The Palaeobotanist 67(2018): 47–66
0031–0174/2018

New fossil leaves of Annonaceae and Achariaceae from Churia Group of Nepal and their phytogeographical implications

MAHESH PRASAD[1], SOMLATA GAUTAM[2*], NUPUR BHOWMIK[2], SANJEEV KUMAR[3] AND SANJAI KUMAR SINGH[1]

[1]*Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow 226 007, India.*
[2]*Department of Botany, University of Allahabad, Allahabad 211 002, India.*
[3]*Department of Applied Geology, School for Environmental Science, Baba Saheb Bhimrao Ambedkar University, Lucknow, India.*
[*]*Corresponding author: gautam.soma02@gmail.com*

(Received 16 June, 2017; revised version accepted 31 January, 2018)

ABSTRACT

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. The Palaeobotanist 67(1): 47–66.

Study on the fossil leaves recovered from Churia Group of Arjun Khola area, western Nepal revealed the occurrence of five new fossil species, four belonging to the family Annonaceae and one to Achariaceae. The analysis of present day distribution of the comparable extant species, *Unona longiflora* Roxb., *Annona reticulata* Linn., *Goniothalamus macranthus* (Kurz) Boerlage, *Artabotrys speciosus* Kurz and *Ryparosa caesia* Blume ex Baill of fossils indicates that they do not grow in and around the study area as well as sub–Himalayan zone of India and Nepal but are presently distributed in the evergreen forests of north–east and south India and South–east Asian region. This suggests that after Miocene these taxa could not survive there most probably due to onset of drier conditions. Based on the data available the phytogeographical aspect of these fossil taxa of both the families has also been discussed.

Key–words—Fossil leaves, Annonaceae, Achariaceae, Churia Group (Middle–Upper Miocene), Arjun Khola, western Nepal, Phytogeography.

नेपाल के चुरिया समूह से प्राप्त एन्नोनेसी एवं एकैरिएसी की नूतन जीवाश्म पत्तियां एवं उनके पादप भूगोलीय आशय

महेश प्रसाद, सोमलता गौतम, नूपुर भौमिक, संजीव कुमार एवं संजय कुमार सिंह

सारांश

अर्जुन खोला क्षेत्र पश्चिमी नेपाल के चुरिया समूह से प्राप्त जीवाश्म पत्तियों पर अध्ययन से पांच अभिनव जीवाश्म जातियों चार एन्नोनेसी व एक एकैरिएसी कुटुंब की उत्पत्ति का पता चला। तुलनीयमौजूदा जातियों *उनोना लॉंगीफ्लोरा* रॉक्सबी, *एन्नोना रेटिकुलेटा* लिन, *गोनियोतलेमस मेंक्रेंथस* (कर्ज़) बोर्ल, *अर्टाबॉट्रीज स्पेसिओसस* कर्ज़ व *रीपरोसा कैसिया* कर्ज़ जीवाश्मों का अग्रणी का समकालीन वितरण का विश्लेषण द्योतित करता है कि वे भारत और नेपाल के इस अध्ययन क्षेत्र में व चहुंओर के साथ–ही–साथ उप–हिमालयी अंचल में नहीं उगते परंतु वे फिलहाल भारत के उत्तर पूरब व दक्षिणी सदाहरित वनों तथा दक्षिण–पूरब एशियाई भू–भाग में फैले हुए हैं। यह जताता है कि संभवतः मध्य नूतनोंपरांत शुष्क स्थितियों के प्रारंभ होने के कारण ये टैक्सा वहां बच न सकीं। उपलब्ध आंकड़े के आधार पर दोनों कुटुंबों के इन जीवाश्म टैक्सा के पादप भूगोलीय पक्ष पर भी विचार विनिमय किया गया है।

सूचक शब्द—जीवाश्म पत्तियां, एन्नोनेसी, एकैरिएसी, चुरिया समूह (मध्य–ऊपरी मध्यनूतन), अर्जुन खोला, पश्चिमी नेपाल, पादप भूगोल।

INTRODUCTION

THE sediments of Churia (Siwalik) Group were deposited continuously by various rivers in the Himalayan foreland during last 20 million years (Johnson *et al.,* 1985). These sediments provide an excellent opportunity to study the plant macrofossils including woods, leaf, fruit and seed impressions entombed in alluvial sediments. These sediments comprise mudstone, sandstone and coarsely bedded conglomerates and are delimited on the south, by the Main Frontal Thrust (MFT) and on the north, by Main Boundary Thrust (MBT). A number of macrofossils, so far, have been reported from the Churia sediments exposed in different localities (e.g. in Koilabas, Surai Khola, Butwal, Tinau Khola, Binai Khola, Arjun Khola and Surkhet area) in the Himalayan foot hills of Nepal (Konomatsu & Awasthi, 1999; Prasad, 1990, 2007; Prasad & Awasthi, 1996; Prasad & Dwivedi, 2008; Prasad & Khare, 2004; Prasad & Pradhan, 1998; Prasad *et al.,* 1999). The present investigation is made on a collection of a variety of plant macrofossils from Arjun Khola, western Nepal.

The fossil locality, Arjun Khola (27º 53' 42.8"N: 82º 30' 31.4"E) lies in the Dang District of Rapti Anchal, western Nepal and is easily approachable through the Mahendra Highway near Lamhi (27º 52' 24.9"N: 82º 32' 22.4"E), a famous town of Deokhuri Valley (Fig. 1). The Lower and Middle Churia sediments are well developed in Arjun Khola area all along the Arjun River and the road leading to Ghorai covering a distance of 15 km. The sediments consist of clays, shales, sandstones and siltstones. A large number of well preserved leaf and fruit impressions are generally collected from thinly bedded shale from different profiles of this sequence. Out of a rich collection of a variety of plant macro fossils made earlier mainly from the Lower and Middle Churia sediments of Arjun Khola sequence, only a few of them have been reported so far (Prasad, 2007, 2013; Prasad & Gautam, 2016; Prasad & Khare, 2004; Prasad *et al*., 2016). Further study on the fossil leaves of these assemblages from the Arjun Khola area revealed the occurrence of five new dicotyledonous taxa which have been described and discussed in their phytogeographical prospective in this communication.

GEOLOGICAL SETUP

The Churia Group is delimited on the south by the Main Frontal Thrust (MFT) and on the north by Main Boundary Thrust (MBT). It consists of basically fluvial deposits of Neogene age ranging from Miocene (15 Ma) to the Pliocene (Tokuoka *et al*., 1994). This extends all along the Himalaya forming the southernmost hill range with width of 8–50 km. The general dip of the beds of the Churia Group has northward trend with varying angles and the overall strike is east west.

The geology of the Churia Group has been studied by several workers like, Gleinnie & Ziegler (1964), Sharma (1980), Kumar & Gupta (1981), Chaudhuri (1983), Tokuoka

