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Latest Maastrichtian palaeoclimatic and depositional environmental perturbations, a record from *Micula prinsii* Zone of Meghalaya, northeastern India

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ABSTRACT

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A significant latest Maastrichtian calcareous nannofossil assemblage is recorded from the exposed section near Syndai Village, Meghalaya. A total of twenty two samples from sedimentary succession consisting of shales and sandy shales, calcareous at places, were studied; out of which ten samples were found productive in terms of calcareous nannofossils recovery. The presence of *Micula prinsii* in all the productive samples along with the other latest Maastrichtian nanno taxa suggests that the assemblage belongs to *Micula prinsii* Zone and well correlates with the CC26b Zone of Perch Nielsen and UC20d^{TP} Zone of Burnett which are an amalgamation of old and new biozonation schemes from a range of palaeolatitudes and biogeographic provinces from both oceanic and shelf palaeoenvironments. *Micula prinsii* Perch–Nielsen, the latest Maastrichtian marker all over the globe, is recorded from both deep–sea sections and shelf areas. It is most evolved form of the genus *Micula* and got extinct just before K–Pg boundary. The *Micula prinsii* Zone is marked by the first occurrence of *Micula prinsii* to the last occurrence of unreworked, non–survivor Cretaceous taxa.

In the present study, cluster analysis envisaged the palaeodepositional environmental changes within the *Micula prinsii* Zone in northeastern India. In the lower part of the section, the abundance of *Micula concava* and *Micula staurophora* with the increased numbers of *Watznaueria barnesiae* indicates environmentally stressful conditions with low productivity in surface water. However, in the upper part the increased numbers of *Calculites obscurus* with the decrease in *Micula concava* and *Micula staurophora* abundance indicates relatively increased productivity in surface water in marginal marine depositional environment.

Key–words—*Micula prinsii*, Palaeoclimate, Depositional environment, Nannofossil, Latest Maastrichtian, Meghalaya.

अद्‌यतन मास्ट्रीच्टियन पुराजलवायवी एवं निक्षेपणीय पर्यावरणीय विचलन, मेघालय, पूर्वोत्तर भारत के मिकुला प्रिन्सयाई मंडल से प्राप्त अभिलेख

आभा सिंह

सारांश

सींडई ग्राम, मेघालय के निकट अनावरित खंड से महत्वपूर्ण अद्‌यतन मास्ट्रीच्टियन चूनेदार परासूक्ष्मजीवाश्म समुच्चय अभिलिखित की गई है। स्थलों पर शेलों एवं बलुई शेलों, चूनेदार सन्निहित अवसादी अनुक्रम से प्राप्त कुल 22 नमूने अध्ययन किए गए; इनमें से चूनेदार परासूक्ष्म जीवाश्मों की प्राप्ति के संदर्भ में 10 नमूने उत्पादी पाए गए। अन्य अद्‌यतन मास्ट्रीच्टियन परासूक्ष्म टैक्सा के साथ समस्त उत्पादी नमूनों में *मिकुला प्रिन्सयाई* की विद्‌यमानता व्यंजित करती है कि समुच्चय *मिकुला प्रिन्सयाई* मंडल नहीं है तथा पर्च नीलसेन के CC26b मंडल व बर्नेट के UC20d^{TP} मंडल से भलीभांति संहसंबंध रखती है। जो दोनो सामुद्रिक व उपतट पुरापर्यावरणों से प्राप्त पुरा अक्षांशों व जैव भूगौलिक प्रान्तों के क्षेत्र से प्राप्त, प्राचीन एवं नूतन जैव अनुक्षेत्र वर्गीकरण योजनाओं के समामेलन हैं। गहरे समुद्र खंडों एवं उपतट क्षेत्र दोनों से अभिलिखित *मिकुला प्रिन्सयाई* पर्च नीलसेन समूचे भूमंडल में अद्‌यतन मास्ट्रीच्टियन चिह्नक है। यह *मिकुला* वंश का सर्वाधिक विकसित प्ररूप है तथा K-Pg सीमा से ठीक पूर्व विलुप्त हो गया। *मिकुला प्रिन्सयाई* मंडल गैर पुनर्रचित, गैर उत्तरजीवी चाकमय टैक्सा की अंतिम प्राप्ति *मिकुला प्रिन्सयाई* की प्रथम प्राप्ति से चिह्नित है।

मौजूदा अध्ययन में , पूर्वोत्तर भारत में *मिकुला प्रिन्सयाई* मंडल के अंदर पुंज विश्लेषण ने पुरानिक्षेपणीय पर्यावरणीय परिवर्तनों पर विचार किया। खंड के अधो भाग में, *वाट्ज़नौरिया बर्नेसीए* की वृद्धित के साथ *मिकुला कानकेवा* और *मिकुला स्टैरोफोरा* की बहुलता पृष्ठीय जल में अल्प उत्पादकता के साथ पर्यावरणीय रूप से दबाव युक्त स्थितियां व्यंजित करती हैं। हालांकि, ऊपरी भाग में *मिकुला कानकेवा* में ह्वास के साथ *कैलकुलाइट्स ऑब्सक्योर्स* की बढ़ती संख्या तथा *मिकुला स्टैरोफोरा* बहुलता उपांतीय समुद्री निक्षेपणीय पर्यावरणीय पृष्ठीय जल में सापेक्षयता बढ़ती उत्पादकता व्यंजित करती है।

सूचक शब्द—*मकुला प्रिन्सयाई*, पुराजलवायु, निक्षेपणीय पर्यावरण, परासूक्ष्मजीवाश्म, अद्यतन मास्ट्रीच्टियन, मेघालय ।

