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Plant fossils from Dafla Formation, West Kameng District, Arunachal Pradesh

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ABSTRACT

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Dicotyledonous leaf impressions collected from the Dafla Formation (=Lower Siwalik) of Arunachal Pradesh are described in the present communication. The fossils belong to Middle–Upper Miocene in age and comprise of seven genera belonging to six families, namely, *Tabernaemontana precoronaria* Prasad (Apocynaceae), *Salacia miocenica* sp. nov. (Celastraceae), *Millettia koilabasensis* Prasad (Fabaceae), *Actinodaphne palaeomalabarica* sp. nov. and *Litsea preglabrata* sp. nov. (Lauraceae), *Memecylon arunachalensis* sp. nov. (Melastomataceae) and *Randia miowallichii* Prasad (Rubiaceae). In addition, *Dicotylophyllum breyniodes* sp. nov., a dicotyledonous leaf of uncertain affinities, is also reported. The distribution of modern counterparts of the fossils indicates tropical vegetation suggesting warm and humid climate during the deposition of the sediments.

Key-words—Leaf impressions, Dafla Formation, Tropical, Middle-Upper Miocene, Arunachal Pradesh.

अरूणाचल प्रदेश में पश्चिमी कामेंग जिले के डाफ्ला शैलसमूह से प्राप्त पादप जीवाश्म

रश्मि श्रीवास्तव एवं आर.सी. मेहरोत्रा

सारांश

अरूणाचल प्रदेश के डाफ्ला शैलसमूह (निम्न शिवालिक) से संगृहीत द्विबीजीपत्री पत्तियों के मुद्राश्म मौजूदा संप्रेषण में वर्णित हैं। जीवाश्म मध्य-ऊपरी मध्यनूतन (मायोसीन) आयु के हैं तथा छः कुटुंबों, नामतः *टेबर्नेमोनटाना प्रीकोरोनेरिया* प्रसाद (एपोसायनेसी), *सेलेसिया मायोसेनिका* नवजाति (सेलेसट्रेसी), *मिलेशिया कोइलाबासेन्सिस* प्रसाद (फैबेसी), *एक्टिनोडेफ्ने पेलियोमालाबारिका* नवजाति एवं *लिट्सिया प्रिग्लैब्रेटा* नवजाति (लॉरेसी), *मेमेसीलॉन अरुणाचलेन्सिस* नवजाति (मेलेस्टोमेटेसी) और *रेन्डिया मायोवेलीचीयाई* प्रसाद (रुबिएसी) सात वंश सन्निहित हैं। इसके अतिरिक्त, अनिश्चित बंधुताओं की एक द्विबीजीपत्री पत्ती *डाइकोटिलोफिल्लम ब्रायनिओएडिस* नवजाति भी मिली है। जीवाश्मों के आधुनिक प्रतिरूपों का वितरण अवसादों के निक्षेपण के दौरान कोष्ण एवं आर्द्र जलवायु सुझाते हुए उष्णकटिबंधीय वनस्पति इंगित करते हैं।

संकेत-शब्द—पत्ती मुद्राश्में, डाफ्ला शैलसमूह, उष्णकटिबंधीय, मध्य ऊपरी, मध्यनूतन, अरूणाचल प्रदेश।

INTRODUCTION

Plant fossils from the Dafla Formation (=Lower Siwalik) of the Kameng region of Arunachal Pradesh are poorly known. Recently Joshi and Mehrotra (2003, 2007) have described pteridophytic and angiospermic remains from the area, viz., *Thelyptridaceophyllum tertiarum* (Thelyptridaceae), *Fissistigma palaeobicolor* (Anonaceae), *Calophyllum suraikholaensis* (Clusiaceae), *Shorea palaeoridleyana* and *S. neoassamica* (Dipterocarpaceae), *Amesoneuron* sp. (Arecaceae) and *Bambusa siwalika* (Poaceae). The fossils belong to Middle–Upper Miocene in age.

The material for the present study was collected from the Pinjoli Nala section situated on the hillock near Bhalukpong- Bomdila Road, West Kameng District, Arunachal Pradesh (Fig. 1). In this location, the rock

