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Institutional Report

Recent Advancement(s) at the Birbal Sahni Institute of Palaeosciences, Lucknow: An Overview

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Introduction

Bestowed with the legacy of Prof. Birbal Sahni for deciphering the evolutionary history of Kingdom Plantae through the study of plant fossils, the Birbal Sahni Institute of Palaeosciences (BSIP), erstwhile Birbal Sahni Institute of Palaeobotany has grown manifold in the fields of the evolutionary history of plants, palaeoclimate, and palaeoecology. The establishment of new instrumentation facilities and the induction of scientists has led to the development of the BSIP in recent years. Presently, this institute's research activities include the study of plant fossils, and associated micro- and macrofossils (palynomorphs, nannofossils, diatoms and others), insects, vertebrates, palaeo-climates, -environments, -ecosystems, -biogeography, -archaeobotany, biostratigraphy, geochemistry, fossil fuel exploration, carbon dating, DNA sequencing and development of analytical techniques. This overview highlights some noteworthy research activities carried out from January 2016 to March 2019 and discusses the significance of these research contributions in developing an understanding of the fossil records in terms of deciphering the evolutionary history of biotapast ecosystem and climatic changes through the earth's history.

Within the realm of the existing mandate, the BSIP executes multidisciplinary research in the field of Palaeosciences. A total of sixty-one project components were incorporated under ten major projects which include:

1. Early life and environment: Evidence from Indian Precambrian basins.
2. Emergence, biotic crisis, adaptation and radiation of life forms during Paleozoic and Mesozoic: An integrated approach.
3. Palaeobiogeography, biotic and climatic events, characterization of the biomarker in the terminal Cretaceous-early Palaeogene sequences of India.
4. Understanding monsoonal variability and its relationship with the global climate during the Neogene using biotic and abiotic proxies.
5. Vegetation dynamics and palaeoclimate of late Quaternary sequences of the Himalayan region.
6. Monsoonal variability and climate change during late Quaternary in Peninsular India inferred from palaeovegetation.
7. Late Quaternary Palaeoclimate and palaeoceanographic variability from marine records.
8. Holocene monsoonal variability and its associated forcing factors inferred from abiotic proxies.
9. Archaeology, Archaeochemistry, Palaeogenomics/metagenomics: Implications to human-environment interaction during the Holocene.
10. Laboratory establishment and protocol development for new proxy parameters and smooth functioning of sophisticated analytical facilities.

Several analytical facilities/laboratories that include X-Ray Fluorescence Laboratory, Nutrient Analyzer Facility, Vertebrate Palaeontology and Preparation Laboratory, Ancient DNA Laboratory, and Modern DNA Laboratoryhave been set up within BSIP, since 2016 (Refer link: www.bsip.res.in). BSIP

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scientists are actively involved in providing help to Oil and Natural Gas Corporation, Oil India Limited, Coal India Limited, and Archaeological Survey of India, in studies involving palaeobotanical and micropalaeontology aspects, in addition to their institutional research activities.

