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Institutional Report

Birbal Sahni Institute of Palaeosciences: An Overview of Recent Advances and Developments

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Introduction

The Birbal Sahni Institute of Palaeobotany was established in the year 1946 with the overall objective of deciphering the evolutionary history of plant kingdom through the study of fossil plants. The credit for this great accomplishment goes to Prof. Birbal Sahni himself, after whom this unique centre of research was named after his untimely demise. Earlier renowned Professor Sir Albert Charles Seward had initiated Late Prof. Sahni into the science of palaeobotany at Cambridge University and recognized the potential of the then young Sahni. Subsequently at one point, Prof. Seward advised the Geological Survey of India to send the plant fossils in its collection to Birbal Sahni, then based at University of Lucknow, instead of sending them to the UK. Studies on plant fossils thus systematically began in India in 1921, and during the next quarter of a century, Sahni, besides studying the plant fossils, also explored the potential

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application of palaeobotany to areas pertaining to the basic and applied aspects of botany and geology. Prof. Sahni's tireless efforts thus laid a firm foundation for studies on plant fossils in India, leading up to the establishment of the Institute of Palaeobotany at Lucknow in 1946. Since then, the institute has grown constantly and has continuously generated new data. Currently, research activities at the Institute include studies on plant fossils and associated micro-and macrofossils, past-climates, -environments and -ecosystems, palaeobiogeography, biostratigraphy, geochemistry, fossil fuel exploration, palaeoethnobotany as well as and development of apppropriate analytical tools. To provide the necessary thrust on multidisciplinarity and an integrated approach within the overall framework of Earth System sciences, this institution was recently renamed *Birbal Sahni Institute of Palaeosciences* (BSIP). The recent induction of analytical facilities and scientists has enabled BSIP to delve deeper into multiple dimensions of palaeosciences. This contribution highlights some of the important scientific activities carried out during the period 2010-15 and discusses their importance in the understanding of biotic evolution, past ecosystems and climates.

Currently the basic mandate of BSIP is to carry out multidisciplinary research in palaeosciences pertaining to evolution of biotas, climates and ecosystems and, under this mandate, the main main thrust areas are:

1. Early life, contemporary environments and evidence from Indian Precambrian basins,
2. Phanerozoic terrestrial and coastal ecosystems: Biostratigraphical, palaeoenvironmental, palaeoecological and palaeogeographical aspects,
3. Marine micropalaeontology with a focus on high resolution biostratigraphy, sea level changes, palaeo-oceanographic and palaeoclimatic events,
4. Organic petrology including characterization of solid fossil fuels in terms of depositional setting and utilizational aspects,
5. Quaternary palaeoclimate reconstructions, vegetation dynamics and sea level changes,
6. Domestication of plants, early farming and ecosystem dynamics during Holocene and Anthropocene,
7. Geochronological and geochemical studies for high resolution dating, regional stratigraphic correlation, palaeoclimatic, tectonic and provenance studies,
8. India-Asia collision and Himalayan uplift and their signetures in palaeobotanical and associated biota in sediments of northwest Himalaya.

Numerous analytical facilities have been set up during the past three years. These include elemental stable isotope and organic geochemistry, (ICP-MS, IRMS, GC-MS), XRD, FE-SEM, CLSM with Raman Spectroscopy, luminescence dating and magnetostratigraphy. Apart from their own research project BSIP scientists help Oil India Ltd., ONGC, Coal India Ltd, Archaeological Survey of India in their studies involving micropalaeontogical and paleobotanical inputs.

Highlights

Precambrian

Carbonaceous fossils in the Precambrian sedimentary successions of India continue to provide important insights into the evolutionary history of early life ranging from single-celled prokaryotes to nucleated eukaryotic cells and multicellular life forms that appeared and evolved during the first three billion years of earth's history. Studies on these remains from India have led to a better understanding of the evolutionary pathways adopted by life forms during the Neoproterozoic Era (1000-541 Ma). All such remains have been investigated for their biogenicity, syngenecity and age because of possible uncertainities in distinguishing the true fossils from pseudofossils. Carbonaceous compression fossils from the various Precambrian basins of India were reviewed by Sharma *et al*. (2012). Sharma and Shukla (2012a) reported annulated compression/impression fossils from the Hulkal Formation of Bhima Basin of India (~750 Ma) and established the existence of Pre-Ediacara epi-benthic organisms. Elsewhere, the earliest multicellular, megascopic benthic algal life has been documented from the Ediacara and slightly older periods (~635-541 Ma) and includes complex multicellular carbonaceous megascopic forms (seaweed) (Yuan *et al*., 2011, 2013). The older ages of carbonaceous fossils from the Bhima basin of India suggest that these forms survived the glaciation events before passing into the Ediacaran time.

