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Fossil leaves belonging to family Annonaceae from Sub–Himalayan zone (Siwalik) of Himachal Pradesh, India and their climatic and phytogeographical implications

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ABSTRACT

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Investigation on the fossil leaves collected from Middle Siwalik sediments of Sarkaghat area, in the Sub–Himalayan zone of Himachal Pradesh revealed the presence of four new species belonging to the family Annonaceae. The fossil leaves have been identified with the extant species, *Annona reticulata* Linn., *Polyalthia longifolia* (Sonn.) Thw., *P. siamiarum* (Buchanan–Hamilton ex J.D Hooker & Thomson and *Cananga odorata* Hook. f. & Th. The analysis of the current distribution of fossils' nearest living relatives (NLRs) shows that these species are currently found in the evergreen forests of northeastern and southeastern Asia, rather than in and around the study area or throughout the Sub–Himalayan zone of India. This suggests that after Miocene, these taxa could not survive there and migrated towards south and southeastern region. Based on the data available, the phytogeographical aspect of these fossil taxa along with family Annonaceae has been discussed.

Key–words—Fossil leaves, Annonaceae, Middle Siwalik (Upper Miocene), Sarkaghat, Himachal Pradesh, Climate, Phytogeographical implications.

INTRODUCTION

THE State of Himachal Pradesh (31.1048º N, 77.1734º E) is bordered by Jammu and Kashmir and Ladakh on the north, Punjab on the southwest, Haryana on the south, Uttarakhand on the southeast and Tibet on the east. Himachal Pradesh is a resource–rich mountainous area with many immense natural resources and biodiversity.

The State can be divided into two distinct regions, the Himalayas and the Sub–Himalayas. The Indo–Gangetic Plain is an active, recent foreland basin made up of alluvial materials that flowed down from the Himalaya. The majority of the sediments found in the foreland basin throughout the Miocene are represented by the Sub–Himalayan sequence. Middle Miocene to Lower Pleistocene sedimentary layers make up the majority of the Sub–Himalayan sequence, also known as the Siwalik Group. The genesis of the sediments is comparable to that of the Indo–Gangetic Plain. On the other hand, sedimentation events persisted until the late Miocene and began before the collision of Asia and India (Brozovic & Burbank, 2000; Yin, 2006).

Palaeobotanical research has been done on plant megafossils, primarily on fossil woods and leaf impressions, from several fossil sites in the Himachal Pradesh Sub–Himalayan zone. Balugoloa near Jawalamukhi in Kangra District is a well known fossil locality for the occurrence of well preserved leaf impressions which has been studied by Lakhanpal and Dayal (1966), Lakhanpal (1969), Lakhanpal and Guleria (1987) and Lakhanpal and Awasthi (1992). Nalagarh, the other well known fossil site, is solely home to petrified wood, which has been thoroughly studied by Prakash (1978) and Yadav (1989). There has only been one recorded bamboo leaf and culm from Ranital, which is close to Jawalamukhi in the Lower Siwalik (Lakhanpal *et al.,* 1987). Ghosh and Ghosh (1958) reported a solitary wood, *Anisopteroxylon jawalamukhi* from the Middle Siwalik of Khundian in Kangra District. From the same area Mathur (1978) reported a seed *Boraginocarpon lakhanpalii* and a leaf of Lauraceae, *Litsea bhatiai* from the Upper Siwalik beds.

Additionally, some poorly preserved dicotyledonous leaves from the Lower Siwalik beds of the Koshalya River near Kalka were reported by Dayal and Chaudhuri in 1967. Many leaf impressions have been found in the Siwalik sediments of Bilaspur, Himachal Pradesh (Prasad, 2006). For the first time, carbonized fossil wood from the Middle Siwalik sediments of Hamirpur District, Himachal Pradesh, was reported by Prasad (2010). This fossilized wood had distinct anatomical features that allowed us to identify it with the extant taxa, *Hopea sulcata* specifically *Hopea sulcata* Sym. and *Duabanga grandiflora* (Roxb. ex DC.) Walp. of the families Dipterocarpaceae and Lytheraceae, respectively.

A variety of fossil leaves from Siwalik sediments of Nahan Formation and sediments of Mandi District, Himachal Pradesh have been reported for the first time (Prasad *et al.* 2013). Prasad *et al.* (2011) recovered for the first time a palynoassemblage comprising algal, fungal, pteridophytic spores, gymnosperm and angiosperm pollen from an exposed section at Nahan–Ponta Saheb Road, Himachal Pradesh. From Siwalik sediments exposed near Sarkaghat in Mandi District, Himachal Pradesh, six fossil leaf impressions comparable with extant taxa have been reported for the first time (Prasad *et al.,* 2013). These include *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).

Our knowledge of the plant megaflora of Himachal Pradesh, particularly in the Sarkaghat area of Mandi District, is relatively limited, despite the richness and long history of megaflora records. The data available is insufficient to make accurate conclusions about the floristics, palaeoclimate, and plant diversification of the Himalayan foothills of Sarkaghat area in Mandi District of Himachal Pradesh during the Miocene Period.

Keeping in view the meagre work done in the Siwalik Group of Sarkaghat as well as the importance of Miocene flora of extra–peninsular India in order to understand the change in the flora as a result of the upheaval of the Himalayas, it is aimed to explore and work out in detail on the plant megafossils from the Siwalik sediments exposed in Sarkaghat and nearby area in Mandi District of Himachal Pradesh. This investigation has added four new taxa, *Annona nepalensis* Prasad *et al., Polyalthia miolongifolia* n. sp., *Polyalthia palaeosiamiarum* Awasthi & Prasad and *Cananga tertiara* Prasad, of the family Annonaceae. On the basis of available data the type of forest complex, floral diversity, palaeoclimate and phytogeography of the Himalayan foothills of Himachal Pradesh have been discussed in the present communication.

GEOLOGY OF THE STUDY AREA

One of the world's newest mountain ranges is the Himalayan Range. From the northwest bend of the Indus River to the east of the Brahmputra River, it forms a wide, continuous arc that stretches around the northern edges of the Indian subcontinent. Between the huge expanse of the high Tibetan Plateau in the north and the broad plains of the Indus and Brahmputra in the south, the Himalayan mountain chain stretches east–west. The eastern and western arcs of the Himalayan bends indicate the boundaries of the Himalayas to the east and west. The Himalayan range stretches between these bends for around 2400 km in length and 200–300 km in width. The detailed stratigraphy of the Sub–Himalayan zone is given in Table 1.

The development of a long, shallow depression along India's northern border is one of the most significant events in

Table 1–The detailed stratigraphy of the Sub–Himalayan zone.

Age	Unit	Lithology	Depositional Environment
Pleistocene–Miocene (11–7Ma)	Siwalik Formation	Sandstone, conglomerate, siltstone	Continent
Miocene (20–13Ma)	Dharamsala Formation	Gray sandstone, siltstone, shale, caliche	Continent
Latest Paleocene–Middle Eocene	Subathu Formation	Limestone, shale, minor fine–grained sandstone	Shallow marine
Late Cretaceous–Paleocene	Singtali Formation	Limestone, minor quartz arenite	Shallow marine

