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TERTIARY PALYNOLOGY OF THE HIMALAYA — A REVIEW*

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ABSTRACT

Palynomorph assemblages recovered from the Tertiary rocks of Himalaya have been reviewed. Most of the Tertiary palynological information available till today has been developed from the western Himalayas. A beginning seems to have been made in regard to the development of Tertiary palynology of the eastern Himalaya, particularly from Arunachal Pradesh. On the basis of palynomorph assemblages some workers have attempted to establish palynological succession both in the Lower and Upper Tertiary rocks of western Himalaya. Palynological evidences have also been used in the interpretation of environment of deposition, dating, correlation of strata and palaeoclimates. The present paper reviews the status of Tertiary palynology of the Himalaya and evaluates some of the assemblages in regard to their applied aspects.

Key-words — Palynology, Tertiary rocks, Himalaya (India).

सारांश

हिमालय की तृतीयक युगीन परागाणुस्तरिकी : एक समीक्षा – हरिपाल सिंह

हिमालय की तृतीयक युगीन चट्टानों से उपलब्ध परागाणविकरूपक समुच्चयों की समीक्षा की गई है। अभी तक उपलब्ध तृतीयक युगीन परागाणविक जानकारी में अधिकतर जानकारी पश्चिमी हिमालय से ही है। पूर्वी हिमालय, मुख्यतया अरुणाचल प्रदेश, के तृतीयक कालीन परागाणुस्तरिकीय अध्ययन की शुरुआत की जा चुकी है। परागाणविकरूपक समुच्चयों के आधार पर कुछ विज्ञानियों ने पश्चिमी हिमालय, अधरि एवं उपरि दोनों तृतीयक चट्टानों में परागाणविक अनुक्रम स्थापित करने के प्रयास किये हैं। निक्षेपणीय वातावरण, कालनिर्धारण, स्तरों के सह-सम्बन्धन तथा पुराजलवायु की व्याख्या करने में परागाणविक प्रमाणों का उपयोग किया गया है। प्रस्तुत शोध-पत्र में हिमालय की तृतीयक युगीन परागाणुस्तरिकीय स्थिति की समालोचना तथा कुछ समुच्चयों के व्यावहारिक पहलुओं का मूल्यांकन किया गया है।

INTRODUCTION

DURING the last twenty years palynological studies have emerged both as an academic as well as an applied tool in solving various problems related to stratigraphy, particularly from the Tertiary rocks of the western Himalaya. The palynomorphs recovered from these sediments include spores, pollen grains, and the remains of algae, fungi or their fruiting bodies. The planktonic algae represented by the dinoflagellate cysts and also by *Pediastrum* and *Botryococcus* have been recorded by Mathur (1963, 1964, 1965; Salujha *et al.*, 1969) from the marine Lower Tertiary rocks of Simla Hills. The discipline of palynology has also been employed (Khanna, Ph.D. dissert., 1977; Singh *et al.*, 1978; Singh & Khanna, 1980) for establishing palynological succession in the Subathu Formation and in interpreting other related aspects like dating, environment of deposition, correlation of strata and relationship of biofacies with lithofacies. Singh and Khanna (1978) and Khanna and Singh (1980) studied the palaeoecological significance of *Pediastrum* and *Subathua* respectively in the Subathu Formation. The progress of Palaeogene palynology in the Simla Hills has been reviewed by Singh (1981). Spores-pollen assemblages have

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also been studied from the Upper Tertiary rocks of Punjab, Himachal Pradesh, Bihar and Arunachal Pradesh. Amongst the prominent workers who have carried out palynological study of these sediments are: Ghosh *et al.* (1963), Banerjee (1968), Lukose (1968), Nandi and Bandyopadhyay (1970), Venkatachala (1972), Nandi (1972, 1975), Mathur (1973), Singh *et al.* (1973), Ghosh (1977), Bhandari *et al.*, (1977), Jain and Dutta (1978), Saxena and Singh (1980) and Dutta and Singh (1980). Distinctive palynological forms have been recorded and utilized for the recognition of different stratigraphical levels (Nandi, 1975; Ghosh, 1977), though the recovery of spore-pollen content has been quite low, both qualitatively and quantitatively. In spite of these snags, palaeoclimate during the Siwalik sedimentation has been inferred by Ghosh (1977). The Miocene sediments of Kameng District, Arunachal Pradesh exhibit mixed type of spore-pollen assemblages. Recently Saxena and Singh (1980) have recovered a palynological assemblage from the Upper Siwaliks exposed near Chandigarh which is very rich in *Laricoidites*-complex.