Organic walled microfossils of eukaryotic affinity occur extensively in the silicified cherts and carbonaceous shale of Meso-Neoproterozoic Vindhyan, Chhattisgarh, Kurnool and Ediacaran sediments of Lesser Himalaya, India (Singh *et al*., 2011; Sharma and Shukla, 2012a,b; Shukla and Tiwari, 2014; Singh and Sharma, 2014). In a monograph by an Indo-Russian team, Sergeev *et al*. (2012) reviewed 50 genera and 90 species of fossil cyanobacteria using petrographic thin sections of different Proterozoic formations across the world. To date, this study provides the most exhaustive account of the morphology, palaeobiology, palaeoecology and geological history of cyanobacterial microfossils. Singh *et al*. (2011) reported an assemblage of cyanobacterial microfossils of endolithic habitats from the carbonate facies of the Bhander Group of the Vindhyan succession. In another important work, Sharma and Shukla (2012b) reported helically coiled microfossils of *Obruchevella,* a Vendian marker, from the Owk Shale of the Kurnool Group, which suggests an Ediacaran rather than a Mesoproterozoic age for this sequence. Babu and Singh (2013) and Babu *et al*. (2014) reported a diverse assemblage of Neoproterozoic chert permineralized microbiota from the carbonate facies of Raipur Group (Chhattisgarh Supergroup) and discussed its biostratigraphic significance. Furthermore, the oldest morphologically complex organic-walled eukaryotic microfossils have been reported from the latest Palaeoproterozoic-Early Mesoproterozoic Chitrakut Formation (>1600 Ma old) of the Vindhyan Supergroup (Singh and Sharma, 2014). This find predates the oldest record of eukaryotic fossils known from ~1500 Ma and takes the antiquity of eukaryotic microfossils farther back in deep time.

The Marwar Supergroup has also yielded varied fossils of Ediacaran to Cambrian age. Contributions from the BSIP have led to a better understanding of the biodiversity of the various Ediacaran to Cambrian lithounits of the Jodhpur Sandstone (Kumar and Ahmad, 2012; 2014; 2016). These finds include the non-vascular megaplant fossils (Kumar and Ahmad, 2016). From the Nagaur Group, trace fossils (Ahmad and Kumar, 2014) including burrows and scratch marks of arthropods have been described from the fine to medium grained sandstones (Ahmad and Kumar, 2014). These and associated finds have enriched our knowledge of the diversity of Ediacaran biosphere and have also helped refine the stratigraphic division of the Ediacara and Lower Cambrian intervals.

Palaeozoic-Early Mesozoic

Contributions from BSIP have a led to a significant refinement of the Gondwana biostratigraphy and the Gondwana biodiversity. Extensive megafloristic studies pertaining to evolutionary, palaeoecological and palaeoenvironmental aspects were conducted in the various Gondwana basins of India during. A comprehensive review on the morpho-taxonomy of Permian spores from the Indian Gondwana successions was published by Vijaya and Murthy, (2013). Another study on the thecamoebians from the Late Permian Gondwana sediments of peninsular India adds a new dimension to our knowledge of the Gondwana biodiversity (Farooqui *et al*., 2014). On the basis of shell morphology and morphometry, sixteen thecamoebian species have been recorded in this study. The study also elucidates the minimal morphological evolution in thecamoebians and their survival during the periods of mass extinction and stressful environmental conditions. The first record of fresh water diatom frustules along with the tests of thecamoebians recovered from Permian sediments (±251-299 Ma) of Chamba basin, Himachal Pradesh and Godavari sub-basin, Andhra Pradesh, India has also been documented (Farooqui *et al*., 2015). This work provides evidence for the existence of diatoms prior to the Permian-Triassic boundary. In another interesting study, charcoal fragments in the deposits of Chintalapudi sub-basin of the Godavari graben provided evidence of palaeo-wildfires (Jha *et al*. 2014). Morphological characters of charcoal were also utilized in taphonomic interpretations (Mahesh *et al*., 2015a). In a similar contribution, palaeo-wildfires, as evidenced by the occurrence of tracheid fragments of charcoals with homogenized cell walls, were documented from the Late Permian Zewan Formation of Kashmir. NW Himalaya (Jasper *et al*., 2016).

