Cenozoic plant fossils and the Himalayan orogeny

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Selected palyno- and megafloras from the Cenozoic Era of extrapeninsular India have been examined in the orogenic context of the Himalaya. Distribution of vegetations and variation in climates are in conformity with the periodic phases of the Himalayan uplift. Continued rise of the Himalaya acted as a barrier for the flow of moisture resulting in lesser precipitation, higher snow cover and increased aridity. In response to the topographical and climatic variations a progressive change occurred in the composition of vegetations during the past 60 Ma. The ancestral tropical floras inhabited the lower slopes, whereas the temperate floras colonized the higher slopes. Altitudinal segregation of floras is clearly evident from the Mid-Miocene orogeny. Palaeocene to Mid-Pleistocene plant diversity generally varies from evergreen, semi-evergreen, dry/moist deciduous, warm temperate to temperate forest types. Migrations/immigrations and extinctions of plant taxa were largely influenced by physiographical and climatic changes. Enrichment and diversification of the Neogene Himalayan floras have also been brought in through the process of evolution. Cult-historical evidences point out that the Himalayan range continued to rise even after the advent of man.

Key-words—Palynology, Palaeobotany, Cenozoic, Himalayan orogeny, India.

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साराँश

नूतनजीवी अश्मित पौधे एवं हिमालय की उत्पत्ति

हरिपाल सिंह

हिमालय की उत्पत्ति के सन्दर्भ में प्रायद्वीपीय भारत के नूतनजीवी कल्प से उपलब्ध परागाणविक एवं गुरुवनस्पतिजातों का अध्ययन किया गया। विभिन्न चरणों में हिमालय के उत्थान के समय वनस्पति के वितरण एवं जलवायु में विभिन्नता में पारस्परिक सम्बन्ध है। हिमालय के लगातार उत्थान से पानी की कमी, उच्चतर बर्फ के शिखर तथा मरुस्थली परिस्थितियाँ उत्पन्न हो गईं। भौगोलिक एवं जलवायवी विविधताओं के कारण पिछले 60 एम-ए० काल में वनस्पति की संरचना में लगातार परिवर्तन होते रहे हैं। पूर्वजी उष्णकटिबन्धीय वनस्पतिजात निचली ढलानों पर विकसित हो गये जबकि शीतोष्ण वनस्पतिजात और ऊँचाई पर स्थापित हो गये। हिमालय के मध्य-मध्यनूतन उद्भव से वनस्पतिजातों में अन्तर स्पष्ट हो जाता है। पुरानूतन कल्प से मध्य-अत्यन्तनूतन कल्प तक के पौधे सामान्यतः सदाहरित से अर्धसदाहरित, शुष्क/नम पर्णपाती, गर्म उष्णकटिबन्ध से उष्णकटिबन्ध प्रकार के वनों को इंगित करते हैं। भौगोलिक एवं जलवायवी परिवर्तनों के कारण पौधों का प्रवासन और विलुप्तीकरण हुआ। पश्चतृतीयक युगीन हिमालय का सघन एवं विविधता युक्त वनस्पतिजात विकास प्रक्रिया का ही एक उदाहरण हैं। अतीतकालीन प्रमाणों से व्यक्त होता है कि हिमालय का उत्थान मानव के पृथ्वी पर पदार्पण करने के पश्चात भी होता रहा है।

THE Himalayan range is the youngest mountain range in the world and is believed to have started uplifting about 60-70 million years ago. Delineating the northern boundary of the Indian subcontinent, it runs about 2,400 km from the west to the east. Several views on its origin, orogeny, extent and limits have been expressed from time to time. Generalized accounts of the Himalayan Tertiary mega-and palynofloras with reference to their emergence, radiation and extinction patterns are available in scattered form. The object of the present paper is to tag the palynological and palaeobotanical data with major geological events so that problems associated with endemism, regionalism and floral evolution as influenced by orogenic movements of Himalaya in time and space are understood through the Cenozoic Era.

