



## **CRISTADINIUM STRIATISERRATUM: A DINOFLAGELLATE CYST FROM THE TROPICAL REGION**

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### **ABSTRACT**

A new organic-walled dinoflagellate cyst *Cristadinium striatiserratum* sp. nov., has been reported from the modern sediments of the northern Indian Ocean. *C. striatiserratum* sp. nov., exhibit paratabulation in the form of parasutural crests that are septate and possess a serrated distal margin. The autophragm is surmounted with non tabular striations, and the archeopyle occupies a mid-dorsal anterior intercalary position (Type 2a). Similar forms have been reported earlier under different generic names viz. *Selenopemphix* (Benedeck, 1972), *Lejeuncysta* (Artzner and Dorhofer, 1978), and *Protoperidinium* (Bergh, 1881) from low latitudes. Taxonomic standardisation of the species that consist crests has been proposed here by describing it under genus *Cristadinium* that is earlier restricted to the Miocene. The study extends the geological range of the peridinioid species that consist of complete paratabulation from the Neogene to Holocene

**Keywords:** *Cristadinium*, non tabular striations, parasutural crest, Peridiniaceae, Eastern Arabian Sea.

### **INTRODUCTION**

Dinoflagellates constitute a major group of microplankton that plays a key role in marine ecosystems (Taylor, 1987; Zonneveld *et al.*, 2013). More than 10-15% of the modern dinoflagellates form fossilizable cysts that can be recovered from the sediments through palynological processing. Furthermore, cysts exhibit provincialism in that they have distinct distribution patterns, spread over tropical, temperate and in polar regions (Marret and Zonneveld, 2003; Zonneveld *et al.*, 2013). Modern dinoflagellate cyst diversity and their distribution pattern have been well studied from the surface sediments of low latitudes (Holzworth *et al.*, 2007, 2010; Limoges *et al.*, 2013; Marret, 1994; Marret and Zonneveld, 2003; Su-Myat *et al.*, 2013; Zonneveld *et al.*, 2013). Tropical seas, bays and oceans support a high diversity of dinoflagellate cysts, particularly the protoperidinioids which have a heterotrophic nutritional mode (Fensome *et al.*, 2008; Zonneveld *et al.*, 2013). However, dinocysts from several tropical basins such as the Bay of Bengal, eastern Arabian Sea and the Andaman Sea are as yet poorly explored. Though a few studies documented the cysts distribution and identified new morphotypes, their taxonomic standardisation has not been attempted yet (D'Silva *et al.*, 2011, 2012, 2013; Narale *et al.*, 2013, 2016; Su-Myat *et al.*, 2013; Uddandam *et al.*, 2015, 2017). In the present study, we describe a new species *Cristadinium striatiserratum* sp. nov. It has been previously identified as *Protoperidinium* sp., *Lejeuncysta* sp. (Mertens *et al.*, 2009; Su-myat *et al.*, 2013) from the tropical region. *Cristadinium striatiserratum* sp. nov. has sub-pentaonal shape and mid dorsal anterior intercalary archeopyle and may be confused with the *Lejeuncysta* at the first site, but greatly differs from it in the ornamentation of the ambitus. Thus we provide the formal description of this new species and its comparison with the genera to which it was assigned earlier, and discuss its present day biogeography and palaeoecology.

### **MATERIAL AND METHODS**

For the present study, multiple sediment samples (surface and sub-surface) collected from the Arabian Sea (SSK-15, SK-117) and Bay of Bengal (SK-308) were analyzed (Fig. 1). Two grams of sediment was treated with hydrochloric acid for 24 hours to remove carbonates. After washing the residue to neutrality, hydrofluoric acid was added to digest the silicate minerals. After two days, the neutralized residues were filtered through a 10 µm sieve. A thin smear of residue mixed with polyvinyl alcohol was spread on the cover slip. The cover slips with dried residue concentrate were mounted on microscope slides using Canada balsam. Identification of the cyst was carried out under the Leica microscope 200 DMX at 400× and 1000× magnifications. Taxonomy of the dinoflagellate cyst mentioned in the text is according to the Lentini and Williams index (Fensome *et al.*, 2008). The holotype and paratype of the current new species are curated in the museum of Birbal Sahni Institute of Paleosciences, India (<http://www.bsip.res.in/>).

### **SYSTEMATIC PALAEOLOGY**

- Division* **Dinoflagellata** (Bütschli 1885)  
Fensome *et al.*, 1993
- Subdivision* **Dinokaryota** Fensome *et al.*, 1993
- Class* **Dinophyceae** Pascher, 1914
- Subclass* **Peridiniphyceae** Fensome  
*et al.*, 1993
- Order* **Peridinales** Haeckel, 1894
- Family* **Protoperidiniaceae** Bujak and Davies,  
1983
- Genus* **Cristadinium** Head *et al.*, 1989
- Type species* *Cristadinium cristatoserratum*  
Head *et al.*, 1989

*Emended diagnosis:* Cysts autophragmal or possibly with closely appressed wall layers, dorso-ventrally compressed, brown, Peridinioid outline and having an apical and two antapical horns.

