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Angiospermous fossil leaves from the Siwalik foreland basins and their palaeoclimatic implications

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ABSTRACT

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The angiospermous fossil leaves so far recorded from the Siwalik foreland basins of India, Nepal and Bhutan have been analysed and an attempt has been made to deduce palaeoclimate and phytogeography of the region during Siwalik (Mio-Pliocene) Period. The physiognomic characters of the fossil leaves have been critically examined in order to infer the climate of the region. The leaf features that have used mainly an aid in determining past climate, are leaf margin, drip tips, leaf size and venation density. The dominance of entire margined species (about 92%) in the Siwalik leaf assemblage indicates the prevalence of tropical climate. The presence of conspicuous drip tips and other features like leaf size, leaf texture, nature of petiole and venation density collectively suggest tropical climate with heavy rainfall (MAT 28°-29° and MAP 308 mm) during Mio-Pliocene.

Almost all the fossil leaves recovered from different fossil localities in the Himalayan foreland basins have been identified with the modern angiospermous taxa up to specific level. From the present day distribution of these comparable species it is evident that most of the comparable species of the fossil assemblage are not found at present in the foot hills and became extinct due to unfavourable climatic condition after Mio-Pliocene. Moreover, on the basis of habit and habitat of comparable taxa of angiospermous fossil leaves it has been concluded that the Siwalik flora consists of three types of constituents in the forest during the sedimentation of Siwalik foreland basins: (1) Evergreen (2) Evergreen and Moist deciduous (3) Mixed deciduous. The Siwalik leaf assemblage is dominated by evergreen constituents like dipterocarps, legumes and other associated taxa in contrast to mixed deciduous constituents of the present day floral assemblage of the regions. This is most probably due to post-Pliocene orogeny of the Himalaya which brought changes in the topography and climate and thus adversely affecting the vegetation scenario of the Himalayan foot hills.

Key-words—Fossil leaves, Angiosperm, Siwalik foreland basins, Mio-Pliocene, Leaf physiognomy, Palaeoclimate.

शिवालिक अग्रभूमि द्रोणियों से प्राप्त आवृतबीजीय जीवाश्म पत्तियाँ एवं उनकी पुराजलवायु युगपत अंतर्वृद्धियाँ

महेश प्रसाद

सारांश

भारत, नेपाल एवं भूटान की शिवालिक अग्रभूमि द्रोणियों से अब तक अभिलेखित आवृतबीजीय जीवाश्म पत्तियाँ विश्लेषित की जा चुकी हैं तथा शिवालिक (मध्य-आदिनूतन) अवधि के दौरान क्षेत्र की पुराजलवायु व पादप-भूगोल को निगमित करने का प्रयास किया गया है। क्षेत्र की जलवायु का अनुमान लगाने के लिए जीवाश्म पत्तियों के रुपात्मक लक्षण आलोचनात्मक रूप से परीक्षित किए गए हैं। पत्ती लक्षण जो गत जलवायु को निर्धारित करने में मुख्य रूप से उपयोग किए गए हैं, पत्ती उपांत, बूँद सिरे, पत्ती आकार व शिराविन्यास घनत्व के हैं। शिवालिक पत्ती समुच्चय में समूची उपांती जात (लगभग 92%) की प्रमुखता उष्णकटिबंधीय जलवायु की व्यापकता इंगित करती है। ध्यानाकर्षी बूँद सिरे व अन्य लक्षण जैसे पत्ती आकार, पत्ती विन्यास, पर्णवृंत की प्रकृति तथा शिराविन्यास घनत्व की विद्यमानता मध्य-आदिनूतन के दौरान भारी वर्षा (एम.ए.टी. 28°-29° और एम.ए.पी. 308 मिमी) के साथ उष्णकटिबंधीय जलवायु सुझाती हैं।

हिमालयी अग्रभूमि द्रोणियों में विभिन्न जीवाश्म उपबस्तियों से प्राप्त लगभग समस्त जीवाश्म पत्तियाँ विशिष्ट स्तर तक आधुनिक आवृतबीजीय वर्गक के रूप में पहचानी जा चुकी हैं। इन तुलनीय जातों के वर्तमान वितरण से यह स्पष्ट है कि जीवाश्म समुच्चय की अधिकांश तुलनीय जात गिरि पादों में मौजूद नहीं हैं तथा मध्य-आदिनूतन के उपरांत प्रतिकूल जलवायु स्थिति के कारण विलुप्त हो गईं। इसके अतिरिक्त, आवृतैकबीजी जीवाश्म पत्तियों की तुलनीय वर्गक की प्रकृति व आवास के आधार पर यह निष्कर्ष निकाला गया है कि शिवालिक अग्रभूमि द्रोणियों के अवसादन के दौरान वन में शिवालिक पेड़-पौधे तीन प्रकार के संघटकों के हैं : (1) सदाहरित (2) सदाहरित आर्द्र पतझड़ी (3) मिश्रित पतझड़ी। क्षेत्र के वर्तमान कालिक समुच्चय के मिश्रित पतझड़ी संघटकों के मुकाबिले शिवालिक पत्ती समुच्चय सदाहरित संघटकों जैसे डिप्टेरोकार्पस, फलियों व अन्य सहयोगी वर्गक द्वारा प्रभावी हैं ये संभवतः हिमालय के पश्च-आदिनूतन पर्वतन के कारण है जिससे स्थलाकृति व जलवायु में परिवर्तन हो गया तथा हिमालयी गिरि पादों के वनस्पति परिदृश्य पर प्रतिकूल प्रभाव डाल रही है।

संकेत-शब्द—जीवाश्म पत्तियाँ, आवृतबीजी, शिवालिक अग्रभूमि द्रोणियाँ, मध्य-आदिनूतन, पत्ती रुपात्मकविज्ञान, पुराजलवायु।

INTRODUCTION

THE Siwalik foreland basins attain an average thickness of 6000 m and are exposed all along the Himalayan foot hills from the Potwar Plateau in the north west to Brahmputra in the north east covering a distance of 2400 km in length. The Siwalik sediments are made up of rock materials resulting from denudation of slopes of the Himalayan mountains and deposited on the flood plains of the foreland basins over a span of time (-20 Ma). Pilgrim (1913) proposed a three fold stratigraphic division of the Siwalik Group, i.e. Lower, Middle and Upper Siwalik and ranges in age from Middle Miocene to Middle Pleistocene.

In Nepal Himalaya, the Siwalik Group is often called Churia Group and has often been classified into two formations (1) Lower Churia Formation (Sandstone facies) and (2) Upper Churia Formation (Conglomerate facies) (Hagen, 1959; Bordet, 1961; Gleinnie & Ziegler, 1964). However, a three fold lithostratigraphic classification of the Churia Group (Lower, Middle and Upper Churia Formation) has been suggested by Chaudhuri (1983).

The Siwalik sediments are characterized by the alternate presence of sandstone and mudstone facies, the later very often containing abundant angiospermous fossils belonging to both monocot and dicot families. During last three decades several workers have recovered enormous amount of plant megafossils including petrified woods and leaf, fruit, seed and

Fig. 1—Map showing extent of Siwalik foreland basins and the location of exposures from where fossil leaves were collected.

Fossil taxa	Modern comparable species	Forest types	Distribution
Arecaceae *Amesoneuron siwalicus* Prasad, 2006	Palm	Tropical forest	Throughout coastal region
DICOTYLEDONS **Anonaceae** *Fissistigma senii* Lakhanpal, 1969	*Fissistigma bicolor* H. f. & Th.	Evergreen	Northeast India
F. senii Lakhanpal; Prasad, 2006	*F. wallichii* Hook. f. & Th.	Evergreen	Northeast India
F. siwalica Lakhanpal & Awasthi, 1992	*F. rubiginosum* Merr.	Evergreen	Assam, Bangladesh, Myanmar, Thailand and Borneo
Clusiaceae *Cratoxylon bilaspurensis* Prasad, 2006	*Cratoxylon prunifolium* Dyer	Evergreen	Myanmar, Cochin China, Martaban Hills and Andamans
Dipterocarpaceae *Dipterocarpus siwalicus* Lakhanpal & Guleria, 1987	*Dipterocarpus tuberculatus* Roxb.	Evergreen to moist deciduous	Northeast India, Andamans, Myanmar and Malaya
Meliaceae *Trichilia siwalica* Prasad, 2006	*Trichilia connaroides* W. & A.	Moist deciduous	Sub-himalayan tract, Assam and south India
Rhamnaceae *Berchemia balugoloaensis* Lakhanpal, 1967	*Berchemia floribunda* Wall.	Moist deciduous	Sub-himalayan region and Northeast India
Zizyphus siwalicus Lakhanpal, 1965, 1967	*Zizyphus incurva* Roxb. *Z. xylopyrus* Willd.	Mixed deciduous	India, Myanmar
Fabaceae *Millettia bilaspurensis* Prasad, 2006	*Millettia pachycarpa* Benth.	Evergreen	Northeast India, Myanmar and Malaya
Sabiaceae *Meliosma eopinnata* Prasad, 2006	*Meliosma pinnata* Hook. f.	Evergreen	Northeast India and Myanmar
Combretaceae *Terminalia balugoloaensis* Lakhanpal & Awasthi, 1992	*Terminalia alata* Roth.	Moist deciduous	Sub-himalayan tract and Myanmar
Lythraceae *Lagerstroemia* sp. Lakhanpal & Dayal, 1966	*?Lagerstroemia indica* Linn.	Mixed deciduous	-
Moraceae *Ficus precunea* Lakhanpal, 1968	*Ficus cunea* Ham.	Mixed deciduous	Himalayan foot hills, Assam and Bangladesh
F. oodlabariensis Antal & Awasthi; Prasad, 2006	*Ficus benjamina* Linn.	Evergreen	Northeast India, Myanmar, Bangladesh and Andamans

Fig. 2—Present day distribution and forest types of modern comparable species of the fossil taxa of Balugoloa Assemblage, Himachal Pradesh.

flower impressions from the Siwalik foreland basins of India, Nepal and Bhutan.

The angiospermous fossil leaves, having both secondary and tertiary venation, usually with isolated termination of veinlets are recovered from the different fossil localities of Siwalik foreland basins (Fig. 1). Almost all the fossil leaves unearthed from Siwalik foreland basins were identified with extant taxa and thus a data base (Figs 2-11) is generated for the precise reconstruction of Siwalik floristics and interpreting the palaeobotanical inferences of the Himalayan foot hills. Keeping in view the extent and thickness of Siwalik foreland basins the data available so for is still unsatisfactory. However, there are record of some important and significant taxa documented from several Siwalik localities. These data are analysed here and an attempt has been made to deduce the palaeoclimate of the region during Siwalik Period (Mio-Pliocene).

ANGIOSPERMOUS LEAVES OF SIWALIK FORELAND BASINS

Sahni (1964) for the first time reported a grass-like monocot leaf, *Poacites siwalicus* from the Chinji Formation near Plandri, Rajouri District, Jammu. Later on several workers investigated the plant fossils from different fossil localities of Siwalik foreland basin and reported a variety of fossil leaves comprising 324 species of 174 genera and 60 families of both monocots and dicots. The later is represented by only four families- Marantaceae, Arecaceae, Smilaceae and Poaceae, the rest are of Dicotyledons. The angiospermous fossil leaves recovered so far from a number of exposures lying in the Himalayan foreland basin between Himachal Pradesh in the west and Bhutan in the east have been categorized into 10 assemblages.

Fossil taxa	Modern comparable species	Forest types	Distribution
DICOTYLEDONS			
Meliaceae			
Meliaceaeophyllum mahagonites Varma, 1968	*Swietenia mahagoni* Jacq.	Evergreen to moist deciduous	Southern and western India
Rhamnaceae			
Ziziphus cf. Z. *rugosa* Prasad, 1994a	*Z. rugosa* Lamk.	Mixed deciduous	Sub-himalayan tract, Myanmar and Sri Lanka
Fabaceae			
Albizia cf. *A. gamblei* Prasad, 1994a	*A. gamblei* Prain *(A. lebbek)*	Evergreen to moist deciduous	Sub-himalayan tract and Myanmar
Cassia cf. *C. fistula* Prasad, 1994a	*C. fistula* Linn.	Mixed deciduous	India and Myanmar
Pongamia cf. *P. glabra* Prasad, 1994a	*P. glabra* Vent.	Evergreen to moist deciduous	Malaya, Sri Lanka, Australia and Polynesia
Dalbergia cf. *D. sissoo* Prasad, 1994a	*P. sissoo* Roxb.	Mixed deciduous	Sub-himalayan tract, Assam and Myanmar
Myrtaceae			
Eucalyptophyllum raoi Varma, 1968	*E. oleosa* F. Muell. *E. gracilis* F. Muell.	Evergreen	Australia
Myrsinaceae			
Myrsine cf. *M. capitellala* Prasad, 1994a	*M. capitellata* Wall.	Evergreen	Northeast India, Myanmar, Sri Lanka and Malaya
Ebenaceae			
Diospyros embryopterisites Varma, 1968	*D. embryopteris* Pers.	Evergreen to moist deciduous	Sub-himalayan tract and Sri Lanka
Euphorbiaceae			
Homonoia cf. *H. riparia* Prasad, 1994a	*H. riparia* Laur.	Evergreen	Northeast India, Sri Lanka and central India
Croton cf. *C. teglis* Varma, 1968	*C. tegles*	Mixed deciduous	Northeast India and central India

Fig. 3—Present day distribution and forest types of modern comparable species of fossil taxa of Haridwar Assemblage, Uttaranchal.

	Leaf Assemblages	*Family*	*Genera*	*Species*
1.	Balugoloa Assemblage	12	13	18
2.	Haridwar Assemblage	7	11	11
3.	Kathgodam Assemblage	28	55	64
4.	Tanakpur Assemblage	6	11	14
5.	Koilabas Assemblage	30	80	112
6.	Surai Khola Assemblage	32	68	82
7.	Arung Khola Assemblage	16	21	22
8.	Bhikhnathoree Assemblage	11	19	19
9.	Oodlabari Assemblage	24	45	53
10.	Bhutan Assemblage	5	5	5

Balugoloa Leaf Assemblage, Himachal Pradesh

The systematic study on a leaf assemblage collected from the fossil localities situated in the foreland basin of Himachal Pradesh revealed the presence of a variety of taxa which are significant from both palaeoclimatic and phygeographic point of view. The well preserved fossil leaves collected from Balugoloa, a well known Siwalik locality near Jawalamukhi in Kangra District were investigated by Lakhanpal (1965, 1967, 1968, 1969), Lakhanpal and Dayal (1966), Lakhanpal and Guleria (1987) and Lakhanpal and Awasthi (1992).

Lakhanpal *et al.* (1987) described a leaf of bamboo from the Lower Siwalik sediments of Ranital on Jawalamukhi-Kangra Road, Kangara District, H.P. Mathur (1978) reported a lauraceous leaf (*Litsea bhatiai*), a papilionaceous leaf (*Paplionid*), a euphorbiaceous leaf (*Mallotus* sp.) and a grass-like leaf from the Siwalik foreland basin of Kangra District. Dayal and Chaudhury (1967) also reported some badly preserved dicot leaves from the Lower Siwalik sediments of Koshalya River, Himachal Pradesh. Systematic study on the fossil leaves collected recently from Ranital and Bilaspur area of Himachal Pradesh (Prasad, 2006) added eight more taxa to the present assemblage (Fig. 2). They are assigned to the genera *Fissistigma, Cratoxylon, Hydnocarpus, Trichilia, Meliosma, Millettia, Ficus* and *Amesoneuron*.

Haridwar Leaf Assemblage, Uttaranchal

The Himalayan foreland basin of Uttaranchal consists of enormously thick succession of fluvial deposits made up of sandstones, grits, conglomerates, pseudoconglomerates, clays and silts and exposed at many places containing within them a rich angiospermous plant remains. The Haridwar beds lie about 30 km south east of Mohand in Dehradun Valley. These beds are nearly 3000 m thick molasse type sediments which can be divided into Middle and Upper Siwalik units on the basis of gross lithological characters.

Varma (1968) first of all described ten angiospermous leaf impressions from the Middle Siwalik sediments at Bagh Rao near Haridwar under form species- *Meliaceaephyllum mahagonites, Diospyros enbryopterisites, Eucalyptophyllum raoi* and *Croton* cf. *C. teglis* of the family Meliaceae, Ebenaceae, Myrtaceae and Euphorbiaceae respectively.

Fossil taxa	Modern comparable species	Forest types	Distribution
MONOCOTYLEDONS			
Marantaceae			
Alpinia siwalica Prasad *et al.*, 2004	*A. buteocarpa* Poepp.	Evergreen	Philippines
Clinogyne ovatus (Awasthi & Prasad) Prasad *et al.*, 2004	*C.grandis* Benth. & Hooker	Moist deciduous	Sub-himalayan tracts
Poaceae			
Bambusa siwalika (Awasthi & Prasad) Prasad *et al.*, 2004	*B. tulda* Roxb.	Moist deciduous	N.E. India, Bangladesh and Myanmar
DICOTYLEDONS			
Anonaceae			
Uvaria siwalika Prasad, 1994c	*U. hamiltonii* Hook. f.	Evergreen to moist deciduous	Sub-himalayan tract, Assam, Sikkim, Khasi Hills, Chhota Nagpur, Bangladesh, Andaman Island and Myanmar
Cananga tertiara Prasad, 1994c	*C. odorata* Hook. f. & Thoms.	Evergreen	Martaban and Tennasserim, Malayan Peninsula and Archipelago
Saccopetalum pretomentosum Prasad *et al.*, 2004	*S. tomentosum* Hook f. & Thoms.	Moist deciduous	Bihar, Orissa, Western Ghats and throughout the Peninsula and Arawali Hills
Capparidaceae			
Capparis palaeomicrantha Prasad *et al.*, 2004	*C. micrantha* DC	Evergreen	Malaya Peninsula, Pegu and Tennasserim
Bixaceae			
Bixa kathgodamensis Prasad *et al.*, 2004	*B. orellana* Linn.	Evergreen	Tropical India and America
Flacourtiaceae			
Gynocardia mioodorata(Prasad *et al.*) Prasad *et al.* 2004	*G. odorata* R. Br.	Evergreen	Sikkim, Khasi Hills, Myanmar and NE India
Hydnocarpus palaeokurzii Prasad 1994c	*H. kurzii* (King) Wrab.	Evergreen	Martaban, Eastern and southern slopes of Peguyoma
Uncobia palaeospinosa Prasad 1994c	*U. (Stuartia) spinosa* Forsk.	Mixed deciduous	Tropical Arabia and Egypt
Clusiaceae			
Mesua tertiara (Lakhanpal) Prasad, 1994c	*M. ferrea* Linn.	Evergreen	Chittagong, Upper Myanmar Andaman Islands, Malaysia, Sri Lanka and south India
Garcinia eocambogia Prasad 1994c	*G. cambogia* Roxb.	Evergreen	Western peninsula from Konkan to Travancore, Sri Lanka and Andamans
Calophyllum suraikholaensis (Awasthi & Prasad) Prasad *et al.*, 2004	*C. polyanthum* Wall.	Evergreen	Bangladesh, Myanmar and Malaya
Dipterocarpaceae			
Dipterocarpus siwalicus (Lakhanpal & Guleria) Prasad, 1994c	*D. tuberculatus* Roxb.	Evergreen to moist deciduous	Myanmar, Cochin China and Thailand
Hopea kathgodamensis Prasad, 1994d	*H. micrantha* Hook f.	Evergreen	Malacca, Myanmar and Borneo
Shorea miocenica (Antal & Prasad) Prasad *et al.*, 2004	*S. buchananii* Fischer	Evergreen	Myanmar
Bombacaceae			
Pachira palaeomalabarica Prasad *et al.*, 2004	*P. malabarica (sesoilis)* Aubl.	Evergreen	Tropical America, Mexico and West Indies
Sterculiaceae			
Sterculia kathgodamense Prasad, 1994c	*S. coccinea* Jack	Evergreen	Sikkim, Assam, Khasi Hills, Bhutan and Myanmar
Tiliaceae			
Grewia kathgodamensis Prasad *et al.*, 2004	*G. laurifolia* Hook.	Evergreen	Malacca & Penang, Maingay and Borneo
Rutaceae			
Geijera siwalica Prasad, 1994d	*G. parviflora* Lindl.	Evergreen	Tropical Australia
Acronychia siwalica Prasad, 1994d	*A. baueri* Schott.	Evergreen to moist deciduous	Australia, Macleay and Clarence rivers
Meliaceae			
Trichilia miocenica Prasad, 1994c	*T. glabra* Vell.	Moist deciduous	Tropical Africa
Toona siwalica (Awasthi & Lakhanpal) Prasad, 1994c	*T. ciliata* Roxb.	Evergreen to moist deciduous	Sub-himalayan tract from Indus eastwards, Western Ghats and hills of western peninsula
Chukrasia miocenica Prasad, 1994d	*C. tubularis* Adr. Juss.	Moist deciduous	N.E. India, Myanmar Chittagong, throughout south India
Dysoxylum mioklanderi Prasad, 1994d	*D. kalanderi* F. Muell.	Evergreen	Australian land masses

contd.

