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Dinoflagellate cyst evidence for the age of Kulakkalnattam Sandstone Member, Garudamangalam Formation, Cauvery Basin, southern India

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ABSTRACT

Khowaja-Ateequzzaman & Rahul Garg 2002. Dinoflagellate cyst evidence for the age of Kulakkalnattam Sandstone Member, Garudamangalam Formation, Cauvery Basin, southern India. Palaeobotanist 51 : 129-143.

Rich and diversified dinoflagellate cyst assemblages comprising 42 genera and 68 species have been recovered from the Kulakkalnattam Sandstone Member of the Garudamangalam Formation exposed in and around Ariyalur, Cauvery Basin, and southern India. First and last appearances of dinoflagellate cyst taxa present in the assemblage, including *Callaiosphaeridium asymmetricum, Circulodiniumm distinctum, Cribroperidinium aceras, C. edwardsii, C. cooksoniae, Conosphaeridium striatoconus, Cyclonephelium compactum, Florentinia cooksoniae, F. mantellii, Heterosphaeridium difficile, Litosphaeridium siphoniphorum* and *Palaeoperidinium pyrophorum*, suggest that the age of the member ranges from Middle to Late Turonian.

Key-words—Dinoflagellate cysts, Middle-Late Turonian, Kulakkalnattam Sandstone Member, Garudamangalam Formation, Cauvery Basin, India.

दक्षिण भारत की कावेरी द्रोणी के गरुड़मंगलम् शैलसमूह के कुलक्कलनट्टम् बालुकाश्म सदस्य के आयु निर्धारण हेतु घूर्णीकशाय पुटी प्रमाण

ख्वाजा अतीकुज़्ज़माँ एवं राहुल गर्ग

सारांश

दक्षिण भारत के अरियालूर, कावेरी द्रोणी में तथा इसके आस-पास अनावरित गरुड़मंगलम् शैलसमूह के कुलक्कलनट्टम् बालुकाश्म सदस्य से 42 वंशों तथा 68 प्रजातियों से युक्त सम्पन्न तथा वैविध्यमय घूर्णीकशाभ पुटी समुच्चय अंकित किए गए। समुच्चय में उपस्थित घूर्णीकशाभ पुटी वर्गकों की प्रथम तथा अन्तिम प्राप्ति में *कैलेइयोस्फ़ेयरीडियम एसाइमीट्रिकम, सर्क्युलोडाइनियम डिस्टिंक्टम, क्राइब्रोपेरिडाइनियम एसीरस, सी. एडवर्ड्साइ, सी. कुकसोनियाइ, कोनोस्फ़ेयरीडियम स्ट्रायाटोकोनस, साइक्लोनीफ़ीलियम कॉमपैक्टम, फ़्लोरेण्टीनिया कुकसोनियाइ, एफ़ मैण्टेलाइ, हेटीरोस्फ़ेयरीडियम डिफ़िसाइली, लिटोस्फ़ेयरीडियम साइफ़ोनीफ़ोरम* तथा *पेलियोपेरिडाइनियम* की उपस्थिति से प्रस्तावित होता है कि सदस्य की आयु मध्य से अन्तिम ट्यूरोनियन के मध्य है।

संकेत शब्द—घूर्णीकशाभ पुटी, मध्य-अन्तिम ट्यूरोनियन, कुलक्कलनट्टम बालुकाश्म सदस्य, गरुड़मंगलम शैलसमूह, कावेरी द्रोणी, भारत.

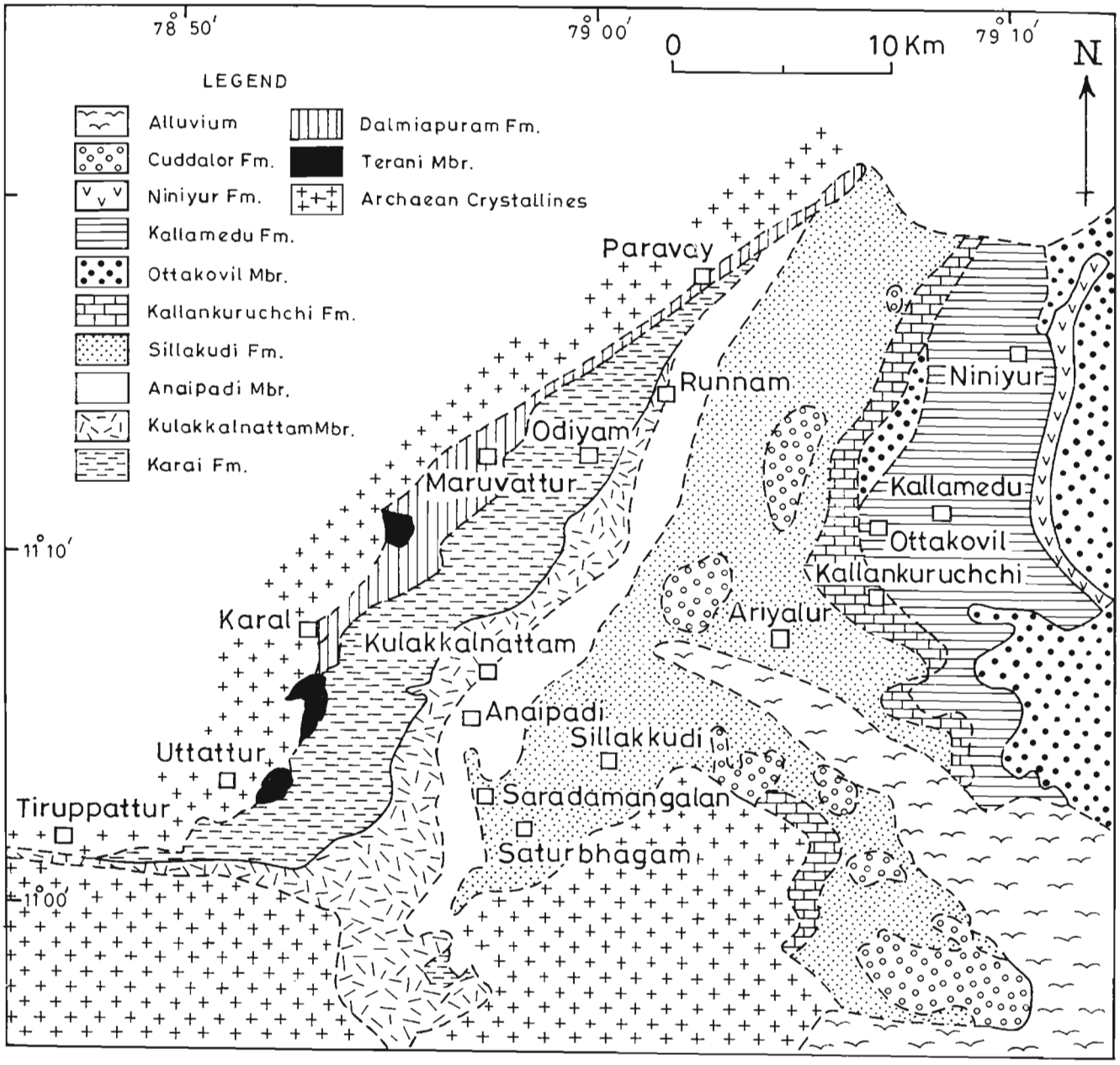


Fig. 1—Geological map of the Ariyalur area (after Blanford, 1864; Sundaram & Rao, 1986).

INTRODUCTION

THE Cauvery Basin is the southernmost basin of the East Coast of India, covering an area of approximately 25,000 sq km, extending from Tuticorin in the south to Pondicherry in the north. The basin shows the development of almost the entire Cretaceous succession, outcrops of which are quite widespread around the town of Ariyalur (Fig. 1), with a low southeasterly dip (Blanford, 1865; Ramanathan, 1968; Sastri *et al.*, 1981).

