

Morphological variations and depositional processes of microforaminiferal linings in the early Tertiary sediments of northeastern and northwestern India

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ABSTRACT

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Microforaminiferal linings, the inner organic remnants of the benthic microforaminifera, occur frequently in the palaeopalynological preparations. The linings usually get buried in the organic rich shallow marine sediments and provide a useful data regarding their burial processes in the host sediments. The study presents records of microforaminiferal linings in the early Palaeogene subsurface of Upper Assam and lignite bearing sedimentary succession in the Cambay Basin, India, their morphology and depositional environments. The number of chambers and size of the linings categorize them into various morphological groups, viz. Uniserial type II, Biserial type II, Planispiral type II, Planispiral type III, Planispiral type IV, Trochospiral type I and Trochospiral type II of which two morphotypes, namely Planispiral type II and Trochospiral Type I are most common in the palynoassemblages. The study on microforaminiferal linings will delineate marine and terrestrial realms in the sequences where other palynofossils are not recovered and may facilitate better interpretation of the depositional environment. Morphological attributes of various microforaminiferal linings along with other palynomorphs, viz. spores, pollen grains, dinoflagellate cysts and fungal fruiting bodies indicate near shore, marine shelf depositional conditions of the studied sections.

Key-words—Microforaminiferal linings, Morphology, Palaeoenvironment, early Palaeogene, India.

उत्तरपूर्वी एवं उत्तर पश्चिमी भारत के प्रारंभिक तृतीयक अवसादों में सूक्ष्मफोरैमिनीफेरीय आस्तरों के आकारिकीय उतार-चढ़ाव एवं निक्षेपणीय प्रक्रम

प्रियंका मोंगा, माधव कुमार एवं योगेश जोशी

सारांश

पुरापरागाणविक विरचनों में नितलस्थ सूक्ष्मफोरैमिनीफेरा के आंतरिक कार्बनिक अवशिष्ट सूक्ष्मफोरैमिनीफेरा आस्तर प्रायः प्राप्त होते हैं। ये सूक्ष्मफोरैमिनीफेरा आस्तर समुद्री अवसादों के प्रचुर कार्बनिक गांध आस्तरों में अंतर्हित हो जाते हैं तथा आतिथेयी अवसादों में उनके शवाधान प्रक्रमों के बारे में उपयोगी आंकड़ा प्रदान करते हैं। यह अध्ययन भारत के ऊपरी असम के प्रारंभिक पैलियोजीन उपपृष्ठ और खम्भात की खाड़ी के भूराकोयलादिक्मान अवसादी अनुक्रम, में पाये गए सूक्ष्मफोरैमिनीफेरीय आस्तरों तथा उनकी आकृतिविज्ञान एवं निक्षेपणीय पर्यावरणों का अभिलेख प्रस्तुत करता है। इनकी कक्षिकाओं की संख्या एवं आस्तरों के आकार कई आकारिकीय समूहों अर्थात् एकपंक्ति प्रकार II, द्विपंक्ति प्रकार II, तलसर्पित प्रकार II, तलसर्पित प्रकार IV, चक्रकुंडल प्रकार I, एवं चक्रकुंडल प्रकार II में वर्गीकृत करती है। जिनमें से नामतः तलसर्पित प्रकार II एवं चक्रकुंडल प्रकार I के दो आकृति प्रकार, परागाणुसमुच्चयों में सामान्यतः उपलब्ध रहते हैं। सूक्ष्मफोरैमिनीफेरीय आस्तरों का अध्ययन अनुक्रमों में समुद्री एवं स्थलीय परिमंडलों को निरूपित (चित्रित) करता है जहाँ अन्य परागाणुसंरूप नहीं प्राप्त हुए हैं तथा निक्षेपणीय पर्यावरण की उत्तम व्याख्या करने में सहायक होता है। अन्य परागाणुसंरूपों अर्थात् बीजाणुओं, पराग कणों, घूर्णीकशाभ पुटियों एवं कवक फलन कार्यों सहित तमाम सूक्ष्मफोरैमिनीफेरीय आस्तरों की आकारिकीय विशेषताएं अध्ययन किए गए खंडों की समुद्र तट निकट, समुद्री उपतट निक्षेपणीय स्थितियाँ बताती हैं।

सूचक शब्द—सूक्ष्मफोरैमिनीफेरीय आस्तर, आकृतिविज्ञान, पुरापर्यावरण, प्रारंभिक पैलियोजीन, भारत।

INTRODUCTION

SEDIMENTARY successions of subsurface horizons of Assam and Cambay basins yield a variety of fossil fuels, mineral reserves with well preserved palynassemblages, along with microforaminiferal linings. The organic linings mostly derived from benthic foraminifera (Tyson, 1995) can be considered as a reliable indicator of depositional setups of marine shelf, shallow or slope conditions (Lister & Batten, 1988; Courtinat, 1989; Stancliffe, 1989; Courtinat & Meon, 1991; Oboh, 1992a, b), although they may be abundant in the estuarine marshes of variable salinities (Farr, 1989; Batten, 1996). The linings represent inner organic remains of the calcareous tests, whose outer tests usually dissolve during their burial in the sediments (Mc Neil, 1997; Tibert *et al.*, 2003; de Vernal, 2009; Fhlaithearta *et al.*, 2013; Concheyro *et al.*, 2014). The taxonomy and application of microforaminiferal linings for studying biostratigraphy and palaeoecology have been highlighted by Stancliffe (1989) with reference to the British Oxfordian sediments. The generic and specific level assignment of microforaminiferal linings based on the formal classification of foraminifera is not possible except for their morphological categorization (Stancliffe, 1989). These linings are common not only in carbonates (Traverse & Ginsberg, 1966), but also in the clastic shelf sediments deposited in warm, shallow marine nutrient upwelling areas that are not generally affected by terrestrial inputs (Cross *et al.*, 1966; van Waveren, 1989; Powell *et al.*, 1990).