It was to the credit of Professor Birbal Sahni (1936a) who made the first attempt to adduce palaeobotanical evidence to explain the Mid-Pleistocene uplift of Himalayas in the Karewas of

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Kashmir. In fact, the discovery of an Early Pleistocene subtropical fossil flora from the lacustrine deposits of Pir Panjal Range at an elevation of about 3,666 m, which at present enjoys a temperate climate, triggered a sense of query in Sahni (1936a) who observed that, "How can we explain the presence of their fossil remains at altitudes where we know that they can not exist today". The extant forms of most of the Pir Panjal fossil flora (Early Pleistocene), viz., *Vallisneria,Trapa, Mallotus, Pittospermum, Myrsine, Cedrus, Pinus,* oaks, laurels, figs, alders, charophytes, etc. are known to inhabit today altitudes lower than 2,000 m. Based on this analysis Sahni (1936a) remarked that, "Since the time when the plants and animals, of which the fossils remains are now found at 11,000 ft. or even higher, flourished in and around this lake, the sediments have been lifted out of their original horizontal position and have been upheaved through at least five thousand feet with (geologically speaking) recent upheaval of the Pir Panjal Range". Even the extant acquatic plants, viz., *Trapa, Vallisneria,* charophytes, etc. still continue to grow in the lakes of Kashmir which are situated at several thousand feet lower than the present elevation of Pir Panjal Range. This led Sahni (1936a) to sum up that "Their study leads to irrestible, though at first incredible, conclusion that the Himalayas have been thrown up by several thousand feet since the advent of man". A decade later Puri (1947) published a comprehensive account of fossil flora from the Pir Panjal Range. This study supported the conclusions of Sahni (1936a). During subsequent years, a considerable palaeobotanical and palynological data have been generated from the Palaeocene to Pleistocene sediments of the Himalaya, yet no effort has been made to examine them in the orogenic perspective of Himalaya.

OROGENIC HISTORY

The rise of the Himalaya is ascribed to several periodic orogenic movements. Five major phases of orogenic episodes have been recognized by Sharma (1984): (i) Karakoram orogeny (Upper Cretaceous); (ii) Post-Kirthar orogeny (end of Eocene-Oligocene); (iii) Sirmurian orogeny (Middle Miocene); (iv) Siwalik orogeny (close of Pliocene-Pleistocene); (v) Post-Pleistocene orogeny. Raina *et al.* (1982) have recognized 3 principal phases of orogenic episodes— (i) the Ladakh phase (Late Cretaceous-Early Eocene); (ii) Dharamsala phase (Miocene); and (iii) the Siwalik phase (Late Pliocene-Middle Pleistocene). Though orogenic movements slowed down considerably after Middle Pleistocene yet their pulsations seemed to have affected the rise of the Himalaya even after the advent of man for which cult-historical evidences are available. The three major Himalayan orogenic belts constitute: (i) the southern most sub-Himalayan Zone, (ii) the lesser Himalayan Zone, and (iii) the Tethyan Himalayan Zone.

During the Late Cretaceous the Tethys sea underwent shallowing and narrowing with the result two or more longitudinal basins appeared in Eocene. The Oligocene Epoch witnessed wide spread regression. The Middle Miocene orogeny of Himalaya created a foredeep along its southern side in which were laid the Siwalik molasse sediments. The Tibetan side received the Kargil molasse and other Miocene sediments of Ladakh Karakoram area. Therefore, the first phase of Himalayan orogeny (Cretaceous-Early Eocene) is observed at Indus-Suture Zone of Ladakh. The second phase of episode is recorded in the Eocene-Pliocene epochs. Rapid sedimentation of Murrees and Siwaliks is due to Middle Miocene orogenic movements of Himalaya which later continued up to Pleistocene Epoch. The present physiognomy of Himalaya was attained as the molassic sediments of Late Pliocene-Pleistocene were uplifted.

