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Tertiary palynology in India—a perspective

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The development of Tertiary palynology at the Birbal Sahni Institute of Palaeobotany and its subsequent spread to other research centres in the country owe much to yester-year's vision of Professor Birbal Sahni[1]. It was only in the mid-forties that this area of palaeobotany attracted the rapt attention of Sahni. He launched palynological studies for the Burmah Oil Company in July 1943 with a project on the 'Correlation of the Tertiary succession in Assam by means of microfossils'. A short report published by Sahni *et al.*[2] brought to light the fact that the oil-bearing Tertiary sediments of Assam, hitherto considered largely unfossiliferous and divisible only on lithological grounds into Disang, Barail, Surma, Tipam and Dihing, contained rich and characteristic palynological assemblages. Basing their inferences on the relative occurrence of palynofossils in the assemblages, their presence or absence, they recognized finer divisions within the formations. They further remarked, 'Apart from the fact these results hold promise of conclusions of economic value to the oil geologists, they include data of palaeobotanical interest.' Thus, the study of Tertiary stratigraphical palynology in India dates back to 1943.

The scope for the development of Tertiary palynology in India as conceived by Sahni[1], is a testimony to his foresight as well as imagination, particularly at a time when palynologists all over the world were concentrating their best efforts in understanding the intricacies of stratigraphic palynology and related fundamental concepts. Reflecting upon different aspects of applied palynology, Sahni[1] identified several thrust areas of work. Besides applied aspects of palynology, he was fascinated by problems of climatic oscillations at global scale between widely separated areas. He advocated palynofossil analyses of the rock matrix, bearing rich floras of leaf impressions, as the recovery of a large number of palynofossils from the same would provide supplementary information in regard to the composition of floras. He also emphasized the need to study botanical affinities of dispersed palynofossils. Recognizing the inherent difficulty involved in this kind of study he remarked, 'While organic connexion is the final court of appeal in all cases of doubt, there is probably a good deal more in the mere association of fossils in a stratum than conservative palaeobotanists generally have been prepared to admit.' Sahni[1] also emphasized that the Upper Tertiary rocks of the Siwalik system in India are exceptionally rich in verteberate faunas which would have obviously been supported by rich floras. He suggested in-depth investigations of these floras along with palynological study. He commented, that '··· would well repay years of labour, for they would bring to light pollen forms which should give a much fuller idea of the forest wealth of the period than the leaf impressions and petrified woods so far collected but not yet adequately examined.' The problem of Pliocene–Pleistocene boundary in Kashmir appeared challenging to him for which he suggested a palynological resolution. Sahni[1] observed, 'The whole of the Pleistocene in Kashmir is a facinating study pregnant with information on the later phases of Himalayan uplift, with its vicissitudes of climate and ecology, to which early man in northern India was witness through a million years.' Some other problems envisaged by Sahni[1] related to the study of the history of the Ice Age in northern India, dating of orogenic movements and emergence of information on modern vegetation after the Pleistocene Epoch. He strongly argued in favour of a pollen study of the stratified mounds pertaining to the pre-historic and historic periods which may provide clues about the wild and cultivated species of plants of that time, and also unravel the history of civilized man beginning from

5000 years. Unfortunately, Sahni did not live long enough to see the results of his envisaged plans. He passed away in 1949. The subsequent achievements made in the field of Tertiary palynology at this institute and other centres of research in the country, are a tribute to the vision of the great man who imagined things beyond time.

At present, Tertiary palynology in India has reached a stage of deliverance. This inference is supported by several reports, published from different parts of the country. Some significant results, discussed in the latter part of this article, relate to: (i) reconstruction of vegetational patterns through the Tertiary period of Himalaya, (ii) palynozonation and correlation of oil and coal-bearing strata in the Assam–Arakan Basin, (iii) dating and identification of tropical rainforest elements in the Kerala Basin (iv) resolution of the age of the Cuddalore Sandstone and lignite-bearing strata in the Cauvery Basin, and (v) palynostratigraphy of the Kutch and Rajasthan basins in relation to lignite explorations.

