Late Cretaceous to Early Tertiary dinoflagellate cysts from the Krishna-Godavari basin—cyst morphology and review of biostratigraphical dating

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A restudy of some of the dinoflagellate type material of our earlier work (Mehrotra & Sarjeant, 1987) from well Narasapur-1, Krishna-Godavari Basin has been undertaken, in order to clear up some confusion created by the comments of Garg *et al.* (1995). The validity of *Fibrocysta variabilis* as a distinct species is amply demonstrated by further elaborating on its morphological characters, with the aid of some additional specimens from the Narasapur assemblage. *Fibrocysta sp.* is tentatively retained in this genus, till further specimens permit fuller understanding of its morphology. Our earlier age assignments of samples at various stratigraphic intervals-Late Cretaceous (Maastrichtian: 3621-3624 m, 3643-3649 m, CC-13) and Paleocene (now further refined to Thanetian: 2703-2706 m; including part of CC-10 at 2703 m)-are reaffirmed, utilizing additional information concerning the global ranges of other dinoflagellate species. Data on microforaminifera, spores and pollen are also presented, conforming with and strengthening these dates.

Key-words—Dinoflagellate cysts, *Fibrocysta variabilis*, Biostratigraphy, Krishna-Godavari basin.

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सारॉंश

कृष्णा–गोदावरी द्रोणी से प्राप्त अन्तिम क्रिटेशस से प्रारंभिक टर्शियरी युगीन घूर्णीकशाभ पुटियों का पुटीय संरचनात्मक अध्ययन तथा जैवस्तरिकीय कालनिर्धारण का पुनर्विवेचन

नरेश चन्द्र मेहरोत्रा एवं विलियम ए.एस. सार्जेन्ट

नरसापुर कूप–1, कृष्णा–गोदावरी द्रोणी से प्राप्त कुछ घूर्णीकशाभयुक्त पदार्थ प्ररूप के हमारे द्वारा किए गए पूर्व अध्ययन (मेहरोत्रा एवं सार्जेन्ट, 1987) का पुनः विश्लेषण किया गया, ताकि इस दिशा में गर्ग आदि द्वारा सन् 1995 ई. में उठाए गए सन्देहों का निराकरण किया जा सके। नरसापुर समुच्चय से एकत्र किए गए कुछ अतिरिक्त प्रादर्शों के संरचनात्मक गुणों का विश्लेषण किया गया और इस आधार पर दुर्लभ प्रजाति *'फाइब्रोसिस्टा वेरियेबिलिस'* की प्रामाणिकता को पर्याप्त ढंग से विश्लेषित किया गया। जब तक अन्य प्रादर्शों से इसकी संरचना के विषय में पूर्ण जानकारी नही प्राप्त हो जाती, तब तक फिलहाल इसे इस प्रजाति के अन्तर्गत रखा गया। अन्य घूर्णीकशाभयुक्त प्रजातियों की सार्वभौमिक जानकारियों का उपयोग करते हुए हमारे पूर्व अध्ययन के आयु निर्दिष्ट प्रादर्शों के संरचनात्मक अन्तराल का विभिन्न स्तरों पर विश्लेषण किया गया और अन्तिम क्रिटेशस (मास्ट्रिख्टयन, 3621–3624 मी., 3643–3649 मी. सी सी–13) तथा पैलियोसीन (अब पुनः परिष्कृत थैनेटियन 2703–2706 मी; सी सी–10 का 2703 मी. पर मिलने वाला भाग सम्मिलित) युग में इसकी पुनः पुष्टि की गई। सूक्ष्म छिद्रयुक्त प्रजातियों (माइक्रोफोरैमिनीफेरा,), बीजाणुओं एवं परागकणों के आँकड़े भी प्रस्तुत किए गए है; जो इन कालनिर्धारणों के समानुरूप है तथा इनकी अभिपुष्टि करते हैं।

HISTORICAL BACKGROUND

THE first detailed morphological accounts of Late Cretaceous-Early Palaeogene dinoflagellate cysts from the Indian subcontinent were given in a series of papers by Mehrotra and Sarjeant (1984a-c, 1986, 1987). In 1987, we reported rich dinoflagellate cyst assemblages from a number of stratigraphic levels in exploratory well Narasapur-1; this was drilled by ONGC Ltd. in connection with its oil exploration programme in the Krishna-Godavari Basin. The well location is shown in Mehrotra and Sarjeant (1987, Fig. 1).

This well had been earlier studied by Venkatachala and Sharma (1984) for spores and pollen; they examined the complete subsurface sequence (0-4032 m) and identified ten palynozones (Late Cretaceous-Miocene). Our own studies focussed on describing in detail the morphology of some of the significant dinoflagellate cyst types present, with interpretation of their age. Four cores and sixteen cuttings samples

were examined, from depths between 1250-4016 m. Out of these, intervals 3643-3649 m-CC13; 3621-3624 m; and 2703-2706 m (including part of CC-10 at 2703 m) were found to be rich in dinoflagellates, a partial description being published (Mehrotra & Sarjeant, 1987). As we stated clearly (Mehrotra & Sarjeant, 1987, p. 151, paragraph 4), that paper did not not fully represent the dinoflagellate biostratigraphy of this well. With the continuing exploration thrust in the Krishna-Godavari Basin, detailed work, including further studies of well Narasapur-1, is still proceeding in the Palynology Laboratory of the K.D. Malaviya Institute of Petroleum Exploration, Oil and Natural Gas Corporation Ltd., Dehra Dun. The publication of further results concerning the morphology of various cyst types, together with further biostratigraphic and palaeoenvironmental interpretations, is planned in due course.