Numerous naked, fossil spore tetrads assignable to *Indotriradites*, *Microbaculispora* and

Microfoveolatispora were recently reported for the first time from the early Permian Lower Barakar Formation of Singrauli Coalfield, Son-Mahanadi Basin, Central India (Saxena *et al*., 2015). This study provides important data to test the hypothesis that the formation of tetrad spores is linked to extreme climatic conditions. Global records of such tetrad spores in the Ordovician-Lower Devonian, Early Permian, Permo-Triassic boundary and thereafter in the Early Triassic sediments, have been correlated with extreme cold (due to Ordovician - Silurian and Carboniferous-Permian glaciations) and hot (due to Early Triassic Siberian volcanic activity) climatic conditions.

BSIP has an ambitious programme on polar studies, and its participation in India's Antarctic and Arctic expeditions has provided important results on palaeobiological and palaeoclimatic aspects. In an important study on the Permian-Triassic palynoflora from the Allan Hills, South Victoria Land, Antarctica (Ram Awatar *et al*., 2014), the Late Permian age of the Weller Formation was corroborated based on the similarity of its palynoassemblage to that of the Upper Stage-5 (Late Permian) of Australia. Also, the Lashly Formation was shown to be correlatable with the *Aratrisporites parvispinosus* Zone of Australia. A heterogeneous and well preserved assemblage of Triassic megafossils, belonging to pteridophytes and gymnosperms, was also described by these workers from the Lashly Formation of Allan hills. The assemblage is dominated by corystosperms and includes many species of the genus *Dicroidium*. Furthermore, it has been suggested that the persistence of green house conditions from the end of the Permian to the Triassic allowed the rich and diverse *Dicroidium* forests to develop in the polar regions of Antarctica (Chatterjee *et al*., 2013). This study indicates a much older origin of *Dicroidium* than previously suspected. Also, a comprehensive documentation of the *Glossopteris* flora from the Permian Weller Formation of Allan Hills, Antarctica has been shown to include well preserved pteridophytes, gymonosperms, and Equisetales (Tewari *et al*., 2015). The recorded flora shows close similarity with the Late Permian assemblages of India, South Africa and Australia. *Gangamopteris,* an index fossil of Early Permian formations of different Gondwana continents, has been shown to have an extended stratigraphic range in the Late Permian Weller Formation of Allan Hills (Tewari *et al*., 2015a). A rich and well preserved *Glossopteris*-dominated plant fossil assemblage has also been described from the Barakar Formation in the coalfields of Makardhokra and Umrer, Wardha Basin, Maharashtra, India (Tewari *et al*., 2012). The flora exhibits several unique characteristics and is Artinskian to Kungurian in age. This study provides the first systematic documentation of the *Glossopteris* flora from the Barakar Formation of the Wardha Basin. Another study, pertaining to the Lower Gondwana plant fossils of Mohpani Coalfield of Satpura Gondwana Basin (Madhya Pradesh), revealed the dominance of *Gangamopteris* species over the *Glossopteris* species as well as the absence of *Noeggerathiopsis*, indicating floral affinities with the Lower Barakar flora of (Srivastava *et al*., 2012).

A comprehensive review of the megaflora, palynology and geological setting of the Talcher Basin of Orissa has also been published recently (Goswami and Singh, 2013). This study concludes that several groups of plants disappeared during the Permian-Triassic interval (Lower Kamthi-Upper Kamthi) and that many new forerunners appeared in a step-wise manner in the Upper Kamthi Formation. The study also advocates the continued survival of plants, rather than a mass extinction, around the Permo-Triassic (P/T) boundary in the Talcher Basin. Another review study on the genus *Euryphyllum* incorporating morphology, cuticular aspects and the affinities suggested that asymmetry of the leaves that used to be an important character for generic distinction, cannot be considered as a distinguishing feature for this genus (Saxena *et al*., 2013). In another study, the utility of plant megafossils in correlation of coal seams in the Gondwana coalfields of India was discussed (Srivastava and Agnihotri, 2013).

