New lauraceous species from the Siwalik forest of Arunachal Pradesh, eastern Himalaya, and their palaeoclimatic and palaeogeographic implications

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Abstract: Leaf remains of 4 lauraceous taxa collected from the Siwalik sediments (Middle Miocene to Pliocene) of Arunachal Pradesh of eastern Himalaya are described in the present communication. One fossil leaf, *Cinnamomum palaeobejolghota* sp. nov., was recovered from the lower part of the Siwalik succession (Dafla Formation; Middle to Upper Miocene), while *Persea mioparviflora* sp. nov., *Persea preglaucescens* sp. nov., and *Lindera neobifaria* sp. nov. were collected from the middle part of the Siwalik succession (Subansiri Formation; Pliocene) of Arunachal sub-Himalaya. The geographic distribution of the fossils and their modern counterparts is discussed and on that basis tropical vegetation under warm and humid climate during deposition of the Siwalik sediments is suggested. The present study also suggests probable migration of these lauraceous taxa in South-East Asia.

Key words: Fossil, lauraceous leaves, Middle Miocene-Pliocene, new species, Siwalik, palaeoclimate, Arunachal Pradesh

1. Introduction

Lauraceae Juss. is a relatively primal family of angiosperms widely distributed in tropical and subtropical warm climate regions of South-East Asia and South America (Cronquist, 1981). It is one of the largest subtropical to tropical families of woody plants, with over 50 genera and 2500 to 3000 species (Rohwer, 1993).

Leaves of fossil members of the family Lauraceae are frequently found in the Tertiary deposits of India (Table 1). The occurrence of lauraz in fossil floras is significant from a palaeovegetational, palaeogeographical, and palaeoclimatic point of view. From the Siwalik strata (Middle Miocene-Lower Pleistocene) of India, Lauraceae leaves were reported frequently (Pathak, 1969; Lakhanpal and Guleria, 1978; Mathur, 1978; Lakhanpal and Awasthi, 1984; Awasthi and Lakhanpal, 1990; Antal and Awasthi, 1993; Prasad, 1994; Mathur et al., 1996; Shashi et al., 2008; Srivastava and Mehrotra, 2009; Khan et al., 2011).

During palaeobotanical fieldwork, rich and diverse types of fossil plant remains including carbonised remains of stems, leaves, seeds, and fruits were recovered from the Siwalik (Middle Miocene-Lower Pleistocene) sediments exposed along the road- and river-cutting sections in different districts of Arunachal Pradesh (situated between 26°27'52"N and 29°29'54"N and 91°29'50"E and 97°24'56"E). It is one of the north-eastern provinces of India, bordering Tibet, Bhutan, China, and Myanmar.

Among the plant remains, 4 lauraceous leaves described in the present communication resembling modern *Lindera bifaria* (Nees) Benth. ex Hook. f., *Persea parviflora* Spreng., *Persea glaucescens* (Nees) D.G.Long, and *Cinnamomum bejolghota* (Buch.-Ham.) Sweet were recovered from the road-cutting sections of the middle part (Subansiri Formation; Pliocene) and lower part (Dafla Formation; Middle-Upper Miocene) of the Siwalik strata in the West Kameng District (27°16'14.2428"N, 92°24'4.0026"E) (Figure 1). These fossil leaves are described here for the first time from the Cenozoic sediments of India. The present paper also discusses their phytogeographical and palaeoclimatic significance.

2. Materials and methods

The present study is based on 4 specimens, which are satisfactorily preserved. The specimens were first cleared with the help of a chisel and hammer and then their photographs were taken using a digital camera (Canon PowerShot A720IS). The external morphology of fossil leaves was studied with a hand lens and incident light compound microscope (Stemi SV 11, Zeiss). Identifications were made by comparison with modern lauraceous leaves collected from forests adjacent to the fossil exposures, as well as with herbarium sheets of modern lauraceous taxa kept in the Central National Herbarium (CAL), Sibpur, Howrah, West Bengal. The terminologies adopted by...
Table 1. Earlier fossil records of Lauraceae from India.