GEOGRAPHY AND STRATIGRAPHY OF HIMALAYA

Geographically, the Himalaya is divided into (i) the sub-Himalaya, (ii) the Lesser Himalaya, and (iii) the Great Himalaya. The sub-Himalayan Zone includes the Neogene sediments of Siwalik ranges whereas the Lesser Himalaya consists of the Palaeogene and pre-Tertiary rocks. The Great Himalaya mainly consists of the central crystallines. To the north of Great Himalaya lies the Tethys Himalaya having Cambrian to Cretaceous rocks which normally yield fossils. It is followed by the zone of Tsangpo Suture in Kashmir Himalaya consisting of geosynclinal Cretaceous to Palaeogene sediments. The trans-Himalaya includes the Ladakh region of Kashmir.

From west to east the horizontal extent of Himalayan range has been divided into various sectors, viz., (i) the western Himalaya, (ii) the central Himalaya, and (iii) the eastern Himalaya. The western Himalaya includes Jammu and Kashmir, Himachal Pradesh, Garhwal and Kumaon sectors. The central Himalaya consists of Nepal, whereas the eastern Himalaya covers Darjeeling, Sikkim, Bhutan, Arunachal Pradesh and Lohit.

Geology and stratigraphy of the Tertiary sediments of Himalaya have been worked out by various workers. It is beyond the scope of this paper to deal in detail with this aspect of study. In the present review the stratigraphical order of Tertiary rocks as adopted by Sahni and Mathur (1964) and Chaudhuri (1968) has been followed:

After Sahni and Mathur, 1964

AGE	UPPER ASSAM	HIMALAYAN FOOT-HILLS
Lower Pleistocene to Pliocene	Dihing Series	Upper Siwalik
....	Unconformity	....
Pliocene	Tipam	Middle Siwalik
Miocene	Surma	Lower Siwalik
....	Unconformity	....
Oligocene to Upper Eocene	Barails	Dharamsala

After Chaudhri (1968)

AGE	HIMALAYAN FOOT-HILLS
Lower Miocene to Upper Oligocene	Kasauli Formation
Lower Oligocene to Upper Eocene	Dagshai Formation
Eocene to Upper Paleocene	Subathu Formation

Stratigraphical correlation of the Tertiary rocks of Himalaya has been a difficult task because most of the lithostratigraphical units exhibit similarity in lithology and structural complexity. This problem is further aggravated by the lack of animal and plant fossils in most of the lithostratigraphical units. However, recovery of plant as well as animal fossils, at some places, though quite often of local importance, has provided such cogent evidences that on the basis of which new interpretations relating to stratigraphy and structure have emerged. The present paper aims to review the palynostratigraphical information derived so far from the Tertiary sediments of Himalaya and also to throw light on such problems that have defied solutions so far.

PALYNOSTRATIGRAPHY OF THE LOWER TERTIARY ROCKS

Palynological information from the Lower Tertiary rocks is mostly available from the western Himalayas. It has been arranged in chronological order. Hence, the Palaeocene horizons have been taken up first for discussion.

In the western Himalaya Srikantia and Bhargava (1967), on the basis of palaeontological studies, established Kakara Series which is a Palaeocene horizon exposed near Kakara-Chapla Village, Simla Hills. Palynology of these sediments has not been worked out so far. In order to confirm the proposed dating of the Kakara Series by Srikantia and Bhargava (1967) it is essential to investigate these sediments palynologically.

The overlying Subathu sediments are developed along the Himalayan foot-hills belt as a narrow discontinuous strip from Jammu in the west to as far as Nepal in the south-east. They rest unconformably on the pre-Tertiary Slates (Auden, 1934; Gansser, 1964). Lithology of the Subathu Formation mainly consists of limestones and carbonaceous shales/coaly bands, calcareous red, green, pale-olive shales, siltstones with rare development of sandstones. A white orthoquartzitic zone generally delineates the top of the Subathu Formation.