Biozonation and age determination of the Cretaceous succession of the Ariyalur area has been done mainly on ammonites (Sastry *et al.*, 1968; Chiplonkar & Phansalkar, 1976, 1978; Ayyasami & Rao, 1981; Ayyasami, 1990). Among planktonic microfossils, foraminifera (Banerji, 1973; Narayanan, 1977; Ramasamy & Banerji, 1991; Govindan *et al.*, 1996) and nannofossils (Kale & Phansalkar, 1992) have also been used. Most of the microfossil records are confined to the Uttatur (Albian-Lower Turonian) and Ariyalur (Santonian-Maastrichtian) groups of rocks. The Garudamangalam Formation, dated as Middle Turonian-Coniacian on ammonite

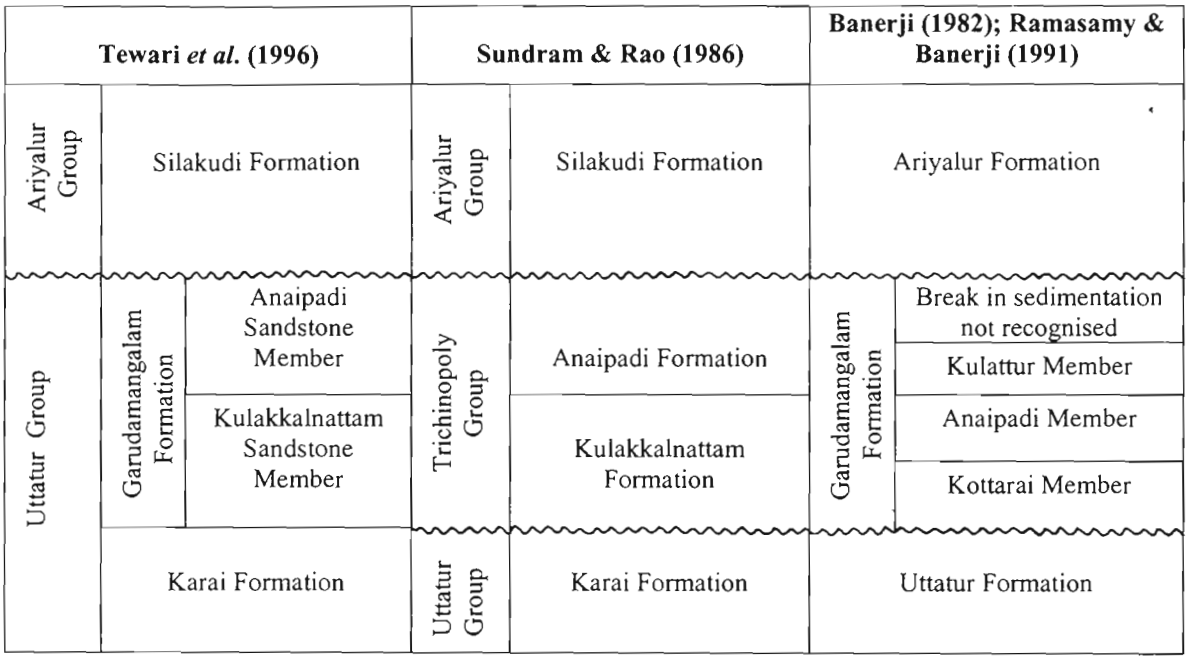


Fig. 2—Correlation of lithostratigraphic classification for the Cauvery Basin (after Tewari *et al.*, 1996).

evidence, has so far yielded only a meagre assemblage of foraminifera (Phansalkar & Kurien, 1980). Recently, its lower range has been extended to Upper Turonian on stratigraphic criteria (Hart *et al.*, 1996; Tewari *et al.*, 1996). A major hiatus within the Upper Turonian has been interpreted based on subsurface data (Govindan *et al.*, 1996). In the present paper, precisely datable Middle-Late Turonian dinoflagellate cysts are documented from the lower part of Garudamangalam Formation (Kulakkalnattam Sandstone Member), highlighting their significance in age determination and their correspondence with ammonite evidence.

The stratigraphic ranges of dinoflagellate cyst taxa described earlier from Kulakkalnattam Sandstone Member, Garudamangalam Formation (Trichinopoly Formation) by Khowaja-Ateequzzaman and Jain (1990), Khowaja-Ateequzzaman *et al.* (1991) and Khowaja-Ateequzzaman and Garg (1995) are revised herein.

STRATIGRAPHY

The Cretaceous succession of the Cauvery Basin has been the subject of intensive research due to its highly fossiliferous nature since the pioneering studies of Blanford (1865). Several modifications to the lithostratigraphic classification of Blanford have been proposed from time to time with use made of renamed or new lithostratigraphic units (Ramanathan, 1968; Banerji, 1973; Sundaram & Rao, 1979, 1986; Sastri *et al.*, 1981; Ramasamy & Banerji, 1991; Tewari *et al.*, 1996). The generalised lithostratigraphical classification of the Cretaceous rocks in the Cauvery Basin proposed by Sundaram and Rao (1986) and Tewari *et al.* (1996) has been followed here (Fig. 2).

The Garudamangalam Formation consists of a coarse sandy to gritty, shaly succession interbedded with highly fossiliferous gritty to conglomeratic calcareous sandstones and shelly calcareous sandstones. It is subdivided into a lower Kulakkalnattam Sandstone Member and an upper Anaipadi Member (Sundaram & Rao, 1979; Tewari *et al.*, 1996). It overlaps the underlying Karai Formation in the southernmost and northernmost parts. The junction between Garudamangalam Formation and Karai Formation (Uttatur Group) is marked by a fossiliferous pebbly calcareous sandstone, occurring as medium to large concretions, observed from the vicinity of Tappy in the south to Kunnam and Odiyam in the north. Between Varagur-Paravay, and Vayalpadi further north the lower beds of the Garudamangalam Formation can be seen to overlap the sandier succession of the Karai Formation. The basal fossiliferous concretionary calcareous sandstone of the Garudamangalam Formation is characterised by the occurrence of pebbles and cobbles of quartz, older Archaean rocks, and lenses of underlying Karai Shale Formation (see Pascoe, 1959; p. 1235). The basal beds of Garudamangalam Formation are well exposed west of Kunnam towards Odium, Mungilpadi and towards Kunnam reserve forest. The basal conglomeratic shelly calcareous sandstone gradually changes upwards into hard fossiliferous calcareous sandstone that is more or less gritty and weathers out in medium to large concretions. These concretions have sandy outer layers that are often rich in large bivalve shells whereas their interiors are fine-grained, more calcareous and contain layers