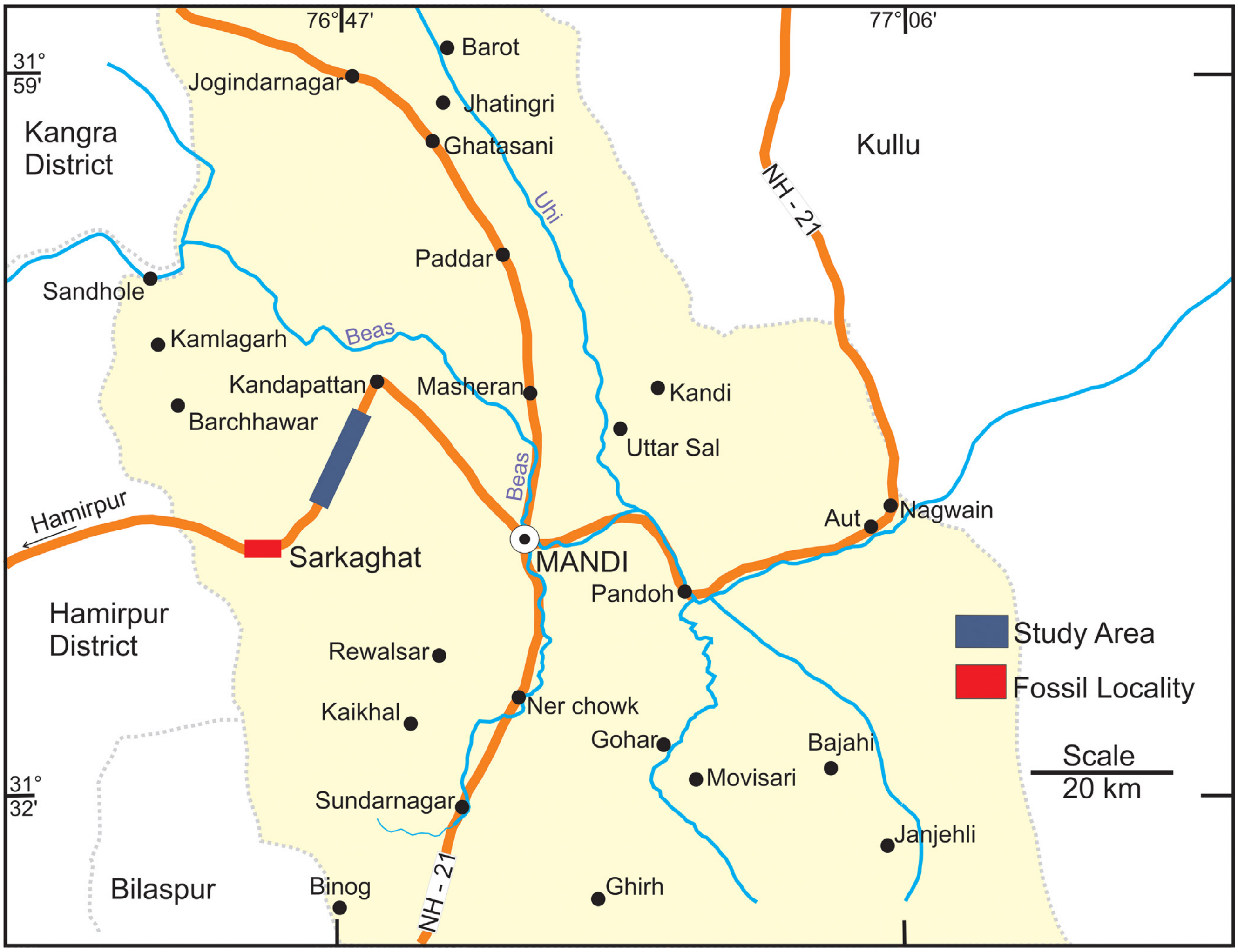

Fig. 1—Map showing location of the study area, Sarkaghat in Mandi district, Himachal Pradesh, India.

the process of creating mountains during the Middle Miocene. Massive amounts of alluvial debris, carried down by rivers, streams, and rain, from the nearby mountain, accumulated in this depression. We refer to this as Siwalik sediments. Their outcrop pattern is roughly confined by two major thrusts: the Indo–Gangetic alluvium on the south and the Main Boundary Fault (MBF) in the north (Tripathi, 1986). They typically have a width of 10–12 km, with a mild slope on the north and a severe scarp towards the south. Siwalik outcrops in the Kalka, Himachal Pradesh area are 16–30 km wide, but because of the Main Boundary Thrust's (MBT) northeastward retreat, they enlarge significantly to reach a width of 90 km in the Nalagarh–Pathankot stretch.

Numerous workers from India and Pakistan contributed to the Siwalik Group's overall stratigraphy. Among these are Falconer (1869), Pilgrim (1910), Colbert (1935), Opdyke *et al.* (1979), Azzaroli and Napoleone (1982) and Johnson *et al.* (1985). Gupta (2000) has determined the local stratigraphy of the Siwalik succession in the Jammu region. Ranga Rao *et al.* (1979) classified the Siwalik Group into three regions: the Upper Siwalik (Purmandal Sandstone, Nagrota Formation, and Boulder Conglomerate), the Middle Siwalik (sandstone dominant unit, alteration of sandstone and clay unit, and pebbly sandstone unit), and the Lower Siwalik (argillaceous unit, arneaous unit).

The Sarkaghat fossil site (31º44'26" N 76º43'33" E) is located close to the Sarkaghat area of Mandi District, Himachal Pradesh, along National Highway 70 (Fig. 1). One section of the middle Siwalik Sarkaghat anticline contains the fossil leaf bearing bed. The Nalad Khad section (31º46' N: 76º43' E) is approximately 8 km away from the leaf fossil location. It has been magnetostratigraphically examined and dated by previous researchers, Brozovic and Burbank (2000). The Nalad Khad segment is situated in the Jawalamukhi thrust sheet and on the western limb of the Sarkaghat anticline. Thick units of fine to coarse, dark grey, indurate, multistoried sandstones with red, yellow, and brown pedogenic mudstones are its primary defining characteristics (Figs 2A, 3B).

Fig. 2—A. Fossil leaf bearing bed in Middle Siwalik section, near Sadhot Bridge Sarkaghat, Mandi district, Himachal Pradesh, India. B. Thick shale bed near Kandapatan, Sarkaghat, Mandi district, Himachal Pradesh, India.

Additionally, Cande and Kent (1992) established a correlation between the local magnetic polarity stratigraphy (MPS) and the global magnetic polarity stratigraphic time scale (MPTS).

MATERIALS AND METHODS

The fossil locality, Sarkaghat (31º44'26" N: 76º43'33" E) lies along the National Highway 70 in Mandi District, Himachal Pradesh (Fig. 1). At around seven kilometres from Sarkaghat Town, on the left side of the main road that leads to Dharampur, there is a exposure of Middle Siwalik section (Figs 2A, 3A) from where more than sixty specimens of fossil leaf impressions were collected from a rich fossiliferous bed (31º44.265' N: 76º 43.339' E). A good amount of leaf impressions are collected from a well exposed Middle Siwalik section near Kandapaten (31º48.411' N: 76º46. 094' E) about 4 km from Dharampur on Sarkaghat–Joginder Nagar Road (Figs 2B, 3B). A low power microscope has been used to study the morphology of the leaf impressions. Herbarium sheets from the Central National Herbarium, Howrah, West Bengal are consulted for the identification of the leaf impression. The terms provided by Hickey (1973) and Dilcher (1974) are used to describe the fossil specimens. To demonstrate how the leaves of contemporary taxa are similar to those of fossils, images of those leaves will be supplied. To demonstrate how the leaves of contemporary taxa are similar to those of fossils, images of those leaves will be supplied. All the fossil specimens, along with photographs and negatives, have been placed in Museum of Birbal Sahni Institute of Palaeosciences, Lucknow.

SYSTEMATICS OF FOSSIL LEAVES

Family: **Annonaceae** Juss.

Genus: ***Annona*** Linn.

Annona nepalensis Prasad *et al.,* 2018

(Fig. 4 A–C, E)