Highlights

Precambrian

Palaeobiological and chemostratigraphic records from Indian Proterozoic successions are well robust to solve the riddle of evolution and diversification of early life. A considerable large dataset on palaeobiology, geochronology, and chemostratigraphy from the Indian Precambrian sedimentary basins is available. Because of the above aspects, palaeobiological evidence of Indian Palaeoproterozoic to Cambrian successions (Sharma *et al.,* 2016; Sharma and Singh, 2019) and new prospects of the Bijaigarh Shale (Ansari, 2017) were appraised. A new enigmatic Ediacaran form (putative seaweed) from the Sonia Sandstone (Marwar Supergroup) was reconstructed (Kumar and Ahmad, 2016; Pandey and Sharma, 2017). Organic walled microfossils were studied in a biostratigraphic framework from the Kurnool Group, Chattisgarh, and Vindhyan supergroups (Singh and Sharma, 2016; Sharma and Shukla, 2016; Shukla and Sharma, 2016). Stable isotopic studies from the Marwar Supergroup and the Garbyang Formation (Tethys Himalaya) suggest the presence of Precambrian-Cambrian boundary within these successions (Ansari *et al.,* 2018, 2019). Two significant trace fossils (*Treptichnus pedum* and *Monomorphichnus multilineatus*) from the Nagaur Sandstone (Marwar Supergroup, Rajasthan) were studied to understand change(s) in the Precambrian-Cambrian ecosystem (s) (Sharma *et al.*, 2018a, 2018b). In Astrobiological context, modern geo-site(s) (e.g., Ladakh: as an off-Earth analog) and Precambrian rock sequences were explored by BSIP scientists (Pandey *et al.*, 2019; Steller *et al*., 2019). Recently, Sharma and Shukla (2019) documented the existence of ancient life in extreme environments based on Akinites from the Vindhyan Supergroup. In a collaborative study, Limaye *et al.* (2018) revealed the possibility of life in the spectral signature reflected from the cloud of planet Venus. This study has opened newer opportunities for exploring life's signature(s) in different planets. Previously, modern glaciers and their catchment areas were studied to understand the sulfur and nitrogen pathways to comprehend similar ancient environments (Ansari *et al.,* 2016a, 2016b).

Palaeozoic-Early Mesozoic

Palynological studies, supplemented by detrital zircon U-Pb ages, from the *Fenestella* Shale Formation (Carboniferous) near the Gund Village in the Banihal area of Jammu and Kashmir State, India have been carried out for the first time (Agnihotri *et al.,* 2018). Geochemistry of the Permian-Triassic sequences of the Guryul Ravine section, Jammu and Kashmir, India, reveals implications for oceanic redox conditions (Kumar *et al.,* 2017). Evidence of repeated fire events in the Early Permian 'peat-forming' vegetation of India has been detected (Jasper *et al.,* 2017). The Lower Triassic deposits represent hot-arid conditions along with the braided river systems (Mishra *et al.,* 2017). Palynological and petrological studies undertaken on the Gondwana coal and associated lithologies encountered in borehole EBM-2 of East Bokaro coalfield of Damodar Basin, India were used to determine the depositional environment of the coal precursor peat swamp (Murthy *et al.,* 2016). Permian (Lower Gondwana) and Late Jurassic-Early Cretaceous (Upper Gondwana) palynomorphs and megafossils have been recorded from Nimugudem area, Godavari sub basin, Telangana, India (Jha *et al.*, 2016). A new species of fossil wood, *Circoporoxylon kotaense*, was systematically described from the Jurassic Kota formation, in the Pranhita-Godavari Basin, India (Chinnappa and Rajanikanth, 2016). The palaeoenvironmental reconstruction of freshwater sequences in the Lingala-Koyagudem Coal belt of the Godavari Graben, using palynofacies was carried out by Agarwal *et al.* (2019). Murthy *et al.* (2018) documented, for the first time, the palynological assemblage from the Rajmahal basin, probably from the Late Pennsylvanian age. Diverse macrofloral assemblage recovered from Tatapani-Ramkola Coalfield, Son-Mahanadi Basin, India suggested that plant life was gradually transformed and evolved near Raniganj-Panchet boundary, rather than a taxonomic turnover (Saxena *et al.,* 2019). A review of the palynostratigraphy of Gondwana sediments from Godavari Graben, India with a global comparison and correlation of Permian-Triassic palynoflora was also carried out by Jha *et al.* (2018).