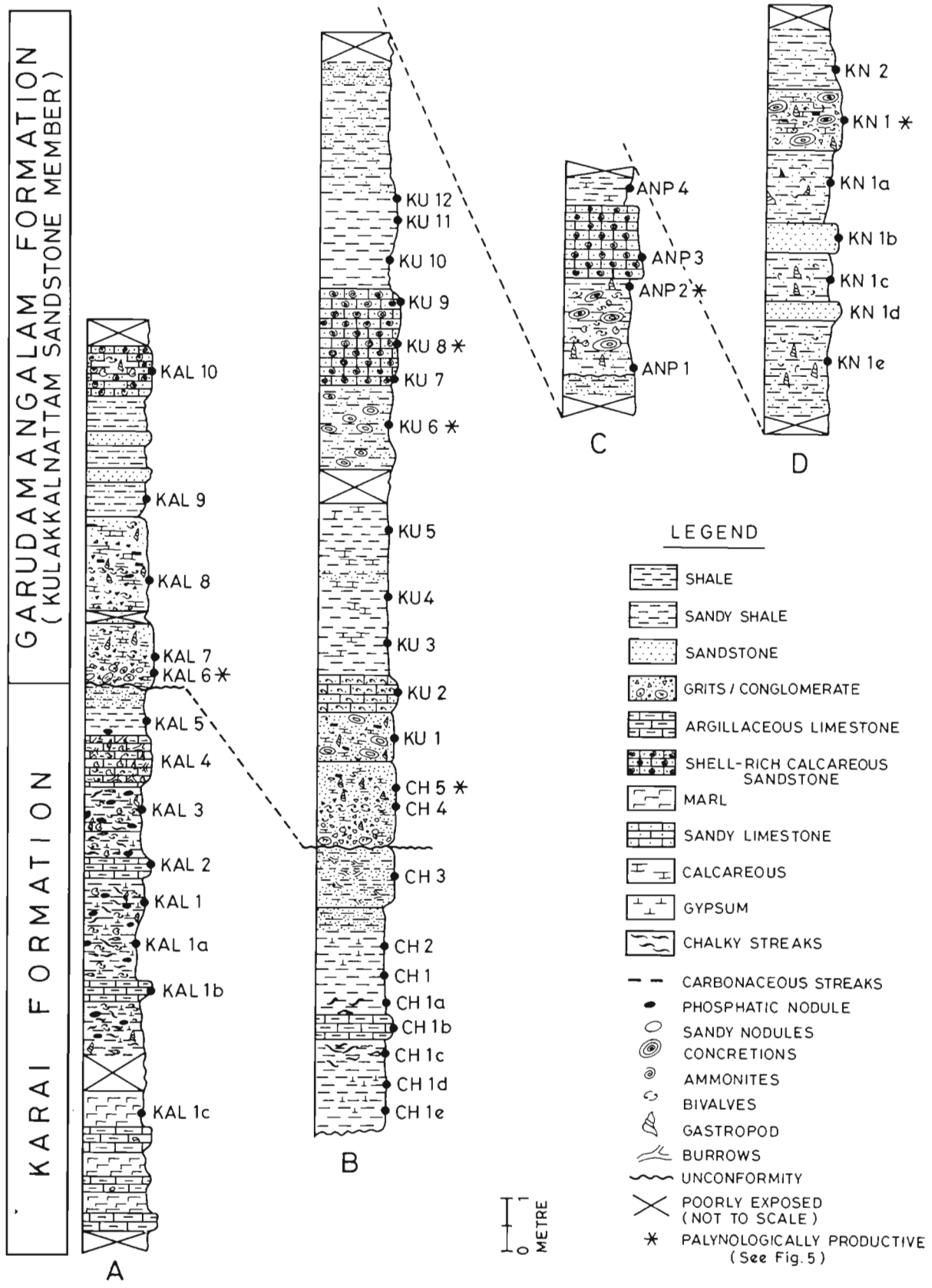


Fig. 3—Lithostratigraphic column of the sections studied. **A**, Kallakudi-Tappy area. **B**, Chittali-Kunnam area. **C**, near Anaipadi. **D**, near Kulakkalnattam.

S. No.	List of dinoflagellate cyst taxa	Plate & Figure reference of illustrated taxa
1.	*Achomosphaera ramulifera* (Deflandre) Evitt, 1963	
2.	*Achomosphaera* sp.	
3.	*Aiora fenestrata* (Deflandre & Courteville) Cookson & Eisenack, 1960	(pl. 3, fig. 15)
4.	*Alterbidinium acutulum* (Wilson) Lentin & Williams 1985 emend. Khowaja-Ateequzzaman *et al.*, 1991	
5.	*A. minus* (Alberti) Lentin &Williams, 1966	(pl. 3, figs 5, 12)
6.	*A. papillatum* Khowaja-Ateequzzaman *et al.*, 1990	(pl. 3. fig. 1)
7.	*Callaiosphaeridium asymmetricum* (Deflandre & Cookson) Davey & Williams *in* Davey *et al.*, 1966	(pl. 1, figs 17-18)
8.	*Cassiculosphaeridia reticulata* Davey, 1969	(pl. 1, fig. 15)
9.	*Cassiculosphaeridia* sp.	
10.	*Cauveridinium indicum* Khowaja-Ateequzzaman & Jain, 1990	(pl. 2, fig. 6)
11.	*C. intermedium* Khowaja-Ateequzzaman & Jain, 1990	(pl. 1, fig. 10)
12.	*C. longispinosum* Khowaja-Ateequzzaman & Jain, 1990	
13.	*Chatangiella* sp. A	(pl. 1, fig. 14)
14.	*Chatangiella* sp. B	(pl. 2, fig. 7)
15.	*Circulodinium distinctum* (Deflandre & Cookson) Jansonius, 1986	(pl. 3, figs 7-8)
16.	*Cleistosphaeridium huguoniotii* (Valensi) Davey, 1969	(pl. 2, fig. 4)
17.	*Conosphaeridium striatoconus* (Deflandre & Cookson) Cookson & Eisenack, 1969	(pl. 1, fig. 4)
18.	*Coronifera oceanica* Cookson & Eisenack emend. May, 1980	(pl. 2, fig. 14)
19.	*C. tubulosa* Cookson & Eisenack, 1974	(pl. 2, fig. 9)
20.	*Cribroperidinium aceras* (Eisenack) emend. Sarjeant,1985	(pl. 3, fig. 19)
21.	*C. cooksoniae* Norvick,1976	
22.	*C. edwardsii* (Cookson & Eisenack) Davey, 1969	(pl. 3, fig. 17)
23.	*Cribroperidinium* sp.	(pl. 3, fig. 4)
24.	*Cyclonephelium chabaca* Below, 1981	(pl. 1, fig. 11)
25.	*C. compactum* Deflandre & Cookson, 1955	
26.	*C. paucimarginatum* Cookson & Eisenack, 1962	(pl. 1, fig. 8)
27.	*C. vannophorum* Davey, 1969	(pl. 1, fig. 12; pl. 2, figs 13, 19)
28.	*Diconodinium multispinosum* (Deflandre & Cookson) Eisenack & Cookson, 1960	
29.	*Dioxya armata* Cookson & Eisenack, 1958	(pl. 1, fig. 1)
30.	*Exochosphaeridium phragmites* Davey *et al.*, 1966	(pl. 1, fig. 9)
31.	*Florentinia buspina* (Davey & Verdier) Duxbury, 1980	(pl. 3, fig. 14)
32.	*F. cooksoniae* (Singh) Duxbury, 1980	
33.	*F. deanei* (Davey & Williams) Davey & Verdier, 1980	(pl. 1, fig. 19)
34.	*F. mantellii* (Davey & Williams) Davey & Verdier, 1973	
35.	*Florentinia* sp.	(pl. 3, fig. 18)
36.	*Hapsocysta peridictya* (Eisenack & Cookson) Davey, 1979	(pl. 2, fig. 20)
37.	*Heterosphaeridium difficile* (Manum & Cookson) Ioannides, 1986	(pl. 3, fig. 11)
38.	*H. heteracanthum* (Deflandre & Cookson) Eisenack & Kjellstrom, 1971	
39.	*Hystrichodinium pulchrum* Deflandre, 1935	
40.	*Hystrichosphaeridium dupulum* (White) Downie & Sarjeant, 1965	(pl. 1, fig. 7)
41.	*H. recurvatum* (White) Lejeune-Carpentier, 1940	
42.	*H. tubiferum* (Ehrenberg) Deflandre 1937 emend. Davey & Williams *in* Davey *et al.*,1966	
43.	*Isabelidinium acuminatum* (Cookson & Eisenack) Stover & Evitt, 1978	
44.	*Jainiella breviornata* Khowaja-Ateequzzaman & Garg,1995	
45.	*Kiokansium polyps* (Cookson & Eisenack) Below, 1982	(pl. 2, fig. 10)
46.	*Litosphaeridium siphoniphorum* (Cookson & Eisenack) Davey & Williams *in* Davey *et al.*,1966 emend. Lucas-Clark, 1984	(pl. 2, fig. 15)
47.	*Meiourogonyaulax bulloidea* (Cookson & Eisenack) Sarjeant, 1969	(pl. 2, fig. 5)
48.	*Odontochitina operculata* (Wetzel) Deflandre & Cookson, 1955	
49.	*Oligosphaeridium complex* (White) Davey & Williams *in* Davey *et al.*, 1966	
50.	*O. complex* sub sp. *brevispinum* Jain, 1977	
51.	*O. pulcherrimum* (Deflandre Cookson) Davey & Williams, 1966	(pl. 1, fig. 16)
52.	*Palaeohystrichophora infusorioides* Deflandre, 1935	(pl. 2, fig. 1)