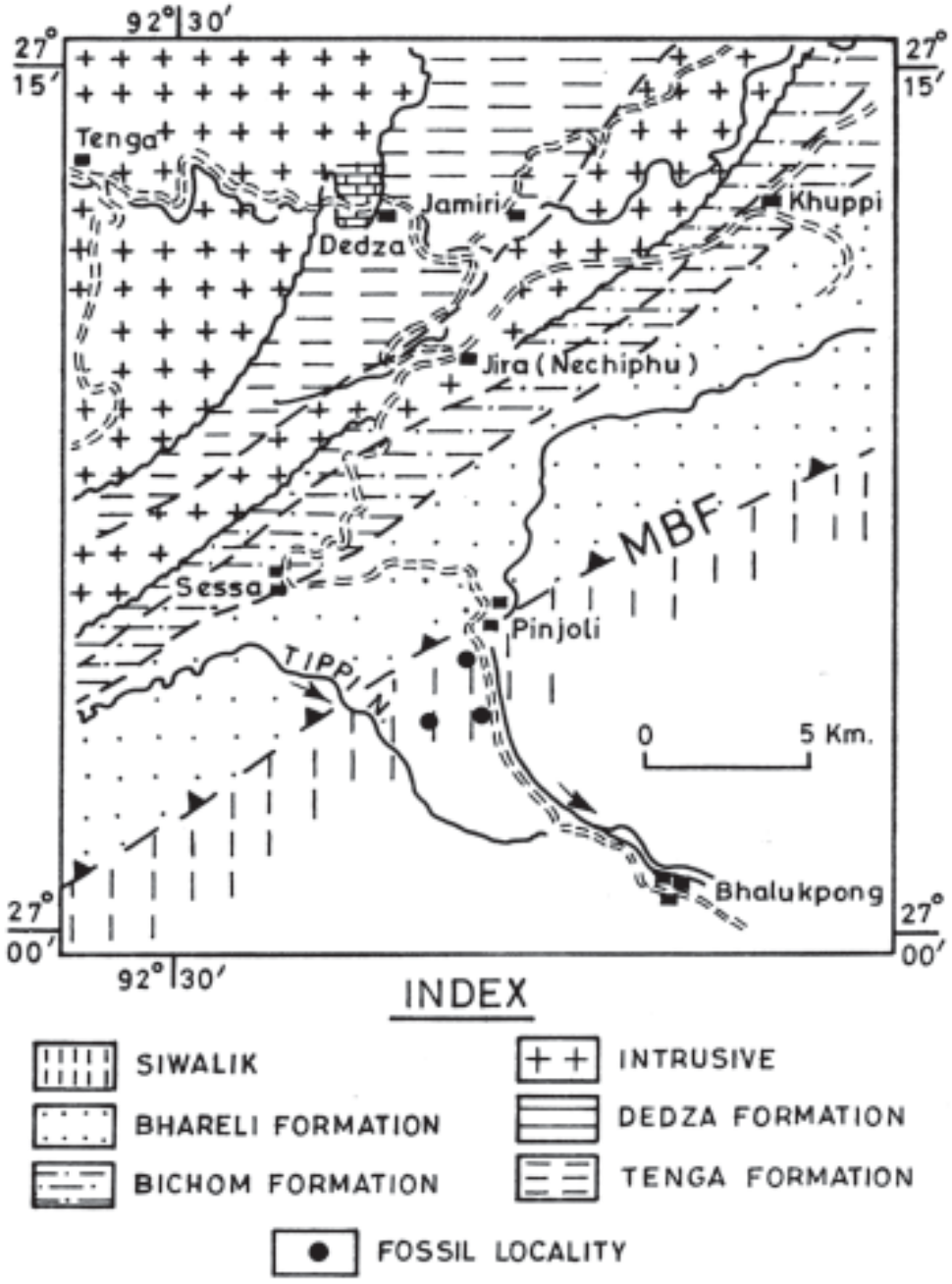

Fig. 1—Geological map of the area showing the fossil locality (after Bhusan *et al*., 1991).

Age	Group	Formation	Member/Unit
Quaternary		Hapoli	
		Frontal Thrust	
Middle Miocene to Lower Pleistocene	Siwalik Group	Kimin Formation Subansiri Formation Dafla Formation	
		Main Boundary Fault (MBF)	
Lower Eocene Cretaceous to Eocene		Dalbhuing Formation Yinkiang Formation	
		Unconformity	
Lower to Upper Permian	Monpa Group	Bhareli Formation Bichom Formation Miri Formation	Upper Member Lower Member Upper Member Lower Member
		Tectonic/ Unconformity	
Middle to Upper Proterozoic	Bomdila Group	Intrusives Dirang Formation Dedza Formation Tenga Formation	 Upper Member Lower Member Upper Member Lower Member
		Main Central Thrust (MCT)	
Lower Proterozoic	Sela Group		

Fig. 2—Stratigraphic succession of the region (after Tewari & Srivastava, 2000).

sequence shows reverse stratigraphic order brought out by the reverse faults. The Main Boundary Fault (MBF) demarcates the northern limit of the Dafla Formation from the overlying Lower Gondwana rocks which rest unconformably over the Bomdila Group (Fig. 2). The plant remains are preserved in fine grained silty shales. The lithological, sedimentological and other geological details of the area have been well documented by Bhushan *et al.* (1989, 1991), Kumar (1997) and Joshi and Chakraborty (2001).

All the type and figured specimens are deposited in the Museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATICS

Family—APOCYNACEAE

Genus—TABERNAEMONTANA Linnaeus

Tabernaemontana precoronaria Prasad, 1990

(Pl. 1.5, 6, 9, 10)

1996 *Tabernaemontana misrai* Mathur *et al*., p. 47, pl. 15, fig. 3.

1996 *Tabernaemontana sahnii* Mathur *et al*., p. 48, pl. 15, fig. 5.

Material—The species is based on two specimens (with their counterparts) having 1/3rd broken apical part.

Description—Preserved length 6 cm; lamina symmetrical, elliptic, width at broadest point 3.5 cm; base symmetrical, normal acute; apex broken; margin entire; petiole present, thin, more than 1 cm in length, attachment with petiole normal; texture chartaceous; venation pinnate, eucamptodromous; primary vein (1°) stout, straight; secondary veins about 5 pairs preserved, alternate, moderately thick, 8-12 mm apart, unbranched, angle of divergence narrow to moderately acute (40-50°); inter-secondary veins absent; tertiary veins fine, percurrent, angle of origin AR-RR, simple, rarely forked, straight, approximately at right angle to primary vein, predominantly alternate, recurved; trace marker present on leaf, about 2 mm thick.

Figured specimens—Museum Nos BSIP 39592, 39600.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila Road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle–Upper Miocene.

Affinities—The fossil leaves are characterized by symmetrical lamina, acute base, entire margin, chartaceous texture and pinnate, eucamptodromous venation with percurrent tertiary veins. These features collectively indicate their affinity with the genus *Tabernaemontana* Linn. of the family Apocynaceae. In order to find out the nearest modern counter part, herbarium sheets as well as published descriptions and photographs of different species of *Tabernaemontana* were critically examined. The study reveals that the fossil leaf shows closest resemblance with *T. coronaria* Willd (FRI Herbarium Sheet No. 75334).

Comparison with the fossil species—So far, ten species of the fossil leaves resembling *Tabernaemontana* have been reported from different parts of the world. These are: *T. bohemica* Ettingshausen from the Tertiary of Bohemia and *T. rhadobojana* Ettingshausen from former Czechoslovakia (in Schimper, 1874), *T. prisca* Mass from the Oligocene of West Indies (in Menzel, 1920), *T. chrysophylloides* (Lesquereux) MacGinitie, 1941 (syn. *T. intermedia* Portburry, 1935) from the Eocene of California, *T. teleaginensis* Avako (1979) from the Miocene of Medjuda, USSR, *Phyllites* (*Tabernaemontana*) and *Tabernaemontanophyllum* sp. from the Eocene of Borneo (Geyler, 1875). Three species are known from Indian subcontinent, namely, *T. precoronaria* Prasad (1990) from the Siwalik sediments of Koilabas, Nepal and *T. misraii* Mathur *et al.* (1996) as well as *T. sahnii* Mathur *et al.* (1996) from the Kasauli Formation, Solan District, Himachal Pradesh, India. All the three species *T. precoronaria* Prasad, *T. misraii* Mathur *et al.* and *T. sahnii* Mathur *et al.* compare with the leaves of modern *T. coronaria* Willd. Since *T. precoronaria* Prasad (1990) has priority over the above mentioned *T. misraii* Mathur *et al.* (1996) and *T. sahnii* Mathur *et al.* (1996), accordingly these two species are merged in *T. precoronaria* Prasad. Present fossil leaf also shows close