<table>
<thead>
<tr>
<th>Fossil taxa</th>
<th>Modern counterparts</th>
<th>Locality</th>
<th>Age</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cinnamomum sp.</td>
<td>Cinnamomum sp.</td>
<td>Darjeeling</td>
<td>Pliocene</td>
<td>Pathak (1969)</td>
</tr>
<tr>
<td>Cinnamomum sp.</td>
<td>Cinnamomum sp.</td>
<td>Kerala</td>
<td>Miocene</td>
<td>Awasthi and Srivastava (1992)</td>
</tr>
<tr>
<td>Cinnamomum sp.</td>
<td>Cinnamomum sp.</td>
<td>Darjeeling</td>
<td>Miocene-Pliocene</td>
<td>Antal and Awasthi (1993)</td>
</tr>
<tr>
<td>Cinnamomum nepalensis</td>
<td>C. caudatum Nees</td>
<td>Uttaranchal</td>
<td>Miocene</td>
<td>Shashi et al. (2008)</td>
</tr>
<tr>
<td>Cinnamomum miotavoyanum</td>
<td>C. tavoyanum Meisn.</td>
<td>Uttaranchal</td>
<td>Miocene</td>
<td>Shashi et al. (2008)</td>
</tr>
<tr>
<td>Persea sp.</td>
<td>Persea sp.</td>
<td>Kashmir</td>
<td>Pleistocene</td>
<td>Puri (1949)</td>
</tr>
<tr>
<td>Persea villosa</td>
<td>Persea sp.</td>
<td>Darjeeling</td>
<td>Pliocene</td>
<td>Pathak (1969)</td>
</tr>
<tr>
<td>Persea punyagiriensis</td>
<td>Persea odoratissima (Nees)</td>
<td>Uttaranchal</td>
<td>Miocene</td>
<td>Lakhanpal and Guleria (1978)</td>
</tr>
<tr>
<td>Persea lakhanpali</td>
<td>Persea lanceolata Nees</td>
<td>Himachal Pradesh</td>
<td>Oligocene</td>
<td>Mathur et al. (1996)</td>
</tr>
<tr>
<td>Persea sibdasii</td>
<td>Persea lanceolata Nees</td>
<td>Himachal Pradesh</td>
<td>Miocene</td>
<td>Mathur et al. (1996)</td>
</tr>
<tr>
<td>Actinodaphne palaoangustifolia</td>
<td>A. angustifolia Nees</td>
<td>Arunachal Pradesh</td>
<td>Pliocene-Pleistocene</td>
<td>Khan et al. (2011)</td>
</tr>
<tr>
<td>Actinodaphne cf. obovata</td>
<td>A. obovata Blume</td>
<td>Arunachal Pradesh</td>
<td>Pliocene-Pleistocene</td>
<td>Khan et al. (2011)</td>
</tr>
<tr>
<td>Lindera cf. pulcherrima</td>
<td>L. pulcherrima Benth.</td>
<td>Arunachal Pradesh</td>
<td>Pliocene-Pleistocene</td>
<td>Khan et al. (2011)</td>
</tr>
<tr>
<td>Michilus sp.</td>
<td>Michilus sp.</td>
<td>Darjeeling</td>
<td>Pliocene</td>
<td>Pathak (1969)</td>
</tr>
<tr>
<td>Michilus miocenica</td>
<td>M. odoratissima Nees</td>
<td>Uttaranchal</td>
<td>Miocene</td>
<td>Prasad (1994)</td>
</tr>
<tr>
<td>Machilus neyveliensis</td>
<td>Machilus sp.</td>
<td>Tamil Nadu</td>
<td>Miocene</td>
<td>Agarwal (2002)</td>
</tr>
<tr>
<td>Litsea bhatiai</td>
<td>Litsea consimilis Nees</td>
<td>Himachal Pradesh</td>
<td>Pleistocene</td>
<td>Mathur (1978)</td>
</tr>
<tr>
<td>Litsea prenita</td>
<td>Litsea nitida Nees</td>
<td>Bihar</td>
<td>Miocene</td>
<td>Lakhanpal and Awasthi (1984)</td>
</tr>
<tr>
<td>Litsea sastryi</td>
<td>Litsea citrata Blume</td>
<td>Himachal Pradesh</td>
<td>Miocene</td>
<td>Mathur et al. (1996)</td>
</tr>
<tr>
<td>Litsea preglabrata</td>
<td>L. glabra (Wall ex Nees)</td>
<td>Arunachal Pradesh</td>
<td>Miocene</td>
<td>Srivastava and Mehrotra (2009)</td>
</tr>
<tr>
<td>Litsea cf. salicifolia</td>
<td>L. salicifolia Roxb.</td>
<td>Arunachal Pradesh</td>
<td>Pliocene-Pleistocene</td>
<td>Khan et al. (2011)</td>
</tr>
<tr>
<td>Phoebe sublancoelata</td>
<td>Phoebe lanceolata Nees</td>
<td>Nangwalbibra, North-East India</td>
<td>Palaeocene</td>
<td>Bhattacharyya (1983)</td>
</tr>
<tr>
<td>Phoebe champarensis</td>
<td>Phoebe lanceolata Nees</td>
<td>Bihar</td>
<td>Miocene</td>
<td>Awasthi and Lakhanpal (1990)</td>
</tr>
</tbody>
</table>
Dilcher (1974) were followed for description of the fossil leaves. All the specimens are kept in the Herbarium cum Museum of the Department of Botany, University of Calcutta (CUH).