This research note was prepared specifically to answer some of the queries raised by Garg *et al.* (1995), in a paper which seems to have created some confusion. Those authors commented mainly upon the validity of our new species *Fibrocysta variabilis* and the form we named *Fibrocystsa* sp.; they claimed that these were junior synonyms respectively of *Apectodinium paniculatum* (Costa and Downie) Lentin and Williams 1977 and *A. quinquelatum* (Williams & Downie) Lentin and Williams 1981 and that we had misdated our samples. These are claims which require to be firmly refuted.

Before we begin dealing with those allegations, a brief account of stratigraphy of the Krishna-Godavari Basin is given. The earlier lithostratigraphic work in this basin was quite briefly presented (Govindan, 1984). Utilizing the wealth of information derived from more than 200 drilled wells, the lithostratigraphy of the Krishna-Godavari Basin has been much more fully dealt with in an internal document of ONGC Ltd. by Venkatarengan *et al.* (1993). A standard lithostrati-graphic nomenclature for the sediments encountered above the Pre-Cambrian basement rocks was established, as follows: Lower Gondwana; Upper Gondwana (Nizampatnam Group); Gudivada Group (Early-Late Cretaceous); Vasishta Group (Basaltic Trap and post-Trappean sequence-Paleocene through Miocene); and Gowthami Group (Miocene-Recent).

In the Narasapur area, Gondwana sediments are not present, the Upper Cretaceous shales resting unconformably on the Precambrian basement. The lithostratigraphic succession met with in well Narasapur-1, based on Venkatarengan *et al.* (1993), is given in Figure 1.

MORPHOLOGICAL OBSERVATIONS

Mehrotra and Sarjeant (1987, p.155) reported a rich occurrence of the genus *Fibrocysta* at stratigraphic levels 3621-3624 m and 2703-2706 m (including part of CC-10 at 2703 m). A new species, *F. variabilis*, was proposed for forms exhibiting variable distal terminations of the processes-bifid, trifid, cruciferate, cauliflorate, denticulate, serrate, recurved or secate. As noted above, Garg *et al.* (1995) considered that species to be a junior synonym of *Apectodinium paniculatum* (Costa and Downie) Lentin & Williams, 1977.

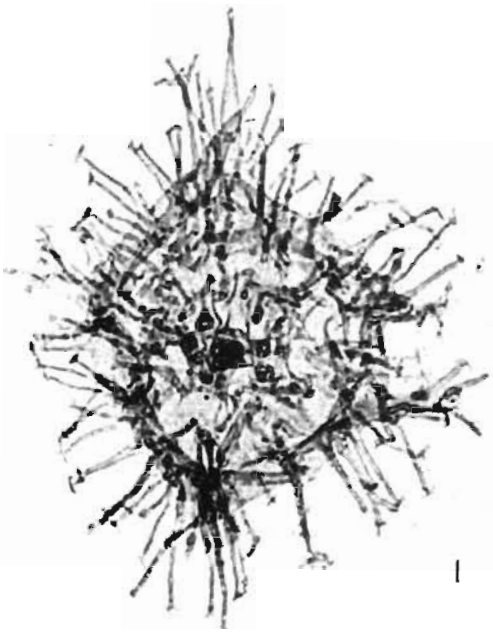
In order to confirm our previous observations, a restudy of the type material, housed at K.D. Malaviya Institute of Petroleum Exploration, Dehra Dun, was undertaken by one of us (N.C.M.). A number of additional specimens were examined and are illustrated herein, along with new illustrations of the holotype

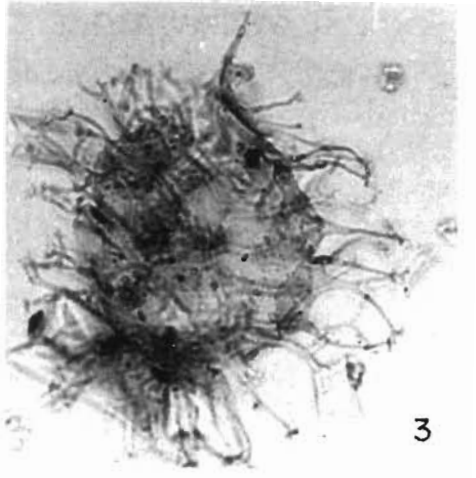
PLATE 1

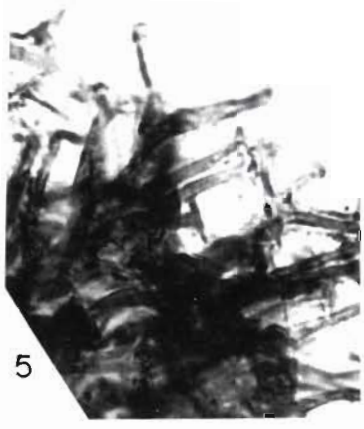
All photomicrographs taken in transmitted light, except figure 7, taken in phase contrast.