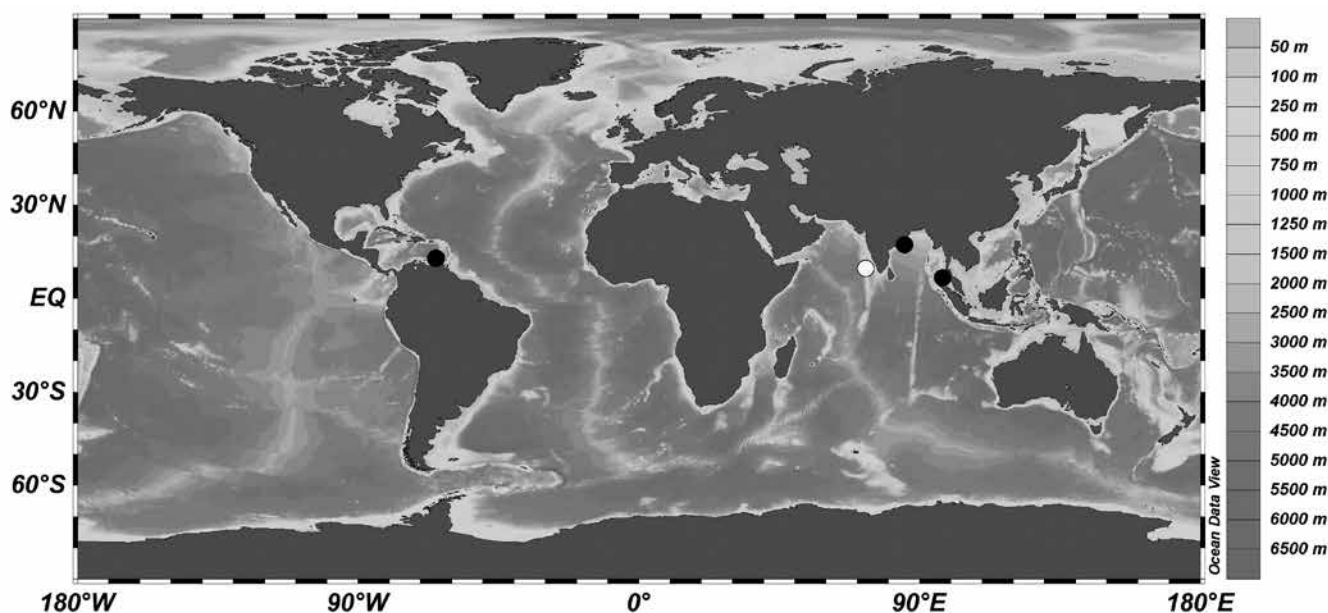


Fig. 1. Distribution of *Cristadinium striatiserratum*, sp. nov. White circle: Present study. Black circles: previous studies.

Paracingulum planar to weakly helicoidal with margins bearing relatively continuous crests. Relatively continuous parasutural crests are present on the epicyst where they may

Incompletely or completely reflect paratabulation. The epicyst and hypocyst may be without or with ornament in the form crests, striations, scattered projections or other form. Wall surface smooth to finely granulate. Archeopyle presumably hexa-intercalary involving paraplate 2a. Paratabulation probably Peridinioid.

*Cristadinium striatiserratum* sp. nov.

(Pl. I, figs. 1-9; Pl. II, fig. 1-8; Pl. III, figs. 1-8)

*Derivation of name:* Latin, stria=striations, serratus=serrated after the undulating longitudinal striations with serrate margin on the autophragm

*Holotype and type locality:* Plate. I: 3-6. Sediments (92-94 cm) from SK 117; GC-01 off Goa, eastern Arabian Sea (Longitude 15° 29.31 °E and latitude 73° 26.23 °N at 31.50 m water depth). Slide number: BSIP 16202. England Finder Reference: S-44/4.

*Paratype and type locality:* Plate. III: 1-4. Recent sediments (0-1 cm) from SK-308 MC 64 from the north-western Bay of Bengal; Offshore Mahanadi river (Longitude 18°55.840 and latitude 85°26.046 at 500 m water depth). Slide number: BSIP 15589. England Finder Reference: Q-52.

*Diagnosis:* A biconical species of *Cristadinium* with a sub-pentagonal outline in dorso-ventral view. Relatively continuous paratabulation is expressed in the form of the parasutural crest (serrated) and anterior intercalary archeopyle (Type 2a). Autophragm is surmounted by undulating non tabular

longitudinal striations with a serrate margin.

