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Pollen evidence of vegetation succession, climatic changes and human impact in southern Madhya Pradesh during last ca 6,700 years

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ABSTRACT

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Pollen records of a 2.0 m deep sediment profile from Barehata Tal portray the vegetation scenarios and contemporaneous climatic events of southern Madhya Pradesh prior to Mid–Holocene. Between 6,700 and 6,015 cal yr BP, the region supported open mixed tropical deciduous forests comprising sparingly distributed trees, viz. *Moringa oleifera*, *Acacia*, *Trewia nudiflora*, *Madhuca indica*, *Terminalia* and *Aegle marmelos* under a warm and less–humid climate than today. The record of Cerealia pollen from the beginning of the pollen sequence denotes the cereal–based arable crop economy in the region. The lake did exist, but it was of small expanse as depicted by the deficient aquatic element, *Potamogeton*. Around 6,015 to 4,848 cal yr BP, the enhancement in *Acacia*, *Moringa oleifera*, *Trewia nudiflora*, *Madhuca indica* coupled with moderate increase in *Terminalia*, *Aegle marmelos*, *Holoptelea*, etc. suggest the proliferation of mixed deciduous forests with the arrival of a warm very humid climate attributed to active SW monsoon. The agrarian activities also intensified with the initiation of favourable climatic condition as testified by the increase in Cerealia and cropland weeds. The lake turned bigger in stretch as documented by the improvement in *Potamogeton* and *Typha* along with sporadic appearance of *Zygnema.* The abrupt decline in the number as well as frequencies of the trees existing earlier implies that the forest became sparse around 4,848 to 3,671 cal yr BP with the onset of a warm and dry climate, most likely due to weak SW monsoon. Between 3,671 and 2,450 cal yr BP, the expansion forests took place with the substantial rise of *Acacia*, *Madhuca indica* and *Holoptelea* and re–incursion of *Tectona grandis*, *Buchanania lanzan*, *Schleichera oleosa*, *Schrebera*, *Aegle marmelos*, *Grewia*, etc. This diversification of the forests signifies the advent of a warm and moderately–humid climate. There was augmentation in the agricultural practice and other human activities as evidenced from the consistent encounter of Cerealia and culture pollen. The lake attained a wider spread as a result of increased monsoon precipitation. Around 2,450 to 1,230 cal yr BP, the forests declined, which is manifested by the depletion in the prominent ingredients, excepting *Grewia*, *Schleichera oleosa*, *Tectona grandis* and *Aegle marmelos*. This change in the vegetation scenario reflects the prevalence of a warm and less–humid climate again. However, from 1,230 cal yr BP onwards, the enrichment of forests elucidates that a warm and humid climate prevailed in response to increased monsoon precipitation.

Key–words—Pollen records, Vegetation, Climate change, Prior to Mid–Holocene, Barehata Tal (M.P.).

पिछले 6,700 वर्षों के दौरान दक्षिणी मध्य प्रदेश में वनस्पति अनुक्रम, जलवायवी परिवर्तन एवं मानव प्रभाव का पराग प्रमाण

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सारांश

बरेहटा ताल से एक 2.0 मीटर गहरी अवसाद परिच्छेदिका के पराग अभिलेख मध्य–होलोसीन से पूर्व दक्षिणी मध्य प्रदेश की वनस्पति परिदृश्य एवं समकालीन जलवायवी घटनाएं आलेखित करते हैं। 6,700 एवं 6,015 वर्ष पूर्व के दरम्यान, अंचल ने आज की अपेक्षा कोष्ण एवं अल्प–आर्द्र

जलवायु में अल्प विस्तृत वृक्षों अर्थात *मोरिंगा ओलीफेरा, एकैसिया, ट्रेविया नडीफ्लोरा , मधुका इंडिका, टर्मिनेलिया* एवं *एग्ले मार्मिलोज* सन्निहित विवृत मिश्रित उष्णकटिबंधीय पतझड़ी वनों को संबल प्रदान किया। अंचल में पराग अनुक्रम की शुरूआत से धान्य पराग का अभिलेख धान्य–आधारित कृष्य उपज निरूपित करता है। झील भी विद्यमान थी, परंतु यह अल्प विस्तृत थी जैसा कि न्यून जलीय तत्व *पोटामोगेटन* से चित्रित है। लगभग 6,015 से 4,848 वर्ष पूर्व के लगभग, *टर्मिनेलिया, एग्ले मार्मिलोज, होलोप्टेलिया* इत्यादि में मध्यम वृद्धि से युग्मित *एकैसिया, मोरिंगा ओलीफेरा, ट्रेविया नडीफ्लोरा, मधुका इंडिका* में वृद्धि सक्रिय दक्षिण–पश्चिम मानसून को समर्पित कोष्ण अति आर्द्र जलवायु के आगमन से मिश्रित पतझड़ी वनों के क्रम प्रसरण व्यंजित करते हैं। धान्य एवं शस्यभूमि घास–पात में वृद्धि से यथा प्रमाणित अनुकूल जलवायवी स्थिति के सूत्रपात से कृष्य सक्रियताएं भी तीव्र हो गईं। *जायग्नेमा* के कदाचनिक प्रगटन के साथ–साथ *पोटामोगेटन* व *टायफा* में उन्नयन से यथा प्रलेखित झील फैलाव में बड़ी हो गई। पहले मौजूद वृक्षों की संख्या के साथ–ही–साथ आवृत्तियों में यकायक पतन संकेत देता है कि दुर्बल दक्षिण–पश्चिम मानसून की सर्वाधिक संभावना के कारण कोष्ण व शुष्क जलवायु के प्रारंभ से 4,848 से 3,671 वर्ष पूर्व के लगभग वन विरल हो गया। 3,671 और 2,450 वर्ष पूर्व के मध्य, *एकैसिया, मधुका इंडिका* व *होलोप्टेलिया* की पर्याप्त वृद्धि तथा *टेक्टोना ग्रांडिस, बुकेनेनिया लेन्ज़न, सायलीचेरा ओलिओसा, सायरेबेरा, एग्ले मर्मेलोज, ग्रेविया* इत्यादि के पुनः अवतार से वनों का विस्तार हुआ। कोष्ण एवं माध्यम रूप से आर्द्र जलवायु का प्रादुर्भाव वनों का विविधरूपण द्योतित करता है। धान्य एवं संवर्धन पराग के सुसंगत समागम से यथा प्रमाणित है कि कृषि कार्य एवं अन्य मानव सक्रियताओं में वृद्धि थी। वृद्धित मानसून वर्षण के परिणामतः झील बहुत बढ़ गई। 2,450 से 1,230 वर्ष पूर्व के आस–पास, वनों का पतन हुआ, जो *ग्रेविया, सायलीचेरा ओलेओसा, टेक्टोना ग्रांडिस* और *मर्मेलोज* के अलावा, उन्नत सामग्री में ह्वास से प्रकट है। वनस्पति परिदृश्य में यह परिवर्तन पुनः कोष्ण एवं अल्प आर्द्र जलवायु की व्यापकता प्रतिबिंबित करता है तथापि 1,230 वर्ष पूर्व से वनों की समृद्धि स्पष्ट करती है कि वृद्धित मानसून वर्षण की अनुक्रिया में कोष्ण एवं आर्द्र जलवायु प्रबल थी।

सूचक शब्द—पराग अभिलेख, वनस्पति, जलवायु परिवर्तन, मध्य–होलोसीन से पूर्व, बरेहटा ताल (मध्य प्रदेश)।

INTRODUCTION

THE southwest (SW) monsoon system largely affects the major landscape of Africa and southeast Asia, including India (Overpeck *et al.*, 1996). In the Indian subcontinent, SW monsoon contributes 80% fraction of the annual precipitation (Gadgil, 2003). It is also influenced by El Nino, La Nina, Indian Ocean dipole and Walker Circulation in the equatorial Pacific (Kumar *et al.*, 1999; Krishnamurthy & Goswami, 2000). The empirical information concerning the climatic variability is only available for ca. 150 years or so for the Indian subcontinent (Singhvi & Krishnan, 2014). Therefore, there is utmost necessity of proxy data such as pollen, geochemical, isotope analyses from the sediment cores of continental and marine origin to supplement the information regarding the past climate change beyond this period on millennium and centennial time scales so as to develop the models for the assessment of future course of climate. The palaeoclimatic studies reveal strong SW monsoon during early Holocene, which gradually diminished with increased aridity by mid–Holocene (Steig, 2000). Global palaeoclimatic records unravel weakening of the SW monsoon ~5,000 to 3,500 cal yr BP including increased aridity in the NW India, Arabia and Sahara regions (Petit–Maire *et al.*, 1995). Although, several marine and continental records from eastern Arabian Sea and NW India respectively reveal a dry climatic spell during the mid–late Holocene (Caratini *et al.*, 1991, 1994; Sukumar *et al.*, 1993; Sarkar *et al.*, 2000), however, it could not be precisely decoded as there is spatial and temporal variability due to wider geographical locations and physiographical set ups of the different basins investigated so far (Kale & Singhvi, 2003). The pollen records from the sediment deposits from the tropical regions in India comprising south Indian mountains (Vishnu–Mittre & Gupta, 1968, 1971; Vasanthy, 1988; Gupta & Bera, 1996), Rajasthan Desert (Singh *et al.*, 1974), coastal region (Van Campo *et al.*, 1982; Van Campo, 1986; Tissot, 1986, 1990; Farooqui & Sekar, 2002; Farooqui & Achyuthan, 2006) and Central Ganga Plain (Chauhan *et al.*, 2009, 2015; Trivedi *et al.*, 2013) have provided comprehensive insight into the terrestrial and coastal vegetation succession in relation to monsoon fluctuations.