53.	*Palaeoperidinium cretaceum* Pocock 1962 emend. Davey, 1970	(pl. 3, fig. 3)
54.	*P. pyrophorum* (Ehrenberg) Sarjeant,1967	(pl. 3, figs 2,13,16)
55.	*Pervosphaeridium pseudhystrichodinium* (Deflandre) Yun, 1981	(pl. 2, fig. 11)
56.	*Psaligonyaulax deflandrei* Sarjeant *in* Davey *et al.* 1966 emend. Sarjeant, 1982	
57.	*Pterodinium aliferum* Eisenack 1958 emend. Sarjeant, 1985	(pl. 1, figs 5-6; pl. 3, figs 9-10)
58.	*Sepispinula huguoniotii* (Valensi) Islam, 1993	
59.	*Spiniferites porosus* (Manum & Cookson) Harland, 1973	(pl. 1, fig. 3)
60.	*S. ramosus* subsp. *gracilis* (Davey & Williams) Lentin & Williams, 1973	(pl. 2, fig. 8)
61.	*S. ramosus* subsp. *ramosus* (Ehrenberg) Davey & Williams, 1966	(pl. 1, fig. 13)
62.	*Subtilisphaera habibii* Masure, 1980	(pl. 2, fig. 3; pl. 3, fig. 6)
63.	*Tanyosphaeridium* sp.	
64.	*Tenua hystrix* Eisenack, 1958	(pl. 2, fig. 16)
65.	*Trichodinium castanea* (Deflandre) Clarke & Verdier, 1967	(pl. 2, fig. 2)
66.	*Valensiella griphus* Norvick, 1976	(pl. 1, fig. 2)
67.	*Xenascus ceratioides* (Deflandre) Lentin & Williams, 1973	(pl. 2, figs 17-18)
68.	*Xiphophoridium alatum* (Cookson & Eisenack) Sarjeant *in* Davey *et al.*, 1966	(pl. 2, fig. 12)

Fig. 4—List of dinoflagellate cyst taxa recovered from the Kulakkalnattam Sandstone Member of the Garudamangalam Formation, listed alphabetically by genera, followed by plate and figure references of illustrated taxa.

of small, broken fragments of bivalves. Current bedding is often prominent. This "conglomerate", considered by most of workers to indicate an unconformable relationship between the two formations, has recently been interpreted as having formed during a transgressive event, indicative of a sequence boundary caused by forced regression at the top of the underlying deeper water Karai Shale.

The succeeding beds consist of a succession of soft silty calcareous shales, which are variegated in colour and poorly fossiliferous. In the upper part the shales contain hard, sandy to calcareous concretions. This shaly succession is overlain by a compact, richly fossiliferous, grey, shell-rich calcareous sandstone, 1-2 m thick ("Shell Limestone" in Pascoe, 1959), typical of the Garudamangalam Formation. These shell-rich calcareous sandstones can be traced almost along the entire strike from Garudamangalam in the south to Kunnam in the north. However, there are significant lateral facies changes from south to north. The younger beds of Garudamangalam Formation (Anaipadi Sandstone Member) are exposed intermittently eastwards of Kulakkalnattam, Anaipadi, Garudamangalam and Kunnam. Better exposures of sandy to silty shales with interbedded medium to coarse sandstones and sandy to gritty fossiliferous calcareous sandstones can be seen between Kunnam, Karambium and Mel Mattur in the north and between Kulakkalnattam-Kullatur.

PLATE 1

(All photomicrographs in Nomarski Interference Contrast; magnified x 500)

1. *Dioxya armata* Cookson & Eisenack 1958, Slide No. BSIP 11501, coordinates 21·6 x 139·6.
2. *Valensiella griphus* Norvick 1976, Slide No. BSIP 10262; coordinates 21·8 x 138·5.
3. *Spiniferites porosus* (Manum & Cookson) Harland 1973, Slide No. BSIP 10263; coordinates 13·5 x 130·0.
4. *Conosphaeridium striatoconus* (Deflandre & Cookson) Cookson & Eisenack 1969, Slide No. BSIP 11499; coordinates 15·2 x 164·3.
5-6. *Pterodinium aliferum* Eisenack 1958 emend. Sarjeant 1985, Slide No. BSIP 11522; coordinates (5) 20·0 x 139·2 (6) 28·2 x 113·9.
7. *Hystrichosphaeridium dupulum* (White) Downie & Sarjeant 1965, Slide No. BSIP 11509; coordinates 11·6 x 138·2.
8. *Cyclonephelium paucimarginatum* Cookson & Eisenack 1962, Slide No. BSIP 11517; coordinates 15·0 x 161·9.
9. *Exochosphaeridium phragmites* Davey *et al.*, 1966, Slide No. BSIP 11511; coordinates 14·0 x 155·8.
10. *Cauveridinium intermedium* Khowaja-Ateequzzaman & Jain 1990, Slide No. BSIP 11509; coordinates 9·5 x 167·8.
11. *Cyclonephelium chabaca* Below 1981, Slide No. BSIP 10262; coordinates 16·3 x 154·1.
12. *C. vannophorum* Davey 1969, Slide No. BSIP 11499; coordinates 8·2 x 155.
13. *Spiniferites ramosus* sub sp. *ramosus* (Ehrenberg) Loeblich & Loeblich 1966, Slide No. BSIP 11502; coordinates 19·5 x 140·9.
14. *Chatangiella* sp. A, Slide No. BSIP 11505; coordinates 7·3 x 129·0.
15. *Cassiculosphaeridia reticulata* Davey 1969, Slide No. BSIP 10264; coordinates 8·0 x 151·0.
16. *Oligosphaeridium pulcherrimum* (Deflandre & Cookson) Davey & Williams 1966, Slide No. BSIP 11509; coordinates 13·5 x 163·7.
17-18. *Callaiosphaeridium asymmetricum* (Deflandre & Courteville) Davey & Williams *in* Davey *et al.* 1966, Slide No. BSIP 11509; coordinates 15·5 x 153·5.
19. *Florentinia deanei* (Davey & Williams) Davey & Verdier 1980. Slide No. BSIP 11516; coordinates 8·0 x 144·0.