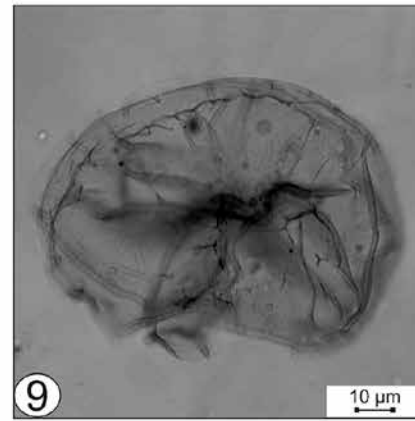
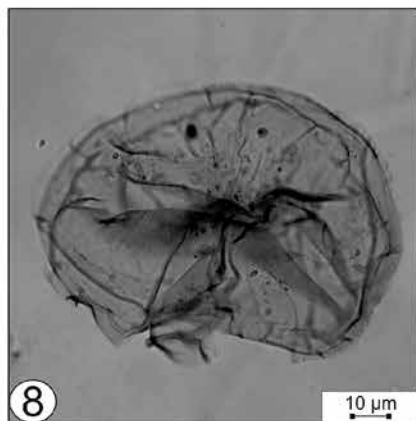
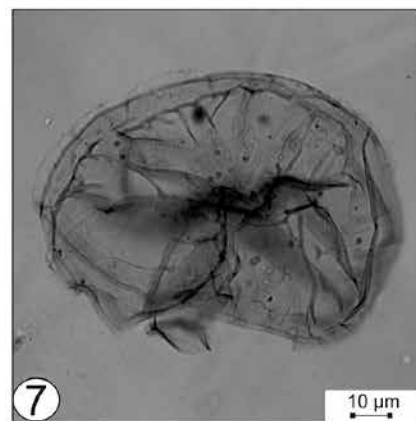
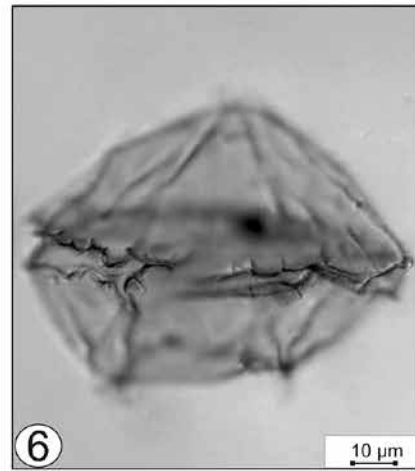
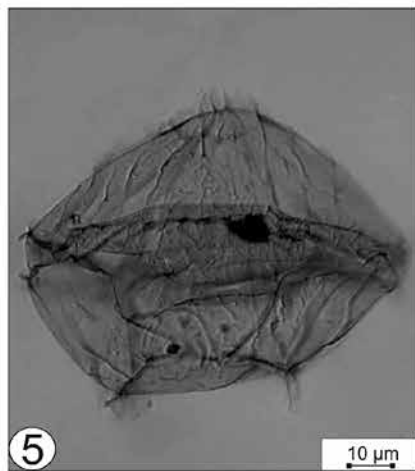
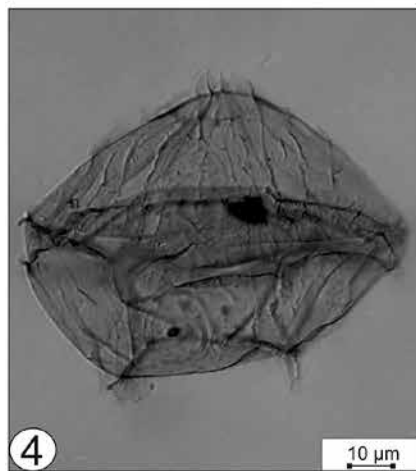
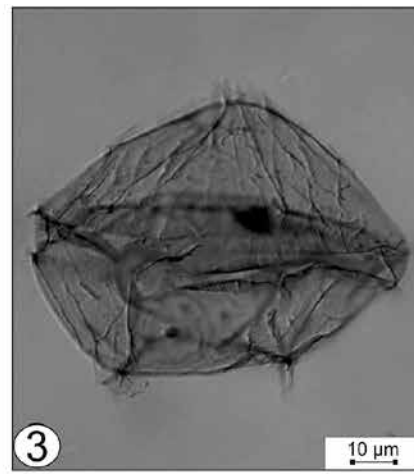
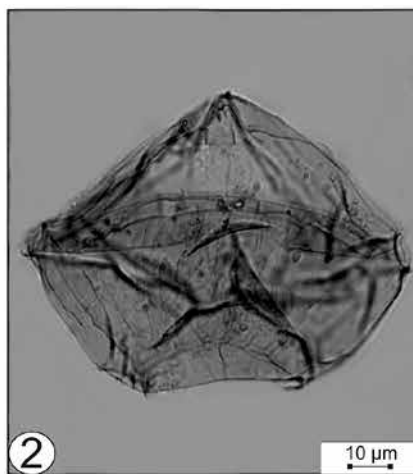
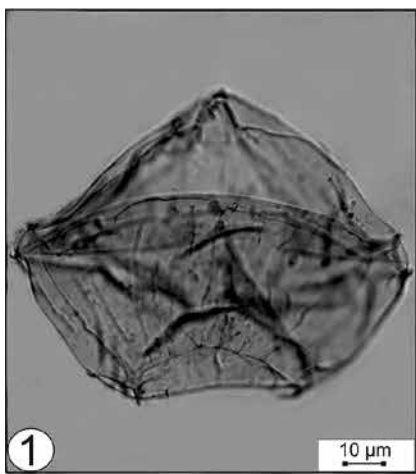
*Description:* A biconical/subpentagonal, proximate species with small, short, apical and antapical horns. The epicyst and hypocyst are sub-triangular in outline, with straight to weakly convex sides, and the hypocyst is slightly larger than the epicyst. Lateral horns or protrusions are absent. This species exhibits dorso-ventral compression. The antapical concavity is small and with a serrate margin. The autophragm is brown in color, of moderate thickness and bears prominent, undulating or serrate, non tabular longitudinal striations (~2 µm width). Tabulation is expressed in the form of the relatively continuous parasutural crest (~5-10 µm) and the anterior intercalary archeopyle (Type 2a). Parasutural crest are undulated or serrated and operculum is hexagonal in shape with a broad posterior and a much shorter anterior margin. The cingulum is prominent and is bordered by two ridges, with a high sutural crest which is septate and have serrated margin. Mid-ventral sulcal depression is prominent. Epicystal parasutural crest adjoins at the tip of the epicyst and hypocystal septa adjoin at the either side of the antapicals. Apical horn often appears in the form of two granules. Hypocystal corners show thickening. Antapicals are surmounted by a crest, giving a tubular appearance.