Rhamnaceae			
Zizyphus miocenicus Prasad, 1994c	*Z. jujuba* Lam.	Mixed deciduous	Throughout India and Myanmar
Z. kathgodamensis Prasad, 1994c	*Z. xylopyrus* Wild.	Mixed deciduous	North western Himalayan foot hills, central India and western Peninsula
Sapindaceae			
Euphorea siwalica Prasad 1994c	*E. didyma* Blanco.	Evergreen	Malayan Archipelago
Cupania miocenica Prasad *et al.*, 2004	*C. jackiana* Heirn.	Evergreen	Nicobar Islands
Anacardiaceae			
Holarrhena nainitalensis Prasad *et al.*, 2004	*H. antidysentrica* Wall.	Mixed deciduous	Sub-himalayan tract, India, Western peninsula, Myanmar
Fabaceae			
Acacia eosericata Prasad, 1994c	*A. sericata* A. cun ex Benth.	Mixed deciduous	Northern Australia
Albizia siwalica (Prasad) Prasad, 1994c	*A. lebbek* Benth.	Evergreen to moist deciduous	Sub-himalayan tract, Peninsulas and Myanmar
Dialium palaeoindum Prasad, 1994c	*D. indum* Linn.	Evergreen	Malayan Peninsula
Cassia siwalica Prasad, 1994c	*C. tora* Linn.	Mixed deciduous	Central Himalaya, Madhya Pradesh and Cosmopolitan
Samanea siwalica Prasad, 1994c	*S. saman* Merrill	Evergreen	Tropical America, Konkan, North Kanara,
Millettia palaeoracemosa (Awasthi & Prasad) Prasad, 1994c	*M. racemosa* Benth.	Moist deciduous	coastal Andhra Pradesh, South Deccan, Myanmar, Pegu and Tennaserim
M. siwalica (Prasad) Prasad, 1994d	*M. ovalifolia* Kurz.	Moist deciduous	Sub-himalayan region and Myanmar
M. kathgodamensis Prasad *et al.*, 2004	*M. atropurpurea* Benth.	Evergreen	Pegu yoma Hills, Martaban and Tennasserim
Cynometra palaeoiripa (Prasad *et al.*) Prasad *et al.*, 2004	*C. iripa* kotel	Moist deciduous	Indo-Malayan region
Ormosia robustoides (Prasad) Prasad *et al.*, 2004	*O. robusta* Wight.	Evergreen	Arunachal Pradesh, Assam, Bangladesh and Myanmar
Derris prakashii Prasad *et al.*, 2004	*D. trifoliata* Lour.	Evergreen	China, N. Australia, Polynesia, Eastern Himalaya, Western Peninsula and Ceyon
Pongamia kathgodamensis Prasad, 1994d	*P. glabra* Vent.	Evergreen to moist deciduous	Oudh forests and sub-himalayan tract, Sri Lanka, Malaya and Tropical Australia
Rosaceae			
Parinari kathgodamensis Prasad, 1994c	*P. excelsa* Sabine.	Evergreen	Tropical Africa, Sierra leon, Don and Bagroo rivers
Combretaceae			
Terminalia miobelerica Prasad, 1994c	*T. belerica* Roxb.	Evergreen to moist deciduous	Sub-himalayan tract, common throughout India and Myanmar except the arid region of Sindh, western Rajasthan and southern Punjab and Malaysia
Lythraceae			
Lagerstroemia patelii (Lakhanpal & Guleria) Prasad, 1994c	*L. flosreginae* Retz.	Evergreen to moist deciduous	Assam, Chittagong, Lower Myanmar, Western Ghats, Sri Lanka and Malayan peninsula
Lagerstroemia jamraniensiss Prasad *et al.*, 2004	*L. speciosa* Pers.	Moist deciduous	Myanmar, Bangladesh, Ceylon, Malayan Peninsula, Assam and Western Ghats
Rubiaceae			
Morinda palaeotinctoria Prasad, 1994c	*M. tinctoria* Roxb.	Evergreen	Central Provinces, Bihar, Myanmar, Malayan Peninsula
Gardenia nainitalensis Prasad, 1994c	*G. jasminoides* Retz. = *(G. scandense)*	Evergreen	Taiwan to Japan
Myrsinaceae			
Ardisia palaeosimplicifolia Prasad, 1994c	*A. simplicifolia* Walp.	Evergreen to Moist deciduous	Tennasserim, Bengal and Assam
Sapotaceae			
Sarcosperma mioarboratum Prasad *et al.*, 2004	*S. arboratum* Benth.	Evergreen	Sub- himalayan tract and outer hills, Eastern India, Upper Myanmar and Yunnan
Ebenaceae			
Diospyros kathgodamensis Prasad, 1994c	*D. cacharensis* (Das & Kanjilal) H.B. Naithani	Evergreen	Cachar and Lakhimpur in Assam, Khasi Hills in Meghalaya, Siang District, Arunachal Pradesh
D. palaeoebenum Prasad, 1994d	*D. ebenum* Kurz.	Evergreen	Ceded Distt. especially Kurnool and Cuddapah, Sri Lanka

contd.

D. nainitalensis Prasad *et al.*, 2004	*D. chloroxylon* Roxb.	Moist deciduous	Western Peninsula and North and eastern part of India
D. palaeoeriantha Prasad *et al.*, 2004	*D. eriantha* (Champ.) Benth.	Evergreen to Moist deciduous	Philippines
Apocyanaceae			
Wrightia siwalica Prasad, 1994c	*W. tinctoria* R. Br.	Moist deciduous	Rajputana, Central Provinces and Western Peninsula
Lauraceae			
Michilus miocenica Prasad, 1994d	*M. odoratissima* Nees.	Evergreen to moist deciduous	Outer himalayan ranges from Indus eastwards, Khasi Hills of Martaban and upper Myanmar
Euphorbiaceae			
Mallotus venkatachalai Prasad, 1994c	*M. cochinchinensis* Lour.	Evergreen	Assam, Bengal, Bangladesh, Myanmar
	M. repandus Muell. Arg.		Sri Lanka and Malaysia
Phyllanthus siwalica Prasad, 1994d	*P. gracilips* Muell. Arg.	Evergreen to moist deciduous	Shady forests of Java
P. mioreticulatus (Prasad *et al.*) Prasad *et al.*, 2004	*P. reticulatus* Poir.	Moist deciduous	India, Myanmar and Sri Lanka
Homonoia mioriparia (Antal & Prasad) Prasad *et al.*, 2004	*H. riparia* Lour.	Evergreen	Myanmar, Sri Lanka, Malaya Peninsula, China and India except in the North-West
Glochidion miocenica Prasad, 1994c	*G. chlorophaes* Baill.	Evergreen	Malaysia
Moraceae			
Ficus precunea Lakhanpal, 1969	*E. cunea* Ham.	Mixed deciduous	Sub-himalayan tract and Outer Hill from the Chenab eastward, Manipur, Khasi hills and Myanmar
Ficus oodlabariensis (Antal & Awasthi) Prasad *et al.*, 2004	*F. benjamina* Linn.	Evergreen	Eastern Himalaya, Assam, Chittangong, Andamans, Pegu and Martaban

Fig. 4—Present day distribution and forest types of modern comparable species of the fossil taxa of Kathgodam Assemblage, Uttaranchal.

Awasthi (1992) opined that the identification of these leaf impressions (expect *Diospyros embryopterisites*) is doubtful on the basis of mainly their phytogeographical distribution. Later on Prasad (1994a) investigated the angiospermous fossil leaves collected from a well exposed section of about 15 km in length from Lalita Rao to Kharkhari and reported some significant taxa belonging to the family Rhamnaceae, Fabaceae, Myrsinaceae and Euphorbiaceae (Fig. 3).

Kathgodam Leaf Assemblage, Uttaranchal

Kathgodam is one of the important fossiliferous localities in the Siwalik foreland basin of Uttaranchal, India. This is located in the district of Nainital which is about 306 km north east of New Delhi on Haldwani–Nainital Road bounded by Siwalik Hills in north and Terai Plain towards south. The Siwalik beds in Kathgodam area found running in a northeast direction and are well exposed along Kathgodam-Nainital Road, Kathgodam-Bhimtal Road near Ranibag bridge and on both sides of Gola and Balia rivers. Geological study of the Siwalik Sequence of the Kathgodam-Rainbag-Amritpur sector of Kumaun sub-Himalaya has been made by Shukla (1984). This sequence consists of several alternations of sandstone and mudstone varying in thickness from 4-54 m. A Middle Miocene age has been assigned to these Siwalik beds on the basis of lithology and vertebrate fauna (Ranga Rao *et al*., 1979).

A rich and diversified assemblage of plant fossils was collected from the Lower Siwalik sediment of Balia and Gola river sections in the Kathgodam area. Their detailed study revealed that they belong to of 64 species represented by 55 genera belonging to 28 families of angiosperms (Prasad, 1994c, d; Prasad *et al*., 2004; Fig. 4).

Tanakpur Leaf Assemblage, Uttaranchal

In the Siwalik foreland basin of Uttaranchal, there is another fossiliferous locality, Tanakpur in Champawat District which contains great variety of angiospermous leaves. Concerted efforts have so far been made by several workers to study the plant fossils from this area. Although a large number of well preserved fossil leaves were collected by the present author from a road cutting section from Thuligad to Purniyagiri Temple yet only few publications were made on the angiospermous fossil leaves of the area. Lakhanpal and Guleria (1978) described a lauraceous fossil leaf, *Persea purniyagiriensis* from the Tanakpur area. Recently, Shashi *et al.* (2006, 2007) reported some fossil leaves from the same road section belonging to the family Anonaceae, Sterculiaceae, Fabaceae, Apocynaceae, Ebenaceae and Lauraceae (Fig. 5).

Koilabas Leaf Assemblage, western Nepal

The fossiliferous locality, Koilabas lies on the Indo-Nepal Border (about 1 km inside western Nepal) near Jarva in Balrampur District of Uttar Pradesh, India. It is bounded by Churia Hills towards north and Terai Plain towards south. The fossil exposures fall in the Dang Section of the Churia Hills in western Nepal. In this area the Lower Churia Formation is observed from Koilabas to Darwaja containing fine grained

Fossil taxa	Modern comparable species	Forest types	Distribution
DICOTYLEDONS			
Anonaceae			
Mitrephora siwalika Antal & Awasthi; Shashi *et al*., 2006	*M. maingayi* Hook. f. & Th.	Evergreen	North east India, Myanmar, Malaya and Sri Lanka
Ellipeia miocenica Shashi *et al*., 2007	*E. cuneifolia* Hook. f. & Th.	Evergreen	Malaya
Comiphora precaudata Shashi *et al*., 2007	*C. caudata* Engl.	Mixed deciduous	Western Peninsula
Sterculiaceae			
Sterculia tertiara Shashi *et al*., 2006	*S. ensifolia* Masters	Evergreen	Philippines and Malaya
Fabaceae			
Cynometra siwalika Awasthi & Prasad; Shashi *et al*., 2006	*C. polyandra* Roxb.	Evergreen	North east India and Malaya
Millettia purniyagiriensis Shashi *et al*., 2006	*M. auriculata* Backer	Mixed deciduous	Sub-himalayan tract, central India
Millettia prakashii Shashi *et al*., 2007	*M. atropurpurea* Benth.	Evergreen	Myanmar, Martaban Hills and South India
Caesalpinia purniyagiriensis Shashi *et al*., 2007	*C. microphylla* G. Don.	Evergreen	North east India and Malaya Peninsula
Ebenaceae			
Diospyros palaeoebenum Prasad; Shashi *et al*., 2007	*D. ebenum* Kurz.	Evergreen to moist deciduous	South and central India and Sri Lanka
Diospyros purniyagiriensis Shashi *et al*., 2007	*D. variegata* Kurz.	Evergreen	Northeast India, Myanmar and Martaban Hills
Apocynaceae			
Chonemorpha miocenica Prasad & Awasthi; Shashi *et al*., 2006	*C. macrophylla* G. Don.	Evergreen	North east India, Western Ghats and Malaya
Lauraceae			
Cinnamomum nepalensis Prasad & Pandey; Shashi *et al*., 2007	*C. caudatum* Nees	Evergreen to moist deciduous	Northeast India and Myanmar
C. miotavoyanum Shashi *et al*., 2007	*C. tavoyanum* Meiss.	Evergreen	South India and Myanmar
Persea purniyagiriensis Lakhanpal & Guleria, 1978	*Persea* spp.	Evergreen	Indo-Malaya

Fig. 5—Present day distribution and forest types of modern comparable species of the fossil taxa of Tanakpur Assemblage, Uttaranchal.

sandstone beds with variegated clay and some pebbles. From Darwaja to Masot Khola the rocks represent the Upper Churia Formation. In Garubir Pass the lower formation is found thrusted over the upper formation (Sharma, 1977). The section belonging the Lower Churia Formation (Lower Siwalik) containing excellently preserved angiospermous leaf impressions is well exposed on the both sides of Koilabas nala (also known Dang nala).

Morphotaxonomical study on the angiospermous leaves collected from Koilabas area (including Jarva and Seria Naka) has been carried out by Tripathi and Tiwari 1983, Prasad and Prakash 1984, Prasad 1990a, b, 1994a, Prasad *et al.* 1999, Dwivedi *et al*. 2006a, b, Prasad and Dwivedi 2007, 2008 to generate palaeobotanical data for precise reconstruction of Siwalik floristics and interpreting the palaeoenvironment and phytogeography of the area. They have identified about 112 taxa belonging to one monocotyledonous and 30 dicotyledonous families (Fig. 6).

Surai Khola Leaf Assemblage, western Nepal

Surai Khola is one of the most important and internationally famous fossil localities in the Siwalik foreland basin of Nepal. There is a complete and uninterrupted sequence of the Siwalik Group exposed along the Mahendra Highway between Surai Naka and Rangsing Khola. This sequence measures about 16 km in length and lies about 70 km west of Butwal, District Kapilbastu in western Nepal.

A multidisciplinary research work (tectonic, lithostratigraphy, magnetostratigraphy, palaeontology and isotopic) has been carried out by workers of different countries (Corvinus, 1988a, b, 1990, 1994; Appel & Rosler, 1994; Quade *et al*., 1995; Sanyal *et al*., 2005). Corvinus (1988a, b) who was the pioneer worker of the Surai Khola Siwalik, measured the whole sequence of the area to 5600 m and further divided into five formations, namely- Bankas (Corresponding to Chinji), Chor Khola (Middle Siwalik), Surai Khola (Middle-Upper Siwalik), Dobata (= Pinjore) and Dhan Khola (Boulder Conglomerate). This is one of the best sequences of Siwalik sediments for palaeobotanical studies. There are more than 55 recognized fossiliferous beds of mainly shales, siltstones, mudstones and fine grained sandstones. A variety of well preserved angiospermous leaf impressions were collected from these beds.

The detailed study on the angiospermous fossil leaves so far collected from the Surai Khola area reveals the presence of a number of significant taxa comprising about 82 species belonging to 68 genera and 32 families of both monocots and dicots (Awasthi & Prasad, 1990; Prasad & Awasthi, 1996; Prasad & Pandey, 2008; Fig. 7).

Fossil taxa	Modern comparable species	Forest types	Distribution
MONOCOTYLEDONS			
Marantaceae			
Donax kasauliensis (Srivastava & Guleria) Prasad & Dwivedi, 2008	*D. cannaeformis* Lour.	Evergreen to Moist Deciduous	Indo-Malayan region
DICOTYLEDONS			
Anonaceae			
Miliusa mioveluntina Prasad *et al.*,1997	*M. veluntina* H. f. & Th.	Mixed deciduous	Sub-himalayan tract and Myanmar
Miliusa siwalica Prasad *et al.*, 1999	*M. thoretii* Finet & Gagnep.	Mixed deciduous	India and China
Anona koilabasensis Prasad *et al.*, 1999	*A. laurifolia* Linn.	Evergreen	Java
Goniothalmus siwalicus Prasad *et al.*, 1997	*G. meboldii* Blume	Evergreen	Malaya
Mitrephora miocenica Prasad *et al.*, 1997	*M. macrophylla* Oliver	Evergreen	Malaya
Melodorum jarwaensis Tripathi *et al.*, 2002	*M. bicolor* H. f. & Th.	Evergreen to Moist deciduous	N.E. India and Myanmar
Polyalthia palaeosumatrana Tripathi *et al.*, 2002	*P. sumatrana* Kurz.	Evergreen to Moist deciduous	Sumatra, Borneo and Malaya
Fissistigma senii **(**Lakhanpal) Prasad & Dwivedi, 2008	*F. wallichii* H. f. & Th.	Evergreen	N.E. India
Fissistigma mioelegans Prasad *et al.*, 1999	*F. elegans* H. f. & Th.	Evergreen	Malaya and Malacca
Uvaria siwalika (Prasad) Prasad & Dwivedi, 2008	*U. hamiltonii* H. f. & Th.	Evergreen to Moist deciduous	N.E. India, Andaman and Myanmar
Dilleniaceae			
Dillenia palaeoindica Prasad & Prakash, 1984	*D. indica* Linn.	Mixed deciduous	India and Myanmar
Polygalaceae			
Securidaca miocenica Prasad *et al.*, 1997	*S. inappendiculata* Hask.	Evergreen to Moist deciduous	N.E. India and Java
Qualea siwalica Prasad & Dwivedi, 2008	*Q. densiflora* Warm.	Evergreen	Tropical America
Flacourtiaceae			
Flacourtia seriaensis Prasad *et al.*, 1997	*F. catafracta* Roxb.	Mixed deciduous	N.E. India, Myanmar and Malaya
F. koilabasensis Prasad & Dwivedi, 2008	*F. montana* Grahm.	Evergreen to Moist deciduous	N.E. India, Myanmar and S. India
Ryparosa prekunstelri Prasad, 1990a	*R. kunstelri* King.	Evergreen	Malaya
Gynocardia mioodorata Prasad *et al.*, 1999	*G. odorata* R. Br.	Evergreen	N.E. India and Myanmar
Clusiaceae			
Mesua tertiara (Lakhanpal) Prasad, 1990a	*M. ferrea* Linn.	Evergreen	N.E. India, Myanmar and Malaya
Kayea kalagarhensis (Prasad) Prasad, 1994e	*K. floribunda* Wall.	Evergreen	N.E. India and Myanmar
Garcinia nepalensis Prasad *et al.*, 1999	*G. cowa* L.	Evergreen	N.E. India, Bangladesh and Myanmar
Dipterocarpaceae			
Isoptera siwalica Prasad *et al.*, 1999	*I. borneonsis* Br.	Evergreen	Java and Myanmar
Dipterocarpus siwalicus (Lakhanpal & Guleria) Prasad, 1990b	*D. tuberculatus* Roxb.	Evergreen to moist deciduous	N.E. India, Myanmar and South east Asia
D. koilabasensis Prasad *et al.*, 1999	*D. turbinatus* Gaertn.	Evergreen	N.E. India, Bangladesh and Myanmar
Hopea mioglabra Prasad, 1994e	*H. glabra* W. & A.	Evergreen	South India
Shorea eutrapizifolia Prasad *et al.*, 1999	*S. trapizifolia* Thw.	Evergreen	Ceylon
S. miocurtisii Prasad & Dwivedi, 2008	*S. curtisii* Dyer	Evergreen	Malaya
Rutaceae			
Evodia koilabasensis Prasad, 1994e	*E. fraxinifolia* Hook. f.	Evergreen to moist deciduous	N.E. India, Malaya and Nepal
Murraya khariensis (Lakhanpal & Guleria) Prasad, 1994e	*M. paniculata* (Linn.) Jacq.	Mixed deciduous	Sub himalayan region, Myanmar, Andaman and Australia
Atlantia miocenica Prasad, 1994e	*A. monophylla* Corr.	Evergreen	South and North India, Myanmar and Andaman
Simaroubaceae			
Brucea darwajensis Prasad *et al.*, 1999	*B. mollis* Wall.	Evergreen	N.E. India and Myanmar

contd.