Late Cretaceous-Cenozoic

BSIP has been conducting significant research to trace the early evolutionary history of angiosperms in a palaeobiogeographic framework. Institute's scientists have been continuously exploring plant fossils and associated microbiota from within the Late Cretaceous-early Palaeogene Deccan volcano-sedimentary sequences of peninsular India and the Palaeogene-Neogene sedimentary sequences in the western and northeastern regions of India. In a recent collaborative study by BSIP, scientists have recorded the earliest fossil record of the family Connaraceae within the Late Cretaceous-early Palaeogene intertrappean beds of central India (Bass *et al.,* 2017). Kathal *et al.* (2017) recorded *Nypa* (*Rhizopalmoxylon nypoides*) from the late Maastrichtian-early Danian intertrappean beds of central India that indicated marine influence in the region. An assemblage of microfossils consisting of non-marine ostracods, charophyte gyrogonites, mollusks, and fish remains were reported from a new Late Cretaceous intertrappean locality near the town of Manawar, District Dhar, Madhya Pradesh, Central India (Kapur *et al.,* 2018) that indicated the presence of a freshwater palustrine/lacustrine depositional system connected to a low energy stream/river in the region. A new adapisoriculid mammal *Bharatlestes kalami* was identified from the early Eocene Cambay Shale sediments of western India (Kapur *et al.,* 2017a, 2017b). Phylogenetic analysis suggested that *Bharatlestes* is derived from the older genera *Deccanolestes* and *Afrodon* and primitive compared to European *Bustylus* and *Adapisoriculus*. Overall, this data provided evidence for the continued survival of a Gondwanan mammal lineage following the Deccan volcanic activity (Cretaceous-Palaeogene transition) in the Indian Subcontinent. Prasad *et al.* (2018a) provided new evidence (based on palynomorphs) from an inland location in the Deccan province suggestive of the existence of a shallow marine embayment in central India during the late Maastrichtian. The study supported "Out of India" dispersal of dipterocarps based on evidence of fossil pollen of Dipterocarpaceae. A fossil leaf of *Aporosa* Blume (Phyllanthaceae) from the Paleogene of the Indian subcontinent supported the origin of the genus on the Indian subcontinent, and subsequent dispersal to Southeast Asia (Shukla *et al.,* 2016). Besides, a record of *Chisocheton* (Meliaceae), *Dioscorea eocenicus* (Dioscoreaceae), *Holigarna grahamii* (Anacardiaceae) and associated fossil flora indicated the presence of tropical evergreen forests in western India during the early Paleogene (Shukla and Mehrotra, 2018, 2019; Shukla *et al.,* 2018).

A study carried out from northeast India indicated that ancestors of '*sweet potato*' originated in India (Srivastava *et al.,* 2018a). Numerous fossil woods from the northeast of India were also recorded from the late Miocene Tipam Group of Tripura and late Oligocene sediments of Assam (Mehrotra *et al.,* 2017; Mehrotra and Srivastava, 2017; Rajkumar *et al.,*2017). Of these, fossils of *Shorea* represent the first record of angiosperm wood from Manipur, while *Careya*is the first record of the genus from the Palaeogene sediments. Numerous Priabonian age calcareous nannofossils have also been reported from the Rewak Formation, Meghalaya (Singh *et al.,* 2016). Sarkar (2016) conducted a microfacies analysis in a palaeoenvironmental framework of the early Eocene Umlatdoh Limestone (Meghalaya) based on the fossil evidence on calcareous algae and foraminifers. Prasad *et al.* (2018b) carried out a multi-proxy study (i.e., incorporating sequence-, bio-stratigraphy, palynology, NLR approach) on the upper Paleocene-lower Eocene Jathang section, Meghalaya in a palaeoclimatic and palaeoenvironmental context. A co-existence analysis was carried on the Jathang pollen fossils that suggested very humid climatic conditions during the extreme global warming event globally known as Paleocene Eocene Thermal Maxima (PETM) event at 55.5 Ma.