A palynological beginning for the study of Subathu sediments was made by Mathur (1963) who reported the occurrence of *Pediastrum*. Subsequently she (Mathur, 1964, 1965) published two more short notes regarding the presence of *Botryococcus*, *Pediastrum* and a varied type of assemblage having hystrichosphaerids and pollen grains surmising subtropical to tropical climate for the miofloral assemblage and assigning Middle to Upper Eocene age. In 1969, Salujha *et al.* studied the palynological composition of the Subathu sediments exposed in the Simla Hills reporting a rich assemblage of spores, pollen grain, hystrichosphaerids and other algal remains. The assemblage, though poorly preserved and much less suitable for taxonomic study, is of academic interest as it brought to light some palynologically productive horizons in the Subathu sediments which were earlier known to be mostly devoid of plant microfossils. They surmised Lower Eocene age for the Subathus. A general review paper of Venkatachala (1972) lists some characteristic palynomorphs, viz., *Baltisphaeridium*, *Hystrichosphaeridium*, *Pediastrum*, *Anacolosia*, *Couperipollis*, *Trialtisporites*, *Triorites*, *Retitricolpites*, *Favitricolpites* and *Pinuspollenites*. Singh *et al.* (1973) and Salujha (1974) reviewed the then existing status of palynological knowledge both for the Lower and Upper Tertiary rocks of western Himalaya and made some general observations on various aspects of the study.

In 1971, systematic palynostratigraphical study of the Subathu sediments was initiated (Singh) at the Birbal Sahni Institute of Palaeobotany, Lucknow. The recovery of reasonably well-preserved dinoflagellates, spores and pollen grains resulted in the identification of 43 genera and 106 species (Khanna Ph.D. Thesis, 1977). Of these, some of the important taxa are: *Cyclonephelium*, *Cleistosphaeridium*, *Oligosphaeridium*, *Homotryblium*, *Hystrichokolpoma*, *Achmosphaera*, *Thalassiphora*, *Cordosphaeridium*, *Subathua* and many more along with spores and pollen grains, viz., *Todisporites*, *Lygodiumsporites*, *Lycopodiumsporites*, *Cyathidites*, *Podocarpidites*, *Laricoidites*, *Liliacidites*, *Couperipollis*, *Palmidites*, *Proxapertites*, *Verrutricolpites*, etc. The palynofloral assemblage has been recovered from several localities, viz., Koti, Jabli, Dharmpur, Dagshai and Kumarhatti. These localities lie on the Kalka-Simla Highway between Baroti and Barog. The type locality Subathu is exposed in the Kuthar Nala near the Subathu town.

Qualitative and quantitative analyses of the palynological data have been carried out by Singh *et al.* (1978) who have established palynological succession in the Subathu section proposing seven cenozones and one barren zone. They have also recognized two subzones. With the exception of the barren zone, the remaining cenozones are characterized by the abundance of a single genus with one or more species together with the occurrence of a few restricted species or with the first appearance of a taxon or taxa. In the ascending order of stratigraphy, the cenozones are as follows:

8. *Todisporites* spp. Cenozone
7. *Subathua sahnii* Cenozone
6. *Cordosphaeridium multispinosum* Cenozone
5. *Hexagonifera* spp. Cenozone

4. *Homotryblium* spp. Cenozone
3. *Cleistosphaeridium* spp. Cenozone
2. Barren Zone
1. *Cyclonephelium* spp. Cenozone

Information on the association of other palynomorphs with the above mentioned cenozones is published by Singh *et al.* (1978) and hence is not repeated here. The distributional pattern of palynoflora within the Subathu Formation exhibits some dissimilarities in its composition. Perhaps these are related to the changing environment of deposition. These dissimilarities are noticeable when a comparative account of the palynological composition is taken into consideration particularly from such sections which are located at the margin in contrast to those located in the deeper part of the epicontinental sea. The apparent effect of the variable environment on the composition of the assemblages falls in three categories: (i) fluctuation in the abundance of long ranging species, (ii) local development of a particular morphotype, and (iii) the appearance of stratigraphically insignificant forms. To examplify Khanna and Singh (1981) have reported the preponderant occurrence of *Cleistosphaeridium diversispinosum*, *Cyclonephelium exuberans* and members of the family Thalassiphoraceae from the shallow water environment particularly exhibiting mesohaline condition. The association of *Hexagonifera* spp. with the highly calcareous facies denotes their preference to hypersaline conditions. *Cleistosphaeridium disjunctum* and *Cyclonephelium compactum* inhabit mostly normal saline condition of depositions. To sum up, it can be said that the gross palynofloral character of the Subathu Formation up to the *Subathua sahnii* Cenozone (Singh *et al.*, 1978) is identified by the abundance of hystrichosphaerids along with other dinocysts. The upper part of the Subathu Formation is easily identifiable both by the development of the red facies and abundance of pteridophytic spores along with gymnospermous and angiospermous pollen grains. Different cenozones of the Subathu section have been traced laterally (Khanna *et al.*, 1981) in the other seven stratigraphically measured sections, viz., Koti, Jabli, Dharmpur, Dagshai A, B, C and Kumarhatti exposed along the Kalka-Simla Highway between Baroti and Barog. Generally the boundaries of the palynological cenozones seem to coincide with the lithological boundaries with a few exceptions. On the basis of this study, these distantly located sections have been successfully correlated by Khanna *et al.* (1981).