*Dimensions:* Cyst body length: 57-69 µm; Cyst body width: 60-67 µm; Epicyst length: 26-30 µm; Hypocyst length: 30-39 µm. 15 specimens were measured.

*Remarks:* The species described in the present study differs from the other *Cristadinium* species in having paratabulation expressed by a parasutural crest with serrate and denticulate margin and non tabular striations which are unique to this species.

#### EXPLANATION OF PLATE I

Figs. 1-9. *Cristadinium striatiserratum* sp. nov. Figs. 1-2. BSIP 16200, EF: Y-47/2. 1. dorsal side, high focus. 2. dorsal side mid focus. Figs. 3-6. (Holotype) BSIP 16202, EF: S-44/4. 3. dorsal view, High focus, apical and antapical horns exposed. 4. slightly low focus, crest is exposed clearly on the apical antapical and dorsal surface. 5. dorsal view, mid focus, showing cingulum. 6. ventral view, low focus, showing cingulum crest clearly on the ventral surface. Figs. 7-9. BSIP 16201, EF: K-53/4.7. polar view, 7. high focus, cingular crest focused. 8. low focus, 9. mid focus showing cingular margin and antapical horn.



#### Comparison with the other species:

The present species differs from the species belongs to the genus *Lejeunecysta* in not possessing the crest. It differs from *Quinquecuspis* in smaller size and possessing crests. It differs from *Selenopemphix* in having a mid dorsal archeopyle. *Gerlachidium aechmophorum* differs in having discontinuous parasutural crest and both on epicyst and cingular region. It differs from *Cristadinium cristoserratum* in having parasutural crest and ornamenta on the hypocyst. *Cristadinium* sp1 Head et al., 1987c differs in having indented distal margins and lacking striations. *Cristadinium* sp2. Head et al., 1987c differs in not having crest on the hypocyst and striations on the autophrgm.

*Cristadinium* aff. *Cristoserratum* shows similarity with *C. striatiserratum* in having crest on epicyst and hypocyst however, differs in the finely indented crest rather than serrated.