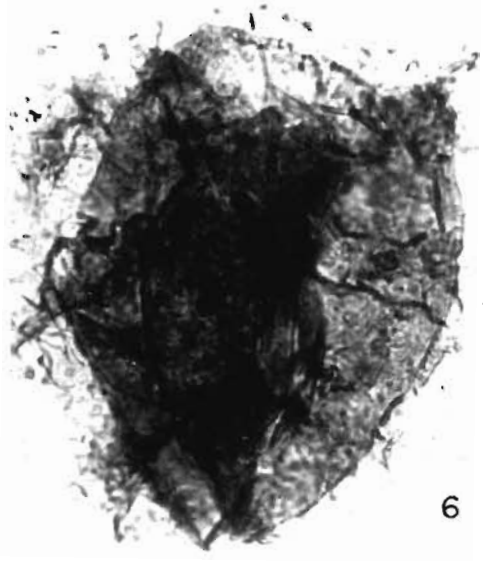
Figs. 1-5, 7 *Fibrocysta variabilis* Mehrotra and Sarjeant 1987. (1) Holotype. Slide IPEP/NSP-1/3621/2 (3621-3624 m). Coordinates: 52 x 106. Magnification x 640. (2, 4-5) Specimen on slide IPEP/NSP-1/2703/2 (2703-2706 m). Coordinates: 44 x 109. Magnifications: (2) x 768, (4-5) x 1200. (2) is the complete specimen with a prominent trifurcate apical process, each branch having an evexate termination; (4) is an enlarged view of the apical process; (5) is an enlarged view of a trifurcate process in the cingular region, the branches having secate terminations. (3, 7) Paratype A. Slide IPEP/NSP-1/2703/3 (2703-2706 m). Coordinates: 47.5 x 111. Magnifications: (3) x 640, (7) x 1600. (3) shows the whole specimen; (7) is an enlarged view showing the long, slender apical process with its cauliflorate distal termination, the apical detachment of the precingular operculum, and the development of accessory archaeopyle sutures.

Fig. 6 *Cladopyxidium saeptum* (Morgenroth) Stover and Evitt 1978. Specimen on slide IPEP/NSP-1/3621/2 (3621-3624 m). Coordinates: 51 x 104.5. Magnification x 960.









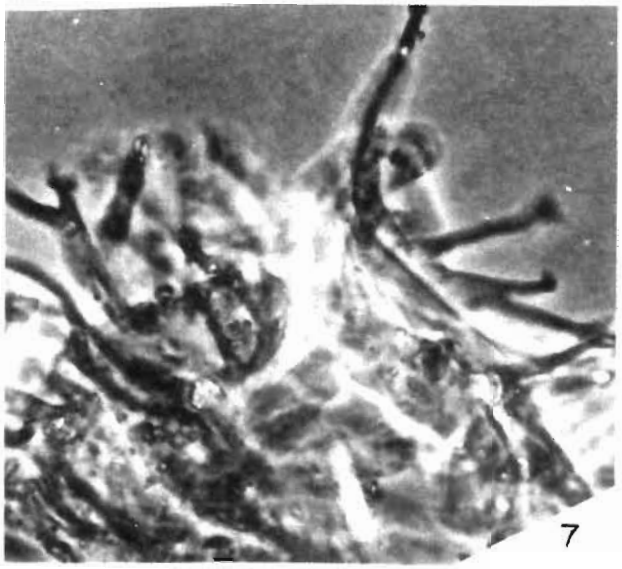


PLATE 1

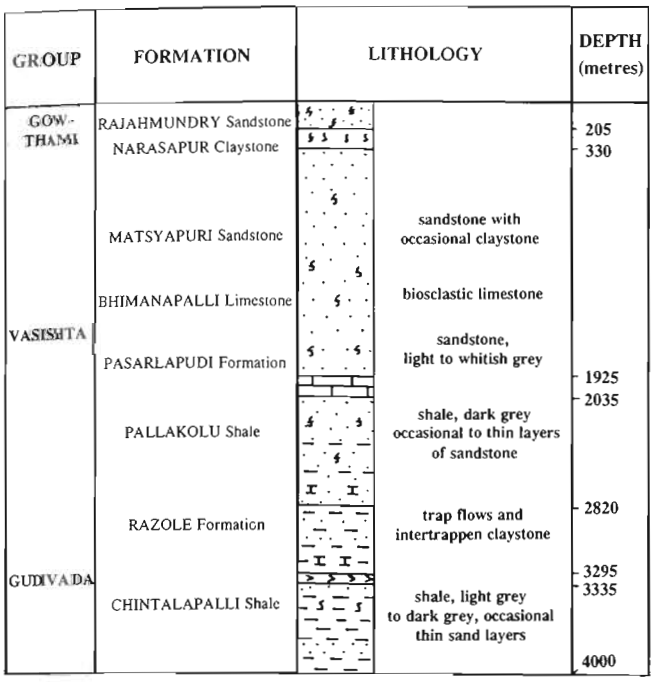


Figure 1.—Lithostratigraphy of well Narasapur-1, Krishna-Godawari basin

and paratypes A and B. The coordinates of these specimens (including the holotype and paratypes A and B of *F. variabilis* Mehrotra and Sarjeant, 1987) are given in the plate explanations.