AGE OF THE SUBATHU FORMATION

A perusal of the literature shows that there has hardly been any unanimity in regard to the age of the Subathu Formation. Pilgrim and West (1928) opined that the basal part of the Subathus particularly consisting of limestone and carbonaceous shales belong to Upper Middle Eocene age whereas the purple sandstone and grits, characteristic of the upper part, represent Oligocene age. Later on, Cox (1931), Vokes (1937), Mandwal (1959), Pascoe (1959), Datta *et al.* (1965), Krishnan (1968), Mathur (1964, 1965), Chaudhri (1968), Salujha *et al.* (1969), Khanna and Singh (1981) have also dealt with the subject and expressed divergent views. In short, the Subathus have been shown to be varying from Palaeocene to Oligocene in age. The present palaeontological and palynological data point out that the Subathus can be assigned to Upper Palaeocene to Upper Eocene age particularly in the Simla Hills. Khanna and Singh (1981) took into consideration (i) the order of superposition of strata, (ii) palaeontology, and (iii) palynology in deciphering the age of the Subathus. They have dated the palynological succession in the type area as Upper Palaeocene to Upper Eocene. The sequence of dating as proposed by them is reproduced below:

(i) Upper Palaeocene-Lower Eocene (represented by strata from the base of the *Cyclonephelium* spp. Cenozone to the top of the *Homotryblium* spp. Cenozone).
(ii) Middle Eocene (represented by strata between the base of *Hexagonifera* spp. Cenozone to the base of *Todisporites* spp. Cenozone).
(iii) Upper Eocene (represented by the remaining part of *Todisporites* spp. Cenozone).

So far as palaeontological (Datta *et al.*, 1965) and palynological data are concerned, they are in agreement for the Upper Palaeocene to Upper Eocene dating for the Subathus. Recently Sarkar (Personal communication) has recovered *Striatriletes susannae* from the top most horizons of the Subathu Formation in the Nahan area. Its first appearance in this horizon has been considered to be age definitive thus confirming the Upper Palaeocene-Upper Eocene dating for the Subathus as proposed by Singh *et al*. (1978) and Khanna and Singh (1981).

ENVIRONMENT OF DEPOSITION

Bhandari and Aggarwal (1966) expressed the opinion that the Subathu sediments were deposited in a shallow linear epicontinental sea opening north westwards, the floor of which was marked by parallel to subparallel ridges resulting in the development of deposition in different parts of the basin. Chaudhri (1976) recognized transgressive-regressive cycles on the basis of fluctuations in the land-sea level changes. Raiverman (1964) considered the environment of deposition of the Subathu sediments as varying from marine to brackish to fresh water. Bhatia and Mathur (1965) are of the opinion that the Subathus were deposited under marine condition with their upper part indicative of fresh water condition. The results of palynological investigations of Subathu succession (Khanna & Singh, 1981) in the Simla Hills show that the rock sequence occurring between the *Cyclonephelium* spp. Cenozone and *Cordosphaeridium multispinosum* spp. Cenozone is indicative of the shallow marine environment whereas the strata between the *Subathua sahnii* Cenozone and the base of *Todisporites* spp. Cenozone represent brackish water conditions. The upper horizon of *Todisporites* spp. Cenozone which is completely devoid of microplanktons seems to have been deposited under fresh water environment. This observation, in general, agrees with the interpretation of Bhatia and Mathur (1965). The appearance of land derived elements together with the absence of microplankton has been considered to be indicative of the onsetting of fresh water environment. Singh (1978) carried out environmental analysis of the Subathu sediments and believes that they were deposited in a shallow sea having some tidal channel characteristics. He has also postulated an embayment having shelf mud zone, tidal flats together with poorly developed alluvial plains though minor part of the succession could have been a product of rivers pouring into the embayment. This observation can be correlated with the palynological findings of Singh *et al*. (1978) in regard to the occurrence of *Pediastrum* Subzone in the Jabli Section and in the upper parts of Subathu succession. Local development of a particular morphotype/morphotypes in stratigraphical sections have been indicative of the prevalence of varying environmental conditions. The utility of such morphotypes in stratigraphy is of no special significance and hence has been considered to be of local importance only though sometimes providing very useful information. The general distributional pattern of microplanktons and spore-pollen shows that the former constitute 97 per cent of the total assemblage in the lower part of the Subathus, but recording an inverse proportion towards its top. The spore-pollen and land derived elements dominate the assemblage in the Upper horizons. This palynological observation lead Singh and Khanna (1980) to recognize one transgressive phase of the sea followed by a regressive phase in the *Todisporites* spp. Cenozone.

