Palaeobotanical studies in a synergistic perspective at the Birbal Sahni Institute of Palaeobotany

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Palaeobotany is the study of past vegetation involving many aspects of both botany and geology. It has application in the understanding of floristics, palaeoclimates, palaeoecology, phytogeography and stratigraphy. The palaeobotanist investigates plant fossils from the distant to the immediate past, understands their form and function, and builds up an evolutionary sequence to discern and compare floristic patterns through nearly 3500 million years of available life records. Palaeobotanical investigations also help in charting the history of modern vegetation and the origins and development of agriculture and plant utilization. The distributional pattern of plant remains in different sedimentary formations serves as a reliable parameter for correlation of geological strata. Its application in coal and petroleum exploration is well known.

Professor Birbal Sahni and a select group of his associates founded The Palaeobotanical Society to give an impetus to palaeobotanical researches in India, with a nucleus of private resources including immovable property, a reference library and fossil collections belonging to Professor Birbal Sahni and Shrimati Savitri Sahni. Subsequently, in September 1946, The Palaeobotanical Society established the 'Institute of Palaeobotany' to provide an institutional base for the study of plant fossils. This Institute was renamed the Birbal Sahni Institute of Palaeobotany in October 1949 in honour of its founder. It now functions as an autonomous research organization funded by the Department of Science and Technology, Government of India.

The main objectives of the Institute are:

i) to develop palaeobotany, including palaeopalynology, in all its botanical and geological aspects;
ii) to constantly update the data for interaction with allied disciplines;
iii) to co-ordinate with other knowledge centres in areas of mutual interest, such as early life, exploration of fossil fuels, vegetation dynamics, climatic modelling, conservation of forests, etc.; and
iv) dissemination of palaeobotanical knowledge.

Ever since the inception of the Institute, a wealth of data has been generated through investigations of plant mega- and micro-fossils. A meaningful appreciation of the past plant life is only possible through a holistic approach involving interaction with various other disciplines. Therefore, in 1986, an integrated multidisciplinary approach with an emphasis on synergistic interaction within the Institute and collaboration with other organizations was adopted as the concept for future planning. Five thrust areas, viz. origin and early evolution of life, patterns of evolution, biostratigraphy, depositional environments and biodiagenesis, and practical applications were identified. Advances made under these areas have provided rich dividends by enhancing accuracy and precision in solving complex problems of plant and earth sciences.

Birbal Sahni

This article deals with the latest advances made at the institute, their impact on related branches of science, and future scope and vistas of palaeobotanical researches.

Archaean palaeobiology

The development of biogenic processes in the Archaean and their effect on the early ecosystem are not yet clearly understood. Structural evidences of the initial steps in the evolution of the living system are rarely found preserved in the rock record. Early evolutionary processes were mostly biochemical in nature. Therefore to understand the early evolutionary steps it became necessary to augment palaeobiological studies with biochemical and isotopic data. In this field the Birbal Sahni Institute of Palaeobotany is actively collaborating with the National Geophysical Research Institute and the Bhabha Atomic Research Centre in a multidisciplinary effort to understand and decipher the antiquity and evolution of the living system.

Fossil remains morphologically comparable to methanotrophic bacteria have been recorded from the graphite samples from Ganacharpur and Kolar schist belts in the Dharwar Craton (>2600 million years old). These samples show a high degree of fractionation of graphitic carbon ($\delta^{13}C = -23‰$ and $-35‰$ vs PDB) which is considered to have resulted by the primary organic matter with normal $\delta^{13}C$ values being consumed by methanogenic bacteria and the released methane ($\delta^{13}C < -40‰$) in turn being taken up by methanotrophic bacteria. The recent discovery of coccoid and rod-shaped bacteria, morphologically comparable to members of Siderocapsaceae and *Thiobacillus*, from 2600 to 3200-million-year-old sediments of Kudremukh Iron Formation provides structural evidence for the existence of sulphate-reducing bacteria. This find predates the earlier known evidence of sulphur bacteria from 2000-million-year-old Gunflint Chert of Canada.