The following morphological characteristics need to be understood in this context. The ambitus of *F. variabilis* is variable; it may be pentagonal, rounded-pentagonal (holotype: pl. 1, fig. 1: paratype B: pl. 2, fig. 2) or ellipsoidal (pl. 2, figs 4-6). The archaeopyle is precingular (type P), formed by the loss of paraplate 3" (paratype A: pl. 1, fig. 7; pl. 2, fig. 6). However, an archaeopyle cannot always be clearly observed.

The apical and antapical processes in *F. variabilis* are usually the most prominent. Each may arise from a slight to pronounced outbulge of the phragma; one or both processes may be branched. Lateral processes are prominent in some specimens, affording to the cyst a pentagonal to subpentagonal outline.

The nature of the processes in the holotype and in paratypes A and B has already been described and illustrated by us. However, it is again discussed here, along with some additional specimens, to facilitate clearer understanding of the morphologies exhibited by this cyst type.

In the holotype (Plate 1, fig. 1 herein), the apical process is long, with an evexate distal termination which gives rise also to a small bud close to its tip. The antapical process arises from an outbulge of the phragma and is bifid. The cingular region bears a prominent branched process on one lateral margin and two processes, both broad and acuminate, on the other.

Paratype A (Plate 1, figs 3 and 7 herein) shows a distinct precingular archaeopyle. The apical process is long, slender and distally cauliflorate. The antapical process is quite long and distally expanded, with a denticulate margin. The lateral processes are not distinct.

In Paratype B (Pl. 2, fig. 2), the apical process is trifurcate, two of its branches being distally trifid while the third is denticulate. The antapical process is also branched. The lateral processes are again not

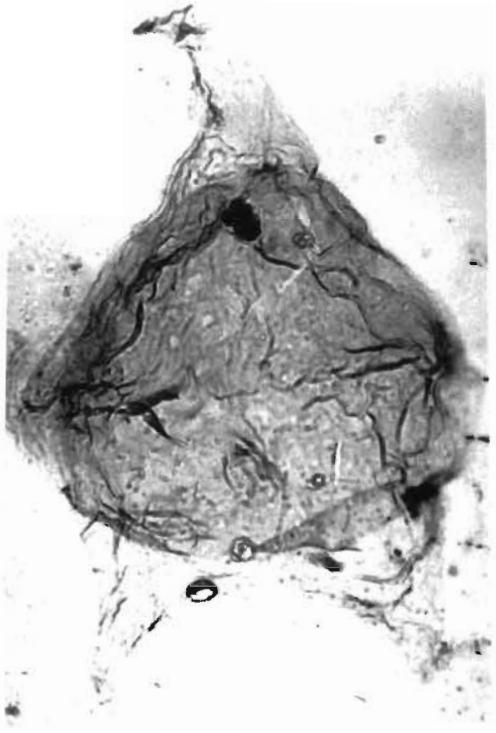
PLATE 2

All photomicrographs taken in transmitted light, coordinates for all figures on Plates 1 and 2 are of the Orthoplan microscope of the Palynology Laboratory, KDMIPE, No. E - 7710-0013.

Fig. 1 *Cerodinium speciosum* (Alberti) Lentin and Williams 1987. Specimen on slide IPEP/NSP-1 /3621/8 (3621-3624 m). Coordinates: 42.5 x 106.5. Magnification x 768.

Figs 2, 4-6 *Fibrocysta variabilis* Mehrotra and Sarjeant 1987. (2) Paratype B. Specimen on slide IPEP/NSP-1/3621/3 (3621-3624 m). Coordinates: 40 x 100. Magnification x 640. Note the branched apical process. (4) Specimen on slide IPEP/NSP-1/2703/2 (2703-2706 m). Coordinates: 46 x 94. Magnification x 960. Note the prominent apical process, distally cauliflorate and the prominent antapical process, secate distally. (5) Specimen on slide IPEP/NSP- 1/2703/2 (2703-2706 m). Coordinates: 44 x 102. Magnification x 960. Note the very prominent, trifurcate apical process, arising from a protuberance (no cavation is discernible, even at the process base); the antapical process is also prominent and branched. Many other processes are branched; processes and process branches may have evexate, secate or cauliflorate distal termination. (6) Specimen on Slide IPEP/NSP-1/2703/2 (2703-2706m). Coordinates: 46.5 x 99. Magnification x 768. Note the long-slender apical process, trifurcate, each branch being evexate distally; the antapical process is very prominent, trifurcate and with evexate distal terminations. The precingular archaeopyle is clearly visible.

Fig. 3 *Apectodinium paniculatum* (Costa and Downie) Lentin and Williams 1977b. Specimen on slide IPEP/NSP-1/2703/2 (2703-2706 m). Coordinates: 51 x 102. Magnification x 960.