MURREE/DHARAMSALA SEDIMENTS

The Subathu sediments are conformably overlain by the Murree Formation (Upper Eocene-Lower Miocene) in the Jammu area. To the east in the Punjab and Himachal Pradesh, the Murree equivalent rocks are known as Dharamsalas and perhaps rest unconformably over the Subathu sediments though the contact between the two has been considered as conformable by Bhandari and Agarwal (1966). Venkatachala (1972) has indicated that the Lower Dharamsala sequence is deposited both under marine and continental conditions whereas the Upper Dharamsalas have been considered to be of fluviatile origin. Further, to the east in Himachal Pradesh, particularly in the Simla Hills, the Dharamsala sediments are represented by Dagshai and Kasauli formations, the former representing perhaps coastal and the latter fresh water condition of deposition.

Murees have not been investigated palynologically so far. As regards the Dharamsala sediments (Upper Eocene-Lower Miocene of Kangra District), Ghosh *et al.* (1963) reported the occurrence of some palynomorphs referable to the genus *Ephedra*. Palynological contents of Dharamsalas are very scantily known. Venkatachala (1972) listed the palynomorphs occurring in the Lower Dharamsala (Eocene) sediments, viz., Chenopodiaceae, Tiliaceae, *Lindsaya*, *Ephedripites*, *Striainaperturites*, *Scabratriporites*, *Pinuspollenites* and *Tetracolpites*. These forms have neither been described nor illustrated. The spore-pollen assemblage of Upper Dharamsala (Venkatachala, 1972) consists of spores of Schizaeaceae, Hymenophyllaceae and Polypodiaceae together with pollen grains of Pine and Chenopodiaceae. The Upper Dharamsalas have been ascribed Upper Oligocene-Lower Miocene age (personal communication by Raiverman to Venkatachala, 1972) and considered to have been deposited under predominantly fluiviatile conditions. Thus the Dharamsala sediments have been dated ranging from Upper Eocene to Lower Miocene in age.

DAGSHAIS/KASAULIS

Palynological information of the Dagshai sediments recorded so far (Singh & Khanna, 1980) is very meagre. However, the most striking feature of the Dagshai assemblage is the absence of microplanktons and the presence of pteridophytic, gymnospermic and angiospermic spores and pollen grains. Some of the important constituents of this assemblage are: *Lygodiumsporites*, *Lycopodiumsporites*, *Todisporites*, *Inaperturopollenites*, *Laricoidites*, *Couperipollis*, *Palmidites*, *Palmaepollenites*, *Tricolpites* and *Verrutricolpites*. In addition to these forms, the occurrence of *Pediastrum* and fungal spores is also noteworthy. The presence of pollen grains of Palm affinity together with the trilete spores seems to be indicative of coastal transitional environment for the Dagshai Formation. Singh (1978) has expressed the opinion that the Dagshai sediments were deposited under marine conditions in an estuarine complex.

The palynological assemblage recorded from the Kasauli sediments near Koti (Singh & Khanna, 1980) is of academic interest only. Preservation of the spores and pollen grains is rather poor. Some of the important constituents of the assemblage are: spongy spicules (27%), angiospermic pollen grains represented by *Palmaepollenites* spp., *Couperipollis* spp., some monoporate and colporate pollen grains (24%). Additionally the representation of *Podocarpidites* spp. (17%), fungal spores (17%) and *Pediastrum* (9%) and the virtual absence of *Inaperturopollenites* is also significantly noteworthy.