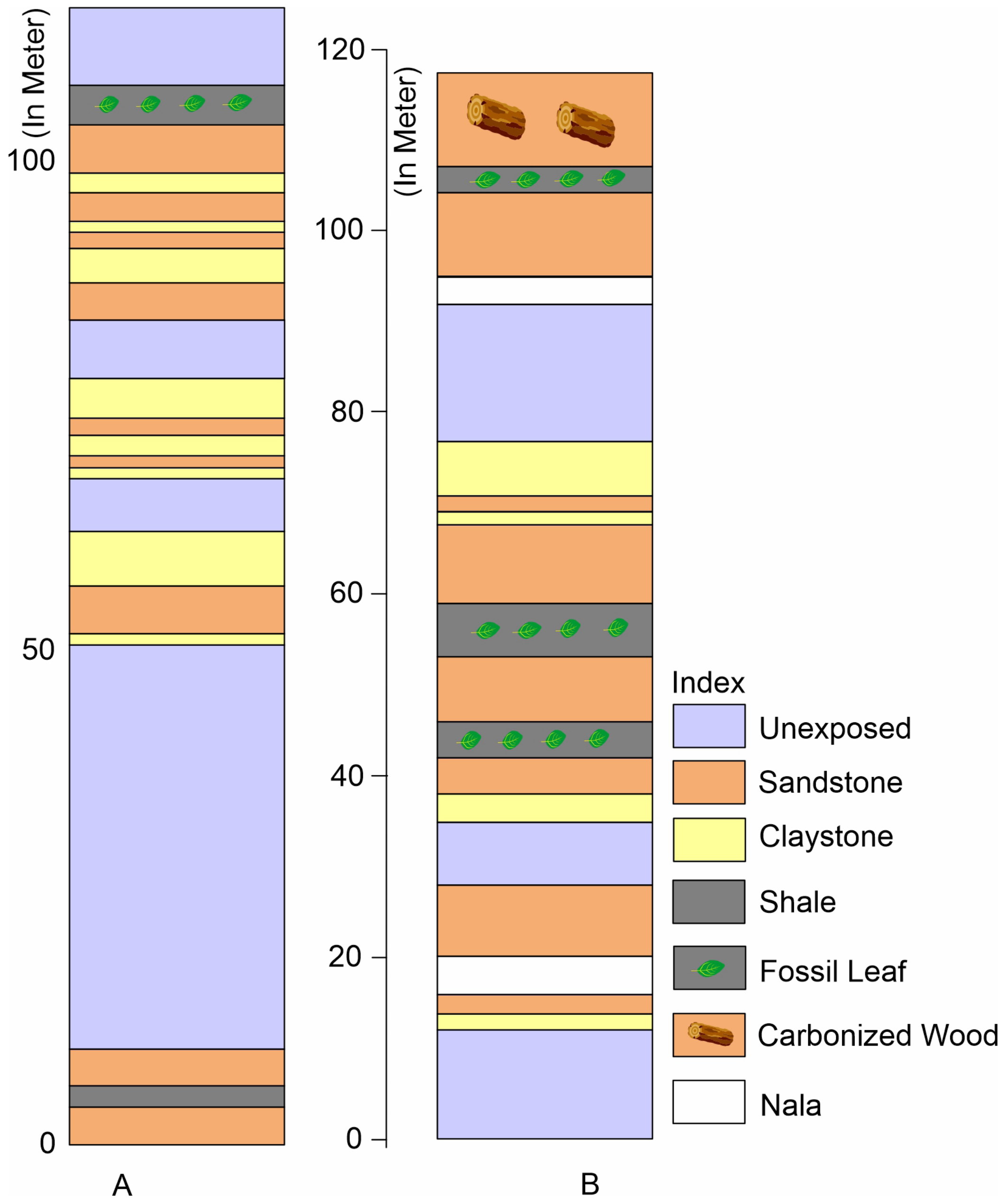

Fig. 3—A. Lithocolumn of the fossil Leaf bearing Siwalik section exposed at about 7 km from Sarkaghat town on the left side of main road which leads to Dharampur. B. Near Kandapaten (31º 48.411': 76º 46. 094') about 4 Km from Dharampur on Sarkaghat–Joginder Nagar Road.

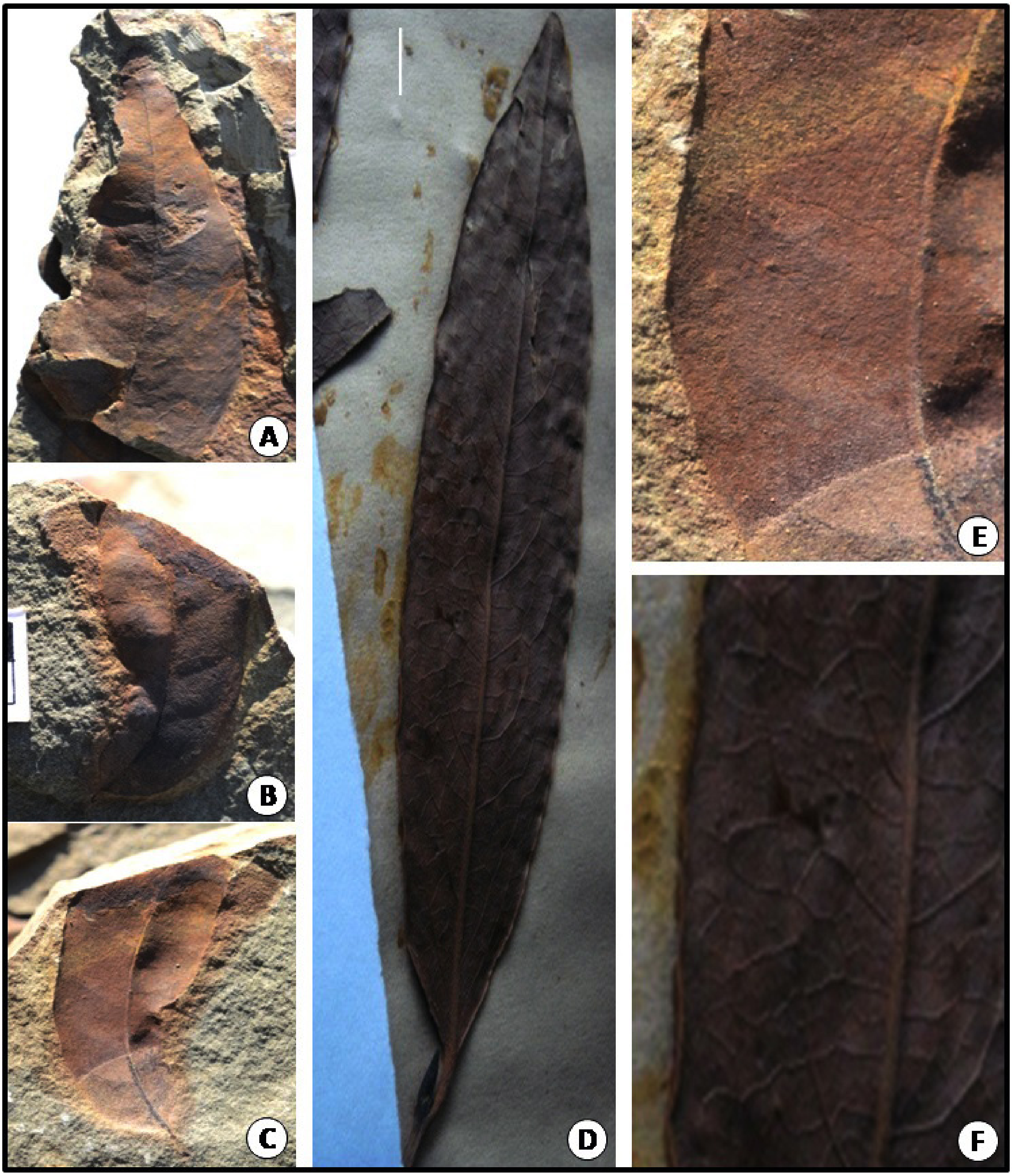

Fig. 4—*Annona nepalensis n*. sp. A–C. Fossil leaves showing shape, size and venation pattern. B.S.I.P Museum specimen nos. 41237, 41238, 41239. D. *Annona reticulata* Linn.–Modern leaf showing similar shape, size and venation pattern. E. *Annona nepalensis n.* sp.–Part of fossil leaf magnified to show details of venation. F. *Annona reticulata* Linn. – Part of modern leaf magnified to show similar details of venation.

2018 *Annona nepalensis* Prasad *et al.,* p. 54, pl. 2, figs 1, 2, 3, 5, 7, 8, 10, 11

Material–This species is based on three (2 basal parts and 1 apical part) specimens. They are incomplete but well preserved showing details of venation.

Description–Leaves simple, almost symmetrical, narrow oblong to elliptic, preserved size 4.8 x 1.9 cm, 3.0 x 1.9 cm and 3.7 x 1.9 cm; apex acute; base wide acute; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, straight to curved, prominent, stout; secondary veins about 7 pairs visible in apical part and 5 pairs in basal part, 0.3 to 0.8 cm apart, usually opposite to alternate, unbranched, angle of divergence 45°–60°, narrow to moderately acute, upper secondary veins more acute than lower ones; tertiary veins fine, angle of origin right angle on both sides, percurrent, straight to sinuous, branched, oblique in relation to mid–vein, predominantly alternate and close.

Specimen–BSIP Museum Specimen No. 41237–41239.

Locality–Near Maseran (31.6918º N: 76.7468º) about 8 km from Sarkaghat on Sarkaghat–Rewaslser Road, Mandi District, Himachal Pradesh, India.

Horizon and Age–Middle Siwalik Group; Upper Miocene.