Archaean stromatolites

Both stratified and columnar stromatolites have been found in the Dharwar Craton. The columnar stromatolites have wall structures and divergent branching, similar to Riphean stromatolites of USSR. These columnar stromatolites provide presumptive evidence of cyanobacterium-dominated biocoenoses in >2600-million-year-old Dharwar sediments. Structural evidences of probable filamentous aerobic photoautotrophs have also been found in the Donimalai Formation of the same area in Karnataka.

These finds thus confirm the presence of anaerobic chemoheterotrophic signatures in >2600-million-year-old sediments of the Dharwar Craton. The association of probable sulphate-reducing bacteria with pyrite traces back anaerobic chemoautotrophic activity to >2600 million years. Evidences of anaerobic photoautotrophs in 3500-million-year-old Warrawoona Group, Australia, and aerobic photoautotrophs in 2800-million-year-old Fortesque Group, Australia, are already known. It is our endeavour to extensively search for biological and chemical signatures from the various Archaean sediments in the country.

Proterozoic fossils

Stromatolites, acritarchs, microfossils, metazoans and metaphytes are important in the study of Proterozoic sediments younger than 1500 million years. The Riphean sequence in the USSR has been subdivided with the help of stromatolites. The same guidelines have to be applied to Indian sediments. It is now necessary to study Indian stromatolitic sequences in detail using uniform techniques to understand their morphology and microstructures.

Cyanobacteria, acritarchs and *Melanocyrillium* (vase-shaped microfossils) from the Vindhyan Supergroup, the Infra-Krol sediments in the Kumaon Himalaya and Deoban Formation in the Lesser Himalaya have been studied with this point of view in mind. The biota comprises sphaeromorphs and filamentous types of cyanobacteria with little or no morphological differentiation. The early evolution is mostly metabolic. It demands an understanding of the metabolic activities and ecology of their modern equivalents.

Other emerging fields include prokaryote–eukaryote transition and advent of metazoans and metaphytes. The attainment of multicellularity represents a significant step in the evolution of the living system and it is very likely that evidences of this event will be found in the terminal Precambrian sediments. The medusoid-dominated soft-bodied metazoan assemblage from Ediacara beds of Australia (680 million years) and from the other equivalent beds in different parts of the world represents the oldest known accepted records of metazoans. A significant contribution by the Institute is the finding of metaphytes and metazoans in >800-million-year-old sediment of the Vindhyan Supergroup. It is necessary to review and reassess the Indian reports as they may represent the earliest known records of metaphytic and metazoan activity.