The study on morphological and depositional aspects of microforaminiferal linings has not been focused earlier in detail. The present study documents its distribution in various facies types of both the basins and may fill a gap of knowledge on its morphological diversities. The use of these linings in stratigraphical and palaeoecological interpretation can provide a definitive evidence of marine and terrestrial constituents of the sediments deposited along the coastal zones.

STRATIGRAPHIC SETTINGS

Bihpuria Well–A (lat. 27°00"–27°20" N; long. 93°45"–93°15" E) is situated in the north of Subansiri and Brahmaputra rivers in North Lakhimpur District of Assam lying near the state border of Assam and Arunachal Pradesh (Fig. 1). The studied early Tertiary subsurface sediments of Upper Assam Basin are not categorized into various formations and considered as parts of the undivided Sylhet Limestone Formation because of the thinness of sediments in Upper Assam shelf in the districts of Lakhimpur and Dhemaji. Early Tertiary sediments occurring in the entire Upper Assam Basin are much significant for their hydrocarbon reserves (Bharali *et al.*, 1999). These sediments occur beneath the surface around Bihpuria in North Lakhimpur District with indistinct lithology in the sedimentary successions between 4444 to 4300 m depth above the Precambrian basement (Kumar &

Borgohain, 2005). The equivalent sediments comprising of Langpar, Lakadong Limestone, Lakadong Sandstone (Danian to Thanetian), Umlatdoh Limestone, Nurpuh Sandstone and Prang Limestone (early Eocene) followed by Kopili (late Eocene) of Jaintia Group in Meghalaya (Raja Rao, 1981; GSI, 1989) are lithologically distinct and their thickness is much greater than those occurring in Upper Assam Basin. The equivalent Mikir Formation (early Eocene) occurs at many places in Nagaon, Karbi–Anglong, Golaghat and Jorhat districts of Assam. The upper horizons, e.g. Tipam (Miocene) and Namsang (Pliocene) formations are not considered in this study due to the lack of microforaminiferal linings.

The Surkha Lignite Mine (21°26'43"–21°42'00" N; 72°07'30"–72°16'30" E) is situated in Bhavnagar District. The mining area lies in Cambay Basin, an intra–cratonic, north–south trending rift sedimentary basin in the Bhavnagar, Bharuch and Surat districts of Gujarat. The deposition of sediments in the basin started during the late Mesozoic with the development of major tensional faults following widespread extrusion of the Deccan trap basalt. The Deccan traps cover a major portion of Saurashtra peninsula and form basement for the development of Tertiary and Quaternary sediments in the basin. The Tertiary sediments comprise of greywacks, dark grey to black grey shales, lignite, silts, fine to medium grained sands and grey reddish–brown clays (Bhandari & Choudhary, 1975). Stratigraphically, rocks and sedimentary sequences of the basin are categorized into eight formations (*viz.* Vagadkhol, Cambay Shale, Ankleshwar, Tadkeshwar, Babaguru, Kand, Jhagadia, Narmada with Deccan traps) as the basement is overlain by the Cambay Shale Formation (Agrawal, 1986). The sediments show a thickness of about 200–300 m and contain various types of plant microfossils (spores, pollen grains, dinoflagellate cysts, sedimentary organic matter, etc.), along with megafloreal and faunal remains, including foraminiferal linings.

MATERIAL AND METHODS

The palynomorphs recovered from subsurface Bihpuria Well–A, Assam and Surkha lignite section, Gujarat, contain well preserved microforaminiferal linings with different morphological features. The foraminiferal organic linings were recovered with other palynomorphs after chemical processing of these sediments. Standard maceration techniques were followed for extraction of palynomorphs and other organic particles (Brown, 1960; Batten & Morrison, 1983). For extraction of microforaminiferal linings and other palynological materials approximately 25–30 g of each sample was crushed, kept in plastic jars and treated with dilute hydrochloric acid for 18–20 hours followed by 40 % hydrofluoric acid for 4–5 days for dissolving silica. Thereafter, dilute nitric acid (20–25%) was added for digesting humic materials followed by treatment with 1–2% aqueous KOH solution. These macerated residues were mixed with a few

drops of polyvinyl alcohol, smeared uniformly over the cover glass. The cover glass dried in an oven for about 30 minutes was then mounted in Canada balsam. The prepared slides were kept in an oven for drying at approx. 70°C. Slides prepared from productive samples were examined under the light

microscope for qualitative and quantitative analysis of the palynomorphs. Slides used for the present study are housed in the Repository of the Birbal Sahni Institute of Palaeobotany, Lucknow for further reference.