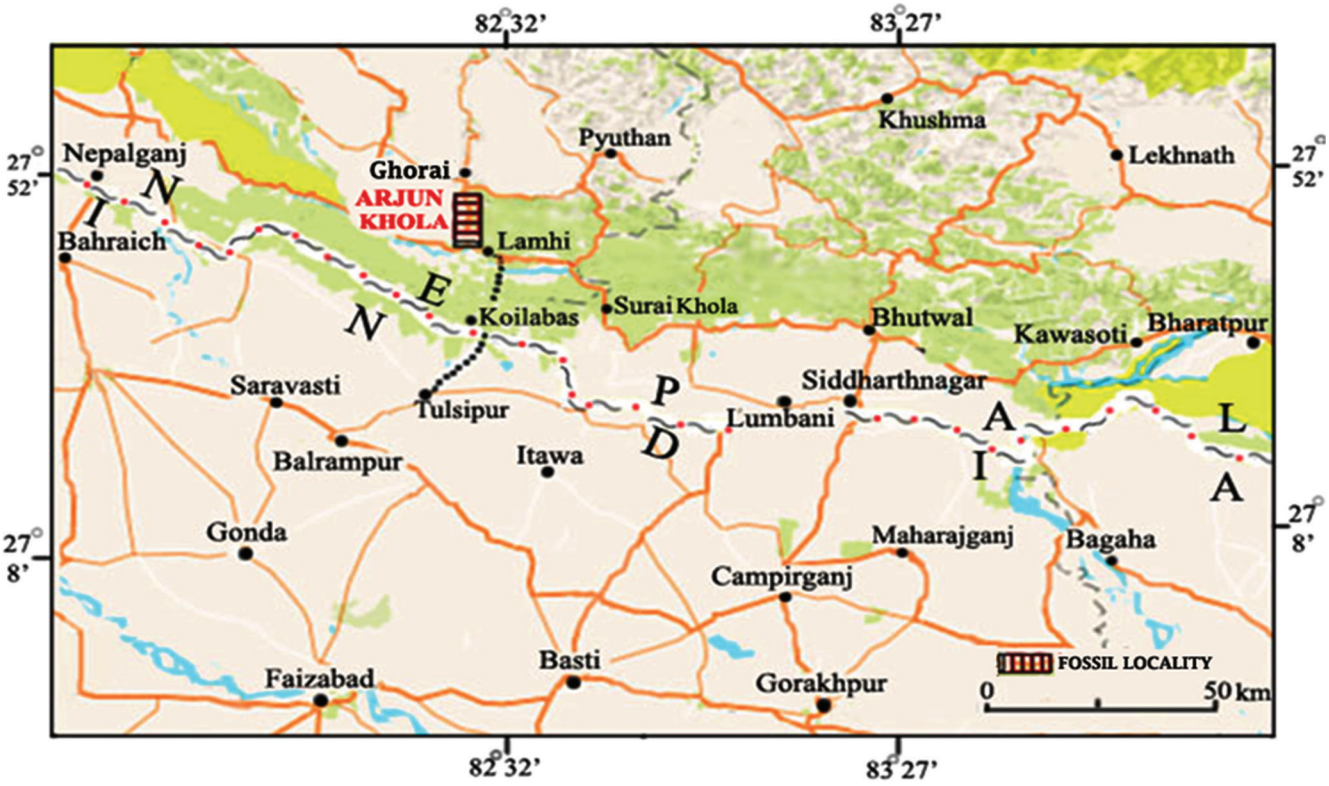

Fig. 1—Map showing location of study area (Arjun Khola).

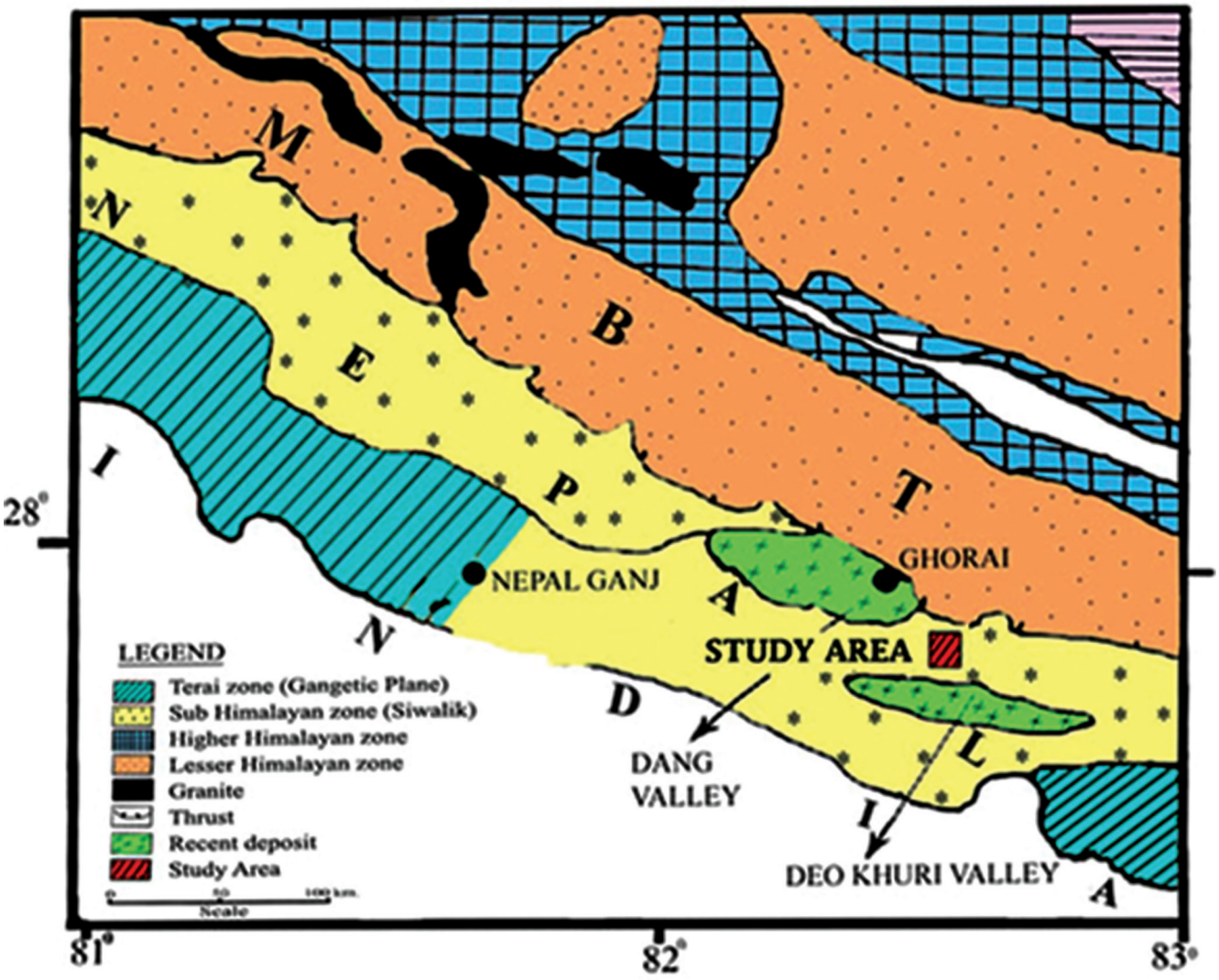

Fig. 2— Map showing Siwalik Formation in the Arjun Khola area of Sub–Himalayan zone, Nepal.

et al. (1986), Corvinus (1990) and Appel *et al.* (1991). Gleinnie & Ziegler (1964) divided the Churia Group into two formations (i) Lower Churia Formation (Sandstone facies) and (ii) Upper Churia Formation (Conglomerate facies). The Lower Churia Formation associated with group of palaeosols developed during brief successive pause in sedimentation and bears a variety of plant fossils. However, Chaudhuri (1983) suggested a threefold classification (Lower, Middle and Upper formations) for the Churia Group in western Nepal Himalaya. The Lower Formation is about 1800 m in thickness and consists of fine grained green chlorite, biotite, muscovite and well bedded indurate sandstones and siltstones). The Middle Formation is about 2000 m in thickness and dominantly comprises arenaceous rocks with intercalation of clay beds. The Upper Formation consists of about 2500 m thick succession and is composed of fine grained, poorly indurate sandy clays in the lower part and boulder conglomerate in the upper part of the succession. The study area falls in the Dang Section of western Nepal. Almost a complete and uninterrupted sequence of Churia Group is well exposed all along the road from Arjun Khola to Ghorai, western Nepal.

In Arjun Khola area, there are molasses sediments of the Lower and Middle Churia formations which are divided into 14 profiles on the basis of their lithological characters. There are number of fossiliferous beds mainly of shales, siltstones and fine grained sandstone containing a variety of well preserved leaf, fruit and flower impressions. The Lower Churia Formation comprises alternation of sandstone and mudstone beds of almost same thickness while in the Middle Churia Formation the thickness of sandstone beds are greater than the mudstone beds (Figs 2, 3, 4).