SIWALIK SYSTEM

The Siwalik rocks, in general, are well-developed all along the sub-Himalayas. They are exposed from west to east and conformably rest on the Murrees. They are broadly divided into Lower, Middle and Upper Siwaliks ranging from Middle Miocene to Lower Pleistocene in age. The Lower Siwaliks usually have bright red shales and clays and brown sandstones, the matrix being well cemented. The Middle Siwaliks are identified by having coarser, micaceous grey sandstones and dull clays, the matrix being less cemented. The Upper Siwaliks usually have boulder conglomerates, grits, loose sandstones and brown clays. The Siwaliks are about 5,000 m thick and are believed to have been deposited in different environments, viz., piedmont, outwash, plains, channel and flood plains and lacustrine. The fine clastics of Siwalik sediments have yielded some palynological assemblages which have been systematically evaluated as below.

PALYNOLOGY

Palynology of the Lower Siwalik rocks has been carried out by Banerjee (1968), Venkatachala (1972), Mathur (1973), Nandi (1975) and Ghosh (1977). Taxonomic study of the recovered palynofloras, in general, need a renewed effort for describing morphological details of many undescribed palynomorphs and to remove anomalies in regard to the use of invalid names of some taxa. Realizing that the Siwalik sediments mostly prove unproductive, the present palynological information developed by the above workers is, indeed, a commendable effort. Amongst the important constituents represented in the Lower Siwalik of Bhakra-Nangal area, Banerjee (1968) reported the presence of palynomorphs probably belonging to the families, viz., Compositae, Gramineae, Palmae and Abietineae. Pteridophytic spores of gleicheniaceous and polypodiaceous affinity were also recorded, besides many other palynomorphs assigned to form genera belonging to angiospermic pollen grains. Venkatachala (1972) mentioned that the Lower Siwalik sediments have the presence of pollen grains belonging to the families Palmae and Graminae together with form genera like *Quercoidites*, *Haloragacidites*, *Cupuliferoidaepollenites*, *Sapotaceoidaepollenites* and *Araceoipollenites*, whereas the Middle Siwalik assemblage contains the pollen grains of Malvaceae, Betulaceae, Anacardiaceae, Pinaceae and spores of Polypodiaceae. Contrary to this observation, Banerjee (1968) opined that the Middle Siwalik assemblage exhibits the dominance of gymnospermous pollen grains together with poor occurrence of pteridophytic spores and angiospermic pollen grains, indicating cool climate. Mathur (1973) has worked out palynology of the Lower Siwalik sediments exposed in Tharukhola-Chepang, north-east of Nepal-Gange, Nepal. The presence of *Sabalpollenites*, *Graminidites* and *Echimonocolpites* in addition to many other pteridophytic forms and gymnospermous forms seems to be quite characteristic for this assemblage. Mathur (1973) has indicated that the angiospermic pollen grains dominate the assemblage. Pteridophytic spores are relatively low in abundance whereas the occurrence of gymnospermous pollen grains is very low. The general palynofloral spectrum of this assemblage is in agreement with the one described from the Lower Siwalik of Bhakra-Nangal area by Banerjee (1968) particularly in exhibiting almost similar type of numerical distribution of various botanical groups. Mathur (1973) opined that the climate during the Lower Siwalik times was of tropical to subtropical type contrary to the opinion held by Banerjee (1968) who inferred tropical to temperate climate during the Lower Siwalik times. The palaeobotanical data based on the study of fossil woods (Prakash, 1975; *Anisopteroxylon*) is in agreement with the views expressed by Mathur (1973).

The Siwalik Group exposed near Dalhousie has been investigated palynostratigraphically by Nandi (1975) and Ghosh (1977). Nandi has recognized four palynological zones in the Siwaliks. Each zone has characteristic palynomorphs. Some of the important constituents of the general assemblage are: Polypodiaceous spores, *Verrucososporites*, *Verrucatosporites*, *Cicatricosisporites*, *Cyathidites*, *Hymenophyllumsporites*, *Cyathidites*, *Gleicheniidites*, *Laevigatosporites*, *Cupuliferoidaepollenites*, *Palmaepollenites*, *Tetradomonosporites*, *Abietinaepollenites*, *Pinuspollenites*, *Piceapollenites*, *Podocarpidites*, *Polyadopollenites*, *Caryapollenites* and *Alnipollenites*. Representation of pteridophytic spores and angiospermic pollen grains is quite prominent in this assemblage. Palynological analysis of this Siwalik unit lead Nandi (1975) to believe that the climate during the Lower Siwalik times was subtropical to tropical. The Middle Siwalik exhibited subtropical to temperate climate whereas the Upper Siwaliks were identified in having a distinctly colder one. Ghosh (1977) reviewed this work and came with some more observations on the palaeoecology and palaeoclimate during the Siwalik sedimentation.