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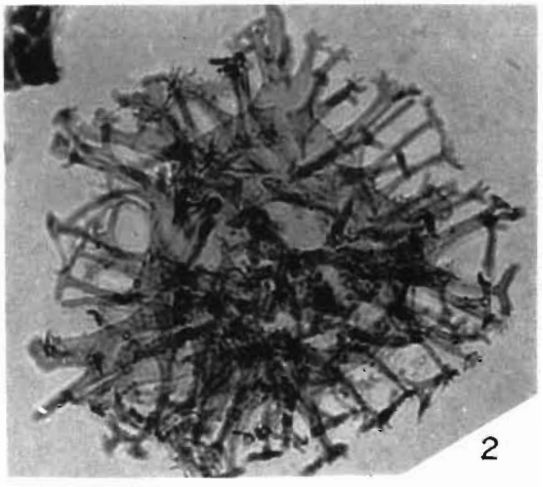

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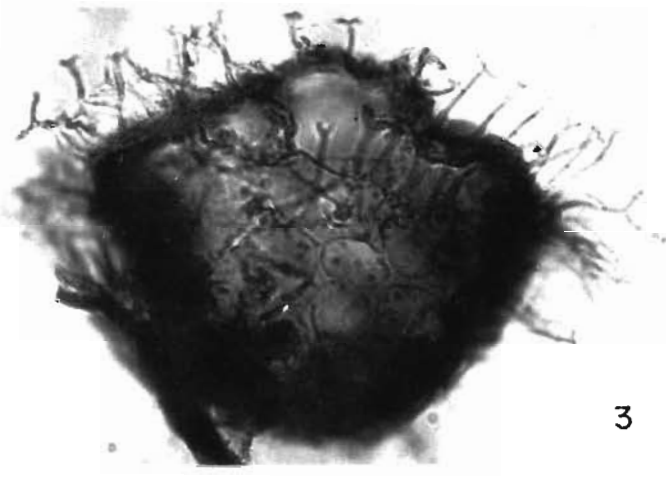

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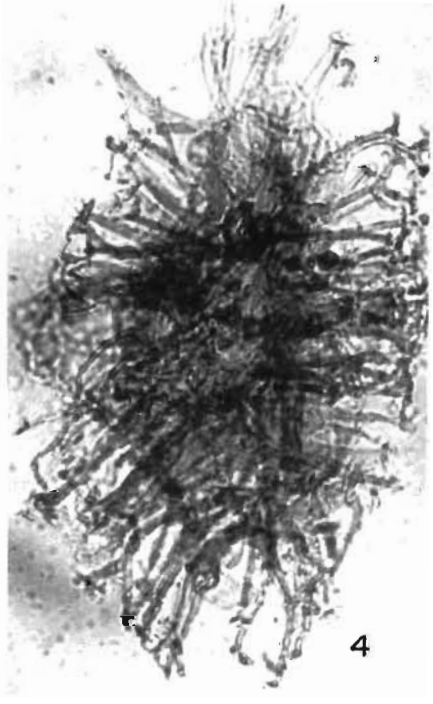

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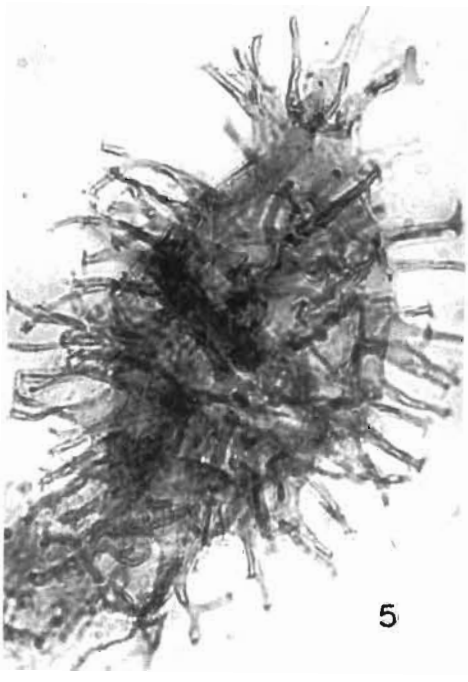

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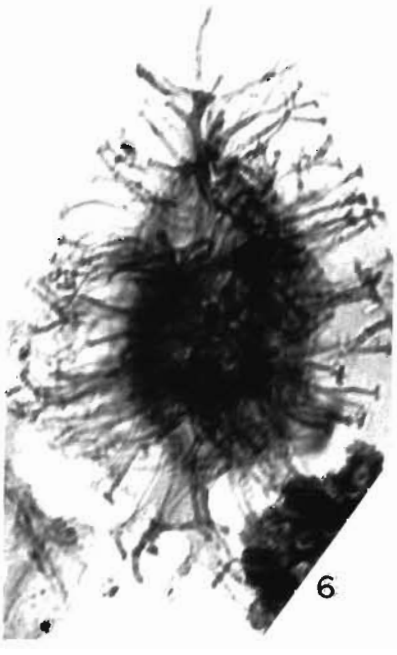

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PLATE 2

prominent.

A specimen very similar to Paratype B is also illustrated (Plate 1, figs 2, 4 and 5). Again, the ambitus is subpentagonal. The apical process is prominent, arising from an outbulge of the phragma; it is trifurcate, each branch having an evexate distal termination. Three processes on the right cingular region are trifid, each having a secate distal termination. All other processes are more or less alike, with a secate distal termination.