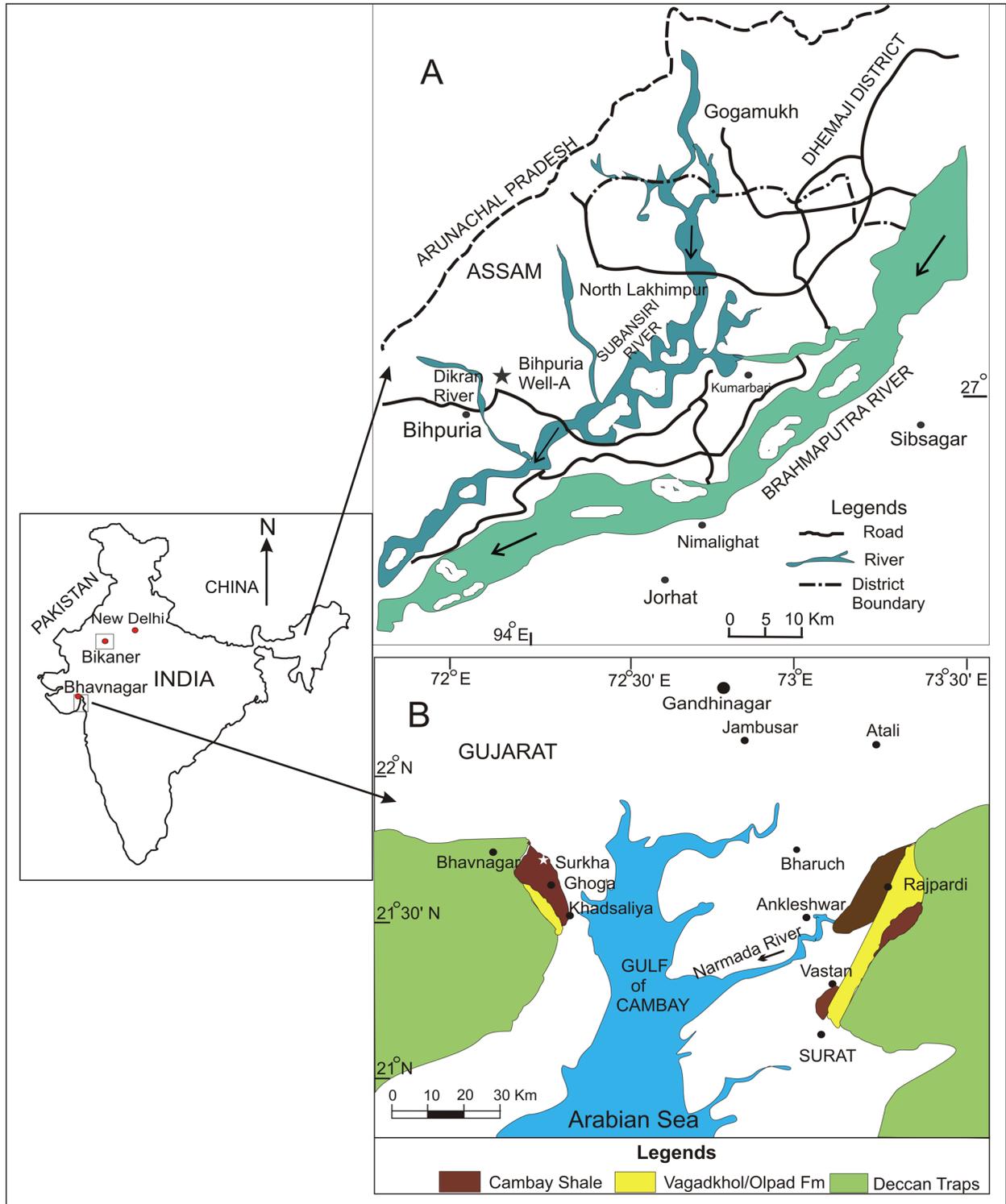


Fig. 1—Location of the study areas (★) in (A) northeastern and (B) northwestern India.