2.1. Geology

The Siwalik sediments lie along the foothills of Arunachal Pradesh and are subdivided into the Lower Siwalik (Dafla Formation, Middle to Upper Miocene), Middle Siwalik (Subansiri Formation; Pliocene), and Upper Siwalik (Kimin Formation, Upper Pliocene to Lower Pleistocene) as exposed in reverse stratigraphic order (Kumar, 1997). The northern limit of the Siwalik group is defined by the Main Boundary Fault, separating it from the pre-Tertiary sequence, while in the south the Brahmaputra Alluvium of the Brahmaputra Plain defines its boundary. The Main Frontal Thrust separates Siwalik sediments from the Quaternary Assam Alluvium (after Joshi et al., 2003). At places the contacts between the Lower and Middle and the Middle and Upper Siwalik are also tectonised and faulted (Table 2).

The middle part of the Siwalik strata is characterised by medium- to fine-grained sandstones and siltstones, locally interbanded with carbonaceous shale and also containing bright fragments of coal/coalified woods. In comparison to the Lower Siwalik, the rocks are more friable and loose. Coarse-grained sandstones at the base are successively overlain by greenish yellow siltstones with profuse ichnofossils, greenish yellow splintery shale, grey silty shale with mud cracks, ripple marks, onion-skin

Table 2. Generalised lithotectonic sequence in the West Kameng District, Arunachal Pradesh (after Joshi et al., 2003).

<table>
<thead>
<tr>
<th>North</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gondwana Group</strong></td>
<td><strong>Carbonaceous shale, sandstone and coal</strong></td>
</tr>
<tr>
<td>.............................................</td>
<td>.............................................</td>
</tr>
<tr>
<td><strong>Lower Siwalik (Dafla Formation)</strong></td>
<td><strong>Well-indurated sandstone, shale, and siltstone with plant fossils</strong></td>
</tr>
<tr>
<td>.............................................</td>
<td>.............................................</td>
</tr>
<tr>
<td><strong>Middle Siwalik (Subansiri Formation)</strong></td>
<td><strong>Weakly indurated sandstone, shale, and siltstone with plant fossils</strong></td>
</tr>
<tr>
<td>.............................................</td>
<td>.............................................</td>
</tr>
<tr>
<td><strong>Upper Siwalik (Kimin Formation)</strong></td>
<td><strong>Sand rock and claystone/shale with plant fossils, fossil wood</strong></td>
</tr>
<tr>
<td>.............................................</td>
<td>.............................................</td>
</tr>
<tr>
<td><strong>Assam Alluvium/ Quaternary deposits</strong></td>
<td></td>
</tr>
</tbody>
</table>
like weathering features, friable yellow-coloured fractures, and silty shale with plant fossils (Figure 2). The lower part of the Siwalik strata is represented by interbanded medium- to fine-grained sandstones and shale containing lenses/fragments of woody materials and lignitic coal. The shale fraction locally contains plant fossils. The rocks are in general compacting, hard, indurated, sheared, and slickensided (Figure 2). Recently, on the basis of magnetostratigraphic data, Chirouze et al. (2012) proposed that the Siwalik Formation in the Kameng section of Arunachal Pradesh was deposited between 13 and 2.5 Ma. The transition between the Lower and Middle Siwaliks is dated at about 10.5 Ma and the Middle to Upper Siwaliks transition is dated at 2.6 Ma.

3. Results

3.1 Systematic description

Family: Lauraceae Juss.
Genus: Lindera Thunb.
Lindera neobifaria Khan & Bera sp. nov. (Figure 3).

Diagnosis: Asymmetrical, elliptic; lamina length 4.5 cm and width 2.1 cm; base asymmetrical, acute; entire margin; eucamptodromous venation; angle of divergence of secondary veins acute; tertiary veins RR, percurrent.

Description: Leaf simple, asymmetrical, elliptic; preserved maximum lamina length 4.5 cm and maximum width 2.1 cm; apex acuminate; base asymmetrical, acute; margin entire; texture chartaceous; petiole missing; venation pinnate, eucamptodromous; primary vein (1º) single, stout, more or less straight; secondary veins seemingly 4 pairs preserved, 0.2 cm to 1 cm apart, alternate, basal secondaries more acute than upper secondaries, secondary veins (2º) uniformly curved up, unbranched, angle of divergence acute, moderate, 50°–60°; tertiary veins (3º) poorly preserved, angle of origin nearly RR, percurrent, oblique in relation to midvein.

Materials: There are 2 well-preserved leaf impressions, the first is complete and the other is without the basal part.

Type: Road section, Bhalukpong area, opposite from Jangchip Chorten of West Kameng District, Arunachal Pradesh (Holotype: Specimen no. CUH/PPL/B/21). Same locality; (Paratypes: CUH/PPL/B/21a; CUH/PPL/B/21b).

Stratigraphic horizon: Middle part of the Siwalik succession of sediments (Subansiri Formation).

Age: Pliocene.

Etymology: Adding the prefix 'neo' to the modern comparable specific epithet bifaria.

