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Early Oligocene (Rupelian) dinoflagellate cysts and calcareous nannofossils from Lumpy Clay Member of Maniyara Fort Formation, Kutch, Gujarat, India

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The Palaeogene succession of Kutch, Gujarat exhibits huge shallow marine carbonate deposits of Middle Eocene and Oligocene ages. These deposits were mainly dated on the basis of larger benthic foraminifers. The paucity of foraminifers in the intermittent units of the succession resulted in discrepancy in precise dating of these strata. Lumpy Clay Member of Maniyara Fort Formation is one such example. This is considered as unfossiliferous in terms of foraminifers and was dated on the basis of foraminiferal assemblages of underlying Basal and overlying Coral Limestone members. In the present study, palynological biostratigraphy is proposed for the Lumpy Clay Member exposed at Bermoti Village, in Kutch. On the basis of age-diagnostic calcareous nannofossil and dinoflagellate cyst assemblages, the studied succession has been dated as Middle Rupelian (~31 Ma). The palynological data suggests a shallow marine neritic depositional setting, occasionally swept by open oceanic water.

Keywords: Calcareous nannofossils, dinoflagellate cysts, Kutch, Lumpy Clay Member, Maniyara Forth Formation, Rupelian.

DURING the Eocene–Oligocene transition, intense climatic and oceanographic changes occurred coupled with the first major continental-scale glaciation of Antarctica[1,2]. These complex series of events occurred over an extended period between ~33.5 and 34.0 Ma, causing environmental disturbances that led to a global biotic turnover seen in both terrestrial and marine records of shallow-water and deep-sea environments. Spanning this transition interval, many thick Cenozoic limestone deposits containing larger benthic foraminifers are common within the Indo-Pacific region[3–6]. However, due to lowered global sea level during the Eocene–Oligocene transition, many stratigraphic sections are incomplete, with hiatuses or unconformities. In India, the Amravati Formation of Cambay Basin[7] and Fulra and Maniyara Fort formations of Kutch Basin[8–10] are considered to be among the most complete sections with some hiatuses.

The Kutch sedimentary basin in the western continental margin of India is a peri-cratonic rift basin which archives almost complete sedimentary records from Middle Jurassic to the present, interrupted by several episodes of non-deposition. The nearly complete, richly fossiliferous and easily accessible outcrops of Cenozoic sediments exposed in the western part of the Kutch mainland extend offshore into the present-day continental shelf.

Particularly, the marine Oligocene outcrops in the western part of Kutch have been initially recognized under the Nari Series of Pakistan[11,12]. Later, Biswas and Raju[13], and Biswas[14] designated the Oligocene strata of Kutch as the Maniyara Fort Formation (Table 1), exposed in a type section near Bermoti Village along the Bermoti River. The Maniyara Fort Formation consists of a succession of bedded, yellow to ochre-coloured foraminiferal limestone with a basal greyish–green glauconitic siltstone overlying the Middle Eocene Fulra Limestone. The formation is richly fossiliferous with a variety of echinoids, pelecypods, gastropods, corals, foraminifers and crabs. *Nummulites fichteli* and *Miogypsinoides* are the

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Table 1. Lithostratigraphic classification and regional chronostratigraphic units of late Palaeogene–Neogene successions in Kutch, Gujarat (after Biswas)[14]

Time (Ma)	SERIES		STAGES	LITHOSTRATIGRAPHY FORMATIONS	MEMBERS	W. COAST/ KUTCH STAGES
	MIOCENE	Upper	Messinian	SANDHAN		KANKAWATIAN SUPER STAGE
10			Tortonian			
		Middle	Serravallian			
			Langhian			
		Lower	Burdigalian	CHHASRA	Siltstone Claystone	VINJHANIAN
20			Aquitanian	KHARI NADI		AIDAIAN
	OLIGOCENE	Upper	Chattian	MANIYARA FORT	Bermoti	WAIORIAN
30		Lower	Rupelian		Coral Limestone Lumpy Clay ★ Basal Member	RAMANIAN
	EOCENE	Upper	Priabonian			
40		Middle	Bartonian	FULRA LIMESTONE		BABIAN
			Lutetian			

characteristic foraminifers present. This formation is divided into four members: (1) the Basal Member consisting of alternating beds of foraminiferal, glauconitic, brownish to yellowish siltstone and calcareous, gypseous claystone; (2) the Lumpy Clay Member consisting of cement-coloured to brownish calcareous, lumpy claystone, occasionally containing thin limestone and marlite beds; (3) the Coral Limestone Member consisting of dirty white-coloured nodular limestone alternating with calcareous claystone in the lower part, and grey to dirty white-coloured massive limestone with abundant corals bioherms in the upper part; (4) the upper Bermoti Member consisting of rusty brown, friable glauconitic argillaceous sandstone. The upper part of this member is composed of thinly bedded, very hard, grey to yellowish foraminiferal limestone with interbeds of silty marlite full of *Spiroclypeus*.