INTRODUCTION

THE Cretaceous–Paleogene (K–Pg) boundary mass extinction event (65.68 Ma) is one of the most fascinating event in the geological history and has been studied globally by the several workers (Alvarez *et al.*, 1980; MacLean, 1985; Courtillot *et al.*, 1986, 1988; Duncan & Pyle, 1988; Pope *et al.*, 1991; Smit *et al.*, 1996; Keller *et al.*, 2003, 2007, 2009a, b; Keller, 2010; Schulte *et al.*, 2010). During this period, planktonic protists thriving in the ocean were almost completely vanished. More than 90% of nannoplanktons and planktonic foraminifer species extinct across the K–Pg boundary (Kaiho, 1994; Bown *et al.*, 2004) and took millions of years to recover from the extinction (Coxall *et al.*, 2006; Fuqua *et al.*, 2008), and diversity did not reach pre–extinction levels for as long as 15 million years after the event (Norris, 2001; Bown *et al.*, 2004). Nevertheless, the extinction and recovery events after K–Pg boundary has been precisely documented for the both plankton groups, but very few studies have been performed on the changes in palaeoclimatic and depositional environmental conditions that have prevailed prior to the K–Pg boundary and precise timing and duration of these changes (Thibault & Gardin, 2006, 2007, 2010; Husson *et al.*, 2014; Thibault & Husson, 2016).

For the past 30 years, Chicxulub impact and Deccan volcanism has been believed as potential cause for the K–Pg boundary catastrophe (MacLean, 1985; Courtillot *et al.*, 1986, 1988; Duncan & Pyle, 1988; Pope *et al.*, 1991; Smit *et al.*, 1996; Schulte *et al.*, 2010). But the recent studies by Keller and group (Keller *et al.*, 2003, 2007, 2009a; Keller, 2010) suggested a pre–KT age for the Chicxulub impact. Deccan volcanism also believed to have occurred over about one million year prior to the mass extinction leaving sufficient time for recovery between eruptions. More recently, major studies of the Deccan Volcanic Province (DVP) have greatly improved our understanding of the age and tempo of eruptions, revealing three major phases: initial phase–1 in C30n at ~67.4 Ma, the main phase–2 in C29r just before the KTB, and the last phase–3 in the early Danian (base C29n). Phase–2 is the most critical period of Deccan volcanism as it accounts for ~80% of the entire 3500 m thick Deccan lava pile, and erupted in rapid pulses over a short interval in C29r just prior to the KTB mass extinction (Chenet *et al.*, 2007, 2008, 2009; Keller *et al.*, 2008, 2009b, c). The present study reports the quantitative

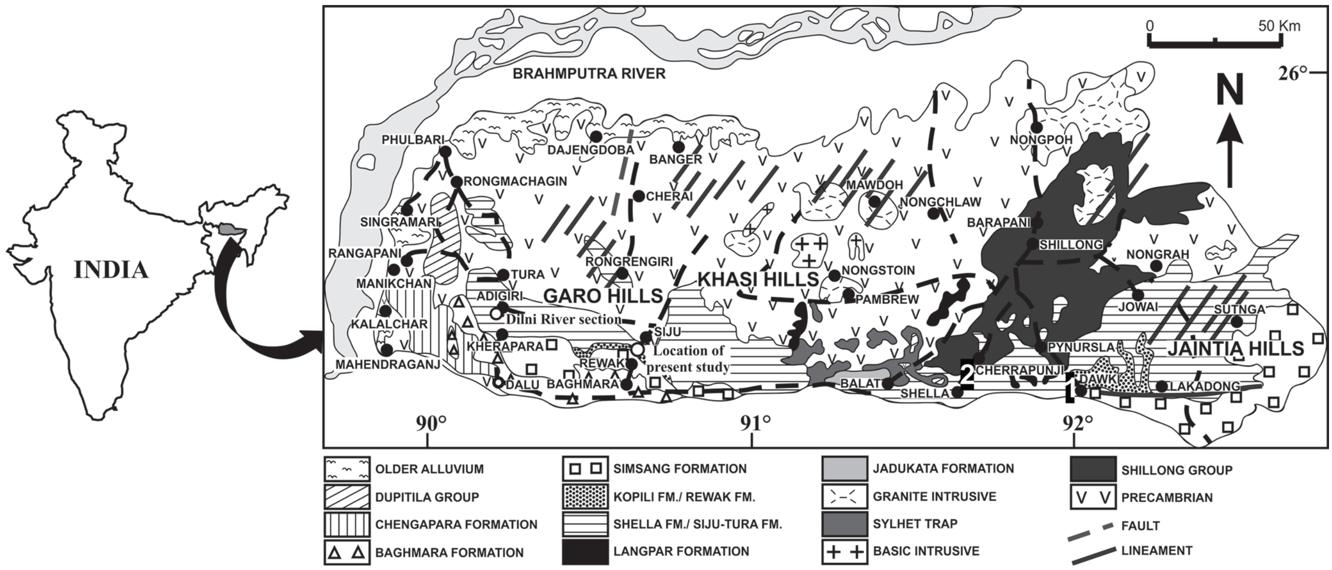


Fig. 1—Geological map of the study area (adapted from website http://www.megdmg.gov.in, Department of Mining & Geology, Government of Meghalaya) showing the location of sampling site (1) and Um Sohryngkew section (2).