Tertiary vegetation — Himalaya and Assam–Arakan Basin

Selected palaeobotanical and palynological data analysed from the Tertiary sediments of Ladakh, Jammu, Himachal Pradesh, Uttar Pradesh, Meghalaya, Assam and Arunachal Pradesh constitute the basis for the reconstruction of vegetational patterns as developed in response to the development of physical barriers brought in by orogenic movements, changes in climate patterns due to rise of Himalaya, evolution and sustained migration of several plant species from adjoining areas.

The Palaeocene vegetation from the Dras Volcanics of Ladakh Himalaya is of semi-evergreen type. It seems to have been supported by a tropical to subtropical climate[3]. The Early Eocene assemblage from the Pashkyum Formation is almost a continuation of Palaeocene components. However, the composition of the Late Eocene to Miocene palynofossils from Tarumsa Formation depicts a gradual shift towards colder climate which marks the appearance of moist deciduous forests[4]. It is estimated that, during the Middle Miocene Epoch, *Trachycarpus* and *Prunus* migrated from the mainland of Asia in response to the onset of colder climatic conditions brought in by the orogeny of Himalaya[5].

The Palaeocene–Eocene palynological assemblages (Subathu Formation) from the Kalakot area of Jammu[6] and Kalka-Simla Hills of Himachal Pradesh are generally conspicuous by the dominance of dinoflagellate cysts[7–11]. Palynofossils comparable to the members of the following families are present: Parkeriaceae, Podocarpaceae, Liliaceae, Nymphaeaceae, Poaceae, Arecaceae, Oleaceae, Anacardiaceae, Alangiaceae, etc. Algal elements are represented by *Pediastrum* and *Botryococcus*. Palynofloras largely belong to the semi-evergreen coastal vegetation having a tropical climate. Based on palynozones, several stratigraphical sections of Subathu Formation in Jammu and Himachal Pradesh have been correlated. A Late Eocene–Oligocene palynological assemblage (Dagshai Formation) shows high incidence of pollen comparable to palms, *Podocarpidites* complex along with *Inaperturopollenites*. It is comparable to coastal transitional type of vegetation[7]. Angiospermous pollen comparable to *Castanea*, *Galium*, *Amaranthus*, members of Arecaceae, Fabaceae, Sapotaceae, etc., also constitute an important part of the Oligocene palynoflora[12,13]. The Early Miocene palynoflora from the Kasauli Formation records the occurrence of *Pinus* pollen from western Himalaya. The assemblage also includes pollen of Bombacaceae and several other angiosperm families indicative of a subtropical climate[14].

Diversified palynofloras from the Palaeocene (Lakadong Sandstone[15]) of Khasi Hills and Palaeocene–Eocene of Jowai–Badarpur road section[16] (Meghalaya) contain largely elements of coastal swamp-type vegetation, having a tropical to subtropical climate. Some important pollen frequently recovered from these areas are of Podocapaceae, Arecaceae, Liliaceae, Brassicaceae, Meliaceae, Clusiaceae, Rhizophoraceae, Anacardiaceae, Euphorbiaceae, Nymphaeaceae, Nelumboniaceae, etc. The palynofloras, in general, contain dinoflogellate cysts, indicating a near-coastal environment of deposition. The Tertiary sediments of Siang district, Arunachal Pradesh, also contain Eocene marker taxa, viz. *Ctenolophonidites*, *Lakiapollis*, etc. It is believed that the post-Eocene Epoch is marked by the migration of *Ctenolophon* and *Durio* (*Lakiapollis*) to Malaya and adjoining areas in order to escape the onset of the changing climate, whereas several other forms perished[18]. Spores comparable to those of Parkeriaceae dominate the Oligocene assemblage of Meghalaya. They have a poor representation of angiospermous pollen. Pollen comparable to the members of the families Arecaceae, Fabaceae, Oleaceae, Bombacaceae, Lamiaceae, Potamogetonaceae, etc. are noticeable. *Pinus*-type pollen seem to have appeared in these strata for the first time[19].