## DISCUSSION AND CONCLUSIONS

The dinoflagellate cyst described here was previously reported as *Selenopemphix* cf. *divaricatum* from the Cariaco basin possibly due to its apical-antapical orientation (Gonzalez et al., 2008). Mertens et al. (2009) transferred similar specimens from the Cariaco basin to the genus *Lejeunecysta* based on the dorso-ventrally preserved specimens. Similar species were also mentioned in the studies of D'Silva et al. (2011) as *Protoperdinium* sp.5 and Su-Myat et al. (2012) as *Protoperdinium* sp. The similar species is reported as *Lejeunecysta* sp. 1 and described to have corrugated surface. These studies have not described it formally perhaps because of the very low occurrence. In a Palynological analysis from the Northern Indian Ocean sediments we have noted the occurrence of this species but in very low numbers. However the well preserved specimens have revealed cyst wall structure is complex with parasutural crests and non tabular striations rather than a smooth surface. The specimens were found to occur mainly in dorsoventral orientation but few also shows an polar (apical- antapical) orientation. The specimens under polar orientation looks similar to the genus *Selenopemphix*. However, as per the emended diagnose of *Selenopemphix* (Bujak, 1980), present specimens under dorso-ventral orientation clearly show a symmetrical position of the intercalary archeopyle with a mid-dorsal position (Plate I, II, III; Su-Myat et al., 2013, Fig. 6-J), excluding it from the *Selenopemphix*, which have archeopyle positioned offset to the mid-dorsal line. The genus *Lejeunecysta* includes the species with pentagonal to sub-rounded pentagonal outline, cyst wall smooth to ornamented and with no lateral horns. In the present study observations on the well-preserved specimens revealed the presence of parasutural crests on the cyst wall clearly separating it from the *Lejeunecysta*. Pentagonal Peridnioid cysts possessing crests on the wall could be assigned to the either of the genera *Cristadinium* (Head, 1989) or *Erymnodinium* (Lentin et al., 1994). The absence of reticulation on the cyst wall provides a justification for assigning it under the genus *Cristadinium* rather than *Erymnodinium*, which is

characterized by sutural crest along with reticulate autophram (Head, 1989).

Peridinioid taxa have a wide geological range and exhibit variety of morphological features (Fensome et al., 1993). The body shape of the cysts varies from spherical to pentagonal, with or without the expression of paratabulation. Pentagonal peridinioid cyst with variable intratabular ornamentation were relatively high during the Cretaceous (*Spinidinium*), Paleocene-Eocene (*Spinidinium*, *Apectodinium*, *Wetzelilla*) and their diversification has been linked with the PETM event (Iakovleva, 2016). Peridinioid dinoflagellate cyst with complete paratabulation in the Cenozoic is only reported from Eocene (eg. *Wetzelilla*), Oligocene (eg. *Gerlachidium*) and Miocene (eg. *Cristadinium*, *Erymnodinium*). In the Holocene Peridinioid cysts with pentagonal outline show a partially expressed paratabulation in the form of archeopyle and cingulum (eg. *Lejeunecysta*, *Quinquecuspis*) or possessing processes in the cingular region (*Stelladinium stellatum*).