Banerjee (1968), Lukose (1969), Nandi and Bandyopadhyay (1970), Venkatachala (1972), Nandi (1972, 1975) and Ghosh (1977) have worked on the palynological assemblages of Middle Siwalik. In general, the Middle Siwalik assemblages tend to exhibit the following characteristics: (i) increase in the occurrence of the gymnospermous pollen grains, and (ii) fall in the incidence of pteridophytic spores and angiospermous pollen grains. Both these characteristic changes have been ascribed to the change in climate by various workers particularly from subtropical to temperate one although the plant megafossil records of Middle Siwalik times indicate the prevalence of mostly tropical climate with comparatively less precipitation. Palynological data, even otherwise, do not synchronize well with the megafossil record. The virtual absence of gymnospermous plant megafossils in contrast to their high incidence of pollen grains rather remains an enigma. It seems possible that the gymnospermous pollen could have come to lie in their place of burial from the surrounding high hills, but the absence of gymnospermous megafossils is quite intriguing. Some of the important constituents recorded from the Middle Siwaliks of Rexaul (Bihar) by Lukose (1968) are: *Retimonoletes*, *Foveomonoletes*, *Retitriletes*, *Monosaccites*, *Disaccites*, *Polyadites*, *Inaperturites*, *Reti-*

monocolpites, *Triporites* and *Retitriporites*. Some of the taxonomic names used here are invalid. The taxonomy of this assemblage needs to be re-done. It seems possible to concur with the interpretation of Lukose (1968) that the assemblage contains a mixture of pollen grains representing temperate to tropical climates. The former could have been derived from the north and the latter from the south. The assemblage recorded by Nandi and Bandyopadhyay (1970) is rather too poor for any comments excepting that it brings to light the presence of pollen grains probably referable to the genera *Pinuspollenites* and *Graminidites* in addition to some others.

The Mohand field assemblage (Nandi, 1972) seems to be quite typical of the Middle Siwaliks. Palynomorphs, in general, can be referred to various pteridophytic families, viz., Lycopodiaceae, Hymenophyllaceae, Schizaeaceae, Gleicheniaceae, Polypodiaceae and Cyatheaceae together with pollen grains perhaps of grasses, palms, *Pinus*, *Podocarpus*, *Abies*, *Larix*, polyporates, tricolporates, etc. Most of the important constituents recorded by Nandi (1975) have been listed earlier in the text and hence are not repeated here. The striking feature of the Middle Siwalik assemblage seems to be the predominance of pteridophytic spores and bisaccate pollen grains in contrast to the Lower Siwalik assemblages.

Palynology of the Upper Siwalik rocks is poorly known. Singh *et al*. (1973) recorded the presence of Pinus-type, monosulcate-type, and inaperturate (non-saccate) pollen grains of gymnospermous affinity from the Pinjor Formation surmising temperate to subtemperate climate during the Upper Siwalik times. This assemblage exhibits the dominance of inaperturate pollen grains. Another possible record of palynomorphs from the basal part of Upper Siwalik sediments has been given by Nandi (1975) with forms referable to the following genera, viz., *Cyathidites*, *Alsophilidites*, *Pinuspollenites*, *Podocarpidites*, *Monoporopollenites*, *Alnipollenites*, *Tetradomonoporites*, etc. Normally the Upper Siwalik sediments prove unproductive. However, Saxena and Singh (1980) have recovered a palynological assemblage from the Pinjor Formation exposed near Chandigarh in which gymnospermous pollen grains represented by *Laricoidites*-complex (including *Araucariacites*) are dominant in distribution. They constitute about 61 per cent of the total assemblage. Pollen grains of *Pinjoriapollis* (perhaps of Magnoliaceae affinity) in addition to the *Laricoidites*-complex are the most striking feature of this assemblage. Pollen grains perhaps belonging to the following families have also been reported, viz., Schizaeaceae, Parkeriaceae, Podocarpaceae, Araucariaceae, Pinaceae, Palmae, Liliaceae, Gramineae, Magnoliaceae, Proteaceae and Oleaceae. Amongst these the occurrence of Araucariaceae and Proteaceae seems to be doubtful. It is likely that some of the forms referred to *Araucariacites* may be reworked pollen grains from the Palaeogene sediments. But most of the remaining lot may belong to the *Laricoidites*-complex. Pollen grains referable to the family Proteaceae may either be reworked or need re-examination for taxonomic study. Vishnu-Mittre (1979), on the basis of high incidence of *Pinus* and possibly of *Larix* pollen grains, opined a cool and moist climate during the Upper Siwalik times.