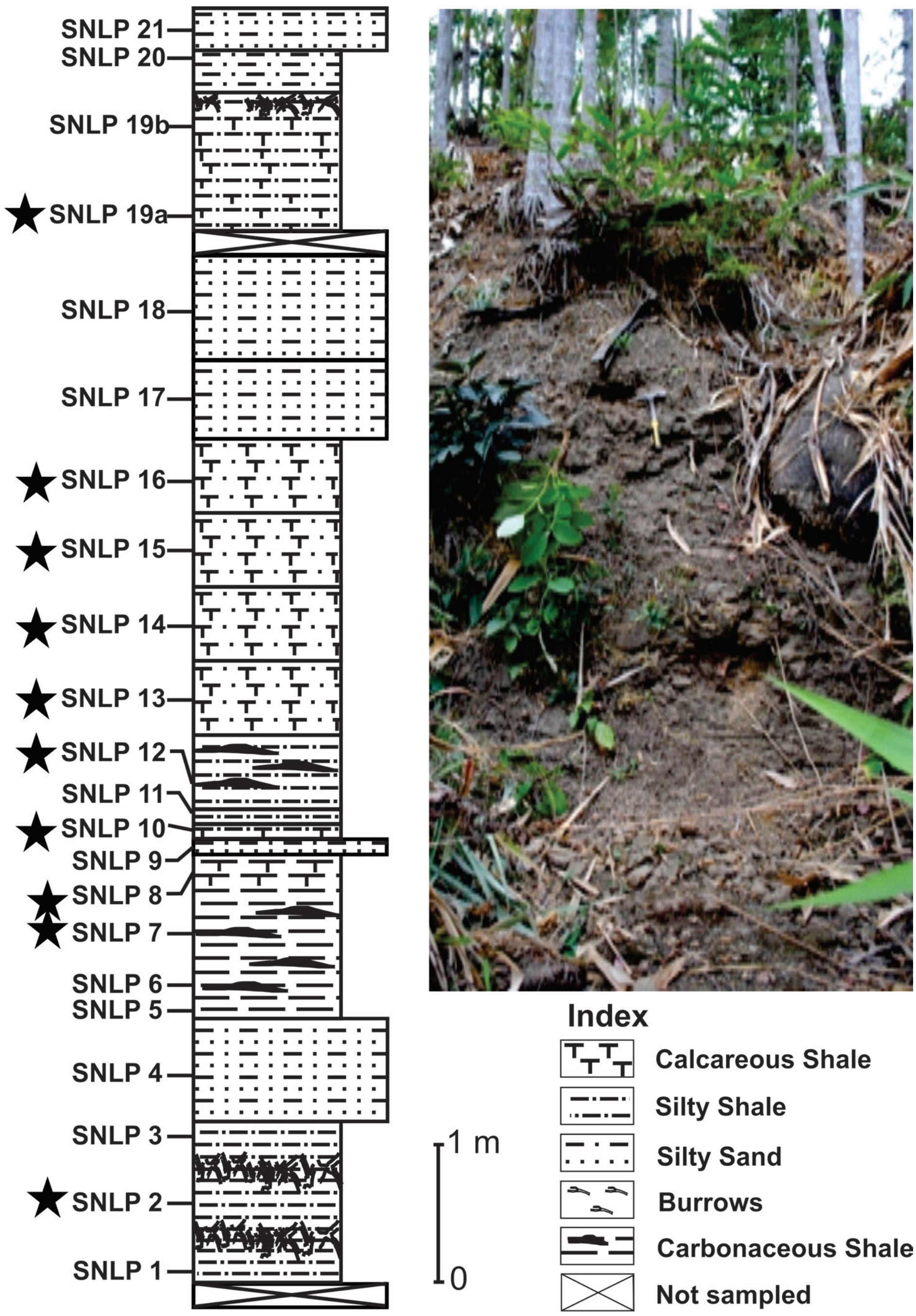


Fig. 2—Lithocolumn and field photograph of the studied section (productive samples are marked with asterisk mark).

fluctuation in nannofossil assemblage caused by climatic and environmental change within late Maastrichtian, during the 2nd phase of Deccan eruption. Our investigations are based on the nannofossil biostratigraphy to provide high–resolution age control and statistical analysis to identify environmental changes and periods of high–stress conditions caused by Deccan Volcanic activity during Late Maastrichtian.

GEOLOGICAL SETTING

The study area lies in Meghalaya State located in the northeastern part of India (Fig. 1). The major area is a part of the Shillong Plateau, which includes Garo, Khasi, Jaintia and Mikir hills. The Shillong Plateau is tectonically related to the formation of Himalaya and corresponds to an uplifted Precambrian massif of the peninsular India shield formation. The phenomenon led to deposition of 6 km thick deposit of marine to continental sedimentary rocks Cretaceous through Miocene time that unconformably overlie the basement along the eastern, western and southern flanks (Reimann, 1993; Rowley, 1996; Das Gupta & Biswas, 2000; Alam *et al.*, 2003; Ghosh *et al.*, 2005; Clark & Bilham, 2008; Rao *et al.*, 2008). The Late Cretaceous sedimentary sequences of Meghalaya are exposed in patches in the southern fringes of more or less narrow belts bounded by two major east–west trending faults namely the Raibah fault to the north and Dowki fault to the south. The lithostratigraphic classification for the Upper Cretaceous–Lower Paleogene succession in Khasi and Jaintia hills has been studied by several workers (Medlicott, 1869; Ghosh, 1940; Biswas, 1962; Chakraborty & Baksi, 1972; Pandey, 1981; Raja Rao, 1981). The lithostratigraphic classification given by Raja Rao (1981) is followed here which divides the Upper Cretaceous–Early Paleocene into three formations, i.e. Mahadeo, Langpar and Therria formations. The studied succession belongs to the Lower part of Langpar Formation exposed in Amlarem Tehsil of Jaintia Hills near India–Bangladesh International Boundary. Langpar Formation was first described as 'Langpar band' comprising pale sandstones with plant remains (Medlicott, 1869). Afterwards, Evans (1932) mapped these bands in patches in the neighborhood of Therria Village. Chakraborty (1974) and Chakraborty and Baksi (1972) designed it as the Langpar Formation. The lower boundary of Langpar Formation is conformably underlain by Mahadeo Formation and the upper boundary is conformable with the overlying Therria Formation.