The lower three members – Basal, Lumpy Clay and Coral Limestone – correspond to the Lower Oligocene Ramanian Stage (Rupelian)[15,16], while the uppermost Bermoti Member corresponds to the Upper Oligocene Waiorian Stage (Chattian)[15,17]. Interestingly, the Ramanian Stage is characterized by larger foraminifera *Eulepidina dilatata* and *Nummulites fichteli* recovered from the Basal and Coral Limestone members, whereas interbedded Lumpy Clay Member is reportedly unfossiliferous[18]. The present study provides an integrated palynological biostratigraphy of calcareous nannofossils, dinoflagellate cysts and sporomorphs from the sediment samples of Lumpy Clay Member of Maniyara Fort Formation, to precisely date and reconstruct the depositional environment based on new fossil data.

In this study recovery of dinoflagellate cysts has been recorded from four samples of Lumpy Clay Member of Maniyara Fort Formation exposed at Bermoti River section (Figure 1) (23°27′44.3″N: 68°36′8.8″E) following standard preparation techniques. Initially, crushed samples were treated with 10% HCl and 40% HF to remove carbonates and silicates respectively. Then the residue was treated with dilute HNO_3 and washed repeatedly at every step. The residue was sieved using a 15 μm sieve. After staining the macerate with safranin, permanent slides were prepared using polyvinyl and Canada balsam. The palynomorphs were photographed using a microscope (Nikon Eclipse i90) attached with a digital camera (Cannon). Figures 2 and 3 show the important specimens. All the photomicrographs are provided with the England Finder position on their respective slides in the figure legends. The slides have been deposited in the museum of the Birbal Sahni Institute of Palaeosciences

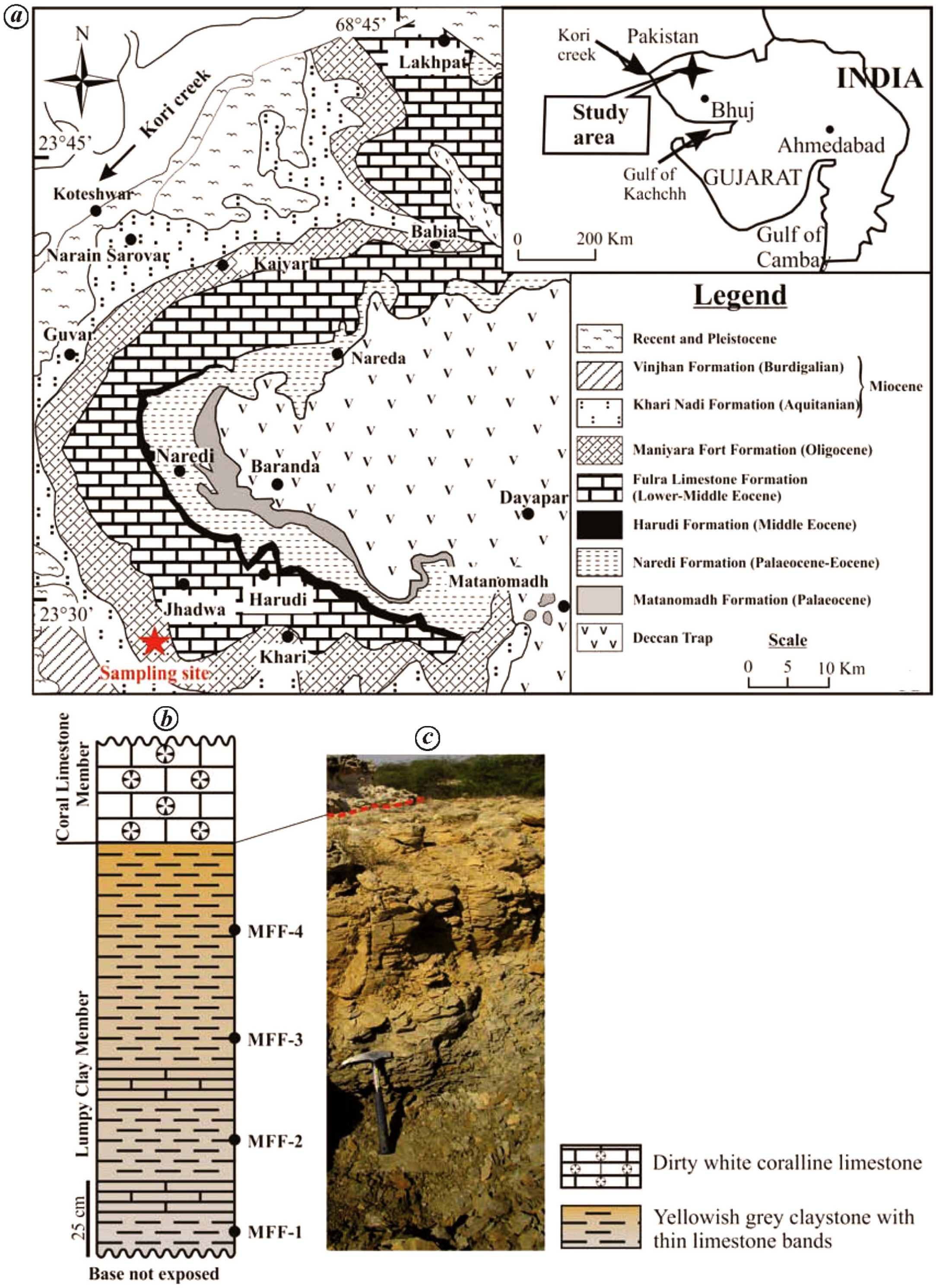

Figure 1. ***a***, Geological map of the Kutch region, Gujarat, western India with location of the study area marked by a star (after Biswas)[14]. ***b***, A general litholog. ***c***, A field photograph of the studied succession of Lumpy Clay Member of Maniyara Fort Formation exposed along Bermoti River section in Kutch.