Remarks–The most important features of the present fossil leaves are narrow oblong to elliptic shape, acute apex and base, eucamptodromous venation pattern, narrow to moderate acute angle of divergence of secondary veins and percurrent, predominantly alternate and close tertiary veins which show nearest affinity with the modern leaves of *Annona reticulata* Linnaeus of the family Annonaceae (C.N.H. Howrah, Herbarium Sheet No. 16063; Fig. 4 D, F).

So far, three fossil leaves showing close affinity with the genus *Annona* Linnaeus have been described from Cenozoic sediments of India and Nepal. Prasad *et al.* (1999) described a fossil leaf as *Annona koilabasensis* from Churia Formation of Koilabas area, western Nepal. This fossil leaf shows close affinity with the modern species, *Annona laurifolia* Linnaeus but differs from present fossil in the presence of intersecondary veins. Prasad *et al.* (2014) described fossil leaf *Annona eocenica* from Cambay Shale of Vastan Lignite Mine, Gujarat, India. This has affinity with *Annona palustris* Linnaeus but differs from the present fossil leaves in having lesser number of secondary veins (5 pairs). *A. miocenica* Prasad *et al.,* 2017 was reported from the Lower Siwalik sediments of Tanakpur area, Uttarakhand. Prasad *et al.,* 2018 reported another fossil leaf as *Annona nepalensis* showing close resemblance with *A. reticulata* Linn. from the Lower and Middle Churia formation of Arjun Khola, Nepal. After comparison of present fossil leaf with above mentioned species it has been found that the Himachal fossil leaf shows close similarity with the fossil leaf, *A. nepalensis* Prasad *et al.,* described from Arjun Khola, Nepal. Thus, the present fossil has been kept under the same species.

Annona Linnaeus comprises about 137 species distributed in America, Africa and India. *Annona reticulata* Linnaeus with which fossils resemble is a small deciduous or semi–evergreen tree growing in Southeast Asia, Taiwan, India, Bangladesh, Pakistan, Tropical America, Australia and Africa (Hooker, 1872; Mabberley, 1997).

Genus: ***Polyalthia*** Blume

Polyalthia miolongifolia n. sp.

(Fig. 5A, C)

Material–This species consists of single, complete and satisfactory preserved leaf impressions.

Diagnosis–Leaf symmetrical, narrow lanceolate, 9.0 x 2.2 cm; apex attenuate; base wide acute; margin entire; venation pinnate, eucamptodromous, rarely brochidodromous; primary vein prominent, weak; secondary veins 25 pairs visible, 0.8 to 0.3 cm apart, alternate to opposite, angle of divergence 45º–75º, uniformly curved up, basal secondaries less acute, unbranched; intersecondary veins present, frequent; tertiary veins with angle of origin AO–RR, percurrent, oblique in relation to mid–vein and close.

Description–Leaf simple, almost symmetrical, narrow lanceolate, preserved size 9.0 x 2.2 cm; apex attenuate; base wide acute; margin entire; texture coriaceous; petiole indistinct; venation pinnate, eucamptodromous, rarely brochidodromous; primary vein (1º) single, prominent, weak, almost straight; secondary veins (2º) about 25 pairs visible, 0.8 to 0.3 cm apart, basal secondaries widely spaced, alternate to opposite, angle of divergence 45º–75º, wide acute, uniformly curved up, moderate, basal secondaries less acute, seemingly unbranched; intersecondary veins present, frequent; tertiary veins (3º) fine, angle of origin AO–RR, percurrent, almost straight, branched, oblique in relation to mid–vein, alternate to opposite and close.

Holotype–BSIP Museum Specimen No. 41241.

Locality–Kandapatan (31º48.411': 76º46.094') about 4 km from Dharampur on Sarkaghat–Joginder Nagar Road, Mandi District, Himachal Pradesh.

Horizon and Age–Middle Siwalik Group; Upper Miocene.

Etymology–By adding prefix 'Mio' to the modern comparable species, *P. longifolia*.

Remarks–The characteristic features of the present fossil leaf such as narrow lanceolate shape, attenuate apex and wide acute base, entire margin, coriaceous texture, usually eucamptodromous venation and narrow to wide acute angle of divergence of secondary veins and fine, percurrent, AO–RR tertiary veins suggest its affinity with the modern leaves of the genus *Polyalthia* Benth. of the family Annonaceae. The herbarium sheets of different species of this genus have been examined in order to find out its specific affinity and it

Fig. 5—*Polyalthia miolongifolia* n. sp. A. Fossil leaf showing shape, size and venation pattern. Specimen no. B.S.I.P Museum specimen no. 41241. B. *Polyalthia longifolia*–Modern leaf showing similar shape, size and venation pattern. C. *Polyalthia miolongifolia* n. sp–Part of fossil leaf magnified to show details of venation. Specimen no. 104. D. *Polyalthia longifolia*–Part of modern leaf magnified to show similar details of venation.

is concluded that the leaves of *Polyalthia longifolia* (Son.) Thw. shows closest similarity with the fossil leaf in shape, size and venation pattern (C.N.H. Herbarium Sheet No. 4/36; Fig. 5B, D).

The other species differ either in shape, size or venation pattern. *Polyalthia angustifolia* Ridl. differs in being elliptic shape with nearly obtuse apex and also possesses comparatively less number of secondary veins. *P. borensis* Kurz and *P. fragrans* (Dalzell) Hook. f. & Thomson differ in having elliptic shape with obtuse apex and base as compared to narrow lanceolate shape and wide acute base and attenuate apex in the present fossil leaf. *P. cauliflora* Hook. f. & Th. differs in being larger size with elliptic shape and acute apex. The leaves of *P. cinnamomea* Hook. f. & Th. although possesses similar shape and size but differ in presence of well developed brochidodromous type of venation pattern. Further, these leaves possess acute apex as compared to attenuate apex in the present fossil. *P. chrysotricha* Ridl. also bears elliptic shape with nearly obtuse apex. It has comparatively less number of secondary veins with different nature of venation. *P. lanceolata* S. Vidal possesses elliptic to lanceolate shape and comparatively very fine, closely placed secondary veins. The leaves of *P. lateriflora* (Blume) Kurz show similarity in shape and size as well as in the nature of apex and base but differ in presence of more number of secondary veins which are comparatively closely placed. *P. luzonensis* Xue & Saunders differs in having elliptic to lanceolate shape and brochidodromous type of venation pattern as compared to narrow lanceolate shape and eucamptodromous to rarely brochidodromous venation in the present fossil leaf. *P. monii* Thwaites is also similar in shape and size but can be distinguished in presence of acute apex and distinct brochidodromous venation pattern. *P. myristica* I. M. Turner can be differentiated due to its large, elliptic shape with fewer secondary veins which joined to their superadjascent secondaries much before the margin. *P. oblongifolia* Burk is similar in lamina size and in the nature and orientation of secondary veins but it in having broadly acute apex as compared to attenuate apex in the fossil. *P. saprosma* I. M. Turner is differentiated in being the elliptic shape of lamina with mucronate apex and the secondaries are comparatively closely placed. *P. spathulata* (Teijsm. and Binn) Boerl. possesses elliptic to lanceolate shape as compared to narrow lanceolate in the present fossil leaf. Further, the secondary veins arise with greater angle and run upward for a long distance. present fossil leaf also shows some superficial similarity with the modern leaves of some species of genus *Eucalyptus* L'Her (*E. alba* Reinw., *E. angustissima* F. Muell., *E. diversicolor* F. Muell., *E. globulus* Labill., *E. leucoxylon* F. Muell. and *E. occidentalis* Endl. etc) of the family Myrtaceae in shape, size and nature of apex and base but differ distinctly in being presence of intramarginal veins on both the margin of lamina.

Polyalthia Blume is well known in the fossil record by woods and leaves from the Cenozoic of India and elsewhere. Based on leaves, four fossil species are known: P. crassipes Engler described from the Cenozoic of Germany (Menzel, 1920) and *P. chaneyi* (Sanborn, 1935) from Europe and North America, respectively; *P. palaeosimiarum* Awasthi and Prasad (1990) from the Lower Siwalik of Suraikhola, Nepal and Lower Siwalik sediments of Oodhalabari area, West Bengal (Antal & Prasad, 1996) and Vagadkhol Formation; Palaeocene–early Eocene sediments of Vagadkhol, Gujarat, India and *P. palaeosumatrana* Tripathi *et al.* (2002) from the Lower Siwalik of Serianaka near the Indo–Nepal border. The present fossil leaf has been compared with the above known fossils and found that this is entirely different from them in being narrow lanceolate shape with greater number of secondary veins. As the present fossil is different from all the already described species, it has been reported under a new species, *Polyalthia miolongifolia*.