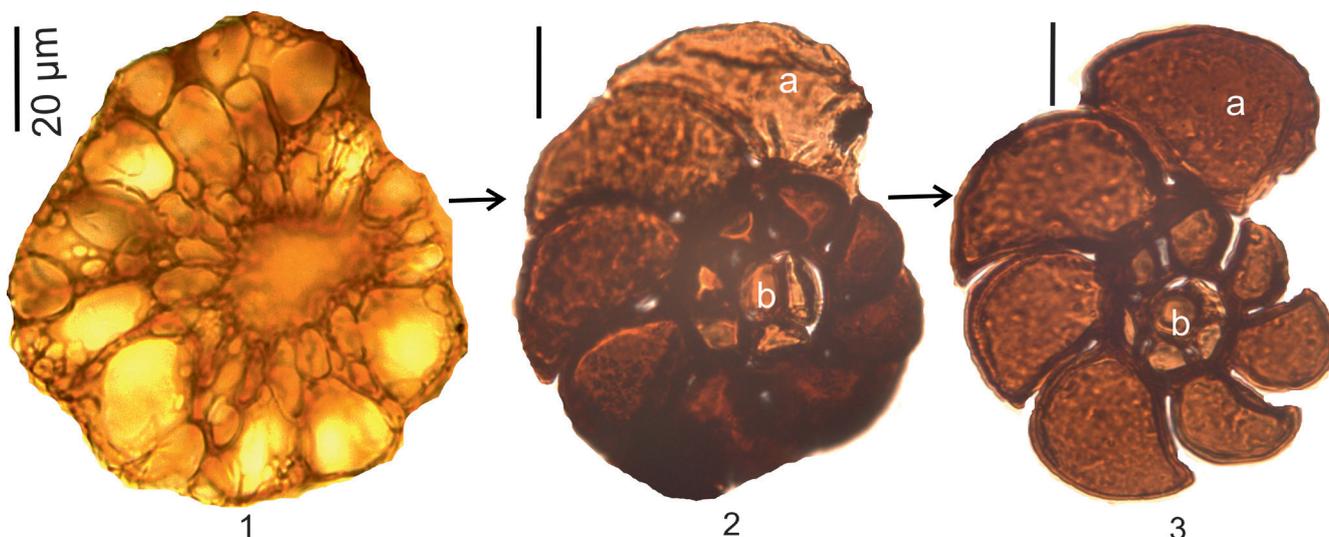


Fig. 2—Enlarged views of (1) partially dissolved test of foraminifera, and (2–3) microforaminiferal linings (a = last chamber, b = proloculus).

AGE OF THE SEDIMENTARY SUCCESSIONS

Age of the sedimentary successions is determined on the basis of dinoflagellate cysts and angiospermic pollen grains. The organic linings are found in marine influenced deposition of the Lakadong Sandstone Formation (late Palaeocene), Mikir Formation (early Eocene) of Jaintia Group of Upper Assam and Cambay Shale Formation (early Eocene) of Cambay Basin, Gujarat. Dinoflagellate cysts, viz. *Apectodinium homomorphum*, *Homotryblium* spp., *Operculodinium* sp., *Cordosphaeridium* sp. and pollen grains of *Lanagiopollis* sp., *Proxapertites emendatus*, *Neocouperipollis kutchensis* and *Perforitricolpites neyvelii*, etc. recorded from the basal part of Bihpuria Well-A (Sylhet Limestone Formation) suggest late Palaeocene to early Eocene age (Kumar & Borgohain, 2005).

The Cambay shale sediments exposed at Surkha Lignite Mine have been assigned to early Eocene age due to the occurrence of dinoflagellate cysts of *Homotryblium* spp., *Cordosphaeridium fibrospinosum*, etc. that can be correlated with the middle part of the Vastan lignite succession, Cambay Basin (Garg *et al.*, 2008). Some significant pollen grains, e.g. *Matanomadhiasulcites maximus*, *Palmaepollenites nadhamunii*, *Arengapollenites ovatus* and *Retipollenites enigmata* recorded from Surkha Lignite Mine also show their presence in Naredi Formation (early Eocene) of Kutch (Kar, 1985) and Cambay Shale Formation of Rajpardi and Vastan (Kar & Bhattacharya, 1992; Kumar, 1996; Samant & Phadtare, 1997; Rao *et al.*, 2013).

MICROFORAMINIFERAL LININGS

Microforaminiferal linings, a term coined by Wilson and Hoffmeister (1952) applies to the acid resistant foraminiferal remains (less than 150 µm in size), found in the palynological preparations (Pl. 1). It is the inner organic layer produced mainly by the calcareous and agglutinated benthic foraminifera (de Vernal, 2009). The composition of the linings is of chitin derivatives, proteins and polysaccharides but some may have even of lignin compounds (Fhlaithearta *et al.*, 2013). The natural dissolution or breakage of calcareous microforaminiferal tests results in liberation of their organic linings (Wetzel, 1957; Golubić & Schneider, 1979; Mc Neil, 1997) which maintain more or less internal test morphology of the original foraminifers (Concheyro *et al.*, 2014) as shown in Fig. 2. The inner surface of agglutinated foraminiferal test bound with organic cement is extremely tolerant of the acidic conditions of salt marshes, organic sediments of estuaries and bays, and shows high preservation potential (Tibert *et al.*, 2003).

Foraminiferal skeletons or tests are built of chambers, which have cavities containing the cytoplasm with a surrounding firm wall. Adjacent chambers are separated by septa but a connection between septa is maintained by a hole or foramen (Culver, 1993). The first chamber is centrally developed called proloculus (Fig. 2, 2–3b) which is commonly thicker than other succeeding chambers, while the second chamber is usually smaller than the proloculus. There is

PLATE 1

(scale bar = 20 µm or given on image)

- | | |
|---|--|
| <p>1. Uniseriate type II, BSIP Slide No. 15535, K 32. 2. Internal features of microforaminifera, BSIP Slide No. 15536, Q 38. 3-9. Planispiral type II, BSIP Slide Nos. 3) 15537, K 44, 4-5) 15538, D 50, D 51, 6) 15539, O 42, 7) 15540, P 47, 8) 15541, V 37 9) 15539, H 50.</p> | <p>10-11. Planispiral type III, BSIP Slide Nos. 10) 15538, L 22, 11) 15542, N 50. 12. Planispiral type IV, BSIP Slide No. 15537, G 25. 13-16. Trochospiral type I, BSIP Slide Nos. 13) 15314, K 24, 14) 15544, G 53, 15) 15541, S 46, 15312, Q 48. 17. Trochospiral type II, BSIP Slide No. 15314, N 42.</p> |
|---|--|