Remarks: In order to compare and find the nearest generic affinity of the present fossil leaf, several modern

Figure 2. a- Lithological column for part of exposed road-section, Bhalukpong, opposite Jangchip Chorten (middle part of the Siwalik strata), b- lithological column for part of exposed road-section along Bhalukpong-Pinjoli road near culvert no. 48/1 (lower part of the Siwalik strata).
genera of Lauraceae were examined. The fossil specimen shows resemblance to the extant leaves of some genera of this family such as *Actinodaphne* Nees, *Litsea* Lamk., *Persea* Mill., and *Lindera* Thunb. Among the species of *Actinodaphne*, *A. angustifolia* Nees and *A. hirsuta* Blume show fairly good resemblance to the fossil leaf, but *A. angustifolia* differs in being larger in size, and the latter species differs in having comparatively more attenuate apex. The secondary veins in *A. angustifolia* towards the apical part are comparatively more sparsely arranged. On the other hand, secondaries in *A. hirsuta* are relatively more densely arranged.

The above-mentioned diagnostic features of the present fossil leaf indicate close resemblance of the fossil leaf to the modern genus *Lindera* Thunb. of the family Lauraceae. Herbarium sheets of the available modern species of this genus were critically examined and it was found that only 2 species, *Lindera bifaria* (Nees) Benth. ex Hook. f. and *Lindera pulcherrima*, are close to the fossil. In *L. pulcherrima*, the secondary veins are relatively more widely spaced and the apex is comparatively more attenuate than in the fossil specimen. Curvature of secondaries is also dissimilar. The leaves of *L. bifaria* show closer similarity to the fossil leaf in size, shape, and venation pattern (Figure 3).

Earlier, a fossil leaf resembling the genus *Lindera* Thunb. was reported by Khan et al. (2011) from the upper part of the Siwalik sediments of Itanagar area in the Papumpare District of Arunachal Pradesh under the fossil species *Lindera cf. pulcherrima*. The present fossil leaf has been compared with the above known species and it was found that it differs from *Lindera cf. pulcherrima* (Khan et al., 2011) in having eucamptodromous venation as compared to the camptodromous-brochidodromous venation pattern in earlier reported species. On the basis of such differences, it has been described as a new species, *Lindera neobifaria* Khan & Bera sp. nov.

Genus: *Persea* Mill.

*Persea mioparviflora* Khan & Bera sp. nov. (Figure 4).

**Diagnosis:** Narrow elliptic shape; length 7 cm, width 1.5 cm; apex and base acute; entire margin; eucamptodromous venation; angle of divergence of secondary veins acute to right angle; absence of intersecondary veins.

**Description:** Leaf symmetrical, simple, very narrowly elliptic; preserved lamina length 7 cm, maximum width 1.5 cm; apex seemingly acute; base wide acute; margin entire; texture coriaceous; venation pinnate, eucamptodromous; primary vein (1º) single, prominent, straight, slightly curved at the basal portion, thicker towards the base; secondary veins (2º) only 4 pairs visible, 0.7 to 1.2 cm apart, curved up, angle of divergence acute to right angle (60°–80°), alternate to opposite, unbranched, thinner towards the margin; intersecondary veins absent; tertiary veins (3º) not preserved.

**Material:** There is a single satisfactorily preserved specimen.

**Type:** Road section, Bhalukpong area, opposite from Jangchip Chorten of West Kameng District, Arunachal Pradesh (Holotype: Specimen no. CUH/PPL/B/20).
On critical examination it was found that the fossil shows better resemblance to the leaves of Persea. Only 5 species of Persea are close to the fossil: *P. parviflora* Spreng., *P. duthiei* (King ex. Hook. f.) Kosterm., *P. odoratissima* (Nees) Kosterm., *P. kingii* (Hook. f.) Kosterm., and *P. gamblei* (King ex. Hook. f.) Kosterm. In *P. duthiei*, *P. odoratissima*, *P. kingii*, and *P. gamblei* the apex is acuminate, whereas in the fossil specimen it is acute. Furthermore, secondary veins in these species of *Persea* are comparatively more densely arranged. On the basis of leaf morphology (size, shape, nature of apex and base, texture, and venation pattern), *P. parviflora* shows the closest resemblance to the fossil specimen (Figure 4).

So far, 5 fossil leaves resembling the genus *Persea* Mill. are known from the Indian subcontinent. These are *Persea* (*Machilus*) *villosa* (Pathak, 1969), *Persea* (*Machilus*) sp. (Puri, 1949), *Persea puryagiriensis* (Lakhanpal and Guleria, 1978), *Persea lakhanpalii* (Mathur et al., 1996), and *Persea sibdassii* (Mathur et al., 1996). The first 3 fossil specimens are incomplete and differ from *Persea lakhanpalii* and *Persea sibdassii*. The last 2 specimens resemble modern *Persea lanceolata* Nees in lanceolate shape of the lamina, craspedodromous venation, acute base, apex, and secondaries. However, our fossil specimen is distinct from the above-described fossil specimens and closely resembles the extant *Persea parviflora* Spreng. in its very narrow elliptic shape, eucamptodromous venation, and wide acute base. As the present fossil leaf is distinct from the earlier described fossil specimens, a new species, *Persea mioparviflora* Khan & Bera sp. nov., is suggested.