DATA ANALYSIS

Palaeobotanical and palynological data sifted from the Tertiary sediments of Ladakh, Jammu, Himachal Pradesh, Uttar Pradesh, Nepal and Arunachal Pradesh have been analysed with the object to select such taxa or groups of taxa which may provide information on their past and present distributional requirements particularly in regard to their possible botanical relationship, climatic tolerance, ecological association, latitudinal and altitudinal adaptation. Although such refined data are not sufficient for precise determination of exact time and corresponding vegetational changes in response to orogenic movements, climatic variations, differential topographic elevations and sustained migration and immigration of several plant species from adjoining areas yet a generalized picture of vegetational changes within the well recognized orogenic pulsations has been deciphered. In order to have a better understanding of vegetation patterns, palyno- and mega-floral evidences from the Cenozoic sediments of Himalaya have been considered together.

Palaeofloras of Ladakh/Post Kirthar orogeny

During the Ladakh/Post Kirthar phase of

orogeny (Palaeocene to Oligocene) the physiography of the Himalaya, both in western and eastern parts, is assumed to support low relief landscapes. It further leads to assume that due to lack of elevated topography the climate was equitable and tropical, supporting evergreen to semi-evergreen type of vegetations covering a wider stretch of areas from north-west to north-east on the southern face of Himalaya. In the absence of altitudinal variation, the latitudinal influence on the composition of flora seems to be less pronounced. The Palaeocene-Eocene vegetations from the Dras Volcanics of Ladakh, Kalakot area of Jammu, Kalka-Simla Hills of Himachal Pradesh, Nepal and Arunachal Pradesh contain largely tropical components of semi-evergreen to coastal swamp-type vegetation. Dinoflagellate cysts constitute a larger part of some assemblages alongwith *Pediastrum* and *Botryococcus* (Sarkar & Singh, 1988; Singh, 1981, 1989). The main palaeofloral components of western Himalaya were palms and several members of tropical families represented by Lycopodiaceae, Schizaeaceae, Matoniaceae, Polypodiaceae, Parkeriaceae, Podocarpaceae, Liliaceae, Nymphaeaceae, Poaceae, Oleaceae, Fagaceae, Anacardiaceae, Alangiaceae, Fabaceae, Clusiaceae, Lecythidaceae, Sapotaceae, Myristicaceae, Bombacaceae, etc. Members of Parkeriaceae, Alangiaceae, Juglandaceae and Fagaceae, which were hitherto known only from the Neogene sediments, have been recorded from the Palaeogene sediments as well (Singh, 1991; Singh & Sarkar, 1990). Based on palaeobotanical and palynological evidence it is surmised that the Palaeocene-Eocene landscape of eastern Himalaya was studded with mixed type of coastal swamp vegetation with a tropical climate. The Eocene assemblage from the Siang District (Arunachal Pradesh) contains palynotaxa, viz., *Ctenolophonidites, Lakiapollis, Pellicieroipollis, Incrotonipollis*, etc. (Tripathi & Singh, 1992). Some important pollen, frequently recovered from areas (Assam-Arakan Basin) adjacent to Himalaya, are of Podocarpaceae, Arecaceae, Liliaceae, Brassicaceae, Meliaceae, Clusiaceae, Rhizophoraceae, Anacardiaceae, Euphorbiaceae, Nymphaeaceae, Nelumboniaceae, etc. Most of the palynofloras studied contain dinoflagellate cysts indicating a near coastal environment of deposition. The Eocene marker taxa, viz., *Ctenolophonidites (Ctenolophon)* and *Lakiapollis (Durio)* from Arunachal Pradesh denote the post-Eocene terminal event. Their absence in the younger successions depict that they migrated to Malaya and adjoining areas of far east in order to escape the adverse onslaught of the changing climate. The aforesaid data denotes that the Palaeocene-Eocene palynological assemblages from western as well as eastern Himalaya broadly contained components of tropical vegetation conforming to semi-evergreen and mixed coastal type though they were represented in different latitudinal areas of Himalaya. It has been estimated that the Indian Plate collided with the Asian Plate during the Eocene which resulted in the rise of Himalaya. Prior to this collision it is apparent that during the later phase of the Ladakh orogeny or earlier part of the post-Kirthar phase of orogeny the floral components of low land coastal vegetation covered the southern face of Himalaya. Based on the present day ecological requirement of the then existing flora, it may be imagined that overall altitudes near to the present Gangetic plains along with tropical climate might have supported these floras. Later this Himalayan landscape appears to have been grossly disturbed by tectonic upheavals. At present the Palaeocene-Eocene strata are located on elevations varying from 800 to 2500 m or higher. Vegetations varying from tropical, subtropical to temperate type inhabit these rocks depending upon the extent of altitude they inhabit and the amount of precipitation they receive. Therefore, their present day altitudinal disposition on these sediments is a secondary phenomenon subsequent to the rise of the Himalaya. Composition of the *in situ* Palaeocene-Eocene floras is altogether different as compared to the present day vegetation growing on these rocks.