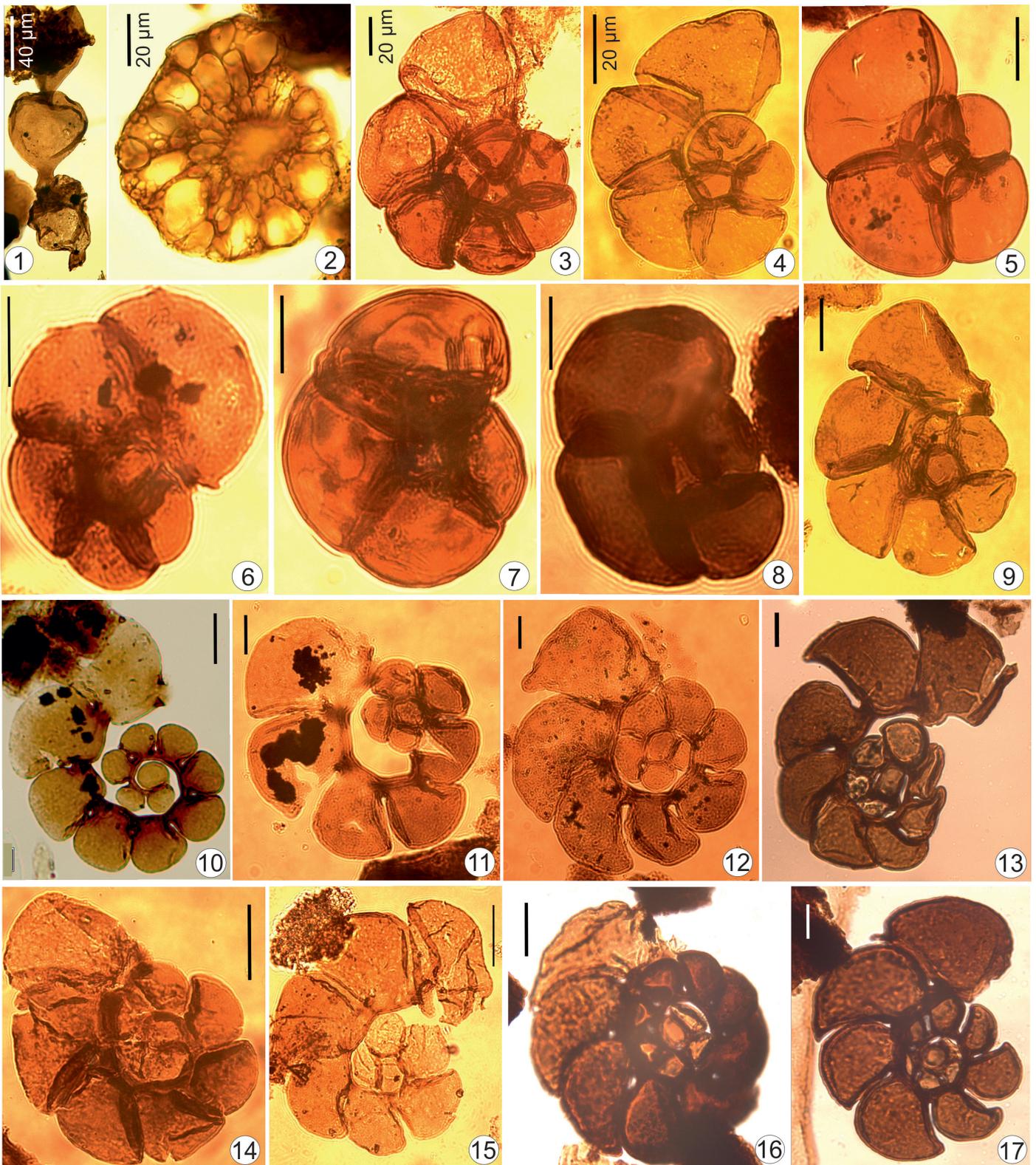


PLATE 1

rarely a visible connection with the second chamber. The size of other succeeding chambers gradually increases. The last or terminal chamber of few microforaminiferal linings appears to be larger than others and is thin walled (Fig. 2, 2–3a). Morphologically, the foraminiferal linings occur as uniserial, biserial and coiled forms (Pl. 1). The uniserial forms have centrally located neck, whereas biserial linings exhibit thickenings at an angle to the direction of the growth of lining. The neck development is not common in coiled forms, however, if neck is present they can be centrally located on the wall or on the side of the chamber nearest to the proloculus. The external wall surface of the microforaminiferal linings can be smooth, granular or bearing short spinules.

CATEGORIZATION OF FORAMINIFERAL LININGS INTO VARIOUS GROUPS

Various palynologists proposed two types of classification system for microforaminiferal linings, namely (i) informal and (ii) formal. The formal system of classification of foraminiferal linings into Sphaeromorphitae and Disphaeromorphitae groups was proposed by Góczán (1962) with five coiled types from the Cretaceous rocks of Hungary. However, Macko (1963) and Deak (1964) proposed generic and specific names for microforaminiferal linings recovered from the Cretaceous and Eocene sediments. Tappen and Loeblich (1965) rejected formal system of the classification and stated that the additional “form species” and “form genera” of foraminiferal linings add burden to the foraminiferal taxonomy. Stancliffe (1989) described an informal classification for microforaminiferal linings; this has been adopted for the present study. The classification includes the description of overall chamber relationship, chamber overlapping, neck development and length to breadth changes (Table 1). Six main types of microforaminiferal linings encountered in the palynological assemblages of both the regions are: Uniserial type II, Biserial type II, Planispiral type II, Planispiral type III, Planispiral type IV, Trochospiral type I and Trochospiral type II, however, the dominant forms are coiled ones with Planispiral as well as Trochospiral types. The quantification of chamber from proloculus to the larger chambers is based on the measurement of length to breadth. A maximum and minimum measurement is recorded for the clearly visible proloculus in all the specimens. The measurement of the first chamber (proloculus) to last preserved chamber indicates good growth rate of the lining in most of the specimens (Stancliffe, 1989) are observed (Pl. 1; Fig. 3). Sometimes linings are affected by bacterial attacks or mechanical processes resulting in pitting or dissolution of outer organic layers. The biogenic (Bajpai *et al.*, 2001) or abiogenic (Berner, 1985; Mc Neil, 1997) pyrites are also observed in the chamber walls (Pl. 1.10–11).