It is clear from the above resumé that the composition of Palaeocene–Eocene palynological assemblages (Ladakh, Jammu, Himachal Pradesh, Meghalaya, Assam and Arunachal Pradesh) exhibits the characteristics of tropical vegetation, particularly reflecting semi-evergreen type to mixed coastal type, depending upon the prevailing environmental conditions, though they have been recovered from widely different latitudes of Himalaya and Assam Arakan Basin.

Therefore, it seems possible to generalize that the floras till then had not adapted themselves to altitudinal tiering, obviously for the lack of elevated topography. It is, in fact, the Eocene collision of the Indian plate with the Asian plate which changed the physiography of northern India by elevating the Himalayan range. Further changes in climate and rate of precipitation are well reflected by the composition and distribution of subsequent floras.

The Siwalik palynofloras (Middle Miocene–Pliocene) are generally poorly preserved because of the wide prevalence of oxidizing environment of deposition. In order to have a better appreciation of these floras a synthesis of palyno- and megafloral data has been done to reveal generalized vegetational patterns[4,5,7,10,14,19–25]. The distinctive feature of the Miocene floras in Himalaya seems to be their adaptation to different altitudinal belts. Some important constituents of floras in western Himalaya are *Albizzia*, *Anisoptera*, *Cassia*, *Dalbergia*, *Diospyros*, *Dipterocarpus*, *Ficus*, *Cynometra*, *Ziziphus* along with members of Moracae, Euphorbiaceae, Myrtaceae, Fabaceae, etc. Pollen grains comparable to *Pinus*, *Podocarpus*, *Abies Cedrus*, *Picea* and *Tsuga* have also been recorded.

On the other hand, the floras in eastern areas generally conform to subtropical moist deciduous vegetation type (*Calophyllum*, *Anisoptera*, *Dipterocarpus*, etc.). Some important elements of Middle to Late Miocene floras are *Podocarpus*, *Elaeocarpus*, *Diospyros*, *Shorea*, *Artocarpus*, *Bursera*, *Sterculia*, *Gluta*, *Terminalia*, etc. The Middle Miocene orogeny of both western and eastern Himalayas elevated the range sufficiently high which accelerated the rate of migration of plant taxa from the Mediterranean, Sino-Japanese and Malayan regions. The Pliocene Epoch in eastern Himalaya has yielded a rather meagre floral information and thus has not been considered for discussion.

Further rise of Himalayas during the Late Pliocene–Middle Pleistocene resulted in colder climate, lesser precipitation and increased aridity. These conditions proved harsh for moisture-loving plants, viz. *Dipterocarpus* and others. They either perished or moved away to peninsular areas in the south where equitable climate proved conducive for their growth. Cold-loving plants established themselves well on the elevated slopes of western Himalaya, whereas in eastern Himalaya the subtropical wet evergreen and wet temperate forests had some of the following constituents: *Picea*, *Podocarpus*, *Pinus*, *Tsuga*, *Betula*, *Alnus*, *Magnolia*, *Bursera*, etc.

A brief history of floristics through the Tertiary Period of Himalaya brings to light the fact that Palaeocene–Oligocene epochs generally supported tropical to mixed coastal type vegetations. The Miocene floras conformed to tropical semi-evergreen, subtropical moist deciduous and humid temperate types, whereas the Pliocene floristics were of dry or moist forest types as the wet subtropical and temperate forests dwindled.

Palynostratigraphy

Assam–Arakan Basin

The Tertiary sediments of Assam–Arakan Basin, particularly from Oligocene–Miocene epochs, are important for exploration of fossil fuel, both hydrocarbons and coal in the country. Most sedimentary sequences are devoid of palaeontological or plant megafossils and other marker horizons. Their stratigraphical order has been established mainly on the basis of lithology and heavy minerals, considered unsatisfactory by most stratigraphers. However, palynostratigraphical studies of surface and subsurface sequences from the Assam–Arakan Basin have proved useful in solving several complex problems of age determination and correlation. Subsurface material from the Barail, Surma and Tipam (Oligocene–Miocene) groups of sediments (rich in fossil fuels) was provided by Oil India Limited and Oil and Natural Gas Commission for palynological investigations. Palynozones established in these strata have been worked out comprehensively and also tested for their lateral continuity. They have also been extensively used for palynostratigraphical correlations. A palynological report jointly prepared by the scientists of this institute and Oil India Limited awaits publication.