The Oligocene Epoch witnessed a large scale sinking evidenced by the thick deposits of sediments, as well as raised elevations after the Eocene collision of the Indian Plate. The raised topography resulted in the development of several land connections between India, Burma and Malaya. These pathways facilitated migration/immigration of several plant taxa. To exemplify members of Fabaceae and Sapotaceae seem to have migrated from Malaya to India. Recovery of pine pollen from the Oligocene strata of eastern Himalaya leads to believe that the pines made a pioneering venture to move from the north to invade the Indian subcontinent. Thereafter, they continued to migrate towards the north-west. The earliest record of pine pollen from the western Himalaya is from the Kasauli Formation (Early Miocene), Himachal Pradesh (Singh & Sarkar, 1984a). Palaeobotanical data sets are meagrely known from the Oligocene Epoch of Ladakh and Himachal Pradesh though they are reasonably well documented from the Assam-Arakan Basin in the north-east which is believed to constitute the same botanical province as that of the

Himalaya. The Oligocene pollen assemblages of Ladakh Himalaya (Bhandari *et al.*, 1977) contain components mostly conforming to moist deciduous type of forest. Some of them are *Carya, Betula, Alnus, Juglans,* Chenopods, grasses, etc. The present day elevation of Ladakh Himalaya supports temperate vegetation. The rise of the Himalaya in this part has been substantial after the Oligocene Epoch through a series of orogenic pulsations. The Oligocene palynoflora of Himachal Pradesh (Singh & Khanna, 1980; Mathur & Venkatachala, 1979; Mathur, 1984) is closely comparable to coastal transitional type of vegetation. It is conspicuous by the absence of dinoflagellate cysts and has high incidence of palm pollen. Pollen grains of *Inaperturopollenites*-complex (including *Araucariacites*) and *Podocarpidites* also abound in abundance. Besides the presence of herbaceous elements and tree forms, pollen comparable to *Castanea, Galium, Amaranthus, Chenopodium,* Arecaceae, Fabaceae, Sapotaceae, Buxaceae, Acquifoliaceae, etc. have been observed (Mathur, 1984). The present day elevation of these strata varies from 800 to about 1,700 m, supporting tropical to subtropical vegetation. Spores comparable to those of Parkeriaceae (*Polypodium*) constitute a major proportion of the Oligocene assemblages in north-eastern part of the Indian subcontinent. Though the representation of angiospermous pollen is poor yet some pollen taxa comparable to those as found in Arecaceae, Fabaceae, Oleaceae, Bombacaceae, Lamiaceae, Potamogetonaceae, etc. are frequently noticeable. Early Miocene palynoflora from the Kasauli Formation (western Himalaya) contains the presence of *Pinus* pollen along with pollen grains of Bombacaceae, Arecaceae, Oleaceae and several other angiosperm families indicative of a subtropical climate. This evidence provides a clue that the Kasauli Formation during the Early Miocene time would have attained sufficient height with a cooling of climate which supported the growth of *Pinus.* The Lower Miocene assemblages, in general, depict a gradual shift towards colder climate which heralded the appearance of moist deciduous components. The Dharamsala palynological assemblages (Oligocene-Lower Miocene) are more varied in the composition of taxa and have pollen comparable to Acquifoliaceae, Rutaceae, Tiliaceae, Chenopodiaceae, Caprifoliaceae, Oleaceae, Pandanaceae, etc. The land topography from the Palaeocene-Lower Miocene time of Himalaya seems to have witnessed several changes particularly in regard to the rise in elevation, change in climate, development of physical barriers and wide spread regression of the sea beginning from the Upper Eocene to Late Oligocene. The continued inflow of subtropical elements into the tropical vegetation by the Early Miocene time is progressively discernible. The gymnospermous pollen particularly of *Pinus* lends substantial support towards this inference. Subsequent changes in the composition and distribution of Neogene floras of Himalaya are well documented.