(BSIP), Lucknow with repository numbers 16275–16282.

For the study of nannofossils, smear slides of all four samples were prepared following standard method[19]. About 2 g of sample was used for slide preparation and the slides were scanned under a polarized microscope (Leica DM2500 P). Photomicrographs were taken under 100× objective with immersion oil (Figure 4) and the

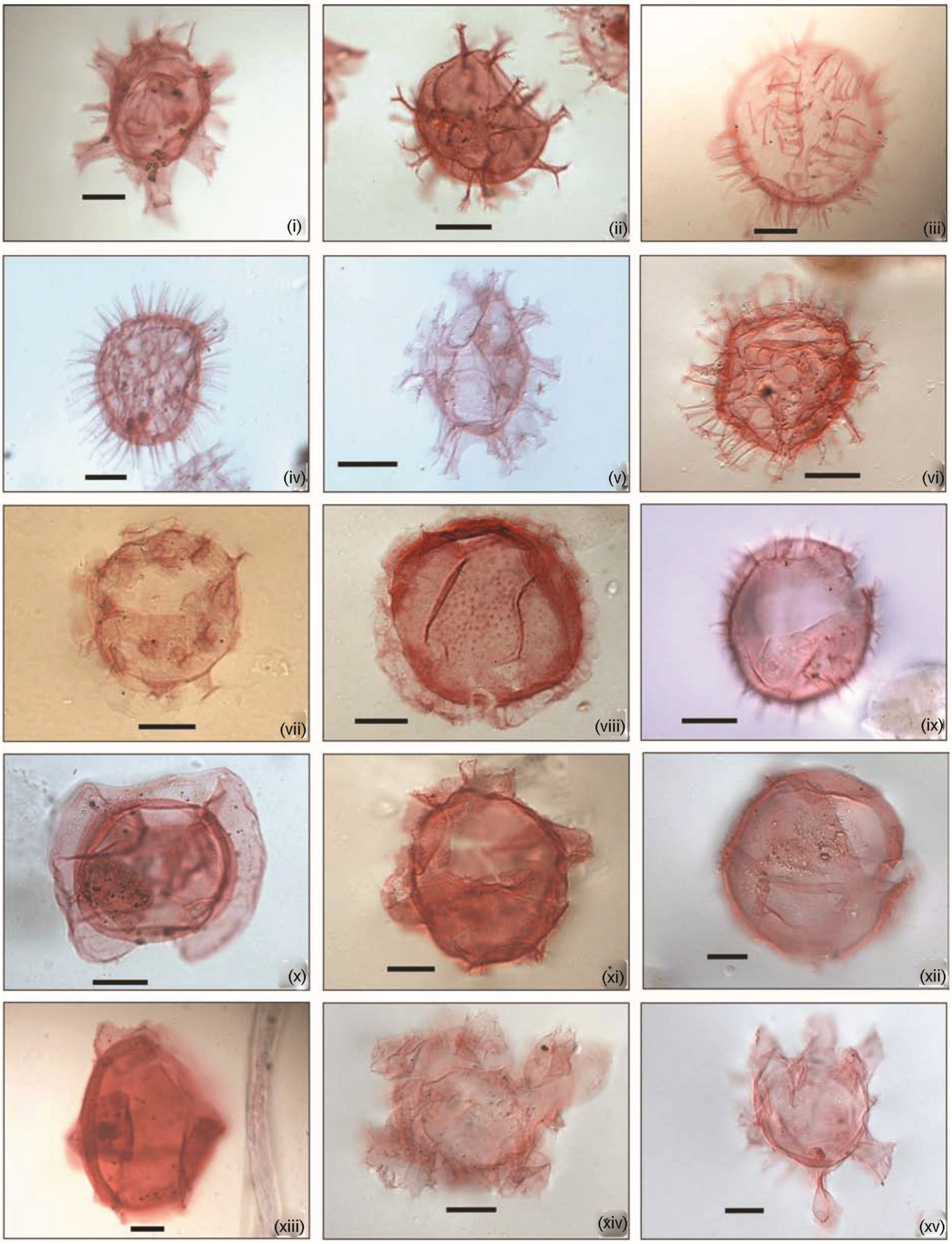

Figure 2. (i) *Achilleodinium biformoides* (Eisenack, 1954) Eaton, 1976, BSIP slide no. 16275, F52. (ii) *Achomosphaera alcicornu* (Eisenack, 1954) Davey and Williams, 1966, BSIP slide no. 16276, M39. (iii) *Polysphaeridium congregatum* (Stover, 1977) Bujak *et al.*, 1980, BSIP slide no. 16277, J53/2. (iv) *Impletosphaeridium machaeroides* Stover and Hardenbol, 1994, BSIP slide no. 16275, V39/1. (v) *Spiniferites pseudofurcatus* (Klumpp, 1953) Sarjeant, 1970, BSIP slide no. 16278, T42. (vi) *Cleistosphaeridium diversispinosum* (Davey *et al.*, 1966) Eaton *et al.*, 2001, BSIP slide no. 16279, O32. (vii) *Tuberculodinium vancampoae* (Rossignol, 1962) Wall, 1967, BSIP slide no. 16279, V52. (viii) *Cyclopsiella granosa* (Matsuoka, 1983) Head *et al.*, 1992, BSIP slide no. 16279, F61/3. (ix) *Lingulodinium machaerophorum* (Deflandre and Cookson, 1955) Wall, 1967, BSIP slide no. 16280, E49. (x) *Pentadinium laticinctum* Gerlach, 1961, BSIP slide no. 16281, E51/4. (xi) *Pentadinium* sp., BSIP slide no. 16279, W39/2. (xii) *Impagidinium elegans* (Cookson and Eisenack, 1965) Stover and Evitt, 1978, BSIP slide no. 16280, M40. (xiii) *Impagidinium* sp., BSIP slide no. 16277, M53/2. (xiv) *Hystrichokolpoma globulus* Michoux, 1985, BSIP slide no. 16282, V36/4. (v) *Hystrichokolpoma rigaudiae* Deflandre and Cookson, 1955, BSIP slide no. 16282, M39/4. Scale bar = 10 μm for each photomicrograph.