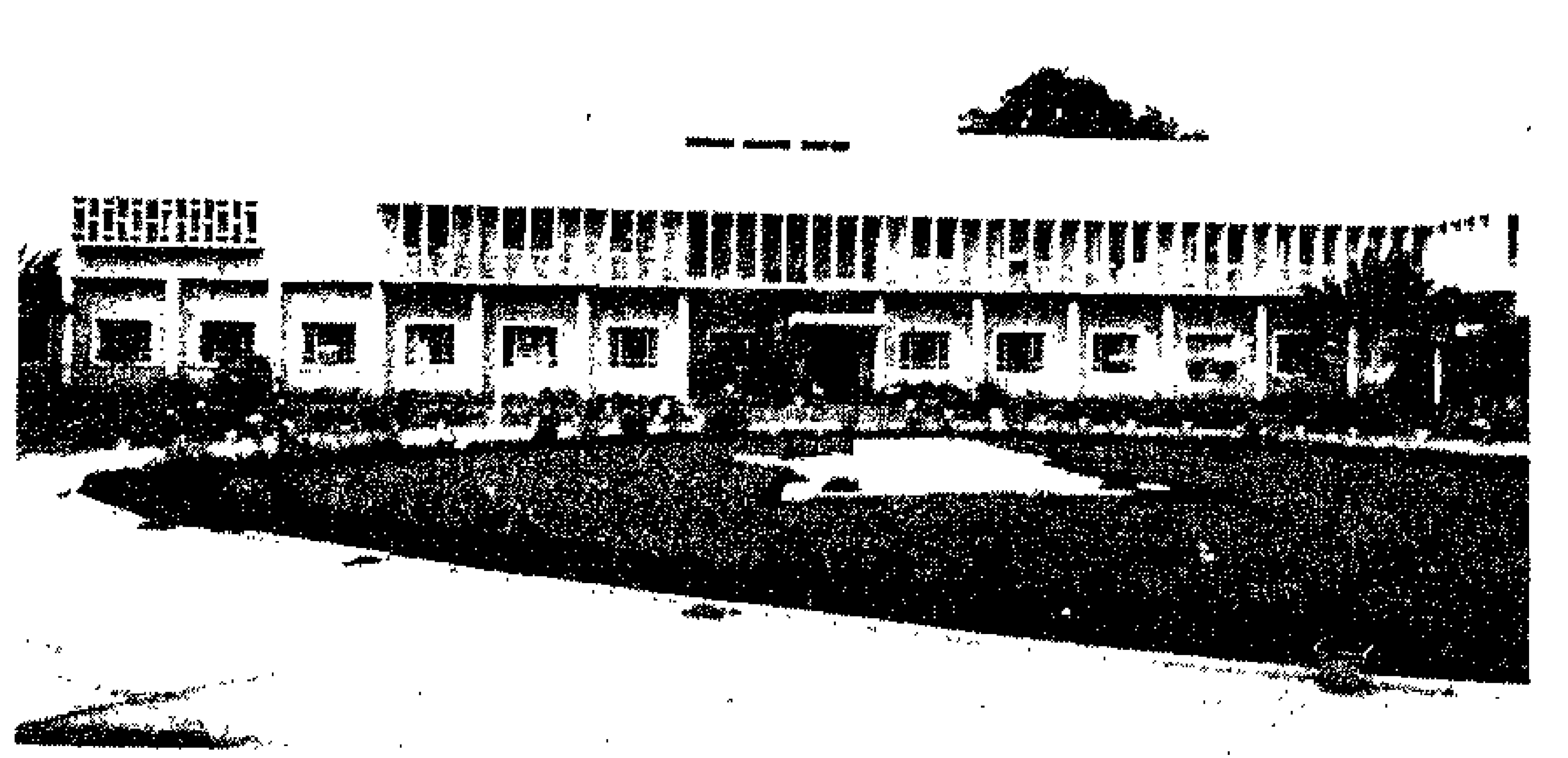
Origin, radiation and decline of the Gondwana floras

The term Gondwana in Indian stratigraphy is generally used for a thick sequence of primarily freshwater sediments of Late Carboniferous/Early Permian to Early Cretaceous age with a typical flora and fauna. However, recent researches have not only proved the presence of marine incursions during Permian and the absence of freshwater Jurassic sediments in peninsular India but have also brought to light the presence of a continuous succession of Early to Late Cretaceous sediments in the subsurface of Cauvery and Krishna–Godavari basins. Recent work done at the Institute suggests that the upper limit of the Gondwana in India can be drawn at the top of the Triassic. In a communication to the recent International Gondwana Symposium held in Brazil, the term Gondwana Supergroup has been formally proposed.

Detailed studies of the coal-forming vegetation from Gondwana grabens have enriched our understanding of the Indian Permian floras. Palynological data generated at the Institute have been utilized by the Coal Mining, Planning and Development Institute and the Geological Survey of India.

Cenozoic plant biogeography

The appearance of flowering plants is one of the significant events in the history of plant evolution. Pollen of angiospermoid morphology have been recorded from subsurface sediments of Aptian–Albian (105 ± 10 million years) age in the Rajmahal Basin. The Deccan Intertrappean flora has been dated as late Late Cretaceous to Early Tertiary. The intertrappean plant fossils from Nagpur–Chhindwara and Mandla areas indicate a warm tropical climate with heavy precipitation. This may be attri-



The institute's main building

buted to an almost equatorial position of the peninsula and the vicinity of sea to central India during this period.