MATERIAL AND METHODS

The studied succession was found exposed along the road–side near Syndai Village (N 25º10'52.8"; E 92º8'57.3") of Meghalaya in Jaintia Hills. The present section was ~50 Km away towards east from famous Um Sohryngkew River section of K–Pg boundary in Meghalaya (Garg & Jain, 1995). The Um Sohryngkew section demonstrates continuous occurrence of youngest Maastrichtian non bioturbated, thinly laminated calcareous fine silty shale sediments containing *Micula prinsii*, K–Pg boundary, Iridium–rich clay layer and Danian age sediments from bottom to top, showed no signature of trap material. In the present study the section mainly consists of carbonaceous, silty and sandy shales which were calcareous at places; burrows are also present at a few levels (Fig. 2). The present section could be placed below the Um Sohryngkew section and it has some overlapping with the same. In this study total twenty–two samples were collected from about 9 m succession. For the nannofossil study smear slides were prepared from all samples by dissolving 1gm of sediments into distil water. Thin smear films were prepared on the glass slides from the suspended material, on the hot plate. Dried slides were mounted with Canada Balsam and studied under Leica DM2500 P polarized microscope. The respective slides were housed in BSIP Museum repository (16304–16313). For the statistical analysis, 300 counts of nannofossils were done from each sample, except one sample (SNLP 15) which was poorly productive; therefore, only 150 counts were made from this sample. For the multivariate cluster analysis, CONISS software was used.

RESULTS AND DISCUSSION

Ten samples out of twenty two were proven productive and contain moderately preserved but less diverse calcareous nannofossil assemblage. Total 38 calcareous nannofossil species were identified including two species of calcareous dinoflagellate *Thoracosphaera* sp. and *Scrippsiella* sp. The genus *Micula* is the most abundant in the present assemblage and the most common species are *Micula concava* and *Micula staurophora.* Both the species together contribute more than 50% of the assemblage. All the recorded species are

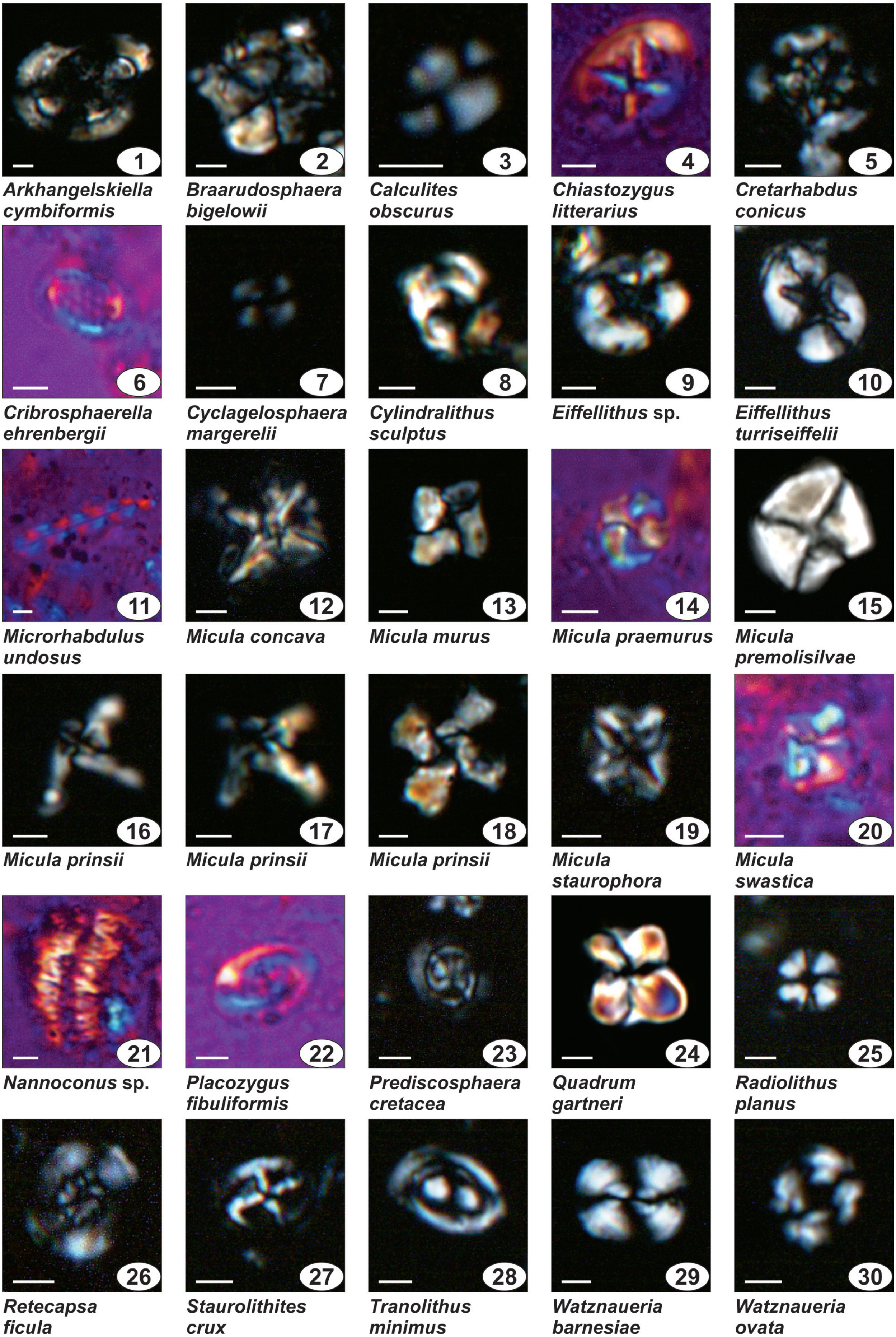
PLATE 1

Scale bar represents 2 µm in all the photomicrographs. ⟶

1. *Arkhangelskiella cymbiformis* Vekshina, 1959.
2. *Braarudosphaera bigelowii* (Gran & Braarud, 1935) Deflandre, 1947.
3. *Calculites obscurus* (Deflandre, 1959) Prins & Sissingh in Sissingh, 1977.
4. *Chiastozygus litterarius* (Górka, 1957) Manivit, 1971.
5. *Cretarhabdus conicus* Bramlette & Martini, 1964.
6. *Cribrosphaerella ehrenbergii* (Arkhangelsky, 1912) Deflandre in Piveteau, 1952.
7. *Cyclagelosphaera margerelii* Noël, 1965.
8. *Cylindralithus sculptus* Bukry, 1969.
9. *Eiffellithus* sp.
10. *Eiffellithus turriseiffelii* (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1965.
11. *Microrhabdulus undosus* Perch–Nielsen, 1973.
12. *Micula concava* (Stradner *in* Martini & Stradner, 1960) Verbeek, 1976.
13. *Micula murus* (Martini, 1961) Bukry, 1973.
14. *Micula praemurus* (Bukry, 1973) Stradner & Steinmetz, 1984.
15. *Micula premolisilvae* Lees & Bown, 2005.

