Changing patterns of vegetation through Siwalik succession

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The palaeobotanical record from the Neogene of Himalaya has been examined and an attempt has been made to reconstruct the vegetation patterns and throw light on palaeoclimate of the region during Siwalik time. Though the flora of the Pre-Siwalik Neogene from which the Siwalik flora evolved is poorly documented, a few palynofossils from the Kasauli and Dagshai formations indicate the existence of subtropical to temperate vegetation in the Upper reaches of the newly built Himalaya. On the contrary, a fairly rich assemblage of megafossils from the Siwalik indicates widespread tropical evergreen to moist deciduous mixed forest in the lowland sub-Himalayan zone during Middle Miocene-Pliocene. The assemblage is dominated by wet-evergreen dipterocarps and associated taxa, most of which are known to have entered the Indian subcontinent from southeast Asia during Miocene and subsequently spread all over and finally reached the lower slopes of sub-Himalaya. This has resulted increase in the diversity of tropical vegetation.

The post-Pliocene orogeny of Himalaya brought great changes in the topography and climate which adversely affected the vegetation patterns of the region. The Early and Middle Siwalik tropical evergreen forest whose chief component are *Anisoptera, Dipterocarpus, Hopea, Shorea* (other than *Shorea robusta*), *Polyalthia, Calophyllum, Aphanamixis, Dysoxylum, Gluta, Dracontomelum, Mangifera, Swintonia, Cynometra, Koompassia, Ormosia, Pongamia, Sindora, Duabanga, Diospyros* spp., *Myristica*, etc. started dwindling towards the end of Middle Siwalik and subsequently disappeared from western and central sectors, though a few taxa like *Mangifera, Litsea, Cinnamomum, Bauhinia, Dalbergia, Ficus*, etc. continued to adjust to the new climatic conditions. Extinction of tropical evergreen taxa and further rise of Himalaya gave way to proliferation and diversification of tropical and subtropical moist deciduous to dry deciduous temperate vegetation in the lower and higher slopes respectively, as is also evidenced from palynological record.

Key-words—Palaeobotany, Vegetation, Evolution, Climate, Siwalik, Neogene, India.

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सारांश

शिवालिक अनुक्रम में वनस्पति का बदलता स्वरूप

नीलाम्बर अवस्थी

हिमालय के पश्चनूतन कल्प से पुरावनस्पतिक अभिलेखों का अध्ययन किया गया तथा वनस्पतिक स्वरूपो की पुर्नरचना का प्रयास किया गया है। इसी के आधार पर शिवालिक क्षेत्र की पुराजलवायु अन्वेषित करनें का प्रयास किया गया है। हालाँकि शिवालिक से पहले के वनस्पतिजात, जिससे शिवालिक वनस्पतिजात का विकास हुआ है, के विषय में कम जानकारी है तथापि कसौली एवं दागशाई शैल-समूहों से प्राप्त कुछ अश्मित परागाणु नवनिर्मित हिमालय के ऊपरी भाग में उपोष्णकटिबन्धीय से शीतोष्ण वनस्पति की उपस्थिति इंगित करते हैं। इसके विपरीत शिवालिक से उपलब्ध गुरुपादपाश्म समुच्चय में मध्य-मध्यनूतन से अतिनूतन कल्प में उष्णकटिबन्धीय सदाहरित से नमपर्णपाती मिश्रित वनों की उपस्थिति इंगित होती है। ये समुच्चय नम सदाहरित डिप्टेरोकार्पस तथा सहयुक्त वर्गकों से प्रभावी हैं। इन वर्गकों में से अधिकतर ने मध्यनूतन कल्प में दक्षिण-पूर्व एशिया से भारतीय उपमहाद्वीप में प्रवेश कर हिमालय के गिरिपादों में सर्वत्र फैल गये हैं। इसी के कारण उष्णकटिबन्धीय जलवायु में विभिन्नता देखने को मिलती है।

अतिनूतन कल्प के पश्चात् हिमालय के विकास से यहां की भौगोलिकी तथा जलवायु में काफी बदलाव आया है तथा जिसका प्रभाव वनस्पति पर असाधारण रूप से हुआ है। **एँनाइसॉप्टेरा, डिप्टेरोकार्पस, होपिया, शौरिआ, पोलिएल्थिया, केलोफ़िल्लम्, एफ़ेनामिक्सिस, डाइसोआइलम, ग्लूटा, ड्रेक्नेन्टोमिलम, मेंजिफ़ेरा, स्विंटोनिआ, साइनोमेट्रा, कूम्पासिआ, ओर्मोसिआ** इत्यादि प्रारम्भिक एवं मध्यशिवालिक के उष्णकटिबन्धीय अवयव मध्य शिवालिक के बाद कम होते चले गये तथा तत्पश्चात् पश्चिमी एवं केन्द्रीय भागों से विलुप्त हो गये। हालाँकि, कुछ थोड़े से वर्गक—**मेंजिफ़ेरा, लिटूसिआ, सिनामोमम्, बॉहीनिआ, डेल्बर्जिया, फ़ाइकस** आदि नई जलवायवी परिस्थितियों में समायोजन करने के कारण अभी भी पाये जाते हैं। सदाहरित