Petrified woods from the Shumar Formation exposed near Jaisalmer indicate a tropical humid climate with a high amount of rainfall during Neogene times in Rajasthan. Occurrence of tropical African genera *Entandrophragma*, *Khaya* and *Tetrapleura* are significant for phytogeographical reconstructions.

The Neyveli lignite deposits in the Cauvery Basin, earlier considered to be of Miocene age, have now been dated to be of Late Palaeocene to Eocene age based on palynological data. A tropical climate supporting mangrove swamps is deduced as their environment of deposition.

Palynological data useful for identification of various stratigraphical intervals and recognition of shallow marine to brackish environments of deposition of the Subathu Formation in the type-area (Himachal Pradesh) and its lateral extension have been obtained. Coastal, transitional and freshwater palynofossils have been recorded from the Dagshai and Kasauli formations respectively. The palynological and plant megafossil studies of Siwalik sediments exposed in the Himalayan foot-hills and in Nepal indicate semi-evergreen vegetation and freshwater swampy conditions of deposition. The floristic composition during the Palaeocene–Eocene time of the Ladakh/post-Kirthar phase of the Himalayan orogeny was made up of palms, several members of Anacardiaceae, Sapotaceae, Myristicaceae, Alangiaceae along with mixed type of coastal swamp elements. The Miocene phase of orogeny brought in drastic changes in floristic composition and saw the incoming of temperate floral elements like Abietineae, *Trachycarpus* and *Prunus*. The Siwalik phase of orogeny (Late Pliocene–Middle Pleistocene) elevated the Himalaya close to the present day elevations. Several moisture-loving plants like *Dipterocarpus* either migrated away or perished. Higher elevations were populated by *Cedrus*, *Magnolia*, *Juglans*, etc.

The Early Palaeogene flora of India has been subjected to numerous changes. Many genera which are recorded in India during Palaeocene–Eocene either migrated or faced extinction.

Evolution of the Neogene floras in the northern region has largely been influenced by the Himalayan orogeny. The mid-Miocene orogeny of the Himalaya led to the proliferation of several gymnospermic groups and appearance of several subtropical angiospermic elements. The influence of Sino-Japanese and Indo-Malayan floras poses several questions. The problems associated with the Pliocene floras are of regionalism, endemism and migration/extinction in response to physical and climatic factors which need to be worked out in detail to unravel the history of the modern flora of India.

Studies on the Tertiary plants of India have established the antiquity of some of the well-known modern plants. History of *Artocarpus*, *Cocos*, *Emblica*, *Musa*, *Sonneratia*, and *Syzygium* goes back to Palaeocene (65 million years) while that of *Buchanania*, *Dipterocarpus*, *Shorea* and *Mangifera* to Miocene (25 million years).

Biostratigraphy and palynofacies of petroliferous basins of India

Palynostratigraphical, palaeoecological and source rock studies of fossil fuel-bearing strata are essential for exploration ventures. The research programmes on palynology were devoted to the development of new palynological information. Efforts were made to trace lateral continuity of the established palynological zones in order to confirm their biostratigraphical credibility. Palynological studies on subsurface sequences based on wells drilled by the Oil India Limited and Oil and Natural Gas Commission in the Arunachal Pradesh, Assam and Tripura–Cachar areas have helped establish palynological zonations in Barail, Surma and Tipam (Oligocene–Miocene) groups of sediments which are important for hydrocarbon exploration. The work was partially sponsored by the Oil Industries Development Board.

Pollen, spore, dinoflagellate and nannoplankton studies on the Mesozoic sediments of the Kutch Basin have been used for biozonation and establishing the Jurassic–Cretaceous boundary.

Dispersed organic matter

Vegetal debris comprising marine phytoplankton and algae as well as lipid-rich land plant remains are the main source for hydrocarbons. Different environments are characterized by different plant communities which upon death and decay yield recognizably different types of organic matter. Diagenesis of organic matter is an important aspect to understand the hydrocarbon potential of the source rock. Different patterns of distribution of organic matter types help also decipher palaeoenvironmental provinces. The Institute has taken up studies of modern sediments in different environmental regimes to build up depositional models for interpreting palaeoenvironment.