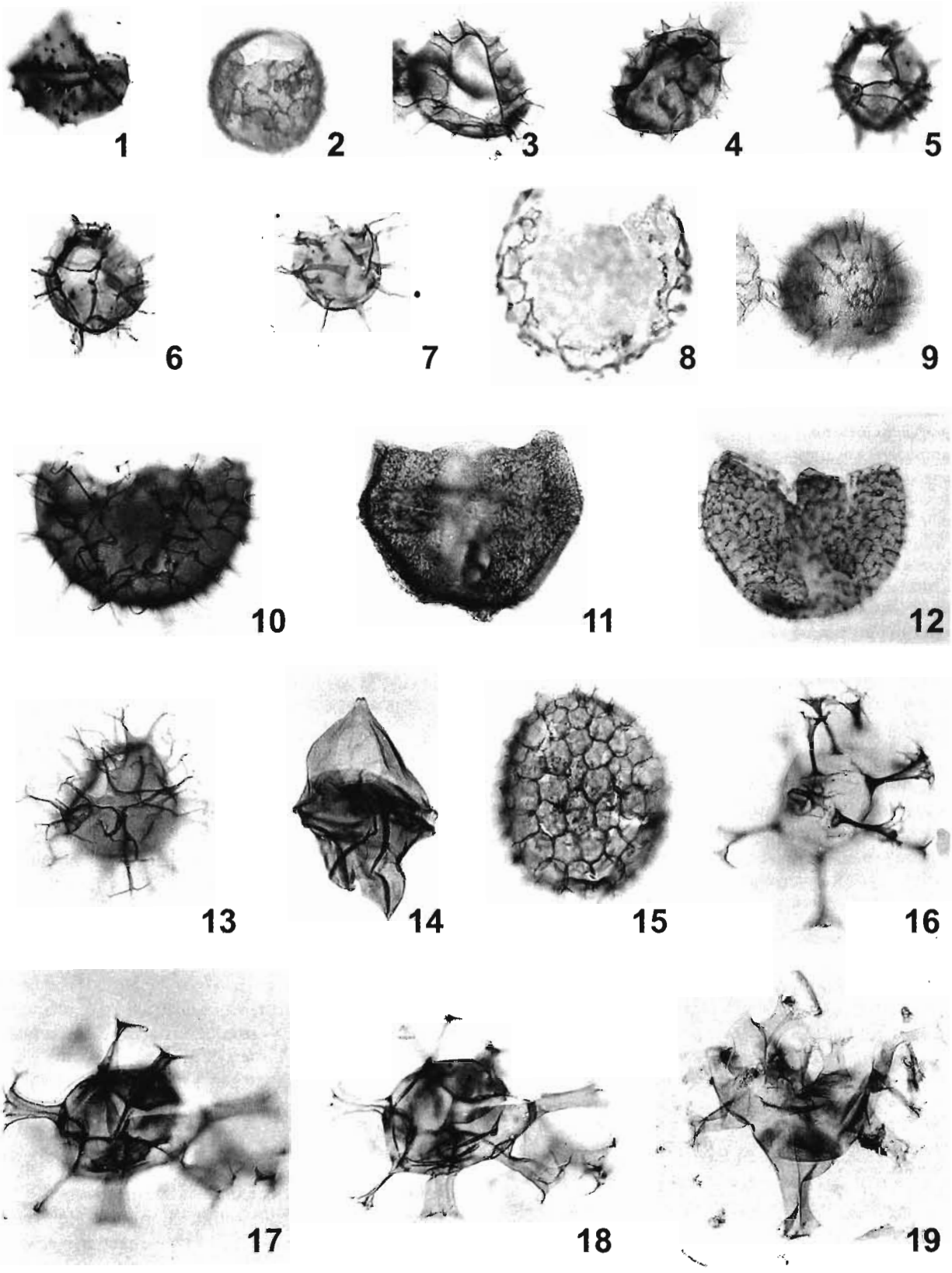


PLATE 1

Dinoflagellate cyst Taxa	Sample KAL 6	CH 5	KU 6	KU 8	ANP 2	KN 1
Spiniferites ramosus sub sp. *ramosus*	■	■	■	■	■	■
Achomosphaera sp.	■		■	■		■
Tenua hystrix	■					■
Cyclonephelium vannophorum	■	■	■	■	■	
Oligosphaeridium complex	■	■	■	■	■	
Cauveridinium indicum	■	■	■	■		
Circulodinium distinctum	■	■	■	■		
Xenascus ceratioides	■	■	■	■		
Cribroperidinium cooksoniae	■	■		■		
Cauveridinium intermedium	■			■		
Alterbidinium minus	■	■	■			
Exochosphaeridium phragmites	■	■	■			
Chatangiella sp. A	■	■				
Criborperidinium edwardsii	■	■				
Cyclonephelium chabaca	■	■				
Kiokansium polyps	■	■				
Psaligonyaulax deflandrei	■	■				
Callaiosphaeridium asymmetricum	■					
Chatangiella sp. B	■					
Cleistosphaeridium huguoniotii	■					
Florentinia cooksoniae	■					
Hystrichosphaeridium dupulum	■					
H. recurvatum	■					
Isabelidinium acuminatum	■					
Litosphaeridium siphoniphorum	■					
Oligosphaeridium pulcherrimum	■					
Palaeohystrichophora infusorioides	■					
Pervosphaeridium pseudhystrichodinium	■					
Sepispinula huguoniotii	■					
Spiniferites ramosus gracilis	■					
Trichodinium castanea	■					
Cyclonephelium compactum		■	■	■		
Spiniferites porosus		■	■	■		
Conosphaeridium striatoconus		■		■		
Hystrichodinium pulchrum		■		■		
Dioxya armata		■	■			
F. mantellii		■	■			
Heterosphaeridium difficile		■	■			
Coronifera tubulosa		■				
Diconodinium multispinosum		■				
Hapsocysta peridictya		■				
Meiourogonyaulax bulloidea		■				
Subtilisphaera ? habibii		■				
Achomosphaera ramulifera			■	■	■	■
Coronifera oceanica			■	■		■
Cribroperidinium sp.			■	■		
Florentinia deanei			■	■		
Palaeoperidinium cretaceum			■	■		
Aiora fenestrata			■			
Alterbidinium acutulum			■			
A. papillatum			■			
Cassiculosphaeridia sp.			■			
Cassiculosphaeridia reticulata			■			
Cribroperidinium aceras			■			
Florentinia buspina			■			

Fig. 5—Stratigraphic distribution of dinoflagellate cyst taxa; see Fig. 3 for sample locations.

Anaipadi-Sattambadi and Garudamangalam-Sardamangalam in the south.

MATERIAL AND METHODS

In order to cover the entire succession as well as to document the lithological variations and nature of contacts, the following traverses were undertaken along and across the strike : Kallakudi – Arogyapuram – Tappy – Siruvayalur; Karai – Kulakkalnattam – Aynapuram – Anaipadi – Garudamangalam; Chittali – Odiyam – Kunnam; Kunnam – Odiyam – Mungalpari; Kalpadi – Kunnam – Varagur – Paravay – Vayalpadi.

More than 200 samples for palynological studies were systematically collected from several sections exposed along *nala* cuttings, hillocks, road cuttings, ponds and dug-wells. A composite lithological log indicating the positions of the productive samples is given in Fig. 3.

Standard palynological techniques were used to recover the dinoflagellate cysts. Samples were treated with HCL and HF and the organic matter recovered oxidised using 40% HNO_3. A 20 µm sieve has been used for washing purposes. The residue was stained with safranine and the permanent slides were prepared using polyvenyl alcohol and Canada balsam. Specimens were photographed using an Olympus BH2 microscope. The slides have been registered and deposited in the repository of the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow, U.P., India.

AGE OF KULAKKALNATTAM SANDSTONE MEMBER, GARUDAMANGALAM FORMATION

The age of the Garudamangalam Formation (*ex* Trichinopoly Group, Trichinopoly Stage, Trichinopoly Formation) has been a matter of controversy since the time of Blanford (1865), despite its fossiliferous nature. The formation is rich in molluscs, including ammonites, which form the main basis for most of the evidence of age determination. There is not much microfossil evidence from surface deposits. A lack of datable plankton and ammonites in the basalmost part of the formation (comprising conglomerate or concretionary calcareous sandstone) has further compounded the situation. Our study is, however, based on precisely datable dinoflagellate cyst assemblages recovered from the lower part of the Garudamangalam Formation.

Different workers have assigned different ages to the Garudamangalam Formation from time to time. A Middle Turonian – Early Senonian age-range was first determined on the ammonite evidence (Kossmat, 1895, 1898 *in* Sastry *et al.*,1968; Pascoe, 1959). Pascoe (1959, p. 1223, 1240) pointed out that the lower part of the Trichinopoly Stage (Garudamangalam Substage) is characterised by the ammonite *Pachydiscus peramplus* and occupies the bulk of Turonian, "representing all but the lower portion of Turonian". This conclusion was also derived from the fact that the uppermost beds of the underlying Uttatur Stage (now Karai Shale) were dated as Early Turonian on ammonite (*Mammites conciliatum*) and inoceramid (*Inoceramus labiatus*) evidence (see Pascoe, 1959; p. 1233). An Ammonite biozonation of the formation was subsequently proposed by Sastry *et al.* (1968); this comprised, in ascending order, *Lewesiceras raju* (Middle – Upper Turonian), *Kossmaticeras theobaldianum* (upper most Turonian-Coniacian) and *Placenticeras tamulicum* zones (Santonian). According to Chiplonkar and Ghare (1979) *Kossmaticeras theobaldianum* Zone does not appear to be a distinct zone including it in the *Proplacenticeras* (*Placenticeras*) *tamulicum* Zone suggesting a Late Turonian – Coniacian age. It is pertinent to note here that Chiplonkar and Phansalkar (1976) and Phansalkar and Kumar (1983) reported the ammonites *Romaniceras ornatissimum* and *R. deverianum* from the lower part of the formation. These can be correlated with the uppermost Middle Turonian – basal Upper Turonian ammonite *Ornatissimum* and *Deverianum* zones of the Type Turonian of France (see Robazynski *et al.*,

1982; p. 136, fig. 7; Haq *et al.*, 1988). All of the above suggest that the Garudamangalam Formation is Middle Turonian – Coniacian in age as favoured by Acharyya and Lahiri (1991, p. 6) on ammonite and inoceramid evidence. Chiplonkar & Tapaswi (1979), however, assigned Late Turonian – Santonian age, based on inoceramids. More recently Hart *et al.* (1996) and Tewari *et al.* (1996) have suggested a Late Turonian – Coniacian age-range for the formation. They reported a planktonic foraminiferal assemblage containing *Whiteinella archaeocretacea* and *Praeglobotruncana helvetica* from the underlying Karai Shale and dated it as early Middle Turonian. Similar assemblages were reported by Govindan *et al.* (1996) also from surface and subsurface sections. Hart *et al.* (1996) interpreted a major regression event towards the top of Karai Shale as a sudden replacement of the planktonic foraminiferal fauna by a dominantly agglutinated microfauna was considered to be indicative of rapid shallowing. They further concluded that the nodular/concretionary calcareous sandstone beds at the base of Garudamangalam Formation formed during a Late Turonian transgressive event that is recognisable over much of the globe. It was thus interpreted as a succession of Late Turonian – Coniacian age with its base constituting a sequence boundary caused by forced regression.