**Genus: Persea Mill.**

*Persea preglaucens* Khan & Bera sp. nov. (Figure 5).

**Diagnosis:** Narrowly elliptic; lamina length 3.2 cm, width 1.9 cm; base acute; margin entire; eucamptodromous; angle of divergence of secondary veins acute; intersecondary veins present; tertiary veins fine with an angle of origin RR and percurrent.

**Description:** Leaf simple, symmetrical, simple, narrow elliptic; preserved lamina length 3.2 cm, maximum width 1.9 cm; apex broken; base acute; margin entire; texture coriaceous; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, straight, slightly curved, thicker in the basal portion than in the middle and upper portion; secondary veins (2°) only 4 pairs visible, 0.5 to 0.9 cm apart, uniformly curved up, angle of divergence acute, narrow to moderate (40°–60°), alternate-opposite, unbranched; intersecondary veins present; tertiary veins (3°) fine with an angle of origin RR, percurrent, branched, alternate to opposite, oblique in relation to midvein and close.

**Material:** The species is based on a single, well-preserved, almost complete leaf impression.

**Type:** Road section, Bhalukpong area, opposite from Jangchip Chorten of West Kameng District, Arunachal Pradesh (Holotype: Specimen no. CUH/PPL/B/19).

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**Figure 4.** *Lindera* leaves. a- Fossil leaf of *Lindera mioparviflora* showing shape, size, base (marked by black arrow), and venation pattern; b- modern leaf of *Persea parviflora* showing similar shape, size, base (marked by black arrow), and venation pattern; c- enlarged portion of the fossil leaf of *Lindera mioparviflora* showing primary vein (red arrow) and secondary vein (yellow arrow); d- enlarged portion of the modern leaf of *Persea parviflora* showing similar primary vein (red arrow) and secondary vein (yellow arrow). Scale bar = 1 cm.
Stratigraphic horizon: Middle part of the Siwalik succession of sediments (Subansiri Formation).

Age: Pliocene.

Etymology: Adding the prefix ‘pre’ to the modern comparable specific epithet *glaucescens*.

Remarks: Size, shape, texture, and venation pattern strongly indicate that the present fossil shows closest affinity with the extant leaves of *Persea*. Comparisons were also made with the leaves of other 2 genera of the family Lauraceae, *Litsea* Lamk. and *Persea* Mill., showing apparent similarity with the fossil. Two species of *Litsea*, *Litsea monopeltata* (Roxb.) Pers. and *Litsea tomentosa* Heyne, show similarity with the fossil, but in both of them the leaves are comparatively larger.

On thorough examination it was found that only 3 species of *Persea*, *P. glaucescens* (Nees) D.G.Long, *P. fructifera* Kosterm., and *P. gamblei* (King ex Hook. f.) Kosterm., are comparable to the fossil specimen. Leaves of *P. fructifera* are longer and narrower than the fossil leaf. Moreover, secondary veins are bifurcated towards the margin. Leaves of *P. gamblei* attain a lanceolate shape in contrast to the narrow elliptic shape in the present fossil specimen. Besides, the secondaries are comparatively more widely spaced. The fossil specimen thus shows closest resemblance to the modern leaves of *Persea glaucescens* in size, shape, and vein architecture (Figure 5).

Among the fossil leaves of *Persea* from the Indian subcontinent, 3 specimens, *Persea* (*Machilus*) *villosa* (Pathak, 1969), *Persea* (*Machilus*) sp. (Puri, 1949), and *Persea puryagiriensis* (Lakhanpal and Guleria, 1978), are incomplete and their photographs are not very clear. It is thus not possible to compare these specimens with the present fossil specimen. Two other earlier reported specimens, *Persea lakhanpali* (Mathur et al., 1996) and *Persea sibdasii* (Mathur et al., 1996), differ in having lanceolate shape of the lamina in contrast to the narrow elliptic shape of the fossil leaf. Moreover, venation pattern of both specimens is of the craspedodromous type, while venation pattern of the present fossil is of the eucamptodromous type. As our fossil specimen is distinct from the earlier reported fossil specimens of *Persea* in size, shape, and venation pattern, a new species, *Persea preglaucescens* Khan & Bera sp. nov., is suggested.

Genus: *Cinnamomum* Schaeffer

*Cinnamomum palaeobejolghota* Khan & Bera sp. nov. (Figures 6 and 7).

**Diagnosis:** Narrowly oblong; length 10.08–11.50 cm and maximum breadth 3.6–4 cm; acute base; margin entire; venation basal acrodromous, secondary veins running approximately at right angles to acute angles, intramarginal veins present.