A comparative study of sedimentary facies and the accumulation of palynofossil and palynodebris in Alleppey and Quilandy mudbanks and Vembanad Lake, Kerala, have been conducted in collaboration with the Centre for Earth Science Studies, Trivandrum. The study has established that the palynodebris present in different sedimentary environments can easily be deciphered. Distribution of organic matter in restricted environments, i.e. lakes, is significantly different from the one in open environments. At Alleppy and Quilandy, structured terrestrial and biodegraded terrestrial organic matter is abundant near the coast. *Per contra* in Vembanad Lake structured terrestrial organic matter is abundant near the shore and biodegraded terrestrial organic matter is found away from the shore. In an open environment spores and pollen are better represented near the coast, but do not show much variation in distribution pattern along different transacts of Vembanad Lake. Studies on the palynofacies in the Chilka Lake and lakes of Kumaon Himalaya are underway.

Quaternary vegetational patterns

Pollen analysis of lake profiles from five sites in the Sat Tal area and from Tarag Tal in Kumaon Himalaya has revealed the dominance of a mixed chirpine-oak vegetation around 1000 years before present. A warm-temperate climate has been deduced for the region. A slight decline in the forest components accompanied by an increase in grasses and culture pollen around 500 years before present indicates activation of agricultural practices in the area. Pollen composition of the Naukuchia Tal profile, Kumaon is indicative of a moist warm-temperate climate in the area about 4000 years before present. About 1000 years ago the climate became relatively less humid. The increase in grasses and sedges, cheno/amaranths and other culture pollen towards the top of the sequence denotes agricultural practices in the region.

Pollen analysis of the Rewalsar Lake profile in Himachal Pradesh also indicates a warm-temperate climate about 1000 years before present. Deforestation for agriculture is noticed about 600 years before present by a sizeable increase in the non-arboreal and culture pollen. A subsequent increase in chirpine and oak pollen reveals regeneration of the forest.

Pollen analytical data from Late Quaternary sediments of western Himalaya lead to the inference that the shifts in vegetation have been rapid. Agriculture was being practised at least by 600 years before present in the region.

Plant economy in pre- and proto-historic cultural settlements

Seeds and wood charcoals of *Vitis vinifera* (grape) recently found from the Harappan sites at Rohira and Mahorana in Punjab, take back the antiquity of viticulture to 2,300 BC. This is associated with *Lablab purpureus* (hyacinth bean) from Mahorana, which also establishes that the advanced arbori-horticulture was in vogue during Harappan period. Carbonized grains of *Oryza sativa* (rice) as well as *Juglans regia* (walnut) and *Prunus amygdalus* (almond) found from the Late-Harappan site at Hulas in western Uttar Pradesh, indicate that rice was cultivated during the second millennium BC and dry-fruits of temperate regions were used.

Remains of the medicinal plants have been found in the Chalcolithic sites at Narhan and Khairadih in eastern Uttar Pradesh. The plants identified are *Strychnos nux-vomica* (kuchla), *Ocimum* cf. *O. sanctum* (basil), *Tinospora cordifolia* (gurch), *Vitis vinifera* (grape, raisin), *Santalum album* (sandalwood), *Emblica officinalis* (emblic-myrobalan), *Terminalia chebula* (chebulic-myrobalan), *Myristica fragrans* (nutmeg), *Buchanania lanzan* (chiraunji), *Aegle marmelos* (bel) and *Boerhaavia diffusa* (punarnava). These findings indicate that the Ayurvedic system of medicine was possibly quite advanced by the first millennium BC.

Geochronology

The ^{14}C ages of Kankar (authigenic soil carbonate) horizons of soil profiles in the Ganga alluvium have given an average sedimentation rate of 2.4 m/1000 years. Based on the formation mechanism of soil carbonates, the thick deposits of Kankar with ages 18000–20000 years and 30000–35000 years can be correlated with arid phases during global glaciation at these periods. The base of the marl bed near Kanpur has been dated to 8500 years indicating the time at which the channel was flooded (which coincides with the sea-level rise during early Holocene) and later abandoned due to changes in river course.