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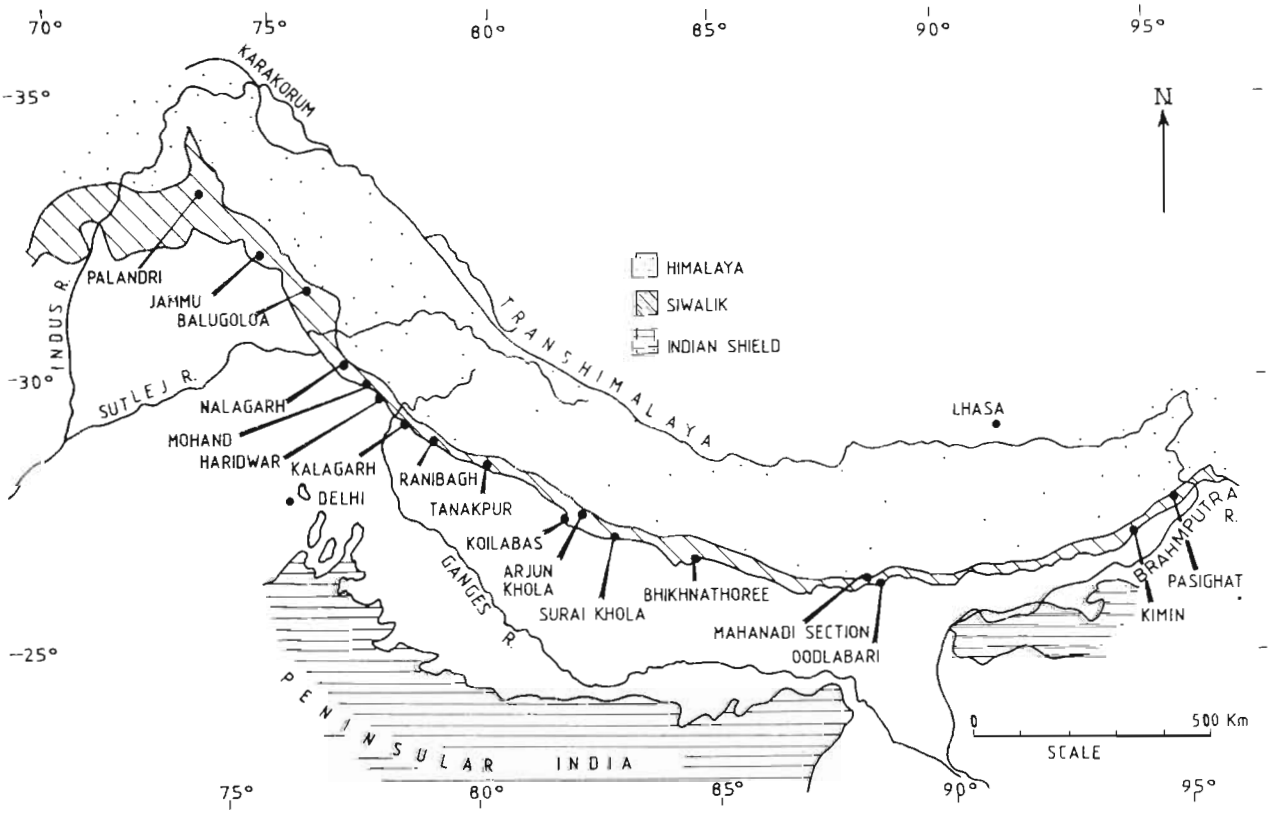
उष्णकटिबन्धीय वर्गकों तथा हिमालय के पुनः उत्थान से उष्णकटिबन्धीय एवं उपोष्णकटिबन्धीय नम पर्णपाती से शुष्क पर्णपाती शीतोष्ण वनस्पति हिमालय के क्रमशः निम्न एवं उच्चतर ढलानों पर विकसित हो गई है। इसकी पुष्टी परागाणविक अभिलेखों से भी होती है।

THE three major sedimentary zones identified in the Himalayan orogenic belt are: (i) the sub-Himalayan Zone, (ii) the lesser Himalayan Zone, and (iii) the Tethys Himalayan Zone. The sub-Himalayan Zone is also known as the Himalayan foot-hill zone which represents the Siwalik rocks of Neogene age. They extend from Potwar Plateau in the west to Arunachal Pradesh in the east covering a distance of about 2,400 km in length and generally 20-25 km in width. They are essentially formed by accumulation of alluvial detritus into a long narrow foredeep derived from the rising Himalaya during Middle Miocene to Lower Pleistocene. Along with erosional debris, the plants and animals which inhabited the then relatively low hills were deposited. The foredeep was formed as a sequel to the collision of Indian Plate with Laurasia and complete evacuation of Tethys Sea during Oligocene. During the final phase of the rise of Himalaya in Pleistocene-Recent, the Siwalik sediments were also upheaved, folded and faulted forming a continuous mountain range of relatively low height ranging from 1,000-1,200 m above mean sea level. The Siwalik sequence is about 6,000 km thick and consists of coarsely bedded sandstone, sandrock, clays and conglomerates. It is believed that they have been deposited in different environments, namely, lacustrine, channel and flood-plains, outwash and piedmont (Sahni & Mathur, 1964).

On the basis of lithology and mammalian fauna Pilgrim (1913) finally proposed a three-fold stratigraphic division of the Siwalik Group, i.e., Lower Siwalik, Middle Siwalik and Upper Siwalik. During the last two decades several workers have unearthed enormous amount of plant megafossils from the Lower and Middle siwalik sediments represented both in India and Nepal. In contrast to Lower and Middle Siwalik, the Upper Siwalik sediments lack well-preserved plant fossils, though fragments of leaves have been occasionally found in friable sandy clays. Their absence in the Upper Siwalik sediments has been attributed to their destruction due to oxidation at the place of origin, during transportation and also the place of burial (Ranga rao *et al.*, 1981).

The systematic study of plant fossils has



Map 1—Extent of the rocks of Siwalik Group.

Table 1—Balugoloa Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
SMILACEAE			
Smilax sp. Lakhanpal & Dayal 1966	*Smilax roxburghiana*, *S. macrophylla*, *S. prolifera*	—	—
ANNONACEAE			
Fissistigma senii Lakhanpal 1969	*Fissistigma bicolor*	Northeast India	Evergreen
F. siwalika Lakhanpal & Awasthi 1992	*F. rubiginosum*	Assam, Bangladesh, Burma, Thailand, Borneo	Evergreen
DIPTEROCARPACEAE			
Dipterocarpus siwalicus Lakhanpal & Guleria 198-	*Dipterocarpus tuberculatus*	Northeast India, Andaman Islands, Mynmar, Malaya	Evergreen
RHAMNACEAE			
Berchemia balugoloensis Lakhanpal 1967	*Berchemia floribunda*	Sub-Himalayan region, Northeast India	Evergreen
Ziziphus siwalicus Lakhanpal 1965, 1967	*Zizipĥus incurva*, *Z. xylopyrus*	India, Mynmar	Moist deciduous to dry deciduous
FABACEAE			
Dalbergia (fruit) Lakhanpal & Dayal 1966	*Dalbergia sissoo*	Greater part of India	Deciduous
COMBRETACEAE			
Terminalia balugoloensis Lakhanpal & Awasthi 1992	*Terminalia alata* var. *nepalensis*	Sub-Himalayan tracts, Punjab eastwards to Mynmar	Deciduous
LYTHRACEAE			
Lagerstroemia sp. Lakhanpal & Dayal 1966	?*Lagerstroemia indica*	—	—
MORACEAE			
Ficus precunea Lakhanpal 1968	*Ficus cunea*	Himalayan foot-hills, Assam region, Bangladesh	Evergreen

generated a rich database for the reconstruction of Siwalik floristics. Realizing the extent and thickness of Siwalik sediments present in India and Nepal, the plant megafossils data available so far is still far from satisfactory. Nevertheless, several important and significant plant taxa have been studied and documented from several localities in the foot-hills (Map 1; Tables 1-7). The data have been used in deciphering palaeoecology and palaeophytogeography of the region. Evolutionary trends of the Siwalik flora have also been traced through time and space. The influence of periodical northward drift of the Indian Plate and rise of Himalaya on the flora has also been one of the objectives of the study.