A detailed analytical account of the work done in this area is beyond the scope of this paper. However, a quick reference to some stratigraphically important palynofossils along with the strata in which they occur is given. The Langpar Formation (Early Palaeocene) is characterized by the presence of *Spinizonocolpites*, *Proxapertites* and *Matanomadhiasulcites*. The acme of *Matanomadhiasulcites* along with *Dictyophyllidites* and *Lycopodiumsporites* is distinguished in the Therria Formation (Palaeocene). *Striatriletes* marks its appearance in Prang Formation (Middle Eocene). The Kopili Formation (Late Eocene) exhibits the common occurrence of *Polypodiaceasporites* and *Polypodiisporites*. The Barail Group of sediments (Oligocene) registers the appearance of *Crassoretitriletes*, *Malayaesporites* and *Bombacacidites*, whereas *Hibisceaepollenites* appears in Surma and Tipam sediments (Early Late Miocene). The Dupitila sediments (Mio-Pliocene) show prolific representation of angiospermous pollen grains. Most of the Tertiary stratigraphic rock units in this basin have been worked out palynologically and correlated.

Kerala Basin

Palaeontologically and palynologically, the Tertiary sediments (Quilon and Warkalli formations) have been considered as Early to Middle Miocene in age[26–28]. However, Poulose and Narayanaswami[29] assigned Upper Miocene to Pliocene age to the Warkalli

Formation. Both the formations have been investigated palynologically by several workers. Yet, it is not possible to build the successional history of the vegetation as the studies do not relate to stratigraphically measured sections.

Palynological studies of the subsurface sequence from the Ambalapuzha bore-hole[30] and the Arthungal bore-hole[31] provide convincing evidence for assigning each succession an Eocene to Early Miocene age. However, palynological assemblages recovered from several localities of Warkalli and Quilon formations have been dated as Miocene by Raha *et al.*[32], in spite of the fact that they also contain typical Eocene palynotaxa, viz. *Dandotiaspora*, *Proxapertites*, *Striatriletes*, *Margocolporites*, *Ctenolophonidites*, etc. These authors attribute the presence of Eocene palynofossils in these assemblages as being reworked from older sediments. Raha *et al.*[32] have analysed eight sections palynologically, yet no information regarding their stratigraphic relationship is provided. Information on the relative frequency and range of distribution of different palynotaxa has also not been given. The confusion is further compounded when palynotaxa, viz. *Dandotiaspora*, *Proxapertites*, *Striatriletes*, *Margocolporites*, *Ctenolophonidites*, etc. are included in the list of Miocene markers. These palynofossils are known to occur in the older sediments as well. Therefore, a restudy of these assemblages from measured sections systematically with the view to ascertain whether the presence of Eocene palynotaxa in the Quilon and Warkalli formations is *in situ* or reworked is suggested. This is considered all the more important in view of the finding of an Eocene sequence in the subsurface.

Ramanujam[28] admits that the Quilon Formation is overlain by the Warkalli Formation, but remarks, 'The possibility that the Warkallis are perhaps the continental equivalents of the Quilons and that the entire Tertiary sequence of Kerala constitutes a single group merits serious consideration.' This view is not tenable theoretically because the older (Quilon) and younger (Warkalli) formations cannot be considered as time equivalents simultaneously.

Ecological analysis of the Tertiary assemblages from the Kerala Basin brings to light upland, lowland, freshwater, sandy beach and mangrove elements representative of tropical rain forests of evergreen type having a warm and humid climate with plenty of rainfall[33]. The presence of pollen grains of *Barringtonia*, *Rhizophora*, *Nypa*, *Calamus*, etc. and dinoflagellate cysts suggest brackish mangrove swamp depositional environment.