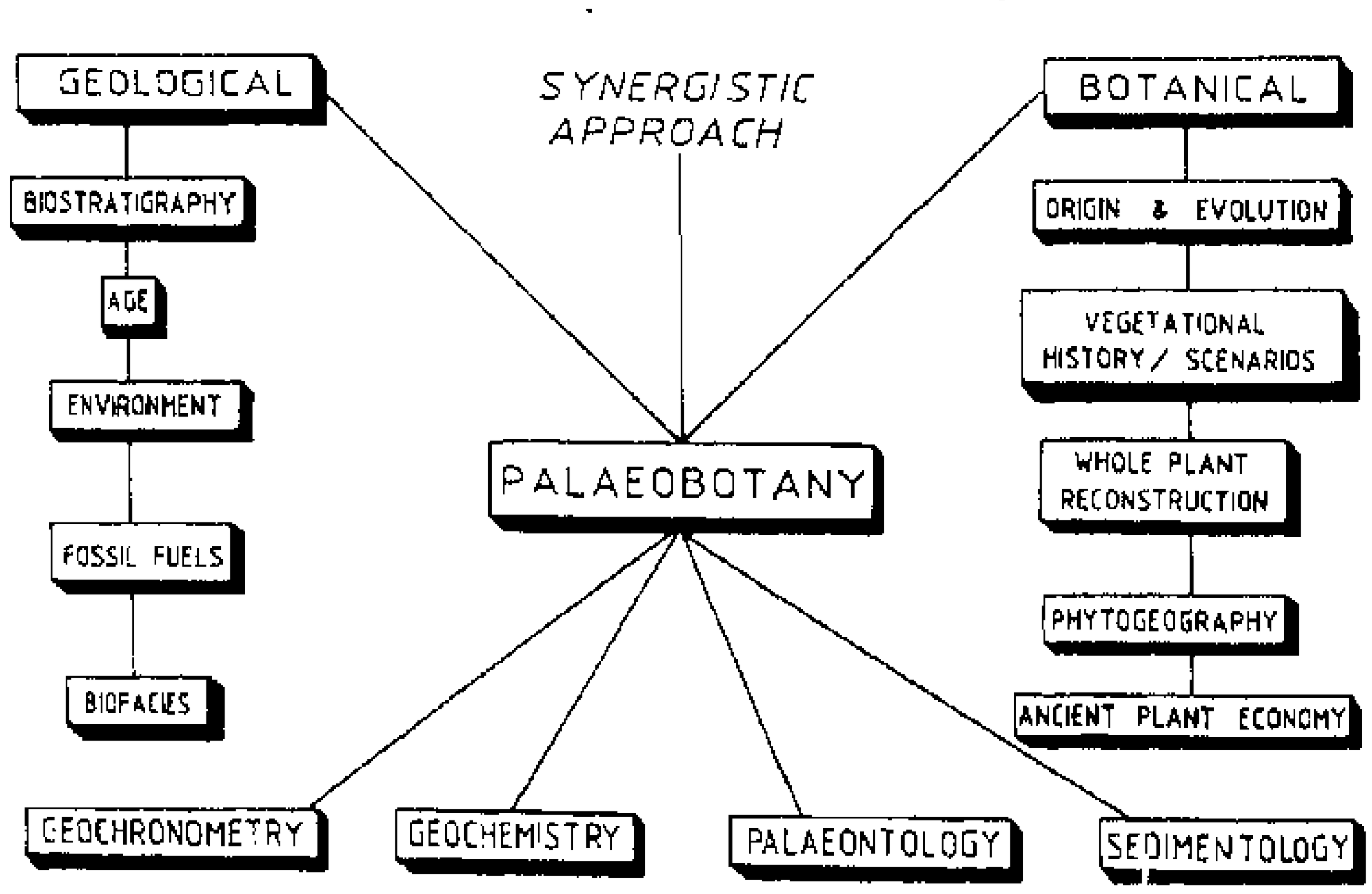
Radiocarbon dating of oceanic cores raised from Arabian sea and ^{18}O analyses of shells of different species of foraminifera indicate a marked negative shift in ^{18}O at 18000 ± 1500 years. This has been interpreted as due to westward advection circulation of low salinity winter monsoon water (poor in ^{18}O). These data limit the duration to 4000 years at the last glacial maximum when the winter monsoon was stronger than today. This work has been carried out in collaboration with the Physical Research Laboratory, Ahmedabad.