Ramanathan (1968) and Sastry *et al.* (1981) indicated that rocks of Garudamangalam Formation are difficult to recognise in the subsurface. Based on planktonic foraminiferal studies of subsurface sections, a major hiatus within the Upper Turonian has recently been identified (Govindan *et al.*, 1996; Raju & Ramesh, 1998). Although, Govindan *et al.* (1996, p. 168) suggested that the unfossiliferous deposits above the *Praeglobotruncana helvetica* Zone (Early – Middle Turonian) may represent the Upper Turonian sediments in the outcrop area, they still favoured a Coniacian – Santonian age for the Trichinopoly Group (see Govindan *et al.*, 1996, figs 4, 11). The occurrence of distinctive Middle – Late Turonian ammonite assemblages, noted above, have probably not been given due consideration. Against this background information, recovery of Middle – Late Turonian dinoflagellate cysts from out crop succession is highly significant.

Palynological assemblages recovered from the Kulakkalnattam Sandstone Member are rich and well preserved. They are dominated by dinoflagellate cysts, spores and pollen grains, and terrestrial organic matter. Dinoflagellate cysts are represented by 68 species (see Fig. 4) and show remarkable changes in their vertical distribution, with distinctive assemblages occurring at different stratigraphic levels (Fig. 5). A comparison of the assemblage overall with that of the type region of the Turonian of France (Robaszynski *et al.*, 1982) shows close resemblance with taxa. The following taxa are common to both regions thus supporting Turonian age for Kulakkalnattam Sandstone Member : *Callaiosphaeridium asymmetricum, Cassiculosphaeridia* spp., *Circulodinium distinctum, Coronifera oceanica, Cyclonephelium vannophorum, Exochosphaeridium phragmites, E. pseudhystrichodinium* (*Pervosphaeridium pseudhystrichodinium*), *Florentinia deanei, F. mantellii, Heterosphaeridium difficile, H. heteracanthum, Kiokansium polyps, Litosphaeridium siphoniphorum, Odontochitina operculata, Oligosphaeridium complex, O. pulcherrimum, Palaeohystrichophora infusorioides, Psaligonyaulax deflandrei, Spiniferites ramosus gracilis, S. ramosus ramosus, Trichodinium castanea* and *Xenascus ceratioides. Conosphaeridium striatoconus, Heterosphaeridium difficile* (First appearance datum for both FAD) at the base of Middle

PLATE 2

(All photomicrographs in DIC x 500)

1. *Palaeohystrichophora infusorioides* Deflandre 1935, Slide No. BSIP 10262; coordinates 19·3 x 152·9.
2. *Trichodinium castanea* (Deflandre) Clarke & Verdier 1967, Slide No. BSIP 11502; coordinates 17·6 x 131·0.
3. *Subtilisphaera habibii* Masure 1988, Slide No. BSIP 10263; coordinates 11·6 x 124·2.
4. *Cleistosphaeridium huguoniotii* (Valensi) Davey 1969, Slide No. BSIP 11502; coordinates 17·0 x 139·4.
5. *Miourogonyaulax bulloidea* (Cookson & Eisenack) Sarjeant 1969, Slide No. BSIP 11494; coordinates 15·4 x 120·9.
6. *Cauveridinium indicum* Khowaja-Ateequzzaman & Jain 1990, Slide No. BSIP 10273; coordinates 3·0 x 146·9.
7. *Chatangiella* sp. B. Slide No. BSIP 11507; coordinates 9·6 x 166·1.
8. *Spiniferites ramosus* sub sp. *gracilis* (Davey & Williams) Lentin & Williams 1973, Slide No. BSIP 11509; coordinates 11·6 x 138·0.
9. *Coronifera tubulosa* Cookson & Eisenack 1974, Slide No. BSIP 11503; coordinates 18·3 x 140·0.
10. *Kiokansium polyps* (Cookson & Eisenack) Below 1982, Slide No. BSIP 11500; coordinates 16·6 x 163.
11. *Pervosphaeridium pseudhystrichodinium* (Deflandre) Yun 1981, Slide No. BSIP 11510; coordinates 16·6 x 142·0.
12. *Xiphophoridium alatum* (Cookson & Eisenack) Sarjeant 1966, Slide No. BSIP 11504; coordinates 5·5 x 137·4.
13. *Cyclonephelium vannophorum* Davey 1969, Slide No. BSIP 11498; coordinates 11·0 x 148·2.
14. *Coronifera oceanica* Cookson & Eisenack 1958 emend. May 1980, Slide No. BSIP 11513; coordinates 11·7 x 156·8.
15. *Litosphaeridium siphoniphorum* (Cookson & Eisenack) Davey & Williams 1966 emend. Lucas-Clark 1984, Slide No. BSIP 11506; coordinates 7·4 x 156·7.
16. *Tenua hystrix* Eisenack 1958, Slide No. BSIP 11503; coordinates 13·6 x 128·4.
17-18. *Xenascus ceratioides* (Deflandre) Lentin & Williams 1973; (17) Slide No. BSIP 11515; coordinates 20 x 144·2; (18) Slide No. BSIP 11513; coordinates 12·5 x 127·4.
19. *Cyclonephelium vannophorum* Davey 1969, Slide No. BSIP 11496; coordinates 17·4 x 161·5.
20. *Hapsocysta peridictya* (Eisenack & Cookson) Davey 1979. Slide No. BSIP 11516; coordinates 17·4 x 161·5.