PALAEOFLORAS OF DHARAMSALA/SIRMURIAN OROGENY

The Dharamsala/Sirmurian phase of orogeny (Miocene) changed the floristic scenario of Himalaya drastically. The most distinctive features of the distributional pattern of floras seem to be their adaptation to different altitudinal belts. The tropical elements continued to inhabit lower slopes of Western Himalaya (< 1000 m) and perhaps transgressed marginally into the subtropical zone of climate, as is the case at present although to draw a precise boundary between the two zones is difficult.

The occurrence of *Prunus* (Kargil Formation) and *Livistona* (Hemis Conglomerate) has been reported by Guleria *et al.* (1983) and Lakhanpal *et al.* (1983) from the Middle Miocene strata of Ladakh Himalaya. The latter authors have also inferred that *Trachycarpus, Prunus* and possibly *Populus* immigrated from the mainland of Asia and became a part of the temperate Himalayan flora. By this time gymnospermous elements of Abietineae and subtropical angiospermous families (Moraceae, Myrtaceae, Euphorbiaceae, Fabaceae, etc.) seem to have adapted themselves to grow on different altitudinal belts (500-2,000 m).

Some important constituents of the Middle-Late Miocene megaflora from Uttar Pradesh and Himachal Pradesh (Prakash, 1972, 1979; Awasthi, 1982) are *Afzelia, Albizia, Anisoptera, Cassia, Cynometra, Dalbergia, Diospyros, Dipterocarpus, Ficus, Fissistigma, Milletia, Polyalthia, Acacia* and *Ziziphus* alongwith other members of Moraceae, Euphorbiaceae, Myrtaceae, Fabaceae, etc. So far no megafossils of gymnospermous plants have been recorded from these areas. Palynological studies of several sections of Middle Siwalik sediments (Upper Miocene) from these areas have brought to light pollen taxa comparable to those of extant equivalents, viz., *Pinus, Abies, Cedrus, Picea, Podocarpus, Tsuga* and members of Arecaceae, Liliaceae, Myricaceae, Juglandaceae, Magnoliaceae, Fabaceae and Moraceae (Banerjee, 1968; Lukose, 1969; Nandi, 1975, 1980; Singh & Saxena, 1981; Saxena & Singh, 1982a, b; Singh & Sarkar, 1984b; Saxena *et al.*, 1984). Because of the absence of gymnospermous megafossils and temperate plants in the Siwalik sediments, authenticity of the identification of gymnospermous pollen in these assemblages was questioned by Lakhanpal (1988). He opined that their occurrence in these sediments was due to their being blown in from the surrounding higher hills. However, palynological information provides compelling evidence to believe that the pines had established themselves reasonably well even during the Early Miocene on wider stretches of Himalaya. Later, they attained a position of near dominance after the Mid-Miocene orogeny. The other members of gymnosperms also seem to have attained a pronounced diversity. Here it may be recalled that near temperate conditions had set in during the Middle Miocene (Ladakh Himalaya) as is evidenced by the occurrence of *Prunus, Trachycarpus*, etc. It is a known fact that by then the Pir Panjal Range had not been upheaved in the Kashmir Valley. This situation might have allowed the cold winds to sweep over several areas in northern India. The earlier inference that these areas were warmer and wetter needs rethinking. It also does not seem logical to imagine that the Siwalik vegetation would have flourished with the exclusive absence of gymnosperms. Palynological evidences strongly suggest that this problem needs reconsideration. Based on palynological information a mangrove swamp vegetation in Jawalamukhi area and a near-shore vegetation in Nahan area as indicated by Mathur (1984) has not been confirmed by our extensive palynological work in the latter area. It is believed that the Eocene epicontinental sea had completely regressed by the close of Early Oligocene. However, in Arunachal Pradesh the end of Middle Eocene witnessed marine transgression which recommenced in the Middle Miocene in a foredeep in front of the mountain range where the Siwalik sediments were laid. These sediments mainly represent fluviatile deposition though palynological evidences indicate the existence of brackish water environment. As the Himalyan orogeny uplifted the Siwalik foredeep, it resulted in quick erosion and deposition simultaneously. Thus a thick mass of strata was accumulated in a short span of geological time.

