Birbal Sahni Institute of Palaeobotany, Lucknow

Sunil Bajpai*

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India

This article highlights the findings of some of the major collaborative studies conducted by the staff of the Birbal Sahni Institute of Palaeobotany during 2014. The article provides a glimpse of ongoing research at BSIP in diverse fields under the umbrella of palaeosciences, such as the origin and evolution of biota, palaeobiogeography, deep time and Quaternary palaeoclimates and palaeoecology, archaeobotany and dating.

Keywords: Evolution, palaeobiogeography, palaeoclimate, palaeoscience.

THE Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow, an autonomous institute of the Department of Science and Technology, Government of India, is constantly striving to generate knowledge about the geological past primarily through palaeobiological and related studies. In 2014, significant studies were conducted at BSIP on several diverse but related subjects under the umbrella of palaeosciences, dealing with palaeoclimates, palaeobiogeography, origin and evolution of biotic communities, palaeoecology, biostratigraphy, archaeobotany, taxonomy, dating, etc.

The period between 2.5 and 1.6 billion years before present, known as the Palaeoproterozoic, is of great importance as it provides a window not only into the formation and growth of the first stable continents on earth, but also on the origin and early evolution of eukaryotes. Fossil evidence continues to play a key role in deciphering how the past biosphere and atmosphere influenced each other. One of the most crucial aspects of palaeoproterozoic research is the evolution of oxygenated environment that led to the diversification of photosynthesizing organisms. A collaborative study carried out by BSIP has revealed fossil evidence of iron-oxidizing bacteria preserved as filamentous iron oxides within the phosphatic palaeoproterozoic stromatolites[1]. The filaments include twisted stalks similar to those produced by modern iron-oxidizing bacteria that are known to metabolize polyphosphate and inhabit steep redox gradients. Chemolithotrophic oxidation of sulphide and iron require oxygen or nitrate as terminal electron acceptors. A growing number of oxygen-utilizing chemolithotrophs are known to accumulate intracellular polyphosphate as an energy reserve that allows them to adapt to the fluctuating redox conditions in their distinctive-gradient habitats. This study suggested that the fossil iron-oxidizing bacteria preserved within some of the oldest known phosphorites serve as indicators of O_2–Fe (II) gradients that may have supported microbially mediated phosphogenesis via polyphosphate metabolism and/or an active iron redox pump.

The Permian–Triassic transition (~252 million years BP) or the boundary between the Palaeozoic and Mesozoic eras, is associated with the most severe extinction event that occurred on earth. This period (the ‘Great Dying’) also witnessed the amalgamation of continents and formation of the supercontinent Pangaea. Around the same time, the Northern edge of the Indian subcontinent was subjected to rifting. A collaborative team of scientists, including those from BSIP recently carried out palynological investigations of the Permian–Triassic succession in the famous Guryul Ravine, Kashmir, India. The study revealed a rich Permian spore-pollen assemblage and a depleted Triassic assemblage[2]. Combined together, these palynofloral assemblages provide a basis for regional as well as global correlation of Permian–Triassic boundary, besides providing significant insights into Permo-Triassic climatic and tectonic events in the Indian context.

The Indian subcontinent has a unique fossil history that has contributed immensely to a better understanding of several fundamental aspects of biotic evolution. Palaeobiogeography, the study of distribution of plants and animals in the past, is an integrative field of inquiry that unites concepts and information from palaeoecology, evolutionary biology and plate tectonics. A recently recorded ~65 million year old plant fossil, *Sabalites dindoriensis*, is the oldest record of a coryphoid palm from the Gondwana-derived continents[3]. This collaborative study suggests that the palm was widespread globally by ~65 Ma and that it probably dispersed into India from Europe via Africa around this time. This finding opens up a new window for understanding palm dispersal in the southern hemisphere. Similarly, the plant fossil record of *Bridelia* (Phyllanthaceae) from the late Oligocene sediments of India indicates that the genus evolved ~25 Ma in North East India, and later diversified and migrated to Southeast Asia via Myanmar and to Africa via the ‘Iranian route’[4].