In another recent contribution (Singh *et al*., 2013), the Carboniferous flora and associated depositional environments in two of the best plant fossil localities in the Pir Panjal Range of Kashmir Himalaya have been studied in detail for the first time. Some of the fine-grained, shallow marine deposits yielded fossil floras dominated by sub-arborescent taxa. Of these, the taxa *Flabellofolium, Botrychiopsis, Annularia* and *Cordaites* have been recorded for the first time from the Indian carboniferous. The assemblage is comparable to other Gondwanan floras assigned to the Paraca floral realm, and has been interpreted as evidence of relatively warm climatic conditions that existed prior to the onset of the Carboniferous-Permian ice age.

A recent study (Tewari *et al*., 2015b) deals with the palynological transition in the Permian-Triassic Boundary sequence of the famous Guryul Ravine Section, Kashmir Himalaya, India. The study revealed an impoverished latest Permian spore pollen assemblage in the uppermost Zewan Formation, a rich palynoassemblage from the basal Kunumuh Formation characteristic of the P-T transition zone, and a depleted Triassic assemblage from a horizon higher up in the Kunumuh Formation. The low spore pollen yields and the poor preservation of the recovered assemblage was attributed to the offshore marine depositional setting on the margin of the Neotethys ocean and the thermal alteration associated with the Cenozoic collision between India and Asia (Tewari *et al*., 2015b). A study on thecamoebians from the same section has confirmed their morphologic stability through the Phanerozoic, unaffected by one of the greatest mass extinction events (P-T) in earth's history (Singh *et al*., 2015).

Based on new collections, Cleal *et al*. (2016) recently made a critical assessment of the lycopsids reported from the Kashmir Himalaya. The material has been shown to belong to a single taxon and the variations have been attributed to variable growth rate during the life of the individual plants. A new taxonomic name, *Spondylodendron pranabii* (Pal) comb. nov., was proposed for all previously reported and the new material from Kashmir. In another interesting study (Singh *et al*., 2016), some exceptionally well preserved, vertical (*in situ*) *Vertebraria* axes and the horizontally preserved allochthonous *Glossopteris* leaves have been described for the first time from the Raniganj Formation of Singrauli Coalfield, Son-Mahanadi Basin.

Cretaceous-Neogene

Tracing the early evolutionary history of angiosperms is an important area of research at BSIP. A collaborative study by BSIP on the *Carnoconites* seeds preserved in the early Cretaceous intertrappean cherts of Rajmahal Hills suggested angiosperm-like traits of the Indian *Pentoxylon* plant (Srivastava and Krassilov, 2012). In another collaborative work, the oldest record of a coryphoid palm (*Sabalites dindoriensis)* was reported from the late Cretaceous Deccan Intertrappean deposits of Central India. This find has opened a new window for understanding palm dispersal in the southern hemisphere since, according to the authors, coryphoid palms dispersed into India from Europe via Africa during the latest Cretaceous (Srivastava *et al*., 2014). Silicified plant tissues (phytoliths) have also been studied from late Cretaceous (~65 Ma) dinosaur dung and associated sediments from a Deccan intertrappean locality in central India (Prasad *et al*., 2011). This study demonstrated the presence of wild rice phytoliths in the dinosaur dung and intertrappean sediments and suggested an early diversification of the grass family Poaceae, with possible origin of rice in India about 65 Ma.

In another study based on palynofacies and sedimentology, Prasad *et al*. (2013) have deciphered palaeoenvironmental conditions and facies architecture of the early Eocene Cambay Shale sequence at the Vastan Lignite Mine in the Cambay basin of western India. This study suggested that the Vastan lignite sequence was deposited in a low-energy coastal marsh-bay complex and that the lower part of this sequence, which possibly represents a Transgressive Systems Tract (3^{rd}-order cycle), comprises four depositional facies representing open bay, restricted bay, creek and channel and coastal marsh.

The Paleocene-Eocene transition has long been known to be a period of extreme global warming. To trace the response of mangrove vegetation to the early Paleogene warming, the species diversity of the spinizonocolpites pollen *Nypa* across the Paleocene-Eocene transition was studied from two paleo-equatorial shallow marine stratigraphic sections in the east Khasi hills, South Shillong Plateau, Meghalaya (Srivastava and Prasad, 2015). The study showed higher diversity around the Paleocene-Eocene boundary in both sections, followed by a significant decline during the Eocene. The variation in species diversity and origination rate of the back mangrove palm genus *Nypa* during the Paleocene-Eocene transition is important in understanding the effect of global warming on mangrove vegetation in paleo-equatorial regions.