PLATE 1

(bar scale = 1 cm)

1. *Memecylon arunachalensis* sp. nov.- A fossil leaf showing shape and size; Specimen No. BSIP 39597.
2. A part of the same specimen enlarged to show brochidodromous venation.
3. *Millettia koilabasensis* Prasad- A fossil leaf showing shape, size and venation pattern; Specimen No. BSIP 39594.
4. A part of the same specimen enlarged to show entire margin and eucamptodromous venation.
5. *Tabernaemontana precoronaria* Prasad- A fossil leaf showing shape, size and a trace marker; Specimen No. BSIP 39592.
6. A part of the above specimen enlarged to show uniformly curved secondary veins.
7. *Dicotylophyllum* sp. - A fragmentary fossil leaf showing its shape and size; Specimen No. BSIP 39599.
8. The same specimen enlarged to show the details of venation.
9. *Tabernaemontana precoronaria* Prasad- Another specimen of the fossil leaf; Specimen No. BSIP 39600.
10. The same specimen enlarged to show eucamptodromous venation.

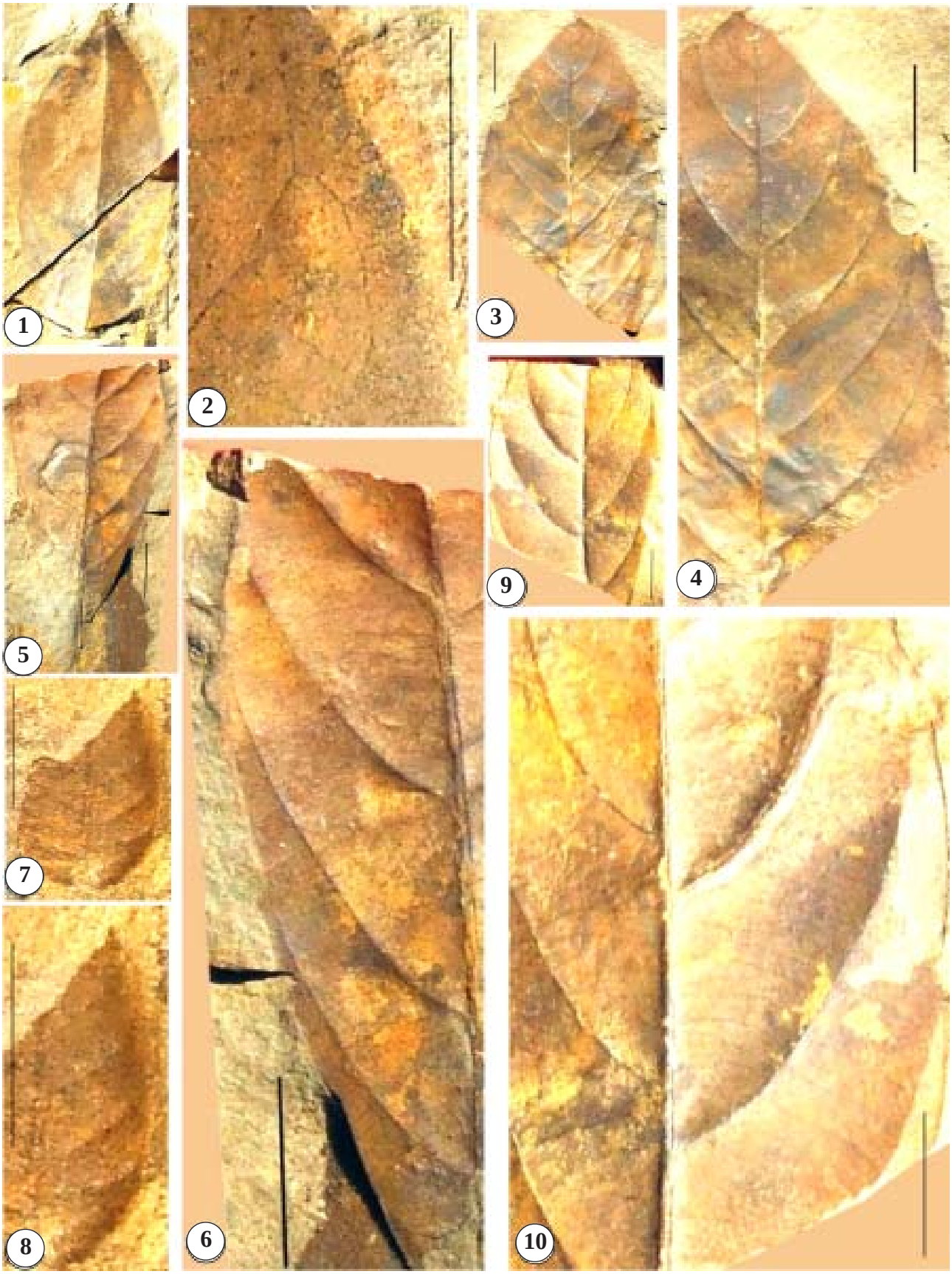

PLATE 1

resemblance with *T. precoronaria* Prasad, accordingly it has also been placed in the same species. However, the specimen designated as paratype of *T. sahnii* (Mathur *et al.* 1996, GSI Type No. 20644; pl. 15, fig. 6) is different from the modern genus *Tabernaemontana* in having lesser and distantly placed secondaries and may belong to any other genus.

Remarks—Prasad (1990) reported craspedodromous venation in *T. precoronaria* while in the modern as well as in the fossil specimens, eucamptodromous venation is observed.

Family—CELASTRACEAE

Genus—SALACIA Linnaeus

Salacia miocenica sp. nov.

(Pl. 2.7, 8)

Material—The species is based on a single specimen whose apical part is missing.

Description—Preserved length 6.8 cm; width at the broadest point 3.5 cm; lamina symmetrical, seemingly obovate; base symmetrical, normal acute, slightly broken; apex broken; margin entire; texture coriaceous; petiole present but broken; venation pinnate, eucamptodromous; primary vein (1°) moderately thick, straight; secondary veins about 8 pairs visible, alternate, thin, 7-8 mm apart, angle of divergence moderately acute (60°), uniformly curved, upturned towards margin and running parallel to it before diminishing; inter-secondary veins not observed; tertiaries ill preserved, ?random reticulate.