*e-mail: director@bsip.res.in

Vertebrate fossils, especially those of tetrapods, are of great palaeobiogeographic and palaeoclimatic interest, and provide critical data required for tracing the evolutionary origins of the various groups of organisms and their subsequent dispersal. A collaborative study among BSIP, Northeast Ohio Medical University, USA and other institutions in the US, was carried out on Anthracobunidae, an extinct (middle Eocene, ~48 Ma) family of large mammals from Indo-Pakistan that was traditionally believed to have given rise to elephants (proboscideans) and sea cows (sirenians)[5]. The new study shows, based on a detailed cladistic analysis, that anthracobunid fossils of Indo-Pakistan are actually the ancestors of perissodactyls, the order which includes modern horses and rhinos. Significantly, this study also reaffirms the previous identification of cambaytheres as basal perossodactyls and strongly supports the hypothesis that the Indian subcontinent was the centre of origin of the order Perissodactyla (i.e. the 'Out of India' hypothesis). Analyses of stable isotopes and long bone geometry also suggest that the ancestors of perissodactyls spent a considerable amount of time in the water. Overall, this new study significantly expands our understanding of the perissodactyl origins, early evolution and palaeoecology.

Quantitative palaeoclimate estimates for the Indian subcontinent around the time of India–Asia collision are of considerable interest. Collaborative work carried out by BSIP on early Eocene (~55–52 Ma) Gurha Lignite Mine, Rajasthan yielded a diversity of fossil leaves, flowers, fruits and seeds[6]. Climate leaf analysis multivariate program (CLAMP) analysis was carried out on the fossil leaves recovered from this lignite succession. The study indicates cool, equatorial (~10°N) temperatures and a monsoonal climate during ~55–52 Ma. It also suggests that the South Asian monsoon already existed at the time of initial stages of the India–Asia collision.

Quantitative palaeoclimate assessment for the period from mid-Miocene to early Pleistocene in the eastern Himalayan Siwaliks (i.e. Darjeeling and Arunachal Pradesh) has been a challenging task. A collaborative study[7] involving CLAMP analysis of fossil leaves from Darjeeling and Arunachal Pradesh suggests mean annual temperatures (MATs) of 25.4°C and 25.3 ± 2.8°C with warm month mean temperatures of 28.4°C and 27.8 ± 3.39°C and cold month mean temperatures of 17.9°C and 21.3 ± 4°C respectively, for the two areas during the mid-Miocene. However, precipitation estimates suggest a weak monsoon with growing seasonal precipitation of 242 ± 92 cm for Darjeeling and 174 ± 92 cm for Arunachal Pradesh. This study also suggests that there has been little change in the intensity of the monsoon in Arunachal Pradesh since mid-Miocene, whereas in the Darjeeling area, monsoon has intensified since the mid- Miocene. The study also reevaluated the 15 Ma flora from the Namling–Oiyug Basin, southern Tibet.

Climate variations in Ziro valley during later part of the Pleistocene have been studied jointly by BSIP, using pollen, magnetic susceptibility and carbon isotope proxies[8]. The study revealed an increase in SW monsoon intensity during the period from ~43,000 to 34,000 cal years BP, followed by a decline. A peak warm and humid phase occurred around 36,181 and 34,145 cal years BP. During the Last Glacial Maximum, the monsoon declined, as evident from a lower *Quercus–Pinus* index. The study is helpful in understanding the climatic variation and its teleconnections with the Himalaya and other parts of the world.

Adaptation to persistent drought conditions faced by ancient civilizations provide a valuable perspective for modern societies in exploring possible strategies in relation to future climate change. A multi-proxy collaborative study involving palynology, phytoliths, sedimentology, clay mineralogy, carbon isotope and magnetic mineralogy on lacustrine sediments from sub-humid zone of mainland Gujarat, in conjunction with archaeobotanical data, was carried out to determine the mid-Holocene climatic fluctuation, and its possible impact on the Harappan culture[9]. Low lake level and dry climate have been documented during the period from ~5560 to 4255 cal years BP, synchronous with the other lake records of western India. It was deciphered that the emergence of cultural complexity of Harappan civilization at the same time is an initial adaptation to the earliest phase of dry climate in this region and that the fall of Harappan culture is probably linked to the excessive dry climate of later phase (~4200–4255 cal years BP) of mid-Holocene.