DISTRIBUTION OF FORAMINIFERAL LININGS AND OTHER PALYNOMORPHS

The late Palaeocene sediments between 4444–4440 m depth of Bihpuria Well–A comprising of laminated clay and shale (Fig. 3A) exhibit less frequency of microforaminiferal linings (5%) as compared to the dinoflagellate cysts (5–10%), viz. *Apectodinium homomorphum*, *Cordosphaeridium* sp., *Operculodinium* sp. and *Spiniferites* sp. Pollen grains, namely *Neocouperipollis kutchensis*, *Matanomadhiasulcites maximus*, *Proxapertites emendatus*, *Palmidites plicatus*, *Tripoporopollenites* sp., *Perforitricolpites neyvelii*, *Lakiapollis ovatus*, *Tricolporopollis rubra* and spores of *Dandotiaspora dilata*, *D. telonata*, *Lycopodiumsporites speciosus* and *Polypodiaceasporites* sp. abundantly occur in the sediments. The overlying early Eocene strata between the depth 4440–4386 m comprising of shale and clay, fine siliceous shale contains abundant microforaminiferal linings (10–18%). Dinoflagellate cysts ranging from 60% to 30% towards the top are represented by *Homotryblum tenuispinosum*, *Homotryblum abbreviatum*, *Cordosphaeridium fibrospinosum*, *C. robustum*, *C. exilimurum*, *Operculodinium israelianum* and *Operculodinium* sp., etc. The pollen grains (25–35 %) observed in this interval are: *Palmaepollenites nadhamunii*, *Matanomadhiasulcites maximus*, *Palmidites plicatus*, *Arecipites bellus*, *Proxapertites microreticulatus*, *Longapertites vaneedenburgi*, *Lakiapollis matanomadhensis*, *Striacolporites cephalus*, *Rhoipites kutchensis* and pteridophytic spores (5–6 %) of *Polypodiaceasporites levis*, *Dandotiaspora telonata*, *Dandotiaspora plicata*, *Lygodiumsporites pachyexinus* and *Acrostichumsporites meghalayaensis*. Occurrence of rich amorphous organic matter in this interval exhibits anoxic condition (Kumar & Borgohain, 2005), which favoured dissolution of test and preservation of organic contents of microforaminifera. No microforaminiferal linings are recorded in post Kopili (Tipam and Namsang) sediments because of the poor incursion of brackish water due to gradual shallowing of the basin during late Eocene onwards.

The basal strata of Surkha Lignite Mine with lignite and carbonaceous shale partings exhibit 2–5% microforaminiferal linings and no dinoflagellate cysts (Fig. 3B). The lignite contains rich spores of families Matoniaceae (*Dandotiaspora telonata*), Polypodiaceae (*Polypodiaceasporites repandus*) and pollen grains of Arecaceae (*Palmidites plicatus*, *Palmaepollenites kutchensis*, *Longapertites vaneedenburgi*, etc.), along with fungal fruiting bodies of *Monoporisorites circularis*, *M. ovaliformis*, etc. Occurrences of a few microforaminiferal linings in lignite indicate less marine influence during the deposition. But upper sequences comprising of shale, carbonaceous shale, cross bedding rippled mudstones and muddy matrices represent 2–3% of microforaminiferal linings with rich dinoflagellate cysts of *Homotryblum* spp., *Cordosphaeridium fibrospinosum*, etc. The spores of the families Matoniaceae (*Dandotiaspora telonata*), Pteridaceae