Combined palynological and stable carbon isotope ($\delta^{13}C$) investigations were compiled in the lignite sequence at Panandhro, Kutch Basin, Gujarat (Agrawal *et al.,* 2017). Dinoflagellate cysts and associated spore-pollen assemblage assign an early Eocene (Ypresian) age to the lignitic succession at Panandhro. Furthermore, a pronounced negative carbon isotope excursion of about 2.7%, correlated to the globally significant hyperthermal event, second Eocene Thermal Maximum (ETM2), was discovered in the middle part of the succession, consistent with the palynological constraints. This is the first record of a hyperthermal event (ETM2) from the Kutch Basin. Earlier, Mathews and Singh (2016), utilizing FTIR, pyrolysis and GC-MS analysis, characterized the handpicked solid bitumen (viscous residue of

hydrocarbon) found as fillings in the lignite of the Panandhro field, Gujarat. Detailed collaborative studies to understand the palaeodepositional history of the early Paleogene lignite sequences of western India by utilizing organic petrography, palynology and palynofacies were also carried out in detail (Singh *et al.,* 2017a, 2017b; Matthews *et al.,* 2018). A palynological and palynofacies analysis of the early Eocene lignitic sediments at Gurha Lignite Mine was carried out by Kumar *et al.* (2016).

The collaborative studies on the amber biota from the early Eocene lignite associated sequences of western India have recorded the insect fossils of family Chironomidae (represented by 192 specimens belonging to five subfamilies) for the first time in India (Stebner *et al.,* 2017a). Earlier, indirect evidence for pheromone-mediated mating behavior was recorded from a new species (*Camptopterohelea odora*) of biting midge preserved within the 54 Ma Indian amber (Stebner *et al.,* 2016). In a separate study, seven extant and three fossil genera of biting midges were recorded from Cambay amber, and five new species were described (Stebner *et al.,* 2017b). Interestingly, this study suggested faunal exchange between Europe, Asia and India before the early Eocene.

An extensive study based on 82 species of planktic and benthic diatoms belonging to 32 genera (recovered from 21 outcrop samples from Neil Island, Andaman, and Nicobar Islands) including that of Ocean upwelling diatom species *Thalassionema nitzschioides*, Chakraborty and Ghosh (2016) provided evidence for prevalence of a robust monsoonal system with weaker intermittent monsoonal activity in the region during the late Miocene (Tortonian).

In a collaborative study based on CLAMP (Climate Leaf Analysis Multivariate Program) analysis on leaf fossils from the southern Tibet and the Himalayan foreland basin, and utilizing data on age-based on U-Pb dating on zircons, Ding *et al.* (2017) quantified the rise of the Himalayan. In separate collaborative work, a proxy of carbonate distribution within paleosol profiles was utilized to infer the appearance of monsoonal circulation of new strength in the Himachal Pradesh segment of the Himalayan foreland by at least 20 My ago (Retallack *et al.,* 2018). Spicer *et al.* (2017), based on the CLAMP analysis of the Paleogene fossil leaves from India and China, suggested that an Indonesian-Australian type of Monsoon system was present in the region. A fossil leaf of coryphoid palm reported from the Late Oligocene sediments of Lunpola Basin (Central Tibet) suggested that a valley system was present in the region (Tao *et al.,* 2019). *Lagerstroemia* L. fossil wood was recorded from the late Miocene sediments of Ladakh and indicated the prevalence of warm and humid climate in the region (Srivastava *et al.,* 2018b). In another collaborative study, a recent discovery of *Ailanthus* fossil from the Late Oligocene sediments of central Tibet indicated a floristic exchange between India and Eurasian plates (Liu *et al.,* 2019).

Concerning the Neogene biotic records, the institute scientists recorded both fauna and flora from the western and northeastern regions of India. Bhandari *et al.* (2018) reported evidence of hominoid (*Sivapethicus*) remains from the late Miocene sediments of Kutch, Gujarat. Kapur *et al.* (2019) recorded numerous microcoprolites (representing three morphotypes) linked to ichthyophagous fishes from the Aquitanian (Miocene) Khari Nadi Formation of Kutch, Gujarat. Various fossil woods were recorded from the Middle and Upper Siwalik sediments of Arunachal Pradesh, indicating less seasonality in temperature and rainfall in the region (Srivastava *et al.,* 2018c; Mehrotra *et al.,* 2018).