Early Paleogene mammal faunas of India are of great importance in understanding the origin and early evolutionary history of different groups in the context of India-Asia collision, hyperthermal events, and biogeographic dispersal. A collaborative study (Cooper *et al*., 2014) on anthracobunids, a middle Eocene family of large ungulate mammals from South Asia demonstrated that this group, as well as the previously named family Cambaytheriidae, are stem perissodactyls. Analyses of stable isotopes and long bone geometry together indicated that most anthracobunids fed on land, but spent a considerable amount of time near water. An equally important recent find is the oldest South Asian tapiroid (*Cambaylophus vastanensis*) from the early Eocene (~54-55 Ma) Cambay Shale at Vastan lignite mine, Gujarat. India (Kapur and Bajpai, 2015). This new taxon appears to be closely nested with the early Eocene (Bumbanian) tapiromorph *Orientolophus* from China and suggests a degree of terrestrial connectivity between the Indian Subcontinent and the Asian landmass Asia around the time of India-Asia collision, at or near the Paleocene-Eocene boundary.

Quantitative estimates of climatic parameters of the Indian subcontinent during pre- and post-India-Asia collision stages are of great interest. Collaborative investigations of the early Eocene (~55-52 Ma) Gurha Lignite Mine section of Rajasthan yielded a diversity of fossil leaves, flowers, fruits and seeds (Shukla *et al*., 2014). CLAMP analysis of the recovered fossil leaves indicated cool equatorial (~10°N) temperatures and a monsoonal climate during the early Eocene. The study also suggested that the South Asian monsoon already existed during the initial stages of India-Asia collision.

Studies on organic petrology of the Indian lignites and coals are also conducted at BSIP (eg. Singh and Singh, 2008). Such studies deal with the estimation of microconstituents (macerals) in coals/lignites formed during the transformation of vegetal matter into coal/lignite. The data on the type and amount of macerals (organic matter) and the degree of maturation (determined through vitrinite/huminite reflectance) of Indian coals/lignites have been variously interpreted in applied and academic research. A multidisciplinary approach involving palynology and palynofacies has been adopted in recent years to characterize and assess the depositional conditions of western Indian lignites. The variable values of tissue preservation and gelification indices and maceral composition of Mangrol lignite (Cambay Basin) indicate fluctuating groundwater conditions and differences in the type of vegetation during the accumulation of peat (Singh *et al*., 2013). High amount of amorphous matter (Kerogen I) in shales resting above the lignite and the high content of liptinite macerals (resinite + liptodetrinite) in lignites suggested the potential of lignite-bearing sequence for generation of hydrocarbons. Integrated petrographical, palynological and organic geochemical investigations were carried out to evaluate the source vegetation, depositional history and hydrocarbon source potential of Matanomadh lignites of Kutch (Dutta *et al*., 2011). The study concluded that the angiosperm-dominated woody forest vegetation served as the source material for lignites deposited in tropical to sub-tropical climatic conditions in coastal areas close to the palaeo-shoreline. High TOC and presence of mixed type II/III kerogens suggested that the lignite-bearing sequence has the potential to generate both oil and gaseous hydrocarbons on maturation. Similar, integrated studies are continuing in other lignite deposits of Gujarat and Rajasthan.