**Description:** Leaf simple, symmetrical, obovate, narrow oblong; preserved maximum length 10.08–11.50 cm and maximum breadth 3.6–4 cm; apex broken; base acute; margin entire; texture coriaceous; venation basal acrodromous, perfect; primary vein (1ª) 3, stout, almost straight, 2 lateral primaries slightly curved, unbranched; secondary veins (2ª) fine, running approximately at right angles to acute angles, sometimes branched, arising from the median primary and joining the 2 laterals, also arising from the outer side of the 2 lateral primaries at acute angle and moving upward and forming the intramarginal veins; tertiary veins (3ª) with angle of origin RR, percurrent, unbranched, relationship to midvein at right angles, opposite; further venation details not observed.

Materials: There are 7 well-preserved specimens; 3 are almost complete, and some specimens are incomplete, containing only the basal portion.
Type: Road-cutting section along East Pinjoli of the West Kameng District, Arunachal Pradesh (Holotype: Specimen no. CUH/PPL/P/29a). Same locality (Paratypes: CUH/PPL/P/29b; CUH/PPL/P/2; CUH/PPL/P/9b; CUH/PPL/P/27a-c).

Stratigraphic horizon: Lower part of the Siwalik succession (D afla Formation).

Age: Middle to Upper Miocene.

Etymology: Adding the prefix 'palaeo' to the modern comparable specific epithet bejolghota.

Remarks: The most important diagnostic feature of the recovered fossil leaves, i.e. basal acrodromous venation with 2 lateral primary veins, indicates their resemblance to the leaves of only 3 genera, Cinnamomum Schaeffer, Neolitsea (Bentham & J.D.Hooker) Merrill, and Lindera Thunb., of the family Lauraceae. Two species of Lindera show general similarity with the fossils, L. caudata Nees and L. melastomecea Fern.-Vill., but in both of them the leaves are relatively smaller. Moreover, the middle part of the leaves is broadest, whereas in the fossil specimens the upper half is broader. Leaves of some species of Neolitsea (such as N. scorbiculata Gamble) show fairly good resemblance to the fossil leaf, but the shape in Neolitsea is ovate in contrast to the narrow oblong shape of the

Figure 6. Cinnamomum leaves. a- Fossil leaf of Cinnamomum palaeobejolghota showing base, shape, size, and venation pattern; b- modern leaf of Cinnamomum bejolghota showing similar base, shape, size, and venation pattern; c- enlarged portion of the fossil leaf of Cinnamomum palaeobejolghota showing median primary vein (red arrow), lateral primary vein (yellow arrow), secondary vein (blue arrow), and tertiary vein (green arrow); d- enlarged portion of the modern leaf of Cinnamomum bejolghota showing similar median primary vein (red arrow), lateral primary vein (yellow arrow), secondary vein (blue arrow), and tertiary vein (green arrow). Scale bar = 1 cm.

Figure 7. Cinnamomum leaves. a- Enlarged portion of the fossil leaf of Cinnamomum palaeobejolghota showing median primary vein (red arrow), lateral primary vein (yellow arrow), secondary vein (blue arrow), and branched secondary vein (white arrow); b- enlarged portion of the modern leaf of Cinnamomum bejolghota showing similar median primary vein (red arrow), lateral primary vein (yellow arrow), secondary vein (blue arrow), and branched secondary vein (white arrow); c- enlarged basal portion of the fossil leaf of Cinnamomum palaeobejolghota showing median primary vein (red arrow), lateral primary veins (yellow arrows), and basal portion of primary vein (white arrow); d- enlarged basal portion of the modern leaf showing median primary vein (red arrow), lateral primary veins (yellow arrows), and basal portion of primary vein (white arrow). Scale bar = 1 cm.
fossil specimen. Furthermore, the leaves in Neolitsea are relatively smaller. The fossil specimens thus show closer resemblance to the leaves of *Cinnamomum*. Gamble (1972) enumerated 24 species of this genus from India.

The fossil leaves have been compared with different modern species of *Cinnamomum* such as *C. pauciflorum* Nees, *C. burmannii* Blume, *C. tavoymatum* Meisn., *C. tamala* (Buch.-Ham.) T.Nees & Eberm., *C. sulphuratum* Nees, *C. obtusifolium* Nees, *C. caudatum* Nees, *C. zeylanicum* Blume, *C. camphora* (L.) J.Presl., *C. nitidum* Blume, *C. bejolghota* (Buch.-Ham.) Sweet, and *C. macrocarpum* Hook. f., and it was found that they have the best resemblance to *Cinnamomum bejolghota* in size, shape, and venation pattern (Figures 6 and 7). Leaves of *C. tavoymatum*, *C. tamala*, *C. sulphuratum*, *C. obtusifolium*, *C. caudatum*, *C. zeylanicum*, and *C. camphora* attain an ovate-elliptic shape as compared to the narrow oblong shape in the present fossil specimens. On the other hand, leaves of *C. pauciflorum*, *C. burmannii*, and *C. nitidum* are comparatively smaller in size. Moreover, the lateral primary veins of these modern leaves lost their identity towards the apical part. In *C. pauciflorum*, the lamina is lanceolate-ovate in shape. In leaves of *C. macrocarpum*, the middle part is broadest, in contrast to the upper broader part in the present fossil specimens. However, lateral primary veins as well as basal part are comparatively less acute than those in the fossil specimens.