Cauvery Basin

The Tertiary strata of Cauvery Basin (South Arcot, Tamil Nadu) contain one of the largest and thickest lignite deposits, known as the Neyveli lignite. The lignites occur within the Cuddalore Sandstones, the age of which has been a matter of controversy. They were dated as Lower Miocene to Pliocene[34–36]. Palynological study of the subsurface sequence from the Karaikal, Mandanam and Manargudi bore-wells established seven palynozones ranging in age from Palaeocene to Upper Miocene[37–39]. Based on the successional history of these palynozones, the age of the Cuddalore Sandstones was questioned by Venkatachala[40], who opined that the lower age limit of the Neyveli lignites and associated sediments may be ascribed to the Eocene. However, the earlier view that the Neyveli lignites and the associated sediments belong to Miocene age was reiterated by Ramanujam[28].

To resolve this controversy a comprehensive palynological project was launched at this Institute. The findings of Saxena[41] have clearly brought to light the fact that the Neyveli Formation is of Late Palaeocene to Middle Eocene age. His inference is based on the correlation of the Neyveli Formation palynozones with the Palaeocene–Eocene ages from the Kutch, Rajasthan, Bengal, Assam–Arakan and Cauvery basins. Palynological composition of the assemblage conforms to the tropical evergreen forests with plenty of rainfall. It has been estimated that these deposits were laid in back-mangrove to mangrove swampy conditions.

Kutch and adjoining basins

The Kutch Basin lies on the western margin of India and exposes almost a complete sequence of Tertiary rocks which have been investigated palynostratigraphically. Geological credibility of palynofossils as related to their distribution in strata has been well established[42–48].

Different formations have been divided into a number of palynozones. Each of these palynozones is characterized by their restricted and significant palynotaxa.

A reference to the palynostratigraphical sequence in ascending order reveals that the Matanomadh Formation (Palaeocene) is identifiable by the presence of *Dandotiaspora*, *Spinizonocolpites*, *Tricolpites minutus* and *Neocouperipollis*. In the Naredi Formation (Early Eocene) the abundance of *Durio* (*Lakiapollis*), *Melia* (*Meliapollis*) and palm pollen, (*Palmaepollenites*, *Neocouperipollis*) is striking. The acme of *Proxapertites microreticulatus* characterizes the Middle Eocene strata represented by the Harudi Formation. The first appearance of *Trisyncolpites ramanujamii* and *Kutchiathyrites* in the Maniyara Fort Formation (Oligocene) distinguishes it from the rest. The Khari Nadi Formation (Early Miocene) is characterized by the dominance of *Ceratopteris* spores (*Striatriletes susannae*) along with *Hibisceaepollenites* and gymnospermous pollen grains. Palynozones established in the Tertiary strata of Kutch Basin are largely correlatable with the contemporary palynozones of India. During the Tertiary Period, the climate in Kutch remained mostly tropical and the environment of deposition has been near coastal. A rich palynological data have been generated from the Tertiary sequence of Kutch. However, no tangible picture regarding the history of vegetation has emerged. This needs to be reconstructed on a priority basis.

Palynological study of the Laki sediments (subsurface) of Kutch[49] and Panandhro lignites[47] has yielded a rich data base. This work needs to be expanded systematically so that palynology is developed as an effective tool for lignite explorations in this region.

Palynological study of Barmer Sandstone and Palana lignites in Rajasthan provides preliminary information from isolated outcrops. Currently, the Mineral Exploration Corporation of India is drilling in Rajasthan for delineating the lignite deposits associated with the Barmer Sandstone. Desirous to know the age of these deposits, they have sent several samples to this institute for palynological study. Palynofloras recovered so far (Tripathi, personal communication) from the Barmer Sandstone show the dominance of *Lakiapollis*, *Proxapertites*, *Dandotiaspora*, etc. These palynotaxa are suggestive of Palaeocene–Eocene age.

To sum up, it is sufficient to state that Tertiary palynology in India has made rapid progress. Several stratigraphical units, both of marine and freshwater origin, have been dated and correlated palynologically. Ancient environments, considered favourable for the accumulation of hydrocarbons, have been more precisely deciphered. The overall information has been utilized by organizations in the country exploring for coal and hydrocarbons. The history of vegetations incorporating information of palaeoclimates, palaeoecology and palaeogeography has been elucidated and this also throws light on problems of evolution, regionalism, migration/immigration of plant taxa and also on the emergence of the modern flora.

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