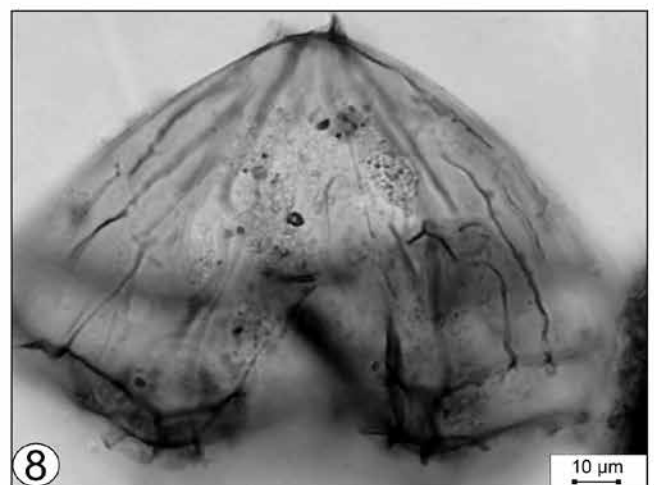
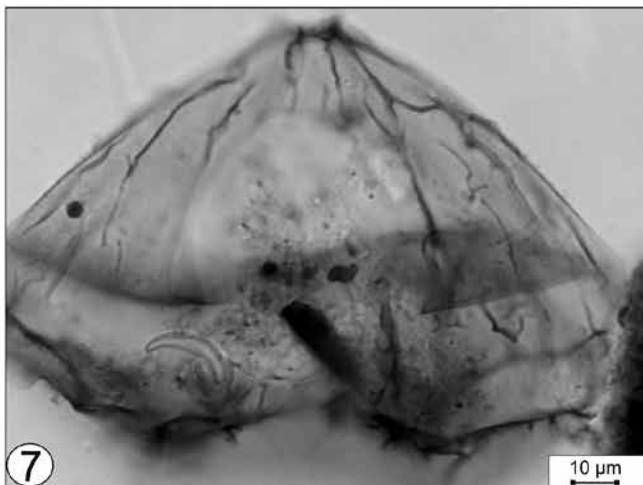
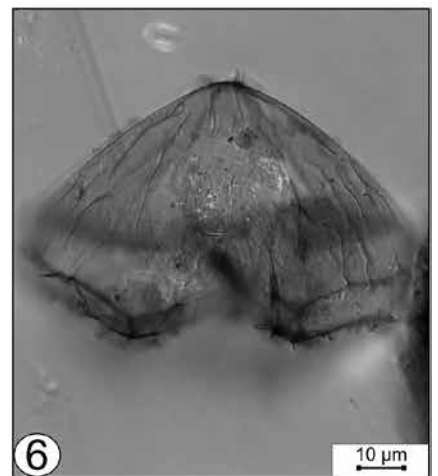
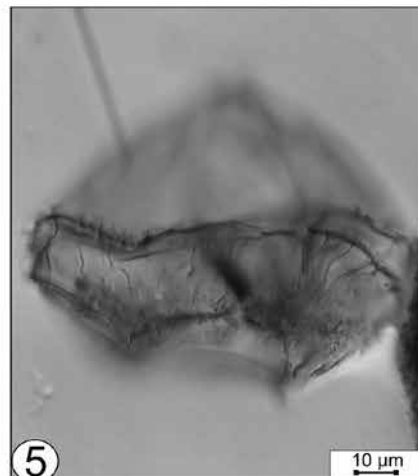
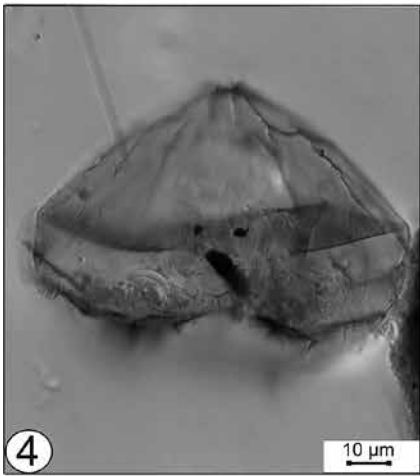
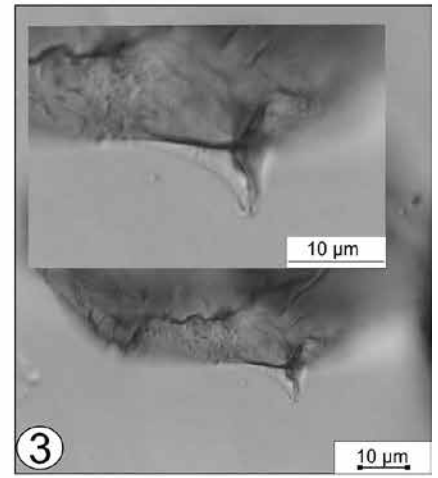
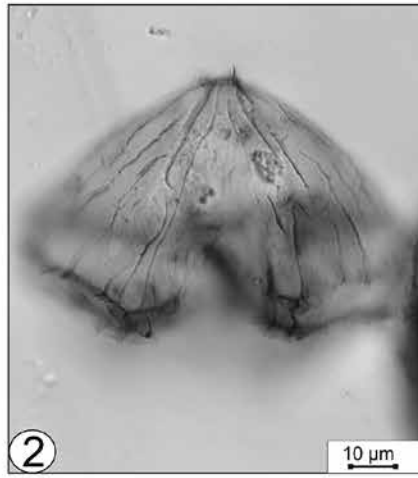
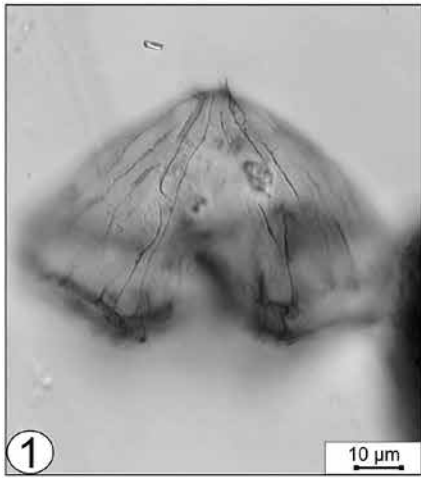
Lentin et al. (1994) provided the taxonomic standardization of crest possessing cysts of Miocene age. As *Sumatrodinium* accommodate the taxa possessing parasutural crests and processes, a new genus *Erymnodinium* was erected to accommodate previous questionably assigned species to the *Sumatrodinium? delectabile* (de Verteuil and Norris, 1992) that shares the features of reticulate autophram with parasutural crest and lack processes. This suggests wall surface ornamentation as the criteria to differentiate the taxa with complete or incomplete parasutural crests.