16–18. *Micula prinsii* Perch–Nielsen, 1979.

19. *Micula staurophora* (Gardet, 1955) Stradner, 1963.
20. *Micula swastica* Stradner & Steinmetz, 1984.
21. *Nannoconus* sp.
22. *Placozygus fibuliformis* (Reinhardt, 1964) Hoffmann, 1970.
23. *Prediscosphaera cretacea* (Arkhangelsky, 1912) Gartner, 1968.
24. *Quadrum gartneri* Prins & Perch–Nielsen *in* Manivit *et al.*, 1977.
25. *Radiolithus planus* Stover, 1966.
26. *Retecapsa ficula* (Stover, 1966) Burnett, 1997.
27. *Staurolithites crux* (Deflandre & Fert, 1954) Caratini, 1963.
28. *Tranolithus minimus* (Bukry, 1969) Perch–Nielsen, 1984.
29. *Watznaueria barnesiae* (Black *in* Black & Barnes, 1959) Perch–Nielsen, 1968.
30. *Watznaueria ovata* Bukry, 1969.


1 Arkhangelskiella cymbiformis
2 Braarudosphaera bigelowii
3 Calculites obscurus
4 Chiastozygus litterarius
5 Cretarhabdus conicus
6 Cribrosphaerella ehrenbergii
7 Cyclagelosphaera margerelii
8 Cylindralithus sculptus
9 Eiffellithus sp.
10 Eiffellithus turriseiffelii
11 Microrhabdulus undosus
12 Micula concava
13 Micula murus
14 Micula praemurus
15 Micula premolisilvae
16 Micula prinsii
17 Micula prinsii
18 Micula prinsii
19 Micula staurophora
20 Micula swastica
21 Nannoconus sp.
22 Placozygus fibuliformis
23 Prediscosphaera cretacea
24 Quadrum gartneri
25 Radiolithus planus
26 Retecapsa ficula
27 Staurolithites crux
28 Tranolithus minimus
29 Watznaueria barnesiae
30 Watznaueria ovata

represented in their order of abundance as follows: *Micula concava, M. staurophora*, *Thoracosphaera* sp., *Quadrum gartneri*, *M. swastica, Watznaueria barnesiae*, *Calculites obscurus*, *Cyclagelosphaera margerelii*, *M. praemurus*, *Braarudosphaera bigelowii*, *Prediscosphaera cretacea*, *Scrippsiella* test fragment, *Cribrosphaerella ehrenbergii*, *M. murus*, *Eiffellithus* sp., *Cretarhabdus conicus*, *W. ovata*, *Microrhabdulus undosus*, *M. prinsii*, *M. premolisilvae*, *Arkhangelskiella cymbiformis*, *Radiolithus planus*, *E. turriseiffelii*, *Chiastozygus litterarius*, *Cylindralithus sculptus*, *Zeugrhabdotus embergeri*, *Tranolithus minimus*, *Retecapsa ficula*, *Broinsonia* sp. *Microrhabdulus helicoides*, *Nannoconus* sp., *Pervilithus varius*, *Prediscosphaera* sp., *Staurolithites crux*, *Zeugrhabdotus* sp., *Microrhabdulus belgicus* and *Lapideacassis* sp.

Two K–Pg survivor species *Braarudosphaera bigelowii* and *Thoracosphaera* sp. are present in the assemblage. These species are believed to have survived the K–Pg boundary biotic crises and extend from the Maastrichtian into the basal Danian (Perch–Nielsen *et al.*, 1982). Genus *Arkhangelskiella, Broinsonia, Calculites, Chiastozygus, Cretarhabdus, Cribrosphaerella, Cylindralithus, Eiffellithus, Microrhabdulus, Micula, Nannoconus, Pervilithus, Prediscosphaera, Quadrum, Radiolithus, Retecapsa, Tranolithus* and *Watznaueria* are restricted to the Cretaceous sediments and not show their single record beyond K–Pg boundary, therefore, considered as non–survivor Cretaceous taxa.

Nannofossil biostratigraphy

In the present study, the biozonation scheme of Burnett (1998) was applied for the biostratigraphy. The distribution of the identified nannofossil taxa is shown in Fig. 3 and some of the representative nannofossil taxa are illustrated in Pl. 1. In the present study, *Micula prinsii* is recorded in all the productive samples throughout the succession. The other records of *Micula prinsii* from Indian sections are very less. Garg and Jain (1995) recorded *Micula prinsii* species and *Micula prinsii* Zone from the Um Sohryngkew section, Meghalaya (Fig. 1). Another record is from southern part of India, Rai *et al.* (2013) recorded *Micula prinsii* from the Virdhachalam area of Cauvery Basin. *Micula prinsii* is the most evolved species of genus *Micula*. It is common low–mid latitudes species and rare in high latitudes (Perch–Nielsen, 1985). It is considered as the marker species of the latest Maastrichtian**,** appeared 0.5 Ma before K–Pg mass extinction. Therefore, presence of *Micula prinsii* along with the other latest Maastrichtian taxa throughout the succession indicates that the present nannofossil assemblage belongs to the UC20d^{TP} subzone of Burnett (1998) and well corresponds to the CC26b Zone of Perch–Nielsen (1985) (Fig. 4). These zonal schemes are the compilation of old and new nannofossil biozonation schemes from a range of palaeolatitudes and biogeographic provinces from both oceanic and shelf palaeoenvironments and useful for the biostratigraphy of various marine depositional environments.