PRE-SIWALIK NEOGENE FLORISTICS AND CLIMATE

Before an attempt is made to reconstruct the changing patterns of the Siwalik vegetational scenarios, it is necessary to furnish background information about the pre-existing vegetation and environment of the Himalayan region particularly of pre-Siwalik time. The pre-Siwalik sediments developed in the Lesser Himalayan zone are designated as Murree, Dharamsala, Dagshai and Kasauli formations.

In comparison to Siwalik sediments these formations are poor in plant megafossils. Sahni (1953, 1964) described for the first time a few plant remains, viz., *Sabalites microphylla* and *Sabalites* sp. resembling leaves of *Sabal*-like palms, leaf fragments cf. palm, other monocotyledonous fragmentary leaves of uncertain affinities and ill-preserved dicotyledonous leaves as *Dicotylophyllum* spp. from the Kasauli Formation of Shimla Hills. Similar ill-preserved indeterminate dicotyledonous leaves have been reported by Chaudhury (1969) from the Koshaliya River bank near Kalka, Himachal Pradesh. However, the only satisfactorily preserved leaf-

Table 2—Nalagarh Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
DIPTEROCARPACEAE			
Dipterocarpoxylon siwalicus Prakash 1975	*D. indicum* *D. turbinatus* *D. gracilis*	Western Ghats northeast India, Andaman Islands, Malaya Peninsula	Evergreen Evergreen
D. nalagarhense Prakash 1975	*D. dyeri*	Malay Peninsula	Evergreen
D. premacrocarpum Prakash 1975	*D. macrocarpus*	Northeast India, Mynmar	Evergreen
MELIACEAE			
Aglaia nahanensis Yadav 1989	*Aglaia edulis*	Northeastern India, Bangladesh, Mynmar, Malay Peninsula	Evergreen
ANACARDIACEAE			
Dracotomelumoxylon mangiferumoides Prakash 1979a	*Dracontomelum mangiferum*	Andaman and Nicobar islands, Malaya Peninsula	Evergreen
FABACEAE			
Acrocarpus siwalicus Yadav 1989	*Acrocarpus fraxinifolius*	India, Mynmar	Moist deciduous
Adenantheroxylon Yadav 1989	*Adenanthera pavonina*	Indo-Malayan region	Moist deciduous
Albizinium eolebbekianum Prakash 1975	*Albizia lebbek*	Himalayan foot-hills	Deciduous
Cassinium prefistulai Prakash 1975	*Cassia fistula*	India, Mynmar	Deciduous
Cynometroxylon holdenii (Gupta) Bande & Prakash. (= *Cynometroxylon indicum*) Chowdhury & Ghosh. Prakash 1975	*Cynometra polyandra*	Northeast India, Mynmar, Malaya	Evergreen
Koompassioxylon elegans Yadav 1989	*Koompassia malaccensis*	Malayan region	Evergreen
Millettioxylon pongamiensis Prakash 1975	*Pongamia pinnata*	India, Mynmar, South-east Asia, North Australia, China	Evergreen
Ormosioxylon bengalensis Bande & Prakash. Yadav 1989	*Ormosia robusta*	India, Bangladesh, Mynmar	Evergreen
LECYTHIDACEAE			
Careyoxylon pondicherriense Prakash	*Careya arborea*	India, Mynmar	Moist deciduous

impression comparable to the leaves of *Artocarpus* is described by Sharma and Gupta (1972) from the Murree sediments in Rajori District, Jammu and Kashmir. Recently, Mehra *et al.* (1990a) have reported a few monocotyledonous and dicotyledonous leaves from typical Dagshai Formation, exposed near Kumarhatti on Kalka-Shimla Highway. They also reported impressions of leaves and flowers from Kasauli Formation exposed along the same highway and provisionally referred them to Fabaceae and Moraceae (Mehra *et al.*, 1990b).

The leaves documented so far are invariably smaller in size which obviously belong to grasses, bushes and small trees. It is astonishing that in a long stretch of well developed Lower Miocene sedimentary sequence not a single bigger dicotyledonous leaf suggesting broad-leaved mesophytic vegetation has been found so far. Leaves and other plant megafossils, reported from Dharamsala, Dagshai, Kasauli and Murree sediments, belong to such plants which were most probably the first ones to invade the newly emerged low hills of the Himalaya from the nearby area.

The available meagre plant megafossils data alone is not enough for precise reconstruction of the

Table 3—Kalagarh Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
ARECACEAE			
Palmoxylon wadiai Sahni. Prasad 1987	*Palm* in general	—	—
ANNONACEAE			
Polyalthioxylon indicum Prakash 1978	*Polyalthia* spp.	Indo-Malayan	Evergreen
DIPTEROCARPACEAE			
Anisopteroxylon kalagarhense Prakash 1978	*Anisoptera scaphula*	Mynmar, Thailand, Malaya Peninsula	Evergreen
A. oblongoides Yadav 1989	*A. oblonga*	Mynmar, Malay Peninsula	Semi-evergreen to deciduous
Dipterocarpoxylon kalagarhense Yadav 1989	*Dipterocarpus obtusifolius*	Mynmar, Thailand, Malay Peninsula	Evergreen
D. parabaudii Prakash 1978	*D. baudii*	Mynmar, Cambodia Thailand, Malay Peninsula	Evergreen
D. surangeii Prakash 1981	*D. tuberculatus*	Bangladesh, Mynmar,	Evergreen
D. nungarhense Trivedi & Ahuja 1980	*D. tuberculatus*	Thailand	
Shoreoxylon ornatum Trivedi & Ahuja) Bande & Prakash 1980	*Shorea* spp.	Indo-Malayan region	Evergreen
Syn. *Pentacmeoxylon ornatum* Trivedi & Ahuja *Vaterioxylon kalagarhense* Trivedi & Misra *V. miocenicum* Trivedi & Misra			
Shoreoxylon siwalicus Prasad & Prakash 1988	*Shorea minor*	Malaysia	Evergreen
Hopenium prenutanoides Prasad & Prakash 1988	*Hopea nutan*	Malaya Peninsula	Evergreen
H. kalagarhensis Prasad & Prakash 1988	*H. sulcata*	Mynmar, Malaya	Evergreen
STERCULIACEAE			
Sterculioxylon kalagarhensis Trivedi & Ahuja 1978a	*Sterculia coccinia* *S. oblonga* *S. rhinopetala*	Northeast India to Malayan region	Evergreen
ANACARDIACEAE			
Dracontomelumoxylon mangiferumoides Ghosh & Roy. Prakash 1981	*Dracontomelum mangiferum*	Andaman Islands	Evergreen
Glutoxylon kalagarhensis	*Gluta* spp.	Mynmar, Malaya	Evergreen
FABACEAE			
Bauhinium palaeomalabaricum Prakash & Prasad 1984	*Bauhinia malabarica*	India, Mynmar	Moist deciduous
B. miocenicum Trivedi & Panjwani 1986	*Bauhinia retusa*	Chota Nagpur, Eastern and Western Ghats	Moist deciduous
Cynometroxylon holdenii (Gupta) Prakash & Bande.	*Cynometra polyandra*	Northeast India	Evergreen
Syn. *C. siwalicus* Trivedi & Ahuja 1978c *Millettioxylon kalagarhensis*	*Millettia pulchra*	Mynmar	Evergreen

Contd.