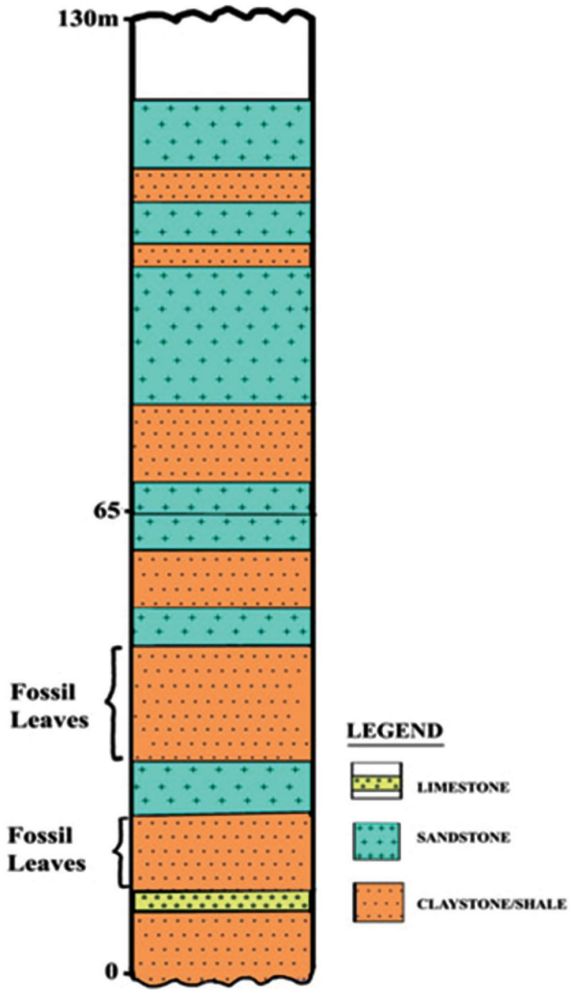

Fig. 3—Lithocolumn of a part of exposed section of Profile 5A indicating the fossiliferous beds from where the leaf fossils were collected.

MATERIAL AND METHOD

The fossil leaves were collected from Churia section exposed on Arjun Khola–Ghorai Road in Deokhuri District of western Nepal. These are collected mainly from profile 5A (27º54'50.6" N: 82º31'00.4" E) of Middle Churia Formation of Arjun Khola sequence (Figs 2, 3, 4). The leaf impressions, preserved on purple/ grey shale were studied morphologically with the help of either hand lens or low power microscope under reflected light. The identification of leaf samples has been carried out at Central National Herbarium, Howrah, West Bengal. For the description of fossil leaves the terminology given by Hickey, 1973; Dilcher, 1974 and Ash *et al*., 1999 has been followed. All the fossil specimens and photographs/ negatives have been deposited in the Museum (Conservatory) of Birbal Sahni Institute of Palaeosciences, Lucknow vide B.S.I.P. Museum specimen nos. 41179–41192.

SYSTEMATICS

Order—MAGNOLIALES

Family—ANNONACEAE

Genus—UNONA Linnaeus the younger

***Unona miocenica* n. sp.**

(Pl. 1.1–4, 6, 8,)

Material—Four specimens.

Diagnosis—Leaves simple, symmetrical, oblong in shape; apex acute; base nearly obtuse; margin entire; venation pinnate, eucamptodromous; secondary veins about 12 pairs visible, angle of divergence moderately acute, uniformly curved upwards and joined their superadjacent secondary, curvature more pronounced near the margin; tertiary veins with angle of origin right angle on both sides, percurrent, veins arising at oblique to right angle in relation to midvein.

Description—Leaves simple, symmetrical, oblong, preserved size 14.7 x 5.0 cm, 14.5 x 6.0 cm, 13.7 x 4.4 cm and 8.6 x 2.7 cm; apex acute; base nearly obtuse, normal; margin entire; texture chartaceous; petiole 0.9–3.1 cm visible, normal; venation pinnate, eucamptodromous; primary vein single, straight, prominent, stout; secondary veins about 9–12 pairs visible, 0.7 to 1.8 cm apart, alternate to sub–opposite, angle of divergence 45°–50°, moderately acute, uniformly curved upwards and joined superadjacent secondary vein before reaching the margin, curvature more pronounced near the margin, unbranched; tertiary veins fine, angle of origin right angle on both sides, percurrent, straight, arising at oblique to nearly right angle in relation to midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum specimen no. 41179.

Paratype—B.S.I.P. Museum specimen nos. 41180–41182.

PLATE 1

1–3. *Unona miocenica* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum specimen nos. 41179 (Holotype), 41180 and 41181 (Paratype).

4. *Unona miocenica* n. sp.–Another fossil leaf showing nature of apex. BSIP Museum specimen no. 41182 (Paratype).

5. *Unona longiflora* Roxburg–Modern leaf showing similar shape, size and venation pattern.

6. *Unona miocenica* n. sp–A part of fossil leaf magnified to show details of venation. BSIP Museum specimen no. 41179.

7. *Unona longiflora* Roxburg–A part of modern leaf showing similar details of venation.

8. *Unona miocenica* n. sp–A part of fossil leaf magnified to show details of venation. BSIP Museum specimen no. 41182.

PLATE 1

Fig. 4—Well exposed section of Lower Churia Formation in Profile 3 from where fossil leaf samples were collected from shale beds.

Type locality—Profile 5A (27°54'50.6" N: 82°31'00.4" E) and Profile 12 (27°57'06.1" N: 82°29'32.2" E), Arjun Khola–Ghorai Road section, Arjun Khola area, Deokhuri District, Rapti Anchal, Nepal.

Horizon & Age—Middle and Lower Churia Formation; Middle–Upper Miocene.

Etymology—The specific name is after Miocene age.

Affinity—The distinguishing features of the present fossil leaves are oblong shape, acute apex, nearly obtuse base, entire margin, eucamptodromous venation, secondary veins with moderately acute angle of divergence having sharp curvature near the margin. These features collectively indicate their closest resemblance with extant taxon *Unona longiflora* Roxburg of the family Annonaceae (C.N.H Howrah, Herbarium Sheet No. 1166; Pl. 1.5, 7). The fossil leaves also resemble with the modern leaves of *Mitrephora macrophylla* Oliver (C.N.H. Howrah Herbarium Sheet No. 13318) and *Cananga odorata* Joseph Dalton Hooker & Thomson (C.N.H. Herbarium Sheet No. 1076) of the same family. The comparative study suggests that the leaves of *M. macrophyla* Oliver differ from present fossils in having greater number of secondary veins which comparatively arise closely. Similarly, the leaves of *Cananga odorata* Joseph Dalton Hooker & Thomson differ in possessing lesser number (8–9 pairs) of secondary veins as compared to those of the fossils.

So far, there is no record of fossil leaf resembling the genus *Unona* Linnaeus the younger, hence these fossils have been described as a new species *Unona miocenica*.

The genus *Unona* Linnaeus the younger (*Xylopia* Linnaeus) consists of about 160 species of trees or shrubs and is distributed in the tropical regions of Africa, Asia and America. The extant species, *Unona longiflora* Roxburg with which present fossil leaves resemble, is a small tree distributed in Assam, Khasia hills, Chittagong and Kasalong forests and the hills tracts (Mabberley, 1997; Gamble, 1972).

PLATE 2

1,3,7,8,10. *Annona nepalensis* n. sp.–Fossil leaves showing shape, size and venation pattern. BSIP Museum specimen nos. 41183 (Holotype), 41184–41187 (Paratype).

2, 4, 9. *Annona reticulata* Linnaeus–Modern leaves showing similar shape, size and venation pattern.

5. *Annona nepalensis* n. sp.–A part of fossil leaf magnified to show details of venation pattern. BSIP Museum specimen no. 41184.

6. *Annona reticulata* Linnaeus–A part of modern leaf showing similar details of venation.

11. *Annona nepalensis* n. sp.–A part of another fossil leaf magnified to show details of venation pattern. BSIP Museum specimen no. 41187.

PLATE 2

Genus—ANNONA Linnaeus

***Annona nepalensis* n. sp.**

(Pl. 2.1, 3, 5, 7, 8, 10, 11)

Material—Five specimens.

Diagnosis—Leaf simple, size 7.5–15.0 x 2.1–3.5 cm; apex acute; base wide acute; margin entire; venation pinnate, eucamptodromous; secondary veins about 8–17 pairs visible, angle of divergence moderately acute; tertiary veins fine with angle of origin right angle on both sides, percurrent and close.

