India*, **99**, 75-101 (1972).
- Adema, F., P.W. Leenhouts and P.C. van Welzen: *Sapindaceae. Flora Malesiana Series*, **11**, 419-768 (1994).
- Antal, J.S. and N. Awasthi: Fossil flora from the Himalayan foot-hills of Darjeeling District, West Bengal and its palaeoecological and phytogeographical significance. *Palaeobotanist*, **42**, 14-60 (1993).
- Antal, J.S. and M. Prasad: Some more leaf impressions from the Himalayan foot-hills of Darjeeling District, West Bengal, India. *Palaeobotanist*, **43**, 1-9 (1996).
- Appel E., W. Rosler and G. Corvinus: Magnetostratigraphy of the Mio-Pleistocene Surai Khola Siwalik in West Nepal. *Geophysics J. Int.*, **105**, 191-19 (1991).
- Ash, A.W., B. Ellis, L.J. Hickey, K. Johnson, P. Wilf and S.L. Wing: Manual of leaf architecture: Morphological description and categorization of dicotyledonous and net-veined mono cotyledonous angiosperms. An informal publication prepared by the Leaf Architecture Working Group (LAWG), privately published and distributed. Smithsonian Institution, Washington, DC. (1999).
- Awasthi, N.: Studies on some carbonised woods from the Neyveli lignite deposits, India. *Geophytology*, **14**, 82-95 (1984).
- Awasthi, N., J.S. Guleria and R.N. Lakhanpal: A fossil dicotyledonous woods from the Pliocene beds of Mothala, district Kutch, Western India. *Palaeobotanist*, **26**, 199-205 (1980).
- Awasthi, N. and R.C. Mehrotra: Further contribution to the Neogene flora of northeast India and significance of the occurrence of African element. *Geophytology*, **23**, 81-92 (1993).
- Awasthi, N. and M. Prasad: Siwalik plant fossils from Surai Khola area Western Nepal. *Palaeobotanist*, **38**, 298-318 (1990).
- Awasthi, N. and R. Srivastava: Some new carbonised woods from Neogene of Kerala coast and their bearing on palaeoclimate. *Palaeobotanist*, **38**, 285-292 (1990).
- Campbell, J.D.: Angiosperm fruit and leaf fossils from Miocene Silcrete, Landslip Hill, northern Southland, New Zealand. *J. Royale Soc. New Zealand*, **32**, 149-154 (2002).
- Carr, D.J., S.G.M. Carr and J.R. Lenz: Leaf venation in *Eucalyptus* and other genera of Myrtaceae: Implication for system of classification of venation. *Aust. J. Bot.*, **341**, 53-62 (1986).
- Chaudhuri, R.S.: Provenance of the Siwalik sediments of Nepal Himalayas. *Contemp. Geosci. Res. Himalaya*, **2**, 85-90 (1983).
- Corvinus, G.: Litho and biostatigraphy of the Siwalik succession in Surai Khola area, Nepal. *Palaeobotanist*, **13**, 163-197 (1990).
- Dayal, R.: *Sapindoxylon schleicheroides* sp. nov. a fossil dicotyledonous woods from the Deccan Intertrappean beds of Madhya Pradesh. *Palaeobotanist*, **13**, 163-167 (1965).
- Dilcher, D.L.: Approaches to the identification of angiosperm leaf remains. *Botanical Review*, **40**, 1-57 (1974).
- Heer, O.: Nachtrae Zur Miocene flora Greenlands konig. *Svenska vetenskaps Akademiens Handlingar*, **13**, 1-29 (1874).
- Hickey, L.J.: Classification of architecture of dicotyledonous leaves. *American J. Bot.*, **60**, 17-133 (1973).
- Hooker, J.D.: *The flora of British India*. Vol. 2. London, pp. 1-799 (1884).
- Jacobs, B.F., N. Tabor, M. Feseha, A. Pan, J. Kappelman, T. Ramussen, W. Sanders, Wiemann M.C., J. Crabaugh and J.L. Garcia Massini: Oligocene terrestrial strata of north-western Ethiopia: A preliminary report on palaeoenvironments and palaeontology. *Palaentologica Electronica*, **8**, 1-19 (2005).
- Kedevés, M.: Présence de types sporomorphs importants dans les sédiments préquaternaires Egyptien. *Acta Botanica Academiae Scientiarum Hungaricae*, **17**, 371-378 (1971).