Quaternary

Himalayan Region

The Quaternary research going on at the BSIP has a wide range of working aspects based on various biotic and abiotic proxies to decipher palaeoclimate and palaeoecology from large geospatial extents. From the eastern Himalaya region, transfer function model for quantitative past climate reconstruction was developed for various climatic variables using the modern pollen-climate dataset (Ghosh *et al.,* 2017) which suggested that winter temperature was the dominant controlling factor for the glacial changes across the Last Glacial Maxima (LGM) in the eastern Himalaya. Ghosh *et al.* (2018) studied hydroclimatic variability and corresponding vegetation response in the Darjeeling Himalaya, India, over the past ~2400 years using multi-proxy records. This study identified a humid climatic phase at the beginning of the last

millennium, a pre-Medieval Warm Period (MWP) less humid phase, while MWP was wetter than the former stage and a wet Little Ice Age (LIA) in the Darjeeling Himalaya. A study based on multi-proxy records on glacial outwash sedimentary profile of Sikkim, eastern Himalaya showed decadal to centennial-scale records and identified five positives and three negative excursions of the Indian Summer Monsoon (ISM) since last ~13 ka (Ali *et al.,* 2018). The most prominent abrupt negative ISM shift was observed during the termination of the Younger Dryas (YD) between ~11.7 and 11.4 ka. The high elevation lake catchment of Arunachal Pradesh, eastern Himalaya, recorded environmental changes around 4.2 cal yr BP (Mehrotra *et al.,* 2019). There were episodes of monsoon intensification during the Mid Holocene, followed by low temperatures and high aridity conditions during the abrupt climate change event period of the early Late Holocene. Pollen analysis has also been carried out on sedimentary core from Loktak Lake (the biggest freshwater lake in Manipur state, northeast India) recorded vegetation and climate of the region during the Late Holocene (Tripathi *et al.,* 2018).

Vegetation and climate during later part of Pleistocene to a significant portion of Holocene (~16.6-3.5 ka) have been reconstructed based on the palynological and magnetic susceptibility proxies from Kinnaur, western Himalaya (Ranhotra *et al*., 2018). The distinct spike in the magnetic susceptibility values between ~8.7 and ~7.8 ka marked as a global 8.2 ka cool event. The palynological study carried out from the wetlands of Jammu and Kashmir recorded four phases of variations in the ISM precipitation, i.e., decreased monsoon precipitation during ~8536-5296 cal yr BP, increased monsoon precipitation during ~5296-2776 cal yr BP, further increase in monsoon precipitation during ~2776-1336 cal yr BP and decrease in monsoon precipitation during ~1336 cal yr BP to present (Quamer, 2019). Additionally, a palaeolake sequence along the River Indus of the Ladakh sector studied for sedimentological characteristics sheds light on depositional environmental changes within the lake from post-LGM to 5 ka (Nag *et al.,* 2016).

Central India

The palynological studies from the Core Monsoon Zone of India recorded palaeoclimate for the Mid to Late Holocene period. The Mid-Holocene pollen records from SW Madhya Pradesh reported a dry climate during 5679-4939 cal yr BP that changed to warm and humid conditions with increased monsoonal precipitation between 4939-3762 cal yr BP (Quamar and Nautiyal, 2016). The pollen records from Chhattisgarh (Quamer *et al.,* 2017) showed a humid climate probably indicative of moderate monsoon precipitation between ~3796 and ~2428 cal yr BP, which subsequently turns into the warm and relatively more humid climate with increased monsoon precipitation during ~2428 and ~1431 cal yr BP. The ISM variability during the Holocene from CMZ of central India was studied based on multi-proxy records and identified the weakening and enhancement of monsoon intensity in different periods of Holocene (Kumar *et al.,* 2019).