Description—Leaves simple, almost symmetrical, narrow oblong to elliptic, preserved size 15.0 x 2.9 cm, 8.9 x 3.5 cm, 7.5 x 2.1 cm, 8.6 x 2.7 cm and 7.0 x 2.0 cm; apex acute; base wide acute; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein single, straight to slightly curved, prominent, stout; secondary veins 8–17 pairs visible, 0.5 to 1.5 cm apart, usually opposite to alternate, unbranched, angle of divergence 40°–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 midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum specimen no. 41183.

Paratype—B.S.I.P. Museum specimen nos. 41184–41187.

Type locality—Profile 2 (27°54'10.8" N: 82°30'55.2" E, Profile 3 (27°54'27.7" N: 82°30'54.6" E, and Profile 5A (27°54'50.6" N: 82°31'0.4" E), Arjun Khola–Ghorai Road section, Arjun Khola area, Deokhuri District, Rapti Anchal, Nepal.

Horizon & Age—Lower and Middle Churia Formation; Middle Miocene to Upper Miocene.

Etymology—The specific name is after the name of country Nepal from where the fossil specimens have been collected.

Affinity—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 show nearest affinity with the modern leaves of *Annona reticulata* Linnaeus of the family Annonaceae (C.N.H. Howrah, Herbarium Sheet No. 13544; Pl. 2.2, 4, 6, 9).

So far, two fossil leaves showing close affinity with the genus *Annona* Linnaeus have been described from Tertiary 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 and differ from Arjun Khola fossil in the presence of intersecondary veins. Recently, (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 and differs in having lesser number of secondary veins (5 pairs) than the present fossil leaves. As the present fossils differ from both the known fossils, Arjun Khola fossils have been described as *Annona nepalensis* n. sp.

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

Genus—GONIOTHALAMUS Blume

***Goniothalamus miocenicus* n. sp.**

(Pl. 3.1, 3)

Material—One specimen.

Diagnosis—Leaf simple, oblong to elliptic in shape, size 15.5 x 8.0 cm; margin entire; texture chartaceous; venation pinnate, eucamptodromous; secondary veins about 12 pairs visible, presence of simple intersecondary veins, percurrent tertiary veins.

Description—Leaf simple, apparently symmetrical, seemingly oblong to elliptic, preserved size 15.5 x 8.0 cm; apex broken; base broken; margin entire; texture thick chartaceous; venation pinnate, eucamptodromous; primary vein single, straight, prominent, stout, moderate; secondary veins 8–9 pairs visible, 1.6 to 2.1 cm apart, usually alternate to opposite, angle of divergence 60°–70°, moderately acute, basal secondary veins closely placed, intersecondary veins present, simple; tertiary veins fine, angle of origin right angle on both sides, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close.

Holotype—B.S.I.P. Museum specimen no. 41188.

Type locality—Profile 5A (27°54'50.6" N: 82°31'00.4" E), Arjun Khola–Ghorai Road section, Arjun Khola area, Deokhuri District, Rapti Anchal, Nepal.

Horizon & Age—Middle Churia Formation; Upper Miocene.

PLATE 3 

1. *Goniothalamus miocenicus* n. sp.–Fossil leaf showing shape, size and venation pattern. BSIP Museum specimen no. 41188 (Holotype).
2. *Goniothalamus macranthus* (Kurz) Boerlage–Modern leaves showing similar shape, size and venation pattern.
3. *Goniothalamus miocenicus* n. sp.–A part of fossil leaf magnified to show details of venation pattern.
4. *Goniothalamus macranthus* (Kurz) Boerlage–A part of modern leaf showing similar details of venation.

PLATE 3

Etymology—The specific name is after Miocene age.

Affinity—Large, oblong to elliptic shape, entire margin, eucamptodromous venation, nature and arrangement of secondary veins and presence of intersecondary veins resemble with the modern leaves of the genus *Goniothalamus* Blume of the family Annonaceae. On critical examination of the herbarium sheets of different species of this genus it has been found that the present fossil leaf closely resembles with the extant *Goniothalamus macranthus* (Kurz) Boerlage (C.N.H. Howrah, Herbarium Sheet No. 751; Pl. 3.2, 4).

So far, two fossil leaves resembling the genus *Goniothalamus* Blume are known from the Miocene sediments of Indian subcontinents. *G. chorkholaensis* Prasad and Awasthi is reported from the Churia sediments of Surai Khola area, Nepal (Prasad & Awasthi, 1996) and *G. siwalicus* Prasad *et al*. from Lower Siwalik sediments of Seria Naka, Gonda District of Uttar Pradesh (Prasad *et al.,* 1997). The former differs from present fossil in being narrow elliptic and possessing frequent intersecondary veins. Besides, venation is brochidodromous type as compared to eucamptodromous of the present fossil. However, the latter can be differentiated from Arjun Khola fossil in the nature and course of secondary veins which curve sharply and run for a long distance before joining the margin. Since the present fossil leaf is entirely different from known fossils, it is described as a new species *Goniothalamus miocenicus*.

Goniothalamus Blume comprises more than 50 Indo–Malayan species distributed in Eastern Tropical Asia, Malayan region, tropical forests of the Sikkim Himalaya, Assam, Myanmar, evergreen forests of Sri Lanka, Travancore and Tirunelveli. *Goniothalamus macranthus* (Kurz) Boerlage is a shrub or small evergreen tree distributed in evergreen forests of West Bengal, islands of Andaman and Nicobar and Sumatra (Mabberley, 1997; Brandis, 1971).

Genus—ARTABOTRYS Robert Brown

Artabotrys nahanii Prasad, 2012

(Pl. 4.3, 5)

Material—One specimen.

Description—Leaf simple, symmetrical, wide elliptic; 6.4 x 3.4 cm; apex seemingly acute; base acute, normal; margin entire; texture chartaceous; venation pinnate, eucamptodromous to brochidodromous; primary vein single, prominent, stout; secondary veins about 6 pairs visible, 0.8 to 2 cm apart, angle of divergence 65°–75°, wide acute, usually alternate, seemingly unbranched, uniformly curved upwards, following a long course towards apex to reach the margin; intersecondary veins present, frequent, simple; tertiary veins fine, angle of origin usually right angle on both sides, percurrent, alternate to opposite, straight to sometimes curved, oblique in relation to midvein and close to nearly distant.

Specimen—B.S.I.P. Museum specimen no. 41189.

Type locality—Profile 5A (27°54'50.6" N: 82°31'00.4" E), Arjun Khola–Ghorai Road section, Arjun Khola area, Deokhuri District, Rapti Anchal, Nepal.

Horizon & Age—Middle Churia Formation; Upper Miocene.

Affinity—The diagnostic features of the present fossil leaves such as elliptic shape, acute apex, acute base, entire margin, eucamptodromous to brochidodromous venation, nature of secondary veins following a long course along the margin and right angle, percurrent tertiary veins are common in modern leaves of the genus *Artabotrys* Robert Brown of the family Annonaceae. On examination of herbarium sheets of the available species of this genus it has been concluded that the present fossil leaves show closest resemblance with the leaves of *Artabotrys speciosus* Kurz (C.N.H. Herbarium Sheet No. 11142; Pl. 4.4, 6).

So far, there is only one record of fossil leaf *Artabotrys nahanii* Prasad resembling the extant species *Artabotrys speciosus* Kurz known from the Lower Siwalik sediments (Nahan Formation) of Himachal Pradesh, India (Prasad, 2012). Since present fossil leaf shows closest similarity with the known fossil leaf in shape, size and venation pattern, it has been described here under the same specific name *Artabotrys nahanii.*

The genus *Artabotrys* Robert Brown includes more than 100 species distributed in the tropical regions of old world (Mabberley, 1997). About 31 species are found in tropical Africa. *Artabotrys speciosu*s Kurz with which fossil leaf shows resemblance is a large woody climber distributed in the tropical forests of the Andaman Islands and Malaya.

Order—MAGNOLIALES

Family—ACHARIACEAE (FLACOURTIACEAE)

Genus—RYPAROSA (RYPARIA*)* BLUME

PLATE 4 →

1. *Ryparosa churiaensis* n. sp. Fossil leaf showing shape, size and venation pattern. BSIP Museum specimen no. 41190 (Holotype).
2. *Ryparosa caesia* Blume ex Baill–Modern leaf showing similar shape, size and venation pattern.
3. *Artabotrys nahanii* Prasad–Fossil leaf showing shape, size and venation pattern. BSIP Museum specimen no. 41189 (Holotype).
4. *Artabotrys speciosus* Kurz–Modern leaf showing similar shape, size and venation pattern.
5. *Artabotrys nahanii* Prasad.–A part of fossil leaf magnified to show details of venation pattern.
6. *Artabotrys speciosus* Kurz–A part of modern leaf showing similar details of venation.