The Late Oligocene was the last major warm interval in earth's history before progressive Neogene cooling to the present day 'icehouse'. A study by Kumar *et al*. (2012) on late Oligocene deltaic sediments from the Tirap coal mine, Assam, NE India carried out CLAMP analysis of 80 fossil leaf morphotypes and worked out a mean annual temperature (MAT) of 26.1 ± 2.7ºC, a warm month mean temperature (WMMT) of 27.9º±3.3ºC and a cold month mean temperature CMMT of 20.1±4.3ºC. Precipitation estimates revealed a marked annual variation in rainfall with a pattern similar to the Sunderbans area of the modern Ganges/Brahmaputra delta. This study suggested that the South Asian Monsoon, with an intensity similar to present-day, was already established by the late Oligocene. In another study on Oligocene megafloral remains (Srivastava and Mehrotra, 2014), the record of *Bridelia* (Phyllanthaceae) indicated that the genus evolved ~25 Ma in Northeast India and later migrated to Southeast Asia via Myanmar and to Africa via the Iranian Route. In a similar finding, the fossil leaf of *Alphonsea* (Family Annonaceae) from the Late Oligocene of Makum Coalfield, Assam also indicates that the genus evolved in India and later migrated to SE Asia (Srivastava and Mehrotra, 2013). In another study, 11 petrified fossil woods belonging to seven families were described from the Tipam Group (Late Miocene-Early Pliocene), Mizoram (Tiwari *et al*., 2012). Using the Coexistence Approach, this study indicated the existence of a tropical warm and humid climate with MAT (mean annual temperature) of 26.1-27.7ºC, a mean temperature of the warmest month (WMT) of 25.4-28.1 C, a mean temperature of the coldest month (CMT) of 25.6-26ºC, and a mean annual precipitation (MAP) of 3180-3263 mm during late Miocene-early Pliocene in Mizoram. The climatic interpretations were considered congruent with anatomical features of the fossil taxa. The study also provided evidence of floral exchanges between India and southeast Asia.

Quaternary

Quaternary research forms the largest sphere of activity at BSIP, and a number of different proxies (microfossils including pollen, diatoms & phytoliths; elemental, stable isotopic and organic geochemistry; environmental magnetism; geomorphology; mineralogy; palaeoethnobotany; C-14 and luminescence dating) in varied climatic settings and terrains are currently investigated. Investigations are also being carried out in Antarctica and the Arctic. Scientists from BSIP regularly participate in the cruises of International Ocean Discovery Programs.

Reconstruction of open basin lakes in the cold arid region of NW Himalaya (Ladakh) is of considerable importance in understanding the tectonic-climate interplay. Three major palaeolakes (17-13 ka, 14-5 ka, 12-1 ka) have been studied recently in a 136 km stretch along the present Indus River valley (Nag and Phartiyal, 2015). Another study from the Tangtse Valley (Phartiyal *et al*., 2015) recorded deglaciation following the Last Glacial Maximum (LGM) and the Holocene warming, together with changing depositional regimes and varied sedimentary architecture comprising fluvial, lacustrine, colluvial, aeolian and flood sediments spanning past 48 ka. The study also found evidence of a sixth lake basin (nearly 40 km in length between 9 to 5 ka) on the western side of Pangong Tso in the present day Tangtse Valley. This palaeolake existed during the periods of high lake levels in Tibet, China.

Using pollen, magnetic susceptibility and carbon isotope proxies late Pleistocene climate variations in the Ziro valley of Arunachal Pradesh, NE India were studied (Bhattacharyya *et al*., 2014). The study revealed an increased intensity of SW monsoon from ~43,000 cal yr BP to 34,000 cal yr BP and a decline thereafter. Peak warm and humid phase occurred around 36,181 cal yr BP and 34,145 cal yr BP., Decline of monsoon during the LGM was inferred from a lower *Quercus*-*Pinus* Index. This study is important in understanding the climatic variations and possible teleconnections with the Himalaya and other parts of the world.

Dendrochronology is an important area of research at BSIP. A 422-year long tree-ring width chronology (spanning AD 1591-2012) from *Picea smithiana* in Khaptad National Park, western Nepalese Himalaya was recently developed in a collaborative study (Thapa *et al*., 2014). Seasonal correlation analysis revealed significant indirect relationship with spring temperatures leading to the reconstruction of March-May average temperature for the past 373 years (AD 1640-2012). The reconstruction was significant based on validation statistics commonly used in tree-ring based climate reconstruction. The temperature reconstruction identified several periods of warming and cooling. The reconstruction did not show a significant pattern of cooling during the Little Ice Age although a few cold episodes were recorded. The spring temperatures revealed relationship with the Sea Surface Temperature index over the equatorial Pacific Ocean, pointing to linkages with climatic variability on a global scale. In another study (Yadav *et al*. 2015), drought variability during the past ~300 years was studied in the Kumaun Himalaya, based on Standardized Precipitation Index (SPI) reconstructed using tree-ring width chronologies of the Himalayan cedar. The study noted a link between the rabi crop failures and food scarcity in the Kumaun region with the drought years recorded in observational and reconstructed SPI7-May series. In the western Himalaya, Yadav and Bhutiyani (2013) used the tree-ring data of Himalayan cedar from a network of six moisture-stressed sites to develop the November-April Snow Water Equivalent (SWE) extending back to A.D. 1460. In the Sikkim Himalaya, NE India, a mean late summer temperature reconstruction extending back to AD 1852 was attempted with the tree ring-width chronology of larch (*Larix griffithiana*) (Yadava *et al*., 2015).