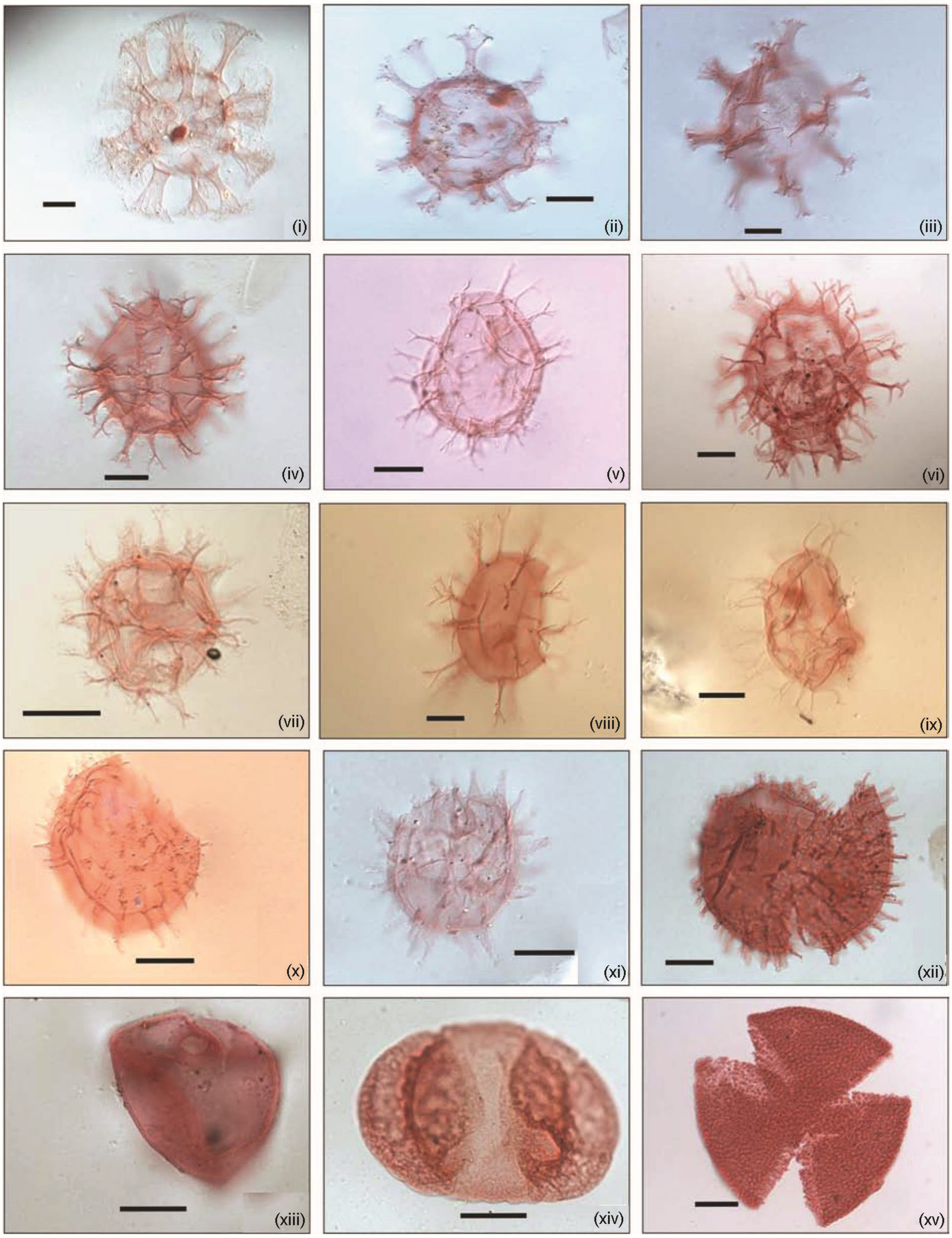

Figure 3. (i) *Cordosphaeridium cantharellus* (Brosius, 1963) Gocht, 1969, BSIP slide no. 16282, G37/29. (ii) *Hystrichosphaeridium* sp., BSIP slide no. 16282, N49/3. (iii) *Homotryblium plectilum* Drugg and Loeblich, 1967, BSIP slide no. 16277, G52. (iv) *Spiniferites* sp., BSIP slide no. 16276, O32/1. (v) *Achomosphaera* sp.1, BSIP slide no. 16282, T31. (vi) *Spiniferites mirabilis* (Rossignol, 1964) Matsuoka, 1974, BSIP slide no. 16277, M62/2. (vii) *Spiniferites ramosus* (Ehrenberg, 1838) Mantell, 1854 emend. Williams, 2001, BSIP slide no. 16282, J35/4. (viii) *Achomosphaera* sp. 2, BSIP slide no. 16282, O34/1. (ix) *Distatodinium* sp., BSIP slide no. 16282, O48. (x) *Operculodinium centrocarpum* (Deflandre and Cookson, 1955) Wall, 1967, BSIP slide no. 16282, H55. (xi) *Dapsilidinium pseudocolligerum* (Stover, 1977) Bujak *et al*., 1980, BSIP Slide No. 16282, N40. (xii) *Polysphaeridium zohrayi* (Rossignol, 1962) Bujak *et al*., 1980, BSIP slide no. 16276, T43. (xiii) *Graminidites* sp., BSIP slide no. 16282, G58. (xiv) *Abiespollenites* sp., BSIP slide no. 16276, U47/3. (xv) *Dipterocarpuspollenites retipilatus* Kar, 1992, BSIP slide no. 16277, M65. Scale bar = 10 µm for each photomicrograph.