Genus *Polyalthia* Blume consists of about 90 species of tree and shrub distributed in the tropical region from Africa to Asia as well as Australia (Hooker, 1872). *P. longifolia* (Son.) Thw. with which fossil shows close resemblance, is a tall, handsome evergreen tree. It is native to south India and Sri Lanka but has been widely introduced elsewhere. It is locally distributed in Andmans and Nicobar Islands, Arunachal Pradesh and Assam etc.

Fig. 6—*Polyalthia palaeosimiarum* Awasthi & Prasad, 1990 A. Fossil leaf showing shape, size and venation pattern. B.S.I.P Museum specimen no. 41240. B. *Polyalthia simiarum* Buchanan–Hamilton ex Hooker Th.–Modern leaf showing similar shape, size and venation pattern. C. *Polyalthia paleosimiarum* Awasthi & Prasad, 1990–Part of fossil leaf magnified to show details of venation. D. *Polyalthia simiarum* Buchanan–Hamilton ex Hooker The–Part of modern leaf magnified to show similar details of venation.

Genus: ***Polyalthia*** Blume

Polyalthia palaeosimiarum Awasthi & Prasad, 1990

(Fig. 6A, C)

1990 *Polyalthia palaeosimiarum* Awasthi & Prasad, p. 300, pl. 2, figs 3, 5

Material–There is a single, incomplete but satisfactorily preserved leaf specimen.

Description–Leaf simple, narrow elliptical; preserved size 6.1 x 2.3 cm; apex and base seemingly wide acute; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein (1º) stout, straight; secondary veins (2º) about 9–10 pairs visible, 0.8–0.4 cm apart, alternate to sub–opposite, uniformly curved cup, curvature more pronounced near margin, unbranched, angle of divergence acute, 60º, moderate; tertiary veins (3º) fine, angle of origin usually RR, rarely AO, percurrent, branched, oblique in relation to mid–vein, predominantly alternate and close.

Specimen–BSIP Museum Specimen No. 41240.

Locality–Sagoti Bridge section near Bawali (31º44.265': 76º43.339') about 7 km from Sarkaghat on Sarkaghat–Dharampur Road, Mandi District, Himachal Pradesh, India.

Horizon and Age–Middle Siwalik Group; Upper Miocene.

Remarks–The diagnostic features present in the leaf such as entire margin, acute angle of divergence of secondary vein, and course of secondary and tertiary veins indicate their affinity with the extant leaves of *Polyalthia simiarum* (Buchanan–Hamilton ex Hooker and Thomson) of the family Annonaceae (CNH Herbarium Sheet No.11900; Fig. 6B, D).

Seven fossil leaves have been reported from India and abroad under four fossil species. They are *P. crassipes* Engler described from the Cenozoic of Germany and *P. chaneyi* Sanborn, 1935 from the Eocene of North America. *P. palaeosimiarum* Awasthi & Prasad, 1990 reported from the Lower Siwalik of Surai Khola, Nepal and Lower Siwalik sediments of Oodlabari area, West Bengal (Antal & Prasad, 1996) and Vagadkhol Formation; Palaeocene–Lower Eocene sediments of Vagadkhol, Gujarat, India. *P. palaeosumatrana* (Tripathi *et al.,* 2002) from the Lower Siwalik of Seria Naka near the Indo–Nepal border and lastly *P. miolongifolia* described earlier in this text from Siwalik of Sarkaghat area, Himachal Pradesh. On comparative study of present fossil leaf with all the above known species it has been concluded that the fossil leaf, *Polyalthia palaeosiamiarum* described from Siwalik of Oodlabari area shows closest similarity with the present fossil. Thus, it has been kept under the same species. Besides, the fossil woods having affinity with genus *Polyalthia*, especially with *P. simiarum*, have been reported from the Deccan Intertrappean (Maastrichtian–Danian) beds by Guleria and Mehrotra (1999) as well as Miocene horizons of Kalagarh, Uttarakhand (Prakash, 1978).

Polyalthia Blume occurs in the tropical regions of Southeast Asia and the modern analogue, *P. simiarum* is a tall tree found in Assam and Andaman in India, Chittagong in Bangladesh and in Myanmar (Gamble, 1972).

Genus: ***Cananga*** Rumph. ex Hook. f.

Cananga tertiara Prasad, 1994

(Fig. 7A, C)

1994 *Cananga tertiara* Prasad, p. 57, pl. 2 fig. 1

Material–This is represented by single, well preserved but incomplete leaf impression.

Description–Leaf simple, slightly asymmetrical at basal region; ovate to elliptical; preserved size 6.3 x 3.8 cm; apex broken; base indistinct, oblique; margin entire; texture coriaceous; venation pinnate, eucamptodromous; primary vein (1º) single, prominent, stout straight, thicker in lower basal region, secondary veins (2º) only 4–5 pairs visible, 0.7–1.8 cm apart, usually alternate to subopposite, angle of divergence 40º–70º, moderate to wide acute, uniformly curved up, unbranched; intersecondary veins not seen; tertiary veins (3º) fine, angle of origin usually RR, percurrent, straight to sinuous, branched, oblique in relation to mid–vein, predominantly alternate and close.

Specimen–BSIP Museum Specimen No. 41242.

Locality–Sagoti Nala section (31º48.496': 76º46.061') on the left side of Sagoti bridge, about 7.5 km from Sarkaghat, Mandi District, Himachal Pradesh, India.

Horizon and Age–Middle Siwalik Group; Upper Miocene.

Remarks–The most important features of the present fossil leaf such as asymmetrical ovate to elliptic shape, entire margin, eucamptodromous venation, moderate to wide acute angle of divergence of secondary veins and RR, percurrent and straight to sinuous tertiaries are found in the extant leaves of *Canaaga odorata* Hook. f. and Th. of the family Annonaceae and *Meliosma sylvatica* of the family Sabiaceae. A critical examination of a large number of leaves of these two taxa shows that the angle of divergence of basal secondary veins in the leaves of *M. sylvatica* is right angle as compared to wide acute angle in the present fossil leaf. The extant leaves of *C. odorata* Hook. f. & Th. show closest affinity with the present fossil in almost all the morphological features (C.N.H. Herbarium Sheet No. 11419; Fig. 7B).

Two fossil leaves showing resemblance with the extant leaves of *C. odorata* Hook f. & Th. have been already reported from the Lower Siwalik sediments of Kathgodam, Uttarakhand and Oodlabari area, West Bengal (Prasad *et al.,* 2010), India under *Cananga tertiara* (Prasad, 1994). On comparison with this fossil leaf, it has been found that *C.*

Fig. 7—*Cananga tertiara* Prasad *et al.*, 1999 A. Fossil leaf showing shape, size and venation pattern. B.S.I.P Museum specimen no. 41242. B. *Cananga odaorata* Hooker f. Th.–Modern leaf showing similar shape, size and venation pattern C. *Cananga tertiara*–Prasad *et al.*, 1999–Part of fossil leaf magnified to show details of venation.

Table 2–Fossil records of family Annonaceae from Tertiary sediments of Indian subcontinents.