Bhandari *et al*. (1977) have worked out the stratigraphy, palynology and palaeontology of the Ladhakh Molasse Group in the Kargil area. On the basis of palynoflora they opined a Palaeocene-Eocene age to the Kargil Formation, Oligocene-Miocene age to the Tarumsa Formation and Miocene age to the Pashykum Formation.

From the eastern Himalayas Jain and Dutta (1978) have studied dinoflagellates, spores and pollen grains from a limestone sample located near the contact of Lower Gondwana and Upper Tertiary succession in the Siang District of Arunachal Pradesh. The assemblage is rich in dinoflagellates and Palmae pollen grains. The presence of *Couperipollis*, *Lakiapollis*, *Polycolpites*, *Triorites* and *Polygonacidites* is quite striking. They have suggested a probable Eocene age for this assemblage which has been confirmed by the occurrence of Nummulitics in the Dihing Valley, Siang District (Tripathi *et al*., 1979). Jain and Dutta (1978) have postulated near shore deposition for the material investigated.

Dutta and Singh (1980) reported a Miocene assemblage from the Siwalik rocks of Lesser Himalaya of Kameng District, Arunachal Pradesh. It consists of reworked palynomorphs characteristic of the Palaeozoic and Eocene times. Palynologically it has been categorized into 4 assemblages pertaining to four rock units D, B+C and A. Jain and Dutta (1978) have observed that the rock unit D which lies near the Lower Gondwana sediments and also contains hystrichosphaerids and some smaller foraminifera indicates marine conditions of deposition for this unit, possibly belonging to the Lower Tertiary rocks. Dutta and Singh (1980) believe that the reworked forms of Palaeozoic and Eocene from the north and south possibly show that the source rocks were of the Lower Gondwanas and Disangs respectively.

CLIMATE

Lakhanpal (1974) believes that the Subathu Formation (Upper Palaeocene-Lower Eocene) had subtropical climate which continued in the Siwalik belt of Miocene-Pliocene times. Khanna and Singh (1980) have suggested coastal transitional environment of deposition for the Dagshai Formation (Upper Eocene to Oligocene) whereas the Kasauli sediments (Lower Miocene) were deposited under fluviatile environment having subtropical elements together with gymnospermous pollen grains coming from the high hills of neighbourhood area.

According to Vishnu-Mittre (1979) megafossil and pollen assemblage evidence from the Siwaliks is rather inadequate to comment upon the past environments, plant communities and vegetational history. He further observes that the identification of spores and pollen grains from the Middle Miocene to the end of Early Pleistocene is ' improper ' and hence the assemblages as such are not useful for palaeoecological interpretations. In spite of these snags he has suggested the local occurrence of semi-evergreen tropical forests during the Lower Siwaliks on flat ground and in hilly country. During the Middle Siwaliks the climatic shift was towards less warmth and moisture. The increase in *Pinus* and possibly *Larix* during the upper part of the Upper Siwalik has been considered to be indicative of a cool and moist climate. The observations indicating these climatic trends have reasonably good support from the pollen evidence.

CONCLUSION

From the foregoing account, it can be inferred that the palynological information from the Tertiary deposits of Himalaya has been gathered mostly during the last decade though the beginning for its development was made two decades earlier. On the basis of palynological composition the Subathus, the Dharamsalas (and their equivalent rocks in Simla Hills) and the Siwaliks can be grossly distinguished. Significance of each assemblage has been discussed particularly in regard to its stratigraphical importance and other applied aspects. Various rock sequences have been dated and correlated palynologically. Palynological information, though scanty, has been utilized in the interpretation of the depositional environment and palaeoclimates during the Tertiary times. Finally, a careful analysis of the palynological data may throw light on the vegetational history of the Tertiary period of this region.

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