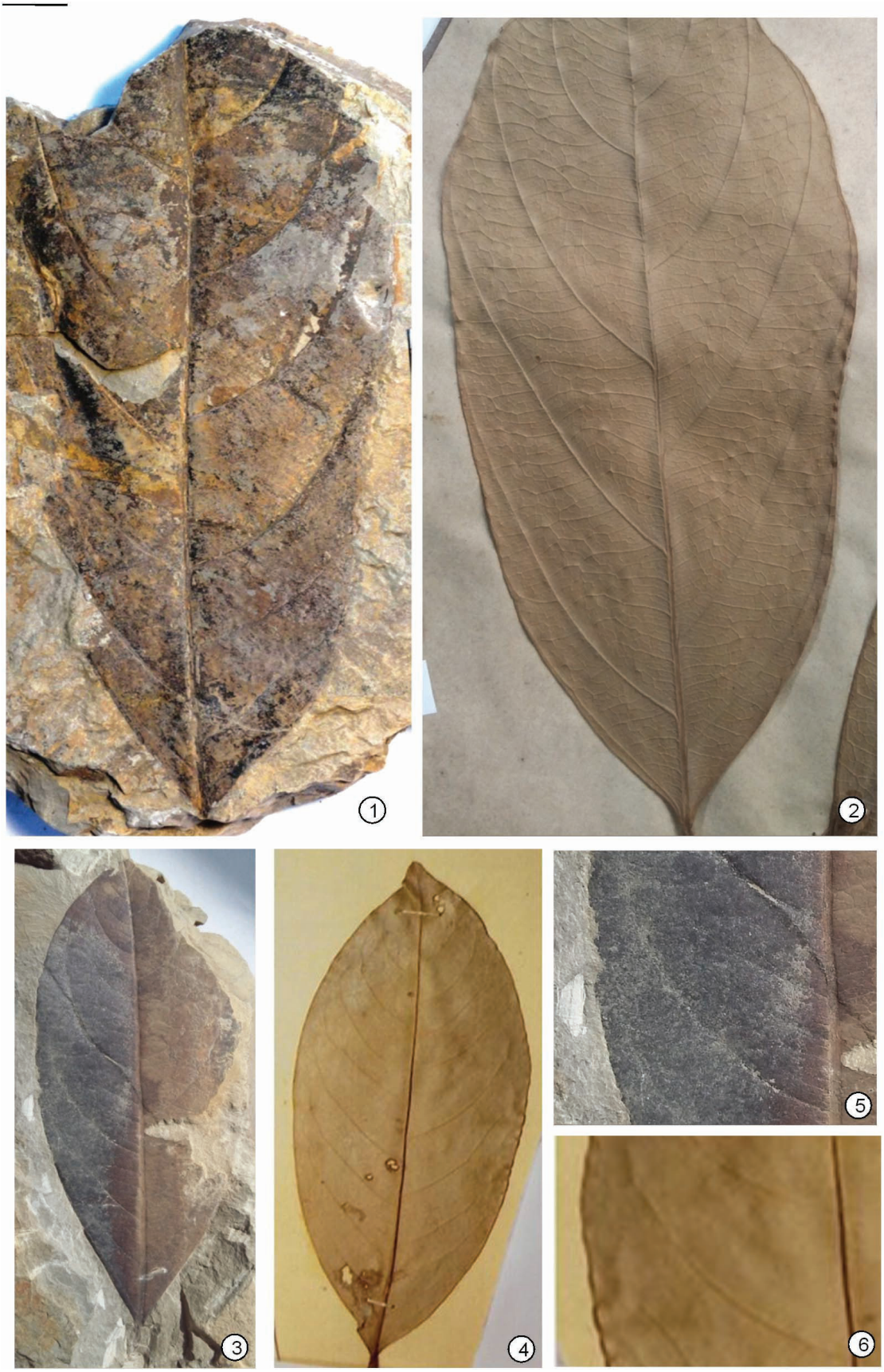

PLATE 4

***Ryparosa churiaensis* n. sp.**

(Pl. 4.1; Pl. 5.1, 2, 3, 4)

Material—Three specimens.

Diagnosis—Leaves simple, symmetrical, wide obovate; base wide acute to obtuse, normal; margin entire; venation pinnate, eucamptodromous; secondary veins 4–5 pairs visible, opposite to alternate, angle of divergence moderately acute; tertiary veins fine with right angle of origin, oblique in relation to midvein.

Description—Leaves simple, symmetrical, wide obovate, preserved size 14.1–15.2 x 7.2–7.9 cm; apex broken; base wide acute to obtuse, normal; margin entire; texture thick chartaceous; venation pinnate, eucamptodromous; primary vein single, straight, prominent, stout; secondary veins 4–5 pairs visible, 2.5 to 3.5 cm apart, opposite to alternate, angle of divergence about 60°, acute, unbranched; tertiary veins moderate, angle of origin right angle, percurrent, straight to sinuous, veins arising at oblique to right angle in relation to midvein, predominantly alternate and close to distant.

Holotype—B.S.I.P. Museum specimen no. 41190.

Paratype—B.S.I.P. Museum specimen nos. 41191–41192.

Type locality—Profile 5A (27°54'50.6" N: 82°31'00.4" E) and Profile 12 (27°57'06.1" N: 82°29'32.2" E), Arjun Khola–Ghorai Road section, Arjun Khola area, Deokhuri District, Rapti Anchal, Nepal.

Horizon & Age—Middle and Lower Churia Formation; Middle–Upper Miocene.

Etymology—The specific name is after Churia Group.

Affinity—The diagnostic features of the present fossil leaves such as fairly large size, wide obovate shape, eucamptodromous venation, distantly placed secondary veins and the nature and arrangement of tertiary veins show nearest affinity with the modern leaves of *Ryparia caesia* Blume ex Baill of the family Achariaceae (C.N.H. Howrah, Herbarium Sheet No. 33854; Pl. 4.2; Pl. 5.5). These fossils also show near resemblance with the extant leaves of *Hydnocarpus castanea* Joseph Dalton Hooker & Thomson of the same family.

So far, there is one record of fossil leaf resembling the genus *Ryparosa* Blume known as *Ryparosa prekunstelrii* from Siwalik sediments of Koilabas area, western Nepal (Prasad, 1990). This leaf has similar obovate shape but is smaller in size (12.4 x 4.8 cm). It further differs in being narrow acute angle of divergence of secondary veins. In view of this, the present fossil leaves have been described as a new species, *Ryparosa churiaensis*.

The genus *Ryparosa* Blume consists of 18 species distributed in Andaman and Nicobar Islands, western Malaysia and north New Guinea. *Ryparosa caesia* Blume ex Baill is a small tree commonly found in inland rain forests, often near streams in Andaman and Nicobar Islands, Malaya Peninsula, Indonesia, New Guinea and Bago (Brandis, 1971; Mabberley, 1997).

DISCUSSION AND CONCLUSION

Investigation on the fossil leaves collected from Churia sediments of Arjun Khola, western Nepal revealed the presence of five angiospermous taxa in the Himalayan foot hills of Nepal during Middle to upper Miocene. They show their affinity with extant taxa, *Unona longiflora* Roxburg, *Annona reticulata* Linnaeus, *Goniothalamus macranthus* (Kurz) Boerlage and *Artabotrys speciosus* Kurz. of family Annonaceae and *Ryparosa caesia* Blume ex Baill of family Achariaceae. Based on habit and habitat and forest type of comparable extant species of the fossils, the assemblage suggests that a tropical, mesophytic, evergreen forest was flourishing in and around the Arjun Khola area during the sedimentation (Table 1). This is in contrast to the mixed deciduous forest growing there presently. The present day distribution of the comparable species indicates that they occur in the evergreen forests of North–East India, Andamans and Nicobar and South–East Asian region (Table 1). It may, therefore, be surmised that a warm and humid climate prevailed in Arjun Khola and nearby area during Miocene. It also suggested that none of the taxa grow now–a–days in the Himalayan foot hills of this region due to the change in the climate.