Depositional environment interpretations

The depositional environment interpretations were mainly delineated by means of the quantitative stratigraphic distributions of the calcareous nannofossil taxa from productive levels and their palaeoecological and palaeoenvironmental preferences. In the present study, percentage data was used for the multivariate cluster analysis. Broadly two clusters were formed (Fig. 5). CLUSTER I includes productive samples from SNLP 2 to SNLP 13 (6 samples) shows dominance of *Micula concava* and *Micula staurophora* with increasing numbers of *Watznaueria barnesiae*. CLUSTER II includes productive samples from SNLP 14 to 16 and SNLP 19a (4 samples), showing decrease of *Micula concava* and *Micula staurophora* with increased numbers of *Calculites obscurus.* Several authors suggested that *Micula staurophora* (synonyms *Micula decussata*) might have preferred cooler temperatures (Wind, 1979; Doeven, 1983; Watkins & Self Trail, 2005). However, biogeographic studies of Wind (1979), Thierstein (1981), Shafik (1990), Henriksson and Malmgren (1997) and Lees (2002) showed that this taxon is clearly cosmopolitan and can reach as far as 80% in both tropical and sub–tropical assemblages. Eshet *et al.* (1992) and Tantawy (2002) interpreted the high abundances of *Micula decussata* as indicative of very low surface water productivity and high–stress environmental conditions. In the present study also, the major component of the assemblage–*Micula concava* and *Micula staurophora* can be used as indicator of low productivity of surface water and high–stress environmental conditions. Among the several cooler water nannofossil species, Wind (1979) and Thierstein (1981) referred *Arkhangelskiella cymbiformis* as a high–latitude taxon of cooler waters. However, Lees (2002) shows that this species is common down into tropical palaeolatitudes, although it prefers high–latitudes. *Micula murus* is considered as a good warm–water indicator and it is clearly restricted to warm tropical waters and totally absent from the high–latitude areas, all along its biostratigraphical range (Worsley & Martini, 1970; Thierstein, 1981; Watkins *et al.*, 1996; Lees, 2002). *Watznaueria barnesiae* is a cosmopolitan species which is generally dominant in tropical latitudes but also recorded commonly in high–latitude sites. Generally, authors used it as a warm–water indicator (Doeven, 1983; Watkins *et al.*, 1996; Watkins & Self Trail, 2005). In addition, several studies showed that *Watznaueria barnesiae* is a low–nutrient indicator (Roth & Krumbach, 1986; Erba *et al.*, 1992; Lamolda *et al.*, 1992; Williams & Bralower, 1995; Fisher & Hay, 1999). Interestingly, it is one of the most dominant

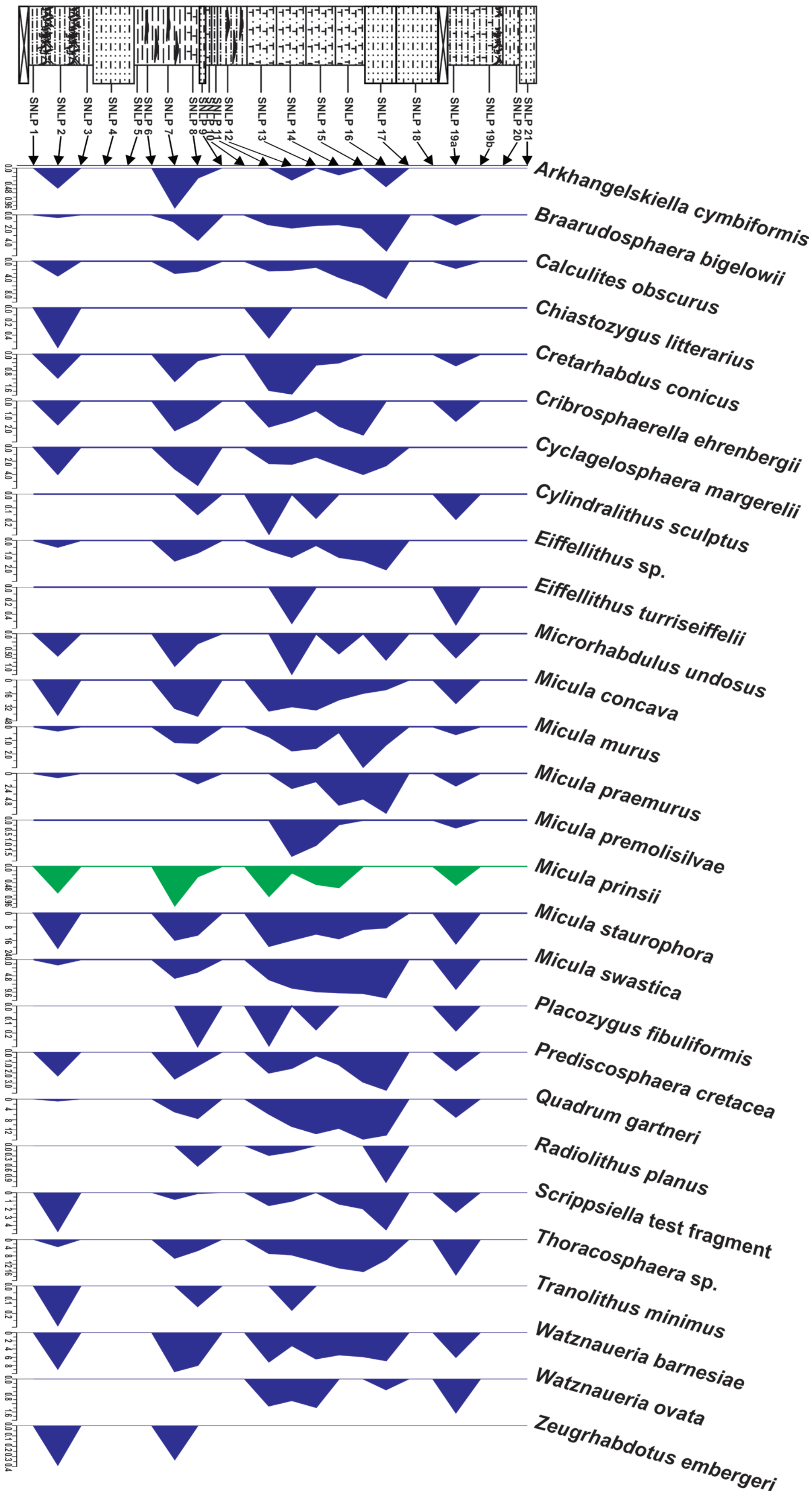


Fig. 3—Distribution and abundance (in percentage) of significant nanofossil taxa recorded in the studied succession.