To assess the mid-Holocene climatic fluctuations and their possible impact on the Harappan culture (Prasad *et al*., 2014), a multi-proxy study involving palynology, phytoliths, sedimentology, clay mineralogy, carbon isotope and magnetic mineralogy was conducted in lacustrine sediments from the sub-humid zone of Mainland Gujarat, in conjunction with archaeobotanical data. The study documented low lake level and dry climate during the period from ~5560 to ~4255 cal yr 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 the Harappan culture was probably linked to the excessive dry climate of the later phase of mid-Holocene (~4200-4255 cal yr BP).

Recently, in a palaeoethnobotanical study dealing with climate-culture relationships, archaeological datasets on small-grained millets from the core and peripheral regions of the Indus/Harappan civilization were studied in relation to crop economy and cultural change (Pokharia *et al*., 2014). These authors evaluated the significance of the fossil grains of sorghum millet, little millet, finger millet, pearl millet and foxtail millet from various archeological sites from the Early (3000-2500 BC), Mature (2500-2000 BC), and the Late Harappan (2000-1400 BC) sites. The study demonstrated a significant role of millets in the Harappan agricultural system since the Early Harappan period. The shift towards drought-resistant millet crops in the peripheral region of the Indus/ Harappan civilization was interpreted as a cultural adaptation in response to the decline of SW monsoon during the late Holocene (~ 4ka). Clearly, such adaptation strategies to persistent drought conditions in ancient civilizations provide a valuable perspective for possible strategic planning in the context of future climate changes.

The soils of the past, especially in the pre-Quaternary period, are of interest because of their value in deciphering ancient atmospheric CO_2 concentrations. Stable isotopic composition of vascular plant biomarkers from the Ganga Plain paleosols formed between 80 and 20 ka was studied recently (Agrawal *et al*., 2014). Carbon isotopic composition of C32 fatty acids suggested mixed C_3-C_4 plants over the Ganga Plain between 80-20 ka and a rapid doubling in 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 in the Ganga Plain. Overall, the study emphasized that the local palaeovegetation history of the Ganga Plain can be reconstructed using the stable carbon isotopic compositions of selected higher plant wax biomarkers and long chain fatty acids, especially C32.

Large Igneous Provinces (LIPs), which host mafic rocks spread over millions of square km, have an important bearing on global sediment production and distribution. Recently, Sharma *et al*. (2013) conducted a case study on the texture, mineralogy, and chemical composition including REE of fine sand/ silt from the Mahi River of western India flowing in a tectonically active, semi-arid region and draining through the Deccan Traps, one of the largest LIPs in the world. This study showed about 70-75% contribution was from the Deccan Traps and 25-30% contributions from the Archaean biotite-rich granitoids. The data are important in ascertaining the source characteristics of the alluvium and in evaluating comparative elemental mobility in relation to the role of climate in weathering processes.

Luminescence dating is one of the recently established laboratories at BSIP. A recently proposed mechanism seeks to understand the role of band-tail states of feldspars in infra-red luminescence production (Pagonis *et al*., 2014). Such studies are important in exploring more stable signals (i.e. less anomalous fading) and may eventually help date older sediments using feldspar (Morthekai *et al*., 2015). A major objective of ongoing efforts in the Luminescence Dating Lab at BSIP is to increase the overall accuracy and precision of ages derived from both quartz and feldspars.

Concluding Remarks

The newly renamed *BSIP* is now well placed to carry out multidisciplinary research in the vast field of palaeosciences including palaeobotany, palaeozoology, palaeoclimatology, palaeoenvironments, palaeobiogeography, palaeogeography, palaeoethnobotany, and numerous other related aspects. It is hoped that the new name will enthuse new energy and the pool of young scientists of BSIP, with nearly half of them below the age of 40 and over one-third of them women, will achieve the potential that the exciting field of palaeosciences offers.

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