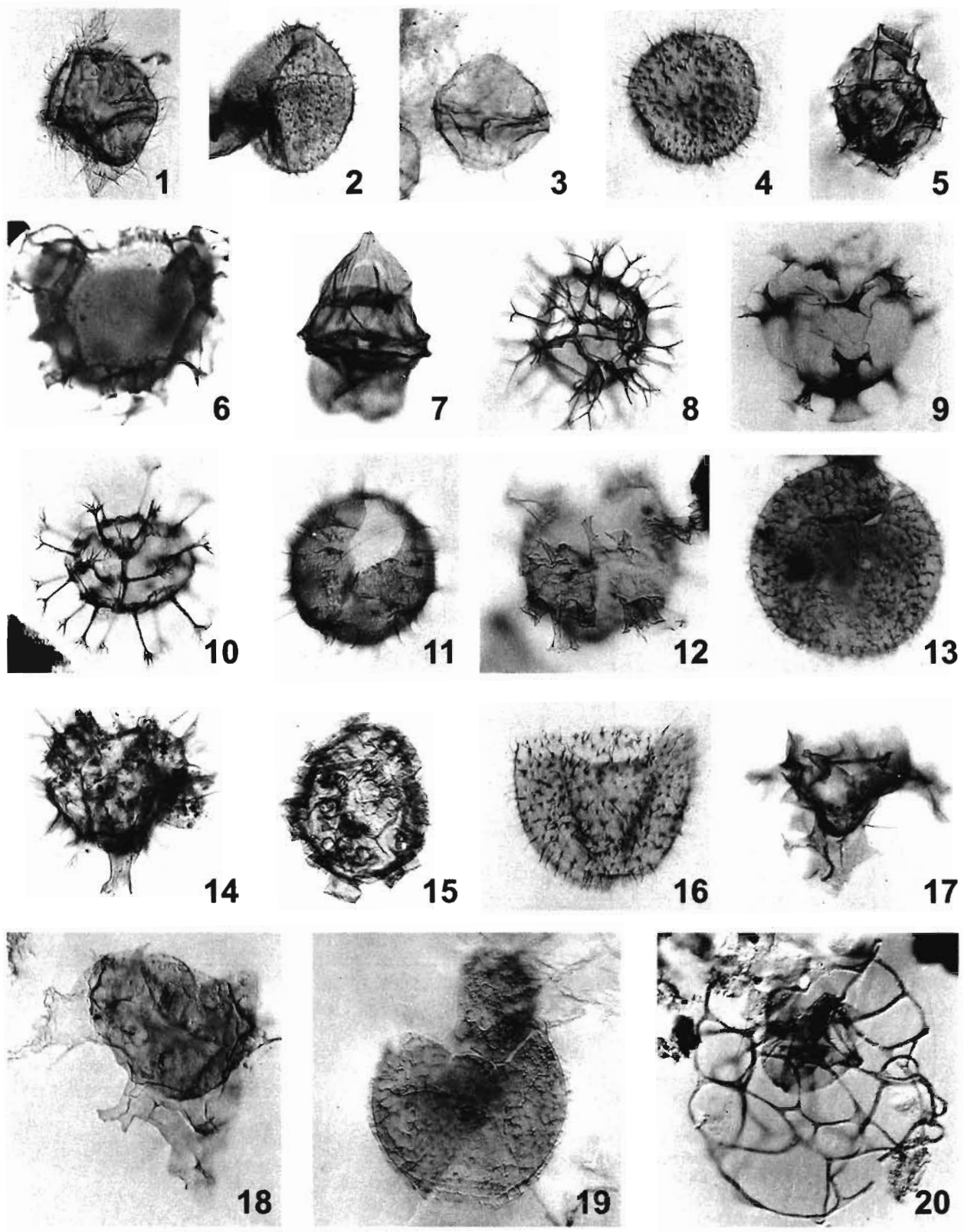


PLATE 2

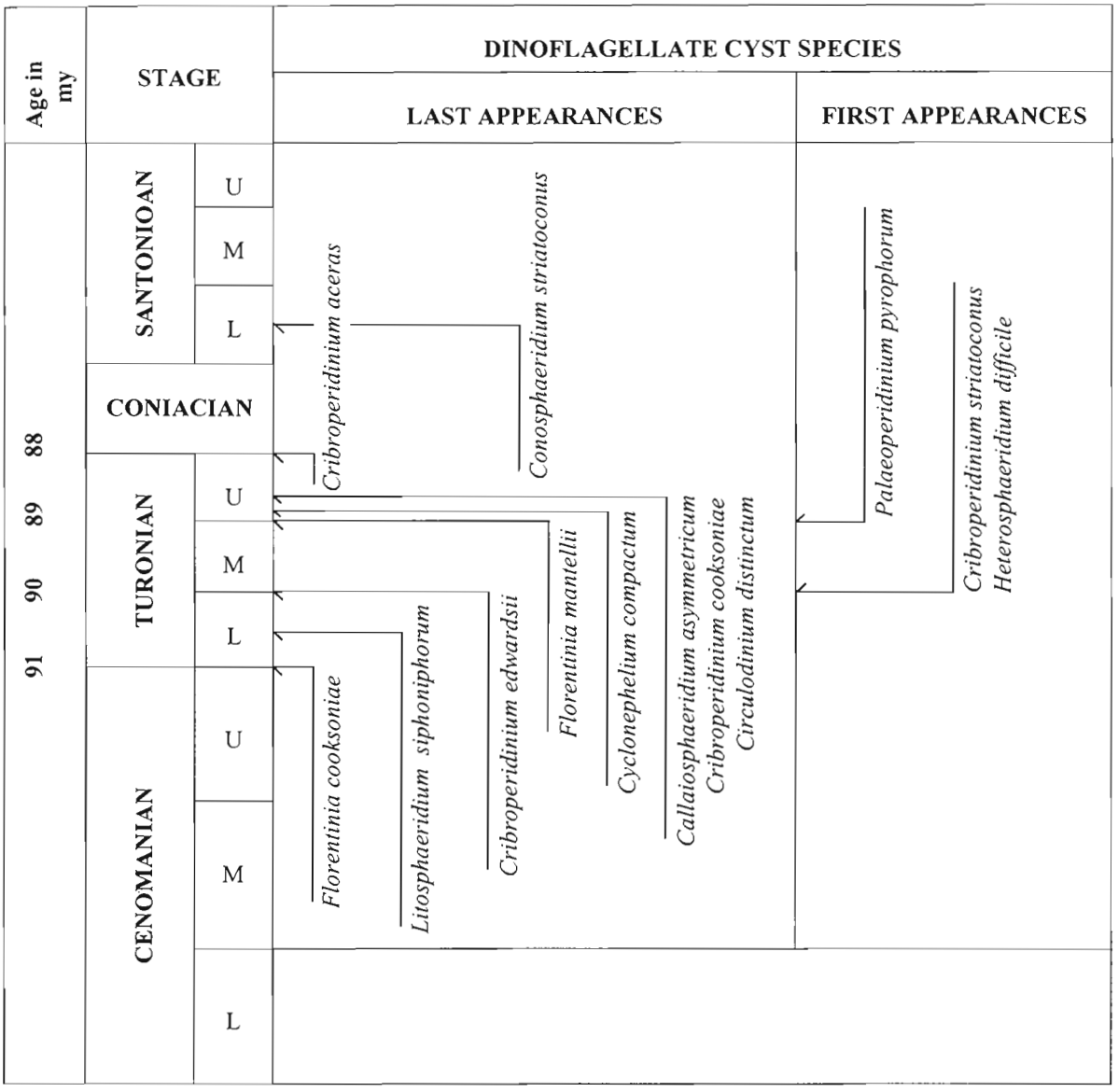
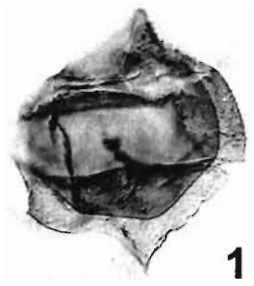


Fig. 6—First and last appearance (FAD & LAD) of significant dinoflagellate cyst taxa (Ranges after : Powell, 1992; Prossl, 1990; Stover *et al.*, 1996; Williams *et al.*, 1993).

PLATE 3

(All photomicrographs in DIC x 500)