- Klassen, R.K.: Wood anatomy of the Sapindaceae. *Internal Association of Wood Anatomists, Journal Supplement*, **2**, 1-214 (1999).
- Kotresha, K. and Y.N. Seetharam: Epidermal studies in some species of *Bauhinia* L. Caesalpiniaceae. *Phytomorphology*, **45**, 127-137 (1995).
- Kouwenberg, L.L.R., F. Wagner, W.M. Kurschner and H. Visscher: Atmospheric CO₂ fluctuation during the past millenium reconstructed by stomatal frequency analysis of *Tsuga heterophylla* needles. *Geology*, **33**, 33-36 (2005).
- Kramer, K.: Die Tertiären Holzer Sdost-Asiens (Under Anschluss der Dipterocarpaceae). *Palaenotographica*, **B 144**, 45-181 (1974).
- Kurschner, W.M., J. Vender Burg, H. Visscher and D.L. Dilcher: Oak leaves as biosensors of late Neogene and early Pleistocene paleoatmospheric CO₂ concentration In: Pliocene climates (Eds.: R. Poore and L.C. Sloane). *Mar. Micropaleontol*, **27**, 299-312 (1996).
- Lemoigne, Y., J. Beauchamp and E. Samuel: Etude palaeobotanique des dépôts volcaniques d'âge Tertiaire des bordures est et ouest du système des rifts Ethiopiens. *Geobios*, **7**, 267-288 (1974).
- Manchester, S.R.: Flowers, fruits and pollen of *Florissantia*, an extinct Malvacean genus from the Eocene and Oligocene of western North America. *American J. Botany*, **79**, 996-1008 (1992).
- Martinez-Cabrera, H.I. and S.R.S. Cevallos-Ferriz: A new species of *Tapiria* (Anacardiaceae) from early Miocene sediments of the El Cien Formation, Baja California Sur, Mexico. *Int. Assoc. Wood Anatomists J.*, **25**, 103-117 (2004).
- Mehrotra, R.C.: A new fossil dicot wood from the Deccan Intertrappean beds of Mandla District, Madhya Pradesh. *Geophytology*, **17**, 204-208 (1987).
- Mehrotra, R.C., D.L. Dilcher and N. Awasthi: A Palaeocene *Mangifera*-like leaf fossil from India. *Phytomorphology*, **48**, 91-100 (1998).
- Mehrotra, R.C., R. Tewari and A. Joshi: Application of fossil cuticles in determining palaeoatmospheric CO₂ concentration. *Curr. Sci.*, **84**, 93-94 (2003).
- Metcalfe, C.R. and L. Chalk: Anatomy of Dicotyledons. Vol. **1** and **2**, Clarendon, Oxford (1950).
- Mishra, S.K. and G.K. Srivastava: Studies on the foliar epidermal architecture of some Indian Cassiinae (Caesalpiniaceae). *Geophytology*, **40**, 105-113 (2011).
- Morley, R.J.: Origin and evolution of tropical rain forests. Chichester: John Wiley and Sons, Ltd. (2000).
- Muller, J.: Palynology of the Predawn and plateau sandstone formations (Cretaceous-Eocene) in Sarawak, Malaysia. *Micropaleontol.*, **14**, 1-37 (1968).
- Navale, G.K.B.: Some contribution to the palaeobotany of Neyveli lignite, South India. *Palaeobotanist*, **20**, 179-189 (1973).
- Parveen, S. and T. Pullaiah: Studies on foliar epidermal traits in some Fabaceae faboideae. *J. Indian Bot. Soc.*, **87**, 105-110 (2008).
- Prakash, U. and N. Awasthi: Fossil woods from the Tertiary of Eastern India. *Palaeobotanist*, **18**, 32-44 (1970).
- Prakash, U. and N. Awasthi: Fossil dicotyledonous woods from the Tertiary of Blue Nile Valley, Ethiopia. *Palaeobotanist*, **30**, 43-59 (1982).
- Prasad, M.: Fossil flora from the Siwalik sediments of Koilabas, Nepal. *Geophytology*, **19**, 79-105 (1990).
- Prasad, M.: Siwalik woods from Kalagarh area in the Himalayan foot Hills and their bearing on Palaeoclimate and Phytogeography. *Rev. Palaeobot. Palynol.*, **76**, 49-82 (1993).