The palynological analysis coupled with sediment grain parameters carried out on lacustrine sediments of eastern Ganga Plain showed ISM variability since 1350 A.D (Saxena and Singh, 2017). The signals of weak monsoon recorded in this proxy record around 1650, 1770, and 1850 A.D. are synchronous with the LIA. In addition to pollen study, diatoms in Lahuradewa lake sediments, Ganga Plain support the contention that the human population was living in this area since early Holocene and agriculture activity started around 8 ka (Thakur *et al.,* 2018). Trivedi *et al.* (2019) highlighted the climate-induced changes in the vegetation, ecology and culture since ~25500 cal yr BP from the central Ganga plain and reported that during the last two millennium and until ~1550 AD, the region was under immense human pressure of Kushana, Gupta and Mughal cultures, which is evident by the artifacts recovered. Similarly, the archaeobotanical dataset produced from the region of Kutch, Gujarat, NW India, has revealed a dominance of millets (drought-resistant crops) during Late Holocene (4.2k cal yr BP), an example of human adaptation in response to climate variability (Pokharia *et al.,* 2017).

Coastal Zone

In India, the coastal wetlands sustain millions of people and are more vulnerable to the effects of rise/fall in relative sea level and changes in marine ecosystems. Mangrove extinction and migration were assessed

through palynological studies in sedimentary cores to address climate, relative sea level and its relation to geomorphology since 8420 cal yr BP in Krishna delta (Farooqui *et al.,* 2016) and since 7000 cal yr BP in Cauvery delta (Srivastava and Farooqui, 2017). Results indicate climate-induced relative sea-level fluctuations highlighting the cooling event of 8.2k cal yr BP from Kanuru site in Krishna delta and duration of intermittent rise/fall of relative sea-level during middle Holocene transgression (Farooqui *et al.,* 2016). The results from Cauvery delta show that mangroves existed since 4000 cal yr BP in the Pichavaram estuary. During this period, evidence of marine palynomorphs have been recorded at present mean sea level in Vellar, Pichavaram, and Coleroon estuary but in TS Pettai it is about 4m below current mean sea level indicating land subsidence of about 2-3m in TS Pettai, the central part of Northeastern Cauvery delta providing a conducive environment for the growth and diversity of mangroves in this part of delta (Srivastava and Farooqui, 2017). Palynological study of surface sediments and shallow sedimentary cores from Pulicat lagoon post floods in Chennai after heavy rainfall in 2015 reveal indicator species of diatom as indicators of extreme events (Santhanam *et al.,* 2016). A sediment core from Kukkal lake, Tamil Nadu, was studied for a continuous sediment record from 9000 cal yr BP to present (Rajmanickam *et al.,* 2017). Climate proxies, including sediment texture, total organic carbon (TOC), total nitrogen, C/N, pollen and geochemical composition, indicate a steady progression to wetter conditions with two stepwise changes at about 8000, and between 3200-1800 cal yr BP. Another palynological study of an organic layer buried ~80 ka in Chaganacherry, Kerala, revealed a rich diversity of rainforest pollen amongst which the *Basella* pollen recorded shows central characters of two extant *Basella* species. Hence, the recovered pollen was ascertained as a new extinct species named as *Basella keralensis* sp. nov. (Farooqui *et al.,* 2019). Surface sediments in the Vembanad wetland system, southwest India, were analyzed for metal contamination using individual and combined metal pollution indices (Manoj *et al.,* 2018). The results show high heterogeneity of sediment characteristics, sources, sedimentary dynamics and geochemical processes. The main contaminated metal contribution appeared to be the anthropogenic input and small amount of the weathered rocks and sediments present in the course of the rivers.