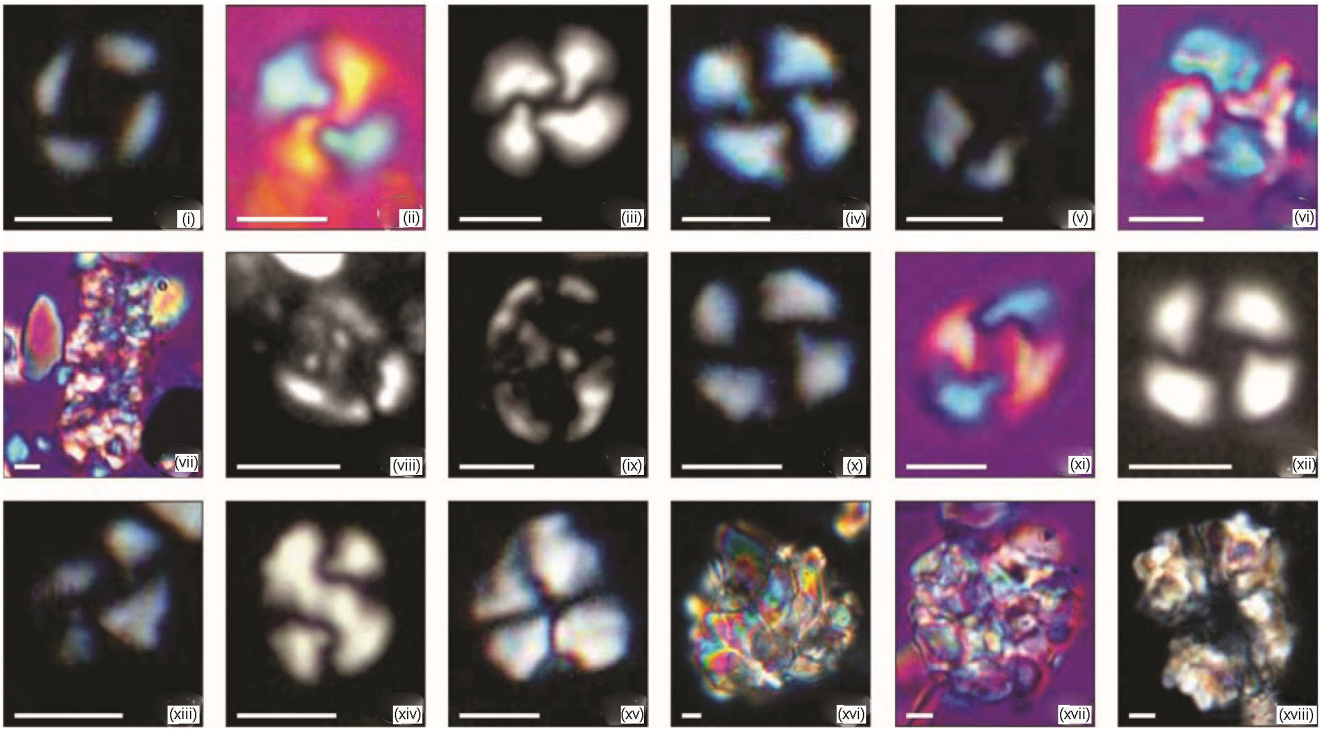

Figure 4. (i) *Coronocyclus* sp.; (ii)–(iv) *Cyclicargolithus floridanus* (Roth and Hay in Hay *et al.*, 1967) Bukry, 1971; (v) *Eiffellithus* sp.; (vi) *Micula murus* (Martini, 1961) Bukry, 1973; (vii) *Nannoconus* sp.; (viii), (ix) *Neochiastozygus* sp.; (x)–(xii) *Reticulofenestra circus* de Kaenel and Villa, 1996; (xiii) *Reticulofenestra minuta* Roth, 1970; (xiv) *Reticulofenestra perplexa* (Burns, 1975) Wise, 1983; (xv) *Sphenolithus moriformis* (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967; (xvi)–(xviii) Ascidian spicules. Scale bar = 2 μm for each photomicrograph.

respective slides housed in the BSIP museum repository (16283–16286).

Well-preserved age-diagnostic species of dinoflagellate cysts and nannofossils were recovered from all the samples (Table 2). Moderately to poorly preserved calcareous nannofossils were recorded from all four samples. The assemblage is mainly dominated by the ascidian spicules and *Cyclicargolithus floridanus*. The productivity is fair in the bottom three samples (MFF 1–3) and reasonably good in the top sample (MFF 4). The diversity is also fair in all the four samples; only 10 nannotaxa are recorded, including reworked taxa of Cretaceous age. The nannofossil assemblage is composed of *Coronocyclus* sp., *Cyclicargolithus floridanus*, *Eiffellithus* sp., *Micula murus*, *Nannoconus* sp., *Neochiastozygus* sp., *Reticulofenestra circus*, *Reticulofenestra minuta*, *Reticulofenestra perplexa* and *Sphenolithus moriformis*.

R. circus was first recorded by de Kaenel and Villa[20] from ODP Site 900, Iberia Abyssal Plain, northeastern Atlantic Ocean. Its presence was restricted within early Oligocene nannofossil zones NP22 to NP23. The first occurrence (FO; 32.92 Ma) of *R. circus* occurred within the NP22 zone and the last occurrence (LO; 29.62 Ma) within the NP23 zone[21]. Therefore, the total presence of *R. circus* envisages the Early–Middle Rupelian (NP22-NP23) age of the studied sequence (Figure 5).

In general, the palynological assemblage in all samples is dominated by marine phytoplankton over terrestrially derived organic matter and sporomorphs. The sporomorphs assemblage mainly consists of bisaccate (*Abiespollenites* sp.), Poaceae (*Graminidites* sp.) and Dipterocarpaceae (*Dipterocarpuspollenites retipilatus*) pollen. The diverse dinoflagellate cyst assemblage consists of 40 taxa, excluding a few unidentified ones. It is characterized by a large number of *Operculodinium* spp., *Polysphaeridium* spp., *Homotryblium* spp., *Spiniferites*–*Achomosphaera* complex and *Cleistosphaeridium* spp. The typical oceanic taxa such as *Pentadinium* and *Impagidinium* are also recorded in all samples. Most of the recovered taxa are long-ranging, which limits their use in age assignment. The stratigraphically most significant dinocysts are *Achilleodinium biformoides*, *Achomosphaera alcicornu*, *Cleistosphaeridium diversispinosum*, *Impletophaeridium machaeroides*, *Polysphaeridium congregatum* and *Tuberculodinium vancampoae*. The dinoflagellate studies from low latitudes of the northern hemisphere, suggest that FO of *A. biformoides* and *A. alcicornu* in the equatorial region is just above the Eocene–Oligocene boundary at ~33.5 and ~33.9 Ma respectively[22,23]. The Lumpy Clay Member section is characterized by presence of *C. diversispinosum* in all samples. Eaton *et al.*[24] have reported the *C. diversispinosum* range from Ypresian to Rupelian in samples from the Grand Banks, offshore eastern Canada. More precisely, it is reported up to D14 na dinocyst subzone (~31 Ma) of Germany[25,26]. In the present study, LO of *C. diversispinosum* envisages an age

Table 2. List of recovered calcareous nannofossil and organic-walled palynomorh taxa