However, the reconstruction of antiquity of the tropical deciduous forests in central India, where most of the landscape supports about 28% forest cover of the country, has not yet been given much consideration, barring some information from northeastern (Chauhan, 1996, 2000, 2004, 2005; Yadav *et al.*, 2006) and southeastern region comprising the areas of Shahdol (Chauhan, 2002; Chauhan & Quamar, 2010) and Anuppur (Chauhan, 2015; Chauhan *et al.*, 2013) districts concerning the origin and history of tropical Sal (*Shorea robusta*) forests since prior to the Holocene, based on pollen evidence derived through the meticulous reconnaissance of sediment cores from swamps. Recently, such studies have been extended to Hoshangabad (Chauhan & Quamar, 2012a) and Betul (Chauhan & Quamar, 2012b) districts in southwestern and Raisen District (Shaw *et al.*, 2007) in central Madhya Pradesh. In the present study, a 2 m deep sediment core has been analysed from Barehata Tal, Narsinghpur District in southern region, deciphering the changing vegetation scenario and concurrent climatic variability as well as human impact since prior to Mid–Holocene.

STUDY SITE

Barehata Tal (Lake) is situated about 10 km north of Mangwani and 24 km southeast of Narsinghpur township on a flat ground in the vicinity of Barehata Village between 22º 50'54.41" N Long. & 79º25'259" E Lat. at an altitude of 800' amsl (Fig. 1). Most of the catchment of the lake is flat; however, the hillocks with flat tops occur in the surroundings

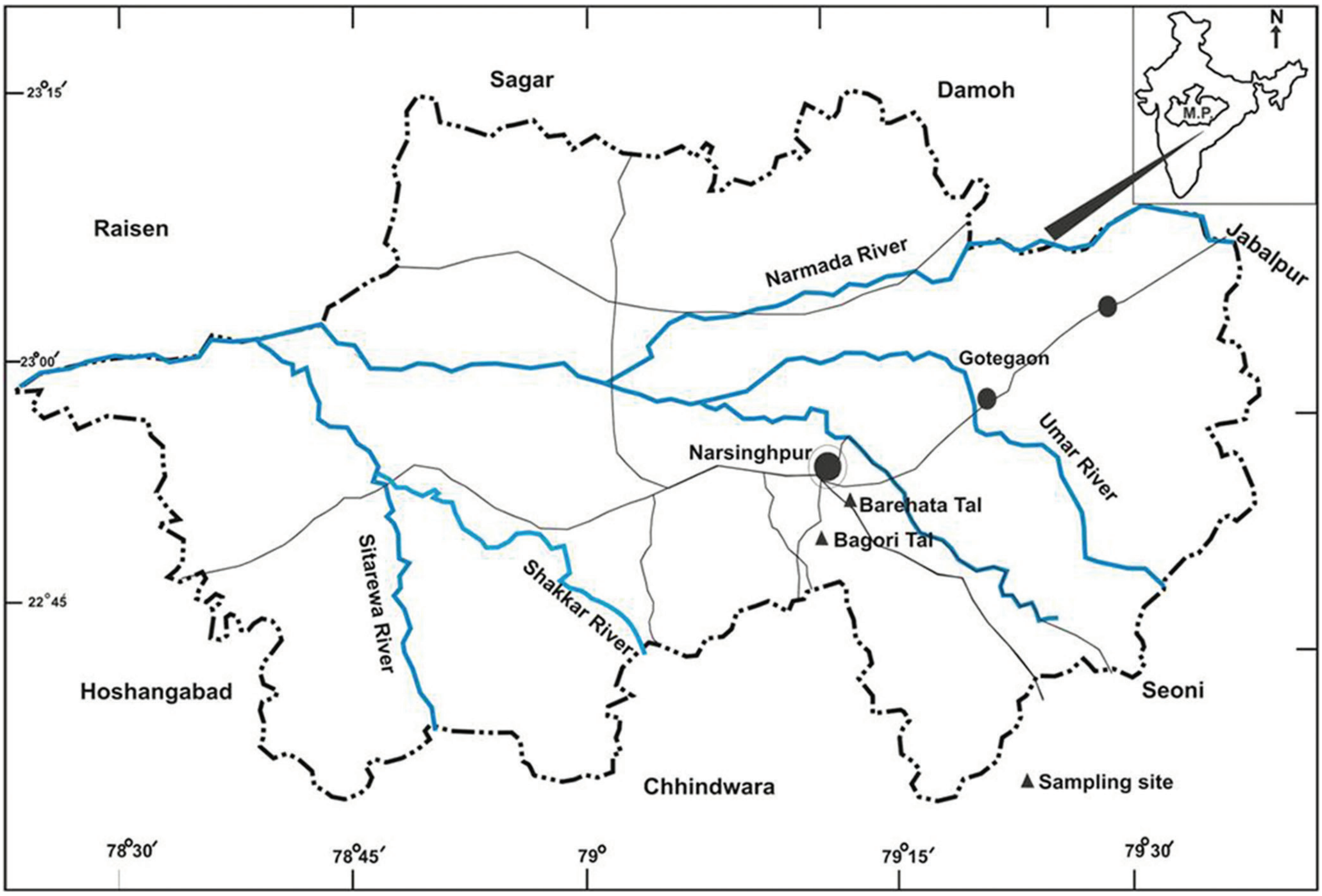

Fig. 1—Map showing the study site–Barehata Tal, Narsinghpur in southern Madhya Pradesh.

of the lake. The lake sprawls over an area of about 32 acres. It is almost circular in shape, measuring 1 km in length and 800 m in breadth at its widest. It is perennial and holds plenty of water even in dry summer months. The lake is personal property of the Gond King of the region and being used for the commercial cultivation of Singhara (*Trapa natans*), Kamal (*Nelumbo nucifera*) as well as fish rearing. The swampy margin of the lake is highly waterlogged and overgrown with *Ipomoea aquatica* and *Typha latifolia*. *Nelumbo nucifera* (Kamal) grows abundantly in the lake. The eastern and northern flanks of the lake are densely inhabited, while the area in the west is under intensive cultivation of conventional crops to a wider extent.

VEGETATION

The region supports mixed tropical deciduous forest of which *Madhuca indica*, *Buchanania lanzan*, *Lagerstroemia parviflora*, *Syzygium cumini*, *Adina cordifolia*, *Mitragyna parvifolia*, *Acacia catechu*, *Terminalia ballerica*, *Tectona grandis*, *Chloroxylon swietenia*, *Emblica officinalis*, *Diospyros melanoxylon* and *Anogeissus latifolia* are the common constituents (Champion & Seth, 1968). On the dry rocky plateaus some forest stands comprising *Emblica officinalis*, *Diospyros melanoxylon*, *Acacia catechu*, *A. arabica*, *Albizia lebbeck*, *Ziziphus mauritiana*, etc. are found sparsely. Around villages and outskirt of the forests *Annona squamosa* occurs profusely, particularly on the rugged hillocks. The pure *Butea monosperma* stands are found around the cultivated fields and along the forests edge. *Eucalyptus globulus*, *Tamarindus indica*, *Acacia nilotica*, *Mangifera indica*, *Melia azaderach*, *Bauhinia variegata*, etc. are the frequent avenue trees. Recently, in some places, particularly around the villages pure crops of *Tectona grandis* (teak) have been raised due to its commercial use as timber.

The ground vegetation in the forest and adjoining open areas is largely composed of grasses. However, *Ageratum conyzoides*, *Vernonia cinerea*, *Mazas japonicus*, *Justicia simplex*, *Sida rhombifolia*, *Chrozophora prostata*, *Gnaphellium* sp., *Leucas aspera*, *Xanthium strumarium*, *Artemisia parviflora*, *Oxalis acetocella*, etc. are common. The marshy fringe of the lake is overgrown with *Cyperus rotundus*, *Scirpus mucronata*, etc. together with *Polygonum plebeium*, *P. serrulatum*, *Ammania baccifera*, *Rotala rotundifolia* and *Centella asiatica*.