Table 3—Contd.

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
(Trivedi & Misra) Guleria 1984 Syn. *Dialiumoxylon kalagarhensis* Trivedi & Misra			
Hopeoxylon eosiamensis Prakash 1981	*Sindora siamea*	Malay Peninsula	Evergreen
Ormosioxylon bengalensis Bande & Prakash. Prasad 1989	*Ormosia robusta*	Northeast India, Bangladesh, Mynmar	Evergreen
ROSACEAE			
Parinarioxylon splendinum Trivedi & Ahuja 1979a	Affinities doubtful	—	—
COMBRETACEAE			
Terminalioxylon palaeomanii Prakash 1981	*Terminalia manii*	Andaman and Nicobar Islands	Dry to moist deciduous
T. siwalicus Prasad 1989	*T. paniculata*	Western Ghats	Deciduous
SONNERATIACEAE			
Duabangoxylon indicum Awasthi. Awasthi & Prasad 1988	*Duabanga* spp.	Northeast Indian region	Evergreen
EBENACEAE			
Ebenoxylon siwalicus Prakash 1981	*Diospyros brandisiana*	Mynmar	Evergreen
E. kalagarhensis Prasad 1989	*D. malabarica*	Indo-Malayan region	Evergeen
LAURACEAE			
Lourinoxylon siwalicus Prasad 1990c	Lauraceous genera	—	—

Table 4—Poornagiri (Tanakpur) Assemblage (Awasthi, MS)

FOSSIL LEAVES: FAMILY/GENUS	COMPARABLE EXTANT SPECIES	DISTRIBUTION OF COMPARABLE EXTANT SPECIES	FOREST TYPE INDICATED
STERCULIACEAE			
Sterculia	*Sterculia urens*	India, Mynmar	Dry deciduous
FABACEAE			
Ormosia	*Ormosia robusta*	Nepal, Northeast India, Bangladesh, Mynmar	Evergreen
COMBRETACEAE			
Terminalia	*Terminalia chebula*	India	Deciduous
MYRTACEAE			
Syzygium	*Syzygium cumini*	India, Mynmar	Evergreen to deciduous
BORAGINACEAE			
Cordia	*Cordia myxa*	India, Mynmar, Southeast Asia	Deciduous
EBENACEAE			
Diospyros	*Diospyros ebenum* *D. sylvatica*	India, Sri Lanka	Moist deciduous
LAURACEAE			
Persea	*Persea* spp.	Indo-Malayan	Evergreen
Cryptocarya	*C. griffithiana*	Indo-Malayan	Deciduous
MORACEAE			
Artocarpus	*Artocarpus integrifolius*	India, Mynmar	Evergreen

Table 5—Bhikhnathoree Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
MALVACEAE			
Urena palaeolobata Awasthi & Lakhanpal 1990	*Urena lobata*	Tropical to subtropical region	Deciduous
MELIACEAE			
Aphanamixis bhikhnathoriensis Awasthi & Lakhanpal, 1990	*Aphanamixis polystachya*	Indo-Malayan	Evergreen
Toona siwalika Awasthi & Lakhanpal 1990	*Toona ciliata* Roxb.	Indo-Malayan, Australia	Evergreen to deciduous
RHAMNACEAE			
Ziziphus champarensis Lakhanpal & Awasthi 1984	*Ziziphus mauritiana*	Tropical to subtropical region of the world	Moist to dry
ANACARDIACEAE			
Mangifera someshwarica Lakhanpal & Awasthi 1984	*Mangifera indica*	Indo-Malayan	Evergreen to deciduous
FABACEAE			
Indigofera prepulchella Lakhanpal & Awasthi 1984	*Indigofera pulchella*	India	Semi-evergreen to dry deciduous
Dalbergia sp. Lakhanpal & Awasthi 1984	*Dalbergia sissoo* *Dalbergia latifolia*	India	Dry deciduous
Derris champarensis Awasthi & Lakhanpal 1990	*Derris scandens*	Indo-Malayan	Semi-evergreen to dry deciduous
Pongamia siwalika Awasthi & Lakhanpal 1990	*Pongamia pinnata*	India, Southeast Asia, North Australia	Semi-evergreen to dry deciduous
Cassia antiqua Lakhanpal & Awasthi 1990	*Cassia glauca*	Indo-Malayan	Evergreen
Bauhinia siwalika Lakhanpal & Awasthi 1984	*Bauhinia* spp. *(B. diptera, B. tomentosa, B. corymbosa)*	Indo-Malayan	Deciduous
MYRTACEAE			
Syzygium palaeobracteatum Awasthi & Lakhanpal 1990	*Syzygium bracteatum*	Northeast India, Orissa	Evergreen
RUBIACEAE			
Gardenia palaeoturgida Lakhanpal & Awasthi 1984	*Gardenia turgida*	Northern India	Moist deciduous
MYRSINACEAE			
Ardisia antiqua Awasthi & Lakhanpal 1990	*Ardisia solanacea*	India, Mynmar, Sri Lanka	Moist deciduous
CONVOLVULACEAE			
Ipomoea eriocarpoides Awasthi & Lakhanpal 1990	*Ipomoea eriocarpa*	India, Mynmar, Sri Lanka	Moist deciduous
LAURACEAE			
Phoebe champarensis Awasthi & Lakhanpal 1990	*Phoebe lanceolata*	India, Mynmar, Sri Lanka	Evergreen
Cinnamomum palaeotamala Lakhanpal & Awasthi 1984	*Cinnamomum tamala*	India, Mynmar	Evergreen to moist deciduous
Litsea prenitida Lakhanpal & Awasthi 1984	*Litsea nitida*	Eastern Himalaya, Assam, Bangladesh	Semi-evergreen
MORACEAE			
Ficus champarense Lakhanpal & Awasthi 1984	*Ficus* spp.	—	—

floral pattern and interpreting the palaeoclimate of the lesser Himalayan zone during Early Miocene. However, on the basis of palynological assemblage from the Kasauli Formation which includes

