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# EARLY STAGES IN THE DEVELOPMENT OF THE HIMALAYAN FLORA

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I am deeply conscious of the distinction conferred upon me by the Indian Botanical Society in awarding me the Birbal Sahni Medal for this year. For me this medal has a special significance as it has been instituted by a distinguished senior botanist of our country in the memory of his revered teacher, who was also my master and guide. The significance is further enhanced by the fact that I am receiving it in the year when we are celebrating the birth centenary of this great doyen of Indian botany. I am indeed grateful to the Society for this very special honour.

In 1936, Professor Birbal Sahni published a paper concerning fossil plants from the Karewas of Kashmir, collected from sediments about 3300 meters above sea level near Gulmarg. These fossils belonged to the same modern species as are found today in and around the Dal and other lakes of the Kashmir Valley, about 1800 m. below. Not only the lay public but even a well known botanist thought that there must have been a lake at that high elevation, in which these fossils got buried. Dispelling this belief, Professor Sahni explained that those plants were initially growing at about 1500 m. when they got fossilized. Later on, because of the uplift of the Himalaya, these fossils were raised up by about 1800 m. to their present situation.

Professor's continued interest in the geological history of the Himalayan flora is evidenced by another paper which he wrote on a small collection of angiosperm leaf impressions, made by him from the Kasauli beds of the Northwest Himalaya. This paper was published posthumously in 1953.

At the time of Professor Sahni's sad demise in 1949, our knowledge about the fore-runners of the Himalayan flora was indeed meagre. However, since then a lot of palaeobotanical studies have been carried out by a number of investigators furnishing sufficient data to build up a fairly reliable sequence of events in the development of the Himalayan flora. As indicated in the title, I will deal only with the earlier aspects of this development, based on the evidence of Tertiary plant fossils of the Himalaya.

## SALIENT FEATURES OF THE MODERN HIMALAYAN FLORA

The Himalaya is a mountain system extending over a length of about 2400 km. from the southward bend of the Brahmaputra in the east to a similar bend of the Indus in the west. The width of the Himalayan system varies from hardly 80 km. to over 300 km. With the tallest peaks, deepest river gorges and largest glaciers (outside the polar regions) it consists of diverse topographical features. Its southeastern region lying at 27° N latitude is the wettest, receiving the full thrust of the monsoon whereas the northwestern limit reaching the latitude 35°50' N is an area of very scanty rainfall. In its vertical aspect, it shows a wide altitudinal range between the tropical foothills and the alpine peaks. With this background of complex physical conditions it is not surprising that the Himalaya has a vegetation far richer and more diverse than any other part of India, if not of the world.

At present the generally accepted view is that there are three major botanical regions of the Himalaya - the western, the central and the eastern Himalaya (Singh & Singh, 1987). The mountain ranges west of 77°E longitude fall within the western region (comprising Kashmir and Himachal Pradesh), between 77°E and 84°E longitudes in the central region (mountains of Uttar Pradesh and Western Nepal) and beyond 84°E longitude in the eastern region (eastern Nepal, North Bengal, Bhutan and Arunachal Pradesh).

Taking the eastern Himalaya first, in the lower ranges of this region are found luxuriant tropical evergreen to semi-evergreen forests, often referred to as tropical rain forests, dominated by *Dipterocarpus turbinatus, Artocarpus chaplasha, Duabanga grandiflora, Syzygium spp., Cinnamomum tamala* etc. In slightly higher ranges, also occur tropical deciduous

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forests with trees of *Shorea robusta, Kydia calycina, Bombax ceiba, Albizia* sp. etc. Other plants in this tropical zone are *Tetrameles nudiflora, Terminalia myriocarpa,* tall Clusiaceae and *Pandanus.* At higher altitudes between 1000 and 2000 m. occur subtropical broad leaved forests with *Schima wallichii, Alnus nepalensis, Quercus* spp., *Rhododendron* spp., *Michelia* sp. *Exbucklandia* sp. and species of *Prunus.* These are followed at 1500 - 1800 m. by subtropical pine forests and from 1800 to 3000 m. by temperate forests consisting of species of *Rhododendron, Quercus, Castanopsis* and *Pyrus* etc. At higher reaches (3500-4000 m) are sub-alpine forests with *Abies, Rhododendron hodgsonii, R. thomsonii, Cotoneaster* and *Berberis* spp. etc. Still higher (4000-5000 m) are the alpine *Primulas, Rhododendron* spp., *Juniperus* spp. and *Aconitum* etc. (Rao & Hajra, 1986).