Meliaceae			
Chloroxylon palaeoswietenia Prasad, 1990a	*C. swietenia* DC.	Mixed deciduous	India and Sri Lanka
Aglaia nepalensis Prasad *et al.*,1999	*A. euryphylla* Koor. & Valeton	Evergreen	Java
Rhamnaceae			
Berchemia nepalensis Prasad & Dwivedi, 2008	*B. hamosa* Brongn.	Mixed deciduous	Nepal, Wallich and Western Peninsula
B. siwalica Tripathi *et al.*, 2002	*B. floribunda* Wall.	Mixed deciduous	N.E. India
Zizyphus miocenica Prasad, 1994e	*Z. jujuba* Lam.	Mixed deciduous	India and Myanmar
Sapindaceae			
Filicium koilabasensis Prasad, 1994e	*F. decipiense* Thw.	Evergreen	South India, Sri Lanka and Tropical Africa
Euphorea nepalensis Prasad, 1994e	*E. longana* Lamk.	Evergreen to moist deciduous	South and North India, Myanmar and Malaya
Otophora miocenica Prasad, 1994e	*O. fruticosa* Blume.	Evergreen	Malaya
Nephelium palaeoglabrum Prasad *et al.*, 1997	*N. glabrum* Noronh.	Evergreen	Malaya
Paranephelium seriaensis Prasad & Dwivedi, 2008	*P. xestophyllum* (Miq.) King.	Evergreen	Malaya and Myanmar
Arytera seriaensis Prasad & Dwivedi, 2008	*A. oshaneiana* Radik.	Evergreen	Australia
Sabiaceae			
Sabia eopaniculata Prasad, 1994e	*S. paniculata* Seem.	Evergreen to moist deciduous	Sub-himalayan region, Myanmar and Malaya
S. siwalica Dwivedi *et al.*, 2006a	*S. malabarica* Bedd.	Evergreen	N.E. India and Malaya
Anacardiaceae			
*Swintonia palaeoschwenckii (*Prasad & Awasthi) Prasad *et al.*, 1999	*S. schwenckii* Teysn.	Evergreen	India, Myanmar and Malaya
Bouea koilabasensis Prasad, 1994e	*B. burmanica* Griff.	Evergreen	South India, Andaman and Myanmar
B. premacrophylla Antal & Awasthi; Dwivedi *et al*., 2006a	*B. macrophylla* Griff.	Evergreen	Java, Borneo and Malaya
Tapiria chorkholiense Prasad, 1994e	*T. hirsuta* Hook. f.	Mixed deciduous	N.E. India, Nepal and Bhutan
Mangifera someshwarica (Lakhanpal & Awasthi) Prasad, 1994e; Prasad *et al.*, 1997	*M. indica* Linn.	Evergreen to moist deciduous	India and Malaya
Dracantomelum seriaensis Prasad *et al.*, 1997	*D. sylvestre* Blume	Evergreen	Borneo
Fabaceae			
Pongamia kathgodamensis Prasad, 1994a	*P. glabra* Vent.	Evergreen to moist deciduous	India, Sri Lanka and Malaya
Albizia siwalica Prasad, 1990b	*A. lebbek* Gamble	Evergreen to moist deciduous	N.E. India and Myanmar
Cassia nepalensis Prasad, 1990a	*C. hirsuta* Linn.	Mixed deciduous	Central India
C. miosiamea Prasad, 1994e	*C. siamea* Lam.	Mixed deciduous	India, Myanmar and Malaya
C. neosophora Prasad, 1994e	*C. sophora* Wall.	Evergreen	South east Asia
Dalbergia eucultrata Prasad *et al.*, 1999	*D. cultrata* L.	Mixed deciduous	India and Myanmar
D. miovolubilis Prasad *et al.*, 1997	*D. volubilis* Roxb.	Mixed deciduous	India and Nepal
D. miosericea Prasad, 1990b	*D. sericea* Boj.	Mixed deciduous	Sub-himalayan region and Madagascar
D. siwalika Prasad, 1994e	*D. sissoo* Roxb.	Mixed deciduous	Sub-himalayan region
Millettia siwalica Prasad, 1990a	*M. ovalifolia* Kurz.	Evergreen to Moist deciduous	Sub-himalayan region and Myanmar
M. ovatus Tripathi *et al.*, 2002	*M. pubinervis* Kurz.	Moist deciduous	Myanmar
M. palaeomanii Dwivedi *et al*., 2006b	*M. manii* Backer	Evergreen	Tropical Africa
M. *imlibasensis* Prasad *et al.*, 1999	*M. brandisiana* Kurz.	Moist deciduous	Myanmar
M. *koilabasensis* Prasad, 1990b	*M. macrostachya* Coll. & Hemsl.	Evergreen to moist deciduous	Myanmar
M. miobrandisiana Prasad, 1994e	*M. brandisiana* Kurz.	Evergreen	Myanmar
Canavalia siwalica Dwivedi *et al*., 2006b	*C. rosea* DC.	Evergreen to Moist deciduous	Malaya and south India

contd.

Ormosia robustoides Prasad, 1990b	*O. robusta* Jacq.	Moist deciduous	N.E. India and Myanmar
Samanea siwalica Prasad, 1994e	*S. saman* Merr.	Evergreen	Tropical Africa and America
Entada palaeoscandens (Awasthi & Prasad) Prasad, 1994e	*E. scandens* Benth.	Mixed deciduous	India and Myanmar
Cynometra palaeoiripa Prasad *et al.*, 1999	*C. iripa* Kotel.	Mixed deciduous	India
C. siwalika (Awasthi & Prasad) Dwivedi *et al*., 2006b	*C. Polyandra* Roxb.	Evergreen	N.E. India and Malaya
Combretaceae			
Anogeissus eosericea Prasad & Prakash, 1984	*A. sericea* Brandis	Mixed deciduous	Central India
Calycopteris floribundoides Prasad, 1990a	*C. floribunda* Lam.	Mixed deciduous	N.E. India, Myanmar and Western Peninsula
Terminalia koilabasensis Prasad, 1990a	*T. angustifolia* Jacq.	Evergreen	Malaya
T. siwalica Prasad, 1990a	*T. pyrifolia* Kurz.	Evergreen to moist deciduous	Myanmar
T. panandhroensis (Lakhanpal & Guleria) Prasad, 1994e	*T. tomentosa* W.A.	Evergreen to moist deciduous	Sub-himalayan region and Myanmar
Combretum sahnii (Antal & Awasthi) Prasad, 1994e	*C. decandrum* Roxb.	Mixed deciduous	Sub-himalayan region, Bangladesh and central India
Lythraceae			
Lagerstroemia siwalica Prasad, 1994e	*L. lanceolata* Wall.	Evergreen	Western Peninsula
L. mioparviflora Dwivedi *et al*., 2006a	*L. parviflora Roxb.*	Evergreen to moist deciduous	N.E. India and Myanmar
L. eomicrocarpa Dwivedi *et al*., 2006a	*L. microcarpa* Linn.	Evergreen to moist deciduous	S. India, Myanmar and Australia
Woodfordia neofruticosa Prasad, 1994e	*W. fruticosa* Kurz.	Mixed deciduous	Sub-himalayan region, Tropical Africa, Arabia and Peninsulas
Anisophylleaceae			
Anisophyllea siwalica Prasad & Awasthi, 1996	*A. apetala* Scort.	Evergreen	Malaya
Myrtaceae			
Syzygium miocenicum Prasad & Prakash, 1984	*S. claviflorum* Roxb.	Evergreen to moist deciduous	North east India, Andaman and Myanmar
Syzygium miooccidentalis Prasad *et al.*, 1999	*S. occidentalis* Bourd.	Moist deciduous	India
Caprifoliaceae			
Lonicera mioquinquelocularis Prasad, 1990a	*L. quinquelocularis* Hardw.	Mixed deciduous	North-west Himalaya, Nepal and India
Rubiaceae			
Canthium siwalica Prasad & Dwivedi, 2007	*C. dydimum* Roxb.	Evergreen	India, Myanmar and Malaya
Randia miowallichii Prasad, 1990a	*R. wallichii* Hook. f.	Evergreen	North east India, Myanmar and Andaman
R. miouncaria Prasad & Dwivedi, 2007	*R. uncaria* Elmer	Evergreen	Philippines
Morinda siwalica Prasad, 1994e	*M. umbellata* Linn.	Evergreen	N.E. India, South India, Sri Lanka and Malaya
Nauclea seriaensis Prasad & Dwivedi, 2007	*N. subdita* (Miq.) Merr.	Evergreen	Malaya
Ebenaceae			
Diospyros koilabasensis Prasad, 1990a	*D. montana* Roxb.	Mixed deciduous	India, Myanmar and Sub-himalayan region
D. pretoposia Prasad, 1990a	*D. toposia* Ham.	Evergreen	N.E. India, Bangladesh and Sri Lanka
D. darwajensis Prasad *et al.*, 1999	*D. dasyphyllea* Kurz.	Evergreen	Martaban
Apocynaceae			
Tabernaemontana precoronaria Prasad, 1990a	*T. coronaria* Willd.	Mixed deciduous	Sub-himalayan region, Sri Lanka and Myanmar
Carissa koilabasensis Prasad, 1994e	*C. paucinervia* A. DC.	Evergreen	N.E. India and Myanmar
Alyxia koilabasensis Prasad & Dwivedi, 2007	*A. fasciculata* Benth.	Evergreen to moist deciduous	N.E. India

contd.

Alstonia nepalensis Prasad & Dwivedi, 2007	*A. angustifolia* Wall.	Evergreen	Malacca, Myanmar and Malaya
Loganiaceae			
Gaertnera siwalica Prasad, 1990a	*G. bieleri* (D. Willd.) E. Petit	Evergreen	Tropical Africa
Solanaceae			
Datura miocenica Prasad, 1990a	*D. fastuosa* Linn.	Mixed deciduous	India, Malaya and Tropical Africa
Oleaceae			
Anacolosa mioluzoniensis Prasad, 1994e	*A. luzoniensis* Merr.	Evergreen	South east Asia
Verbenaceae			
Vitex prenegundo Prasad, 1990a	*V. negundo* Linn.	Mixed deciduous	India, Sri Lanka and China
V. siwalica Prasad, 1990a	*V. pubescens* Vahl.	Evergreen	India and Myanmar
Lauraceae			
Cinnamomum mioinuctum Prasad, 1990a	*C. inuctum* Meissn.	Evergreen to moist deciduous	Myanmar and Malaya
Moraceae			
Ficus precunia (Lakhanpal) Prasad, 1990a	*F. cunia* Ham.	Mixed deciduous	Sub-himalayan region, Assam, Myanmar and India
F. retusoides Prasad, 1990a	*F. retusa* Linn.	Evergreen	Malaya
F. nepalensis Prasad, 1990a	*F. glaberrima* Blume	Evergreen	India and Malaya
F. eomysorensis Tripathi *et al.*, 2002	*F. mysorensis* Heyn.	Moist deciduous	N.E. India, Myanmar, Sri Lanka and Western Ghats
Artocarpus nepalensis (Prasad & Awasthi) Prasad & Dwivedi, 2007	*A. integrifolia* Linn. f.	Evergreen	N.E. India, Myanmar and Western Ghats
Protiaceae			
Helicia eoerretica Prasad *et al.*, 1999	*H. erretica* Hook J.	Evergreen	N.E. India and Martaban
Euphorbiaceae			
Phyllanthus koilabasensis Prasad *et al.*, 1999	*P. collumnaris* Muell. Arg	Mixed deciduous	Myanmar
P. mioreticulatus Prasad *et al.*, 1999	*P. reticulatus* Poir.	Mixed deciduous	India, Myanmar and Ceylon
Antedesma siwalica Prasad *et al.*, 1999	*A. montanum* Bl.	Evergreen	Malaya
A. miocenica Prasad & Dwivedi, 2007	*A. veluntinosum* Blume	Evergreen	Myanmar and Malaya

Fig. 6—Present day distribution and forest types of Modern comparable species of the fossil taxa of Koilabas Assemblage, western Nepal.

Arung Khola Leaf Assemblage, west central Nepal

The Siwalik (Churia) sediments of Arung Khola, Binai Khola and Tinau Khola area, west central Nepal lie between Main Boundery Thrust (MBT) to the north and Frontal Churia Thrust (FCT) to the south. It consists of about 6000 m thick fluvial deposits having gradual coursing towards top of the sequence. The geological works (geological mapping, lithostratigraphy, sedimentology and magnetostratigraphy) of the Churia (Siwalik) Group of Arung Khola area has been carried out by Tokuoka *et al*. (1986, 1988, 1990). Lithostratigraphically, the whole sequence is divided into Arung Khola Formation, Binai Khola Formation, Chitvan Formation and Deorali Formation in ascending order. The former two are further divided into Lower, Middle and Upper units and are highly fossiliferous possessing mostly angiospermous fossil leaves and occasionally flower, fruit and seed fossils. They are mostly preserved in mudstone, claystone and fine grained sandstones in the form of impressions. The morphotaxonomical study on these leaf impressions was done by Konomatsu and Awasthi (1996, 1999). They have reported a number of palaeobotanically significant angiospermous genera and species from the Arung Khola Formation exposed in Tinau Khola and Jhumsa Khola near Butwal and from the Binai Khola Formation along Mahendra Highway between Barghat and Dumkibas (Fig. 8).

Bhikhnathoree Leaf Assemblage, Bihar

The Bhikhnathoree Assemblage recovered from a small patch of fossiliferous beds exposed at Indo-Nepal border near the Bhikhnathoree in West Champaran District of Bihar. A good assemblage of angiospermous leaves comprising 19 species of 11 dicotyledonous families were reported by Lakhanpal and Awasthi 1984, Awasthi and Lakhanpal 1990, Fig. 9.

Oodlabari Leaf Assemblage, West Bengal

In the eastern part of Siwalik foreland basin, the palaeobotanical work was initiated by Pathak, (1969) who first of all described a few fragmentary angiospermous leaves as *Castanopsis tribuloides, Cinnamamum tamala, Machilus villosa, Litsea polyantha, Bridelia stipularis, B. verrucosa, Mallotus philippinensis* and *Rhododendron lepidotum* from the Middle Siwalik sediments of Mahanadi Section in the Darjeeling District. According to Awasthi (1982) the generic and specific determination are doubtful. It is most probably due to their fragmentary nature. After a gap of long period a systematic and detailed morphotaxonomical study on the angiospermous fossil leaves was carried out by Antal and Awasthi (1993) who reported a large number of well preserved fossil leaves from the both Lower and Middle Siwalik units of Ghish, Lish and Ramthi River sections and near Tista Bridge

Fossil taxa	Modern comparable species	Forest types	Distribution
MONOCOTYLEDONS			
Marantaceae			
Clinogyne ovatus Awasthi & Prasad, 1990	*C. grandis* Benth. & Hook.	Moist deciduous	Sub-himalayan tract
Arecaceae			
Caryota siwalica Awasthi & Prasad, 1990	*C. urens* L.	Evergreen to moist deciduous	N.E. India, Sub-himalayan tract, Sri Lanka, Myanmar and Malaya
Poaceae			
Bambusa siwalika Awasthi & Prasad, 1990	*B. tulda* Roxb.	Moist deciduous	N.E. India, Bangladesh and Myanmar
DICOTYLEDONS			
Anonaceae			
Mitrephora siwalica (Antal & Awasthi) Prasad & Awasthi, 1996	*M. maingayi* Hook. f.	Evergreen	N.E. India, Myanmar, Malaya, Sri Lanka and Java
Goniothalamus chorkholaensis Prasad & Awasthi, 1996	*G. thwaitesii* Hook. f. & Thoms. *G. sesquipedalis* Hook. f. & Thoms.	Evergreen Evergreen	N.E. India and Myanmar Travancore, Tirnelvelli and Sri Lanka
Polyalthia palaeosimiarum Awasthi & Prasad, 1990	*P. simiarum* Bl.	Evergreen	N.E. India, Bangladesh, Myanmar and Andamans
Menispermaceae			
Cocculus miotrilobus Prasad & Pandey, 2008	*C. trilobus* DC.	Evergreen	China, Japan and Philippines
Flacourtiaceae			
Xylosma nepalensis Prasad & Pandey, 2008	*X. racemosum* Miq.	Evergreen	Tropical regions of Japan and Taiwan
Flacourtia nepalensis Awasthi & Prasad, 1990	*F. ramontchii* L. Herit.	Mixed deciduous	India, Sri Lanka and Malaya
Flacourtia tertiara Prasad & Awasthi, 1996	*F. inermis* Roxb.	Evergreen	Malaya
Hydnocarpus siwalicus Prasad & Awasthi, 1996	*H. glaucescens* Blume	Evergreen	Malaya and Sumatra
H. chorkholaensis Prasad & Awasthi, 1996	*H. ovoides* Elmer.	Evergreen	Philippines
Clusiaceae			
Calophyllum suraikholaensis Awasthi & Prasad, 1990	*C. polyanthum* Wall.	Evergreen	N.E. India, Bangladesh and Myanmar
Garcinia corvinusiana Prasad & Pandey, 2008	*G. speciosa* Wall.	Evergreen	Tennasserim and Andamans
Mesua tertiara Lakhanpal (Prasad, 1994c) Prasad & Pandey, 2008	*M. ferrea* Linn.	Evergreen	Bengal, Eastern Himalayas, western Peninsula, Assam, Myanmar and Andaman Islands
Dipterocarpaceae			
Dipterocarpus siwalicus (Lakhanpal & Guleria) Awasthi & Prasad, 1990	*D. tuberculatus* Roxb. *D. turbinatus* Gaertn.	Evergreen to moist deciduous Evergreen	N.E. India and Myanmar N.E. India, Bangladesh, Myanmar and Malaya
D. suraikholaensis Prasad & Pandey, 2008	*D. alatus* Roxb.	Evergreen to moist deciduous	Pegu, Tennasserim, Thailand, Combodia, Myanmar and Andaman Islands
Shorea palaeostellata Prasad & Pandey, 2008	*S. stellata* Dyer.	Moist deciduous	Tropical Asia and Indian archipelago, Tennasserim, Pegu and Thailand
Vatica nepalensis Prasad & Pandey, 2008	*V. astrotricha* Hance	Evergreen	Throughout N.E. India
Ancistrocladaceae			
Ancistrocladus suraikholaensis Prasad & Pandey, 2008	*A. griffithii* Planch.	Evergreen	Tropical Asia, Tropical Africa, Indian archipelago, Tennasserim and Myanmar
Sterculiaceae			
Sterculia mioensifolia Prasad & Pandey, 2008	*S. ensifolia* Mast.	Evergreen	Malaya, Philippines and Mergui
S. premontana Prasad & Pandey, 2006	*S. montana* Merrill.	Evergreen to moist deciduous	Malaya Peninsula
Malpighiaceae			
Stigmaphyllon chorkholaensis Prasad & Pandey, 2008	*S. periplocaefolium* A. Juss.	Evergreen	Tropical America
Rutaceae			
Zanthoxylum siwalicum Prasad & Awasthi, 1996	*Z. hamiltonianum* Wall.	Evergreen to moist deciduous	N.E. India and Myanmar

contd.