The Miocene assemblages from the eastern Himalaya are few. They are restricted to areas in Kameng, Subansiri and Siang districts (Dutta, 1980; Dutta & Singh, 1980; Singh & Tripathi, 1990). Pollen grains comparable to the members of Lycopodiaceae, Polypodiaceae, Matoniaceae, Schizaeaceae, Osmundaceae, Parkeriaceae, Pteridaceae, Podocarpaceae, Pinaceae, Arecaceae, Araceae, Ctenolophonaceae, Bombacaceae, Meliaceae, Liliaceae, Loranthaceae, Malvaceae are present. One of the assemblages (Dutta & Singh, 1980) also contains reworked Permian and Eocene palynofossils in addition to Miocene palynofossils like those of Parkeriaceae, Arecaceae, Meliaceae, Malvaceae, Bombacaceae, Labiatae, Pinaceae, Araucariaceae, Potamogetonaceae, *Nyssa* and several others. Palynofossils of Parkeriaceae and Arecaceae point out that the site of deposition was not far away from the coastal environment. Similar observation has been made by Singh and Tripathi (1990).

PALAEOFLORAS OF NEPAL HIMALAYA

Palaeobotanical and palynological investigations of the Siwalik sediments of Nepal Himalaya, though at a preliminary stage, bring to light the fact that the fossil leaf assemblage consists of Marantaceae, Poaceae (Gramineae), Arecaceae (Palmae), Anonaceae, Flacourtiaceae, Clusiaceae (Guttiferae), Dipterocarpaceae, Anacardiaceae, Fabaceae (Leguminosae), Combretaceae, Ebenaceae, Myristicaceae and Euphorbiaceae (Awasthi & Prasad, 1990). These authors inferred that the vegetation varied from tropical evergreen to semi-evergreen elements. The climatic shift from the tropical humid to tropical dry has been reflected by the vegetation from the older to younger horizons in Siwalik sediments. It is interesting to record that modern equivalents of these fossil taxa are represented in the tropical evergreen and moist deciduous forests of Assam, Bangla Desh, Burma and the Malayan region. The Early Siwalik flora from Surai Khola contains evergreen elements like *Polyalthia, Dipterocarpus, Calophyllum* and *Cynometra*. The lower part of the Late Siwalik flora consists of moist deciduous to dry deciduous elements, viz., *Clinogyne, Flacourtia, Milletia, Bauhinia, Diospyros, Breynia*, etc. The change in vegetation pattern seems to have been caused by the northward movement of the Indian Plate and subsequent rise of Himalaya.