In the rich vegetation of this region are also innumerable varieties of orchids, bamboos and tree ferns. In fact the eastern Himalaya, including Assam, is one of the richest botanical provinces of the world and is regarded as a part of Takhtajan's "cradle of flowring plants", (Sahni, 1984).

On the other hand, the drier western Himalaya is characterized by drought resistant plants, commonly occurring in the sub-tropical belt, dominated by legumes, grasses, members of Asteraceae, *Ziziphus, Calatropis, Oleander* etc. At slightly higher elevations evergreen forests of *Olea ferruginea, Dodonea viscosa, Pistacia integerrima, Punica granatum* and others are found. *Syringa emodii,* a handsome shrub, occurs only in the west.

Tree ferns are absent. Bamboos are very scarce in Himachal Pradesh and disappear in the Kashmir Valley. Whereas there are 16 species of palms in eastern Himalaya, in the western region they are reduced to only four. The landscape is dominated by vast and gregarious conifer forests of chir, blue pine, deodar and fir with patches of dry juniper forests.

In the western Himalaya, the eastern Himalayan gymnosperms, such as *Larix griffithiana, Tsuga dumosa, Picea spinulosa, P.brachytyla, Abies delavayi, Cephalotaxus griffithii, Podocarpus neriifolius, Cycas pectinata* and *Gnetum montanum* are lacking. Likewise, *Magnolia* and *Michelia,* the spectacular trees of eastern Himalaya, are completely lacking in the west.

The western *Pinus gerardiana* is entirely absent in the east. Similarly *Cedrus deodara,* a characteristic feature of the western Himalayan landscape, is lacking in the eastern Himalaya.

The Central Himalaya is the meeting place of the eastern and western Himalayan floras. The eastern Himalayan elements here are *Pandanus, Castanopsis indica, Schima wallichii, Quercus lamellosa, Magnolia campbellii, Larix griffithiana,* many orchids and some tree ferns. The western elements are *Euphorbia royleana, Quercus leucotrichophora (Q.incana), Q. semecarpifolia, Cedrus deodara* (in western Nepal), *Picea smithiana, Abies pindrow* etc.

Several alpine species are distributed throughout the Himalaya from Kashmir to Arunachal Pradesh, e.g., *Primula denticulata, P. stuartii, Thylacospermum rupifragrum* and *Arenaria musciformis. Saussurea gossypiphora,* a most striking woolly herb, occurs from Kashmir to Sikkim at 4500 m. and above. This shows that although there are differences in the tropical and temperate components of the eastern and western Himalaya, in the alpine zone the vegetation is more or less uniform throughout the Himalaya.

To complete this brief account of the modern Himalayan flora, let us also hurriedly consider its phytogeographical affinities. The western Himalayan region shows pronounced Euro-Mediterranean and Middle Asiastic affinities. As examples of Mediterranean elements may be cited *Quercus ilex, Celtis australis, Olea* spp. *Acer, Aesculus, Alnus, Fraxinus, Cupressus, Juniperus, Prunus* and *Pinus.* Plants of Middle Asiastic affinities are found in the interior of the north-western Himalaya, e.g., *Acantholimon lycopodioides, Eremurus, Physochlaina, Caragana, Rosalaria alpestris, Salix karelinii, Sorbaria tomentosa, Lathyrus humilis, Myricaria squamosa* etc.

In the eastern Himalayan region, the two main elements are (i) Sino-Japanese and (ii) Malayan in the forest covered ranges. Above the timberline, besides the high altitude elements of Middle and Central Asia are also found representatives of the Manchurian element.

In addition, there are also plants of the original Indian subcontinent, which according to Singh and Singh (1987) should be designated as representatives of the Deccanian element, growing up to 2000 m on the southern slopes of the Himalaya.

Realizing the great diversity of the present day Himalayan flora, the question arises as to how and when did it come about. For this we have to go back in time and examine the available geological and palaeobotanical data having a bearing on this problem.