The fixed–floating hydrophytes, viz. *Potamogeton nodusus*, *Nymphoides cristata*, *Nymphaea nouchali* and *Typha latifolia* are seen in shallow lakes and ponds. *Hydrilla verticillata* and *Potamogeton purpurascens* are fixed–submerged hydrophytes in the less–deep water bodies. The free–floating aquatic plants such as *Pistia stratiotes* and *Trapa natans* are common in the deeper part.

CLIMATE

The region experiences a humid climate, which is chiefly controlled by southwest (SW) monsoon. The annual average minimum winter temperature for the region is 8.2ºC; however, temperature goes down to 2ºC during the severe coldest month of January. The average maximum summer temperature recorded for the region is 33.2ºC. The temperature usually attains a maximum of 42.5ºC in the hottest month of May. The SW monsoon commences from middle of June and lasts till the end of September. The annual average rainfall recorded for the region is 1217 mm (District Ground Water Information Booklet, Narsinghpur District, Madhya Pradesh, 2013). The region receives the maximum rainfall about 91.3% of the total annual precipitation during the monsoon period i.e. Mid–June to September. The weather becomes oppressive throughout the monsoon period. The relative humidity exceeds 90% in the months of July and August. The summer season from April to mid–June is the driest period, when relative humidity falls down to 39%.

MATERIALS AND METHOD

The materials for the present study include surface soil samples and sediment profile. Six surface samples were collected from the vicinity of the lake to study pollen deposition pattern. In the meanwhile, a detailed survey of the lake margin was conducted and finally the western dried flank about 20 m away from the lake shore was found suitable for digging a trench. A 2 m deep trench was dug for the collection of the sediment profile for pollen analysis. In all, 20 samples were picked up from the trench profile at 10 cm intervals for the present investigation. In addition, 5 bulk samples were also taken for radiocarbon dating at wider intervals from the profile.

The sediment profile exhibits four distinct lithozones, taking into account the variability in the sediment composition at different depth intervals. The topmost lithozone is constituted of sandy clay with abundant rootlets and other plant debris and is the thinnest zone in the entire profile. The subsequent lithozone is made up of blackish clay with traces of rootlets. The bottommost lithozone comprising blackish clay is the thickest stratum in the profile. This overlies the hard stratum, which was not feasible for further sampling due to presence of pebbles and boulders. The depth–wise lithological composition of the profile is set out in the Table 1.

Two absolute radiocarbon ages 5,840 ± 100 yr BP (BS–3609) at the depth of 155–170 cm and 4,790 ± 110 yr BP (BS–3619) at 110–125 cm depth have been determined for the sediment profile. Hence, considering the surface modern and almost little variation throughout in the profile sediment texture, the sedimentation rate has been calculated 23.3yr/cm. This sedimentation rate has been used to calculate six extrapolated dates, i.e. 6,700 cal yr BP at 200 m depth, 6,015 cal yr BP at 175 cm depth, 4,848 cal yr BP at 125 cm depth, 3,671 cal yr BP at 95 cm depth, 2,450 cal yr BP at 65 cm depth and 1,230 cal yr BP at 35 cm depth to deduce the temporal variability in vegetation and climate in the region prior to Mid–Holocene. The age–depth curve for the sediment profile is shown in Fig. 2.

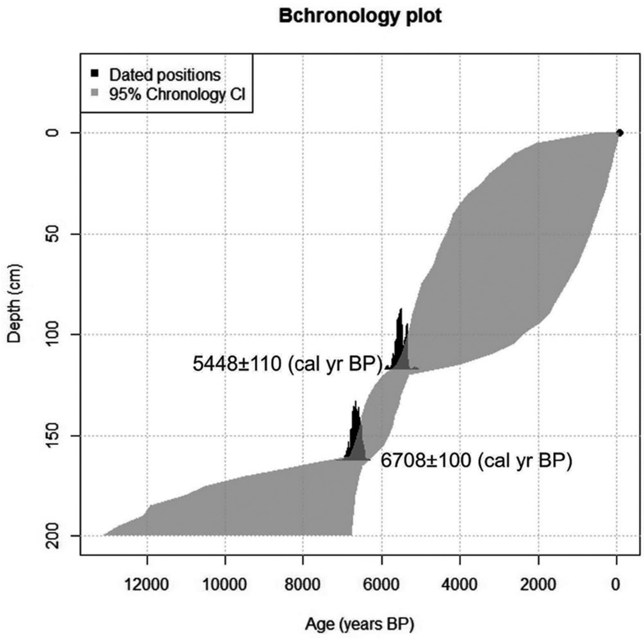

Fig. 2—Age–depth curve for the sediment profile investigated.

Table 1—Lithological composition of the profile.

Depth (cm)	Lithology
0–20	Sandy clay with rootlets and other plants debris
20–70	Blackish clay with traces of rootlets
70–200	Blackish clay
200–?	Blackish clay with abundance of pebbles and boulders

Table 2—Plant taxa recovered in the sediment profile.

Arboreals		Non-arboreals	
Trees	**Shrubs**	**Herbs**	**Others**
Tropical moist deciduous (annual av. rainfall 1200-1800 mm): *Butea monosperma*, *Diospyros*, *Flacourtia indica*. *Madhuca indica*, *Terminalia*, *Adina cordifolia*, *Symplocos racemosa*, *Moringa oleifera*, *Syzygium cumini*, *Tectona grandis*, *Shorea robusta*, *Schleichera oleosa*, *Buchanania lanzan*, *Trewia nudiflora*, *Paracalyx*, *Ailanthus*, *Semecarpus*, Sapotaceae, Anacardiaceae, *Annona squamosa*. **Tropical dry deciduous (annual av. rainfall 900-1200 mm):** *Emblica officinalis*, *Holoptelea*, *Lannea coromandelica*, *Grewia*, *Aegle marmelos*, *Schrebera*.	*Ziziphus*, Fabaceae, *Acanthus*, Acanthaceae, *Loranthus*, *Adhatoda vasica*, *Combretum*.	**Grasses:** Poaceae **Cultural taxa:** Cerealia, *Artemisia*, Cheno/Am, *Alternanthera*, Brassicaceae, Caryophyllaceae, *Cannabis sativa*. **Heathland taxa:** Asteraceae (Tubuliflorae & Liguliflorae), *Impatiens*, *Xanthium strumarium*, *Justicia simplex*, *Borreria*, *Chrozophora*, Ranunculaceae, Malvaceae. **Wetland taxa:** Cyperaceae, *Polygonum plebeium*, *Solanum*, Apiaceae. **Aquatic elements:** *Typha*, *Potamogeton*, *Nymphoides*.	**Ferns:** Ferns producing monolete and trilete spores. **Algal remains:** *Zygnema*, *Pseudoschizea*. **Fungal remains:** *Nigrospora*, *Alternaria*, *Helminthosporium*, *Glomus*, *Microthyrium*, *Curvularia*, *Diplodiocladeilla*, Ascospores.

10 g samples were boiled in 10% aqueous KOH solution in order to deflocculate the pollen and spores from the sediments and to remove the humus. The samples were sieved with 150 mesh sieve and washed thrice with distilled water. This was followed by treatment of samples with 40% HF solution to dissolve the silica content. Thereafter, the standard procedure of acetolysis (Erdtman, 1943) was followed, using acetolysing mixture (9: 1 ratio of acetic anhydride and concentrated sulphuric acid). Finally, the samples were prepared in 50% glycerin solution for microscopic examination. A few drops of phenol were added in the samples to avoid the microbial degradation of pollen/spores.

POLLEN ANALYSIS

All the surface and profile samples analysed were found rich in pollen and spore content. The pollen sums vary from 200 to 250 in the samples, depending on their potential. The pollen sums include only the pollen of terrestrial and marshy plants. The pollen of aquatic plants and spores of ferns and algae have been excluded because of their origin from local sources. The percentage frequencies of all the recovered taxa have been calculated from the pollen sums. The appropriate identification of the pollen and spores (Pls 1, 2) has been executed by consulting the reference pollen slides available at BSIP Herbarium as well as the pollen photographs and descriptions in the published literature (Nayar, 1990; Chauhan & Bera, 1990). The recovered pollen taxa in the sediments categorized as trees, shrubs, herbs, ferns, algal spores and drifted are put in the same order in the pollen spectra and pollen diagram**.** The taxa with frequencies of less than 0.5% have been indicated with '+'sign in the pollen diagram and pollen spectra. The plant taxa recovered in the sediment profile are set out according to their ecological habits and habitats in Table 2.