Murraya khariensis (Lakhanpal & Guleria) Prasad & Awasthi, 1996	*M. paniculata* (Linn.) Jacq.	Mixed deciduous	N.E. India, Myanmar, Sri Lanka, China and Australia
Ochnaceae *Ochna siwalika* Prasad & Pandey, 2008	*O. integrifolia* Presl.	Evergreen	Tropical Asia and Africa
Meliaceae *Chisocheton suraikholaensis* Prasad & Pandey, 2008	*C. divergens* Bl.	Evergreen	Malayan peninsula and Myanmar
Toona siwalica (Awasthi & Lakhanpal) Prasad, 1994c	*T. cedrella* Roxb.	Evergreen to moist deciduous	Tropical Himalaya, Myanmar, Java, Australia, Hills of Western Peninsula, Assam and Manipur
Dysoxylum raptiensis Prasad & Awasthi, 1996	*D. procerum* Hiern.	Evergreen	N.E. India and Myanmar
Chukrasia miocenica Prasad & Awasthi, 1996	*C. tabularis* Adr. Juss.	Evergreen to moist deciduous	N.E. India, Sri Lanka, Myanmar and Andamans
Ctenolophonaceae *Ctenolophon chorkholaensis* Prasad & Pandey, 2008	*C. philippinensis* Hallier. f.	Evergreen to moist deciduous	Malaya and Philippines
Sapindaceae *Harpullea siwalica* Prasad & Awasthi, 1996	*H. cupinoides* Roxb.	Evergreen	Sri Lanka, Bangladesh and Andamans
Xerospermum mioglabratum Prasad & Pandey, 2008	*X. glabratum* (=*X. norohianum)* (Blume) Rump.	Evergreen	N.E. India, Tennasserim, Singapore, Malacca, Malaya and Java
Euphorea siwalica Prasad, 1994c	*E. longana* Lamk.	Evergreen to moist deciduous	India, Pegu, Sri Lanka and Western Peninsula
Anisophyllaceae *Anisophyllea siwalica* Prasad & Awasthi, 1996	*A. apetala* Sart.	Evergreen	Malaya
Anacardiaceae *Bouea koilabasensis* (Prasad) Prasad & Awasthi, 1996	*B. burmanica* Griff.	Evergreen	Sundarban, Tennasserim and Malaya
Mangifera someshwarica Awasthi & Prasad, 1990	*M. indica* Linn.	Evergreen to moist deciduous	Sub-himalayan tract, Thailand, Myanmar and Malaya
Mangifera suraikholaensis Prasad & Pandey, 2008	*M. sylvatica* Roxb.	Moist deciduous	Nepal, Sikkim, Assam, Andaman, Pegu and Toungoo
Gluta siwalica Awasthi & Prasad, 1990	*G. renghas* Linn.	Evergreen	Malaya
Swintonia miocenica Awasthi & Prasad, 1990	*S. floribunda* Griff.	Evergreen	Bangladesh, Myanmar and Tennasserim
S. palaeoschwenckii Prasad & Awasthi, 1996	*S. schwenkii* Teysm. & Benn.	Evergreen	Bangladesh and Myanmar
Connaraceae *Rourea palaeorugosa* Prasad & Pandey, 2008	*R. rugosa* Planch.	Evergreen	N.E. India, Malaya and Singapore
Fabaceae *Mucuna miogigantea* Prasad & Pandey, 2008	*M. gigantea* DC.	Evergreen	Plains of western Peninsula, Andamans, Malaya, Philippines, Sunderbans and Polynesia
Cynometra palaeoiripa Prasad *et al*., 1999	*C. iripa* Kotel.	Evergreen	Indo-Malayan region
Millettia koilabasensis (Prasad) Prasad & Pandey, 2008	*M. macrostachya* Coll. & Hemsl.	Evergreen	Southern Shan Hills
Millettia churiensis Prasad & Awasthi, 1996	*M. prainii* Dunn.	Evergreen	N.E. India
Millettia palaeoracemosa Awasthi & Prasad, 1990	*M. racemosa* Benth.	Evergreen to deciduous	South & central India, Myanmar and Malaya
Millettia palaeocubithii Awasthi & Prasad, 1990	*M. cubithii* Dunn.	Moist deciduous	Malaya
Koompassia suraikholaensis Prasad & Awasthi, 1996	*K. malaccens* Maing ex. Benth.	Evergreen	Malaya. Sumatra and Malacca
Albizia microfolia Prasad & Awasthi, 1996	*A. julibrissin* Durraz.	Moist deciduous	Sub- himalayan tract and Nepal, N.E. India and Tennasserim
Albizia siwalica (Prasad) Prasad & Awasthi, 1996	*A. gamblei* Prain	Moist deciduous	Myanmar
Pterocarpus dalbergiocarpoides Prasad & Awasthi, 1996	*P. dalbergioides* Roxb.	Evergreen	Andamans
Bauhinia nepalensis Awasthi & Prasad, 1990	*B. malabarica* Roxb.	Mixed deciduous	Central and south India and Myanmar
Entada palaeoscandens Awasthi & Prasad, 1990	*E. scandens* Benth.	Mixed deciduous	Sub- himalayan tract, Nepal, N.E. India, Andaman and Western Ghats

contd.

Pongamia kailakholaensis Prasad & Awasthi, 1996	*P. pinnata* Vent.	Evergreen	India, Myanmar and Sri Lanka
Combretaceae *Terminalia palaeochebula* Awasthi & Prasad, 1990	*T. chebula* Ritz.	Mixed deciduous	Sub- himalayan tract, Sri Lanka, India and Nepal
T. panandhroensis Awasthi & Prasad, 1990	*T. coriacea* (Roxb.) W. & A.	Mixed deciduous	South & central India and Myanmar
Myrtaceae *Syzygium palaeocuminii* Prasad & Awasthi, 1996	*S. cuminii* Roxb.	Evergreen to moist deciduous	Throughout India, Myanmar and Sri Lanka
Lythraceae *Duabanga siwalica* Prasad & Pandey, 2008	*D. sonneratioides* Ham.	Evergreen to moist deciduous	Nepal, Assam, Andaman & Nicobar, Myanmar, Sikkim and Bhutan
Rubiaceae *Randia palaeofasciculata* Prasad & Awasthi, 1996	*R. fasciculata* DC.	Moist deciduous	Sub-himalayan tract, Nepal, N.E. India and Tennasserim
Anthocephalus siwalica Prasad & Awasthi, 1996	*A. macrophyllum* Havil	Evergreen	Malaya
Diplospora siwalica Prasad & Awasthi, 1996	*D. singularis* Korth.	Evergreen	N.E. India, Myanmar and Tennasserim
Myrsinaceae *Myrisine precapitellata* Prasad & Pandey, 2008	*M. capitellata* Wall.	Evergreen to moist deciduous	Nepal, Assam, Myanmar, Bhutan, Sikkim and Andamans & Nicobar
Ebenaceae *Diospyros miokaki* Awasthi & Prasad, 1990	*D. kaki* Linn. f.	Moist deciduous	N.E. India, Myanmar, China and Japan
D. miocenicus Prasad & Awasthi, 1996	*D. lanceaefolia* Roxb.	Evergreen	N.E. India, Tennasserim and Myanmar
Olacaceae *Olax bankasii* Prasad & Pandey, 2008	*O. wightiana* Wall.	Evergreen	Western Peninsula, Malacca and North Kanara
Apocynaceae *Wrightia palaeotinctoria* Prasad & Awasthi, 1996	*W. tinctoria* R. Br.	Mixed deciduous	India and Myanmar
Chonemorpha miocenica Prasad & Awasthi, 1996	*C. macrophylla* G. Don.	Mixed deciduous	N.E. India, Tennasserim, Myanmar and Sri Lanka
Myristicaceae *Myristica palaeoglomerata* Awasthi & Prasad, 1990	*M. glomerata* Miq.	Evergreen	Malaya
Lauraceae *Cinnamomum nepalensis* Prasad & Pandey, 2008	*C. caudatum* Nees.	Evergreen	Sub-himalayan tract, Outer range, Nepal east wards and Upper Burma
Actinodaphne palaeoangustifolia Prasad & Pandey, 2008	*A. angustifolia* Nees.	Evergreen	Eastern Asia and Malaya
Machilus miocenica (Prasad) Prasad & Pandey, 2008	*M. odoratissima* Nees.	Evergreen to moist deciduous	Sub-himalayan tract, N.E. India and Myanmar
Euphorbiaceae *Bridelia siwalica* Prasad & Pandey, 2008	*B. burmanica* Hook. f.	Evergreen	Myanmar
Bridelia mioretusa Prasad & Pandey, 2008	*B. retusa* Spreng.	Mixed deciduous	Throughout India, Myanmar and Sri Lanka
*Mallotus kalimpongensis (*Antal & Awasthi) Prasad & Pandey, 2008	*M. philippinensis* Muell.	Evergreen to moist deciduous	Tropical India, Myanmar, Andaman islands, Sri Lanka, Malaya and Australia.
Mallotus venkatachalai (Prasad) Prasad & Awasthi, 1996	*M. repandus* Muell. Arg.	Evergreen	N.E. India, Sri Lanka, Myanmar and Malaya
Cleistanthus suraikholaensis Prasad & Awasthi, 1996	*C. helferi* Hook. f.	Evergreen	India and Myanmar
Phyllanthus palaeoreticulatus Prasad & Awasthi, 1996	*P. reticulatus* Poiret	Evergreen to moist deciduous	India and Mayanmar
Excoecaria palaeocrenulata Awasthi & Prasad, 1990	*E. crenulata* White K. T.	Evergreen	Western Ghats and Andamans
Breynia prerhamnoides Awasthi & Prasad, 1990	*B. rhamnoides* Muell.-Arg.	Mixed deciduous	India, Myanmar and Malaya
Moraceae *Ficus raptiensis* Prasad & Awasthi, 1996	*F. hispida* Linn.	Evergreen to moist deciduous	Sub-himalayan tracts, India and Myanmar
Artocarpus nepalensis Prasad & Awasthi, 1996	*A. integrifolia* Linn. f.	Evergreen	Western Ghats and Myanmar

Fig. 7—Present day distribution of comparable species of the fossil taxa of Surai Khola Assemblage, western Nepal.

Fossil taxa	Modern comparable species	Forest types	Distribution
MONOCOTYLEDONS **Poaceae** *Bambusa* sp. Konomatsu & Awasthi, 1996	*Bambusa* spp.	Evergreen to moist deciduous	Indo-Malayan region
Marantaceae *Clinogyne ovatus* Awasthi & Prasad; Konomatsu & Awasthi, 1996	*C. grandis* Benth. & Hook.	Moist deciduous	Sub-himalayan tract
DICOTYLEDONS **Anonaceae** *Orophea siwalika* Konomatsu & Awasthi, 1999	*O. uniflora* A. DC. *O. polycarpa* A. DC.	Evergreen	South India, Andamans and Martaban Hills
Miliusa brochidodroma Konomatsu & Awasthi, 1999	*M. roxburghiana* Hook. f. & Th.	Moist deciduous	Sub-himalayan tract, Assam and Myanmar
Flacourtiaceae *Gynocardia butwalensis* Konomatsu & Awasthi, 1999	*G. odorata* R. Br.	Evergreen	Sub-himalayan tract, Assam, Bangladesh and Myanmar
Clusiaceae *Calophyllum* sp. Konomatsu & Awasthi, 1996	*Calophyllum* spp.	Evergreen	Indo-Malayan region
Dipterocarpaceae *Dipterocarpus siwalicus* Lakhanpal & Guleria; Konomatsu & Awasthi, 1996	*Dipterocarpus tuberculatus* Roxb.	Evergreen to moist deciduous	North east India, Myanmar and Thailand
Shorea miocenica Konomatsu & Awasthi, 1999	*S. sericea* Dyer	Evergreen	Malaya, Borneo and Malacca
S. nepalensis Konomatsu & Awasthi, 1999	*S. leprosula* Miq.	Evergreen	Sumatra and Borneo
Hopea siwalika Konomatsu & Awasthi, 1999	*H. wightiana* Wall.	Evergreen	South India
Tiliaceae *Grewia mallotophylla* Konomatsu & Awasthi, 1999	*Grewia* sp. *Mallotus philippinensis* Muell.	Moist deciduous	India and South east Asia
Meliaceae *Chisocheton ellipticus* Konomatsu & Awasthi, 1999	*C. patens* Bl. *C. divergence* DC.	Evergreen	Malaya
Rhamnaceae *Ziziphus siwalicus* (Lakhanpal) Konomatsu & Awasthi, 1996	*Z. xylopyrus* Wild. *Z. incurva* Roxb.	Evergreen to moist deciduous	India and Myanmar
Ventilago ovatus Konomatsu & Awasthi, 1999	*V. calyculata* Tul.	Evergreen to moist deciduous	North east India, Myanmar and Nepal
Anacardiaceae *Swintonia butwalensis* Konomatsu & Awasthi, 1999	*S. schwenckii* T. *et* B.	Evergreen	Myanmar and south India
Fabaceae *Bauhinia siwalica* (Lakhanpal & Awasthi) Konomatsu & Awasthi, 1996	*Bauhinia* spp.	Evergreen to moist deciduous	Indo-Malayan region
Rubiaceae *Mitragyne tertiara* Konomatsu & Awasthi, 1999	*M. parvifolia* Korth.	Mixed deciduous	Sub-himalayan tract, central India and Myanmar
Mussaendopsis suborbiculatus Konomatsu & Awasthi, 1999	*M. buccariana* Baill.	Evergreen	Malaya, Borneo and Sumatra
Alangiaceae *Alangium nepalensis* Konomatsu & Awasthi, 1999	*A. salvifolium*	Mixed deciduous	Sub-himalayan tract and central & western India
Euphorbiaceae *Homonoia lanceolata* Konomatsu & Awasthi, 1999	*H. riparia* Lour.	Evergreen	North east India, Myanmar and Malaya
Moraceae *Ficus miocenicus* Konomatsu & Awasthi, 1999	*F. bengalensis* Linn.	Evergreen to moist deciduous	Sub-himalayan tract, south India, Andamans, Myanmar and central India
Lauraceae *Cinnamomum palaeotamala* Lakhanpal & Awasthi; Konomatsu & Awasthi, 1996	*C. tamala* Nees.	Evergreen	Indo-Malayan region

Fig. 8—Present day distribution and forest types of modern comparable species of the fosil taxa of Arung Khola Assemblage, western Nepal.

Fossil taxa	Modern comparable species	Forest types	Distribution
DICOTYLEDONS **Malvaceae** *Urena palaeolobata* Awasthi & Lakhanpal, 1990	*U. lobata* (var. *U. mauritiana* W. Merais.	Mixed deciduous	Sub-himalayan tract
Meliaceae *Aphanamixis bhikhnathoriensis* Awasthi & Lakhanpal, 1990	*A. polystachya* W. & A.	Evergreen	Indo-Malaya
Toona siwalika Awasthi & Lakhanpal, 1990	*Toona ciliata* Roxb.	Evergreen to moist deciduous	Indo-Malaya and Australia
Rhamnaceae *Ziziphus champarensis* Lakhanpal & Awasthi, 1984	*Z. mauritiana* Lam.	Mixed deciduous	Cosmopolitan
Anacardiaceae *Mangifera someshwarica* Lakhanpal & Awasthi, 1984	*Mangifera indica* Linn.	Evergreen to Moist deciduous	Indo-Malayan region
Fabaceae *Indigofera prepulchella* Lakhanpal & Awasthi, 1984	*I. pulchella* Roxb.	Mixed deciduous	India
Dalbergia sp. Lakhanpal & Awasthi, 1984	*D. sissoo* Linn. *D. latifolia* Roxb.	Mixed deciduous	India and Myanmar
Derris champarensis Awasthi & Lakhanpal, 1990	*D. scandens* Benth.	Evergreen to moist deciduous	Indo-Malayan region
Pongamia siwalika Awasthi & Lakhanpal, 1990	*P. pinnata* Vent.	Evergreen to moist deciduous	India, south east Asia and Australia
Cassia antiqua Awasthi & Lakhanpal, 1990	*C. glauca* Lam.	Evergreen	Indo-Malaya
Bauhinia siwalika Lakhanpal & Awasthi, 1994	*Bauhinia* sp.	Mixed deciduous	Indo-Malayan region
Myrtaceae *Syzygium palaeobractiatum* Awasthi & Lakhanpal, 1990	*S. bracteatum* Miq.	Evergreen	North east India and central India
Rubiaceae *Gardenia palaeoturgida* Lakhanpal & Awasthi, 1984	*Gardenia turgida* Roxb.	Moist deciduous	Sub-himalayan tract
Myrsinaceae *Ardisea antiqua* Awasthi & Lakhanpal, 1990	*A. solanacea* Roxb.	Moist deciduous	India, Myanmar and Sri Lanka
Convolvulaceae *Ipomoea eriocarpoides* Awasthi & Lakhanpal, 1990	*I. eriocarpa* R. Br.	Moist deciduous	India, Myanmar and Sri Lanka
Lauraceae *Phoebe champarensis* Awasthi & Lakhanpal, 1990	*Phoebe lanceolata* Nees.	Evergreen	India, Myanmar and Sri Lanka
Cinnamomum palaeotamala Lakhanpal & Awasthi, 1984	*C. tamala* Nees & Ebrem.	Evergreen to moist deciduous	India and Myanmar
Litsea prenitida Lakhanpal & Awasthi, 1984	*Litsea nitida* Nees.	Evergreen to moist deciduous	North east India and Bangladesh
Moraceae *Ficus champarensis* Lakhanpal & Awasthi, 1984	*Ficus* spp.	Evergreen to moist deciduous	Cosmopolitan

Fig. 9—Present day distribution and forest types of modern comparable species of fossil taxa of Bhikhnathoree Assemblage, Bihar.

on Siliguri-Gangtok Road. Later on Antal and Prasad (1995, 1996a, b, c, 1997, 1998) have investigated the angiospermous fossil leaves collected from different exposures of the same area. The qualitative and quantitative method of comparison of the range of variation in the morphological features between the fossil and extant leaves reveals the occurrence of 53 species of 45 genera belonging to 24 families of both monocots and dicots (Fig. 10).