Table 6—Koilabas Assemblage

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
DILLENIACEAE			
Dillenia palaeoindica Prasad & Prakash 1984	*Dillenia indica*	India, Mynmar	Moist evergreen
FLACOURTIACEAE			
Ryparosa prekunstleri Prasad 1990b	*Ryparosa kunstleri*	Malaya	Evergreen
CLUSIACEAE			
Mesua tertiara Prasad 1990b	Affinities doubtful	—	—
DIPTEROCARPACEAE			
Dipterocarpus siwalicus Lakhanpal & Guleria. Prasad 1990a	*Dipterocarpus tuberculatus*	Northeast India, Mynamar, Southeast Asia	Evergreen to moist deciduous
MELIACEAE			
Chloroxylon palaeoswietenia Prasad 1990b	*Chloroxylon swietenia*	India, Sri Lanka	Deciduous
FABACEAE			
Albizia siwalika Prasad 1990a	*Albizia gambelei*	Northeast India	Moist deciduous
Cassia nepalensis Prasad 1990b	*Cassia hirsuta*	Central India	—
Dalbergia miosericea Prasad 1990b	*Dalbergia sericea*	Sub-Himalayan region, Madagascar	Deciduous
Millettia siwalica Prasad 1990b	*Millettia ovalifolia*	Jammu to Sikkim, Upper Mynmar	Moist deciduous
Millettia koilabasensis Prasad 1990b	*Millettia macrostachya*	Upper Mynmar	—
Ormosia robustoides Prasad 1990a	*Ormosia robusta*	Northeast India, Mynmar	Evergreen
COMBRETACEAE			
Anogeissus eosericea Prasad & Prakash 1984	*Anogeisus sericea*	Central India	Deciduous
Calycopteris floribundoides Prasad 1990b	*Calycopteris floribunda*	Western Peninsula, Northeast India, Mynmar	Deciduous
Terminalia koilabasensis Prasad 1990b	*Terminalia angustifolia*	Malaya	Evergreen
Terminalia siwalica Prasad 1990b	*T. pyrifolia*	Mynmar	—
Terminalia sp. Tripathi & Tiwari 1983	*Terminalia arjuna*	Throughout India, Mynmar	Deciduous
RUBIACEAE			
Randia miowallichii Prasad 1990b	*Randia wallichii*	Northeast India to Mynmar, Andaman Islands	Evergreen
APOCYNACEAE			
Tabernaemontana precoronaria Prasad 1990b	*Tabernaemontana coronaria*	Sub-Himalayan region, Sri Lanka, Mynmar	Evergreen
SOLANACEAE			
Datura miocenica Prasad 1990b	*Datura fastuosa*	Tropical region	—
VERBENACEAE			
Vitex prenegundo Prasad 1990b	*Vitex negundo*	India, Sri Lanka, China	Deciduous
Vitex siwalicus Prasad 1990b	*Vitex pubescens*	India, Mynmar	Evergreen

Contd.

Table 6—Contd.

FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
LAURACEAE			
Cinnamomum mioinunctum Prasad 1990b	*Cinnamomum inunctum*	Mynmar, Malaya	Evergreen to moist deciduous
MORACEAE			
Ficus precunea Lakhanpal & Prasad 1990b	*ficus cunea*	Sub-Himalaya region, Assam, Mynmar	Deciduous
Ficus retusoides Prasad 1990b	*Ficus retusa*	Indo-Malayan	Evergreen
Ficus nepalensis Prasad 1990b	*Ficus glaberrima*	Indo-Malayn	Evergreen

Table 7—Surai Khola Assemblage in stratigraphical sequence

STRATI-GRAPHIC SEQUENCE	FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
Surai Khola beds	MARANTACEAE			
	Clinogyne ovatus Awasthi & Prasad 1990	*Clinogyne grandis*	Indo-Malayan region	Moist deciduous
	FLACOURTIACEAE			
	Flacourtia nepalensis Awasthi & Prasad 1990	*Flacourtia ramnotchii*	India, Mynmar, Sri Lanka	Deciduous
	FABACEAE			
	Millettia miocubithii Awasthi & Prasad 1990	*Millettia cubithii*	Malayan region	Moist deciduous
	Bauhinia nepalensis Awasthi & Prasad 1990	*Bauhinia malabarica* *B. variegata*	India, Mynmar	Evergreen to deciduous
	EBENACEAE			
	Diospyros miokaki Hu & Chaney. Awasthi & Prasad 1990	*Diospyros kaki*	India, Mynmar, China, Japan	Moist deciduous
	EUPHORBIACEAE			
	Breynia prerhamnoides Awasthi & Prasad 1990	*Breynia rhamnoides*	Indo-Malayan region	Moist deciduous
Kaila Khola	ARECACEAE			
	Caryota siwalika Awasthi & Prasad 1990	*Caryota urens*	Indo-Malayan region	Evergreen to moist deciduous
	ANACARDIACEAE			
	Mangifera someshwarica Lakhanpal & Awasthi. Awasthi & Prasad 1990	*Mangifera indica*	India, Southeast Asia	Evergreen
	Gluta siwalika Awasthi & Prasad 1990	*Gluta renghas*	Mynmar, Malaysia	Evergreen
	Swintonia miocenica Awasthi & Prasad 1990	*Swintonia floribunda*	Bangladesh, Mynmar	Evergreen
	FABACEAE			
	Entada palaeoscandens (seed) Awasthi & Prasad 1990	*Entada scandens*	Indo-Malayan region	Moist deciduous to evergreen
	COMBRETACEAE			
	Terminalia palaeochebula Awasthi & Prasad 1990	*Terminalia chebula*	India, Mynmar, Sri Lanka	Moist deciduous

Contd.

Table 7—Contd.