| Types | Morphology |
|---------------------------------------|---|
| Uniserial type II (Pl. 1.1) | The chambers of the lining are appressed without development of distinct necks. The connection between each chamber is marked by the thickening of the wall. Dimensions (one specimen): Number of the chambers: 3, first chamber: $41 \times 27 \mu\text{m}$, second chamber: $44 \times 47 \mu\text{m}$, last chamber: $55 \times 27 \mu\text{m}$; overall size: $146 \mu\text{m}$ |
| Planispiral type II (Pl. 1.3–9) | The chambers of the planispiral type II overlaps with each other with varying degree. In most of the Planispiral type II observed, the final chambers are wide with respect to the direction of growth. Dimensions (nine specimens): Number of the chambers: 5–9, first chamber: $13\text{--}22 \times 11\text{--}25 \mu\text{m}$, second chamber: $11\text{--}22 \times 11\text{--}27 \mu\text{m}$, last chamber: $30\text{--}68 \times 19\text{--}50 \mu\text{m}$; overall size: $55\text{--}125 \mu\text{m}$ |
| Planispiral type III (Pl. 1.10–11) | It is characterized by non-overlapping of the chambers which are wide with respect to their length. The second whorl of the chambers is not oppressed to the first one. Dimensions (two specimens): Number of the chambers: 10–13; first chamber: $12\text{--}13 \times 12\text{--}13 \mu\text{m}$; second chamber: $12\text{--}16 \times 11 \mu\text{m}$; last chamber: $41\text{--}47 \times 33\text{--}44 \mu\text{m}$; overall size: $97\text{--}111 \mu\text{m}$ |
| Planispiral type IV (Pl. 1.12) | Chambers do not overlap each other and are wider with respect to their length. Chambers after the completion of the first whorl touches those of the secondary whorl. Dimensions (one specimen): Number of the chambers: 12; first chamber: $16 \times 19 \mu\text{m}$; second chamber: $13 \times 11 \mu\text{m}$; last chamber: $50 \times 55 \mu\text{m}$; overall size: $125 \times 139 \mu\text{m}$ |
| Trochospiral type I (Pl. 1.13–16) | It is characterized by distinct overlapping of the adjacent chambers, larger chambers have proximal connections with the succeeding and preceding chambers. Maximum two numbers of whorls are recorded. The chambers of the second whorl are dark brown in colour while outer chambers are comparatively thin walled and translucent. Chamber's surface ornamentation varies from smooth to granular. Dimensions (four specimens): The number of the chambers: 10–15; first chamber: $11\text{--}19 \times 8\text{--}13 \mu\text{m}$; second chamber: $11\text{--}16 \times 8\text{--}13 \mu\text{m}$; last chamber: $39\text{--}72 \times 27\text{--}41 \mu\text{m}$, overall size: $103\text{--}111 \mu\text{m}$ |
| Trochospiral type II (Pl. 1.17) | It has discrete chambers in primary whorl and chambers of the second whorl overlap chambers of the first whorl. Dimensions (one specimen): Number of the chambers: 13; first chamber: $13 \times 13 \mu\text{m}$; second chamber: $11 \times 8 \mu\text{m}$; last chamber: $69 \times 55 \mu\text{m}$; overall size: $123 \mu\text{m}$ |

Table 1—Various types of microforaminiferal linings (according to Stancliffe, 1989) observed in both the sections.

(*Acrostichumsporites meghalayaensis*) and pollen grains of the families Areaceae (*Palmidites plicatus*, *Arengapollenites achinatus*, *Proxapertites microreticulatus*), Annonaceae (*Matanomadhiasulcites maximus*), Bombacaceae (*Lakiapollis ovatus*), etc. are recorded along with fungal fruiting bodies of *Monoporisporites ovaliformis*, *M. circularis*, *Callimothallus pertusus* and fresh water algal spores of *Psiloschizosporis* sp. as well as *Botryococcus braunii*. The high frequency of dinoflagellate cysts indicates flooding of the sea at outer neritic zone. Sedimentary organic matter recorded from upper part of the studied section shows prevalence of oxic conditions with rich black debris, structured terrestrial and biodegraded terrestrial organic matter. Such sedimentary environment was not congenial for preservation of microforaminiferal linings.

DEPOSITIONAL PROCESSES AND PALAEOECOLOGY

Foraminifera have been successful inhabitants of every aquatic environment from deep oceans to brackish water lagoons, estuaries and rarely in freshwater streams, lakes, etc. (Gandhi & Solai, 2010). The acidic pH condition of marine facies causes dissolution of calcareous foraminifers; such conditions also favour decay of organic remains by aerobic and anaerobic bacteria under reducing condition (Mc Neil, 1997). Under such circumstances production of carbon dioxide and carbonic acids (H_2CO_3) may lead dissolution of calcareous foraminifers (Golubić & Schneider, 1979).

Bradford (1977) suggested that distribution of linings in marine sediments is comparable to the occurrence of benthic foraminifera deposited in shallower condition with high salinity and high summer temperatures. Batten (1982) demonstrated that microforaminiferal linings frequency increases in marine facies associated with rich amorphous organic matter. The linings are mostly recorded with dinoflagellate cysts in the sediments deposited along the coasts (Warrington, 1982; Davies, 1985; Kumaran & Rajshekhar,

1992; Singh *et al.*, 2013). Based on the abundance of microforaminiferal linings as well as dinoflagellate cysts, the marine influenced depositions are identified in both the studied sections. Warrington (1982) noted an inverse relationship between microforaminiferal linings and dinoflagellate cysts. In the present study of Surkha Lignite Mine section frequency of linings decreases with increase in dinoflagellate cysts, whereas the case is reverse in Bihpuria–Well A of Assam. But some strata of Surkha Lignite Mine represent