## THE HIMALAYA AND ITS SEDIMENTARY ZONES

It is well known that the formation of the Himalaya is a result of the collision of the Indian landmass with the Asiatic mainland. The story goes back to the Jurassic period. At that time India lay about 4000 km. south of its present position, adjacent to Africa, Antarctica and Australia, forming a part of the large landmass known as the Gondwanaland. The large expanse of water between India and Asia was occupied by an ocean called "Tethys". Towards the end of Jurassic, about 140 million years ago, the Indian landmass, known as the Indian Plate, broke away from the Gondwanaland and started drifting northwards. Towards the end of the Cretaceous period, the Indian plate came close to the Asian plate and collided with it. This resulted in underthrusting or subduction of the Indian plate and its consequent involvement in the rise of the Himalaya.

It is an accepted belief that the stupendous Himalayan uplift is the result of several orogenic movements. According to the current view (Sharma, 1984) there were five major phases of these orogenic episodes. The *first,* Karakoram orogeny in Upper Cretaceous; *second,* Post-Kirthar orogeny towards the end of Eoceno-Oligocene; *Third,* Sirmurian orogeny in Middle Miocene; *fourth,* Siwalik orogeny at close of Pliocene-Pleistocene; and the *fifth,* Post-Pleistocene orogeny which seems to have continued to the present day albeit at a slow pace.

In a way, the history of the Himalaya belongs to the Cenozoic era which comprises the last 65 million years of the geological time. The various subdivisions of this era and their respective ages are given in Table 1.

The northern part of the Tethys ocean, that lay between the Indian and the Asian plates, also extended westwards between Europe and Africa, and is usually referred to as the Tethys sea.

As a result of orogenic movements, there was a progressive shallowing and narrowing of the Tethys during Late Cretaceous, culminating in the splitting of the sea into two or more longitudinal basins in Eocene. By the end of Oligocene, the sea waters had completely evacuated the region, giving way to fresh water or sub-aerial facies.

Table 1: Simplified geological time-scale for the cenozoic era (In Millions of Years).

| Era | Period | Sub-Period | Epoch | Duration | Time of Commencement |
|---|---|---|---|---|---|
| CENO-ZOIC (65) | QUATE-RNARY (1.64) | PLEIST-OGENE | HOLOCENE | 0.01 | 0.01 |
| | | | PLEIST-OCENE | 1.63 | 1.64 |
| | TERTI-OCENE | NEOGENE | PLIOCENE | 3.5 | 5.2 |
| | | | MIOCENE | 18.3 | 23.5 |
| | | PALAEO-GENE | OLIGOCENE | 12.0 | 35.5 |
| | | | EOCENE | 21.0 | 56.5 |
| | | | PALAEO-CENE | 8.5 | 65.0 |

After Harland *et al.* (1990)

The most vigorous elevation was during the Middle Miocene as a result of which a foredeep was created along the southern side of the rising Himalaya, into which the Siwalik molassic sediments were deposited. Some furrows also developed on the northern Tibetan side, into which the Kargil molasse and other Miocene sediments of Ladakh-Karakoram area were deposited. From Late Pliocene to Pleistocene the molassic sediments were uplifted and the continued elevation even after the Pleistocene resulted in the development of the present day topography. Thus by the end of Oligocene, the ground was literally prepared for the development of the Himalayan land flora. Its major components were established from Miocene to Pleistocene and the final details acquired thereafter.

On the basis of orographical and geological characters, four longitudinal belts can be broadly identified in the Himalaya, running east-west. These are (i) Sub-Himalaya or the Siwalik; (ii) Lesser or Lower Himalaya; (iii) Higher Himalaya or the Central Crystallines; and (iv) Tibetan or Tethys Himalaya.

Except the Central Crystallines, the other three belts consist of sedimentary deposits and each is known as a sedimentary zone. The sub-Himalayan zone, is mainly represented by Neogene and recent deposits, constituting the Siwalik Group. Its maximum development is observed in Jammu and Kashmir and it gradually thins out towards the eastern flank of the Himalaya.

The Lesser Himalayan zone consists of two distinct sub-zones. The first subzone is well represented by unmetamorphosed sediments developed in N.W. Himalaya. It thins out progressively towards the east, ranging from Palaeocene to Early Miocene in age. The second subzone is mainly represented by metasediments, the age and stratigraphic position of which are uncertain.

The Tethys Himalayan zone is well exposed in Kumaun,Garhwal, Spiti, Kashmir, Zanskar and Ladakh regions. The Indus Suture Zone, marking the northern boundary of the Tethyan belt, exposes the sediments which vary in age from Cretaceous to Mio-Pliocene.