Holotype—Museum No. BSIP 39593.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila Road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle–Upper Miocene.

Etymology—After the age of the sediments bearing the fossil leaf.

Affinities—The diagnostic features of the present fossil leaf are: symmetrical lamina and base, entire margin, coriaceous texture with pinnate, eucamptodromous venation. These features collectively indicate its affinity with the genus *Salacia* Linnaeus, particularly with *S. beddomei* Gamble of the family Celastraceae (Pascal & Ramesh, 1987).

Comparison with the fossil species—As far as the authors are aware, there is no record of fossil leaf showing resemblance with the genus *Salacia*. Hence, the fossil leaf is described as *Salacia miocenica* sp. nov.

Family—FABACEAE

Genus—MILLETTIA Wight & Arnot

Millettia koilabasensis Prasad, 1990

(Pl. 1.3, 4)

PLATE 2 →

(bar scale = 1 cm)

1. *Actinodaphne palaeomalabarica* sp. nov.- A fossil leaf showing shape, size and venation pattern; Specimen No. BSIP 39595.
2. The same specimen enlarged to show stout primary vein and course of the secondary and tertiary veins.
3. *Litsea preglabrata* sp. nov.- A fossil leaf showing narrow elliptic lamina, entire margin and eucamptodromous venation; Specimen No. BSIP 39596.
4. A part of the same specimen enlarged to show angle of divergence of secondary veins and percurrent tertiary veins.
5. *Randia miowallichii* Prasad.- A fossil leaf showing shape, size and venation pattern; Specimen No. BSIP 39598.
6. The same specimen enlarged to show stout primary vein and course of the secondary veins.
7. *Salacia miocenica* sp. nov.- A fossil leaf showing obovate shape, entire margin and eucamptodromous venation; Specimen No. BSIP 39593.
8. A part of the same specimen enlarged to show thick and straight primary vein and uniformly curved secondary veins.