Head et al. (1989) erected the genus '*Cristadinium*' to accommodate pentagonal cysts with parasutural crests. This study describes the relatively continuous parasutural crests, which may be straight-topped or surmounted by various ornaments as the characteristic feature of this genus. It suggested the ornamentation and variation in the crest type as the principle character for the speciation within the genus *Cristadinium*. So far, four species of *Cristadinium*; *C. cristoserratum* (epicystal and hypocystal crest which in places are finely indented rather than serrated), *C. sp. 1* (epicyst; hypocystal crest with distal margin indented) *C. sp. 2* (absence of serrated or denticulate ornament on the hypocyst) and *C. diminutivum* (that has thin crest on epi and hypocyst, smaller in size) are described from the Baffin Bay and Labrador Sea of early /mid Miocene and early Pliocene age (Head et al., 1989 a,b).

The original diagnosis for the genus specifies "Relatively continuous parasutural crests are present on the epicyst where they may incompletely reflect Paratabulation" (p.456). No other ornament occurs on the epicyst". However, the present new species consist of ornamentation in the form of non tabular striations. To avoid erection of the new genus we have accommodated the present new species under the genus '*Cristadinium*'. We propose that the taxa with parasutural crest having smoothed or granulated or surmounted with variable ornamentations on the cyst wall as the characteristic features of genus *Cristadinium*.

## EXPLANATION OF PLATE II

Figs. 1-8. *Cristadinium striatiserratum* sp. nov. Figs. 1-8. paratype. BSIP 16201, EF: N 51. 1-2. ventral surface with crests in focus. 3. antapical horn enlarged. 4. high focus- ventral view upper ambitus in focus. 5- low focus- dorsal side lower ambitus in focus. 6- high focus, ventral view, cingular crest exposed. 7-8. specimens under higher magnification showing archeopyle and crest details.



### Geographical distribution and ecology

The present study extends the geological range of the genus '*Cristadinium*' from Miocene to Holocene. Similar forms have been reported from the Cariaco basin, Caribbean Sea, Atlantic Ocean (Mertens *et al.*, 2009); East China Sea, Pacific Ocean (Wang *et al.*, 2004), Andaman Sea, Indian Ocean (Su-Myat *et al.*, 2012), Bay of Bengal (Uddandam *et al.*, 2017), Indian Ocean, suggesting its wide geographical range in low latitudes. This suggests its preference to tropical oceans and warm waters. It is important to note that these basins are influenced with the high input of runoff and nutrients. Though in the Arabian Sea, Bay of Bengal, *C. striatiserratum* occurs rarely, it was reported to have common occurrence in the assemblage and dominate the assemblage in some locations, off Myanmar, Andaman Sea (Su-Myat *et al.*, 2013). This species is a part of assemblage which is composed with 60-88 % of the protoperidinoid species with the dominance of *Selenopemphix quanta*, *Brigantedinium* spp. Protoperidinoides feed mainly on the diatoms, small dinoflagellates, bacteria and organic matter and their dominance indicates the high nutrient and prey availability. Thus the present species can be regarded as a tropical species preferring warm and nutrient rich water conditions.

Over the past few years, several studies have been deciphered to determine cyst-theca relationships for some dinoflagellate species including peridinoides (Matsuoka, 1988, Matsuoka and Kaumai, 2013, Gu *et al.*, 2015). Several pentagonal species were germinated from the protoperidinoid species (Liu *et al.*, 2015). Careful observation of both the motile and cyst stage is required to separate species, and molecular techniques such as large subunit (LSU) rDNA also can provide valuable information (Matsuoka, 1988, Matsuoka and Kaumai, 2013, Gu *et al.*, 2015). However the very distinct morphological features which have more similarities with Neogene taxa rather than any existing taxa from the modern ocean, allow us to erect a new species on paleontological basis. In addition, the observed specimens with very low abundance points out the difficulty of conducting cyst-theca relationship at present. Besides, present study gains its significance revealing that low saline basins with seasonal fluctuation in the environment have high diversity of dinoflagellate cyst which is yet to be explored.