Relevant to our topic are the Tertiary deposits of all these three sedimentary zones, which have furnished data ranging in age from Palaeocene to Pliocene. There are about thirty important localities dotted all over the Himalaya, from which mega as well as palynofossils have been recovered by research workers engaged in the palaeobotanical studies. Usually megafossils are identified according to the natural code of botanical nomenclature. However, palynofossils are commonly named according to an artificial system of nomenclature. But some of the palynofossils are so characteristic that they can be identified also to their natural affinities as botanical taxa. It is after ascertaining the botanical identities of such palynofossils, culled from a very large data base of palynostratigraphy, and combining them with the plant taxa based on megafossils that floristic assemblages have been compiled of plants belonging to the various Tertiary sediments of the Himalaya (Singh & Sarkar, 1990). We shall deal with them in chronological order, first taking up the Tethys Himalayan, then the Lesser Himalayan and lastly the outer or sub-Himalayan zone.

## TERTIARY FLORISTIC ASSEMBLAGES

*Tethys Himalaya* From the Dras Volcanics of Ladakh, a Palaeocene assemblage of palynofossils worked out by Mathur and Jain (1980) exhibits the occurrence of a rich coastal vegetation. Some of the important taxa in this composition are *Calamus, Carpinus, Carya, Corylus, Casuarina* (?), *Ephedra, Fraxinus, Galium, Gunnera, Nypa* and *Pelliciera* alongwith some members of the families Arecaceae, Cycadaceae, Fabaceae, Podocarpaceae, Ranunculaceae etc. A low salinity environment is indicated by the presence of taxa belonging to the Arecaceae, *Nypa* and *Pelliciera*. Pollen of *Ephedra* and palms suggest a sandy, coastal region. On the whole the assemblage represents tropical vegetation although an explanation is required for the occurrence of *Carpinus, Carya* and *Corylus*. A little younger, the Eocene palynofloristic assemblage from Pashkyum described by Mathur (1984) indicates the continuation of conditions similar to those of the Palaeocene of Dras. Tropical elements like *Calamus, Gunnera, Nypa,* palms and many pteridophytic elements confirm this view.

From the same area, Bhandari *et al.* (1977) had reported a Later Eocene-Miocene palynological assemblage from the Tarumsa Formation. Its composition shows that in Ladakh the Palaeocene coastal semi -evergreen type of vegetation was transformed into moist deciduous type by the Middle Tertiry time. This denotes the onset of sub-temperate climate.

An important Palaeogene megafossil, *Livistona wadiai* based on the leaf impression of a tropical palm, has been described from the Hemis Conglomerate horizon of Ladakh, which is Late Eocene-Oligocene in age. It was earlier reported as *Sabal major* but revised to its present identity by Lakhanpal *et al.* (1983). It provides further evidence that till the Oligocene epoch, the climate in the Himalaya was tropical and became temperrate only later in Miocene.

The advent of temperate element in the Ladakh Himalayan flora was confirmed by the recovery of two Miocene megafossils. The first was a petrified wood of *Prunus* described by Guleria *et al.* (1983) from the Kargil Formation and the second were leaf impressions of *Trachycarpus*, a warm temperate palm described by Lakhanpal *et al.* (1984) from the Liyan Formation of Ladakh. Actually *Trachycarpus* was recognised earlier than *Prunus* but the paper on *Prunus* got published before that on *Trachycarpus* ; hence they have been mentioned in the same sequence.

Literature survey also showed that more than half a century ago (De Terra, 1935, p.38) leaf impressions of *Populus*, another temperate plant, had already been reported from the Kargil basin.

*Lesser Himalaya of the West* From Himachal Himalaya, the Subathu Formation of Upper Palaeocene-Eocene age has been investigated by a number of palynologists (see Singh & Sarkar, 1990, p.336) generating rich information. The assemblage is dominated by Dinoflagellate cysts. The terrestrial elements are represented by taxa belonging to Lycopodiaceae, Matoniaceae, Parkeriaceae, Polypodiaceae, Schizaeaceae, Podocarpaceae, Arecaceae, Liliaceae, Poaceae, Alangiaceae, Anacardiaceae, Fagaceae, Nymphaeceae Oleaceae etc. Algal elements, viz., *Pediastrum* and *Botryococcus,* have also been recorded in abundance. The environment of deposition varies from shallow marine to coastal transitional with a tropical climate. The vegetation conforms to a coastal semi-evergreen type and is similar to that of the early Tertiary of Ladakh.