Fossil taxa	**Fossil Locality**	**Horizon/Age**	**Present distribution**
Annona eocenica Prasad *et al.,* 2014	Vastan Lignite Mine, Western India	Cambay Shale Formation (Early Eocene)	South Africa, South Asia, Central America
Annona nepalensis Prasad *et al.*, 2018	Arjun Khola, Nepal	Churia Formation	Southeast Asia, Africa, Australia
Annona koilabasensis Prasad *et al.*, 1999	Koilabas, Nepal	Churia Fomation	Java
Unona miocenica Prasad *et al.*, 2018	Arjun Khola, Nepal	Churia Formation	Northeast India, Bangladesh
Metrophora miocenica Prasad *et al.,* 1997	Seria Naka, U.P.	Siwalik Group	Malaya
M. mioreticulata Prasad *et al.*, 2019	Arjun Khola, Nepal	Churia Formation	Northeast India, South east Asian region
M. siwalika Antal & Awasthi, 1993; Prasad & Awasthi, 1996; Prasad & Tripathi, 2000; Prasad *et al.*, 2016	Oodlabari area, West Bengal; Arjun Khola, Nepal; Surai Khola, Nepal; Lakshmi River Section, Bhutan	Siwalik Group; Churia Formation; Churia Formation; Siwalik Group	India, Myanmar, Malaya Java
Anaxagorea mioluzonensis Prasad *et al.*, 2019	Arjun Khola, Nepal	Churia Formation	Southeast Asian region, South India
Cananga tertiara Prasad, 1994	Kathgodam, Uttarakhand	Siwalik Group	Martaban, Tennasserim, Malaya peninsula
Melodorum arjunkholaensis Prasad *et al.,* 2016	Arjun Khola, Nepal	Churia Formation	Africa, Southeast Asia, Australia, Malaya
M. jarwaensis Tripathi *et al.,* 2002	Koilabas village near Jarwa, U.P.	Siwalik Group	Northeast India and Myanmar
Uvaria siwalica Prasad, 1994; Prasad & Dwivedi, 2008;	Kathgodam, Uttarakhand; Koilabas, Nepal	Siwalik Group; Churia Formation	Sub–Himalayan tract, central India, Andamans, Myanmar
Uvaria ghishia Antal & Prasad, 1998	Oodlabari area, West Bengal,	Siwalik Group	Myanmar, Malaya
Uvaria nepalensis Prasad *et al.,* 2016	Arjun Khola, Nepal	Churia Formation	Southern China, East Asia, Vietnam
U. miolucida Prasad *et al.*, 2019	Arjun Khola, Nepal	Churia Formation	South Africa
Artabotrys siwalicus Prasad *et al.*, 2015;	Oodlabari area, West Bengal,	Siwalik Group	Peninsular India and South India
A. *nahanii* Prasad*,* 2012	Vikrambag, H.P.	Siwalik Group	Andaman and Malaya
Pseudouvaria mioreticulata Prasad *et al.,* 2015	Oodlabari area, West Bengal	Siwalik Group	Malaya, Sumatra, Java, Borneo
Fissistigma senii Lakhanpal, 1969; Prasad & Dwivedi, 2008; Prasad, 2012; Prasad *et al.*, 2015	Balugoloa, Himachal Pradesh, India; Oodlabari area, West Bengal; Vikrambag, H.P.; Seria Naka, U.P.	Siwalik Group	Sub–Himalayan tract, Myanmar, Assam
F. mioelegans Prasad *et al.*, 1999	Koilabas, Nepal	Churia Formation	Malaya and Malacca
F. shankerii Mathur *et al.*, 1996	Daghota, Solan District, H.P.	Lower Miocene, Kasauli Formation	Tropical region of Old world
F. siwalica Lakhanpal & Awasthi, 1992	Balugoloa, near Jawalamukhi, H.P.	Siwalik Group	Northeast India, Southeast Asia

F. himachalensis Singh *et al.*, 2022	Sarkaghat, Mandi, Himachal Pradesh	Siwalik Group	Malaysia
Polyalthioxylon indicum Prakash, 1978	Kalagharh, Uttarakhand	Siwalik Group	Northeast India
P. parapaniense Bande, 1973; Mehrotra, 1990; Guleria & Mehrotra, 1999; Srivastava, 2001	Parapani, M.P.; Ghughua, M.P.; Shahpura, M.P.; Pyangaadi, Kerala, S. India	Deccan Intertrappean beds; Warkalli Formation (Miocane)	Northeast India, Odisha, Mayurbhanj
Polyalthia palaeosiamiarum Awasthi & Prasad, 1990; Antal & Prasad, 1996; Prasad *et al.*, 2013	Surai Khola, western Nepal; Oodlabari area, West Bengal; Keria, Chhindwara District, M.P.	Churia Formation; Siwalik Group; Deccan Intertrappean beds	Northeast India, Bangladesh, Myanmar, Andaman
P. palaeosumatrana Tripathi *et al.*, 2002	Koilabas village near Jarwa, U.P.	Siwalik Group	Sumatra, Borneo, Malaya
Meiogyne sevokensis Prasad *et al.*, 2015	Oodlabari area, West Bengal	Siwalik Group	Western Ghats, South and Central Sahyadris
M. purniyagiriensis Prasad *et al.*, 2017	Tanakpur, Uttarakhand	Siwalik Group	Western Ghats, South and Central Sahyadris
Miliusa pretomentosa Prasad *et al.*, 2013	Keria, Chhindwara, District, M.P.	Deccan Intertrappean beds	Uttar Pradesh, Bihar, Central & South India
M. miovelutina Tripathi *et al.*, 2002	Koilabas village near Jarwa, U.P.	Churia Formation	Sub–Himalayan foot Hills, Myanmar
M. siwalica Prasad *et al.*, 1999	Koilabas, Nepal	Churia Fomation	India and China
M. brochidodroma Konomatsu & Awasthi, 1999	Arung Khola, Nepal	Churia Formation (Arung Khola Formation)	Sub–Himalayan tract, Assam, Myanmar
Orophea siwalika Konomatsu & Awasthi,1999	Tinau Khola, Nepal	Churia Formation (Arung Khola Formation)	South India, Andaman, Martaban
Popowia siwalica Prasad *et al.*, 2017	Tanakpur, Uttarakhand	Siwalik Group	South India
Dendrokingstonia palaeonervosa Prasad *et al.*, 2017	Tanakpur, Uttarakhand	Siwalik Group	Malaya
Saccopetalum palaeolongiflorum Awasthi & Mehrotra, 1995	Makum Coal field Assam, India	Oligocene, Tikak Parbat Formation	Bangladesh
S. pretomentosum Prasad *et al.*, 2004	Jamrani, Kathgodam, Uttarakhand	Siwalik Group	Western Ghats, Bihar, Orissa, peninsular India
Goniothalamus siwalicus Prasad *et al.*, 1998	Seria Naka village, Tulsipur, U.P.	Siwalik Group	Malaya
G. chorcholaensis Prasad & Awasthi, 1996	Surai Khola, western Nepal	Churia Formation	Northeast India, South India, Myanmar
G.miocenicus Prasad *et al.*, 2018	Arjun Khola, Nepal	Churia Formation	Sumatra, West Bengal, Andamans
Ellipeia miocenica Shashi *et al.*, 2007	Tanakpur area, Uttarakhand	Siwalik Group	Malaya
Comiphora precaudata Shashi *et al.*, 2007	Tanakpur area, Uttarakhand	Siwalik Group	Western Penninsula
Alphonsea makummensis Srivastava & Mehrotra, 2013	Makum Coal field, Assam	Oligocene, Tikak Parbat Formation	Indo–Malayan region

tertiara Prasad shows closest resemblance with Himachal fossil. The fossil leaf, *C. tertiara* differs only in being of greater width. However, in the venation pattern both leaves match each other. Hence, the present fossil has been described under the same species, *C. tertiara* Prasad.

The modem comparable taxon, *C. odorata* Hook f. and Th. is a tall tree distributed in the evergreen forests of Martaban, and Tenasserim, Malaya peninsula and Archipelago (Ridley, 1967; Gamble, 1972).

RESULT AND DISCUSSION

A very significant and well exposed Siwalik section from the Sarkaghat area has been studied. These megafloral assemblages of Sarkaghat area are the excellent sources of taxonomic and ecological environmental studies. These plant megafossils from Siwalik sediments of Sarkaghat and nearby area have been studied in order to reconstruct the palaeofloristic picture of the Sub–Himalayan zone as well as to throw light on the climatic changes through the deposition of Siwalik succession. Out of a rich collection of plant megafossils, the authors have investigated the well–preserved fossil leaf impressions documented from the Middle Siwalik section exposed on Sarkaghat–Dharampur along the road cutting site which revealed the occurrence of four new fossil taxa, viz. *Annona nepalensis, Polyalthia miolongifolia, P. siamiarum* and *Cananga tertiara* showing their modern affinity with *Annona reticulata* Linn.*, Polyalthia longifolia* (Son.) Thw., *P. siamiarum* (Buchanan–Hamilton ex Hooker & Thomson. These prehistoric species' current equivalent species' distribution patterns show that they are primarily found in the evergreen forests of north–eastern and Southeast Asia (Myanmar, Bangladesh, Java, Borneo, Phillippines & Malaya, Sumatra, etc.). Therefore, it can be assumed that, in contrast to the comparatively dry environment of today, a warm and humid climate predominated in Sarkaghat and the surrounding Sub–Himalayan zone at the time of sedimentation.