Polar Region

BSIP is also involved in various Quaternary palaeoclimatic studies in the polar area (Antarctic and Arctic) and oceanic sector (Southern Ocean, Bay of Bengal, and the Arabian Sea). Geochemical and sedimentological analysis of the lake core (L-6) in the Schirmacher Oasis (SO), East Antarctica was conducted to understand the spatial and temporal extension of the paleoenvironmental evolution of the lakes in SO (Govil *et al.,* 2016). The present study identified a colder phase (or re-advancement of the continental ice sheet) during the early to mid-Holocene and initiation of ice-free or continental ice-sheet retreat during the late Holocene and their implications on the productivity changes. The study of quartz grain morphology and microtexture along with sand percentage is used to reconstruct the paleoenvironmental changes in the Proglacial Lake situated in the Schirmacher Oasis, East Antarctica during the Holocene (Mazumdar *et al.,* 2017). The study suggests probable alternative colder and less cold phases in the study area, which is also well supported by the respective sand percentages in the sediments. To understand the role of sedimentary processes and their periodicities to understand the forcing mechanism responsible for the regional climate variations, various sedimentary parameters and biogenic silica were used in the lake of SO, East Antarctica (Govil *et al.,* 2018). The long-term trends in the data suggest the possible fluctuation of the Antarctic ice-sheet superimposed on global climatic fluctuations due to solar activity. Studies were also carried out in the Arctic region to understand past environmental changes. Quartz grain microtextures have been used to deduce the past environmental changes from the Ny-Alesund area, Svalbard, along with magnetic susceptibility data (Kar *et al.,* 2018). Mid- and late Holocene is marked by a predominantly glacial environment characterized by meltwater streams originating from the glaciers and flowing into the fjord.

Marine Records

The high-resolution records of diatom frustules from the Southern Ocean sediment cores revealed the control of iron availability or other environmental conditions such as Sea Surface Temperature (SST) and/or sea ice presence on the morphometric variation of different diatom species. Shukla *et al.* (2016)

reported the first study on modern sediments from the Southern Ocean to explore the variability of the mean valve area of *Thalassiosima lentiginosa* concerning productivity and current environmental conditions. *T. lentiginosa* means valve area variations in four deep-sea cores across the frontal zones in the Atlantic and Indian sectors of the Southern Ocean resulted from changes in SST and sea-ice presence modulating the species ability to make use nutrient stocks and controlling the length of its growing season, respectively. Shukla and Crosta (2017) suggested that more favorable SST, within the *Fragilariopsis kerguelensis* ecological range, during the Last Glacial period might have enabled *F. kerguelensis* to make better use of the low silica stocks prevailing in the subtropical zone leading to larger valves. Shukla and Romero (2018) studied *F. kerguelensis* size variation in core GeoB3606-1 collected in the Benguela Upwelling System, where *F. kerguelensis* valves were preserved during the glacial period (68-30 ka) as a consequence of silicic acid leakage from polar to mid-latitudes. Nair *et al*. (2019) documented the interactions between Southern Hemisphere high-latitude (Antarctica & Southern Ocean), southern Indian Ocean subtropics (Agulhas leakage), and Asian summer monsoon.

Based on new studies, the spatial distribution of organic-walled dinoflagellates cyst is studied in the 50 surface samples of eight transects from the western Bay of Bengal, to infer variation in the environmental conditions in the region (Uddandam *et al.,* 2017). Statistical analyses indicate that salinity and silicates, as a significant source of nutrients, played a vital role in the distribution of dinoflagellate cyst in the Bay of Bengal. A new organic-walled dinoflagellate cyst *Cristadinium striatiserratum* has been reported from the modern sediments of the northern Indian Ocean (Uddandam *et al.,* 2018). The study extends the geological range of the peridinioid species that consist of complete paratabulation from the Neogene to Holocene. The presence of Australasian microtektites was studied in U1452 core retrieved during the International Ocean Discovery Program (IODP) Expedition 354:Bengal Fan (Kawsar *et al.,* 2018). Other than microtektites, the presence of a possibly polymetallicex solution structure (Widmanstätten texture), shocked minerals and unmelted and partly melted ejecta within the microtektite-bearing layer in the northern Indian Ocean provides further evidence that the Australasian microtektites might have been formed by the impact of an extraterrestrial projectile at ~0.8 Ma, somewhere in Indo-China.