A Late Eocene-Oligocene palynological assemblage recorded by Singh and Khanna (1980) from the Dagshai Formation is not as rich as that of Subathu, but marked by absence of marine dinoflagellate cysts and the presence of palm pollen. Gymnosperms are represented by *Inaperturopollenites* and *Podocarpidites* complex. The high incidence of *Pediastrum* and presence of palms indicate a coastal transitional type of vegetation.

From the early Miocene sediments of the Kasauli Formation there have been a few reports of poorly preserved plant megafossils. The earliest were fragments of palm leaves resembling those of *Sabal,* which were designated either as *Sabalites* or *Sabal* proper. This palm and a few ill-preserved dicot leaves were described by Professor Sahni from Kasauli in his posthumous paper of 1953. Some more poorly preserved small dicot leaves were described from the Kasauli Formation by Chaudhri in 1969. Better preserved leaf impressions comparable to those of *Artocarpus* were described by Sharma and Gupta (1972) from Murree sediments of Rajori in Jammu and Kashmir, which are equivalent to Kasauli. Recently Mehra *et al.* (1990a, 1990b) have reported leaves provisionally referred to Fabaceae and Moraceae from the Dagshai beds and leaves and flowers from the Kasauli Formation. The flowers, though difficult to identify, have tentatively been compared with those of Clusiaceae and Rutaceae. The possibly Clusiaceous flower has seven sepals and seven petals and thought to resemble in shape and size the flower of *Hypericum japonicum.* A notable feature about the leaves reported from Kasauli beds is that they are of smaller size suggesting a rather dry climate.

The palynological assemblage from Kasauli comprises representatives of Cyatheaeceae, Schizaeaceae, Lindsaeaceae, Polypodiaceae, Pinaceae, Liliaceae, Arecaceae, Bombacaceae, Oleaceae etc. and indicates tropical conditions. *Pinus* seems to have had come from the fairly high elevations of the Miocene western Himalaya.

According to Mathur and Venkatachala (1979) more or less similar palynofossils also occur in the Dharamsala sediments which are equivalent to Dagshai and Kasauli Formations.

*Lesser Himalaya of the East*: Very little work has been done on the Tertiary plant remains from the eastern sector of the Lesser Himalaya proper. In a paper still in press Tripathi and Singh have described Early Tertiary palynotaxa from Siang District of Arunachal Pradesh. These contain Eocene marker taxa *Ctenolophonidites, Lakiapollis, Pellicieroipollis, Tricolpites* and *Incrotonipollis.* The first two of these palynotaxa represent the genera *Ctenolophon* and *Durio.*

Recently Awasthi *et al.* (in press) have described leaf impressions of *Podocarpus* and *Mesua* from the Oligocene of Eastern Himalaya.

During the later Neogene the flora growing on the southern slopes of the eastern Himalaya is known from petrified woods of plants resembling the following taxa (Vishnu-Mittre, 1984) :

| | |
|---|---|
| *Adenanthera pavonina* | *Lagerstroemia flos-reginae* |
| *Albizia procera* | *Lannea grandis* |
| *Bursera serrata* | *Mallotus phlippinensis* |
| *Cassia siamea* | *Mangifera indica* |
| *Diospyros ehretioides* | *Pometia tomentosa* |
| *Elaeocarpus/Echinocarpus* | *Swintonia floribunda* |
| *Gluta melanorrhoea* | *Terminalia tomentosa* |
| *Homalium tomentosum* | *Vitex canescens* |

*Sub-Himalaya* The Sub-Himalayan zone extending all along the Himalayan foothills, from Jammu to Arunachal Pradesh is occupied by the

Siwalik flora which is rich in plant megafossils mainly preserved as leaf impressions and petrified woods. The commonest and widely distributed genera are *Albizia, Anisoptera, Bauhinia, Calophyllum, Cassia, Cinnamomum, Cynometra, Dalbergia, Diospyros, Dipterocarpus, Duabanga, Ficus, Fissistigma, Gluta, Hopea, Litsea, Mallotus, Mangifera, Phoebe, Polyalthia, Shorea, Sindora, Smilax, Sterculia, Swintonia, Syzygium, Terminalia, Urena* and *Ziziphus*.