Furthermore, the fact that none of the recovered species currently found growing in this region of the Sub–Himalayan zone suggests that the climate changed after the Mio–Pliocene, most likely as a result of the Himalaya's rise and the Tethys Sea's disappearance. According to Richardson *et al.* (2004), the family Annonaceae is pantropical, with the majority of its species found in rainforests and only a small number in temperate zones. The family is represented by more than 40 fossil species split among 20 genera. The widely spread genera are *Annona, Metrephora, Miliusa, Uvaria, Polyalthia, Anaxagorea, Fissistigma,* etc. (Table 2).

The oldest known fossils of Annonaceae comprise seeds and pollen from the Maastrichtian of India, Nigeria and Colombia, respectively (Chesters, 1955; Sole de Porta, 1971), indicating a west Gondwanan origin for the family. The fossil woods showing affinity with the genus *Polyalthia* and especially with *P. simiarum* have been reported earlier from the Deccan Intertrappean beds (Maastrichtian–Danian) and Palaeocene–Eocene in India (Guleria & Mehrotra, 1999; Singh *et al.*, 2011; Table 1). The above record along with the present report of Annonaceae from the Upper Miocene of western India seems to reinforce a Gondwanan origin for the family.

Annonaceae has a west Gondwanan origin, as evidenced by the oldest known fossils of the family, which are seeds and pollen from the Maastrichtian of India, Nigeria and Colombia (Chesters, 1955; Sole de Porta, 1971). Previous reports have indicated that fossil woods from the Deccan Intertrappean beds (Maastrichtian–Danian) and Palaeocine–Eocene in India exhibit affinities with *Polyalthia*, particularly with P. *simiarum* (Guleria & Mehrotra, 1999; Singh *et al.*, 2011; Table 2). The aforementioned information appears to support the family's Gondwanan ancestry, as does the current study on Annonaceae from western India's Upper Miocene.

CONCLUSIONS

Four new fossil leaves (*Annona nepalensis, Polyalthia miolongifolia, P. siamiarum* and *Cananga tertiara)* were discovered during an investigation into plant fossils from Middle Siwalik sediments in the Sarkaghat area of Himachal Pradesh, India. These fossil leaves demonstrated affinities with extant *Annona reticulata* Linn., *Polyalthia longifolia* (Son.) Thw., and *P. siamarum* (Buchanan–Hamilton ex Hooker & Thomson and *Cananga odorata* Hook. f. & Th. of the family Annonaceae.

The systematic description of each recovered fossil taxon including modern affinity, details of fossil record and necessary comparative accounts has been documented properly. The current distribution of all the aforementioned similar species shows that they are now found in the evergreen forests of North–east India, South India, and South–east Asia, rather than in the Sub–Himalayan zone of Himachal Pradesh. The existence of these evergreen species in the Sub–Himalayan zone of Himachal Pradesh during the Upper Miocene suggests that the evergreen forest was more flourishing than the mixed deciduous kind of forest that exists today. This implies that drier conditions occurred after the Himalaya upliftment, making it impossible for such moist–loving taxa to exist there.

The fossil records (Table 2) along with the present report of Annonaceae from the Upper Miocene of western India seems to reinforce a Gondwanan origin.

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REFERENCES

Antal JS & Awasthi N 1993. Fossil flora from the Himalayan foot hills of Darjeeling District, West Bengal and its palaeoecological and phytogeographical significance. Palaeobotanist 42: 12–60.

Antal JS & Prasad M 1996. Leaf–impressions of *Polyalthia* Bl. in the Siwalik sediments of Darjeeling District, West Bengal. Geophytology 26(1): 125–127.

Antal JS & Prasad M 1998. Morphotaxonomic study of some more fossil leaves from the Lower Siwalik sediments of West Bengal, India. Palaeobotanist 47: 86–98.

Awasthi N & Mehrotra RC 1995. Oligocene flora from Makum Coalfield, Assam, India. Palaeobotanist 44: 157–188.

Awasthi N & Prasad M 1990. Siwalik plant fossils from Surai Khola area, western Nepal. Palaeobotanist 38: 298–318.

Azzaroli & Napoleone 1982. Magnetostratigraphic investigation of the Upper Siwalik nears the Pinjor, India. Rivsta Italiana di Paleontologia e stratigrafia 87: 739–762.

Bande MB 1973. A petrified dicotyledonous wood from the Deccan Intertrappean beds of Mandla District, Madhya Pradesh. Botanique 4(1): 41–47.

Brozovic N & Burbank DW 2000. Dynamic fluvial systems and gravel progradation in the Himalayan foreland. G.S.A. Bulletin 112: 394–412.

Cande SC & Kent DV 1995. A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. Journal of Geophysical Research 100: 6093–6095.

Chesters KIM 1955. Some plant remains from the Upper Cretaceous and Tertiary of West Africa. Annals and Magazine of Natural History 12(8): 498–504.

Dayal R & Chaudhuri RS 1967. Dicotyledonous leaf–impressions from the Nahan beds, north–west Himalaya. Science Culture 25: 238–241.

Colbert EH 1935. Siwalik mammals in the American Museum of Natural History. Transactions of the American Philosophical Society 26: 1–401.

Dilcher DL 1974. Approaches to identification of angiosperm leaf remains. Botanical Review 40(1): 1–157.

Falconer H 1869. Introductory observations on the geography, geological structure and fossil remains in the Siwalik Hills. Palaeontological Memoire 1: 1–29.

Gamble JS 1972. A Manual of Indian Timbers. London

Ghosh SS & Ghosh AK 1958. *Anisopteroxylon jawalamukhii* sp. nov., a new fossil record from the Siwalik. Science Culture 24: 238–241.

Guleria JS & Mehrotra RC 1999. On some plant remains from Deccan Intertrappean localities of Seoni and Mandla Districts of Madhya Pradesh, India. Palaeobotanist 47: 68–87.

Gupta SS 2000. Lithostratigraphy and structure of the Siwalik succession and its relationship with the Murree succession around Ramnagar area, Udhampur District, Jammu and Kashmir. Himalayan Geology 21: 53–61.

Hickey LJ 1973. Classification of architecture of dicotyledonous leaves. American Journal of Botany 60: 17–33.

Hooker JD 1872. Flora of British India. I. Kent.

Johnson GD, Stix J, Tauxe L, Cerveny CF & Tahirkhell RAK 1985. Palaeomagnetic chronology, fluid processes and tectonic implication of Siwalik deposits near Chinji Village, Pakistan. Journal of Geology 93: 27–40.

Konomastsu M & Awasthi N 1999. Plant fossils from Arung Khola and Binai Khola formations of Churia Group (Siwalik), west central Nepal and their palaeoecological and phytogeographical significance. Palaeobotanist 48: 63–181.

Lakhanpal RN 1969. Fossil *Fissistigma* from the Lower Siwalik near Jawalamukhi, India. *In*: Santapau *et al.* (Editors)–Journal of Sen Memorial Volume: 311–312.

Lakhanpal RN & Awasthi N 1992. New species of *Fissistigma* and *Terminalia* from the Siwalik sediments of Balugoloa, Himachal Pradesh. Geophytology 21: 49–52.

Lakhanpal RN & Dayal R 1966. Lower Siwalik plants from near Jawalamukhi, Punjab. Current Science 35(8): 209–211.

Lakhanpal RN & Guleria JS 1987. Fossil leaves of *Dipterocarpus* from the Lower Siwalik beds near Jawalamukhi, Himachal Pradesh. Palaeobotanist 35: 258–262.

Lakhanpal RN, Tiwari AP & Awasthi N 1987 Occurrence of Bamboo in the Siwalik beds near Ranital, Himachal Pradesh. Palaeobotanist 35: 184–188.

Mabberley DJ 1997. The Plant Book. A portable Dictionary of the Vascular plants. 2nd Ed. Cambridge University Press, Cambridge.

Mathur AK 1978. Some fossil leaves from the Siwalik Group. Geophytology 8: 98–102.

Mathur AK, Mishra VP & Mehra S 1996. Systematic study of plant fossils from Dagsai, Kasauli and Dharamsala formations of Himachal Pradesh. Geological Survey of India, Palaeontologia Indica (New Series) 50: 1–121.

Mehrotra RC 1990. Further contribution on some fossil woods from Deccan Intertrappean beds of central India. Phytomorphology 43: 169–174.

Menzel P 1920. Uber Pflanzen reste aue Basaltluffen des Kamerungebietes. Beitrage Zur geologischen Erforschung der deutschen Schutzgebiete 18: 7–72.