Palynological assemblages from the Early, Middle and Late Siwalik Group of sediments from Surai Khola area of Nepal (Sarkar, 1990) show that the palynological spectra changed from fresh water swampy environment to a bottom land habit having largely semi-evergreen palaeoassociations of vegetation. Specimens comparable to *Botryococcus, Pediastrum, Zygnema* and *Mougeotia* have been recorded. Palynofossils comparable to *Lygodium, Ceratopetris, Schizaea*, Polypodiaceae, Matoniaceae, *Azolla*, Cycadaceae, *Pinus, Hibiscus*, Gramineae, Nymphaea, Liliaceae, Palms, *Acacia*, Typhaceae, Compositae, etc. constitute a large part of the assemblages. The changes in vegetational pattern from swampy evergreen, moist deciduous to dry deciduous vegetation are seen in the Early, Middle and Late Siwalik palynological successions respectively, the later part being rich in graminaceous pollen alongwith bisaccate pollen indicating the onset of drier conditions. The pinaceous pollen are detected in the Middle Siwalik which is coincident with the Mid-Miocene orogeny of Himalaya. By the middle of Miocene, floral evidences indicate that the Himalayan range had risen sufficiently high which provided favourable environment to the immigration of several cold loving plants from the Mediterranean and Sino-Japanese regions.

PALAEOFLORAS OF SIWALIK OROGENY

The Siwalik phase of orogenic movements (Late Pliocene-Middle Pleistocene) led to climatic changes, increased continentality, semi-arid conditions and further rise of Himalaya forcing the moisture loving plants like *Dipterocarpus* and others to migrate or perish. Cold loving plants like *Cedrus, Picea, Abies, Pinus, Magnolia, Alnus, Betula, Clematis, Juglans, Quercus, Rhododendron, Tsuga,* etc. established themselves well on the elevated landscapes of western Himalaya. The Pliocene assemblages though scantily known from Punjab, Himachal Pradesh, Haryana and Jammu and Kashmir bring out the fact that cool dry climate had set in, which supported growth of *Pinus, Larix* and magnoliaceous plants. Ranga Rao *et al.* (1981) ascribed the poor and bad preservation of organic matter in the Pliocene assemblages due to the prevalence of largely oxidising environment. Palynofossils comparable to some extant families, viz., Poaceae, Arecaceae, Pinaceae, Fabaceae, Betulaceae, Chenopodiaceae, Amaranthaceae, Euphorbiaceae, Linaceae, etc., distributed in the Mio-Pliocene assemblages from these regions have been studied (Saxena & Singh, 1982a, b; Singh, 1982; Singh & Saxena, 1981; Singh & Sarkar, 1984b). Abundance of palm pollen alongwith grass pollen representing the palm savana in the Boulder Conglomerate Bed has also been observed (Vishnu-Mittre, 1984).

Palaeobotanical evidence for the uplift of the Himalaya during the post Pliocene to Middle Pleistocene was provided by Sahni (1936b) and Puri (1947) in the Kashmir Valley. Plant megafossils of subtropical climate, viz., *Trapa, Typha, Vallisneria,* oaks, laurels, figs, alders, *Malotus, Pittospermum, Myrsine, Rhamnus, Cedrus, Pinus* which cannot grow beyond 1,730 m have been recovered from the Pir Panjal Range at a height of 3,660 m or more which at present has a temperate climate. Extant plants of these fossil taxa continue to thrive in the subtropical zone of climate at about 1,600 m or so. This evidence conclusively proves that the Pir Panjal Range was upheaved at least by 2,000 m during the mid-Pleistocene time. As a consequence of this uplift the subtropical climate changed to a temperate one on the high hills of Pir Panjal Range.

GENERAL DISCUSSION

Imprints of Cenozoic floras leave evidences of their altitudinal disposition. The temperate floras (Sino-Japanese) inhabited the higher slopes whereas the tropical forests (Malayan and South-east Asian taxa) continued to grow on the lower slopes. To decipher the limits and extinction of subtropical plants between the two belts remains to be understood squarely as floral elements of this type marginally grow in either of the two environments.