The family Annonaceae is represented by four fossil taxa showing affinity with *Annona reticulata* Linn., *Unona longiflora* Roxb., *Goniothalamus macranthus* (Kurz.) Boerl. and *Artabotrys speciosus* Kurz.. This is a pantropical family of tropical America and Africa (Mabberley, 1997) occurring mainly in rainforests and with few species in temperate regions (Richardson *et al*., 2004; Fig. 5). *Annona* is the second largest genus of this family which comprising 137 species of trees and shrubs distributed mainly in America and Africa. Only five species are known to occur in India. The modern comparable species, *Annona reticulata* is a small deciduous to semi–evergreen tree found in eastern part

PLATE 5 →

1, 2. *Ryparosa churiaensis* n. sp. Fossil leaves showing shape, size and venation pattern. BSIP Museum specimen nos. 41191–41192 (Paratype).

3. *Ryparosa churiaensis* n. sp.–A part of fossil leaf magnified to show details of venation pattern. BSIP Museum specimen no. 41191.

4. *Ryparosa churiaensis* n. sp.–A part of another fossil leaf magnified to show details of venation pattern. BSIP Museum specimen no. 41192.

5. *Ryparosa caesia* Blume ex Baill–A part of modern leaf magnified to show similar detail of venation pattern.

PLATE 5

Table 1—Showing habit, forest type and present day distribution of modern comparable species of the fossils recovered from Churia Group of Arjun Khola area, western Nepal.

Fossil taxa	Extant taxa	Habitat	Forest type	Distribution
Unona miocenica n. sp.	*Unona longiflora* Roxburg	Tree	Evergreen	North East India, Bangladesh
Annona nepalensis n. sp.	*Annona reticulata* Linnaeus	Tree	Evergreen to Deciduous	South East Asia, India, Bangladesh, Tropical Africa and Australia
Goniothalamus miocenicus n. sp.	*Goniothalamus macranthus* (Kurz) Boerlage	Tree	Evergreen	West Bengal, Andaman and Nicobar, Sumatra
Artabotrys nahanii Prasad	*Artabotrys speciosus* Kurz	Large woody climber	Evergreen	Andaman and Nicobar
Ryparosa churiaensis n. sp.	*Ryparosa caesia* Blume ex Baill	Tree	Evergreen	Andaman and Nicobar, Malaya peninsula, Indonesia and New Guinea

of India, Bangladesh, Pakistan, Tropical America, Africa and Australia. *Goniothalamus macranthus* and *Artabotrys speciosus* are presently distributed in Andaman and Nicobar region while *Unona longiflora* is found in North–East Indian regions. Their fossil record from the neotropics is richer as compared to that from the Indo–Malayan region (Burnham & Johnson, 2004). However, more than 33 fossil taxa are recorded from Tertiary sediments of all over India (Table 2). The oldest known fossils of Annonaceae comprising seeds and pollen from the Maastrichtian of Nigeria and Colombia, respectively (Chesters, 1955; Sole de Porta, 1971) indicate a west Gondwanan origin for the family. The record of annonaceous fossil wood *Polyalthioxylon parapaniense* (Guleria & Mehrotra, 1999), fossil leaves *Polyalthia palaeosiamiarum* and *Miliusa pretomentosa* (Prasad *et al*., 2013) from the Deccan Intertrappean beds (Maastrichtian–Danian), and fossil fruit and leaf of *Annona palustris* and *Polyalthia palaeosiamiarum* (leaf) from Palaeocene–Eocene of Cambay Shale Formation, India (Prasad *et al.,* 2014; Singh *et al.*, 2011) as well as other fossil reports of Annonaceae from

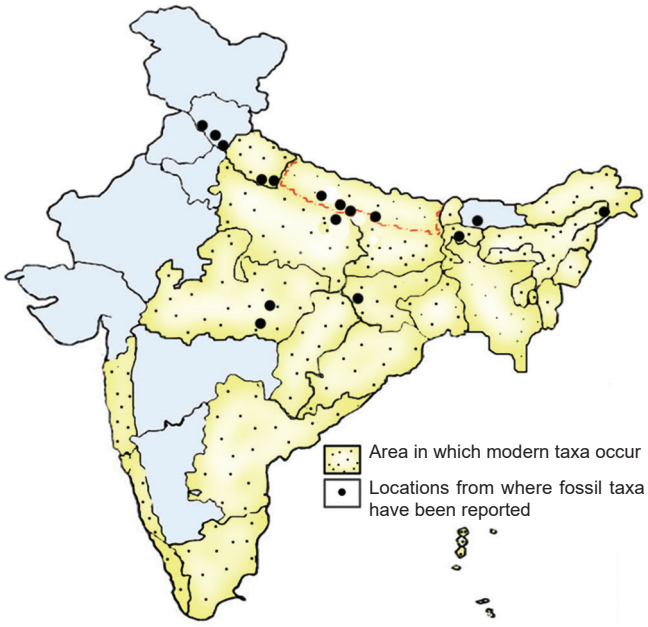

Fig. 5—Map showing present and past distribution of family Annonaceae in India.

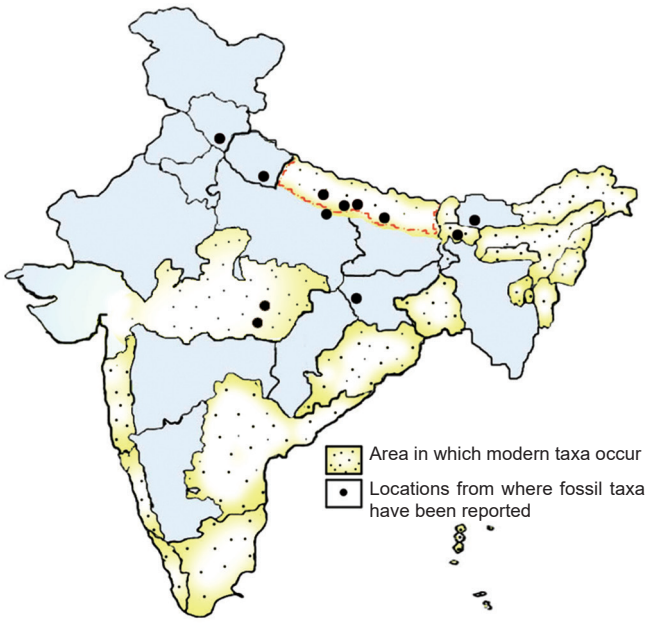

Fig. 6—Map showing present and past distribution of family Achariaceae in India.

Table 2—Fossil leaves of family Annonaceae from Tertiary sediments of Indian subcontinents.