Another specimen (pl. 2, fig. 5) furnishes an excellent example of very prominent development of the apical and antapical processes. The apical process again arises from an outbulge of the phragma and is trifurcate, the branches respectively having (from left to right) an evexate, an acuminate and a bifid distal termination. The antapical process is likewise branched. The other processes may have secate, evexate or cauliflorate distal terminations; some are branched. The processes in the cingular region are not distinctive. All the processes are moderately fibrous. The ambitus is ellipsoidal, the archaeopyle being indistinct.

Another ellipsoidal specimen likewise shows prominent apical and antapical processes (Plate 2, fig. 4). The apical process is distally cauliflorate, while the antapical process is secate. All other processes have evexate or secate distal terminations, these being sometimes branched. Lateral processes are again not prominent, while the processes are again moderately fibrous and the archaeopyle not distinct.

A third specimen (pl. 2, fig. 6) is similar in most respects to the last, the apical and antapical processes being trifurcate with evexate distal terminations. In this case, however, the precingular archaeopyle may be seen distinctly.

The consistent occurrence of prominent apical and antapical processes, the presence of a precingular archaeopyle, the absence of any cavation (even at process bases) and the moderately fibrous nature of the processes rule out any possibility of *Fibrocysta variabilis* being a junior synoym of *Apectodinium paniculatum*, as claimed by Garg *et al.* (1995). In the latter species, the intercalary archaeopyle (Type I) is invariably distinct; a specimen is illustrated here (Pl. 2, fig. 3). It may be noted that Mehrotra and Sarjeant (1987, p. 151) did not attempt to describe the complete assemblage; in fact, the stratigraphical level 2703-2706 m contains a good representation of *Apectodinium* species.

The lateral development of a few distinct processes in some specimens (including the holotype and paratype B), imparting somewhat pentagonal to subpentagonal shape, should not cause any confusion. In species of *Apectodinium* the archaeopyle, as observed in this assemblage (at 2703-2706 m), is always distinct, the cysts being frequently cornucavate. No specimens of *Fibrocysta variabilis* show any development of cavation. Hence, we retain our attribution of the species *variabilis* to the genus *Fibrocysta*.

A future subdivision of *F. variabilis* into two or more distinct subspecies or varieties may eventually be desirable, on the basis of variations in the development of processes in the cingular region, resulting in a change of the ambitus from ellipsoidal to pentagonal or subpentagonal. However, the study of an extensive range of specimens is needful before such variations can be clearly and consistently demonstrated.

The specimen illustrated by us as *Fibrocysta* sp. (Mehrotra & Sarjeant, 1987, pl. 5, figs 3-4) has also been re-examined. The archaeopyle is discernible only with difficulty. The autophragm exhibits a fine punctoreticulate ornamentation, masked by secondary mineral features. We prefer to retain this species tentatively as *Fibrocysta* sp. until the precingular character of the archaeopyle is clearly established from study of additional specimens; these are expected to be encountered in our ongoing studies.

STRATIGRAPHICAL DATING

Regarding our age determinations of the studied samples from 3643-3649 m (CC-13), 3621-3624 m and 2703-2706 m (including part of CC-10 at 2703 m) depths, our previous conclusions were based on the information available at that time vertical ranges of dinoflagellate species. With the availability of more information—in particular, the work of Haq *et al.* (1987) and Williams *et al.* (1993)—and the development of a data base on the Krishna-Godavari Basin assemblages at KDMIPE, Dehra Dun, we are now able to confirm our earlier conclusions.

Figure 2 shows the occurrence of marker dinoflagellate species at the three studied intervals. This has been tied up with the foraminiferal zones (both benthonic and planktonic) of Govindan (1984). Earlier work on the dating of spore-pollen assemblages (Venkatachala & Sharma, 1984) is also presented. Figure 2 demonstrates the stratigraphic ranges of significant species recorded for the well Narasapur-1.

The presence of two dinoflagellate species—*Dinogymnium acuminatum* and *Achomosphaera regiensis*—indicates a Maastrichian age for the CC-13 (3643-3649 m)interval. This is supported by foraminiferal dating and is roughly equivalent to the *Globotruncana gansseri* Zone of Govindan (1984), dated as Middle Maastrichtian. An almost similar (early late Maastrichtian) age is determined for a slightly higher stratigraphic level (3621-3624 m), based on the dinoflagellate species *Cerodinium speciosum* and *Cladopyxidium saeptum*. This interval represents the FAD [First Appearance Datum] of these two significant taxa in the well and is dated as early late Maastrichtian (70 Ma)- Figure 3. Interestingly, *Fibrocysta variabilis* also has its FAD at this interval. Not a single specimen of *Apectodinium* was recorded between 3621-3649 m. This is understandable, as the species of the genus are known globally to have their FAD in the late Paleocene (Thanetian).

The dinoflagellate assemblage of stratigraphic interval 2703-2706 m (including part of CC-10 at 2703 m) contains a good number of *F. variabilis* and *Apectodinium* species. *A. paniculatum* has a globally known range from Late Paleocene (Thanetian) to early Eocene (early Ypresian). This interval falls within the planktonic foraminiferal zone *Morozovella angulata* zone of Govindan (1984), equivalent to the P_3 zone of Berggren (1972) and the *Globorotalia pusilla* - *Globorotalia angulata* Zone of Bolli (1937), all of which are dated as late Paleocene. Hence a late Paleocene (Thanetian) age, suggested by both dinoflagellate and foraminiferal evidence, is assigned to interval 2703-2706m.