POLLEN RAIN–VEGETATION RELATIONSHIP

Six surface samples were analysed to study pollen deposition pattern in relation to the floristic composition of the study site. This comparative database has served as a modern analogue for the precise assessment of the pollen sequence from the sediment deposit in terms of past vegetation and climate change (Fig. 3). The pollen assemblage has shown the relatively higher frequencies of herbaceous elements (non–arboreals) compared to trees and shrubs (arboreals). Among the trees, *Madhuca indica* (4.23–7.05%), *Acacia* (2.08–3.84%) and *Holoptelea* (1.93–4.31%) are constant with moderate values. *Aegle marmelos* (1.49–5.51%), *Moringa oleifera* (1.58–3.44%), *Terminalia* (1.05–2.06%), *Syzygium cumini* (1.58–2.58%) and *Schleichera oleosa* (0.52–0.68%) are retrieved with low to moderate frequencies. *Tectona grandis*, *Annona squamosa* (2.58% each), *Ailanthus* (3.2%), *Buchanania lanzan* (1.32–1.58%), *Emblica officinalis*, *Symplocos* (1.37% each), *Adina cordifolia* (0.52–0.68%) and *Schrebera* (1.12%) are infrequent. The shrubs, viz. Fabaceae (1.28–2.64%) and *Ricinus communis* (0.52–1.12%) are better represented compared to *Adhatoda vasica* (0.64–1.37%), *Combretum* (1.12–1.28%) and *Ziziphus* (0.64%), which are intermittent.

The ground flora is marked by the high frequencies of Poaceae (28.5–36.5%). Chenopodiaceae/Amaranthaceae (Cheno/Am 4.23–7.67%) is also recovered constantly in moderate frequencies. Cerealia (3.7–8.27%), Brassicaceae (1.58–1.93%) and *Artemisia* (0.52–5.85%) are also met with in moderate values, though sporadically. Caryophyllaceae (0.86%), *Cannabis sativa* (0.68–0.86%) and *Alternanthera* (0.52–0.68%) are infrequent. Tubluliflorae (3.4–6.34%) exhibits steadily high values among the heathland taxa. Liguliflorae (1.2–1.37%), *Justicia* (0.64–2.06%) and *Impatiens* (0.52–0.68%) are scarce. *Xanthium strumarium* (1.12%) and *Chrozophora* (3.84%) are recorded in one sample each. The wetland taxon, Cyperaceae (0.86–16.9%) shows much deviating frequencies. *Polygonum plebeium* (1.05–3.8%) and *P. serrulatum* (1.28%) are sporadic. *Typha* (3.44%) and *Potamogeton* (2.06–4.31%) meagrely represent the aquatic vegetation. The fern trilete spores (0.52–2.06%) are frequent, while monoletes (1.05–3.12%) are irregular. The fungal spores, *Glomus* (3.44–14.3%), *Curvularia* (2.06–15.5%) and *Nigrospora* (2.84–13.1%) are in higher values than *Helminthosporium* (0.86–1.25%), *Alternaria* (0.62–o.68%) and ascospores (0.62%).

Thus, the pollen assemblage documents the relatively reduced frequencies of trees in the study site, located barely 500 m away from the dense tropical mixed forest. Among them, *Acacia*, *Madhuca indica* and *Holoptelea* are consistently present, reflecting their frequent occurrence in the nearby forest. Rest of the trees such as *Aegle marmelos*, *Terminalia*, *Buchanania lanzan*, *Syzygium cumini*, etc. are much sporadic. The under–representation of all these taxa could be ascribed to their sparse presence in the vicinity of the lake, poor pollen dispersal efficiency as well as low pollen productivity since most of the tropical trees are insect pollinated (Vinscens *et al.*, 1997). The microbial degradation of pollen cannot be ruled out since fungal spores have been recovered in the sediment very frequently. In all, the trees constitute a small chunk of av. 21% of the pollen rain. The poor shrubby elements are represented by av. 4.98% pollen only. Collectively the arboreals (trees & shrubs) form an av. 26% fraction of the pollen rain. Similar representation of the trees has also been observed in the pollen rain studies from northeastern Madhya Pradesh (Chauhan, 1994, 2007). Among the herbaceous elements, Poaceae (grasses) with av. 35.16% pollen emerges the most dominant taxon. Together with culture taxa av. 12.5%, heathland taxa av. 11% and marshy elements av. 13.48%, they constitute av. 72.14% chunk of non–arboreals pollen, reflecting their factual composition of the ground vegetation. This comparative database on pollen rain–vegetation relationship signifies the existing climate in the region. This has been used as modern analogue for the appropriate appraisal of the pollen sequence from the sediment deposit in terms of past vegetation and climate change in the region in a definite time frame.

DESCRIPTION OF POLLEN DIAGRAM

The pollen diagram constructed from Barehata Tal sediment profile has been divided into six pollen zones, taking into account the fluctuating trends of prominent arboreals and non–arboreals (Fig. 4). They are prefixed with the initials "BHT" after the name of study site–Barehata Tal and are numbered from bottom to top (BHT–I, BHT–II, BHT–III, BHT–IV, BHT–V & BHT–VI). The pollen composition of the pollen zones is given below.

Pollen Zone BHT–I (200–175 cm): Acacia–Moringa oleifera–Madhuca indica–Aegle mormelos–Trewia nudiflora–Poaceae–Cerealia–Chenopodiaceae/Amaranthaceae Assemblage

This pollen zone covering the time bracket of 6,700 to 6,015 cal yr BP is characterized by the reduced number and frequencies of arboreals (trees and shrubs) compared to non–arboreals. *Moringa oleifera* (1.49–8.55%), *Acacia*

PLATE 1

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1.	*Acacia*
2, 3.	*Buchanania lanzan*
4.	*Grewia*
5.	*Aegle marmelos*
6, 7.	*Madhuca indica*
8.	Anacardiaceae
9.	*Holoptelea*
10, 11.	*Schleichera oleosa*
12, 13.	*Terminalia*
14, 15.	*Emblica officinalis*
16.	*Schrebera*
17.	*Symplocos*
18.	*Diospyros*
19, 24.	*Trewia*
20, 21.	Fabaceae
22.	*Adhatoda vasica*
23.	Acanthaceae.

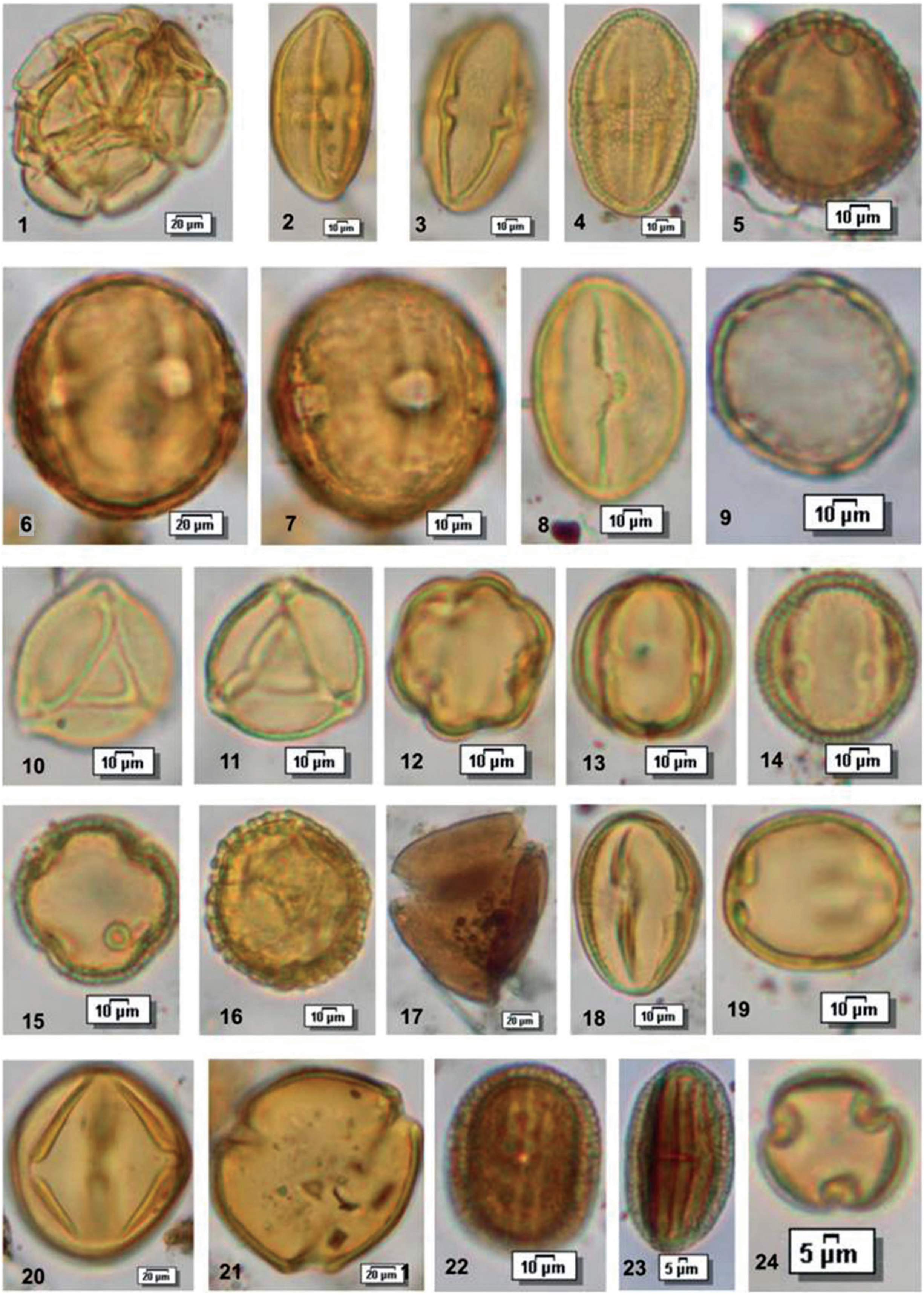
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PLATE 1

(2.48–5.84%), *Trewia nudiflora* (0.99–5.26%), *Madhuca indica* (1.49–3.28%) and *Holoptelea* (0.65–1.98%) are consistently recovered in moderate frequencies. *Emblica officinalis*, *Terminalia*, *Aegle marmelos* (0.65–1.49% each), *Shorea robusta* (0.64–0.65%), *Schleichera oleosa* and *Adina cordifolia* (0.49–0.65% each) are met with steadily in low values. *Tectona grandis*, *Buchanania lanzan* (1.29% each), *Grewia* and *Schrebera* (0.65% each) are recovered in one sample each.