Bhutan Leaf Assemblage, Bhutan

Although a variety of angiospermous fossil leaves have been recorded from the Himalayan foreland basin of India and Nepal yet a very little work was carried out so far considering the wide extent of Siwalik sediments in the Bhutan sub-himalaya. Banerjee and Das Gupta (1984) described few angiospermous fossil leaves from the Lakshmi and Darranga River sections under some artificial genera like, *Siwalikiphyllum, Dilcheria, Ghosia, Pseudopaxilatophyllum* and *Darrangiophyllum.* These artificial form genera could not be compared with any extant taxa because their fragmentary nature. Prasad and Tripathi (2000) investigated the fossil leaves collected from Middle Siwalik (Formation II) sediments of

Fossil taxa	Modern comparable species	Forest types	Distribution
MONOCOTYLEDONS **Poaceae** *Bambusa* sp. Antal & Awasthi, 1993	*Bambusa* sp.	Mixed deciduous	Sub-himalayan tract and Cosmopolitan
Marantaceae *Clinogyne ovatus* Awasthi & Prasad; Antal & Prasad, 1995	*C. grandis* Benth. & Hook.	Moist deciduous	Sub-himalayan tract
DICOTYLEDONS **Dilleniaceae** *Dillenia palaeoindica* Prasad & Prakash; Antal & Awasthi, 1993	*Dillenia indica* Linn.	Evergreen to moist deciduous	Sub-himalayan tract, Myanmar, South east Asia and south India
Anonaceae *Mitrephora siwalika* Antal & Awasthi, 1993	*Mitrephora maingayi* Hook. f. & Th.	Evergreen	North east India, Myanmar, Bangladesh and Malaya Peninsula
Polyalthia palaeosiamiarum Awasthi & Prasad; Antal & Prasad, 1996c	*Polyalthia siamiarum* Bl.	Evergreen	North east India, Bangladesh, Myanmar and Andamans
Uvaria ghishia Antal & Prasad, 1998	*Uvaria hirsuta* Jack.	Evergreen	Myanmar and Malaya
Flacourtiaceae *Casearia pretomentosa* Antal & Awasthi, 1993	*Casearia tomentosa* Roxb.	Mixed deciduous	Sub-himalayan tract, Nepal, central and south India and Bangladesh
Alsodeia palaeozeylanicum Antal & Awasthi, 1993	*Alsodeia zeylanicum* Thw.	Evergreen	Malabar Hills, south India and Sri Lanka
A. palaeoracemosa Antal & Prasad, 1997	*A. racemosa* Hook. f.. & Th.	Evergreen to moist deciduous	North east India and south India
A. palaeoechinocarpa Antal & Prasad, 1998	*Adsodeia echinocarpa* Korth.	Evergreen	Sumatra and Cochin China
Flacourtia tertiara Prasad & Awasthi; Antal & Prasad, 1997	*Flacourtia inermis* Roxb.	Evergreen	Malayan archipelago
Hydnocarpus palaeokurzii Antal & Awasthi, 1993	*Hydnocarpus Kurzii* (King) Warb.	Evergreen	Myanmar and Martaban Hills
Clusiaceae *Calophyllum suraikholaensis* Awasthi & Prasad; Antal & Awasthi, 1993	*Calophyllum polyanthum* Wall.	Evergreen	Andamans, Malaya, south India and Sri Lanka
Dipterocarpaceae *Shorea siwalika* Antal & Awasthi, 1993	*Shorea assamica* Dyer.	Evergreen	North east India
S. miocenica Antal & Prasad, 1996b	*Shorea buchananii* Fischer	Evergreen	Myanmar
S. bengalensis Antal & Prasad, 1997	*S. roxburghii* (*S. talura* Roxb.)	Evergreen	Malaya and south India
Dipterocarpus siwalicus Lakhanpal & Guleria; Antal & Prasad, 1996b	*Dipterocarpus tuberculatus* Roxb.	Evergreen to moist deciduous	Myanmar, Cochin China and Thailand
Hopea siwalika Antal & Awasthi, 1993	*H. wightiana* Wall.	Evergreen	Indo-Malayan region
Hopea kathgodamensis Prasad; Antal & Prasad, 1998	*H. micrantha*	Evergreen	Myanmar, Mallacca and Borneo
Sterculiaceae *Pterospermum palaeoheynianum* Antal & Awasthi, 1993	*Pterospermum heynianum* Wall.	Mixed deciduous	South and central India
P. siwalicum Antal & Prasad, 1996a	*P. semi-sagitatum* Ham.	Moist deciduous	Myanmar and Bangladesh
Tiliaceae *Grewia ghishia* Antal & Awasthi, 1993	*Grewia umbellifera* Bedd.	Evergreen	Western Ghats and south India
G. tistaensis Antal & Prasad, 1998	*G. tiliaefolia* Vahl.	Moist deciduous	Sub-himalayan tract, south and central India
Xanthophyllaceae *Xanthophyllum mioflavescens* Antal & Prasad, 1996a	*X. flavescens* Roxb.	Evergreen	Indo-Malaya
Burseraceae *Bursera preserrata* Antal & Awasthi, 1993	*Bursera serrata* Colebr.	Evergreen	North east India, central India and Myanmar
Meliaceae *Beddomia palaeoindica* Antal & Prasad, 1998	*Beddomia indica* Hook. f.	Evergreen	South India
Rhamnaceae *Ziziphus palaeoapetala* Antal & Prasad, 1997	*Ziziphus apetala* Hook. f &Th.	Mixed deciduous	North east India
Ventilago tistaensis Antal & Prasad, 1997	*Ventilago calyculata* Thw.	Mixed deciduous	India, Myanmar and Sri Lanka

Anacardiaceae *Nothopegia eutravancorica* Antal & Awasthi, 1993	*Nothopegia travancorica* Bedd.	Evergreen	South India
Bouea premacrophylla Antal & Awasthi, 1993	*Bouea macrophylla* Grifth.	Evergreen	Andaman, Sunderban, Myanmar and Malaya
Swintonia miocenica Antal & Prasad, 1996a	*Swintonia floribunda* Grifth.	Evergreen	Myanmar, Bangladesh and south India
Fabaceae *Bauhinia ramthiensis* Antal & Awasthi, 1993	*Bauhinia acuminata* Linn.	Moist deciduous	Sub-himalayan tract, Myanmar, Andamans and Malaya
Cynometra tertiara Antal & Awasthi, 1993	*Cynometra cauliflora* Linn.	Evergreen	Malacca, Sri Lanka and Malaya Peninsula
Albizia palaeolebbek Antal & Awasthi, 1993	*Albizia lebbek* Benth.	Moist deciduous	Sub-himalayan tract, central & south India, Myanmar and Andamans
Millettia oodlabariensis Antal & Prasad, 1996a	*Millettia albiflora* Thw.	Evergreen	Myanmar and Malaya
Pongamia siwalika Antal & Awasthi, 1993	*Pongamia pinnata* Vent.	Evergreen	India, Sri Lanka and Myanmar
Combretaceae *Combretum sahnii* Antal & Awasthi, 1993	*Combretum deccandrum* Roxb.	Mixed deciduous	Sub-himalayan tract and South & central India
Terminalia miobelerica Prasad; Antal & Prasad, 1998	*Terminalia belerica* Roxb.	Evergreen to moist deciduous	Sub-himalayan tract, Myanmar and Malaya
Myrtaceae *Syzygium palaeocuminii* Prasad & Awasthi; Antal & Prasad, 1997	*Syzygium cuminii* Roxb.	Evergreen to moist deciduous	India, Myanmar and Sri Lanka
Lythraceae *Lagerstroemia patelii* Lakhanpal & Guleria; Awasthi & Antal, 1993	*Lagerstroemia speciosa* Pers.	Moist deciduous	North east India, central & south India and Myanmar
Rubiaceae *Randia miowallichii* Prasad; Antal & Awasthi, 1993	*Randia wallichii* Hook. f.	Evergreen to moist deciduous	North east India, Myanmar, Andamans and Malaya
Asteraceae *Vernonia palaeoarborea* Antal & Awasthi, 1993	*Vernonia arborea* Ham.	Evergreen	North east India, Myanmar, south India and Andamans
Ebenaceae *Diospyros koilabasensis* Prasad; Antal & Awasthi, 1993	*Diospyros montana* (Var. *cordifolia*) Hyne ex. A. DC.	Moist deciduous	India and Myanmar
Apocynaceae *Alstonia mioscholaris* Antal & Awasthi, 1993	*Alstonia scholaris* R. Br.	Evergreen	India and Myanmar
Verbenaceae *Callicarpa siwalika* Antal & Awasthi, 1993	*Callicarpa arborea* Roxb.	Moist deciduous	Sub-himalayan tract, central India and Myanmar
Lauraceae *Cinnamomum* sp. Antal & Awasthi, 1993	*Cinnamomum* sp.	Evergreen	Tropical region, South east Asia and Indo-Malayam region.
Actinodaphne palaeoangustifolia Antal & Awasthi, 1993	*Actinodaphne angustifolia* Nees.	Evergreen	North east India, Bangladesh and Myanmar
Euphorbiaceae *Mallotus kalimpongensis* Antal & Awasthi, 1993	*Mallotus philippinensis* Muell. Arg.	Mixed deciduous	Throughout India, Myanmar
Macaranga siwalika Antal & Awasthi, 1993	*Macaranga peltata* Muell. Arg.	Evergreen	South and central India and Sri Lanka
Glochidion (Phyllanthus) palaeohirsutum Antal & Prasad, 1996a	*Glochidion hirsutum* Muell. Arg.	Evergreen	North east India, Myanmar, Malaya, Bangladesh and Andamans
Homonoia mioriparia Antal & Prasad, 1997	*Homonoia riparia* Lour.	Evergreen	India, Myanmar, Malaya and China
Urticaceae *Ficus retusoides* Prasad; Antal & Awasthi, 1993	*Ficus retusa* Linn.	Evergreen	Sub-himalayan tract, Myanmar, Andamans and Sri Lanka
F. oodlabariensis	*F. benjamina* Linn.	Evergreen to moist deciduous	North east India, central India, Myanmar and Java

Fig. 10—Present day distribution and forest types of modern comparable species of the fossil taxa of Oodlabari Assemblage, West Bengal.

Fossil taxa	Modern comparable species	Forest types	Distribution
DICOTYLEDONS			
Anonaceae *Mitrephora siwalica* Antal & Awasthi; Prasad & Tripathi, 2000	*Mitrephora maingayi* Hook. f. & Thoms.	Evergreen	North east India, Myanmar, Malaya and Sri Lanka
Meliaceae *Toona siwalika* Awasthi & Lakhanpal; Prasad & Tripathi, 2000	*Toona ciliata* Roxb.	Moist deciduous	Sub-himalayan tract
Dipterocarpaceae *Dipterocarpus siwalicus* Lakhanpal & Guleria; Prasad & Tripathi, 2000	*Dipterocarpus* sp.	Evergreen to moist deciduous	Myanmar, Malaya, Assam and Andamans
Combretaceae *Combretum miocenicum* Prasad & Tripathi, 2000	*Combretum flagrocarpum* Herb. & Cale	Evergreen to Moist deciduous	North east India, Myanmar and Bhutan
Fabaceae *Millettia koilabasensis* Prasad; Prasad & Tripathi, 2000	*Millettia macrostachya* Coll. & Hemls.	Evergreen	Myanmar

Fig. 11—Present day distribution and forest types of modern comparable species of the fossil taxa of Bhutan Assemblage.

Lakshmi River Section in south east Bhutan and reported five species of angiospermous families (Fig. 11).

FLORISTIC ANALYSIS AND PALAEOCLIMATE ESTIMATION

The important aspects of studying the fossil plants from Siwalik foreland basin are to reconstruct the Siwalik floristic and to throw light on the climatic changes through Siwalik succession (Middle Miocene-Middle Pliocene) in the whole Himalayan foot hills. The extensive study on plant megafossils specially leaf impression provides reliable data for inferring the above aspect more precisely. The fossil leaf assemblages (Figs 2-11) indicated that in the Himalayan foot hills, the tropical forest flourished luxuriantly with variety of angiospermous taxa during Middle Miocene-Pliocene times. The angiospermous fossil leaves so far recovered from Siwalik foreland basins of India, Nepal and Bhutan are identified with 298 species of 167 genera belonging to 60 families of both monocotyledon and dicotyledon. The monocot is represented by the families, viz. Marantaceae, Arecaceae, Smilaceae and Poaceae. The rest are of dicotyledons families. Among them the most common and widely distributed genera are : *Mitrephora, Fissistigma, Calophyllum, Mesua, Dipterocarpus, Shorea, Hopea, mangifera, Bouea, Swintonia, Sterculia, Gynocardia, Toona, Zizyphus, Euphorea, Millettia, Albizia, Cynometra, Pongamia, Bauhinia, Syzygium, Terminalia, Lagerstroemia, Gardenia, Diospyros, Mallotus, Cinnamomum, Phyllanthus, Ficus,* etc. The angiospermous fossil leaf assemblage of Siwalik foreland basin is over all dominated by fabaceous taxa representing 46 species of 18 genera. The next dominant family is Euphorbiaceae constituted by 21 species and the families like Anonaceae, Dipterocarpaceae and Flacourtiaceae come on the third position in the diversification of the over all present assemblage.

In the orogenic movement of Himalaya the Siwalik Period (Mio-Pliocene) has been considered as the most important. During this period several significant changes took place in physiography and environment which ultimately changed the floral characteristics. The older forms, which could not adjust themselves to the new environment, gradually became extinct and in their place new plants came into existence and flourished there. Several taxa migrated from South east Asia to Indian sub-continent via Myanmar and vice versa after the establishment of land connection between India and South east Asia (Smith & Briden, 1979). With the result many taxa, especially members of Dipterocarpaceae which were present during the Palaeogene in South east Asia appeared in the Neogene in the Indian sub-continent (Prasad, 1994b).

The analysis of the present day distribution of modern comparable species of all the fossil leaf assemblages from Siwalik foreland basin indicates that they presently grow in different geographical regions (Figs 2-12). They are distributed mostly in north-east and southern regions wherever favourable climatic conditions are found now-a-days. In the present fossil assemblages about 33% of comparable taxa growing in the evergreen to moist deciduous forests of northeast region suggest that the taxa which were present in the Himalayan foot hills during Siwalik Period do not grow now-a-days there (excluding eastern part of Bengal). They have migrated towards east in the Assam, Sikkim, Meghalaya, Bangladesh and Myanmar because of getting better climatic conditions.

In the fossil leaf assemblages of Siwalik foreland basin there are a good amount of comparable taxa which grow presently both in India and Malaya peninsula (Fig. 12). They are *Alpinia buteocarpa, Bambusa tulda, Dillenia indica, Mesua ferrea, Calophyllum polyanthum, Alsodeia echinocarpa, Dipterocarpus tuberculatus, Hopea micrantha, Shorea buchananii, Evodia, fraxinifolia, Sabia paniculata, Aphanamixis polystachya, Bouea burmanica, Mangifera indica, Swintonia schwenkii, Cynometra iripa, C. cauliflora,*

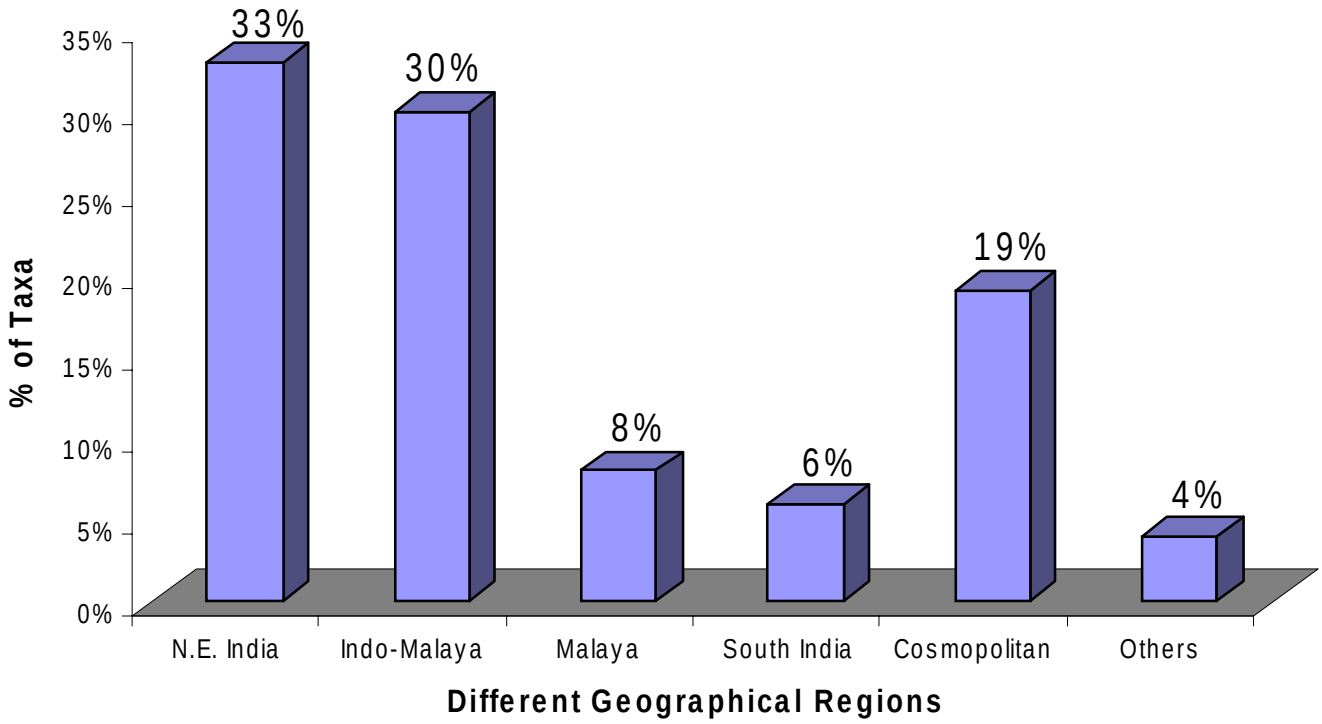

Fig. 12—Diagramatic representation of modern comparable taxa of the fossil leaves of the Siwalik foreland basin in different geographical regions.

Ormosia robusta, Albizia lebbek, Cassia siamea, C. glauca, Derris scandens, Millettia albiflora, Dalbergia sericea, Grewia umbellata, G. tiliaefolia, Terminalia bellerica, Lagerstroemia flosreginae, L. speciosa, Morinda umbellata, M. tinctoria, Cinnamomum inuctum, Mallotus repandus, Homonoia riparia, Ficus retusa, F. glaberrima, Ficus cunea, etc. which suggest that there has been a fair exchange of plant taxa between the two subcontinents after the land connections were established during early Miocene Period. About 8 percent taxa of the Siwalik leaf assemblages have their restricted distribution in the Malaya region (Figs 2-11). These are *Elliepia, Cuniefolia, Uvaria hirsuta, Ryparosa kunstelri, Hydnocarpus kurzii, H. glaucuscens, H. oides, Flacourtia inermis, Capparis micrantha, Sterculia ensifolia, Chisocheton divergense, C. patens, Aglaia, euryphylla, Ctenolophon philippinensis, Shorea sericea, S. leprosula, Isoptera borneonsis, Euphoria didyma, Anisophyllea apetala, Gluta renghas, Koompassia malaccens, Millettia cubithii, M. atropurpurea, Dialium indum, Myristica glomerata, Anthocephalus macrophylla, Mussaendopsis baccariana, Diospyros eriantha, Cleistanthus helferi, Glochidion chlorophaes* and *Antidesma montanum,* obiously indicating that these taxa had migrated from Malaya region to Indian sub-continent during Miocene and flourished all along the Himalayan foot hills at the time of deposition of Siwalik sediments but later on they disappeared from there after prevailing unfavourable condition most probably due to further uplift of the Himalaya. Only some of the comparable taxa of the fossil leaves recovered from the Siwalik foreland basins are found to grow still at different altitudes all along the Himalayan foot hills especially in Bengal region. This suggests that such taxa have susceptibility to adapt to the new climatic conditions prevailing after Middle Miocene.