Calcareous nannofossils
Ascidian spicules
Coronocyclus sp.
Cyclicargolithus floridanus (Roth and Hay, *in* Hay *et al.*, 1967) Bukry, 1971
Eiffellithus sp.
Micula murus (Martini, 1961) Bukry, 1973
Nannoconus sp.
Neochiastozygus sp.
Reticulofenestra circus de Kaenel and Villa, 1996
Reticulofenestra minuta Roth, 1970
Reticulofenestra perplexa (Burns 1975) Wise1983
Sphenolithus moriformis (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967
Dinoflagellate cysts
Achilleodinium biformoides (Eisenack, 1954) Eaton, 1976
Achomosphaera alcicornu (Eisenack, 1954) Davey and Williams, 1966
Achomosphaera spp.
Cleistosphaeridium diversispinosum (Davey *et al.*, 1966) Eaton *et al.*, 2001
Cleistosphaeridium placacanthum (Deflandre and Cookson, 1955) Eaton *et al.*, 2001
Cordosphaeridium cantharellus (Brosius, 1963) Gocht, 1969
Cordosphaeridium spp.
Cribroperidinium sp.
Cyclopsiella granosa (Matsuoka, 1983) Head *et al.*, 1992
Cyclopsiella sp.
Dapsilidinium pseudocolligerum (Stover, 1977) Bujak *et al.*, 1980
Distatodinium sp.
Ecladopysis sp.
Homotryblium plectilum Drugg and Loeblich, 1967
Homotryblium tenuispinosum Davey and Williams, 1966
Homotryblium vallum Stover, 1977
Hystrichokolpoma rigaudiae Deflandre and Cookson, 1955
Hystrichokolpoma globulus Michoux, 1985
Hystrichosphaeridium sp.
Impletosphaeridium machaeroides Benedek, 1972
Impagidinium elegans (Cookson and Eisenack, 1965) Stover and Evitt, 1978
Impagidinium sp.
Lingulodinium machaerophorum (Deflandre and Cookson, 1955) Wall, 1967
Lanternosphaeridium sp.
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
Operculodinium microtriainum (Klumpp, 1953) Islam, 1983
Pentadinium laticinctum Gerlach, 1961
Pentadinium sp.
Polysphaeridium congregatum (Stover, 1977) Bujak *et al.*, 1980
Polysphaeridium subtile Davey and Williams, 1966
Polysphaeridium zoharyi (Rossignol, 1962) Bujak *et al.*, 1980
Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970 emend. Sarjeant, 1981
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854 emend. Williams, 2001
Spiniferites mirabilis (Rossignol, 1964) Matsuoka, 1974
Spiniferites spp.
Tuberculodinium vancampoae (Rossignol, 1962) Wall, 1967
Undientified Gen et sp.1
Undientified Gen et sp.2
Undientified Gen et sp.4
Spore-Pollen
Abiespollenites sp.
Graminidites sp.
Dipterocarpuspollenites retipilatus Kar, 1992

not younger than mid-Rupelian (~31 Ma) for Lumpy Clay Member (Figure 5).

Originally *T. vancampoae* was reported from the Miocene[27], and studies from northwest Germany[26] also placed its First Appearance Datum (FAD) in D16 dinocysts zone (Early Miocene). However, its range was extended to late Oligocene ~27 Ma in offshore eastern Canada records long ago[27–29]. Interestingly, *T. vancampoae* was also encountered in the stratotype section of Rupelian in Belgium[30] and NSO-3 biozone (Rupelian) of the