In another important collaborative study, an assessment of archaeological data on small-grained millets from core (Upper Indus) and peripheral regions of the Indus/Harappan civilization was made to understand their role in the ancient crop economy and their diversity and spatial extent in relation to cultural change[10]. The presence of fossil grains of sorghum millet, little millet, finger millet, pearl millet and foxtail millet from various archaeological sites from the Early Harappan (3000–2500 BC), Mature Harappan (2500–2000 BC) and Late Harappan (2000–1400 BC) was documented. The continued presence of millets since the Early Harappan period shows their dominant role in the Harappan agricultural system. The shift towards drought-resistant millet crops in the peripheral region of the Indus/Harappan civilization is interpreted as a cultural adaptation in response to the decline of SW monsoon during the late Holocene (~4 ka), to which millets are better suited.

Palaeosol or fossil soil is a soil that formed on a past landscape. Current interest in pre-Quaternary palaeosols arises from their remarkable utility in the determination of ancient atmospheric CO_2 concentrations. In a collaborative study, stable isotopic composition of vascular plant biomarkers from the Ganga Plain palaeosols around 80,000 and 20,000 cal years BP was analysed to understand the palaeo-vegetation history[11]. The carbon isotopic composition of C32 fatty acid (δ^{13}C32 : 0) suggests mixed C_3–C_4 plants over the Ganga Plain between 80 and 20 ka, and a rapid doubling of C_4 plant abundance around 45 ka. Comparison with a set of palaeoenvironmental proxies suggested that C_4 plant expansion was closely controlled by hydrological conditions of the Ganga Plain. Overall, the study emphasizes that the local Ganga Plain palaeovegetation history can be reconstructed using the stable carbon isotopic composition of selected higher plant wax biomarkers and the long-chain fatty acids, especially C32.

The Earth has undergone a significant climate switch from greenhouse to icehouse conditions during the Plio-Pleistocene transition around 2.7–2.4 million years ago (Ma), marked by the intensification of Northern Hemisphere Glaciation (NHG) at ~2.7 Ma. Evidence from oceanic CO_2 [(CO_2)aq], supposed to be in close equilibrium with the atmospheric CO_2 [(CO_2)atm], suggests that the CO_2 decline might drive such climate cooling. However, the rarity of direct evidence from (CO_2)atm during the interval prevents determination of the atmospheric CO_2 levels and the assessment of impact of its fluctuation. A collaborative study was aimed to reconstruct the (CO_2)atm levels during 2.77–2.52 Ma based on a newly developed proxy of stomatal index on *Typha orientalis* leaves from Shanxi, North China, and to depict the first (CO_2)atm curve over the past 5 Ma using stomata-based (CO_2)atm data[12]. Comparison of the terrestrial-based (CO_2)atm and the pre-existing marine-based (CO_2)aq curves shows a similar general trend, but with different intensities of fluctuation. The study revealed that the high peak of (CO_2)atm occurred at 2.77–2.52 Ma with a lower (CO_2)aq background. The subsequent sharp fall in (CO_2)atm level might be responsible for the intensification of NHG, based on its general temporal synchroneity. These findings provide important insights into the (CO_2)atm change and its ecological impact since 5 Ma.

Luminescence dating is based on the phenomenon in which certain minerals release previously absorbed radiation energy upon being moderately heated, a mechanism that helps determine the age of the minerals. A recently proposed mechanism (recombination of trapped electrons to the randomly distributed trapped holes via excited state), seeks to understand the role of band-tail states of feldspar in thermoluminescence and infrared luminescence production[13]. This analysis shows that the trapping level is not in a particular energy but in a distribution of energy levels, and that this can be explained using the existence of band-tail states in feldspar. The study also analysed the IRSL signals using Becquerel kind of decay function[14]. Overall, these studies are likely to pave the way for exploring more stable signals (i.e. less anomalous fading), which can be used to date older sediments using feldspar.

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