The above age assignments—Upper Cretaceous

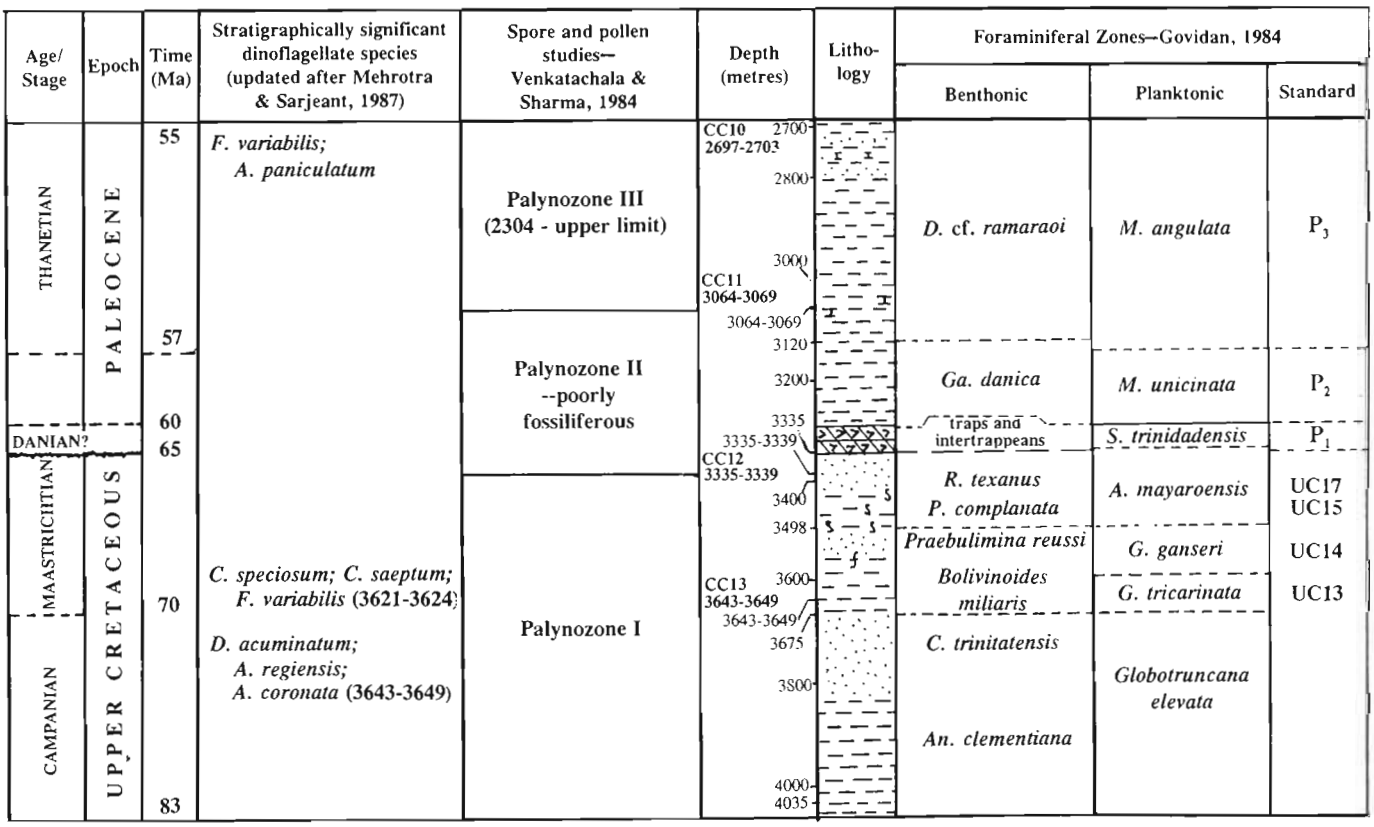

Figure 2— Occurrence of stratigraphically significant dinoflagellates at selected intervals and corresponding microforaminiferal and spore-pollen zones, Well Narasapur-1, Krishna-Godavari Basin.

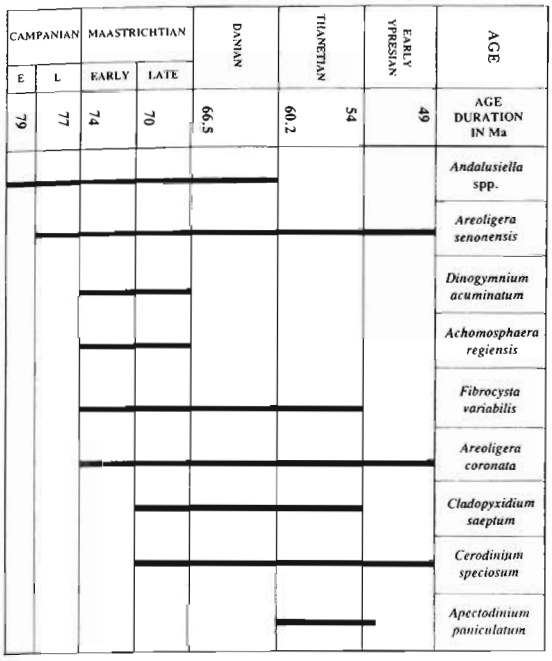

Figure 3— Ranges of stratigraphically valuable dinoflagellate species (based on Haq *et al.*, 1987; Williams *et al.*, 1993; and known Indian Ranges).

for (3621-3649 m, two samples) and Paleocene (2703-2706 m)— fully agree with our earlier interpretation. However, the additional information on dinoflagellate ranges and foraminiferal work in this well have helped us to further refine these age determinations. More information on dinoflagellate biostratigraphy and FAD's and LAD's [Last Appearance Datum] of significant taxa is expected to be available in the future, when our detailed dinoflagellate biostratigraphic work in the Krishna-Godavari basin is completed.