### ACKNOWLEDGEMENTS

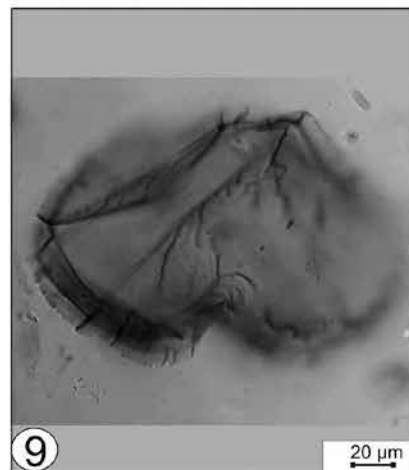
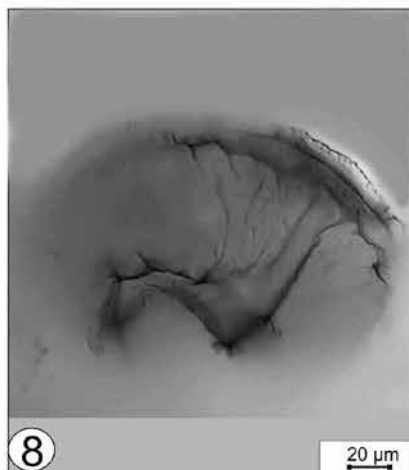
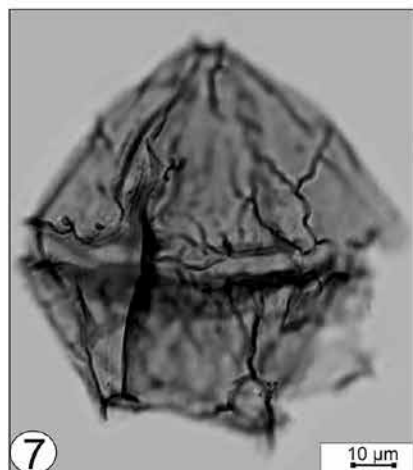
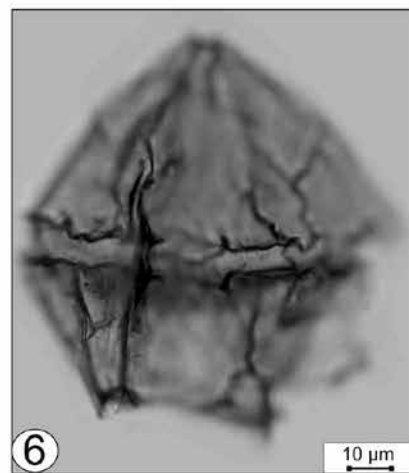
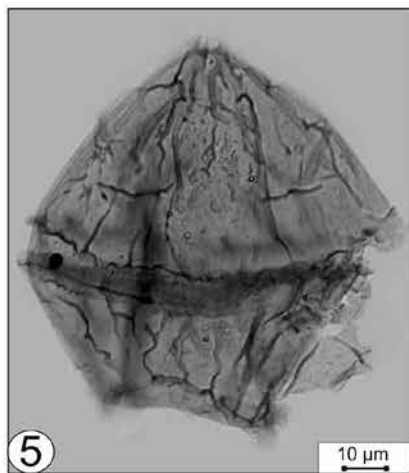
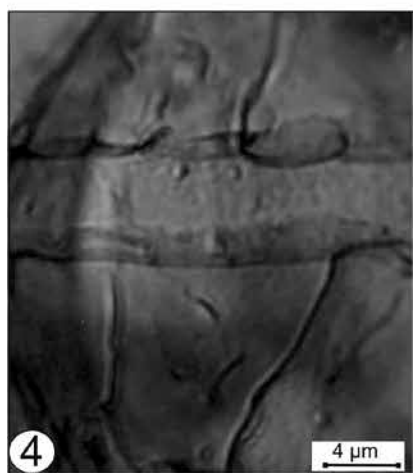
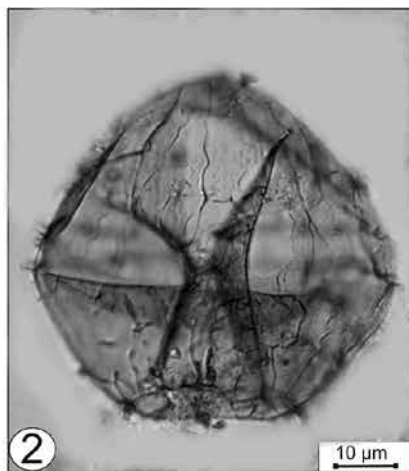
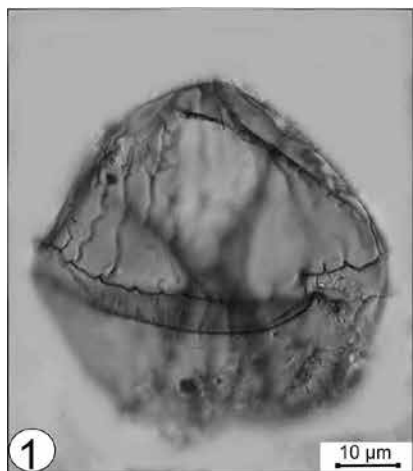
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### EXPLANATION OF PLATE III.

Figs. 1-9. *Cristadinium striatiserratum* sp. nov. Figs. 1-4. BSIP 15589, Q 521-dorsal view showing cingulum and archeopyle. 2-dorsal view slightly low focus, archeopyle and antapical groove focused. 3.ventral view, hypocyst focused. 4. upper and lower cingulum ridges exposed along with striations. Figs. 5-7. BSIP 16227. EF: U59. 5. high focus, dorsal view. 6. mid focus, showing crest. 7. low focus, ventral view. Figs. 8-9. BSIP 16228, EF: Y52. 8. low focus, hypocyst in view-cingulum crest and antapicals in focus. 9. high focus, ventral view-epicyst in focus.



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