There are 10 fossil records of *Cinnamomum* leaves from India and Nepal (Table 1). Pathak (1969) reported a leaf of *Cinnamomum* sp. cf. *C. tamala* Nees. from the Middle Siwalik sediments in the Mahanadi River section, near Darjeeling, West Bengal. *C. eokachchhensis* (Lakhanpal and Guleria, 1981) was reported from the Eocene of Kachchh, western India, while *C. palaeotamala* (Lakhanpal and Awasthi, 1984) was described from the Siwalik sediments of Bhikhnhathoree, West Champaran District of Bihar. *C. palaeotamala* was also reported from the Lower Siwalik sediments of Nepal by Konomatsu and Awasthi (1996). *C. mioinuctum* (Prasad, 1990) was described from the Lower Siwalik sediments exposed near Koilbas, Nepal. Awasthi and Srivastava (1992) and Antal and Awasthi (1993) reported *Cinnamomum* sp. from the Warkalli Formation (Miocene) of Kerala and from the Lower-Middle Siwalik sediments of Darjeeling, West Bengal, respectively. Prasad and Pandey (2008) and Shashi et al. (2008) described another leaf of *C. nepalensis* from the lower Siwalik sediments of Surai Khola, western Nepal, and Uttarakhand, respectively. A fossil leaf of *Cinnamomum tavoymatum* Meisn. was also reported by Shashi et al. (2008) from the Lower Siwalik sediments of Uttarakhand.

A comparison of the present fossil leaves with all the above known species showed that earlier described species differ from the present fossils in size, shape, and venation pattern. *C. mioinuctum* differs from the present fossils in having an eucamptodromous type of venation as compared to the acrodromous venation. The other earlier reported species, such as *C. miotavoyanum*, *C. nepalensis*, *C. palaeotamala*, *Cinnamomum* sp., and *C. eokachchhensis*, mostly differ in possessing an ovate to narrow elliptic shape in contrast to the narrow oblong shape in the present fossils. Moreover, in these specimens, the middle part is broadest, in contrast to the upper broader part in the present fossil specimens. The present fossil leaves have thus been assigned a new specific name, *Cinnamomum palaeobejolghota* Khan & Bera sp. nov.

4. Discussion
The leaf remains described in the present communication, along with the earlier fossil records from the Dafila Formation (= lower part of the Siwalik) and Subansiri Formation (= middle part of the Siwalik) of the West Kameng District, are useful in evaluating the palaeoclimate of the region.

Most of the earlier fossil records of the Lauraceae come from the Siwalik sedimentary strata of India (except Jammu and Nepal, i.e. the Middle (Pliocene) and Lower (Middle Miocene) Siwalik sediments of Himachal Pradesh (Mathur, 1978; Mathur et al., 1996); the Lower Siwalik (Middle Miocene) sediments of the Kathgodam area, Uttarakhand (Lakhanpal and Guleria, 1978; Prasad, 1994; Shashi et al., 2008); the Lower-Middle Siwalik sediments (Middle Miocene to Pliocene) of Darjeeling (Pathak, 1969; Antal and Awasthi, 1993); the Lower Siwalik (Middle to Upper Miocene) sediments of West Kameng District, Arunachal Pradesh (Srivastava and Mehrotra, 2009); the Upper Siwalik (Upper Pliocene-Lower Pleistocene) of Papumpare District, Arunachal Pradesh (Khan et al., 2011); and the Lower Siwalik (Middle Miocene) sediments of western Nepal (Prasad, 1990; Konomatsu and Awasthi, 1996; Prasad and Pandey, 2008). The present record of lauraceous leaves from the Lower (Middle to Upper Miocene) and Middle Siwalik (Pliocene) sediments of Arunachal Pradesh in appreciable number and earlier records suggest that it was a common forest element growing in parts of north-western, central, and eastern Himalayan sectors during the Siwalik sedimentation (Middle Miocene-Lower Pleistocene).