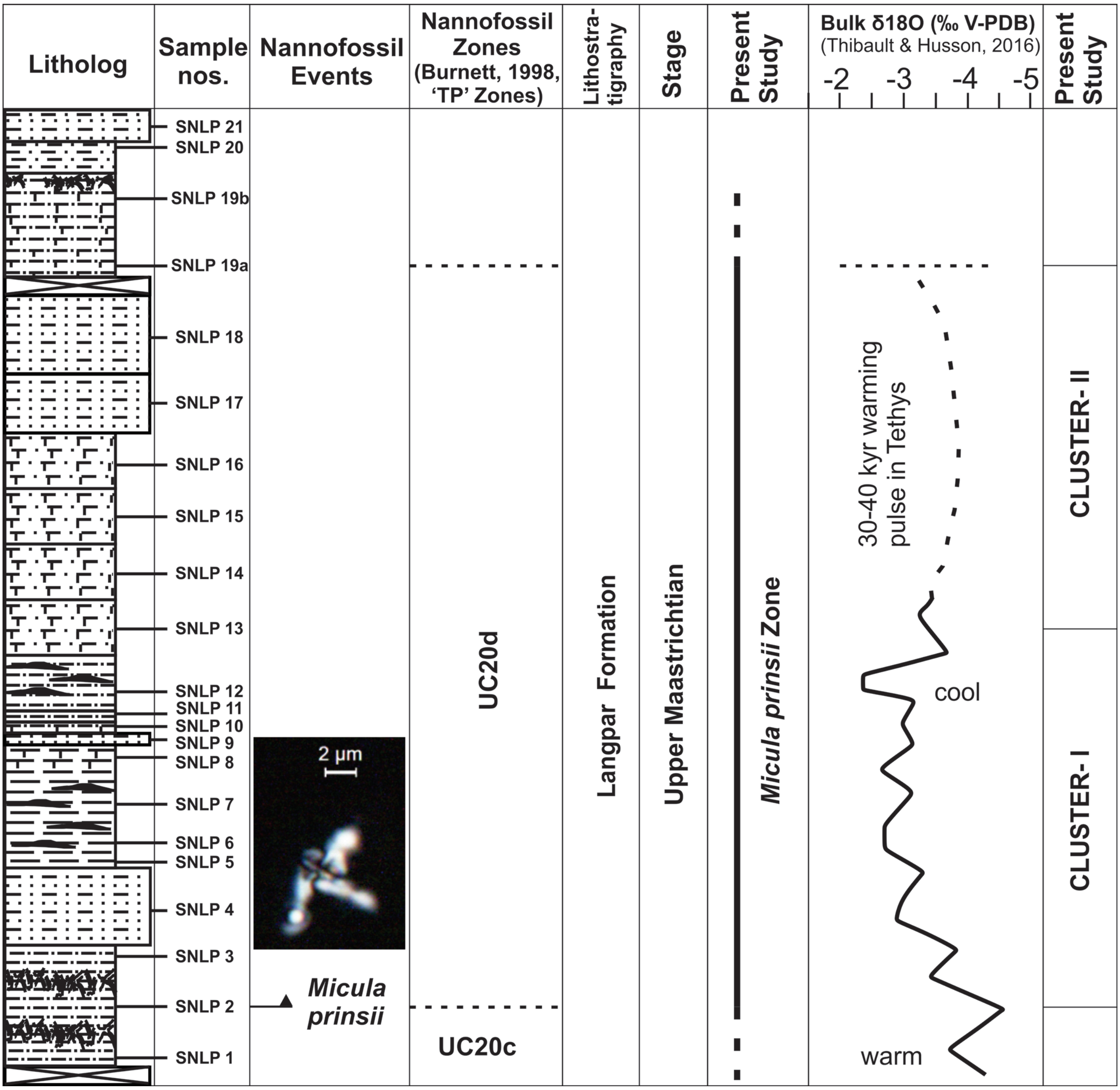


Fig. 4—Correlation of Latest Maastrichtian nannofossil zone and changes in bulk $\delta^{18}O$ (Thibault & Husson, 2016) along with studied section.

species that shown a strong inverse correlation with depth such as holococcoliths (*Calculites obscurus*) which prefer shallow marine environment. Therefore, based on the abundance variation of *M. staurophora*, *W. barnesiae* and *C. obscurus*, the relative depositional environment of succession could be infer from shallow marginal shelf to basinward marine conditions (Hadavi & Maghaddam, 2014). Other common taxa of Maastrichtian assemblages are *Cribrosphaerella ehrenbergii* and *Retecapsa* spp., but they do not show any latitudinal preferences nor sensitivity to environmental changes.