The non–arboreals are dominated by Poaceae (grasses 49.2–59.8%), whereas Cerealia (1.98–4.5%) and Chenopodiaceae/Amaranthaceae (1.32–5.96%) and Caryophyllaceae (0.99–1.94%) are also consistent in good frequencies. Brassicaceae (0.65–0.99%) is extremely sporadic. *Artemisia* (1.98%) and *Alternanthera* (0.99%) are infrequent. Tubuliflorae (3.84–5.96%), Liguliflorae (1.29–1.98%), *Justicia simplex* (0.99–1.29%) and *Impatiens* (0.65%) are recorded sporadically. *Xanthium strumarium* and Ranunculaceae (0.65% each) are extremely low. Among the wetland taxa, Cyperaceae (3.26–7.95%) is appreciably present. *Polygonum plebeium* (0.99–1.29%), *Polygala* and Apiaceae (0.49% each) are rare. *Typha* (0.99%) and *Potamogeton* (0.49–0.64%) are the only representatives of aquatic flora. The ferns spores (monolete 1.49% and trilete 0.64–0.99%) are trivial.

Pollen Zone BHT–II (175–125 cm): Moringa oleifera–Acacia–Trewia nudiflora–Madhuca indica–Holoptelea–Poaceae–Cerealia–Tubuliflorae–Cyperaceae Assemblage

This pollen zone with an absolute radiocarbon age 5,840 ± 100 yr BP and encompassing the time interval of 6,015 to 4,848 cal yr BP exhibits significant improvement in the tree taxa, viz. *Moringa oleifera* (0.45–5.12%), *Acacia* (4.34–7.72%), *Trewia nudiflora* (2.48–6.43%), *Madhuca indica* (1.83–4.34%), *Grewia* (0.85–2.58%), *Holoptelea* (1.98–3.41%), *Terminalia* (0.86–2.75%) and *Aegle marmelos* (0.45–2.14%). *Adina cordifolia* and *Schrebera* (0.86% each) are encountered sporadically in low frequencies. *Butea monosperma* (0.42–5.17%), Anacardiaceae (0.86–2.29%), *Syzygium cumini* (0.49–1.28%), *Lannea coromandelica* (0.85%), *Paracalyx*, *Flacourtia indica* (0.97% each) and *Semecarpus* (0.49%) are the maiden elements in variable frequencies. The shrubby elements, viz. *Loranthus* (0.91%), *Ziziphus* and Fabaceae (0.45% each) turn up very occasionally.

Poaceae (42.2–51.6%) retains dominance over other non–arboreals. Cerealia (0.86–9.17%) is also steady with increased frequencies followed by Chenopodiaceae/Amaranthaceae (1.83–3.47%) and Brassicaceae (0.45–1.72%) with some improved values. Caryophyllaceae, *Artemisia* and *Alternanthera* (0.49% each) turn up sparsely. The heathland taxon, Tubuliflorae (1.73–17.2%) attains the high frequency. *Xanthium strumarium* (0.42–2.98%), *Justicia simplex* (0.86–2.14%), *Chrozophora* (0.85–0.99%), *Impatiens* (1.49%), Liguliflorae (0.91–0.99%) and Malvaceae (0.86%) are irregular. The marshy element, Cyperaceae (0.85–5.46%) shows a rising trend. However, Apiaceae (1.37%) and *Solanum* (0.91%) are noticed poorly in one sample each. The aquatic elements, *Potamogeton* (1.37–1.73%) and *Typha* (0.42–1.98%) are better represented. The fern spores (monolete & trilete 0.86–1.72% each) are infrequent together with freshwater alga, *Zygnema* (0.47%).

Pollen Zone BHT–III (125–95 cm): Madhuca indica–Holoptelea–Shorea robusta–Poaceae–Cyperaceae Assemblage

This pollen zone with a solitary ^{14}C age 4,790 ± 110 yr BP and covering a temporal range of 4,848 to 3,671 cal yr BP depicts the sharp decline of both arboreals and non–arboreals. *Holoptelea* (1.12–1.22%) has reduced frequencies. *Emblica officinalis* (2.48%), *Shorea robusta* (1.86%), Sapotaceae (1.68%), *Terminalia* (1.24%), *Madhuca indica* and *Tectona grandis* (1.12% each) are recorded in one sample each only. *Symplocos* (1.12%) appears for the first time. *Adhatoda vasica* (0.56%) and Fabaceae (0.62%) are the only shrubby taxa with stray presence.

Poaceae (55–59.3%) shoots up in contrast to the previous pollen zones. Cerealia (1.68–2.48%) and Chenopodiaceae/Amaranthaceae (3.72–3.93%) retain almost same values as in the preceding zone. Caryophyllaceae (0.56–1.24%) increases slightly. *Cannabis sativa* (1.12%) appears in the beginning of

PLATE 2

1. Poaceae
2. Cerealia
3. Chenopodiaceae/Amaranthaceae
4. Brassicaceae
5. Caryophyllaceae
6. *Alternanthera*
7. *Artemisia*
8. *Xanthium strumarium*
9. Tubuliflorae
10. Liguliflorae
11. Malvaceae
12, 13. *Borreria*
14. *Impatiens*
15. *Justicia simplex*
16. *Solanum*
17. Apiaceae
18, 19. Cyperaceae
20. *Polygonum plebeium*
21. *Nymphoides*
22. *Typha*
23. *Potamogeton*
24. *Zygnema*
25. *Microthyrium*
26. *Diplodiocladeilla*.

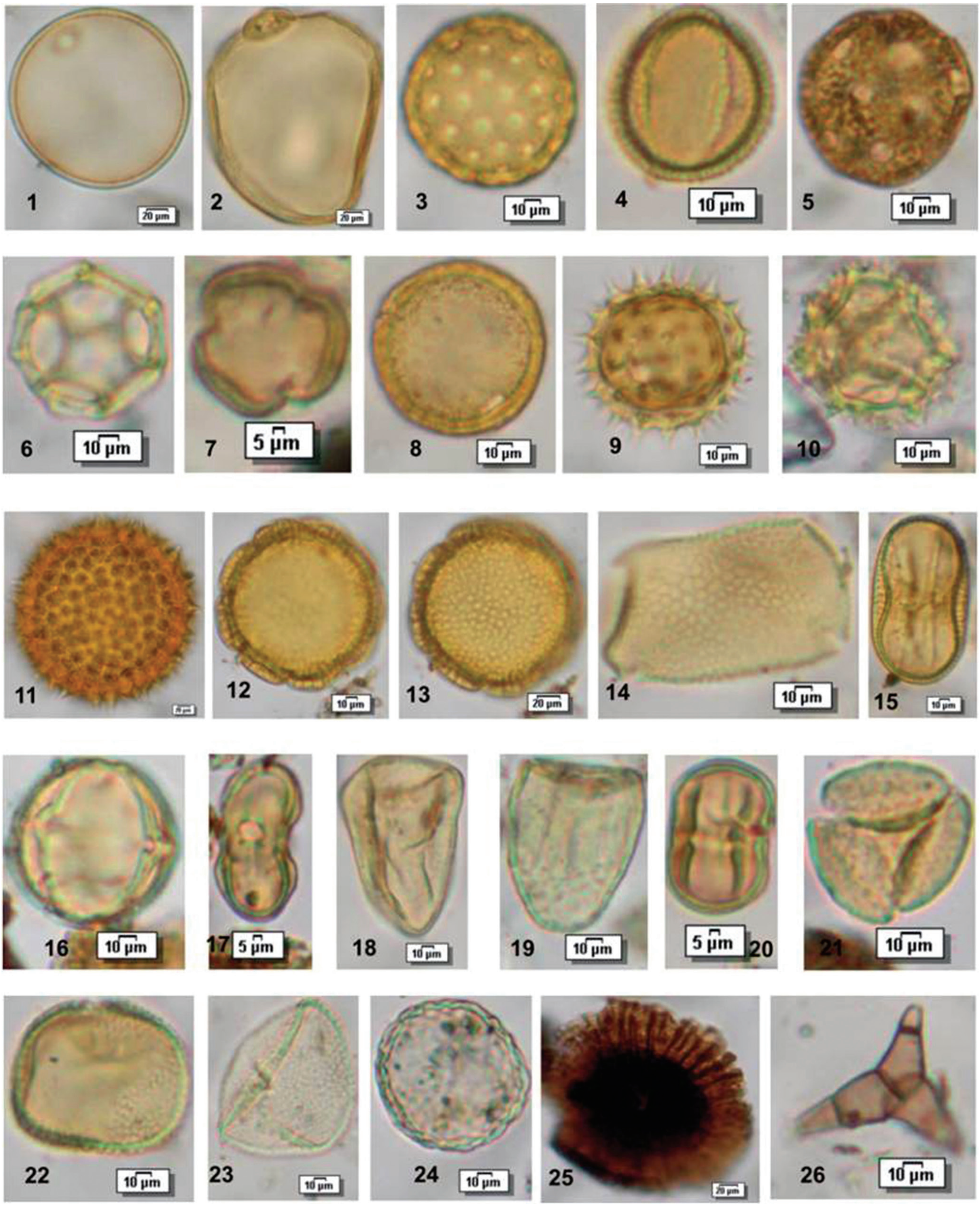
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PLATE 2