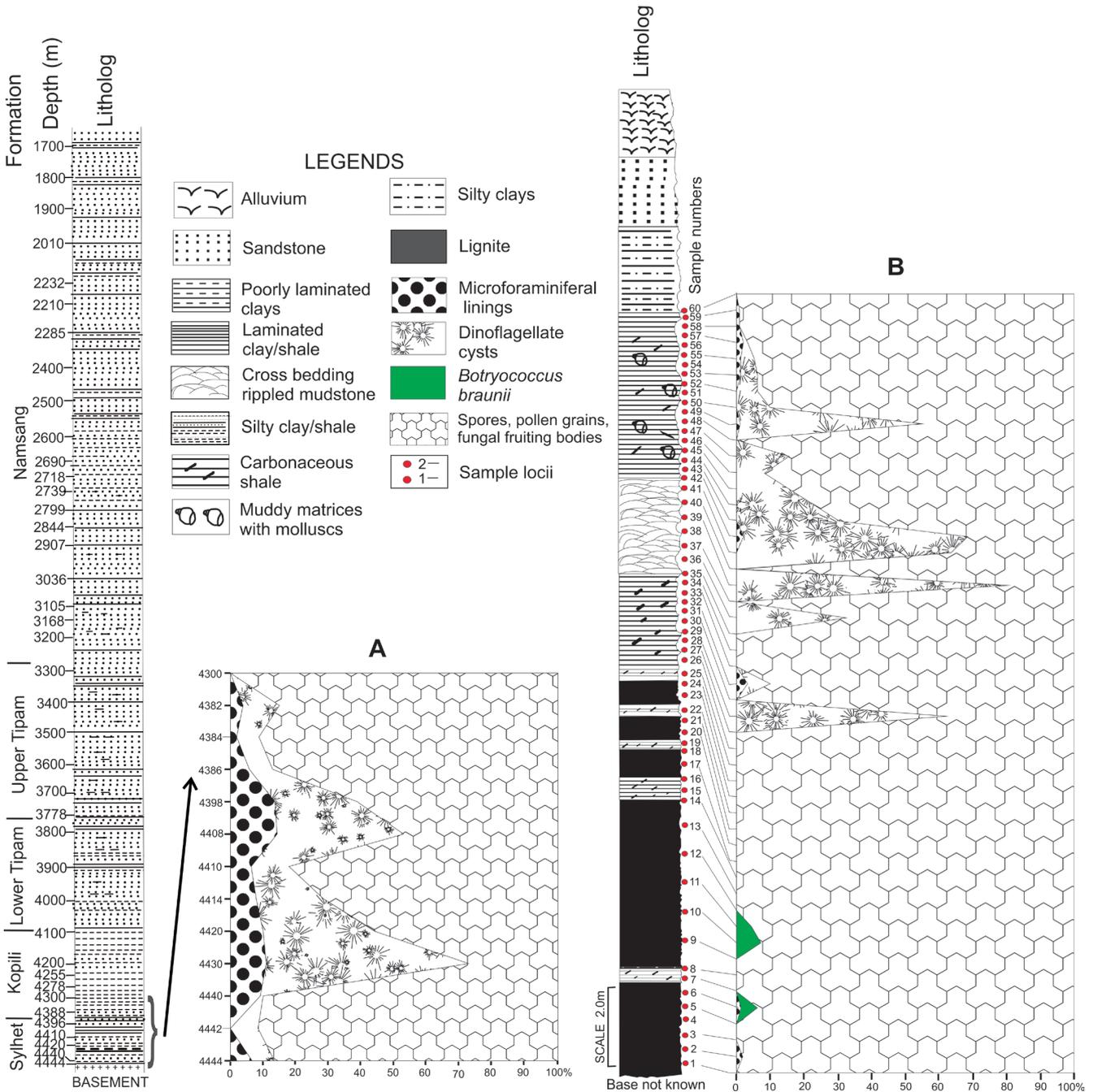


Fig. 3—Lithostratigraphy and abundance of microforaminiferal linings, dinoflagellate cysts, *Botryococcus braunii*, spores, pollen grains and fungal fruiting bodies in A) Bihpuria Well-A and (B) Surkha Lignite Mine section.

microforaminiferal linings with pollen grains deposited along the coast influenced by both riverine and brackish water. Uniseriate type II occurred in the facies dominated with amorphous and biodegraded organic matter in Bihpuria–Well A indicating its preservation under reducing condition (Tibert *et al.*, 2003). Diagenesis of linings results in the genesis of pyrite (Pl. 1.10–11) in the chambers by the activity of sulphate reducing bacteria and availability of iron and sulphur in anoxic burial conditions where sulphate–reducing bacteria get abundant supply of organic matter in shallow marine environments including oceanic, fluvio–deltaic with *in situ* detritus contributions (Kaczmarek & Ehrman, 1990; Mc Neil, 1997; Álvarez–Iglesias & Rubio, 2012).

CONCLUSIONS

1. Microforaminiferal linings provide means of reconstructing nature of the marine influenced depositional set ups. Abundant microforaminifera linings with varied morphology were observed in subsurface Bihpuria Well–A, Assam and Surkha lignite section, Gujarat. Six main morphotypes recovered in the section were Uniserial type II, Planispiral type II, Planispiral type III, Planispiral type IV, Trochospiral type I, Trochospiral type II of which Planispiral type II and Trochospiral type I were found in abundance.
2. The palaeoenvironment of linings, along with dinoflagellate cysts signifies that such deposition took place in low lying shallow marginal marine conditions. The marine incursion was more constant in Bihpuria Well–A, Assam than Surkha lignite section, Gujarat.
3. The occurrence of foraminiferal linings in the pollen spore dominated assemblages indicates that vegetal matter was deposited adjacent to the ancient shoreline.
4. The varied taphonomic processes and variabilities in environmental setups might have affected distribution of the benthic foraminifera resulting in an increase or decrease in the frequency of linings.
5. Occurrence of pyrite in the chambers indicates burial under anoxic condition produced by the activity of aerobic and sulphur reducing anaerobic bacteria. Such conditions favour preservation of Uniserial type linings.

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