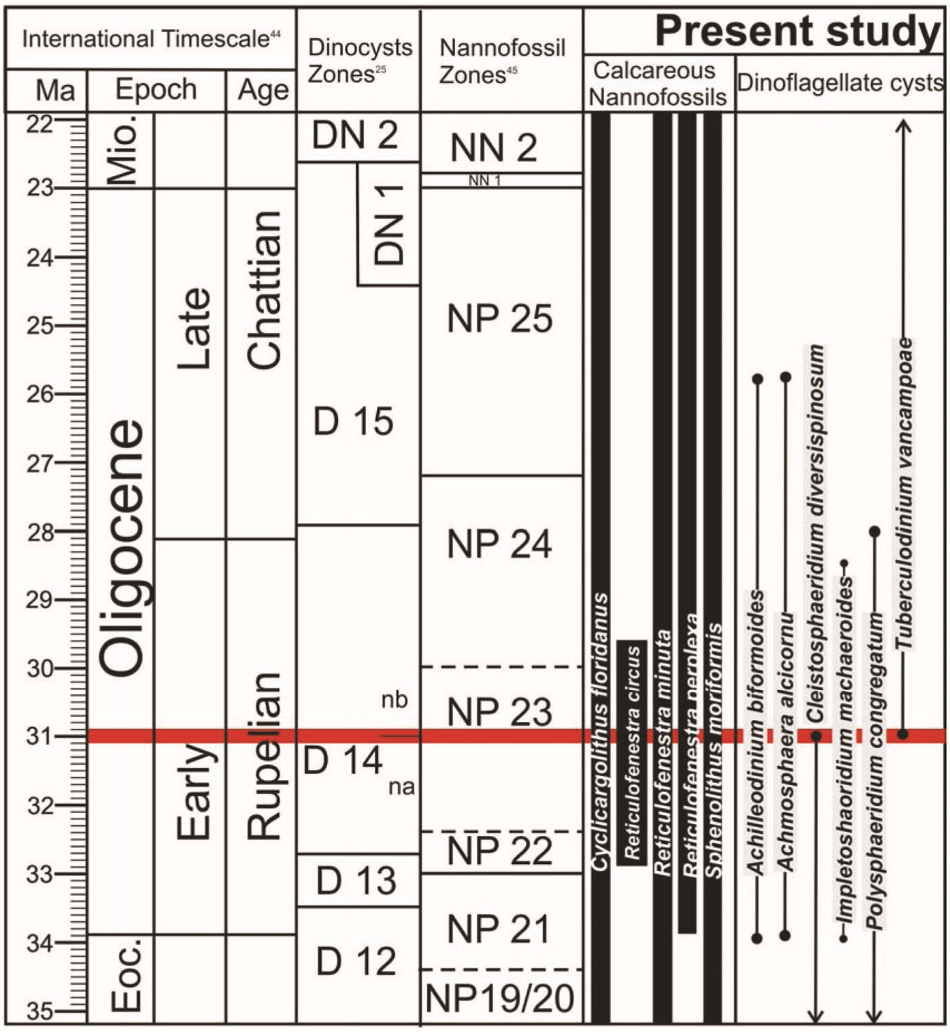

Figure 5. Composite representation of calcareous nannofossil and dinoflagellate cyst ranges and their correlation with standard calcareous nannofossil and dinoflagellate cyst zones.

North Sea Basin[31]. The recent records of *T. vancampoae* from eastern Equatorial Atlantic, West Africa[32] mark its FO in Rupelian and have recalibrated its occurrence in D14 nb dinocysts subzone[26]. The other recovered dinocyst, *I. machaeroides* was recorded from Rupelian of Boom Clay Formation in Belgium[33]. The *P. congregatum* with its LO at ~28 Ma has also been commonly recorded in all samples[29]. The abundance of *Spiniferites* spp. and *Homotryblium* spp. in this succession is also known from Rupelian successions of the North Sea Basin[31].

The *Polysphaeridium* group (*Polysphaeridium* spp. and *Homotryblium* spp.) generally occurs in the coastal, tropical–subtropical regions, where sea-surface salinity and temperature are high[34]. However, a few offshore occurrences, such as in the Atlantic shelf[35] and ODP Hole 959D[36] are also known. In the present study, abundant *Polysphaeridium*, *Operculodinium* and *Homotryblium* species are considered as indicative of inner neritic, possibly lagoonal environments with increased salinity[37]. However, the Oligocene–Miocene dinocyst records of Denmark suggest that the genus Homotryblium produces cysts with different morphology of processes as a response to variations in salinity, and occurs in high abundance in low-salinity settings[38]. *Lingulodinium machaerophorum* is indicative of areas of increased nutrient availability[39]. *Operculodinium*, group which includes the genus *Impletosphaeridium* represents restricted marine to open marine neritic environments. The data suggest that most species of the *Spiniferites*–*Achmosphaera* complex can attain high abundances in near-shore and open marine settings[40]. The presence of typical oceanic taxa such as *Impagidinium* and *Pentadinium* indicates occasional incursion of open oceanic waters into neritic environment[41–43]. This may have possibly benefitted the calcareous nanoplankton to flourish in temporarily more offshore conditions.

The present preliminary study is an endeavour to precisely date the Lumpy Clay Member on the basis of integrated records of dinoflagellate cysts and calcareous nannofossils. The palynological results helped us to date the succession to Middle Rupelian[44] (~31 Ma). The inferred date corresponds to part of NP23 nannofossil zone[45] and the boundary between D14 na and D14 nb dinocysts subzones[26]. The palynological assemblage implies that the deposition took place mainly in shallow marine neritic lagoonal environment.