- Prasad, M.: Fossil wood and leaf of the genus *Chrysophyllum* Linn. from Churia (Siwalik) group of Himalayan foot hills of western Nepal and its significance. *Phytomorphology*, **57**, 177-184 (2007).
- Prasad, M.: Angiospermous fossil leaves from the Siwalik foreland basin and their palaeoclimatic implications. *Palaeobotanist*, **57**, 177-215 (2008).
- Prasad, M. and H.D. Dwivedi: Some plant megafossils from the Sub-Himalayan zone (Middle Miocene) of Western Nepal. *J. Palaeontol. Soc.*, **53**, 51-64 (2008).

- Prasad, M. and E. G. Khare: Cuticular studies on the fossil leaves from Churia (Siwalik) sediments of Arjunkhola sequence, Western Nepal, *Palaeobotanist*, **53**, 105-112 (2004).
- Prasad, M., M. Panjwami, A.K. Kannaujia and Alok: Siwalik fossil leaves from the Himalyan foot hills of Darjeeling district, West Bengal, India and their significance. *Proc. Nat. Semi. Environ. Degr. Biodiv. Problem Prospects*, Kanpur, 27-32 (2010).
- Punt, W.: Pollen morphology of the Dichapetalaceae with special reference to evolutionary trends and mutual relationships of pollen types. *Rev. Palaeobot. Palynol.*, **19**, 1-97 (1975).
- Qun Chen, Li, Li Cheng-Sen, W.G. Chaloner, D.J. Beerling, Sun Qi-Gao, M.E. Collinson and P.L. Mitchell: Assessing the potential for the stomatal characters of extant and fossil *Ginkgo* leaves to signal atmospheric CO₂. *American J. Botany*, **88**, 1309-1315 (2001).
- Purkayashtha, S.K.: Indian Woods: Their identification, properties and uses. Controller of Publication, Delhi. **4**, (1982).
- Ramirez, J.L. and S.R.S. Cevallos-Ferriz: A diverse assemblage of Anacardiaceae from Oligocene sediments, Tepexi de Rodríguez, Puebla, Mexico. *American J. Botany*, **89**, 535-545 (2002).
- Raven, P.H. and D.I. Axelrod: Angiosperm biogeography and past continental movements. *Ann. Missouri Botanical Garden*, **61**, 539-673, (1974).
- Roy, S.K. and P.K. Ghosh: On the occurrence of fossil woods of *Gluta* and *Anogeissus* in the Tertiary of Birbhum Distt., West Bengal, India. *Geophytology*, **9**, 16-21 (1979).
- Roy, S.K. and S. Mukhopadhyay: Fossil wood resembling *Pterospermum* Schreb. (Sterculiaceae) and *Tectona* Linn. (Verbinaceae) from the Tertiary of West Bengal, India. In: Gleaning in Botanical Research: Current Scenario, (Ed., Bir Bahadur) Ramanujam Commemoration volume, Dattson, Nagpur, India, pp. 221-231 (2005).
- Salisbury, E.J.: On the cause of ecological significance of stomatal frequency with special reference to wood land flora. *Ohil. Trans. Roy. Soc. London*, **216**, 1-65 (1928).
- Takhtajan, A.: Diversity and classification of flowering plants. Columbia University Press. New York, USA (1997).
- Tokuoka, T., K. Takayasu, M. Yoshida and K. Hisatomi: The Churia (Siwalik) Group of the Arung Khola area, west central Nepal. *Mem. Fac. Sci. Shriane Univ.*, **20**, 135-210 (1986).
- Vander, B.J., H. Visscher, D.L. Dilcher and W.M. Kurschner: Paleotatmospherical signatures in Neogene fossil leaves. *Sci.*, **260**, 1788-1780 (1993).
- Wagner, F., D.L. Dilcher and H. Visscher: Stomatal frequency responses in a hardwood swamp vegetation from Florida during 60 years continuous CO₂ increase. *American J. Bot.*, **92**, 162-168 (2005).
- Watson, L.: The taxonomic significance of stomatal distribution and morphology of Eparidaceae. *New Phytol.*, **61**, 36-40 (1962).
- Wheeler, E. A., M.C. Wiemann and J.G. Fleagle: Woods from the Miocene Bakate Formation, Ethiopian Anatomocal characteristics, estimates of original specific gravity and ecological inferences. *Rev. Palaeobot. Palynol.*, **146**, 193-207 (2007).