Opdyke ND, Lindsay E, Johnson GD, Johnson NM, Tahirkeli RAK & Mirza MA 1979. Magnetic polarity stratigraphy and vertebrate palaeontology of Upper Siwalik Subgroup of northern Pakistan. Palaeogeography Palaeoclimatology Palaeoecology 27: 1–34

Pandey SM & Prasad M 2008. Siwalik (Middle Miocene) leaf impressions from Tanakpur area, Uttaranchal and their bearings on climate. Geophytology 37: 99–108.

Pilgrim GE 1910. Preliminary note on a revised classification of the Tertiary fresh water deposits of India. Geological Survey of India Record 40: 145–205.

Prakash U 1975. Fossil woods from the Siwalik beds of Himachal Pradesh, India. Palaeobotanist 22(3): 192–210.

Prakash U 1978. Fossil woods from the Lower Siwalik beds of Uttar Pradesh, India. Palaeobotanist 25: 278–392.

Prakash U 1979. Some more fossil woods from the Lower Siwalik beds of Himachal Pradesh, India. Himalayan Geology 8: 61–68.

Prasad M 1994. Siwalik (Middle Miocene) leaf impressions from the foot–hills of the Himalaya, India. Tertiary Research 15(2): 53–90.

Prasad M 2006. Plant fossils from Siwalik sediments of Himachal Pradesh and their palaeoclimatic significance. Phytomorphology 56: 9–22.

Prasad M 2010. Carbonised fossil woods from the Siwalik Group of Himachal Pradesh, India and their significance. Journal of Palaeontological Society of India 55(1): 23–28.

Prasad M 2012. First record of megafossils from Nahan Formation, Himachal Pradesh and their significance. Indian Association of sedimentologist 31: 105–115.

Prasad M, Alok, Kannaujia AK, Kumar S & Singh SK 2017. Middle Miocene flora from Siwalik foreland basin of Uttarakhand, India and its phytogeographic and palaeoclimatic implications. Palaeobotanist 66(2): 223–312.

Prasad M, Antal JS & Tiwari VD 1997. Investigation on plant fossils from Seria Naka in the Himalayan foot hills of Uttar Pradesh, India. Palaeobotanist 46: 13–30.

Prasad M, Antal JS, Tripathi PP & Pandey VK 1999. Further contribution to the Siwalik flora from the Koilabas area, western Nepal. Palaeobotanist 48: 49–95.

Prasad M & Awasthi N 1996. Contribution to the Siwalik flora from Surai Khola sequence, western Nepal and its palaeoecological and phytogeographical implications. Palaeobotanist 43(3): 1–42.

Prasad M & Dwivedi HD 2008. Some plant megafossils from the Sub–Himalayan zone (Middle Miocene) of western Nepal. JOurnal of the Palaeontological Society of India 53(1): 51–64.

Prasad M, Gautam S, Bhowmik N, Kumar S & Singh SK 2018. New fossil leaves of Annonaceae and Achariaceae from Churia Group of Nepal and their phytogeographical implications. Palaeobotanist 67: 47–66

Prasad M, Gautam S, Bhowmik N, Kumar S & Singh SK 2019. Miocene flora from the Siwalik of Arjun Khola area, Nepal and its palaeoclimatic and phytogeographic implications. Palaeobotanist 68: 1–111.

Prasad M, Gautam, S, Bhowmik N & Singh SK 2016. Plant macrofossils from the sedimentary sequence of Churia Group, Nepal: their phytogeographic

and palaeoclimatic significance. Geophytology 46(2): 173–206.
Prasad M, Ghosh R & Tripathi PP 2004. Floristics and climate during the Siwalik (Middle Miocene) near Kathgodam in the Himalayan foot hills of Uttaranchal, India. Journal of the Palaeontological Society of India 49: 35–93.
Prasad M, Kannaujia AK, Alok & Singh SK 2015. Plant megafossils from Siwalik (Upper Miocene) of Darjeeling District, West Bengal, India and their palaeoclimatic and phytogeographic implications. Palaeobotanist 64: 13–94.
Prasad M, Khare EG, Mukherjee D & Singh SK 2011. Palynological investigation of the Middle Miocene sediments of Gambhorala, Bilaspur District, Himachal Pradesh. Indian Association of Sedimentologist 30(2): 82–89.
Prasad M, Khare EG & Singh SK 2013. Plant fossils from the Deccan Intertrappean sediments of Chhindwara District, Madhya Pradesh, India: their palaeoclimatic significance. Journal of the Palaeontological Society of India 58(2): 229–240.
Prasad M, Mohan L & Singh SK 2013. First record of fossil leaves from Siwalik (Upper Miocene) sediments of Mandi District, Himachal Pradesh, India: palaeoclimatic and phytogeographical implications. Palaeobotanist 62(2): 165–180.
Prasad M, Panjawani M, Kannaujia AK & Alok 2010. Siwalik fossil leaves from the Himalayan foot hills of the Darjeeling District, West Bengal, India and their significance. Proceedings of "National Seminar on Environmental Degradation and Biodiversity– Problem and Prospects" 29–30 Nov. 2009. pp. 27–32.
Prasad M, Singh H & Singh SK 2014. Early Eocene *Annona* fossils from Vastan Lignite Mine, Surat District, Gujarat, India. Age Origin and Palaeogeographic significance. Current Science 107 (1025): 1730–1735.
Prasad M & Tripathi PP 2000. Plant megafossils from Siwalik sediments of Bhutan and their climatic significance. Biological Memoirs 26: 6–19.
Ranga Rao, Khan NN, Venkatachala BS & Sastri VV 1979. Neogene Quaternary Boundary and the Siwalik. Field Conference NIQ Boundary, India Proceeding 1981: 131–142.
Richardson JE, Chatrou LW, Mols JB, Erkens RHJ & Pirie MD 2004. Historical biogeography of two cosmopolitan families of flowering plants: Annonaceae and Rhamnaceae. Philosophical Transactions of the Royal Society of London B 359: 1495–1508.
Ridley HN 1967. The flora of Malaya Peninsula–I. Amsterdam. Reeve & Co., Great Britain.
Sanborn Calvi W 1935. Oberrheinisches Fossilkatalog. Lieferung 3(10): 1–53.
Singh H, Prasad M, Kumar K & Singh SK 2011. Palaeobotanical remains from Palaeocene, Lower Eocene Vagadkhol Formation, western India and their palaeoclimatic and phytogeographic implication. Palaeoworld 20: 332–356.
Singh H, Ranjan R, Singh PK & Prasad M 2022. Two new fossil leaf species, *Fissistigma himachalensis* (family: Annonaceae) and *Berberis siwalica* (Family: Berberidaceae) from Middle siwalik Sarkaghat, Himachal Pradesh, India. Geophytology 52: 57–66.
Sole de Porta N 1971. Algunos Himalaya nuevos de pollen procedentes de la formation Gauduas (Masstrichtiense–Paleocene) de Colombia. Studia Geologica Salamanca 2: 133–143.
Srivastava G & Mehrotra RC 2013. Further contribution to the low latitude leaf assemblage from the Late Oligocene sediments of Assam and it phytogeographical significance. Journal of Earth System Science 122(5): 1341–1357.
Srivastava R 2001. Angiospermous fossil woods from lignite beds of Warkalli Formation, Kerala Coast, India. *In*: Dutta *et al.* (Editors)–Proceeding of National Seminar on Recent Advances in Geology of Coal and Lignite basin of India. Calcutta (1997). Geological Survey of India Special Publication no. 54, pp. 134–144.
Tripathi C 1986. Siwalik of Indian subcontinent. Journal of the Palaeontological Society of India 31: 1–8.
Tripathi PP, Pandey SM & Prasad M 2002. Angiospermous leaf impressions from Siwalik sediments of the Himalayan foot hills near Jarva, U.P. and their bearing on palaeoclimate. Biological Memoire 28: 79–90.
Yadav RR 1989. Some more fossil woods from the Lower Siwalik sediments of Kalagarh, Uttar Pradesh and Nalagarh, Himachal Pradesh. Palaeobotanist 37(1): 52–62.
Yin A 2006. Cenozoic tectonic evolution of the Himalayan orogen as constrained by along–strike variation of structural geometry, exhumation history and foreland sedimentation. Earth Science Reviews 76(1&2): 1–131.