STRATI-GRAPHIC SEQUENCE	FAMILY/FOSSIL TAXA	COMPARABLE EXTANT SPECIES	DISTRIBUTION	FOREST TYPE INDICATED
	Terminalia panandhroensis Lakhanpal & Guleria. Awasthi & Prasad 1990	*Terminalia coriacea*	India, Mynmar	Deciduous
Chor Khola beds	MYRISTICACEAE *Myristica palaeoglomerata* Awasthi & Prasad 1990	*Myristica glomerata*	Malay peninsula	Evergreen
	POACEAE *Bambusa siwalika* Awasthi & Prasad 1990	*Bambusa tulda*	India, Mynmar	Moist deciduous
	FABACEAE *Millettia palaeoracemosa* Awasthi & Prasad 1990	*Millettia racemosa*	India, Mynmar	Deciduous
	Entada palaeoscandens (Leaf). Awasthi & & Prasad 1990	*Entada scandens*	India, Mynmar	Moist deciduous to to semi-evergreen
	EUPHORBIACEAE *Excoecaria palaeocrenulata* Awasthi & Prasad 1990	*Excoecaria crenulata*	Southern India	Evergreen
	CLUSIACEAE *Calophyllum suraikholaensis* Awasthi & Prasad 1990	*Calophyllum polyanthum*	Sikkim and Khasi Hills	Evergreen
	DIPTEROCARPACEAE *Dipterocarpus siwalicus* Lakhanpal. Guleria, Awasthi & Prasad 1990	*Dipterocarpus tuberculatus* *D. turbinatus*	Northeast India to Southeast Asia	Evergreen
Paira Khola beds and Bankas beds	DIPTEROCARPACEAE *Dipterocarpus siwalicus* *D. turbinatus*	*Dipterocarpus tuberculatus*	Northeast India to Southeast Asia	Evergreen
	ANNONACEAE *Polyalthia simiarum* Awasthi & Prasad 1990	*Polyalthia simiarum*	Northeast India, Mynmar	Evergreen
	FABACEAE *Cynometra siwalika* Awasthi & Prasad 1990	*Cynometra polyandra*	Khasi and Cachar Hills, Malay Peninsula	Evergreen

representatives of modern families of upland and lowland vegetations, viz., Cyatheaceae, Schizaeaceae, Lindasaeaceae, Polypodiaceae, Pinaceae, Liliaceae, Arecaceae, Bombacaceae, Oleaceae, etc. Singh and Sarkar (1990) have broadly inferred that the vegetation in the western Himalaya during Lower Miocene was subtropical and humid. A similar assemblage of palynofossils representing the families Hymenophyllaceae, Schizaeaceae, Polypodiaceae, Lycopodiaceae, Pinaceae, Arecaceae, Aquilifoliaceae, Rutaceae, Tiliaceae, Chenopodiaceae and Pandanaceae is reported from Dharamsala sediments (equivalent to Dagshai and Kasauli formations) of Himachal Pradesh by Mathur and Venkatachala (1979) and Mathur (1984). Saxena and Bhttacharyya (1990) added a few new families, viz., Parkeriaceae, Adiantaceae, Araucariaceae, Potamogetonaceae, Lentibulariaceae, Malvaceae and

Mimosaceae to the Dharamsala palynoflora assemblage, suggesting prevalence of tropical to subtropical humid conditions. Occurrence of *Pinus* pollen in the Kasauli and Dharamsala sediments suggests that during Early Miocene the Himalaya seem to have attained sufficient elevation enabling Pinaceae and other subtropical and temperate elements from the North and West Asian mainland to immigrate and subsequently proliferate all over in the higher reaches.

SIWALIK FLORISTICS

The Siwalik flora includes the following assemblages from a number of exposures located in the foot-hills, covering an area between Jammu in the west and Arunachal Pradesh in east (Map 1).

Jammu—The study of Siwalik plant fossils was infact initiated by Professor Sahni (1931) who for the first time reported two petrified woods as *Palmoxylon jammuense* and *P. wadiai* from the alluvial boulder deposits from the banks of Tawi and Tarangiri rivers near Jammu, but the exact stratigraphical position of the rocks from which these woods were derived is not known. However, detailed account of these woods by Sahni was posthumously published (Sahni, 1964). The only other known plant fossil from Jammu area is *Poacites-siwalicus*, a grass-like monocot leaf from the Palandri Formation = Chinji Formation near Palandri, Rajouri District (Sahni, 1964).

Himachal Pradesh—Balugoloa near Jawalamukhi in Kangra District and Nalagarh in Solan District are two important localities of the Lower Siwalik which have been subjected to palaeobotanical study. The former is famous for excellently preserved leaf-impressions borne on fine to coarse-grained hard sandstone. They have been studied by Lakhanpal (1965, 1967, 1968, 1969), Lakhanpal and Dayal (1966), Lakhanpal and Guleria (1987) and Lakhanpal and Awasthi (1992). The latter contains exlusively petrified woods which have been worked out intensively by Prakash (1975, 1979a, 1979b) and Yadav (1989). They have been listed in the Tables.

Besides, Lakhanpal, Tiwari and Awasthi (1987) reported leaf and culm of bamboo from the Lower Siwalik' of Ranital, Kangara-Jawalamukhi Road, Kangara District. From Khundian, a locality of Middle Siwalik in Jawalamukhi area, a solitary wood — *Anisopteroxylon jawalamukhi* comparable to *Anisoptera* of Dipterocarpaceae is described by Ghosh and Ghosh (1958). From the same area Mathur (1974, 1978) reported a seed (*Boraginocarpon lakhanpalii*) and a leaf of Lauraceae—*Litsea bhatiai*, from the Upper Siwalik beds, and a papilionaceous leaf, *Papilionid, Mallotus* sp. and grass-like leaves from Lower Siwalik. Dayal and Chaudhri (1967) also reported some ill preserved dicotyledonous leaves, from Lower Siwalik beds of Koshalya River near Kalka.

Uttar Pradesh—In the foot hills of Uttar Pradesh, from Mohand in Saharanpur District to Tanakpur in Nainital District, there are a number of exposures of Lower and Middle Siwalik which contain a great variety of woods and leaves. However, concerted efforts have so far been made by several workers to study the petrified woods from Kalagarh area, Pauri Garhwal District (Prakash, 1978, 1981; Prakash & Prasad, 1984; Awasthi & Prasad, 1988; Prasad, 1987, Prasad & Prakash, 1988; Prasad, 1989, 1990b, 1990c; Trivedi & Ahuja, 1978a, b, c, 1979a, b, 1980; Trivedi & Misra, 1978, 1979, 1980; Trivedi & Panjwani, 1986) and leaf-impressions from Poornagiri Hill (also spelt as Punyagiri Hill) near Tanakpur, Nainital District (Lakhanpal & Guleria, 1978; Awasthi, unpublished data).

In Mohand area, district Saharanpur, the Middle Siwalik sediments contain semi-carbonised and petrified woods which have been meagrely studied. Rawat (1964, 1964-1965), in his preliminary reports briefly described two fossil woods as *Dipterocarpus* and *Bauhinia*. The Siwalik beds near Hardwar, locally known as "Hardwar beds" contain leaf-impressions. Varma (1968) described a few leaves from Bagh Rao near Hardwar as *Meliaceaephyllum mahagonites, Eucalyptophyllum raoi, Diospyros embryopterisites* and a leaf cf. ? *Croton tegelis*. Except for *Diospyros embryopterisites* the identification of these leaves is doubtful. *Meliaceaephyllum mahagonites* cannot be a leaf of *Sweitenia mahagoni* since it is an exotic plant which is known to have been introduced in India from central America about 200 years ago. The leaf assigned to *Eucalyptophyllum raoi* does not exhibit the characters of *Eucalyptus*; *Eucalyptus* too is an introduced Australian tree.