On the basis of geographic distribution and climatic preferences of the modern comparable taxa, it appears that the studied lauraceous taxa are confined to the evergreen forests of India and neighbouring South-East Asian countries where conditions are more suitable for their luxuriant growth. *Lindera bifaria* (Ness) Hook. f., the nearest modern counterpart of one fossil specimen, is a small evergreen tree (2–10 m tall) growing in valleys or on mountain slopes (700–2500 m) of China (Fujian,
Guangdong, Guangxi, Hainan, Jiangxi, Sichuan, SE Xizang, Yunnan), Myanmar (Kachin, Mandalay), Bhutan, India, Nepal, and Vietnam (Brandis, 1971; Gamble, 1972). In India, this species occurs in the Himalaya from Kumaon eastwards (1524 m), Manipur, Upper Assam, Mishmi Hills, and Khasi Hills (914–1219 m). The other comparable taxon, Persea glaucescens (Nees) D.G.Long, is a medium-sized evergreen tree (8–22 m tall) found to grow in China (Yunnan), Bangladesh, Bhutan, India (Western Ghats and adjoining hill ranges, sub-Himalayan tract), Myanmar, and Nepal. Persea parviflora Spreng. is a small tree distributed in the evergreen forests of India (Khasi Hills, Assam, at 1219–1524 m) and the Malayan region (Brandis, 1971; Hooker, 1999). Cinnamomum bejolghota (Buch.-Ham.) Sweet, the nearest modern counterpart of our fossil specimens, grows in the sparse or dense evergreen forests on mountain slopes and valleys (600–1800 m) of China (Guangdong, Hainan, Yunnan), Bangladesh, Bhutan, India, Laos, Myanmar, Nepal, Thailand, and Vietnam (Gamble, 1972).

There is a well-accepted hypothesis that the land connection between the Indian plate and the mainland masses of South-East Asia was established during the Neogene (Smith and Briden, 1979), causing possible migration of some tropical plants from South-East Asia to the Indian subcontinent and vice versa (Bande and Prakash, 1986). So far, the present fossil taxa have not been reported from either the Palaeogene or the Neogene of South-East Asia (Bande and Prakash, 1986; Mehrotra et al., 2005), and their present occurrence from the Neogene of India suggests a probable migration of these lauraceous taxa from the Indian landmass to South-East Asian regions after the land connections between these 2 land masses were established during the Neogene (Figure 8).

It is interesting to note that, at present, Persea parviflora is not a common element in the vegetation of the West Kameng District from which the fossil leaves were recovered (Giri et al., 2008). This species is now growing in the dense tropical evergreen rain forests of the Siang and Tirap districts. It is presumed that significant

![Figure 8. Showing modern distribution and possible migratory path of studied lauraceous taxa in South-East Asia.](image-url)
drying of the climate due to the Himalayan orogeny during Miocene to Pliocene times might be a possible reason for the disappearance of this species of Lauraceae from the present-day vegetation in the fossil locality and that it migrated to the moist evergreen forests of the bordering districts of Arunachal Pradesh and adjoining south-east Asian regions.

It is thought that after the first (HOM-1 during Middle Eocene) and second (HOM-2 in Upper Oligocene) phases of the Himalayan orogenic movement (HOM), the Siwalik sedimentation in Arunachal Pradesh continued through the Miocene into the Lower Pliocene (Kumar, 1997). Epeirogenic uplift of Himalaya (HOM-3) became quite strong during the Upper Pliocene and Siwalik sedimentation terminated due to strong compressional forces of the last phase of the HOM (HOM-4).

Thus, gradual changes in climate and physiography mainly caused by the strong uplift of the Himalaya through Miocene to Lower Pliocene time brought considerable alteration and diversification in the floral pattern. Some of the taxa could adapt to the changed climatic conditions and continued to flourish there, while others either suffered extinction in the region or migrated to suitable areas with tropical littoral and swampy conditions. Thus, it is assumed that *Persea parviflora* might have disappeared from West Kameng and adjoining areas of the Arunachal sub-Himalaya and later migrated to regions with congenial ecoclimatic conditions for its survival.

Based on analysis of the nearest living species, we conclude that the climate of the Siwalik sediments in the West Kameng District during the Mio–Pliocene was close to that of the areas of distribution of the living relatives. The modern analogues of fossil specimens described above form a natural association in the evergreen forests of India and South-East Asia and suggest that during Siwalik sedimentation forests developed under a tropical, warm, humid climate. This is consistent with the earlier interpretations based on megaplant fossil data (Mehrotra et al., 1999; Bera et al., 2004; Joshi et al., 2003; Joshi and Mehrotra, 2007; Khan and Bera, 2007, 2010; Bera and Khan, 2009; Srivastava and Mehrotra, 2009; Khan et al., 2008, 2009, 2011). However, at present, a tropical semievergreen forest cover is found in the area investigated (Hazra et al., 1996). This clearly shows that there has been a substantial change in the climate of this region since the Mio–Pliocene time. Furthermore, Himalayan uplift is likely to have been responsible for this change. Foliar physiognomic characters of the fossil leaves such as tip, base, size, margin, and venation pattern are also in conformity with our interpretation of climatic conditions in the Arunachal sub-Himalaya during Siwalik sedimentation.

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**References**