this zone. Among the heathland taxa, Tubuliflorae (2.8–6.82%) declines drastically, whereas *Justicia simplex*, Liguliflorae (1.12–1.86% each) and *Chrozophora* (0.56–1.24%) exhibit somewhat increased frequencies. *Xanthium strumarium* (2.24%) and Malvaceae (1.86%) are met with in one sample each. Among the marshy elements, sedges (Cyperaceae 13.46–15.7%) and *Polygonum plebeium* (1.12–1.24%) and *Solanum* (0.56%–1.86%) have enhanced values. *Typha* (1.92%) and *Potamogeton* (1.86%) are recovered in the upper part of this zone. The fern spores (monolete 1.86% and trilete 3%) are noticed in the topmost sample only. *Pseudoschizea* (2.48%) is recorded for the first time.

Pollen Zone BHT–IV (95–65 cm): Acacia–Holoptelea–Madhuca indica–Terminalia–Tectona grandis–Acanthaceae–Poaceae–Cerealia–Chenopodiaceae/Amaranthaceae–Tubuliflorae Assemblage

This pollen zone covering a time slot of 3,671 to 2,450 cal yr BP demonstrates considerable improvement in numbers and frequencies of trees. *Holoptelea* (3.4–6.4%), *Acacia* (1.71–5.72%), *Madhuca indica* (1.29–4.47%) and *Terminalia* (0.57–1.49%) depict constantly moderate frequencies. *Tectona grandis* (5.2%), *Aegle marmelos* (2.85%), *Buchanania lanzan* (1.14–1.93%), *Grewia* (0.64–1.7%), *Schleichera oleosa* (1.14–1.49%) and *Emblica officinalis* (0.57–0.64%) also show slightly improved values, though sporadically. *Schrebera*, *Flacourtia indica* and Anacardiaceae (0.57% each) are occasional. *Acanthus* (0.57–1.93%) is encountered steadily for the first time. Fabaceae (3.42%) and *Adhatoda vasica* (0.57–1.29%) are sporadic.

The herbaceous vegetation is dominated by grasses (Poaceae 34.8–43.2%), though with much reduced values. Chenopodiaceae/Amaranthaceae (4–7.7%) and Cerealia (1.29–3.42%) have increased values. Brassicaceae (0.57–1.49%), Caryophyllaceae (1.1–1.49%) and *Artemisia* (1.71%) are intermittent. Tubuliflorae (4.5–5.2%), *Xanthium strumarium* (0.74–1.29%), Ranunculaceae (0.64–1.14%) and Malvaceae (0.64–1.49%) are better represented compared to Liguliflorae (1.49%) and *Justicia* (0.57%), which are stray. The marshy element, Cyperaceae (23.4–26.4%) increases significantly. *Polygonum plebeium* (0.57–1.29%) is constant with reduced values than in the preceding zone. The aquatic element, *Potamogeton* (0.64–1.14%) is consistent in low values, whereas *Typha* (0.69%) is occasional. The fern spores (trilete 1.29–1.92% & monolete 3%) are irregular. *Zygnema* zygospores (0.47%) are rare. *Pseudoschizea* (2.33%) and fungal remains, *Microthyrium* (0.57%) are recorded for the first time.

Pollen Zone BHT–V (65–35 cm): Acacia–Madhuca indica–Grewia–Buchanania lanzan–Poaceae–Cerealia–Tubuliflorae–Cyperaceae Assemblage

This pollen zone with a time bracket of 2,450 to 1,230 cal yr BP documents the decline in the arboreals. *Madhuca indica* (2.4–3.12%), *Acacia* (1.21–1.87%) and *Holoptelea* (0.60–0.62%) have reduced values. *Schleichera oleosa* (1.21–3.12), *Grewia* (0.62–3%), *Aegle marmelos* (0.60–1.87%) and *Emblica officinalis* (0.62–0.81%) show some improvement. *Buchanania lanzan* and *Moringa oleifera (*0.62% each) reappear sporadically after a long lapse. Anacardiaceae (1.87%), *Semecarpus* (1.81%) and *Schrebera* (0.62%) are scarce. *Lannea coromandelica*, *Tectona grandis* (5% each) and *Symplocos* (0.6%) are present in one sample each. The shrubby element, *Acanthus* (1.87–2.6%) is better represented than *Adhatoda vasica* (1.87%) and Fabaceae (0.60%).

Poaceae (36.1–40.4%) has high frequencies. Chenopodiaceae/Amaranthaceae (3.75–7.87%), Tubuliflorae (3.75–5.4%) and Cerealia (1.81–1.87%) are recovered with higher frequencies than before. Caryophyllaceae, Ranunculaceae (2.5% each), Brassicaceae, *Justicia*, *Chrozophora*, *Impatiens* (1.25% each), *Artemisia* and Malvaceae (0.62% each) are sporadic. Among the wetland taxa, Cyperaceae (22.4%) has reduced values, whereas Apiaceae (1.25%) is met with in one sample only. The aquatic elements, viz. *Potamogeton* (1.21–3.12%) and *Typha* (1.2%) show some improvement. The fern trilete spores and *Pseudoschizea* (0.60–1.25% each) are occasional.

Pollen Zone BHT–VI (35–0 cm): Madhuca indica–Acacia–Holoptelea–Grewia–Poaceae–Cerealia–Chenopodiaceae/Amaranthaceae–Brassicaceae–Tubuliflorae Assemblage

This topmost pollen zone with a time span of 1,230 cal yr BP to present reveals the better representation of trees, viz. *Acacia* (2.6–6.21%), *Madhuca indica* (4.6–4.9%), *Holoptelea* (1.3–2.48%), *Grewia* (2.1–3.1%), *Emblica officinalis* (1.24–2.06%) and *Terminalia* (0.66–1.2%) with increased frequencies. *Buchanania lanzan* (3.62%), *Tectona grandis*, Anacardiaceae (3.3% each) and *Schleichera oleosa* (2.06%) are sporadic with moderate values. *Shorea robusta* (1.4%) and Meliaceae (0.72%) are feebly present. *Adina cordifolia* (2.48%) and *Syzygium cumini* (0.62%) reappear scarcely after a long lapse. The shrubby elements such as *Acanthus* (1.86–2.89%) and Fabaceae (1.3–1.86%) become more prominent.