Fossil taxa	**Locality/Place**	**Horizon/Age**	**Present day distribution**
Mitrephora siwalika Antal & Awasthi, 1993; Prasad *et al*., 2016; Prasad & Awasthi, 1996 Prasad & Tripathi, 2000	Oodlabari area, Darjeeling District, West Bengal, Arjun Khola, western Nepal Surai Khola, western Nepal Lakshmi River Section, Bhutan	Siwalik Formation Churia Formation Churia Formation Siwalik Formation	India, Myanmar, Malaya Java
M. miocenica Prasad *et al.,* 1997	Seria Naka Village, Tulsipur, U.P.	Siwalik Formation	Malaya
Annona eocenica Prasad *et al.,* 2014	Vastan Lignite Mine, Gujarat, western India	Cambay Shale Formation (Early Eocene)	South Africa, South Asia, Central America
Annona koilabasensis Prasad *et al*., 1999	Koilabas, western Nepal	Churia Formation	Java
Cananga tertiara Prasad, 1994	Kathgodam, Nainital District, Uttarakhand	Siwalik Formation	Martaban, Tennasserim, Malaya peninsula
Melodorum arjunkholaensis Prasad *et al.,* 2016	Arjun Khola, western Nepal	Churia Formation	Africa, South–East Asia, Australia and Malaya
M. jarwaensis Tripathi *et al.,* 2002	Koilabas Village near Jarwa, Balrampur District, U.P.	Siwalik Formation	North–East India and Myanmar
Uvaria siwalica Prasad 1994; Prasad & Dwivedi, 2008	Kathgodam, Nainital District, Uttarakhand; Koilabas, western Nepal	Siwalik Formation Churia Formation	Sub–Himalayan tract, Sikkim, central India, Bangladesh, Andaman, Myanmar
Uvaria ghishia Antal & Prasad, 1998	Oodlabari area, Darjeeling District, West Bengal,	Siwalik Formation	Myanmar, Malaya
Uvaria nepalensis Prasad *et al.,* 2016	Arjun Khola, western Nepal	Churia Formation	Southern China, East Asia, Vietnam
Artabotrys siwalicus Prasad *et al*., 2015 *A. nahanii* Prasad*.,* 2012	Oodlabari area, Darjeeling District, West Bengal, Near Markande Bridge, Vikrambag, H.P.	Siwalik Formation Siwalik Formation	Peninsular India and South India Andaman and Malaya
Pseudouvaria mioreticulata Prasad *et al.,* 2015	Oodlabari area, Darjeeling District, West Bengal	Siwalik Formation	Malaya, Sumatra, Java, Borneo
Fissistigma senii Lakhanpal 1969; Prasad *et al*., 1997, 2015; Prasad & Dwivedi, 2008	Balugoloa, Himachal Pradesh, India Oodlabari area, Darjeeling District, West Bengal, Near Markande Bridge, Vikrambag, H.P. Seria Naka, U.P. India	Siwalik Formation	Sub–Himalayan tract, Myanmar, Assam
F. mioelegans Prasad *et al.,* 1999	Koilabas, western Nepal	Churia Formation	Malaya and Malacca

F. shankerii Mathur *et al.*, 1996	Daghota, Kalka–Shimla Road, Solan District, H.P.	Lower Miocene, Kasauli Formation	Tropical region of Old world
F. siwalika Lakhanpal & Awasthi, 1992	Balugoloa, near Jawalamukhi, Kangra District, H.P.	Siwalik Formation	Assam, Bangladesh, Myanmar, Thailand, and Borneo
Polyalthia palaeosiamiarum Awasthi & Prasad, 1990; Antal & Prasad, 1996; Prasad *et al*., 2013	Surai Khola, western Nepal Oodlabari area, Darjeeling District, West Bengal Keria, Chhindwara, District, M.P.	Churia Formation Siwalik Formation Deccan Intertrappean beds	North–East India, Bangladesh, Myanmar, Andaman
P. palaeosumatrana Tripathi *et al*., 2002	Koilabas Village near Jarwa, Balrampur District, U.P.	Siwalik Formation	Sumatra, Borneo, Malaya
Meiogyne sevokensis Prasad *et al*., 2015	Oodlabari area, Darjeeling District, West Bengal	Siwalik Formation	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, Balrampur District, U.P.	Siwalik Formation	Sub–Himalayan foot Hills, Myanmar
M. siwalica Prasad *et al.,* 1999	Koilabas, western Nepal	Churia Fomation	India and China
M. brochidodroma Konomatsu & Awasthi, 1999	Arun Khola, Nepal	Churia Formation (Arun Khola Formation)	Sub–Himalayan tract, Assam, Myanmar
Orophea siwalika Konomatsu & Awasthi, 1999	Tinau Khola, Nepal	Churia Formation (Arun Khola Formation)	South India, Andaman, and Martaban
Saccopetalum palaeolongiflorum Awasthi & Mehrotra, 1995	Makum Coalfield Assam, India	Oligocene, Tikak Parbat Formation	Bangladesh
S. pretomentosum Prasad *et al.,* 2004	Jamrani, Kathgodam, Nainital District, Uttarakhand	Siwalik Formation	Western Ghats, Bihar, Orissa, peninsular India
Goniothalamus siwalicus Prasad *et al.,* 1997	Seria Naka Village, Tulsipur, U. P.	Siwalik Formation	Malaya
G. chorcholaensis Prasad & Awasthi, 1996	Surai Khola, western Nepal	Churia Formation	North–East India, Myanmar and South India
Ellipeia miocenic Shashi *et al.,* 2007	Tanakpur area, Champawat District, Uttarakhand	Siwalik Formation	Malaya
Comiphora precaudata Shashi *et al*., 2007	Tanakpur area, Champawat District, Uttarakhand	Siwalik Formation	Western Penninsula
Alphonsea makummensis Srivastava & Mehrotra, 2013	Makum Coalfield, Assam	Oligocene, Tikak Parbat Formation	Indo–Malayan region

Table 3—Fossil leaves of family Achariaceae (Flacourtiaceae) from Tertiary sediments of Indian subcontinents.

Fossil taxa	Locality/Place	Horizon/Age	Present day distribution
Hydnocarpus palaeokurzii Antal & Awasthi, 1993; Prasad, 1994	Oodlabari area, Darjeeling District, West Bengal Kathgodam, Nainital District, Uttarakhand	Siwalik Formation	Nilgiri, Western Ghats, Sri Lanka
H. mioalpinus Prasad, 2006	Bilaspur, Himachal Pradesh, India	Siwalik Formation	Western Ghats, Sri Lanka
H. siwalicus Prasad & Awasthi, 1996	Surai Khola, western Nepal	Churia Formation	Malaya and Sumatra
H. chorkholaensis Prasad & Awasthi, 1996	Surai Khola, western Nepal	Churia Formation	Philippines
Hydnocarpus lamhiensis Prasad *et al.,* 2016	Arjun Khola, western Nepal	Churia Formation	Travancore Ghats, India, Myanmar
H. ghishiensis Prasad *et al.,* 2015	Oodlabari area, Darjeeling District, West Bengal	Siwalik Formation	Western Ghats, South and Central Sahyadris
Gynocardia mioodorata Prasad, 1994; Prasad *et al.,* 2004; Prasad *et al*., 1999, Prasad *et al*., 2017	Kathgodam, Nainital District, Uttarakhand Koilabas, western Nepal	Siwalik Formation Churia Formation	Sikkim, North East India, Khasi Hills, Myanmar
Gynocardia butwalensis Konomatsu & Awasthi, 1999; Prasad *et al*., 2015	Tinau Khola, Butwal, Nepal Oodlabari area, Darjeeling District, West Bengal	Churia Formation (Arun Khola Formation) Siwalik Formation	Sikkim, North–East India Khasi Hills, Myanmar
Uncobia palaeospinosa Prasad, 1994	Kathgodam, Nainital District, Uttarakhand	Siwalik Formation	Tropical Arabia and Egypt
Casearia pretomentosa Antal & Awasthi, 1993	Oodlabari area, Darjeeling District, West Bengal	Siwalik Formation	Sub–Himalayan tract of India and Nepal South & Central India, Bangladesh
Casearia tomentosa Srivastava, 1998	Mahuadanr Valley Palamau District, Jharkhand	Late Cenozoic	Sub–Himalayan tract of India and Nepal South & Central India, Bangladesh
Casearia graveolens Dalz. Singh & Prasad, 2009	Mahuadanr Valley Palamau District, Jharkhand	Late Cenozoic	Throughout India including Palamau District, Sri Lanka, Malaya, Australia
Alsodeia palaeozelanicum Antal & Awasthi, 1993	Oodlabari area, Darjeeling District, West Bengal	Siwalik Formation	Malabar Hills, South India, Sri Lanka
A. palaeoracemosa Antal & Prasad, 1997	Oodlabari area, Darjeeling District, West Bengal	Siwalik Formation	North–East India and South India
A. palaeoechinocarpa Antal & Prasad, 1998	Oodlabari area, Darjeeling District, West Bengal	Siwalik Formation	Sumatra and Cochin China

Flacourtia tertiara Prasad & Awasthi, 1996, Antal & Prasad, 1998	Surai Khola, western Nepal Oodlabari area, Darjeeling District, West Bengal	Churia Formation Siwalik Formation	Malayan Archipelago
F. koilabasensis Prasad & Dwivedi, 2008	Koilabas, western Nepal	Churia Formation	North–East India, Myanmar, Malaya
F. seriaensis Prasad *et al.,* 1997	Seria Naka, near Tulsipur, U.P.	Siwalik Formation	North–East India, Myanmar, Malaya
F. nepalensis Awasthi & Prasad, 1990	Surai Khola, western Nepal	Churia Formation	India Sri Lanka and Malaya
F. indica Linn. Singh & Prasad, 2007	Mahuadanr Valley, Jharkhand	Late Cenozoic	Sub–Himalayan tract, Central India, Chotanagpur
Flacourtiates intertrappeum Nambudiri, 1966	Mohgaonkala, Chhidwara District, M.P.	Deccan Intertrappean beds (Early Eocene)	Tropical Asia and Africa
Ryparosa prekunstelri Prasad, 1990	Koilabas, western Nepal	Churia Formation	Malayan region
Xylosma nepalensis Prasad & Pandey, 2008	Surai Khola, western Nepal	Churia Formation	Tropical region of Japan and Taiwan

the Tertiary of India and Nepal (Table 2) seem to reinforce a Gondwanan origin for the family.