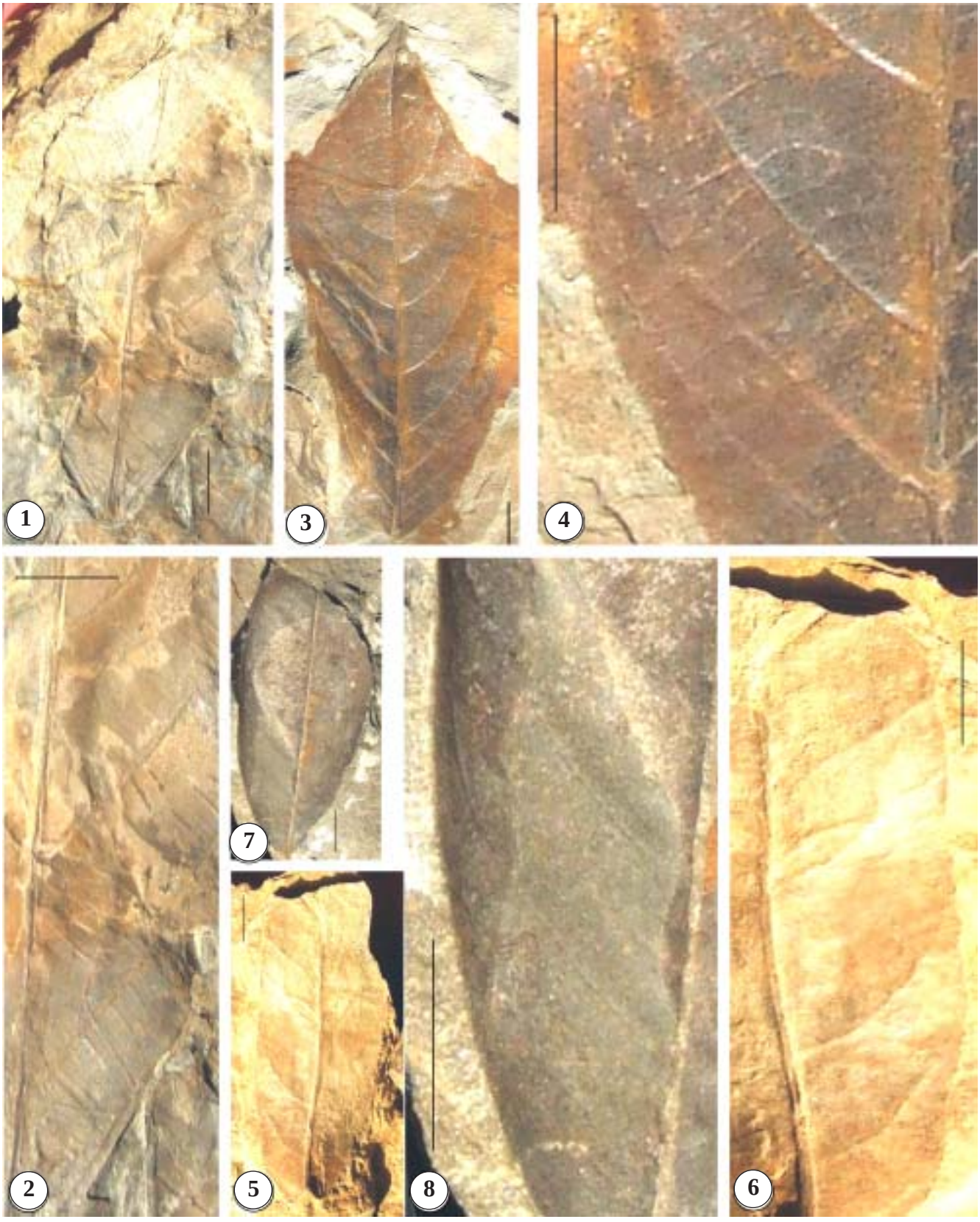

PLATE 2

S.l.	Name of fossil species	Modern comparable species	Locality	Horizon & Age	References
1.	*Millettia asymmetrica*	*Millettia ovalifolia*	Khari Nadi bed, Kachchh District, Gujarat; Kumarhatti, Solan District, Himachal Pradesh	Khari Series, Lower Miocene; Dagshai Formation, Oligocene	Lakhanpal & Guleria, 1982; Mathur *et al*., 1996
2.	*M. auriculata*	*M. auriculata*	Mahuadanr, Palamu District, Gujarat	Late Cenozoic	Bande & Srivastava, 1990
3.	*M. bilaspurensis*	*M. pachycarpa*	Bilaspur- Swarghat Road, Bilaspur District, Himachal Pradesh	Siwalik Group	Prasad, 2006
4.	*M. churiensis*	*M. pranii*	Surai Khola, Nepal; Neyveli Lignite deposits, South Arcot District, Tamil Nadu	Middle Siwalik, Upper Miocene; Miocene	Prasad & Awasthi, 1996; Agarwal, 2002
5.	*M. imlibasensis*		Koilabas, Nepal	Lower Siwalik, Middle Miocene	Prasad, 1994c
6.	*M. impressa* (Harms)	*M. impressa*	Cameroon (Kamerun), West Africa	Tertiary- Recent	Menzel, 1920
7.	*M. indakabalensis*		Inda Ka Bala, Bikaner District, Rajasthan	Mar Formation, Neogene	Mathur & Mathur, 1998
8.	*M. kathgodamensis*	*M. atropurpurea*	Kathgodam, Nainital District, Uttaranchal	Lower Siwalik, Middle Miocene	Prasad *et al*., 2004
9.	*M. koilabasensis*	*M. macrostachea*	Koilabas, Nepal; Bhutan; Surai Khola, Nepal	Lower Siwalik, Middle Miocene; Middle Siwalik, Upper Miocene	Prasad, 1990; Prasad & Tripathi, 2000; Prasad & Pandey, 2008
10.	*M. miobrandisiana*	*M. brandisiana*	Koilabas, Nepal	Lower Siwalik, Middle Miocene	Prasad, 1994c
11.	*M. miocenica*	*M. auriculata*	Khari Nadi bed, Kachchh District, Gujarat; Katni, Jabalpur District, Madhya Pradesh	Khari Series, Lower Miocene; Dagshai Formation, Oligocene; Katni Formation, Jabalpur	Lakhanpal & Guleria, 1982; Yadekar & Pitchai Muthu, 1988

12.	*M. notoensis*		Noto Peninsula, Honshu, Japan	Eocene	Ishida, 1970
13.	*M. oodlabariensis*	*M. albiflora*	Sevok, Darjeeling District, West Bengal	Lower Siwalik, Middle Miocene	Antal & Prasad, 1996
14.	*M. ovatus*	*M. pubinervis*	Koilabas village near Jarwa, Balrampur District, Uttar Pradesh	Lower Siwalik, Middle Miocene	Tripathi *et al*., 2002
15.	*M. palaeocubithii*	*M. cubithii*	Surai Khola, western Nepal	Siwalik, Miocene	Awasthi & Prasad, 1990
16.	*M. palaeomanii*	*M. manii*	Koilabas, western Nepal	Lower Siwalik, Middle Miocene	Dwivedi *et al*., 2006
17.	*M. palaeopachycarpa*	*M. pachycarpa*	Neyveli Lignite deposits, South Arcot District, Tamil Nadu	Miocene	Agarwal, 2002
18.	*M. palaeoracemosa*	*M. racemosa*	Surai Khola, western Nepal; Kathgodam, Nainital District, Uttaranchal	Lower Siwalik, Middle Miocene	Awasthi & Prasad, 1990; Prasad, 1994a
19.	*M. purniyagiriensis*	*M. auriculata*	Tanakpur District, Uttaranchal	Middle Siwalik, Upper Miocene	Shashi *et al*., 2006
20.	*M. singhii*	*M. brandisiana*	Daghota, Solan District, Himachal Pradesh	Kasauli Formation, Lower Miocene	Mathur *et al*., 1996
21.	*M. siwalica*	*M. ovalifolia*	Kathgodam, Nainital District, Uttaranchal	Lower Siwalik, Middle Miocene	Prasad, 1989; Prasad, 1994b
22.	*Millettia* sp.	*Millettia* sp.	Daghota, Solan District, Himachal Pradesh	Kasauli Formation, Lower Miocene	Mathur *et al.*, 1996
23.	*Millettia* sp.	*Millettia* sp.	Ube Coalfield, Honshu, Japan	Eocene	Huzioka & Takahashi, 1970
24.	*Millettia* sp. aff. *asymmetrica*	*Millettia* sp. cf. *M. ovalifolia*	Solan District, Himachal Pradesh	Lower Miocene; Dagshai Formation, Oligocene	Mishra & Mathur, 1992

Fig. 3—Table showing fossil leaves resembling *Millettia*.

Material—The species is based on a single specimen preserved as part and counter part and basal part (about 1/3rd) is broken.

Description—Preserved length 7 cm; lamina symmetrical, seemingly elliptic, width at the broadest point 3.8 cm; basal part not preserved; apex appearing acute; margin entire, undulating at apical portion; texture chartaceous; venation pinnate, eucamptodromous; primary vein (1º) moderately thick, straight; secondary veins about 6 pairs visible, alternate, moderately thick, 8-11 mm apart, narrow acute angle of divergence (40-45º), unbranched; inter-secondary veins absent; tertiary veins preserved at only one place, percurrent, fine, closely placed.

Figured specimen—Museum No. BSIP 39594.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila Road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle–Upper Miocene.

Affinities—Present fossil leaflet in having symmetrical lamina, entire margin, acute apex, eucamptodromous venation with percurrent tertiaries compares with the leaflets of *Millettia* Wight & Arnot particularly with *M. macrostachya* Collett & Hemsl. of the family Fabaceae. The specimen also shows resemblance with the leaves of *Alphonsea lucida* and *Unona longifolia* of the family Anonaceae but differs in having acuminate apex, distantly placed lesser number of secondaries and other finer details.

Comparison with the fossil species—Fossil leaflets showing close resemblance with modern leaflets of different extant species of *Millettia* are very common in the Indian subcontinent. So far, twenty three leaflets are reported from all over the world. Amongst them twenty species are reported from India and Nepal, two from Japan and one from South Africa. They, along with their modern counterparts, localities, horizons and ages, are enlisted in the form of a table (Fig. 3).