Poaceae (31.1–34%) decreases slightly, however, the cultural taxa, viz. Chenopodiaceae/Amaranthaceae (7.45–21.7%), Caryophyllaceae (0.66–4.4%), Cerealia (2.48–3.3%) and Brassicaceae (0.72–2%) have enhanced frequencies. The heathland taxa, Tubuliflorae (0.96–10.6%) and Liguliflorae (0.66–2.48%) have increased values. *Justicia* (1.86%), Malvaceae (1.3–1.4%), *Chrozophora* (1.4%) and *Xanthium strumarium* (0.66–0.72%) are infrequent. The marshy element, Cyperaceae (8.0–15.2%) is consistently present with moderate to high frequencies followed by *Polygonum plebeium* (0.57–1.28%) with some increased values. *Solanum*

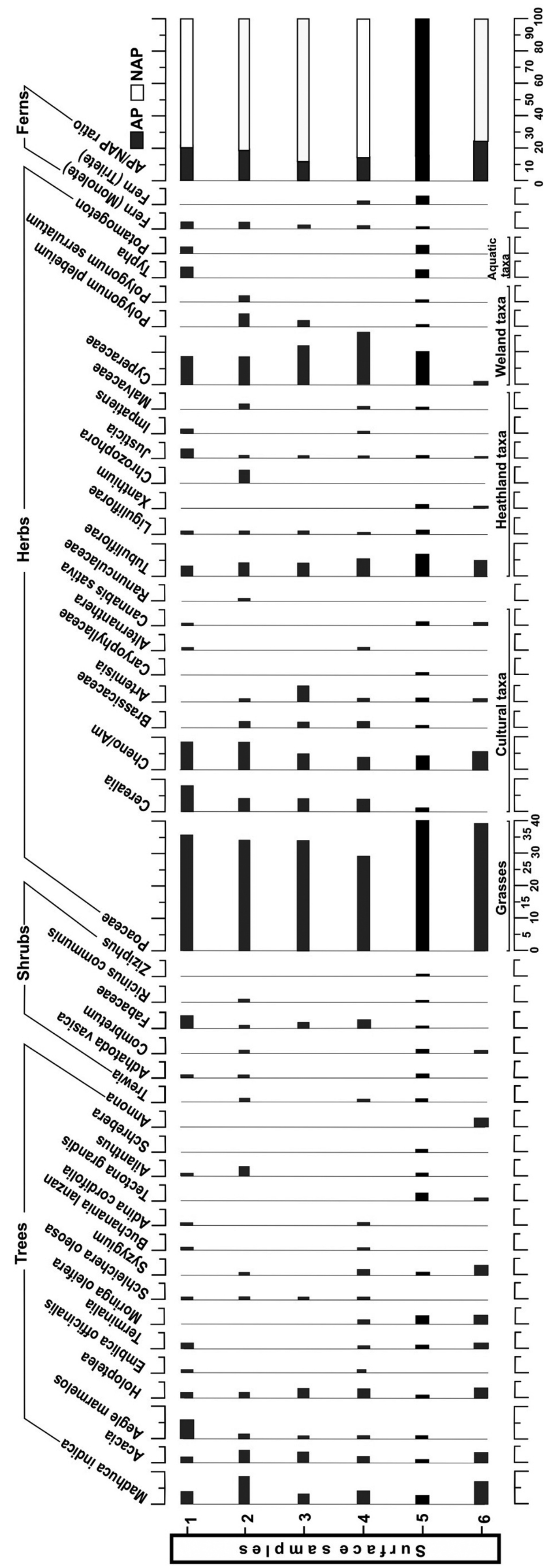

Fig. 3. Pollen spectra from Barehata Tal, Narsinghpur.

(1.3%), Apiaceae (0.68%) and *Polygala* (0.62%) are stray. The aquatic element, *Potamogeton* (1.3–2.48%) demonstrates a rising trend; whereas *Typha* (0.62%) is sporadic. The fern trilete spores (0.66–5.5%) are better represented than monolete spores (0.72%). *Zygnema* (0.62–1.3%) is steadily recovered. *Pseudoschizea* (0.63–0.72%) is trivial.

VEGETATION AND CLIMATE CHANGE

The pollen analytical investigation of a 2 m deep sediment profile from Barehata Tal (Lake), Narsinghpur has unfolded the chronicle of vegetation succession and concurrent climatic variability in the southern Madhya Pradesh prior to the Mid–Holocene in a definite time frame supported by absolute radiocarbon and extrapolated dates. Around 6,700 to 6,015 cal yr BP (Pollen Zone BHT–I) the landscape in the milieu of the lake supported the open mixed tropical deciduous forests to a wider extent, which largely comprised *Moringa oliefera*, *Acacia*, *Madhuca indica*, *Trewia nudiflora*, *Terminalia*, etc. with scarce presence of *Schleichera oleosa*, *Adina cordifolia*, *Buchanania lanzan*, *Tectona grandis*, *Schrebera*, etc. If the face value pollen composition of this phase is compared with the modern analogue on the pollen rain vis–a–vis vegetation, dealt elsewhere in the text, it could be surmised that the region was under a regime of a warm and relatively less–humid climate attributed to reduced monsoon precipitation in contrast to that prevails today. During 6,000 to 5,409 cal yr BP, the southwestern Madhya Pradesh also supported open mixed deciduous forests under a warm and relatively less–humid climate (Chauhan & Quamar, 2012b). A weaker summer monsoon around 6.3 cal yr BP has also been noticed from Lonar Lake sequence in Central India as indicated by salinity and pH related enrichment of $^{13}C_{org}$ and ^{15}N (Prasad *et al.*, 2014). The ground flora was dominated by grasses together with the members of Asteraceae, Chenopodiaceae/Amaranthaceae, *Impatiens*, etc. However, the debut of Cerealia pollen from the beginning of the pollen sequence suggests that the area adjoining to study site was under some Cereal–based arable crop economy. The other low intensity human activities are attested by the retrieval of ruderal plants, viz. Chenopodiaceae/Amaranthaceae, Brassicaceae and Caryophyllaceae. The scanty record of the aquatic element–*Potamogeton* only denotes the existence of a small lake, which was encircled with a narrow marshy fringe overgrown with sedges and other wetland elements.

Between 6,015 and 4,848 cal yr BP (Pollen Zone BHT–II) the much expansion of *Acacia*, *Trewia nudiflora*, *Moringa oleifera*, *Madhuca indicia* and *Holoptelea* with improvement in *Grewia*, *Emblica officinalis*, *Aegle marmelos*, etc. coupled with invasion of *Butea monosperma*, *Syzygium cumini*, *Paracalyx* and *Flacourtia indica* elucidates that the forests became much varied and dense in floristic composition. This proliferation of the tropical deciduous forests might have occurred with the inception of a warm and very–humid climate in response to intensification of SW monsoon. In global perspective, this phase falls to some extent within the temporal limit of Period of Climatic Optimum, which has been documented between 9,000 and 4,000 yr BP (Bradley, 1999). Similarly, the expansion of tropical deciduous forests took place in southeastern (Chauhan, 2000, 2002, 2015; Chauhan *et al.*, 2013) and southwestern Madhya Pradesh (Chauhan & Quamar, 2012a) encompassing altogether same time slot on account of more clement climate. The Rajasthan desert also witnessed >50 cm rainfall around 5,000 cal yr BP than today, which is evidenced from the increase in trees and aquatic flora in Lunkaransar Lake deposit (Singh *et al.*, 1974). A warm and wet climate between 5,730 and 4,150 cal yr BP has also been noticed by Sm/K and dissolution and precipitation of calcretes and formation of blocky calcite needles in voids in the Ganga Plains (Sinha & Sarkar, 2009). The pollen records from southwestern China have also depicted a warm and humid climate between 6,100 and 3410 cal yr BP (Xiao *et al.*, 2014). Such a favourable climatic condition also induced the agrarian practice in the region, which is confirmed by the rising trend of Cerealia and concomitant cropland weeds belonging to Chenopodiaceae/Amaranthaceae, Brassicaceae, Caryophyllaceae, etc. The pastoral activities such as grazing or browsing in the forest and around settlements is clearly substantiated by the abrupt spurt of Asteraceae (Tubuliflorae) since the plants of this family are unpalatable to cattle and goats, hence, their pollen are retrieved appreciably in the sediments (Vincens *et al.*, 1997). This is also in agreement with the pollen evidence from the southeastern Madhya Pradesh (Chauhan *et al.*, 2013) and Central Ganga Plain (Chauhan *et al.*, 2009; Trivedi *et al.*, 2013). The lake achieved a wider stretch as validated by the rich aquatic flora comprising *Potamogeton*, *Typha* and algal remain–*Zygnema*.