In none of the megafossil collections have the temperate gymnosperms been found although palynological investigations have revealed the occurrence of *Pinus, Abies, Cedrus, Picea* and *Tsuga*. As early as 1970, I had suggested that entry of the pollen of the above gymnospermous genera into the Siwalik beds was due to their growing at higher elevations from where their grains flew into the sediments in which leaves and woods of plants around the depositional sites got buried. There are a large number of other taxa besides those mentioned above, recovered as mega- or palynofossils from the Lower and Middle Siwalik sub-groups. In contrast the megafossils from the Upper Siwalik sub-group are very scarce. A fruit of Boraginaceae, *Boraginocarpus lakhanpalii*, (Mathur, 1974) and leaves of *Litsea bhatiai* (Mathur, 1978) from the Tatrot Formation and two palms, *Palmoxylon wadiai* and *P. jammuense* (Sahni, 1964) along with grasses (Poacites) from the Boulder Conglomerate Formation, are about all that we know by way of higher plant life from the Upper Siwalik of Western Himalaya. However, from the Lower Karewa beds of Kashmir, to which we had referred at the very start and which are equivalent to the Upper Siwalik beds (of Upper Pliocene age), a rich flora comprising a large number of angiosperms, six species of gymnosperms and three of pteridophytes, is known (Vishnu-Mittre, 1984). Some of the angiosperms are *Acer, Aesculus, Alangium, Alnus, Artemisia, Berberis, Berchemia, Betula, Carpinus, Castanopsis, Cinnamomum, Clematis, Cornus, Desmodium, Egelhardtia, Fraxinus, Hedera, Jasminum, Juglans, Lannea, Litsea, Machilus, Mallotus, Nelumbo, Olea, Phoebe, Populus, Prunus, Quercus, Rhus, Rosa, Salix, Spiraea, Syringa, Trapa, Typha, Ulmus, Viburnum and Woodfordia*. The gymnosperms are *Abies pindrow, Cedrus deodara, Juniperus* sp., *Picea smithiana, Pinus wallichiana* and *Taxus* sp. The Pteridophytes are *Adiantum, Dryopteris* and *Selaginella*. Excepting a few, most of the Lower Karewa plants have been identified with the modern speices.

## DISCUSSION AND CONCLUSION

With the available data on the composition of floristic assemblages from different subdivisions of the Tertiary period, considered in the background of the changing topography and climate of the rising Himalaya, an outline can be drawn up of the various stages in the development of its flora. After the first orogeny, during the Palaeocene and Eocene epochs the landscape had low relief and was dotted with palms and many tropical angiospermous elements like Alangiaceae, Anacardiaceae, Bombacaceae, Clusiaceae, Lecythidaceae, Myristicaceae and Sapotaceae. Podocarpaceae represented the gymnosperms. This was the stage when the Indian plate, consisting of mainly the Indian Peninsula and inhabited by indigenous tropical plants, came in contact with the Asian plate and brought the Indian element to occupy the Himalayan region. Pollen grains of temperate type of plants like *Carpinus, Carya* and *Corylus* most probably came in from the northern Asian landmass.

By the end of Oligocene, the sea waters were completely squeezed out but the low relief and tropical vegetation of the Eocene type still persisted. Palms, *Mesua* and *Podocarpus* were some of the prominent taxa of the Oligocene epoch.

The Tethys sea was obliterated first in the northeast and the older Peninsular Indian Block came into contact with the young rocks being deposited from the Tethyan sediments of Asia, giving rise to the North Burma-Assam region. This region was the meeting point where the flora and fauna from the east and southeast Asia converged before entering India, thus bringing Indian Mass into direct land-connection with South China, Indo-China and Malaya etc. The floristic and faunal influx from these areas took place through Assam which may appropriately be described as the eastern gateway of India and was established soon after the Oligocene obliteration of the Tethys sea in Northeast Himalaya. This gateway not only served for the immigration of eastern and southeastern elements into India but also for the emigration of Indian elements in the reverse direction. It is believed that *Ctenolophon* and *Durio*, whose pollen grains are found in the Eocene of Eastern Himalaya, migrated from here to Malaya and adjoining areas.

During the early part of Miocene, tropical plants of rather dry climate bearing comparatively smaller leaves, grew on the southern face of the Himalaya.