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Water retention and transmission characteristics of containerized growing media amended with differential proportions of compressed coir bricks

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The hydraulic characteristics of growing media play an equally important role as do the architectural properties in the production of ornamental potted plants. The reuse of biological agri-wastes, amended with cocopeat and soil, has potential for ameliorating the hydro-physical environment in growing media substrates, affecting air–water relations. A study was undertaken to evaluate the water retention and transmission characteristics of four biological wastes as base media (farmyard manure (FYM), leaf mould (LM), rice husk ash (RHA) and composted sewage sludge (CSS)) amended with different proportions of soil : coir mixture (0 : 75, 25 : 50, 50 : 25, 75 : 0) respectively. These media mixtures were filled in 3.5 l pots. Utilization of coir <50% (per cent of pot volume) as an amendment in FYM and CSS-based media mixtures improved hydraulic characteristics of pot-growing media. The use of RHA amended with soil : coir was not suitable as a growing medium due to higher relative evaporation rate and higher rate of infiltration. Water retention in terms of maximum water-holding capacity and available water increased with coir addition, the increase being enormous with 75% coir. Infiltration rate of water in the media improved with addition of coir (0–50%), showing a steep increase (4.25–8.10 cm min^{-1}) at highest (75%) proportion of coir. Drainage rate was highest in FYM and LM-based media mixtures.

Keywords: Coir bricks, hydraulic characteristics, infiltration rate, pot media, water retention.

CONTAINERIZED ornamental plants are not only confined to private homes, but also aesthetically placed in mass multiplexes due to scarcity of spaces for beautification. Production of sustainable[1], environment-friendly substrates[2], also referred to as growing media, has been utilized as an amendment for improving physio-chemical characteristics of media contained in finite-volume pots. However, research on pot–media hydraulics is still in its infancy, which is of vital importance to ornamental potted plant industry worldwide. The hydraulic characteristics responsible for air–water relations have been

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