Later on, around 4,848 to 3,671 cal yr BP (Pollen Zone BHT–III), the mixed deciduous forests got significantly reduced and turned much open and sparse in the floristic composition as conspicuous from the feeble representation of only a few trees, viz. *Madhuca indica*, *Holoptelea*, *Terminalia*, *Emblica officinalis*, *Tectona grandis*, *Shorea robusta*, etc. and disappearance of several forest associates. Nevertheless, a few thickets of *Adhatoda vasica* and Fabaceae invaded scantily the open space in the forests. This replacement of luxuriant mixed deciduous forests by the much open and less varied mixed deciduous forest stands might have occurred as a consequence of the commencement of a regime of warm and dry climate with the prevalence of weak SW monsoon. The Lonar Lake core data from Central India has also shown the increase in lake salinity between 4.6 and 3.9 cal ka BP due to prolong droughts (centennial long intervals of weak summer monsoon). This is well corroborated by the negative ^{13}C values, decline in pollen of dry deciduous forests, increase in light demanding species and drop in C_{org}/N ratio to ≤10 (Prasad *et al.*, 2014). The harsh climatic condition also adversely affected the agricultural activities, which is inferred by the

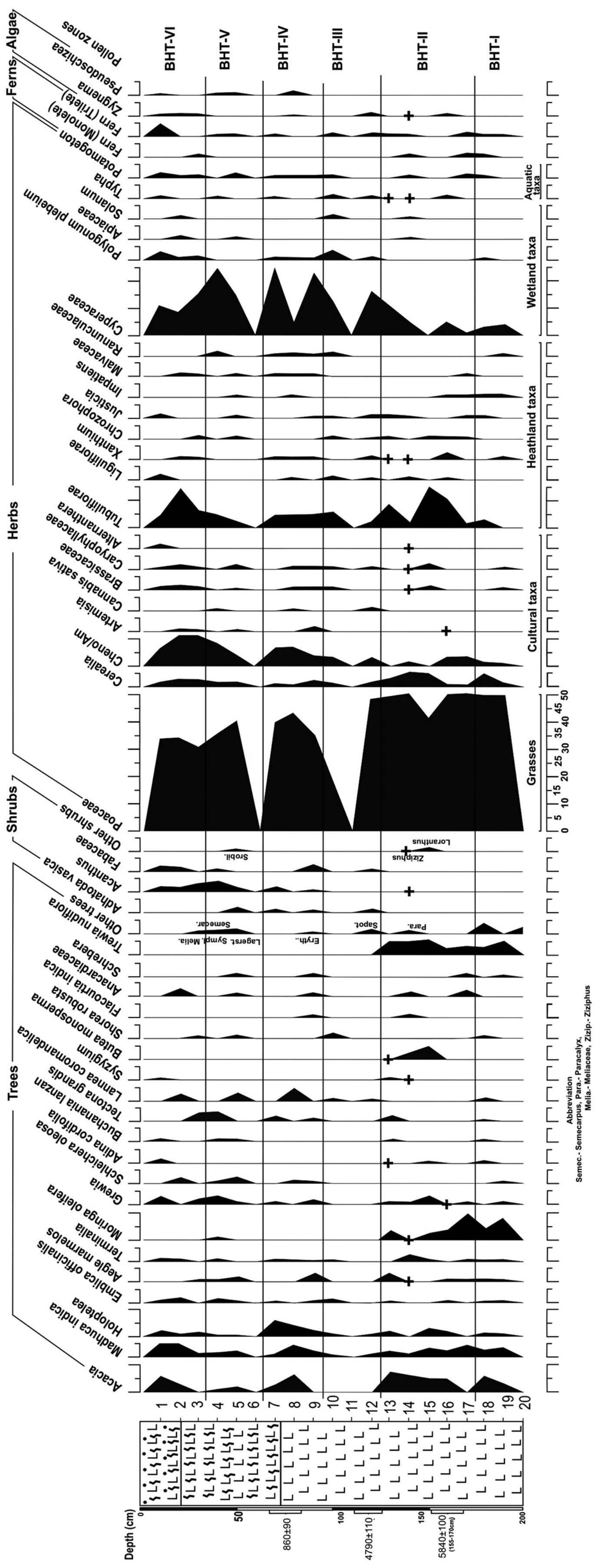

Fig. 4. Pollen diagram from Barehata Tal, Narsinghpur.

sharp decline in Cerealia and associated cropland weeds. The paucity of aquatic vegetation suggests that the lake shrank to the lowest level with a much smaller expanse. Most of the lake area got transformed into marshy land abundantly overgrown with sedges (Cyperaceae) and *Polygonum plebeium*.

The mixed deciduous forests were re–established around 3,671 to 2,450 cal yr BP (Pollen Zone BHT–IV) as well documented by the moderate improvement in the forest ingredients. By this time *Holoptelea*, *Acacia*, *Madhuca indica*, *Terminalia*, *Tectona grandis*, *Grewia*, *Schleichera oleosa*, etc. became the principal forest associates. In addition, *Buchanania lanzan*, *Aegle marmelos* and *Schrebera*, which were prominent in the phase preceding the previous one also, re–immigrated thinly, probably with the availability of some required moisture level in the soil for their propagation. Thus, by and large the changing vegetation scenario reveals that the region enjoyed a warm and moderately humid climate with increased precipitation. The expansion of mixed deciduous forests in northeastern (Chauhan, 2000) and southeastern Madhya Pradesh (Chauhan *et al.*, 2013) also substantiates the similar climatic regime encompassing the same time brackets. This recuperation of the forests also corresponds with the mild improvement in the forest floristic in southwestern region of Madhya Pradesh (Chauhan & Quamar, 2012b) and moderate presence of forest groves in restricted pockets in the Central Gangetic Plain (Chauhan *et al.*, 2009; Trivedi *et al.*, 2013) for altogether same time interval. The gradual humidification with the change of arid thorn shrub vegetation to semi–humid deciduous forests around 3.9–2 cal ka BP and disappearance of gaylussite in the lake sediments are in agreement with the increase in monsoon precipitation (Prasad *et al.*, 2014). The enhancement in culture pollen taxa implies the acceleration of agriculture practice and other human during this phase. A moderate expansion of lake occurred, which is indicated by the improvement in *Potamogeton* and *Typha* and maiden presence of fresh–water algae, viz. *Pseudoschizea* and *Zygnema*. The marshy fringe around the lake also got widened and supported luxuriant growth of sedges and other wetland elements.

A warm and less–humid climatic regime has been inferred for the time bracket of 2,450 to 1,230 cal yr BP (Pollen Zone BHT–V) since there is depletion in the forest elements, viz. *Acacia*, *Madhuca indica*, *Holoptelea*, etc. more particularly, compared to the preceding phase, except for the drought tolerant elements, viz. *Emblica officinalis*, *Grewia*, *Schleichera oleosa*, *Aegle marmelos, Lannea coromandelica* and *Tectona grandis*, which were slightly better represented than before. This alteration in vegetation composition could be the result of reduced precipitation due to weakening of SW monsoon. This phase of deficient monsoon precipitation falls partially within the drought episode witnessed between 2 and 0.6 cal ka BP in the Lonar Lake core study from the Central India (Prasad *et al.*, 2014). A contemporaneous climatic deterioration has been deduced from the severe decline in the trees and aquatic elements in Rajasthan desert, (Singh *et al.*, 1974) and the shrinking of the forest groves into very restricted pockets in the Central Ganga Plain (Chauhan, 2009; Trivedi *et al.*, 2013).

Since 1,230 cal yr BP (Pollen Zone BHT–VI) onwards, the relatively high frequencies of the forest elements particularly *Acacia*, *Madhuca indica*, *Grewia*, *Holoptelea*, *Schleichera oleosa*, *Terminalia*, *Emblica officinalis*, *Syzygium cumini*, etc. signify that the tropical deciduous forests became profuse in floristic set up. From the changing vegetation it is obvious that the region enjoys a warm and humid climate alike to that prevails at present. This phase of the favourable climate has also been noticed around 2,000 cal yr BP in the eastern region (Chauhan, 2013, 2015), around 1,800 cal yr BP southeastern region (Chauhan, 2002) and around 1,600 cal yr BP northeastern region of Madhya Pradesh (Chauhan, 1996), where the modern Sal forests were established with the arrival of active SW monsoon (Meher–Homji, 2000). However, the temporal differences for the prevailing a warm and humid climate could be the result of early access of active SW monsoon in the eastern Madhya Pradesh as well as wider geographic locations of the sites studied. Contrary to this, during the almost same time interval or so the dwindling of the arboreal vegetation in the Ganga Plain (Chauhan *et al.*, 2009; Trivedi *et al.*, 2013) and Rajasthan desert (Singh *et al.*, 1974) suggests the deterioration in the climate, attributable to regional climatic variability as a result of sharp diminishing trend of SW monsoon.

CONCLUSIONS

The pollen proxy records have delineated six phases of vegetation changes and coeval climatic events in the southern Madhya Pradesh since prior to the Mid–Holocene.

- Between 6,700 and 6,015 cal yr BP the region supported open mixed tropical deciduous forests under a warm and less–humid climate than at present. A lake of small expanse existed as evidenced from the infrequent aquatic flora.
- Around 6,015 to 4,848 cal yr BP, the mixed deciduous forests got diversified with the advent of a warm and very humid climate attributable to active SW monsoon. The agrarian practice also intensified due to clement climatic conditions. The lake assumed a larger stretch, which is indicated by the improvement in aquatic elements.
- A warm and dry climate is registered between 4,848 and 3,671 cal yr BP. This is confirmed by the presence of open and less–varied mixed deciduous forests.
- Around 3,671 to 2,450 cal yr BP the proliferation of the mixed deciduous forests took place with the initiation of a warm and humid climate.
- Between 2,450 and 1,230 cal yr BP, the decline in the floristic composition of mixed deciduous forests occurred in response to inception of a warm and less–humid climate.

- Since 1,230 cal yr BP onwards the mixed deciduous forests recuperated with arrival of a warm and humid climate equivalent to that prevails at present. The rising trend of Cerealia and other culture pollen taxa implies acceleration of crop economy owing to conducive climate.

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