1. *Alterbidinium papillatum* Khowaja-Ateequzzaman *et al.* 1990, Slide No. BSIP 10263; coordinates 7·6 x 128·2.
2,13,16. *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant 1967, Slide No. BSIP 11521; coordinates (2) 13·4 x 146·5 (16) 16·3 x 127·2 (13) Slide No. BSIP 11519; coordinates 9·0 x 154·2.
3. *Palaeoperidinium cretaceum* Pocock 1962 emend. Davey 1970, Slide No. BSIP 11517; coordinates 9·7 x 149·7.
4. *Cribroperidinium* sp., Slide No. BSIP 11503; coordinates 11·5 x 167·8.
5,12. *Alterbidinium minus* (Alberti) Lentin & Williams 1985, Slide No. BSIP 10263; coordinates (5) 11·5 x 167·8, (12) 5·4 x 143·6.
6. *Subtilisphaera habibii* Masure 1988, Slide No. BSIP 10263; coordinates 14·6 x 131·6.
7-8. *Circulosphaeridium distinctum* (Deflandre & Cookson) Jansonius 1986; (7) Slide No. BSIP 11503; coordinates 15·3 x 133·4, (8) Slide No. BSIP 11508; coordinates 10·2 x 133·7
9-10. *Pterodinium aliferum* Eisenack 1958 emend. Sarjeant 1985, (9) Slide No. BSIP 11495; coordinates 22·8 x 155·0, (10) Slide No. BSIP 11501, coordinates 12·5 x 128·2.
11. *Heterosphaeridium difficile* (Manum & Cookson) Ioannides 1986, Slide No. BSIP 11512; coordinates 9·6 x 155·3.
14. *Florentinia buspina* (Davey & Verdier) Duxbury 1980, Slide No. 11520; coordinates 22·2 x 163·3.
15. *Aiora fenestrata* ((Deflandre & Cookson) Cookson & Eisenack 1960, Slide No. BSIP 11494; coordinates 14·6 x 130·7.
16. *Cribroperidinium edwardsii* (Cookson & Eisenack) Davey 1969, Slide No. BSIP 10263; coordinates 9·7 x 123·2.
18. *Florentinia* sp., Slide No. BSIP 11514; coordinates 5·8 x 142·5.
19. *Cribroperidinium aceras* (Eisenack) emend. Sarjeant 1985, Slide No. BSIP 11506; coordinates 22·8 x 124·1.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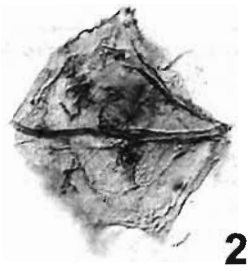
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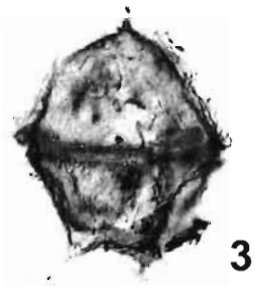
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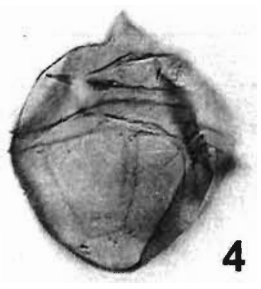
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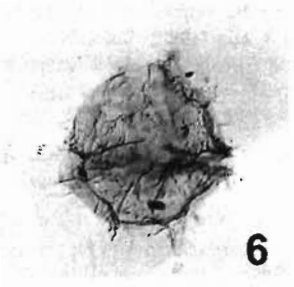
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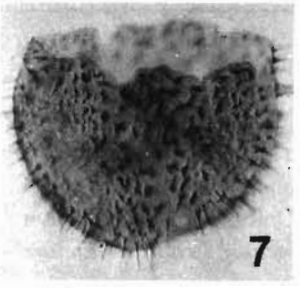
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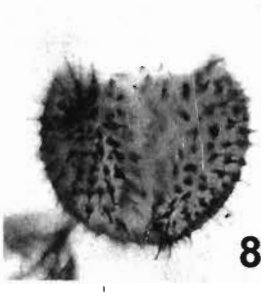
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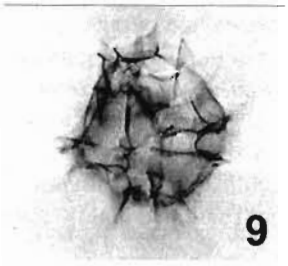
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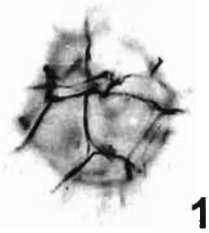
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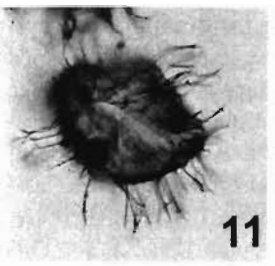
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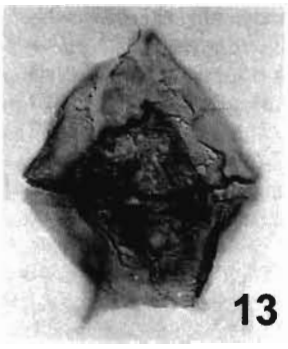
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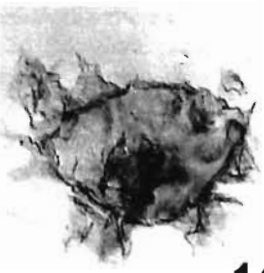
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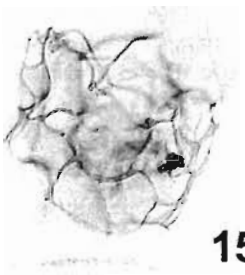
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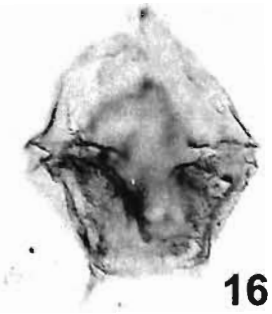
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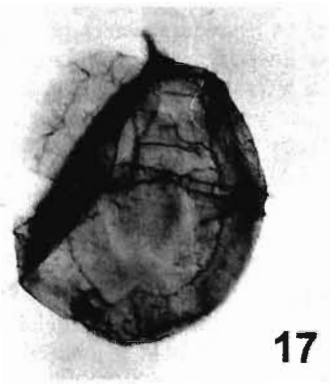
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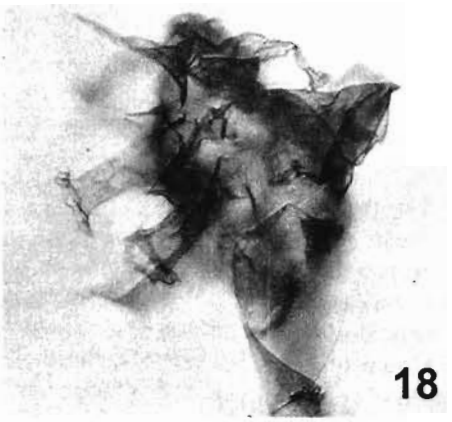
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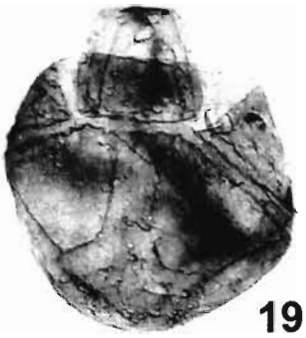
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PLATE3

Taxa	Occurrence (sample no.)	Previous age determination	Revised age
Cauveridinium indicum	KAL6, CH5, KU6, KU8	Turonian-Santonian	E. to M. Turonian
C. intermedium	KAL6, KU8	Turonian-Santonian	E. to M. Turonian
C. longispinosum	KU8	Turonian-Santonian	Late Turonian
Alterbidinium papillatum	KU6	Turonian-Santonian	Middle Turonian
A. acutulum	KU6	Turonian-Santonian	Middle Turonian
A. minus	KU6, CH5, KL6	Turonian-Santonian	E. to M. Turonian
Jainiella breviornata	KAL6, CH5, KU6	Late Cretaceous	Middle Turonian

Fig. 7—Revised ages for the taxa earlier described by Khowaja-Ateequzzaman & Jain (1990), Khowaja-Ateequzzaman *et al.* (1991) and Khowaja-Ateequzzaman & Garg (1995), from Kulakkalnattam Sandstone Member of the Garudamangalam Formation.

Turonian, *Florentinia mantellii* (Last appearance datum LAD) at top of Middle Turonian; *Palaeoperidinium pyrophorum* (FAD at the base of Late Turonian), and *Callaiosphaeridium asymmetricum, Circulodinium distinctum, Cribroperidinium aceras, C. cooksoniae* and *Cyclonephelium compactum* (LADs within or at the top of Late Turonian) clearly suggest a Middle – Late Turonian age-range for dinoflagellate cyst assemblage, except for the lowermost assemblage recovered from sample KAL 6 (Figs 5, 6). Dinoflagellate cyst assemblage recovered from this particular sample indicates a latest Cenomanian – Early Turonian age due to the presence of *Cribroperidinium edwardsii, Florentinia cooksoniae* and *Litosphaeridium siphoniphorum* having LADs at the base, within or at the top of Lower Turonian (Figs 5, 6). This calcareous shale samples represents reworking of the underlying Karai Shale in the basal conglomeratic or concretionary sandstone beds of the Garudamangalam Formation. Several samples collected from the Karai Shale, however, proved unproductive of dinoflagellate cysts, possibly due to preservation factors.

Kale and Phansalkar (1992) assigned the youngest nannofossil assemblage from the Karai Shale to the *Quadrum gartneri* Zone (CC11), based on the first occurrence of the nominate taxon. They pointed out, however, that the top of the zone is not observed in the Uttatur Group and dated the basal part of the Garudamangalam Formation as late Middle Turonian (Kale & Phansalkar, 1992, figs 3-4). It is pertinent to note that the FAD of *Quadrum gartneri* predates the FAD of ammonite *Romaniceras ornatissimum,* which lies within the upper Middle Turonian (Robazynski *et al.,* 1982; Haq *et al.,* 1987). The occurrence of typical Middle Turonian dinoflagellate cyst assemblages from the lower part of the Kulakkalnattam Sandstone Member (samples CH5, KU6) underlying the typical shell-rich calcareous sandstone ("Shell Limestone") is, therefore, quite significant in this context. It agrees well with the ammonite evidence and indicates that the hiatus between deposition of the Karai Shale Formation and the Garudamangalam Formation may have been of extremely short duration. Furthermore, the Late Turonian transgressive event at the base of the Garudamangalam Formation may actually be slightly older, i.e., late Middle Turonian. Dinoflagellate cysts also provide convincing evidence for the presence of Upper Turonian sediments in the outcrop succession.

Khowaja-Ateequzzaman and Jain (1990), Khowaja-Ateequzzaman *et al.* (1991) and Khowaja-Ateequzzaman and Garg (1995) described some dinoflagellate cyst taxa from Kulakkalnattam Sandstone Member of the Garudamangalam Formation viz., *Alterbidinium acutulum, A. minus, A. papillatum, Cauveridinium indicum, C. intermedium, C. longispinosum,* and *Jainiella breviornata.*

The ages assigned in these publications are revised in Fig. 7 in the light of the observations presented in this paper.

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