The present fossil leaflet has been compared with all the above known species of fossil *Millettia* and shows close resemblance with *M. koilabasensis* Prasad and hence it has been placed in the same species.

Family—LAURACEAE

Genus—ACTINODAPHNE Nees

Actinodaphne palaeomalabarica sp. nov.

(Pl. 2.1, 2)

Material—The species is based on a single specimen (preserved with part and counterpart).

Description—Preserved lamina length 9.5 cm, width 4.5 cm, mesophyll, symmetrical; base normal, acute; apical part broken; margin entire; texture chartaceous; petiole present but broken, preserved length 2 mm; lamina elliptic to obovate; venation pinnate, eucamptodromous; primary vein (1º) stout, straight; secondary veins (2º) 5 pairs preserved, opposite, 1.2-1.8 cm apart, angle of divergence moderately acute (45º), uniformly curved and then upturned and run parallel to the margin up to a certain distance, moderately thick; tertiary veins (3º) angle of origin AR-RR, percurrent, predominantly alternate, closely placed, oblique to mid-vein, mostly unbranched, occasionally forked, usually straight, recurved also; intersecondaries absent; higher order venation not seen.

Holotype—Museum No. BSIP 39595.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila Road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle-Upper Miocene.

Etymology—Prefixed ‘palaeo’ to the name of modern comparable species *A. malabarica.*

Affinities—Elliptic to obovate leaf having acute base, entire margin, eucamptodromous venation with percurrent tertiary veins shows its affinities with the genus *Actinodaphne* Nees of the family Lauraceae. In order to find the nearest modern comparable form, herbarium sheets as well as published literature were critically examined. The fossil leaf shows close resemblance with *A. malabarica* Balakr. and *A. lawsonii* Gamble (Pascal & Ramesh, 1987, figs 200, 201). *A. lawsonii* leaves are different in possessing

broader middle portion, while *A. malabarica* shows maximum resemblance with the present fossil leaf.

Comparison with the fossil species—The genus *Actinodaphne* is well documented in the Tertiary sediments of various countries: *Actinodaphne hoettingensis* Ettingshausen and *A. frangula* Ettingshausen from the Tertiary of Germany (Ettingshausen, 1888), *A. germari* Heer (1859) from the Eocene of Darmstadt, Germany, *A. martiniana* Crie (1888) from the Pliocene of Java, *A. nipponica* Tanai (1961) from the Neogene of Hokkaido, Japan and *A. oishii* Huzioka (1964) from the Miocene of Honshu, Japan and *A. pseudogermai* from the Tertiary of Bohemain Massif (Kvacek & Teodoridis, 2007). From the Indian subcontinent *A. palaeoangustifolia* Antal and Awasthi (1994) is the only species which is reported from the Siwalik sediments of Oodlabari, Darjeeling District, West Bengal and Suraikhola, Nepal (Prasad & Pandey, 2008). The present specimen differs from all the known species in having broader lamina and other finer details and hence is described as *Actinodaphne palaeomalabarica* sp. nov.

Genus—LITSEA Lamarck

Litsea preglabrata sp. nov.

(Pl. 2.3, 4)

Material—The species is based on a single well preserved specimen.

Description—Preserved length 11 cm; lamina symmetrical, narrow elliptic, width 3.5 cm at the broadest point; base slightly broken, symmetrical, normal acute; apex acute or acuminate, margin entire, undulating; petiole broken; texture chartaceous; venation pinnate, eucamptodromous; primary vein (1º) thick, stout, straight; secondary veins about 10 pairs visible, alternate, moderately thick, 5-15 mm apart, moderately acute angle of divergence (45-60º), lower pairs more acute, uniformly curved, upper 3 secondaries forming loops, mostly unbranched except upper 3 which divide to form loops with super adjacent secondaries at about right angles; inter-secondary vein observed only at one place between 4th and 5th secondaries from the base, simple; intra-marginal vein absent; tertiary veins percurrent, angle of origin RR to AR, simple, rarely forked, straight, recurved also, oblique in relation to primary vein; predominantly alternate, closely placed; quaternary veins present, thick, orthogonal.

Holotype—Museum No. BSIP 39596.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila Road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle-Upper Miocene.

Etymology—By adding prefix 'pre' to the name of modern comparable species *L. glabrata.*

Affinities—Fossil leaf is characterized by symmetrical, narrow elliptic lamina, acute or acuminate apex, acute base, entire and undulating margin, eucamptodromous venation with percurrent tertiary veins. These characters collectively indicate its affinities with the genus *Litsea* Lamark of the family Lauraceae. On critical examination of a number of species of *Litsea*, it was found that the fossil leaf shows nearest resemblance with the leaf of *L. glabrata* (Wall ex Nees) Hooker f. (Pascal & Ramesh, 1987, fig. 219).

Comparison with the fossil species—The genus *Litsea* is well documented in the Tertiary sediments and its five species are known from India. Amongst them, *L. polyantha* Juss. (Pathak, 1969) reported from the Middle Siwalik of the Mahanadi River Section, Darjeeling District, West Bengal differs from the present leaf in having obtuse apex and probably obovate to oblong-ovate shape. *L. bhatiai* Mathur (1978) reported from the Tatrot Formation (Miocene-Pliocene) of Kangra District, Himachal Pradesh resembles the present leaf in having similar shape, apex and base but differs in having only seven pairs of secondary veins and absence of inter-secondaries. *Litsea* sp. Bhattacharyya (1983) reported from the Tura Formation (Eocene) of Nangalbibra entirely differs in having elongate lanceolate shape. *L. prenitida* Lakhanpal and Awasthi (1984) reported from the Upper Siwalik of Bhikhnathori, West Champaran District, Bihar differs in having broader obtuse apex and lesser number of

secondaries (7 pairs). *L. sastryi* Mathur *et al.* (1996) from the Kasauli Formation, Solan District, Himachal Pradesh and *Litsea* sp. Mathur and Mathur (1998) from the Mar Formation, Bikaner District, Rajasthan can be differentiated in having smaller size (less than half) and craspedodromous venation. From outside India, four species, viz., *L. ehattia* Engelhardt, *L. elongata* Engelhardt and *Litsea* (?) sp. Engelhardt (Engelhardt, 1922) and *L. dermatophyllum* Engelhardt (1911) have been described from Germany (Salomon-Calvi, 1934) and about ten species are known from the Palaeogene of America. These are: *L. carbonensis* Ward (1885), *L. cuneata* Knowlton (1899), *L. lamarensis* (Knowlton) Lamotte (1952), *L. lata* (MacGinite) Lamotte (1952), *L. magnifica* Saporta (1868), *L. praecursoria* (Lesquereux) Lamotte (1952), *L. sagitata* (Ball) Lamotte (1952), *L. sessiliflora* (Lesquereux) Lamotte (1952), *L. texensis* (Ball) Lamotte (1952), *Litsea* sp. (Berry) Lamotte (1952). The present fossil leaf differs from all the previously known species in shape, size and finer details, hence it is being described as *Litsea preglabrata* sp. nov.