Paleoclimatic studies using multi-proxy records from the NE Arabian Sea revealed the variations in the shelf environment of the western continental margin of India (Azharuddin *et al.,* 2017, 2019). The periodicities in the multi-proxy record consisted of similar cycles, which also match with previously reported solar insolation influenced Southwest Monsoon (SWM) and other global and regional cycles. The observations suggested that the solar insolation was a leading factor responsible for the SWM trends during the Holocene, which might have further influenced the productivity, regional sea-level fluctuations and depositional conditions in the NE Arabian Sea.

Tree-ring Studies

Tree-ring studies from the Himalaya region were carried out on various aspects such as climate reconstruction, glacial behavior, and tree-line dynamics. In the western Himalaya region, tree-rings of *Cedrus deodara* and *Pinus gerardiana* were used to reconstruct boreal spring (March-May) precipitation covering the last millennium (1030-2011 C.E.) and established its large-scale consistency with hydrological records from westerly-dominated regions in Central Asia (Yadava *et al.,* 2016). The behavior of western Himalayan glaciers for the past four centuries was studied using tree-ring based reconstructed glacial mass balance data (Shekhar *et al.,* 2017), which showed that the fluctuation of the Himalayan glaciers largely depends on oceanic currents and total solar irradiance. Three different climatic reconstructions for Jammu and Kashmir, Northwest Himalaya, were developed using tree-rings data of conifers. These are a 275-year (1740-2014 C.E.) eight-month May SPI reconstruction (Singh *et al.,* 2017c), April-June precipitation from 1723 to 2013 C.E. (Shah *et al.*, 2018) using *C. deodara* and compared with the documented extreme flood, famines and drought events in Kashmir Valley. The winter (November-March) temperature reconstruction (1840-2012 C.E.) from Kashmir valley based on tree-ring of *Pinus wallichiana* recorded marked warming trend at the beginning of the late twentieth century till

2012 (Shah *et al.,* 2019). From the eastern Himalaya region, a first tree-ring chronology of broad-leaved taxon, *Toona ciliata*, was developed (Shah and Mehrotra, 2017). Besides, the impact of climate change on treeline dynamics using tree-rings was investigated, which showed that *P. wallichiana* had shifted towards the upper elevation with varying rates of 11-54 m/10 yrs (Yadava *et al.,* 2017).

Ancient DNA Studies

In addition, BSIP also conducted the largest-ever study of ancient human DNA in South Asia and sequenced the first genome of an individual from the ancient Indus Valley Civilization, which revealed unprecedented shifting ancestry of central and south Asian populations over time. The research on similar aspects also answered longstanding questions about the origins of farming and the source of Indo-European languages in South Asia. The first ancient human genome from mature Indus valley civilization has revealed no evidence of ancestry from Central Asia, Steppe, and Early Iranian farmers disprove the hypothesis that Agricultural practices in Indus Valley Civilization were expanded from Neolithic Iran (Shinde *et al.,* 2019).

Modern Pollen Analogues

Studies on modern pollen analogues have long been a valuable tool used in the qualitative and quantitative reconstruction of vegetation and environment of Quaternary. Recently, modern palynological studies from coastal wetlands (Srivastava *et al.,* 2019; Pandey and Minckley, 2019), high altitudinal regions of Himalayas (Dubey *et al.,* 2017; Ghosh *et al.,* 2017; Bajpai and Kar, 2018; Quamar *et al.,* 2018; Roy *et al.,* 2018), northeastern region of India (Tripathi *et al.,* 2017; Basumatary *et al.,* 2018), North India (Trivedi *et al.,* 2016; Saxena *et al.,* 2017; Bera *et al.,* 2018) and central India (Quamar and Bera, 2019) have assessed its potential in the interpretation of fossil pollen records to reconstruct past climate in tropical, sub-tropical and temperate zones at different timescales during the Quaternary.

Conclusions

The contributions from more than 250 staff members of the BSIP, including the scientific, technical, and administrative personnel, have brought forth the research accomplishments of BSIP, Lucknow. The constant zeal to seek excellence and put forth substantial results is the primary aim for each member of the institute. Staff at BSIP is grateful to all the funding agencies for supporting the various scientific ventures leading to the success of institute.

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