Based on fossil leaves, the family Achariaceae (Flacourtiaceae) is represented by more than 22 fossil species from Tertiary sediments, out of which ten species are enumerated from Churia sediments of Nepal (Table 3). The present day distribution of their modern comparable species shows that they are distributed mainly in tropical regions of North–East and South India and South–East Asian regions (Table 3; Fig. 6). In the present assemblage this family is represented by a single taxa *Ryparosa* (*Ryparia*) *churiensis* which shows affinity with extant taxa *R. caesia* Blume ex Baill. The fossil record (Table 3) suggests that it was common in India and Nepal during the Miocene. The earliest record of Achariaceae is represented by a fossil wood *Hydnocarpoxylon indicum* (Bande & Khatri, 1980) and a fossil leaf Flacourtiates intertrappeam Nambudiri, 1966 in Deccan Intertrappean beds (Maastrichtian–Danian) of central India. The extant comparable species, *R. caesia* Blume ex Baill is an evergreen tree distributed in Andaman and Nicobar islands, Malaya peninsula, Indonesia and New Guinea. Thus, the present day distribution of these taxa indicates that they do not grow in and around the fossil locality in the Himalayan foot hills of Nepal but have either migrated toward south east or died out in the foot hills area because of change in climate after Miocene due to uplift of Himalaya.

Acknowledgements—*The authors are thankful to Prof. Sunil Bajpai, Director, Birbal Sahni Institute of Palaeosciences, Lucknow for providing the basic facilities and permission to carry out this work. We are also thankful to the authorities of Central National Herbarium, Sibpur, Howrah for giving kind permission to consult their Herbarium for the identification of the fossil leaves.*

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 1997. Angiospermous fossil leaves from the Siwalik sediments (Middle–Miocene) of Darjeeling District, West Bengal. Palaeobotanist 46(3): 95–104.

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.

Appel E, Rosler W & Corvinus G 1991. Magnetostratigraphy of Mio–Pliestocene Suraikhola Siwalik in West Nepal. Geology Journal International 105: 191–198.

Ash AW, Ellis B, Hickey LJ, Johnson K, Wilf P & Wing SL 1999. Manual of Leaf Architecture: Morphological Description and Categorization of Dicotyledonous and Net–veined Monocotyledonous Angiosperms. An informal publication prepared by the Leaf Architecture Working Group (LAWG), Privately published and distributed. Smithsonian Institution, Washington.

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.

Bande MB & Khatri SK 1980. Some more fossil woods from the Deccan Intertrappean beds of Mandla District, Madhya Pradesh, India. Palaeontographica 173B (4–6): 147–165.

Brandis D 1971. *Indian Trees.* Bishen Singh Mahendra Pal Singh, Dehradun.

Burnham RJ & Johnson KR 2004. South American Palaeobotany and the origins of neotropical rainforests. Philosophical Transactions of the Royal Society of London B 359: 1595–1610.

Chaudhuri RS 1983. Provenance of the Siwalik sediments of Nepal Himalaya. Contemporary Geosciences researches in Himalaya 2: 85–90.

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.

Corvinus G 1990. Litho–and biostratigraphy of the Siwalik succession in Surai Khola area, Nepal. Palaeobotanist 38: 293–297.

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

Gamble JS 1972. *A Manual of Indian Timbers*. London.

Gleinnie KW & Ziegler MA 1964. The Siwalik Formation in Nepal. 22nd International Geological Congress XV: 82–95.

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.

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.

Konomatsu 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.

Kumar R & Gupta VJ 1981. Stratigraphy of Nepal Himalaya. Contemporary Geoscience Researches in Himalays, Dehradun: 161–176.

Lakhanpal RN 1969. Fossil *Fissistigma* from the Lower Siwalik near Jawalamukhi, India. In: Santapau *et al*. (Editors)–J. 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.

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

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.

Nambudiri EMV 1996. Some new leaf impressions from the Deccan Intertrappean beds of India. Journal of Biological Science 9(1, 2): 30–35.

Prasad M 1990. Fossil flora from the Siwalik sediments of Koilabas, Nepal. Geophytology 19(1): 74–105.

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(1 & 2): 9–22.

Prasad M 2007. 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.

Prasad M 2008. Angiospermous fossil leaves from the Siwalik foreland basins and its palaeoclimatic implications. Palaeobotanist 57: 177–215.

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

Prasad M 2013. Record of leaf impressions from Middle Churia Formation of Arjun Khola area in the Sub–Himalayan zone of Nepal and their palaeoclimatic and palaeophytogeographical implications. Himalayan Geology 34(2): 158–167.

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 Palaeontological Society of India 53(1): 51–64.

Prasad M & Gautam S 2016. Dipterocarpaceous macrofossils from Churia Group of Arjun Khola area, western Nepal and their phytogeographical and palaeoclimatic implication. Palaeobotanist 65: 247–270.

Prasad M & Khare EG 2004. Cuticular studies on the fossil leaves from Churia (Siwalik) sediments of Arjun Khola sequence, western Nepal. Palaeobotanist 53: 105–112.

Prasad M & Pradhan UMS 1998. Studies on plant fossils from the Siwalik sediments of Far western Nepal. Palaeobotanist 48: 99–109.

Prasad M & Pandey SM 2008. Plant diversity and climate during Siwalik (Miocene–Plicene) in the Himalayan foot hills, western Nepal. Palaeontographica 278B: 13–70.

Prasad M & Tripathi PP 2000. Plant megafossils from Siwalik sediments of Bhutan and their climatic significance. Biological Memoires 26: 6–19.

Prasad M, Alok, Chauhan DK, Singh SK & Pandey SM 2017. Middle Miocene (Siwalik) megafossils from the Sub–Himalayan zone of Uttarakhand and its palaeoclimatic implications. Journal of Palaeontological Society of India 62: 97-120.

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, 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 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 & Singh SK 2013. Plant fossils from the Deccan Intertrappean sediments of Chhindwara District, Madhya Pradesh, India: their palaeoclimatic significance. Journal of Palaeontological of Society, India 58(2): 229–240.

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.

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.

Sharma CK 1980. *Geology of Nepal*. Kathmandu, Nepal.

Shashi, Pandey SM & Prasad M 2007. Siwalik (Middle Miocene) leaf impressions from Tanakpur area, Uttaranchal and their bearings on climate. Geophytology 37: 99–108.

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 SK & Prasad M 2007. Late Tertiary leaf flora of Mahuadanr Valley, Jharkhand. Journal of Palaeontological Society of India 52(2): 175–194.

Singh SK & Prasad M 2009. Fossil leaf–impressions from the Late Tertiary sediments of Mahuadanr Valley, Latehar District, Jharkhand, India. Proceedings of Diamond Jubilee International Conference, On Changing Scenario in Palaeobotany and Allied Subjects. Palaeobotanist. 57(3): 479–495.

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 GP 1998. Impact of Himalayan uplift on the Late Cenozoic flora of India. Geophytology 27: 97–102.

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.

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.

Tokuoka T, Takayasu K, Yoshida M & Hisatomi K 1986. The Churia (Siwalik) Group of Arung Khola area, west central Nepal. Memoire Faculty .of Science, Shimane University 20: 135–210.

Tokuoka T, Takayasu K, Hisatomi K, Tanaka T, Yamazaki H & Konomatsu M 1994. The Churia (Siwalik) Group in west central Nepal. Himalayan Geology 15: 23–35.