Family—MELASTOMATACEAE

Genus—MEMECYLON Linnaeus

Memecylon arunachalensis sp. nov.

(Pl. 1.1, 2)

Material—The species is based on a single specimen having a crack in the middle.

Description—Length 7.5 cm, width at middle portion 3.5 cm; narrow ovate; lamina and base symmetrical, mesophyll; apex slightly broken, acute-acuminate; petiole not seen; base rounded; margin entire; texture coriaceous, venation pinnate, brochidodromous; primary vein (1º) moderately thick, straight; secondary veins (2º) 7 pairs, alternate, 6-10 mm apart, fine, angle of divergence narrow acute (35-45º), abruptly curved to form loops with superadjacent secondaries at acute angle, loops enclosed by secondary and tertiary arches; intersecondary veins absent; tertiary veins (3º) fine, random reticulate; areoles well developed.

Holotype—Museum No. BSIP 39597.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle-Upper Miocene.

Etymology—After Arunachal Pradesh from where the fossil was collected.

Affinities—The fossil leaf in overall characters, such as, rounded base, coriaceous texture and brochidodromous venation indicates its affinity with the genus *Memecylon* Linnaeus, particularly with *M. terminale* Dalzel. and *M. wightii* Thw. of the family Melastomataceae (Pascal & Ramesh, 1987). However, it shows superficial resemblance with some of the species of *Humboldia* (Caesalpinioideae) having brochidodromous venation but coriaceous texture and finer venation differentiate it from them.

Comparison with the fossil species—So far, only one species showing resemblance with *Memecylon*, viz., *M. amplexicaulensis* Awasthi and Mehrotra (1995) is known from the Oligocene sediments of the Makum Coalfield, Assam. The species differs from the present leaf in having broader lamina and markedly curved primary vein which is straight in the present specimen. Since the fossil leaf is different from the only known species, it is described as *Memecylon arunachalensis* sp. nov.

Family—RUBIACEAE

Genus—RANDIA Linnaeus

Randia miowallichii Prasad, 1989

(Pl. 2.5, 6)

Material—The species is based on a single specimen.

Description—Preserved length 7.5 cm; width 3 cm; mesophyll; lamina symmetrical, narrow oblong; base

symmetrical, slightly broken, seemingly acute; apex broken; margin entire; petiole broken; texture coriaceous; venation pinnate, eucamptodromous; primary vein (1º) stout, straight; secondary veins (2º) about 6 pairs visible, alternate, thin, 7-17 mm apart, moderately thick, angle of divergence moderately acute (45-65º), uniformally curved upwards and almost touching the margin; inter-secondary veins absent; tertiaries (3º) not preserved.

Figured specimen—Museum no. BSIP 39598.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle–Upper Miocene.

Affinities—The diagnostic features of the present fossil leaf are: symmetrical, narrow oblong shape, acute or acuminate apex, seemingly acute base, entire margin, eucamptodromous venation and moderately acute angle of divergence of secondary veins. These features collectively suggest its affinities with the genus *Randia* Linnaeus, especifically with *Randia wallichii* Hook f. (CNH Herbarium sheet no. 286) of the family Rubiaceae.

Comparison with the fossil species—So far, seven records of fossil leaves of the genus *Randia* Linn. are known from abroad and India. These are: *Randia prodroma* Unger (in Salomon-Calvi, 1934) from the Miocene of Salzhuasen, Germany; *R. gossferiana* K. Schun from the Tertiary of Kamerun (now Republic of Cameroon), West Africa (Menzel, 1920); *R. mohavensis* Axelrod (1950) from the Miocene of North America, *R. neyveliensis* Agarwal (1990) from the Neyveli Lignite deposits, South Arcot District, Tamil Nadu, *R. miowallichii* Prasad (1990) from the Siwalik sediments of Koilabas, Nepal and Darjeeling District, West Bengal (Antal & Awasthi, 1994), *R. palaeofasciculata* Prasad and Awasthi (1996) from the Siwalik sediments of Suraikhola, Nepal and *R. miouncaria* Prasad and Dwivedi (2007) from Seria Naka, Western Nepal. Amongst them, the first three species reported from Germany, Africa and America could not be seen due to unavailability of the original literature. The fossil leaf shows close resemblance with *R. miowallichii* particularly reported from the Darjeeling District, West Bengal and hence has been placed in the same species.

Remarks—Prasad (1990) and Antal and Awasthi (1994) described secondary veins as craspedodromous in *R. miowallichii*, but in the present specimen and in extant leaves of *Randia wallichii*, eucamptodromous venation is observed.

INCERTAE SEDIS

Genus—DICOTYLOPHYLLUM Saporta, 1894

Dicotylophyllum breyniodes sp. nov.

(Pl. 1.7, 8)

Material—The species is based on a single tiny specimen.

Description—Preserved length 1.7 cm; width 1.2 cm; microphyll; lamina and base symmetrical shape; ovate; base normal, rounded, slightly broken; apical part broken; margin entire; texture chartaceous; petiole not seen, broken; venation pinnate, eucamptodromous; primary vein (1º) stout, straight; secondary veins 4 pairs visible, alternate, 2-3 mm apart, angle of divergence moderately acute (45-50º), uniformly curved, moderately thick; tertiary vein (3º) not seen.

Holotype—Museum No. BSIP 39599.

Locality—Pinjoli Nala section near Bhalukpong-Bomdila Road, West Kameng District, Arunachal Pradesh.

Horizon—Dafla Formation (=Lower Siwalik).

Age—Middle-Upper Miocene.

Etymology—By adding suffix '*oides*' to the name of modern comparable genus *Breynia*.