Palaeoclimatic interpretations

Recently, Thibault and Husson (2016) presented palaeoecological data for late Maastrichtian calcareous nannofossil assemblages from the Indian Ocean and the Boreal epicontinental Chalk Sea. The data was compiled with recent results in the tropical Atlantic, Pacific, and Tethys oceans in order to characterize environmental changes by the end of the Cretaceous. They demonstrated the evolution of sea–surface palaeo–temperatures for the last ca. 350–380 kyr of the Cretaceous: the end–Maastrichtian greenhouse warming lasted

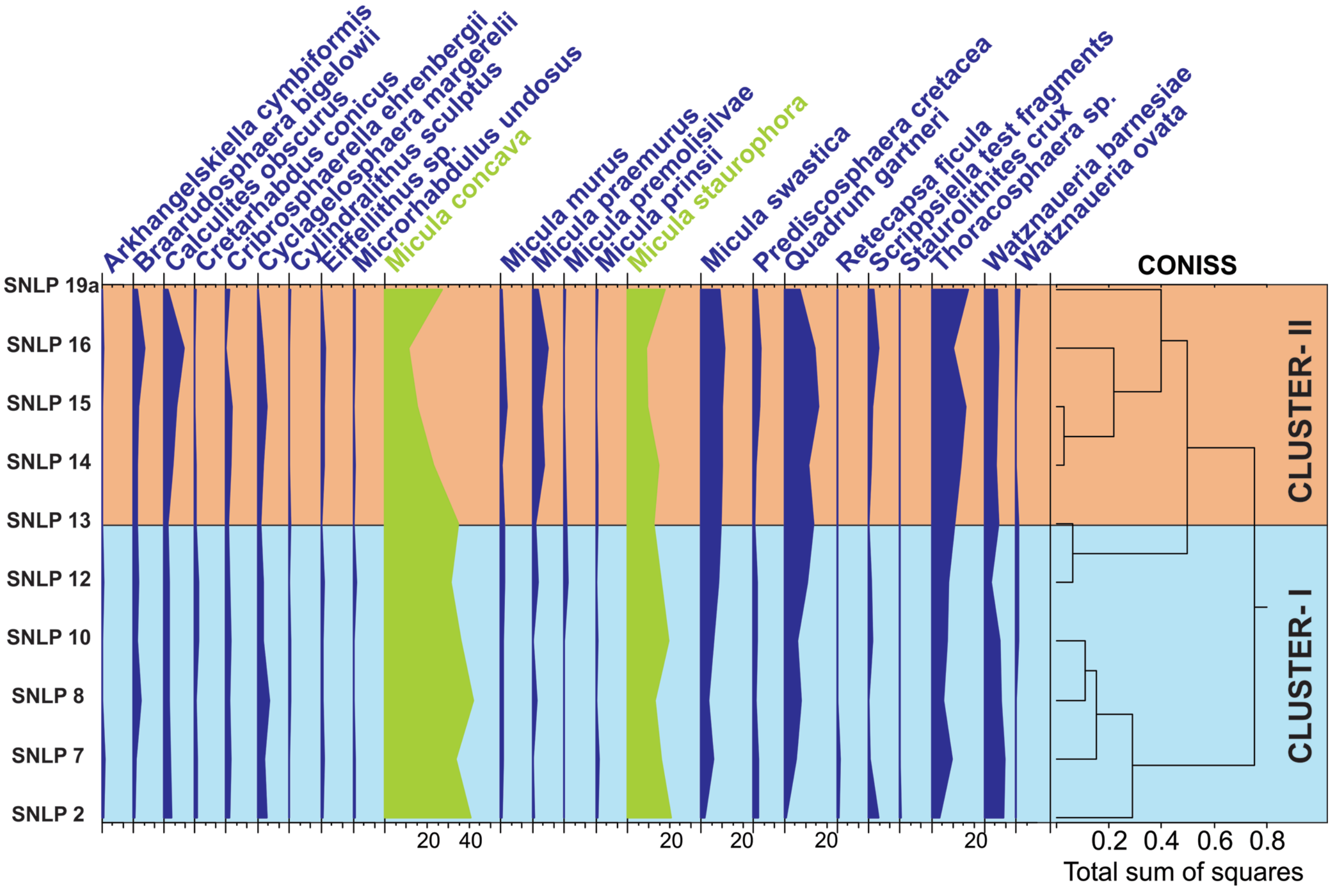


Fig. 5—Percentage abundance of the significant taxa in productive samples and dendrogram of cluster analysis.

on average a little more than 200 kyr and was followed by a ca. 100–120 kyr cooling. In the Tethys, a 30–40 kyr additional pulse of warming is recorded immediately below the K–Pg boundary. These findings indicate an important fluctuation of the climate system at the end of the Maastrichtian. The present investigation attests the record of additional pulse of warming just below the K–Pg boundary preceding high–stress conditions especially for marine planktonic life (Fig. 4). The quantitative fluctuations recorded in the nannofossil assemblages from bottom to top in the studied succession, most likely controlled by environmental factors mainly by temperature and nutrient availability in the surface water. The dominance of *M. concava* and *M. staurophora* (indicator of very low surface water productivity and high–stress environmental conditions) along with the increasing numbers of *W. barnesiae* (availability of low nutrient indicator) in the lower part of the section indicates high–stress conditions with low surface water productivity in lower part of the section most probably caused by the 2nd phase of deccan eruption. In the upper part of the succession, decreased numbers of *M. concava* and *M. staurophora* along with decreased numbers of *W. barnesiae* and increased numbers of *C. obscurus* (holococcolith, indicator of marginal marine environment) suggests that the upper part of the section is deposited relatively in marginal marine depositional environment with increased surface water productivity. Most probably the upper part of the section is deposited during the additional warming phase before the K/Pg boundary recorded in the Tethyan region (Thibault & Husson, 2016). However, the present preliminary record is needed to be affirmed by detailed multiproxy studies from the lateral sections exposed in nearby areas.

CONCLUSIONS

Significant terminal Maastrichtian calcareous nannofossil assemblage is recorded from the Meghalaya, northeastern part of India. Presence of *Micula prinsii* in all productive samples restricts the assemblage in *Micula prinsii* Zone corresponding to the UC20d^{TP} subzone of latest Maastrichtian (Burnett, 1998). Distribution patterns of calcareous nannofossils in the studied sections envisaged climatic variability within the *Micula prinsii* Zone. Abundance of *Micula concava* and *Micula staurophora* with increased numbers of *Watznaueria barnesiae* in lower part of section suggests high–stress conditions with low surface water productivity in relatively deeper marine depositional environment. In the upper part of the section decreased abundance of *Micula concava* and *Micula staurophora* with increased numbers of *Calculites obscurus* suggests relatively increasing surface water productivity in marginal marine depositional environment during the additional warming pulse recorded from the Tethyan province prior to K–Pg boundary.

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