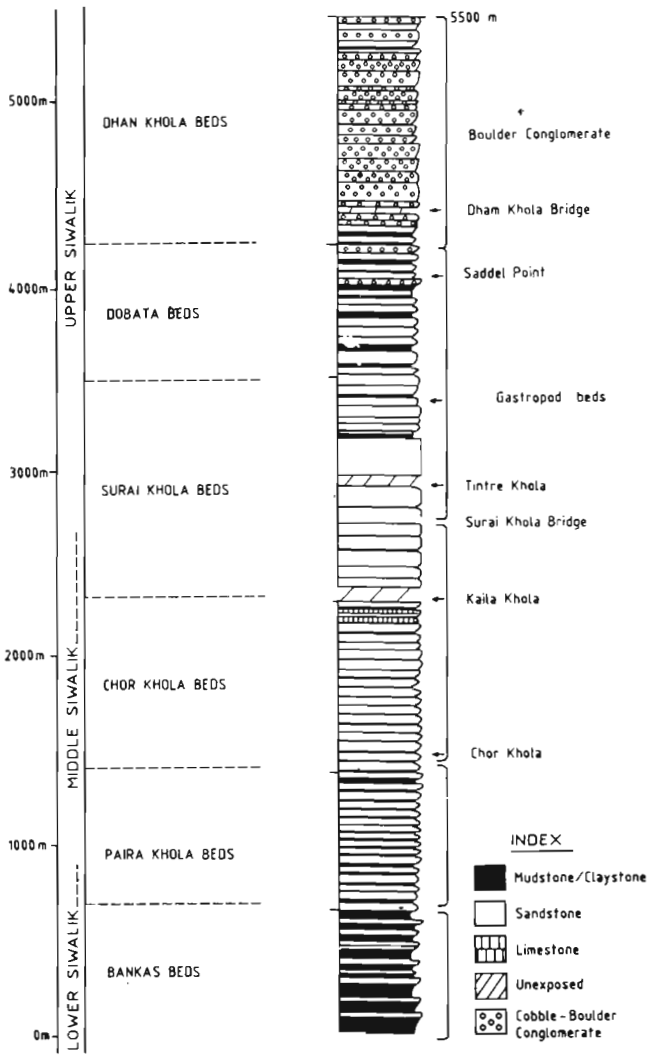
Bihar-Nepal Border—From a small patch of fossiliferous beds of the Siwalik exposed near India-Nepal boundary Post no. 35 Bhikhnathoree, West Champaran District, Bihar, Lakhanpal and Awasthi (1984) and Awasthi and Lakhanpal (1990) have reported 20 species of dicotyledonous leaves.

Nepal—The Siwalik Hills of India extended into Nepal are designated as Churia Hills and the sedimentary sequence is known by Churia Group. Our recent study of plant megafossils from the Siwalik of the western sector of India and the Churia Group of Nepal indicates better representation of

plants both qualitatively and quantitatively. The plant remains from the Churia Group have been studied in detail.

(i) *Koilabas*—Koilabas is a small village situated at the base of foot-hills, 1 km inside Nepal territory, near Jarwa, Gonda District, Uttar Pradesh. The sediments are exposed along the upstream of Koilabas Nala. Unfortunately, detailed stratigraphical information of the sequence is lacking. However, the sediments show gradual coarsening from fine-grained hard calcareous sandstone and shales to sandstone and shales obviously representing the Lower and Middle Siwalik. The fossil plants comprising leaf-impressions have been studied by Prasad and Prakash (1984), Prasad (1990a, 1990b) and Tripathi and Tiwari (1983).

(ii) *Surai Khola*—Geologically, Surai Khola is one of the important areas in the Churia Hills where a complete and uninterrupted sequence of the Siwalik Group is exposed along Mahendra Highway, covering a distance of about 16 km from Surai Naka to Rangsing Khola in Kapilvastu District, Nepal. This sequence measures about 5,650 m in thickness, representing the Lower, Middle and Upper Siwalik (Corvinus, 1988, 1990). On the basis of lithology Corvinus (1990, text-fig. 2) divides the whole sequence into the Bankas beds, Paira Khola beds (Upper part of Lower Siwalik), Chor Khola beds (Lower part of Middle Siwalik), Surai Khola beds (Upper part of Middle Siwalik), Dobata beds and Dhan Khola beds (Upper Siwalik). The first four beds contain large number of excellently preserved leaf-impressions and rarely fruits/seeds in the fine grained calcareous sandstone, mudstone and shales while the last three beds show rare occurrence of unidentifiable fragmentary grass-like leaves in clays and friable sands. Out of a big collection of leaves, Awasthi and Prasad (1990) have so far identified the following taxa which are listed in the stratigraphical sequence (see Text-figure 1).



Text-figure 1—Surai Khola profile (after Corvinus 1990).

BENGAL AND ARUNACHAL PRADESH

In the eastern sector of India Siwalik has received very little attention for palaeobotanical study. There are some stray published report on megafossils from the foot-hills of Bengal and Arunachal Pradesh. Pathak (1969) documented a few fragmentary leaves as *Castanopsis tribuloides, Cinnamomum tamala, Machilus villosa, Litsea polyantha, Bridelia stipularis, B. verrucosa, Mallotus philippinense* and *Rhododendnon lepidotum* from the Middle Siwalik sediments of Mahanadi section in the foot-hills of Darjeeling District. Since the fossil leaves are fragmentary, Awasthi (1982) opines that their generic and specific determinations are doubtful.

From Arunachal Pradesh leaves of *Ziziphus* and *Dioscoria* have been reported by Singh and Prakash (1980) from a small exposure, about 5 km north of Pasighat, district Siang. A small collection of semisilicified and semi-carbonised woods from the Upper Subansiri of Ghoghra River section in Siang and near Kimin in Subansiri District show the presence of mostly evergreen taxa, viz., *Shorea, Euphoria, Gluta, Albizia, Afzelia-Intsia, Cynometra, Cassia* and *Sindora* (Awasthi, unpublished data). From the same area dicotyledonous leaves of uncertain generic affinities have been reported by Chowdhury *et al.* (1970).