Affinities—The small symmetrical ovate leaf with eucamptodromous venation clearly indicates that the fossil specimen is a dicot leaflet. In shape, size and venation pattern the leaflet shows resemblance with *Breynia* Foster & Foster f., particularly with *B. rhamnoides* Muell. Arg. of the family Euphorbiaceae. However, its affinity with leaflets of Fabaceae and other families can not be ruled out.

Comparison with the fossil species—So far, only one fossil leaflet showing affinities with *Breynia*, namely, *B. prerhamnoides* Awasthi & Prasad (1990) is known from the Siwalik sediments of Surai Khola, Nepal. Present leaflet shows resemblance with the Siwalik species, but its affinity is not properly defined. Hence, it is being placed under the form genus *Dicotylophyllum* Saporta (1894) instituted to include dicotylednous leaves of uncertain affinities. A number of *Dicotylophyllum* species are known from different Tertiary exposures of India (Srivastava, 1991; Guleria & Mehrotra, 1999; Srivastava & Guleria, 2006; Joshi & Mehrotra, 2007). The present specimen is different from all the species in having very small size and other finer details. Hence it is described as *Dicotylophyllum breyniodes* sp. nov. showing its probable affinities with the genus *Breynia*.

DISCUSSION

The leaf impressions described in the present communication, along with the fossil assemblage known so far from the Dafla Formation (=Lower Siwalik), are useful to evaluate palaeoclimate of the region. For climatic inferences, it is necessary to know the geographic distribution and climatic preferences of the modern comparable taxa.

The genus *Tabernaemontana* Linnaeus (Apocynaceae) consists of 99 species of shrubs and small trees, amongst them 55 are distributed in the Old World (Mabberley, 1997). About 10 species are reported to occur in India. *T. precoroneria* Willd., the nearest modern counterpart of the fossil is an evergreen shrub growing in the sub-himalayan tracts from Dehradun eastwards, commonly found in lower Darjeeling hills and Myanmar (Brandis, 1971; Gamble, 1972). The genus *Salacia* Linnaeus of the family Celastraceae consists of about 200 species distributed in the tropics. *S. beddomei* Gamble is an endangered and rare endemic woody timber found in the evergreen forests of the Western Ghats. It rarely occurs in the Annamalai and Palghat hills of Kerala. The genus *Millettia* Wight & Arnot consists of 180 species of trees, shrubs and woody climbers distributed in the warmer regions of Africa, Asia and Australia. About 30 species of it are reported to occur in India and Myanmar. *M. macrostachya* Call. & Hemsl, the nearest modern counterpart, is a tree of the Shan Hills of Upper Myanmar (Gamble, 1972). The genus *Actinodaphne* Nees of the family Lauraceae consists of about 100 species distributed in the Indo-Malaysian and eastern Asian regions (Mabberley, 1997). *Actinodaphne malabarica* Balakr., a nearest modern counterpart of our fossil, grows in the evergreen forests of the Western Ghats, Assam, Khasi Hills, Sylhet, Rinkheong Valley and also in Chittagong (Bangla Desh) and Myanmar (Gamble, 1972). The genus *Litsea* Lamark (Lauraceae) consists of about 400 species of trees and shrubs distributed mainly in warm and tropical regions, especially in Asia and Australia (Mabberley, 1997). *Litsea glabrata* (Wall ex Nees) Hooker is found in wet-evergreen forests of the Western Ghats. *Memecylon* Linnaeus **(**Melastomataceae) consists of about 250 species of evergreen trees or shrubs distributed in tropics of the Old World (Santapau & Henry, 1973; Mabberley, 1997). Amongst the nearest modern equivalent, *M. terminale* Dalzel., is a shrub of 2-3ft. distributed in the Southern Ghats of Deccan Peninsula while *M. wightii* Thw. is a large tree of about 25ft found in Western Peninsula and Sri Lanka at an altitude of 3,000-4,000 ft. (Hooker, 1879). The genus *Randia* Linnaeus (Rubiaceae) consists of about 100 species distributed in the tropical and subtropical regions of the world (Mabberley, 1997). In India, about a dozen species of this genus occur as small trees and shrubs (Pearson & Brown, 1932; Purkayastha, 1982). *Randia wallichii* Hook, f. is a small tree distributed in the moist deciduous to evergreen forests of northeast Himalaya, Khasi Hills, Sikkim and Sylhet (Gamble, 1972). It is also found in Andaman Island, Pegu, Bangla Desh, Myanmar and Malaysian Peninsula (Brandis, 1971; Purkayastha, 1982). *Breynia* Foster & Foster f. of the family Euphorbiaceae is a small genus of 25 species, mostly distributed from China to New Caledonia and Australia (Mabberley, 1997). *B. rhamnoides* Muell. Arg. with which the fossil leaflet shows closest affinity, is a small tree or shrub growing in Upper Assam, Western Peninsula, Andamans,

Myanmar and Sri Lanka. It is a moisture loving tree commonly found in the Malaysian region, Philippine and China (Brandis, 1971; Gamble, 1972).

Modern analogs of the fossils described above and previously recorded genera, namely, *Fissistigma palaeobicolor* (*Fissistigma bicolor), Calophyllum suraikholaensis* (*Calophyllum* sp.), *Shorea palaeoridleyana* (*Shorea ridleyana*), *S. neoassamica* (*S. bracteolata*), *Thelyptridaceophyllum tertiarum* (Thelypteridaceous fern), *Bambusa siwalika* (*Bambusa*), *Amesoneuron* (palm) suggest that most of them form a natural association in the wet-evergreen to semi-evergreen forests of India and adjoining countries. These genera are presently distributed in tropical wet-evergreen forests of Assam, Sikkim, Western Ghats, Tamil Nadu, Sri Lanka, Bangla Desh, Myanmar, etc. The assemblage indicates occurrence of thick tropical forest cover with plenty of rainfall at the time of deposition. Since most of the plants are members of inland forests, it is envisaged that the depositional conditions must have been largely lacustrine or fluvio-lacustrine. However, a few genera found in littoral swamps (thelypteridaceous fern, *Terminalia catappa*, *Millettia macrostachya*) suggest near shore conditions in depositional site and nearby areas. This view gets support from the palaeopalynological and sedimentological studies made in the region by Singh and Tripathi (1990) and Joshi and Chakraborty (2001) respectively.

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