They belonged to Cyatheaceae, Schizaeaceae, Liliaceae, Arecaceae, Clusiaceae, Rutaceae, Moraceae etc. The Sino-Japanese and Malayan elements also came in and mixed with the Indian taxa. With the rise of the mountains during the Miocene orogeny, monsoon climate was well established in this region resulting in wet environment in which the mesophytic vegetation, consisting of the Indo-Malayan elements, flourished at its best. Dipterocarpaceae, Fabaceae, Clusiaceae, Moraceae, Lauraceae etc. were the common families in the tropical rain forest that grew in the lower belt of the Himalaya. In the higher belt, temperate plants that came in with the Sino-Japanese influx had spread all over. Thus it appears that the Miocene vegetation of the Himalaya was disposed altitudinally in two belts-the tropical forests on the lower slopes and the temperate on the higher ones. It is also apparent that the tropical rain forest in the Himalayan region was established only during the Miocene, most probably in the middle Miocene. Before that, during Eocene to early Miocene times the tropical forests were of drier type.

Along the rising ranges, a fore-deep was created on the south side into which the Siwalik sediments were deposited. Into these beds were buried the leaves and woods of the well known Siwalik flora. Along with the megafossils of the tropical taxa, the tiny pollen grains of the temperate plants from the higher reaches also got in. They belonged to plants like *Pinus, Abies, Cedrus, Picea* and *Tsuga.*

While the Siwalik flora was being deposited on the southern side, Miocene sediments were also being formed in the Tethyan zone on the north side. Into them got buried macro-remains of warm temperate elements of which *Trachycarpus, Prunus* and *Populus* have been recognised. In the meantime land connection had also been established between the north-western Himalaya and Afghanistan, Iran etc. on the west. By and by the climate in the western Himalaya became drier.

In the Upper Siwalik beds of Jammu belonging to Upper Pliocene, the landscape was covered by palms and grasses. Slightly north, in the Karewa beds, which are equivalent to the Upper Siwalik and also belong to Upper Pliocene, plant taxa prevalently of temperate nature and growing in lacustrine environment were preserved. Some members of the alpine elements, e.g, *Betula utilis* and *Quercus semecarpifolia* were also included. A small proportion of tropical/subtropical elements like *Ficus cunia, Mallotus philippinensis* and *Woodfordia floribunda* and species of *Berchemia,* also got into the record, most probably as extension of the tropical elements into the threshold of the temperate belt (Vishnu-Mittre, 1984).

The fact that most of the Lower Karewa fossils have been identified with the extant species, strongly suggests that towards the close of the Tertiary period, during the Upper Pliocene, the Himalayan flora had started acquiring its modern composition. In the ensuing Quaternary period, the last two orogenies together with the Ice Age with alternating glacial and interglacial spells, led to the addition of an alpine belt in the higher altitudes and gradual changes in the distribution of taxa, ultimately resulting in its modern complexion.

## REFERENCES

Awasthi N, R C Mehrotra & R N Lakhanpal (in press) Leaves of *Podocarpus and Mesua* from the Oligocene sediments of Makum Coalfield, Assam, India *Geophytology.*

Bhandari L L, B S Venkatachala & Pratap Singh 1977 Stratigraphy, palynology and palaeontology of Ladakh Molasse Group in the Kargil area, *Proc IV Colloq Indian Micro-palaeont Stratigr (1974-75)* 127-133.

Chaudhri R S 1969 Some leaf impressions from the Kasauli Series of the Simla Hills, *Curr Sci* **38** (4) 95-97.

De Terra H 1935 Geological studies in the Northwest Himalaya between the Kashmir and Indus Valleys *Mem Connecticut Acad Arts Sciences* **VIII** Article II 17-76.

Guleria JS, V C Thakur, N S Virdi & R N Lakhanpal 1983 A fossil wood of *Prunus* from the Kargil (= Liyan) Formation of Ladakh *In* V C Thakur & K K Sharma eds *Geology of Indus Suture Zone of Ladakh* 187-193 Wadia Institute of Himalayan Geology, Dehradun.

Harland W B, RL Armstrong, A V Cox, L E Craig, A G Smith & D G Smith 1990 *A Geologic Time Scale* Cambridge Univ. Press 1-263.

Lakhanpal R N 1970 Tertiary floras of India and their bearing on the historical geology of the region *Taxon* **19** (5) 675-694.