PALAEOCLIMATE AND FLORAL EVOLUTION

From a perusal of the above assemblages of

Siwalik flora (Table 1-7), provided with comparable extant taxa, their distribution and type of forest indicated, it is evident that in the Himalayan foot-hills tropical forest with overwhelming majority of evergreen elements existed during Middle Miocene-Pliocene times when the Siwalik sediments were laid down. Among them the most common and widely distributed genera are: *Polyalthia, Calophyllum, Dipterocarpus, Anisoptera, Hopea, Shorea* (other than *Shorea robusta*), *Aglaia, Dracontomelum, Mangifera, Gluta, Swintonia, Sterculia, Dysoxylum, Koompassia, Cynometra, Pongamia, Ormosia, Sindora, Dialium, Bauhinia, Albizia, Cassia, Duabanga, Syzygium, Diospyros, Mallotus, Litsea, Cinnamomum, Phoebe*, etc. The flora includes a sizeable number of evergreen taxa of southeast Asian distribution, e.g., *Anisoptera, Gluta, Koompassia, Sindora, Swintonia* and some species of *Dipterocarpus* and *Hopea*. Besides, a number of other taxa which occurred during Siwalik and continued to exist even today were not found in the pre-Siwalik sediments of peninsular and extra-peninsular regions. Obviously, such taxa must have come from the neighbouring countries.

With the rise of Himalaya a large area previously occupied by Tethys was converted into land with numerous water basins. Thus the major changes in the physiography brought about progressive changes in the climate all along the foot-hills which became more warm and humid with high precipitation. During that time the Indian Plate had already joined with Eurasia resulting in the formation of land connection between India and neighbouring continents. It is widely accepted that through land connections several tropical moist evergreen to semi-evergreen elements from Southeast Asia led by dipterocarps entered the Indian subcontinent possibly via Mynmar where they spread all over and ultimately reached the Himalayan foot-hills region and got mixed up with the then existing local vegetation. Thus in the Tertiary floral history of Indian Peninsula and extra-peninsula Middle Miocene was the time of maximum proliferation, diversification of tropical vegetation, particularly of the evergreen forest.

The megafloral assemblage of Siwalik has no representation of gymnosperms. However, the palynological studies of Siwalik sediments by Banerjee (1968), Lukose (1968), Nandi (1972, 1975), Mathur (1974), Saxena and Bhattacharyya (1987), Singh and Saxena (1980, 1981), Saxena and Singh (1980, 1982a, b), Singh and Sarkar (1984) and Saxena *et al.* (1984) have revealed a wide representation of gymnospermous pollen comparable to *Pinus, Podocarpus, Abies, Cedrus, Picea, Tsuga* and pollen of temperate angiospermous genera, like *Alnus, Betula, Carya, Juglans*, etc. The pollen evidence suggests that these had already occupied the higher reaches of the newly emerged Himalaya from northern side before Miocene orogeny. The occurrence of tropical and subtropical to temperate pollen taxa together in the Siwalik sediments, therefore, leads to infer that the vegetation during Miocene was disposed altitudinally, tropical forest on the lower slopes up to 1,000 m elevation and temperate forest on the higher slopes and with perhaps a subtropical belt in between.

As a result of the rising Himalaya small fresh water basins also formed on the Tibetan side in which the Kargil molasse and other Miocene sediments of Ladakh-Karakoram area were laid down. Occurrence of temperate elements of Sino-Japanese origin, such as *Trachycarpus, Prunus* and *Populus* in the Liyan/Kargil Formation (Guleria *et al.*, 1983; Lakhanpal *et al.*, 1984a) further supports a different floral pattern on the higher slopes where tropical plants like *Livistona* had grown earlier in the lower slopes (Lakhanpal, 1982; Lakhanpal *et al.*, 1984b).

The tropical forest mostly comprised overwhelmingly the taxa of Malayan and southeast Asian distribution while the subtropical and temperate forests had a considerable Sino-Japanese and Russian elements. In the lower slopes, as is evident from megafossil record, the flora remained nearly unchanged in its overall composition and distribution pattern until the close of Pliocene.

The Surai Khola megafossil assemblage of Nepal is the only floral assemblage known from a continuous and uninterrupted sequence of Lower, Middle and perhaps the basal part of Upper Siwalik. It depicts a gradual change in the floral composition (Awasthi & Prasad, 1990). The basal sediments assigned to the Lower Siwalik contain more of lowland evergreen elements. The most important amongst them are *Polyalthia, Dipterocarpus, Calophyllum, Gluta, Cynometra*, etc. Along with the leaves of these taxa, algal forms, viz., *Pediastrum, Botryococcus, Zygnema, Mougeotia* and pteridophytes such as *Azolla* and *Ceratopteris* have also been recovered (Sarkar, 1990) suggesting the existence of fresh water bodies like swamps and flood plains in the area which created excessive humid conditions for the luxuriant growth of evergreen forest. More or less similar conditions seem to have prevailed during the Middle Siwalik as evidenced from the Chor Khola assemblage. But the total absence of evergreen taxa in the Surai Khola beds which are assigned to the upper part of Middle

Siwalik, provides evidence that the luxuriant evergreen forest started dwindling towards the end of Middle Siwalik or the beginning of Upper Siwalik and ultimately were replaced by deciduous elements such as *Clinogyne, Flacourtia, Millettia, Bauhinia, Breynia*, etc. This is corroborated by high incidence of pollen of the members of Malvaceae and Mimosaceae (Sarkar, 1990).

The last phase of the Himalayan uplift which occurred during Early Pleistocene brought further change in the physiography. The climatic conditions progressively changed from warm humid to drier and cooler adversely affecting the vegetation patterns of the entire region. The dipterocarps community growing luxuriantly suffered a big setback when all its members totally disappeared from the western and central sectors of the Himalayan foot-hills. *Dipterocarpus* and *Shorea assamica* are the sole survivors which have restricted distribution in the evergreen forest of Assam and Arunachal Pradesh. As replacement of dipterocarps and their associates some new taxa had evolved while others adapted the changing conditions, e.g., *Ziziphus*. This genus, occurred in association of *Dipterocarpus* and other evergreen taxa, is now growing luxuriantly in moist to dry deciduous and grassland forest (Savannah). Amongst dipterocarps, *Shorea robusta* is the only taxon which today occurs as a dominant tree in the Himalayan foot-hills of central and western sector. Surprisingly not a single piece of wood or a leaf of this species has been found in the Neogene sediments of India, although a leaf of *Shorea robusta* has been reported from the Pleistocene (most probably Holocene) deposits of Mahuadanr, Palamu District, Bihar, along with a number of other taxa which grow in nearby deciduous forest (Bande & Srivastava, 1990). Thus the diversity of environment especially cooler climate and mountainous physiography during Pleistocene have affected the plant life of the entire region and must have given impetus to hybridization, an important mechanism in providing generic diversity and preserving the adaptability in plants (Vishnu-Mittre, 1969). *Shorea robusta* may be considered as an example of this phenomenon. This taxon seems to have evolved sometimes during Pleistocene. It is now widely accepted that changes in physiography and climate of the Himalayan region during different phases of its upheaval have largely been responsible for the changes of vegetational scenario and evolution its flora.

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