The present and past distribution of the family Dipterocarpaceae indicates that it is pan tropical and specially distributed in tropical Asia. The fossil record suggests that the family Dipterocarpaceae originated in western Malaysia during early Middle Oligocene (Merrill 1923; Muller, 1970; Lakhanpal, 1974). About two third of the members of Dipterocarpaceae are found to grow today in the Malaysian region (Desch, 1957). This region is also quite rich in dipterocarpaceous fossils (Lakhanpal, 1974; Bande & Prakash, 1986). Thus it is evident that the dipterocarps spread from western Malaysia eastward to Philippines and north ward to eastern India through Myanmar, and then spread throughout Himalayan foot hills and flourished luxuriantly there during Middle Miocene to Middle Pliocene. The possible time for their migration was early Miocene when the land connections among Malaya, Myanmar and eastern India were established. The palaeoclimatic estimation from fossil plants is of the most important contribution of palaeobotanical study. The conservative approach to the study of palaeoclimate of a

PHYSIOGNOMIC CHARACTERS								
	Average Leaf Size	**Leaf margin**	**Drip tip**	**Nature of Petiole**	**Leaf Texture**	**Leaf base**	**Leaf Org.**	**Venation**
Fossil Taxa	Sq. cm	Entire (E)	Present (P)	Swollen (s)	Charta. (CH)	Acute (A)	Compound (C)	Close (C)
		Non-entire (N)	Absent (-)	Normal (N)	Coriace. (CO)	Obtuse (O)	Simple (S)	Distant (D)
				Indist. (-)		Cuneate (C)		
						Attenuate (At)		
Clinogyne ovatus Awasthi & Prasad	84	E	-	-	CH	-	S	C
Alpinia siwalica Prasad *et al.*	62.88	E	-	-	CH	-	S	C
Bambusa siwalica, Awasthi & Prasad	38.8	E	-	-	CH	-	S	C
Uvaria siwalica Prasad	60	E	+	N	CH	O	S	C
Cananga tertiara Prasad	51	E	-	-	CO	O	S	D
Saccopetalum pretomentosum Prasad *et al.*	30.66	E	-	-	CH	O	S	C-D
Capparis palaeomicrantha Prasad *et al.*	22.4	E	-	-	CH	-	S	C-D
Bixa kathgodamensis Prasad *et al.*	44.16	E	-	-	CO	-	S	C-D
Hydnocarpus palaeokurzii Prasad	28.4	E	+	N	CO	A	S	D
Uncobia palaeospinosa Prasad	4	N	-	-	CH	A	S	D
Gynocardia mioodorata Prasad *et al.*	57.63	E	-	N	CO	A	S	C-D
Mesua tertiara Lakhanpal	3.5	E	-	N	CH	A,O	S	C
Garcinia eocambogia Prasad	18	E	-	-	CH	A	S	D
Calophyllum suraikholaensis Awasthi & Prasad	12.98	-	-	-	CH	-	S	C
Dipterocarpus siwalicus Lakhanpal & Guleria	48	E	+	-	CO	-	S	D
Hopea kathgodamensis Prasad	10.04	E	-	-	CO	O	S	C
Shorea neoassamica Prasad	10.6	E	-	N	CO	-	S	C
S. miocenica Antal & Prasad	71.76	E		-	CO	-	S	C
Pachira palaeomalabarica Prasad *et al.*	35.28	E	+	N	CH	A-O	S	D
Sterculia kathgodamense Prasad	33	E	-	N	CH	A	S	D
Grewia kathgodamensis Prasad *et al.*	22.94	E	-	-	CH	O	S	C
Geijera siwalica Prasad	4.2	E	-	-	CO	C	S	-
Acronychia siwalica Prasad	15.7	E	-	-	CH	A	C	C
Trichilia miocenica Prasad	13.86	E	+	N	CH	A	C	C
Toona siwalica Prasad	13.6	E	-	N	CH	A	C	D
Chukrasia miocenica Prasad	13.75	E	+	-	CO	A	C	-
Dysoxylum möklandëri Prasad	17.5	E	+	-	CO	O	C	C
Zizyphus miocenicus Prasad	2.4	E	-	-	CO	O	S	D

Z.kathgodamensis Prasad	3.8	E	-	-	CH	-	S	D
Euphorea siwalica Prasad	13.6	E	-	N	CO	-	S	D
Cupania miocenica Prasad *et al.*	39.9	E	-	N	CO	O	S	C-D
Holarrhena nainitalensis Prasad *et al.*	81.76	E	-	-	CH	A	S	C
Acacia eosericata Prasad	11	E	-	-	CH	AT	C	D
Albizia siwalica Prasad	3.26	E	-	N	CH	O	C	D
Dialium palaeoindum Prasad	6.34	E	+	N	CH	A	C	C
Cassia siwalica Prasad	2.94	E	-	-	CH	O	C	C
Samanea siwalica Prasad	1.6	E	-	-	CH	O	C	D
Millettia palaeoracemosa Awasthi & Prasad	9.6	E	+	N	CO	C	C	D
M. siwalica Prasad	7	E	-	-	CH	O	C	C
Millettia kathgodamensis Prasad *et al.*	21	E	+	-	CH	A	C	C
Cynometra palaeoiripa Prasad *et al.*	7.56	E	-	-	CH	A	C	C
Ormosia robustoides Prasad	20.25	E	+	-	CH	O	S	C
Parinari kathgodamensis Prasad	10.8	E	+	-	CH	-	S	C
Terminalia miobelerica Prasad	56	E	-	-	CO	-	S	D
Lagerstroemia patelii Lakhanpal & Guleria	13	E	+	-	CH	-	S	C
Lagerstroemia jamraniensis Prasad *et al.*	68.34	E	-	-	CO	A	S	C
Morinda palaeotinctoria Prasad	70	E	-	-	CO	-	S	D
Gardenia nainitalensis Prasad	7.8	E	+	-	CH	-	S	C
Ardisia palaeosimplicifolia Prasad	55	E	+	-	CH	C	S	D
Sarcosperma mioarboreum Prasad *et al.*	50.82	E	+	-	CH	C	S	C
Diospyros kathgodamensis Prasad	8	E	-	N	CH	A	S	D
D. palaeoebenum Prasad	30.8	E	-	-	CH	-	-	C-D
D. nainitalensis Prasad *et al.*	43.68	E	-	-	CO	-	S	C-D
D. palaeoeriantha Prasad *et al.*	8.82	E	+	-	CO	A	S	C
Wrightia siwalica Prasad	13	E	+	N	CO	O	S	D
Machilus miocenica Prasad	33.8	E	+	N	CO	A	S	-
Mallotus venkatachalai Prasad	14.6	N	+	-	CH	O	C	D
Phyllanthus mioreticulatus Prasad *et al.*	4.48	E	-	-	CH	A-O	C	C
Homonoia mioriparia Antal & Prasad	15.34	E	-	-	CH	A	S	C-D
Glochidion miocenica Prasad	29.3	E	-	-	CO	O	S	D
Phyllanthus siwalicus Prasad	6.4	E	+	-	CH	O	C	C
Ficus oodlabariensis Antal & Awasthi	15.99	E	-	-	CO	-	S	C
Ficus precunia Lakhanpal	25.75	E	-	-	CO	C	S	C

Fig. 13—Physiognomic characters of the fossil leaves of Kathgodam Assemblage, Uttaranchal.

PHYSIOGNOMIC CHARACTERS								
Fossil Taxa	**Average leaf size sq. cm**	**Leaf margin Entire (E) non- entire (N)**	**Drip tips presence (P) absence (A) indistinct (-)**	**Nature of Petiole normal (N) indistinct (-)**	**Leaf texture chartaceous (CH) coriaceous (CO)**	**Leaf base shape acute (A) obtuse (O) cuneate (C) cordate (CR) attenuate (AT) indistinct (-)**	**Leaf Organization Compound VS Simple**	**Venation pattern Close (C) Distant (D)**
1	2	3	4	5	6	7	8	9
Donax kasauliensis	46.8	E	-	-	CH	O	S	C
Anona koilabasensis	31.15	E	-	-	CH	O	S	C
Miliusa siwalica	42.75	E	-	-	CO	-	S	C
M. mioveluntina	63.00	E	-	-	CH	-	S	C
Melodorum jarwaensis	71.50	E	P	-	CH	-	S	C
Polyalthia palaeosumatrana	19.68	E	-	-	CH	-	S	C
Mitrephora miocenica	44.10	E	P	N	CH	O	S	C
Fissistigma senii	17.55	E	A	-	CH	A	S	C
F. mioelegans	17.48	E	P	-	CO	O	S	C
Goniothalamus siwalica	18.78	E	-	-	CH	A	S	C
Uvaria siwalica	44.00	E	-	-	CH	-	S	C
Dillenia palaeoindica	52.50	N	-	-	CH	-	S	C
Qualea siwalica	24.50	E	-	-	CH	-	S	C
Securidaca miocenica	24.00	E	-	-	CO	O	S	C
Ryparosa prekunstelri	61.92	E	-	N	CO	A	S	D
Gynocardia mioodorata	32.75	E	-	-	CO	A	S	D
Flacourtia koilabasensis	29.75	E	-	-	CH	-	S	C
F. seriaensis	7.60	N	-	-	CO	-	S	C
Mesua tertiara	10.00	E	P	N	CH	A	S	C
Kayea kalagarhensis	41.60	E	-	N	CO	A	S	C
Garcinia nepalensis	35.00	E	-	N	CO	A	S	C
Dipterocarpus siwalicus	128.00	E	P	N	CH	O,CR	S	D
D. koilabasensis	236.25	E	-	-	CO	-	S	C
Shorea eutrapizifolia	13.25	E	A	-	CO	A	S	C
S. miocurtisii	8.00	E	A	N	CH	A	S	C
Hopea mioglabra	28.44	E	A	-	CO	A	S	D
Isoptera siwalica	34.20	E	-	-	CH	O	S	D
Evodia koilabasensis	20.90	E	A	-	CH	O	C	C
Murraya khariense	07.30	E	A	-	CO	A	C	D
Atlantia miocenica	05.22	E	A	-	CH	A	C	C
Brucea darwajensis	08.27	E	P	N	CO	A	S	C
Iodes koilabasensis	12.25	E	A	-	CH	A,O	S	C,D
Chloroxylon palaeoswietenia	05.60	E	-	-	CH	A	C	C
Aglaia nepalensis	25.50	E		-	CH	-	C	C
Berchemia nepalensis	16.38	E	P	-	CH	C	S	C
B. siwalica	8.00	E	-	-	CH	A	S	C
Zizyphus miocenica	05.60	E		-	CH	O	S	D
Ochna miowallichii	24.84	E	P	-	CH	A	S	C
Filicium koilabasensis	26.25	E	P	N	CH	A	S	C
Euphorea nepalensis	27.00	E	P	-	CO	A	S	C
Nephelium palaeoglabrum	45.00	E	-	N	CH	A	S	C
Otophora miocenica	14.25	E	A	-	CO		S	D
Paranephelium seriaensis	27.00	E	-	-	CH	A	S	C
Arytera seriaensis	27.20	E	-	-	CH	C	S	C
Sabia eopaniculata	21.98	E	P	-	CH		S	C
S. siwalica	21.00	E	P	-	CH	A	S	C
Bouea koilabasensis	22.00	E	P	N	CO	A	S	D
B. premacrophylla	37.00	E	P	-	CH	A	S	C
Swintonia palaeoschwenckii	3.50	E	-	N	CH	O	S	C
Tapiria chorkholiense	11.25	E	-	-	CO	O	S	D
Mangifera someshwarica	28.40	E	P	N	CH	A	S	D
Dracantomelum seriaensis	33.15	E	-	-	CH	-	S	C
Albizia siwalica	07.50	E	A	N	CO	A	C	D
Casssia nepalensis	10.08	E	P		CH	O	C	D
C. miosiamea	05.25	E	A	N	CH	O	C	C

C. neosophora	03.80	E	A	N	CH	O	C	C
Dalbergia miosericea	14.40	E	A	N	CH	A	C	D
D. eucultrata	06.46	E	A	-	CH	A	C	C
D. siwalica	07.20	E	-	-	CH	O	C	C
D. miovolubilis	02.00	E	-	N	CH	A	C	C
Millettia koilabasensis	28.40	E	P	-	CH	A	C	D
M. miobrandisiana	02.53	E	-	-	CH	O	C	D
M. imlibasensis	07.48	E	-	-	CH	O	C	C
M. palaeomanii	4.8	E	-	N	CO	O	C	C
M. ovatus	8.75	E	P	-	CH	O	C	C
Ormosia robustoides	35.00	E	P	-	CH	O	C	C
Canavalia siwalica	3.52	E	A	N	CH	O	C	C
Cynometra palaeoiripa	02.80	E	A	N	CH	A	C	C
C. siwalika	56.00	E	P	-	CO	A	C	C
Samanea siwalica	02.00	E	-	-	CH	O	C	D
Anogeissus eosericea	10.75	E	-	N	CH	O	S	D
Calycopteris floribundoides	12.48	E	P	-	CO	O	S	D
Terminalia koilabasensis	11.20	E	P	-	CH	A	S	D
T. siwalica	35.60	E	P	N	CO	A	S	D
T. panandhroensis	57.60	E		N	CO	O	S	D
Combretum palaeodecandrum	15.75	E	P	-	CH	-	S	D
Lagerstroemia siwalica	42.00	E	-	-	CH	-	S	D
L. eomicrocarpa	9.45	E	P	-	CH	A	S	C
L. mioparvifolia	10.80	E	A	-	CH	A	S	C
Woodfordia neofruticosa	03.00	E	-	-	CO	CR	C	D
Anisophyllea siwalica	20.80	N	-	-	CH	O	S	C
Syzygium miocenicum	24.44	E	-	N	CH	C	S	C
S. miooccidentalis	08.00	E		N	CH	A	S	C
Lonicera mioquinquelocularis	08.75	E	-	-	CH	O	C	D
Randia miowallichii	13.80	E	-	N	CH	C	S	D
R. miouncaria	49.90	E	-	-	CH	C	S	C,D
Canthium siwalica	7.79	E	A	-	CH	-	S	C,D
Nauclea seriaensis	45.58	E	E	-	CH	O	S	C
Morinda siwalica	07.56	E	P	-	CH	-	S	C
Diospyros koilabasensis	09.00	E	-	-	CH	CR	S	D
D. darwajensis	55.90	E	-	-	CO	O	S	C
D. pretoposia	108.00	E		N	CO	O	S	D
D. tulsipurensis	32.42	E	A	-	CH	O	S	C
Tabernaemontana precoronaria	13.86	E	P	N	CH	C	S	D
Alyxia koilabasensis	4.16	E	-	-	CH	A	S	C
Alstonia nepalensis	17.50	E	-	N	CO	C	S	C
Carissa koilabasensis	05.60	E	A	-	CH	A	S	D
Gaertnera siwalica	12.00	E	-	-	CH	A	S	D
Datura miocenica	59.20	N	P	N	CH	A	S	C
Anacolosa mioluzoniensis	23.12	E	A	N	CO	A	S	D
Vitex prenegundo	20.90	E	P	N	CH	A	S	C
V. siwalica	31.50	E	-	-	CH	-	S	C
Cinnamomum mioinuctum	06.48	E	A	N	CH	C	S	D
Ficus precunia	20.25	E	-	-	CO	CR	S	D
F. retusoides	31.32	E	P	N	CH	A	S	C
F. nepalensis	28.00	E	-	-	CO	O	S	D
Helicia eoerretica	42.00	E	-	N	CH	A	S	C
Phyllanthus koilabasensis	08.93	E	A	N	CH	A	C	C
P. mioreticulatus	03.50	E	A	N	CH	A	C	C
Antedesma siwalica	47.15	E	-	-	CH	A	S	C
A. miocenica	33.60	E	-	-	CH	O	S	C
Artocarpus nepalensis	49.50	E	-	-	CO	A	S	C

Fig. 14—Physiognomic characters of the fossil leaves of Koilabas Assemblage, western Nepal

PHYSIOGNOMIC CHARACTERS								
Fossil Taxa	**Average leaf size** sq. cm.	**Leaf margin** Entire (E) Non-entire (N)	**Drip tips** Present (P) Absent (-)	**Nature of petiole** Normal (N) Indistinct (-)	**Leaf texture** Chartaceous (CH) Coriaceous (CO)	**Leaf base** Acute (A) Obtuse (O) Cuneate (C) Cordate (CR) Attenuate (AT) Indistinct (-)	**Leaf Organization** Compound (C) Simple (S)	**Venation Pattern** Close (C) Distant (D)
1	2	3	4	5	6	7	8	9
Clinogyne ovatus	20.28	E	-	-	CH	-	S	C
Caryota siwalica	19.33	E	-	-	CO	C	S	C
Bambusa siwalika	15.02	E	A	-	CH	A	S	C
Mitrephora siwalika	16.95	E	A	N	CH	O	S	C
Goniothalamus chorkholaensis	33.00	E	A	-	CH	-	S	C
Polyalthia palaeosimiarum	32.00	E	-	N	CH	A	S	C
Cocculus miotrilobus	11.88	E	-	A	CH	(rounded)	S	C
Xylosma nepalensis	3.36	N	A	-	CO	O	S	C
Flacourtia tertiara	2.99	N	A	-	CH	O	S	C
Hydnocarpus siwalicus	71.25	E	P	-	CO	-	S	D
H. chorkholaensis	18.75	E	P	N	CO	A	S	C
Calophyllum suraikholaensis	20.3	E	-	N	CO	A	S	C
Garcinia corvinusiana	36.00	E	-	N	CH	A	S	C
Mesua tertiara	7.6	E	P	N	CH	A	S	C
Dipterocarpus siwalicus	104.00	E	-	-	CH	CR	S	C
D. suraikholaensis	124.26	E	-	-	CO	O	S	C
Shorea palaeostellata	27.4	E	-	-	CH	-	S	C
Vatica nepalensis	36.5	E	-	N	CO	O	S	C
Ancistrocladus suraikholaensis	11.2	E	P	-	CO	AT	S	C
Sterculia mioensifolia	58.46	E	P	-	CH	A	S	C
S. premontana	47.36	E	P	-	CO	-	S	C
Stigmaphyllon chorkholaensis	14.7	E	-	-	CO	-	S	C-D
Zanthoxylum siwalicum	22.4	E	-	-	CH	O	S	C
Murraya khariensis	18.00	E	P	-	CH	O	C	C
Ochna siwalika	19.95	E	P	-	CH	O	S	C
Chisocheton suraikholaensis	32.00	E	-	-	CO	A	C	C
Toona siwalica	13.44	E	P	-	CH	O	C	C
Dysoxylum raptiensis	72.30	E	P	N	CO	A	C	C
Chukrasia miocenica	18.50	E	P	N	CH	O	C	C
Ctenolophon chorkholaensis	14.56	E	-	-	CH	A-O	S	C
Harpullia siwalica	27.9	E	A	N	CH	A	S	C
Xerospermum mioglabratum	23	E	P	-	CH	O	S	C
Euphorea siwalica	19.2	E	-	-	CH	O	S	C
Anisophyllea siwalica	55.00	E	A	-	CO	A	S	C
Bouea koilabasensis	90.45	E	-	-	CH	O	S	C
Mangifera someshwarica	60.5	E	-	N	CH	A	S	C
M. suraikholaensis	38.5	E	P	-	CH	A	S	C
Gluta siwalika	190.44	E	P	N	CO	C	S	C
Swintonia miocenica	30.16	E	A	-	CH	A	S	C
S. palaeoschwenckii	22.4	E	-	N	CH	O	S	C

Rourea palaeorugosa	7.05	E	P	N	CH	O	S	C
Mucuna miogigantea	16.43	E	-	-	CH	O	S	C-D
Millettia koilabasensis	37.2	E	-	-	CH	A	S	C
M. churiensis	5.04	E	A	N	CH	O	C	C
M. palaeoracemosa	14.1	E	P	-	CO	C	C	C
M. palaeocubithii	15	E	-	-	CO	-	C	C
Cynometra siwalika	15	E	A	-	CH	A	C	C
Koompassia suraikholaensis	11.25	E	-	-	CH	O	C	C
Albizia microfolia	1.5	E	-	-	CH	O	C	C
A. siwalica	17.5	E	-	-	CH	O	C	C
Pterocarpus dalbergiocarpoides	3.6	E	-	-	CH	A	S	C
Entada palaeoscandens	13.52	E	-	-	CH	A	C	C
Bauhinia nepalensis	42.75	E	-	N	CH	Auriculate	C	C
Terminalia palaeochebula	78.00	E	-	N	CO	O	S	C
T. panandhroensis	168.00	E	-	-	CH-CO	-	S	C
Syzygium palaeocuminii	30.82	E	A	N	CH	A	S	C
Duabanga siwalica	49.3	E	P	N	CO	CR	S	C
Randia palaeofasciculata	107.30	E	P	-	CH	A	S	C
Anthocephalus siwalicus	138.6	E	-	-	CH	-	S	C to D
Diplospora siwalica	31.50	E	-	-	CH	-	S	C
Myrsine precapitellata	16.53	E	A	N	CO	-	C	C
Diospyros miokaki	40.8	E	P	-	CH	-	S	C
D. miocenicus	15.4	E	P	-	CO	A	S	C
Olax bankasii	27.39	E	-	-	CH	A	S	C
Wrightia palaeotinctoria	54.60	E	-	-	CH	O	S	C
Chonemorpha miocenica	102.00	E	A	-	CH	O	S	C-D
Myristica palaeoglomerata	77.5	E	A	-	CH	-	S	C
Cinnamomum nepalensis	17.05	E	-	-	CH	O	S	C
Actinodaphne palaeoangustifolia	25.00	E	A	N	CH	A	S	C
Machilus miocenica	29.38	E	-	-	CH	A-C	S	C
Bridelia mioretusa	88.56	E	-	N	CO	O	S	C
Mallotus kalimpongensis	39.00	E	-	-	CH	A	S	C-D
M. venkatachalai	14.96	E	P	-	CH	O	S	C-D
Cleistanthus suraikholaensis	40.18	E	-	-	CH	O	S	C
Phyllanthus palaeoreticulatus	4.8	E	-	-	CH	O	C	C
Exoecaria palaeocrenulata	16.56	N	A	-	CO	-	S	C
Breynia prerhamnoides	2.4	E	A	N	CH	O	C	C
Ficus raptiensis	66.70	E	-	-	CO	O	S	C-D
Artocarpus nepalensis	36.8	E	A	N	CH	A	S	C

Fig. 15—Physiognomic characters of the fossil leaves of Surai Khola Assemblage, western Nepal.