A cursory glance of floras through the Cenozoic Era of Himalaya brings out the fact that the Palaeocene-Oligocene time generally supported tropical to mixed coastal type vegetations which grew between 100-500 m. The Miocene floras varied from tropical wet semi-evergreen, wet subtropical to humid temperate types having altitudinal disposition between 500-2,000 m. The Pliocene floras conformed to dry or moist forest types as the wet subtropical and temperate forest dwindled (1,000-3,000 m). The Pliocene-Pleistocene floras of Himalaya exhibited the presence of several Sino-Japanese floral elements. The Pleistocene vegetation above the tree line limit (3,000 m) in Ladakh is distinct in having *Artemisia*/Chenopod grass steppe typical of glacial environment. The Pleistocene rise of Himalaya brought in the arctic-alpine elements from Chinese and Euro-Siberian regions.

Enrichment and diversification of the Neogene Himalayan flora took place due to several factors some of which are: the development of physical barriers brought in by orogenic movements, change in climatic patterns as controlled by the rise of Himalaya and sustained migration/immigration of several plant species from the adjoining areas. The modern flora of Himalaya contains the Euro-Mediterranean, Malayan-Burmese, African and Sino-Japanese elements. Spatial invasions and subsequent proliferation of immigrant plant taxa through the Tertiary Period of Himalaya is an inviting enquiry which needs indepth study in the chronological and orogenic context.

Cult-historical data (Sahni, 1936b) provide evidence that cultural contacts between China and India existed via Himalaya during Palaeolithic and

Neolithic times as the Pir Panjal Range was not high enough to act as an effective barrier for the migration of Palaeolithic or even Neolithic man. This evidence clearly brings out the fact that the Himalayan range continued to rise even after the advent of man.

The position of the Indian Plate during the Early Tertiary was at 45° to 50° south of its present position. It was more or less like a large island. Therefore, the possibility of the existence of land connections in Palaeocene with the northern continents seems to be remote. It also seems likely that no land connections existed between India, Africa and central Asia during the Eocene as well. The endemic character of plant communities provides evidence of restricted communication between India and the rest of Asia. Early Oligocene witnessed a wide spread regression of the sea and also uplift of the Himalaya leading to raised land topography which resulted in inflow and outflow of plant species in the eastern part of India. The endemic features of vegetation started vanishing in Early to Middle Miocene assemblages though several endemic forms continued to flourish. The Late Miocene and Pliocene floral evidences (9.5 Ma-2.5 Ma) exhibit restricted provincialism due to the development of lofty mountain ranges separating the Indian subcontinent from the rest of Eurasia. Migration and immigration of plant taxa seems to have continued up to 2.5 Ma. The final phase of Himalayan orogeny (mid-Pleistocene) raised the range so high that it restricted migration and immigration of plant taxa. Plant communities at present display a more or less regional character due to selective adaptation.

The exact mechanism of horizontal and vertical movements of land resulting in uplift of the Himalaya is widely debated. It has been observed that larger areas of land were elevated to approximately half of the value between 10-5 Ma. Areas of low land topography, viz., southern China and South-east Asia have continued to support tropical vegetation for the last 40 Ma. History of the vegetation and variations in climate by and large match with the periodic phases of the Himalayan uplift. The continued rise of the Himalaya, in general acted as a barrier for the flow of moisture from the Indian Ocean resulting in lesser precipitation, higher snow cover and increased aridity. The progressive change in vegetation during the last 60 Ma particularly corresponding to the altitudes and latitudes of the Himalaya, is clearly reflected by rapid diversity in the composition of taxa evolving from evergreen, semi-evergreen, moist deciduous, dry deciduous, warm temperate, temperate to alpine types (Singh & Sarkar, 1990). However, low lands and plains of South-east Asia and India have continued to remain warm and wet/dry even after the uplift of the Himalaya. Immigration and extinction of plant taxa have played a major role from the Miocene time onwards when land connections among circum-Mediterranean areas had mostly been established. Beside climatic consideration, it seems possible that the immigrating plant taxa might have caused extinction of several endemic forms through tough competition and vigorous colonization of the newly acquired lands. All these factors are likely to have contributed in developing the modern flora of extra-peninsular India.

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