Lakhanpal R N, Gyan Prakash, J L Thussu & J S Guleria 1984 A fossil fan palm from the Liyan formation of Ladakh (Jammu and Kashmir) *Palaeobotarist* **31** (3) 210-207.

Lakhanpal R N, S C D Sah, Kewal K Sharma & J S Guleria 1983 Occurrence of *Livistona* in the Hemis Conglomerate horizon of Ladakh *In* V C Thakur & K K Sharma eds *Geology of Indus Suture Zone of Ladakh* 179-185 Wadia Institute of Himalayan Geology, Dehradun.

Mathur A K 1974 A new fossil seed (Boraginaceae) from the Siwalik Group *Bull Ind geol Assoc* **7** (1) 43-49.

Mathur A K 1978 Some fossil leaves from the Siwalik Group, *Geophytology* **8** (1) 98-102.

Mathur Y K 1984 Cenozoic palynofossils, vegetation, ecology and climate of the north and northwestern sub-Himalayan region, India *In* R O Whyte ed *The evolution of the East Asian environment* **II** 504-551 Centre of Asian Studies, Univ of Hong Kong.

Mathur Y K & A K Jain 1980 Palynology and age of the Dras Volcanics near Shergol, Ladakh, Jammu and Kashmir, India, *Geosci J* **I** (1) 55-74.

Mathur Y K & B S Venkatachala 1979 Palynological studies of the Cenozoic sediments of the Himalayan foot-hills, *Him Geol Semin Misc Pubs geol Surv India* **41** (5) 103-110.

Mehra S, V P Mishra & Anil K Mathur 1990a Fossil flowers from Kasauli Formation near Barog, Himachal Pradesh, *Curr Sci* **59** (1) 47-49.

Mehra S, V P Mishra & Anil K Mathur 1990b Biostratigraphic studies of the Lower Tertiary sequence, in particular Dagshai and Kasauli Formations, of Himachal Pradesh, *Rec geol Surv India* **123** (8) 258-261.

Rao R R & P K Hajra 1986 Floristic diversity of the eastern Himalaya-in a conservation perspective *Proc Indian Acad Sci* (Anim Sci/Plant Sci) Suppl 103-125.

Sahni B 1936 The Karewas of Kashmir *Curr Sci* **V** 10-16.

Sahni B 1953 Angiosperm leaf-impressions from the Kasauli beds, N.W. Himalayas, *Palaeobotanist* **2** 85-87.

Sahni B 1964 Revisions of Indian Fossil Plants, Part III - Monocotyledons *Monogr Birbal Sahni Inst Palaeobot Lucknow* **1** 89pp.

Sahni K C 1984 Himalayan flora and physiography-a study in contrasts *In* G S Paliwal ed *The Vegeetational Wealth of the Himalayas* 194-200.

Sharma K K 1984 The sequence of phased uplift of the Himalaya *In* R O Whyte ed *The evolution of the East Asian environment* **1** 56-70 Centre of Asian Studies, Univ of Hong Kong.

Sharma T R & K R Gupta 1972 New angiospermic plant fossils from the Murree shales near Liranwali, Thannmandi area, J & K *Univ Review Jammu* **3** (5) 66-71.

Singh H P & A K Khanna 1980 Palynology of the Palaeogene marginal sediments of Himachal Pradesh, India *Proc IV int palynol Conf, Lucknow (1976-77)* **2** 462-471 Birbal Sahni Institute of Palaeobotany, Lucknow.

Singh H P & Samir Sarkar 1990 Vegetational dynamics of Tertiary Himalaya *In* K P Jain & R S Tiwari eds *Proc Symp Vistas in Indian Palaeobotany, Palaeobotanist* **38** 333-344.

Singh J S & S P Singh 1987 Forest Vegetation of the Himalaya *Bot Rev* **53** (1) 80-192.

Tripathi S K M & Trilochan Singh (in press) Record of Early Teritary palynotaxa from Siang District, Arunachal Pradesh, India, *Palaeobotanist.*

Vishnu-Mittre 1984 Floristic change in the Himalaya (Southern slopes) and Siwaliks from the Mid-Tertiary to Recent times *In* R O Whyte ed *The evolution of the East Asian environment* **II** 483-503 Centre of Asian Studies, Univ of Hong Kong.