PHYSIOGNOMIC CHARACTERS							
Fossil Taxa	**Average leaf size** sq. cm.	**Leaf margin** Entire (E) Non-entire (N)	**Drip tips** Present (P) Absent (-)	**Leaf texture** Chartaceous (CH) Coriaceous (CO)	**Leaf base** Acute (A) Obtuse (O) Cuneate (C) Cordate (CR) Attenuate (AT) Indistinct (-)	**Leaf Organization** Compound (C) Simple (S)	**Venation Pattern** Close (C) Distant (D)
1	2	3	4	5	6	7	8
Bambusa sp.	38.0	E	P	CH	-	S	C
Clinogyne ovatus	79.8	E	-	CH	O	S	C
Dillenia palaeoindica	36.5	N	-	CH	A	S	C
Mitrephora siwalika	41.6	E	-	CH	O	S	C
Polyalthia palaeosiamiarum	30.4	E	-	CH	A,O	S	C
Uvaria ghisia	54.9	E	-	CO	-	S	C
Casearia pretomentosa	54.6	E	-	CO	O	S	C
Alsodeia palaeozeylanicum	5.25	E	-	CH	A	S	C
A. palaeoracemosa	37.5	E	P	CH	A	S	C
A. palaeoechinocarpa	91.0	N	-	CH	A	S	C
Flacourtia tertiara	34.2	N	-	CH	A	S	C
Hydnocarpus palaeokurzii	29.7	E	-	CH	A	S	C
Calophyllum suraikholaensis	36.7	E	-	CH	C	S	C
Shorea siwalika	50.5	E	-	CH	O	S	C
S. miocenica	83.6	E	-	CO	-	S	C
S. bengalensis	66.0	E	P	CO	CR	S	C
Dipterocarpus siwalicus	85.2	E	-	CO	A,O	S	C
Hopea siwalika	15.3	E	-	CH	O	S	C
H. kathgodamensis	25.2	E	-	CH	O	S	C
Xanthophyllum mioflavescens	21.0	E	-	CH	A	S	C
Pterospermum palaeoheynianum	16.4	E	-	CH	O	S	C
P. siwalicum	52.8	E	-	CO	-	S	D
Grewia ghisia	19.0	N	P	CH	O	S	C
G. tistaensis	65.5	N	-	CH	-	S	C
Beddomia palaeoindica	37.0	E	-	CO	O	S	C
Bursera preserrata	9.7	E	P	CH	A	S	C
Zizyphus palaeoapetata	44.0	E	-	CH	A	S	C
Ventilago tistaensis	44.1	E	-	CH	A	S	C
Nothopegia eutravancorica	51.0	E	-	CO	A	S	C
Bouea premacrophylla	140.0	E	-	CO	O	S	C
Swintonia miocenica	89.1	E	P	CH	A	S	C
Bauhinia ramthiensis	38.7	E	-	CH	CR	C	C
Cynometra tertiara	19.2	E	-	CH	A	C	C
Albizia palaeolebbek	1.98	E	-	CH	O	C	C
Millettia oodlabariensis	50.0	E	P	CO	A	C	C
Pongamia siwalica	33.7	E	-	CH	O	C	D
Combretum sahnii	40	E	P	CO	A	S	C

Terminalia miobellerica	10.8	E	P	CH	-	S	C
Syzygium palaeocuminii	15.8	E	P	CH	A	S	C
Lagerstroemia patelii	71.2	E	P	CO	A	S	C
Randia miowallichii	30.4	E	-	CO	A	S	C
Vernonia palaeoarborea	57.2	E	-	CH	A	S	C
Diospyros koilabasensis	8.3	E	-	CH	CR	S	C
Alstonia mioscholaris	14.3	E	-	CO	C	S	C
Callicarpa siwalika	87.5	E	-	CH	O	S	C
Cinnamomum sp.	50	E	-	CO	O	S	C
Actinodaphne palaeoangustifolia	7.5	E	-	CH	A	S	C
Mallotus kalimpongensis	27.5	E	-	CH	A	S	C
Macranga siwalika	36.4	E	-	CO	Peltate	S	C
Glochidion (Phyllanthus) palaeohirsutum	34.2	E	-	CH	-	S	C
Homonoia mioriparia	16.8	E	-	CH	A	S	C
Ficus retusoides	18	E	-	CO	-	S	C
F. oodlabariensis	30.8	E	-	CO	O	S	C

Fig. 16—Physiognomic characters of the fossil leaves of Oodlabari Assemblage, West Bengal.

particular region is to compare fossil flora recovered from there with the modern vegetation. This study becomes more accurate as we go from Palaeocene upward until the Pleistocene because the modern equivalents of the fossil forms still exist in the present day for their comparison and identification. In this case all the plant fossils have been collected from Mio-Pliocene sediments of Himalayan foreland basins and their modern comparable taxa still exist in the forests of different geographical regions and thus it has become easier to deduce the palaeoclimate of the area.

The other widely accepted parameter for deducing palaeoclimate is the morphological features of the plant fossils. The fossil leaf impressions in any fossil assemblage play an important role in estimating the palaeoclimate of the region in the case of any geological ages. This parameter does not depend on any systematic relationship of the modern species and therefore, it is likely that the errors in interpretation are minimum.

On the basis of fossil leaf impressions the estimation of palaeoclimate/palaeoecology can be drawn by two methods: (1) Co-existence method and (2) Foliar physiognomic method.

Co-existence Method

In this method the climatic preferences of modern comparable plants of the fossils are used to interpret the past climate. It requires three bits of information (1) a living relative, i.e. modern comparable species of the fossils (ii) autecology of the living relatives of each fossil taxa (iii) The plant association of both modern and fossil taxa. The Siwalik foreland basin flora is of mostly Middle Miocene age. During Middle Miocene this region was occupied by a long and narrow river, later on it was converted into a series of small to large lakes due to sedimentation of rock materials coming down from erosion of mountain rocks. This is suitable for the luxuriant growth of water loving plant in the inner core and other towards outer core. The fossil plants so far recorded from the whole Siwalik foreland basin comprise about 324 fossil taxa which were compared with the modern species (Pls 1-5). The present habit and habitat of the modern comparable taxa of the fossils show that they mostly occur in the evergreen and moist deciduous forests of northeast India, Bangladesh, Myanmar, Malaysia and adjoining area (Figs 2-12) where suitable climatic condition is found. The occurrence of abundant evergreen taxa (up to 60%) in the Siwalik fossil assemblages indicates that a warm and humid climate with plenty of rainfall prevailed all along the Himalayan foot hills at the time of deposition in contrast relatively dry climate found at present. The analysis of present day distribution of the modern comparable species (about 80%) shows that most of the comparable species do not grow all along the Himalayan foot hills of India, Nepal and Bhutan but they have migrated to different suitable geographical regions (Fig. 12). This obviously indicates that changes in climate must have taken place after the sedimentation in the Himalayan foreland basins.

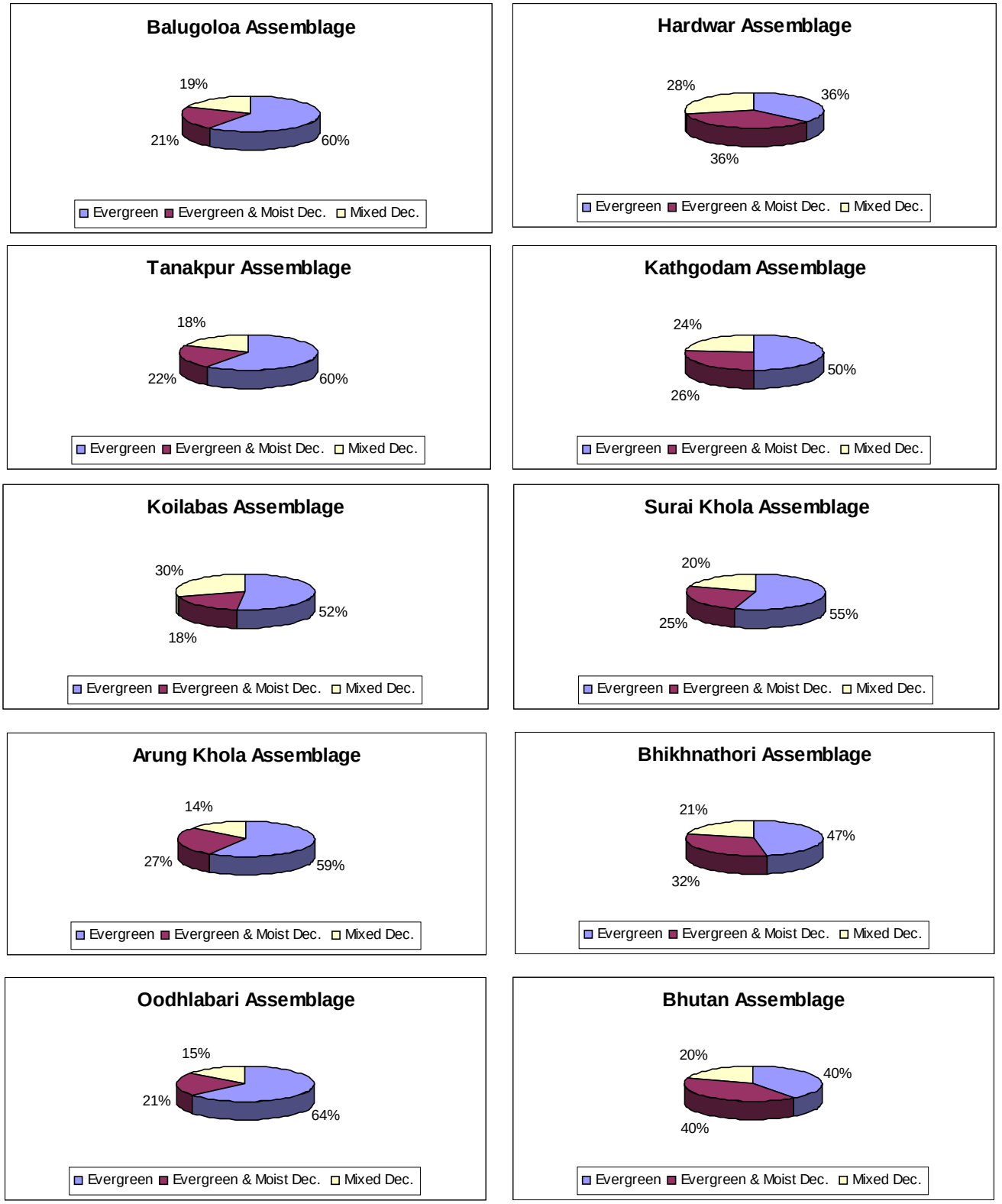

Fig. 17—A comparative diagrammatic representation of different types of forest elements in the assemblages of Siwalik foreland basins.

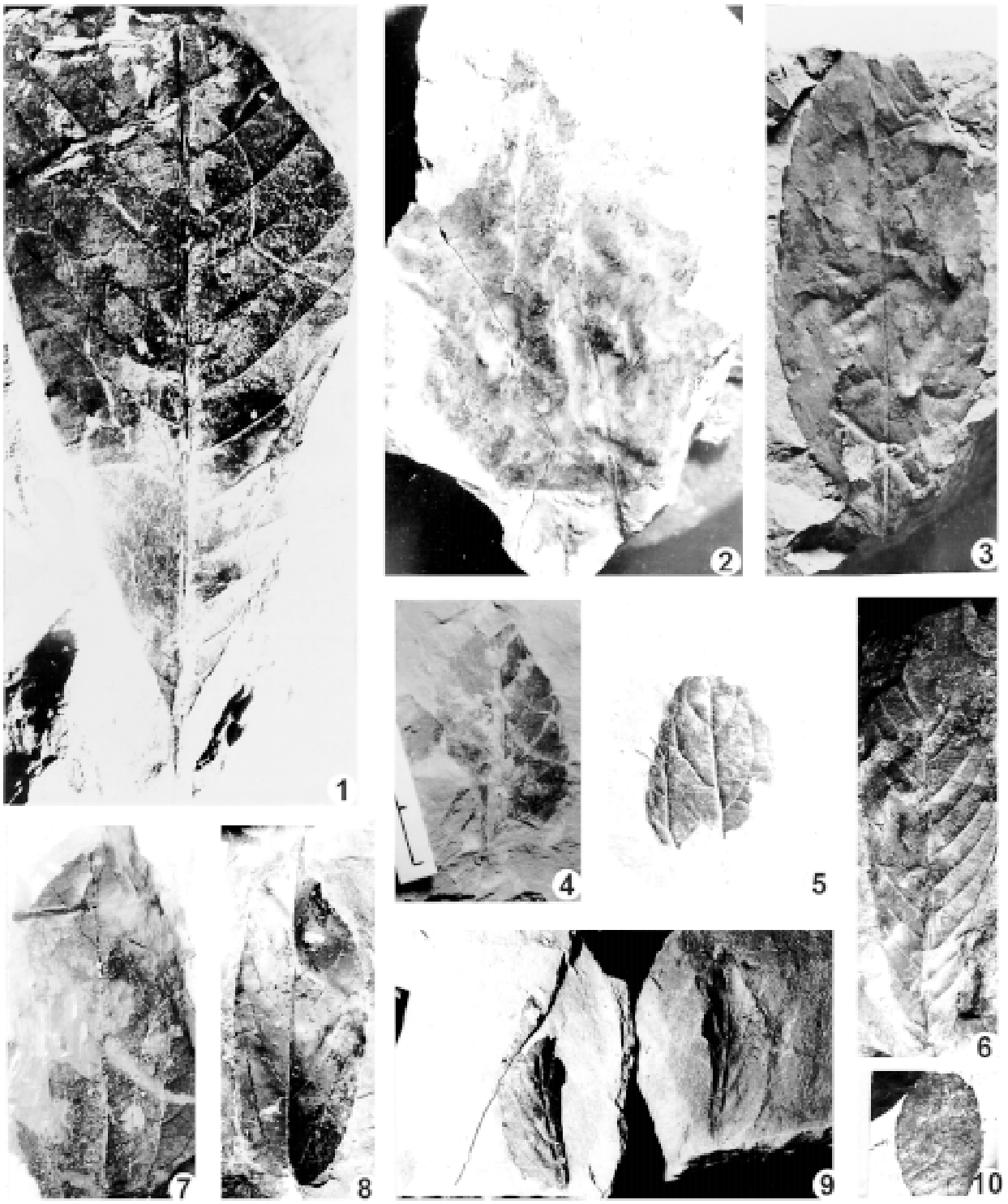

PLATE 1

Figs 1-10 showing the fossil leaves with non-entire margin.

1. *Alsodeia palaeoechinocarpa* Antal & Prasad
2. *Datura miocenica* Prasad
3. *Flacourtia tertiara* Prasad & Awasthi
4. *Flacourtia seriaensis* Prasad *et al.*
5, 7. *Anisophyllea siwalica* Prasad & Awasthi
6. *Dillenia palaeoindica* Prasad & Prakash
8. *Grewia ghishia* Antal & Awasthi
9. *Uncobia palaeospinosa* Prasad
10. *Flacourtia nepalensis* Awasthi & Prasad.

Physiognomic Method

The co-existence method totally depends on the palaeobotanist who may or may not be able to correctly identify each fossil taxon and to match it to an appropriate modern taxon. It becomes more difficult where fossil groups do not have their modern analogue or where it is uncertain about which living plant might be most closely related to a fossil form. In such cases the leaf physiognomy which is instrumental in maintaining water and temperature balance is used. The morphological features affect functional and physiological features of the plant. For example thick waxy succulent leaves indicate arid environment in which plant must conserve water. Leaf physiognomy is used to reconstruct the palaeoclimate either by CLAMP or by leaf margin analysis method.

Climate Leaf analysis Multivariate Programme (CLAMP) Method

Wolfe 1995 has studied the physiognomic features of modern angiospermous leaves and correlated them with climate in hundreds of communities throughout the world. He took a multivariate approach which compares many combination of leaf characters using computer programme. His original CLAMP Method used 29 leaf characters related to leaf margin, size, apex, base and shape. Later on Herman and Spicer 1996, 1997 used Wolfe's CLAMP data base with an additional leaf size characters to estimate palaeotemperature and palaeoprecipitation for four fossil assemblages. Kovach and Spicer (1996) also used Wolfe's data for the estimation of palaeotemperature and found that the CLAMP Method worked well for MAT (Mean Annual Temperature) in the range of 10º-20º C but above or below this range, it could not be accurately estimated. Thus keeping in view the above fact the application of CLAMP to the present Siwalik flora for the estimation of palaeoclimate would not be useful.

Only a few leaf features such as margin, size, driptips, petiole, texture, apex and base, organization and venation density of the angiospermous fossil leaf assemblages of Siwalik foreland basin have been analysed here for reconstruction of the palaeoclimate (Figs 13-16).

Leaf Margin Analysis—Leaf Margin Analysis (LMA) is a frequently used quantitative technique of palaeoclimate reconstruction that applies present day correlation between the proportion of woody dicot species with untoothed leaves and mean annual temperature to estimate palaeotemperature from the fossil leaf assemblages. Baily and Sinnot (1915, 1916) were the first who observed that the percentage of woody species with entire margined leaves is higher in tropical flora than that of the temperate flora. Moreover, the entire margined leaf families like, Anonaceae, Lauraceae, Ebenaceae, Clusiaceae, Sapotaceae, Dipterocarpaceae are particulary absent from cold/ temperate regions. On the other hand the nonentire-leaved families like, Betulaceae, Aceraceae, Plantanaceae, etc. are absent from low land tropical regions. Wolfe (1969, 1971, 1979) further analysed this convolution between leaf margin types of flora and climate and concluded that the tropical rainforests have the highest percentage of entire margined species and the percentage decreases with decreasing temperature either with increasing altitude to the submontane and montane rain forests or with increasing latitude to the warm temperate forests. Application of the above criterion to the different assemblages in which most of the fossil leaves possess entire margin indicating a warm tropical climate (Figs 13-16) has been used.

The leaf margin analysis of the whole leaf assemblages shows that there are only about 8% fossil taxa which possess non-entire margin (Pl. 1). They are *Caryota siwalica, Dillenia palaeoindica, Flacourtia tertiara, F. nepalensis, F. seriaensis, Uncobia palaeospinosa, Alsodeia palaeoechinocarpa, Leea nepalensis, Grewia ghisia, Grewia kathgodamensis, G. tistaensis, Meliosma eopinnata, Bursera preserrata, Cocculus miotrilobus, Xylosma nepalensis, Anisophyllea siwalica, Ventilago ovatus, Urena lobata, Datura miocenica, Mallotus, kalimpongensis, M. venkatachalai, Excoecaria palaeocrenulata, Ficus raptiensis*, etc. The remaining taxa (92%) in the assemblages are with entire margin. Wolfe (1971) presented a comparison of Mean Annual Temperature (MAT) and percentage of species with entire margined leaves for 19 modern floras which increase from 10-86% of entire margined species corresponding to an increase from 40º-28º C in temperature. Similar models were derived from the plot of MAT and percentage of entire margined species by Wolfe, 1979 for the species of eastern Asia, Greenwood (1992) for the species of Australia and Wilf (1997) for the species of America. Converting the plots into linear equations they have given regression models as follows.

MAT = 1.4 + 0.306 X (% entire) by (Wolfe, 1979; Wing & Greenwood, 1993)

MAT = 2.24 + 2.86 X (% entire) by (Wilf, 1997)

[In these equations, (% entire) are the percentage of leaves in the assemblage that have entire margins].

PLATE 2 →

Figs 1-10 showing the fossil leaves with drip tips.