The Fission Track ages of over 45 samples from Vindhyans extending from Son Valley to Chittorgarh range from 600 to 1400 million years. The age bracket of 1300 to 1360 million years for the glauconite sandstone bed at Chopan indicates that this overlies the Porcellanite Formation in Son Valley area—an addition to the local lithology. The pellet limestone, taken as a marker bed in Chitrakut area has been dated to 1120–1200 million years. In western part, the Vindhyan deposits are younger than the eastern part and represent upper part of Rewa Formation/lower part of Bhander Formation except at Chittorgarh where it is older. Petrified woods from Deccan Intertrappean beds have been dated as 45–54 million years.

The F–T dating laboratory of the Institute is one of the sixteen laboratories in the world that work on international F–T age standard samples of apatite and zircon.

Concluding remarks

Palaeobotanical research in India is emerging as an interpretative and interdisciplinary science. The data on morphology of fossil plants and palaeofloristics generated so far need to be reassessed and categorized in the form of atlases, catalogues and monographs of topical value. This exercise will enhance its academic and applied utility for those engaged in evolutionary botany, forestry, environmental interpretation, climatology and exploration of fossil fuels. Based on the authentic and refined palaeobotanical knowledge, a palaeobotanist reconstructs vegetational scenarios through time, unravels evolutionary linkages and reflects on problems related to provincialism, endemism, phytogeography and migratory pathways of plants. The Institute has already made a beginning in this direction. Vegetational scenarios of early biosphere and Deccan Intertrappean floras have been reconstructed; addi-



tional ones depicting Gondwana coal-forming vegetation are nearing completion.

The synergistic approach at the Institute has sufficiently increased inter-institutional and multi-disciplinary collaborations. The Institute has endeavoured to share its expertise and resources with other organizations. Its contribution to the development of a national programme on palaeoclimate and environmental research is noteworthy. Some of the major organizations with which we have collaborative programmes are the Geological Survey of India, Oil India Ltd, Oil and Natural Gas Commission, Coal India Ltd, Central Mine Planning and Design Institute Ltd, Neyveli Lignite Corporation of India, National Geophysical Research Institute, Bhabha Atomic Research Centre, Wadia Institute of Himalayan Geology and Indian Institute of Tropical Meteorology. Recently an interaction with representatives of universities has helped to evolve a uniform curricula for bachelor and masters degree courses and is being considered by the University Grants Commission.

The Institute is committed to generate new knowledge, expand frontiers of palaeobotanical research and disseminate the accrued information. Conferences, symposia, workshops and group discussions have provided opportunities to plant- and earth-scientists to share their expertise. The recent workshop on 'Concepts, limits and extension of the Indian Gondwana' has brought forth a state-of-the-art report on the Indian Gondwana and has earned acclaim both within the country and overseas. The symposium on 'Vistas in Indian Palaeobotany' was organized at the Institute to discuss latest trends and futuristic researches in Indian palaeobotany.

The museum holds one of the finest collections of fossil plants in the world and maintains an active exchange of fossils. Specimens are gifted to university and college departments for teaching and demonstration. Popular lectures and exhibitions on plant fossils are organized periodically at the Institute and elsewhere in order to bring general awareness.

A closer interaction with scientists of related disciplines, viz. ecology, ecophysiology, plant geography, palaeozoology, sedimentology, oceanography, climatology and geochemistry is envisaged in the coming years. It will greatly enhance the relevance of palaeobotany in understanding of earth processes and the cause and effects of the developmental pattern of floras during earth's history.

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