FURTHER OBSERVATIONS

The above discussion should eliminate most of the confusion created by Garg *et al.'s* (1995) critique. However, with regard to certain specific queries which have not been fully answered, we will elaborate further.

With regard to the sample intervals contested by Garg *et al.* (1995, p. 364), clarification has been given in Figure 1. Venkatachala and Sharma's (1984) spore-pollen zones were not formally defined. The exact depth interval of their zone III A and III B, along with phytoplankton species, is not clearly specified; however, their published biostratigraphic figure suggests CC-10 (2697-2703 m) as being the approximate base of Zone IIIB. Hence, we have simply included our dinoflagellate assemblage (at 2703-2706 m interval) as part of Venkatachala and Sharma's Zone III B.

Concerning the status of *Fibrocysta variabilis*, our observations have been presented in the preceding text and confirmed by reillustrations of the holotype, the two paratypes A and B, and a number of additional specimens. All the specimens have been restudied in orientations determined by the position of the precingular archaeopyle, this being clearly visible in some specimens (see paratype A in pl. 1, figs 3, 7; pl. 2, fig. 6). The consistent occurrence of prominent apical and antapical processes (arising from an outbulge of the phragma), the absence of any cavation, and the very frequent occurrence of branched processes leaves us with no doubt regarding the attribution of this taxon to the genus *Fibrocysta*. As noted earlier (p. xx), the ambitus varies from ellipsoidal to pentagonal or subpentagonal, depending upon the development of processes in the cingular region.

In this context, it should be stressed that *Apectodinium* spp. specimens, of which a good number were recorded at the 2703-2706 m interval, consistently show a distinct intercalary archaeopyle (Plate 2, fig. 3).

With reference to Garg *et al.'s* (1995, p. 368) questions regarding the age of the sample at the 3621-3624 m interval, we must stress that not a single specimen of *Apectodinium* has been discovered in samples between 3621-3649 m, dated as Maastrichtian. However, the sample from the 2703-2706 m interval does contain a good number of *Apectodinium* spp., not described by us in our previous publication; that sample is appropriately dated as late Paleocene (Thanetian). This is in accordance with the global vertical distribution of the genus *Apectodinium.*

There has been no 'mixing' or 'wrong labelling' of samples at 3621-3624 m, as was claimed by Garg *et al.* (1995). This interval is dated as early Late Maastrichtian based on FAD's of the two significant dinoflagellate species *Cerodinium speciosum* and *Cladopyxidium saeptum*. *Fibrocysta variabilis* likewise has its FAD at this level in the well.

Dinogymnium acuminatum is recorded at 3643-

3649 m. Its details are slide IPE/NSP-1/3643/5 (3643-3649 m), with coordinates 102/45.

Regarding the specimen named by us as *Dinogymnium* sp. (Mehrotra & Sarjeant, 1987, p. 170, pl. fig. 4), we must again differ from the opinions of Garg *et al.* (1995). It cannot be attributable to *Andalusiella*, which is a genus entirely distinct in its shape (compressed ellipsoidal with a prominent apical horn and two antapical horns), its possession of an intercalary archeopyle and its cornucavate character. Based on our observations and illustration (cited above), we see no need to change our existing interpretation.

The distribution of *Tityrosphaeridium gracile* should be read as infrequent at 2703-2706 m (late Paleocene) and 3643-3649 m (Maastrichtian) on P. 158 and Table 1, p. 153. In the plate explanation (Plate 7, fig. 4) the slide number is IPE/NSP-1/3643/5 (CC-13 : 3643-3649 m).

CONCLUSIONS

1. The contention of Garg *et al.* (1995), that *F. variabilis* is a junior synonym of *A. paniculatum*, is strongly refuted by the illustration of additional specimens and further elaboration of the morphological characteristics of the former species.
2. *Fibrocysta* sp. has been tentatively retained in the genus *Fibrocysta*, pending establishment by future studies of the character of its archaeopyle.
3. Our earlier age determinations of the studied samples at 3621-3624 m and 3643-3649 m, C13 level (Maastrichtian) and 2703-2706 m (Thanetian, including the upper part of CC-10 at 2703 m) is reaffirmed and strengthened by additional information concerning the ranges of dinoflagellates and microforaminifera in well Narasapur-1.
4. It is categorically denied that the genus *Apectodinium*, an essentially Palaeogene dinoflagellate taxon, is present at the 3621-3624 m level (Maastrichtian). The Species of the genus are present only at a higher level-the 2703-2706 m (Thanetian) interval.

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