1. *Bouea premacrophylla* Antal & Awasthi
2. *Duabanga siwalica* Prasad & Pandey
3. *Combretum sahnii* Antal & Awasthi
4. *Ochna miowallichii* Prasad & Dwivedi
5. *Cassia nepalensis* Prasad
6. *Millettia oodlabariensis* Antal & Prasad
7. *Tabernaemontana precoronaria* Prasad
8. *Mesua tertiara* Lakhanpal
9. *Millettia palaeoracemosa* Awasthi & Prasad
10. *Millettia purniyagiriensis* Shashi *et al.*

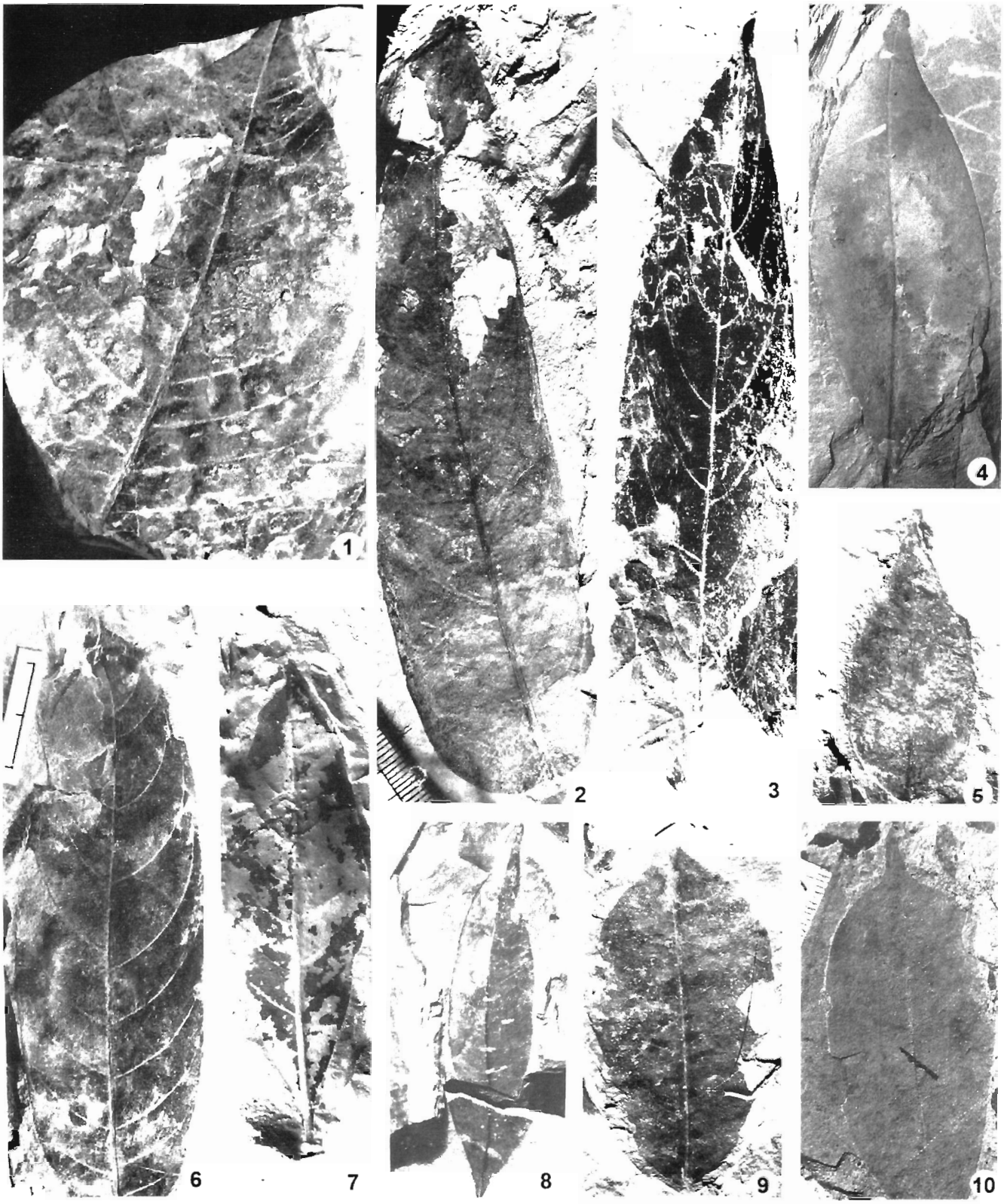

PLATE 2

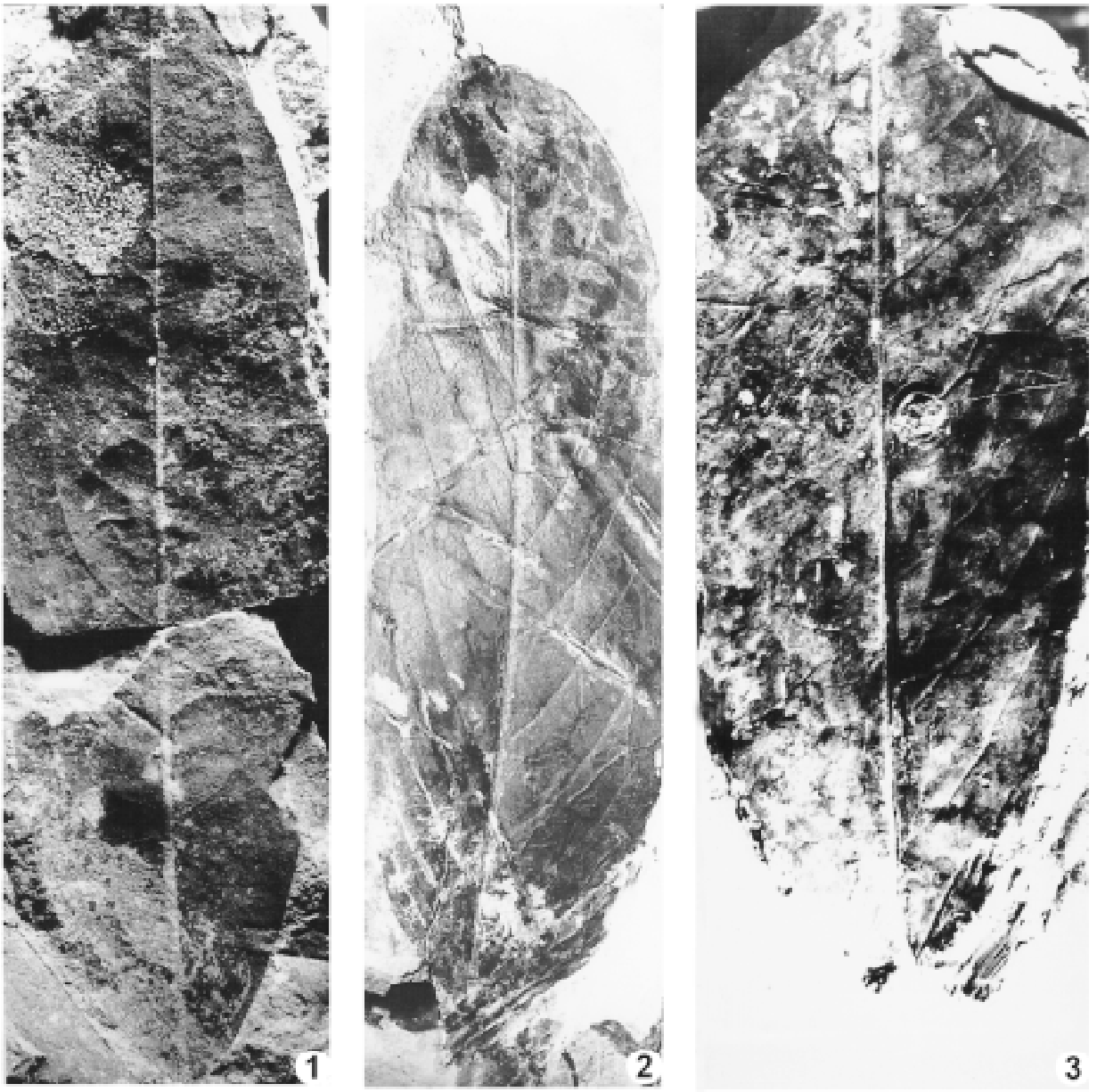

PLATE 3

Figs 1-3 showing fossil leaves of macrophyll type.

1. *Diospyros pretoposia* Prasad
2. *Cananga tertiara* Prasad
3. *Diospyros purniyagiriensis* Shashi *et al.*

When these equations are applied to the present Siwalik foreland basin assemblage it has been found that the MAT value are 29.29º C and 28.55º C respectively. These values, obtained from two different equations are almost same. This suggests that the MAT (Mean Annual Temperature) during Mio-Pliocene time all along the Himalayan foreland basin was 28º-29º C which was reduced by (3.6º-4.6º C) at present day (the present day MAT of the Himalayan foot hills zone is 24.40º C, data of 20 year obtained from Indian Meteorological Department and Champion & Seth, 1968).

The present estimated MAT (28º-29º C) is very significant as it corresponds to the present day MAT value of northeast India (29.04º C) where more than 33% comparable taxa of the fossils of Siwalik foreland basin are found at present (Figs 2-12). Similarly more than 8% comparable taxa of the fossil assemblages are growing now-a-days in the south Indian

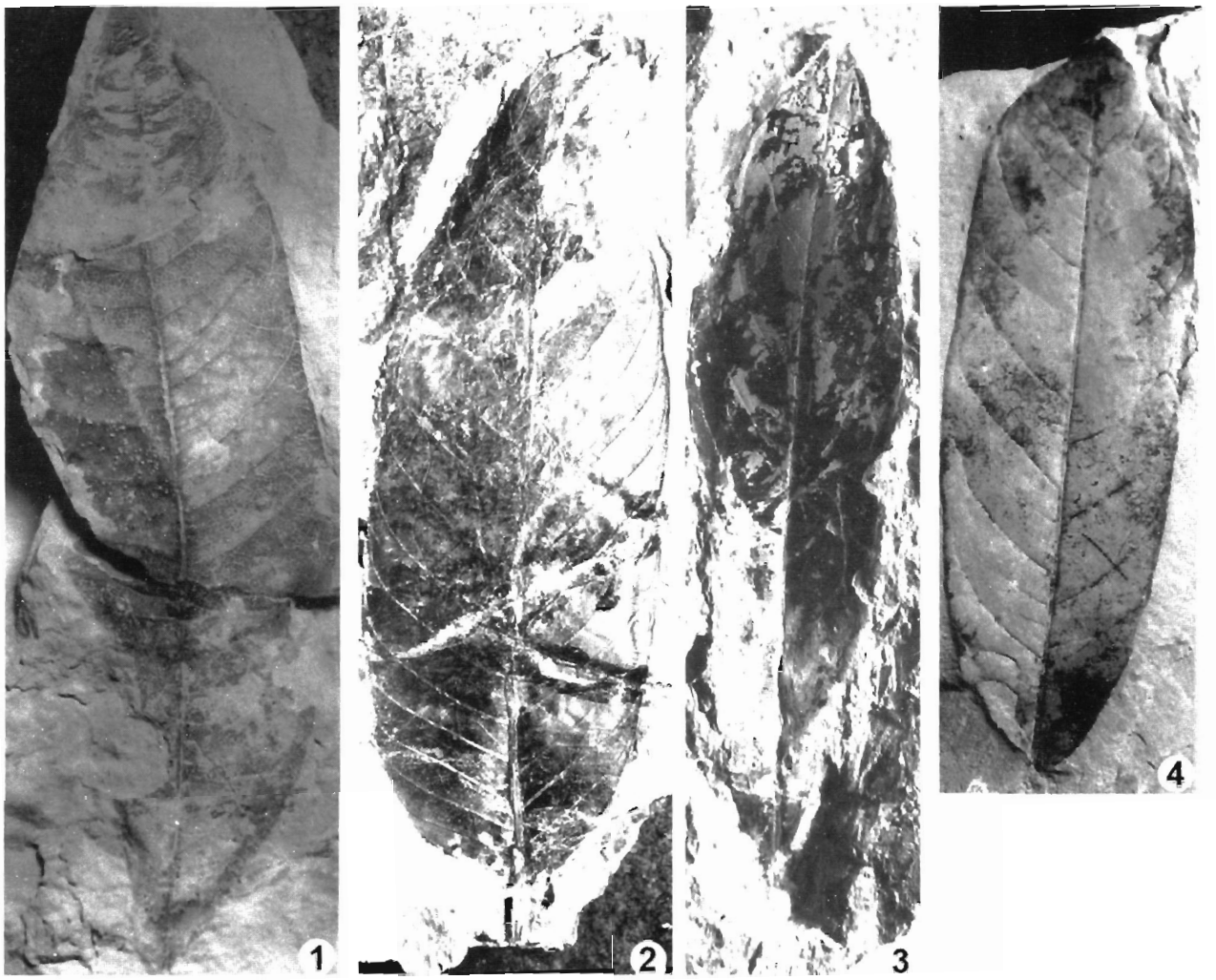

PLATE 4

Figs 1-4 showing fossil leaves of meso-macrophyll types

1 *Mangifera someshwarica* (Lakhanpal & Awasthi) Prasad *et al.*
2 *Uvaria siwalica* Prasad
3 *Diospyros palaeoebenum* Prasad
4. *Chisochcton suraikholaensis* Prasad & Pandey

region where MAT value varies from 25° to 27° C and is responsible for the existence of evergreen forest (Champion & Seth, 1968).

The other leaf characters that have been used for determining the palaeoclimate are leaf size, drip tips, organization of leaf, venation density, leaf texture and leaf base. The leaf size distribution in any forest type is correlated with under story plant of humid evergreen forests and decreases with low temperature and precipitation. Dilcher (1973) opined that the leaf size decreases with decreasing rainfall. Givnish 1976 postulated that optimal size should be greatest in the tropics. Wilf *et al.* (1998) found a strong relation between the Mean Annual Precipitation (MAP) and average leaf area (Pls 3, 4). He has formulated an equation to estimate the MAP by using the proportion of large size leaves in the assemblage of any region. This equation is as follows.

MAP = 47.5 + 6.18X (% Large leaves)

[(% Large leaves) is the percentage of leaves in an assemblage of mesophyll size or larger in area.]

In order to estimate the MAP of Himalayan foreland basin during Mio-Pliocene time the above equation is applied to the four leaf assemblages (Kathgodam Leaf Assemblage Koilabas Leaf Assemblage , Surai Khola Leaf Assemblage and Oodlabari Leaf Assemblage) of Siwalik foreland basin and found that the MAP estimates for each assemblage are as followers:

Kathgodam Leaf Assemblage, Uttaranchal	- 258 mm
Koilabas Leaf Assemblage, W. Nepal	- 303 mm
Surai Khola Leaf Assemblage, W. Nepal	- 288 mm
Oodlabari Leaf Assemblage, West Bengal	- 386 mm

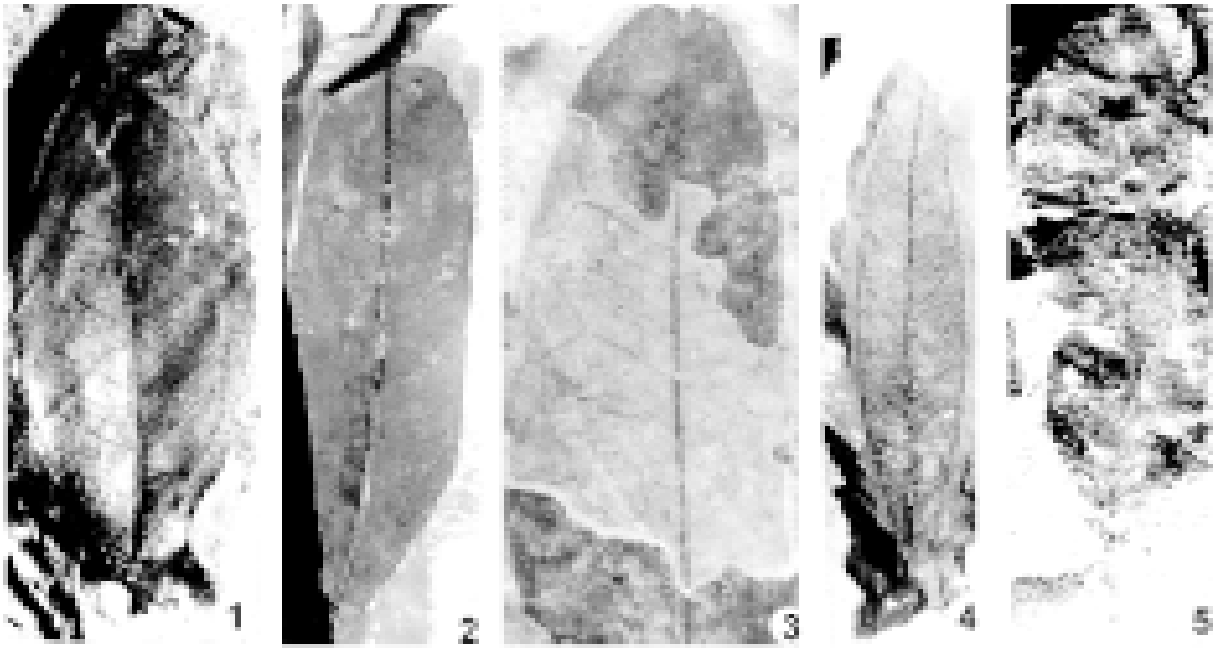

PLATE 5

Fig 1-5 showing the fossil leaves with higher venation density.

1. *Acronychia siwalica* Prasad
2. *Filicium koilabasensis* Prasad
3. *Chloroxylon palaeoswietenia* Prasad
4. *Syzygium miooccidentalis* Prasad *et al.*
5. *Calophyllum suraikholaensis* Awasthi & Prasad

Thus the average MAP of the whole Siwalik foreland basin will be 308 mm. When this MAP value has been compared with the present MAP value of different places in the Himalayan foot hills (i.e. Jammu 89 mm, Kathgodam (Haldwani) 167 mm, Haridwar (Dehradun) 180 mm, Surai Khola and Koilabas (Gorakhpur) 106 mm and Oodlabari (Siliguri 279 mm) it has been seen that their average MAP value (164 m) is reduced by 144 mm. This difference in MAP value of the present and past is much higher which can affect the flora of the region.

Moreover, the MAP value estimated from the fossil leaf assemblages of Himalayan foreland basin has also been compared with the present MAP of those regions (south and northeast India) where most of the comparable species of the fossils are growing luxuriantly. It shows very less difference in the MAP value of northeast India (i.e. Assam 274 mm, Kuchagaon 335 mm, Siliguri 279 mm) and South India (Kerala 278 mm and Karnataka 281 mm.)

The attenuate apex (Drip tips) is also important physiognomic feature of angiospermous leaves which is seen in wet tropical forest elements (Dorf, 1969). This is useful for hastening the runoff of water from the leaf. Richard (1952) pointed that it facilitates them to retard the growth of epiphytes and the deciduous leaves generally lack drip tip because of their short life span. The analysis of the leaf apex (tip) of all the leaf assemblages shows that a majority of taxa possess conspicuous drip tips (Figs 13-16; Pl. 2). However, in some specimens the tips either got broken or indistinct due to bad preservation. Thus it also shows the prevalence of tropical humid climate in the Himalayan foreland basin during Mio-Pliocene times.

The other physiognomic features like simple organization of leaf and close venation density commonly observed in the fossil leaf assemblages (Figs 13-16), are also related with available moisture or precipitation and thus indicating higher precipitation in the Himalayan foreland region during Mio-Pliocene as compared to that of the present day with reduced precipitation.

CONCLUSION

The evergreen elements (54-60%) dominate the fossil flora of Siwalik foreland basins during Middle Miocene in contrast to mixed deciduous elements occurring today (Fig. 17).

The predominance of evergreen elements in the Siwalik fossil assemblage indicates the prevalence of tropical warm humid climate with plenty of rainfall during the deposition of Siwalik sediments.

The family Fabaceae (Legume family) represented by 18 genera and 46 species, is the most dominant family in the Siwalik fossil assemblage followed by Euphorbiaceae (21

species), Dipterocarpaceae (16 species), Anonaceae (16 species) and Flacourtiaceae (14 species). The family Fabaceae which appeared in Upper Palaeocene became a major component of the evergreen forest during Mio-Pliocene all along the Himalayan foot hills.

The analysis of present day distribution of all the 324 species recovered from the Siwalik foreland basins shows that they are mostly known to occur in northeast India, Bangladesh, Myanmar and Malaysia wherever favourable climatic conditions exist.

Only about 20% taxa of the total assemblage are found to grow presently in the Himalayan foot hills and the remaining 80% taxa are locally extinct, suggesting changes in the climatic condition.

The dominance of entire margined species (about 92%) in the Siwalik foreland basin indicates the presence of tropical climate during the period of deposition. The other features like drip tips, leaf size, leaf texture, nature of petiole and venation density (Pls 2-5) collectively suggest tropical climate (with MAT 28°-29° and MAP 308 mm) during the deposition of Siwalik sediments.

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