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HIGH RESOLUTION NEOGENE DINOFLAGELLATE CYST BIOSTRATIGRAPHY AND CALCAREOUS NANNOPLANKTON BIOCHRONOSTRATIGRAPHY OF THE KRISHNA-GODAVARI BASIN, INDIA

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ABSTRACT

Since the discovery of hydrocarbons in the Neogene sediments of G-1 and Ravva structures, these sediments have become one of the prime targets for oil exploration in the Krishna - Godavari basin situated on the east coast of Peninsular India. The Neogene environmental set up encompasses marginal marine, shelf and bathyal environments including early Miocene delta complexes. Erosion and recycling of sediments is a common geological phenomenon under such a set up. The lithostratigraphic units of Neogene sediments include Rajahmundry Sandstone, Narsapur Claystone, Ravva Formation and Godavari Clay. These formations are facies variants and are partial equivalents in time. Because of varying lithofacies and biofacies, biochronostratigraphy based on a single group of microfossils may not provide any meaningful subdivision of the rock column for regional correlation. Secondly, zonal boundaries provided by a certain group of microfossils does not correlate with the interpreted events of seismic stratigraphy.

A 2315 m thick section of an offshore well G-2-D in the northeastern part of the basin has been studied for its dinoflagellate cysts and calcareous nannoplankton. Nine bio-events in the early Miocene and nine in the Late Miocene to the Pliocene sedmients are recognized on the basis of Last Appearance Datums (LADs) of dinoflagellate cysts. These events are correlated with events of planktic foraminifera and calcareous nannoplankton biochrono-zones. This framework provides a more reliable biozonal scheme. There is a major unconformity between early Miocene and late Miocene sediments.

INTRODUCTION

Neogene sediments in the offshore Krishna-Godavari (K.G.) Basin are petroliferous. Ravva oil field and many other neighbouring structures have proven oil/gas reservoirs. The early Miocene-late Miocene boundary is marked by an unconformity and is a well recognizable erosional surface demarcated in the seismic section. Below this erosional surface, "Ravva Sandstone Unit" of Ravva Formation is present which is the main reservoir of oil/gas. There are several sandstone reservoirs in the offshore Godavari delta region dated as Pliocene sand belong to the Ravva Formation. The source rocks for these Mio-Pliocene reservoirs are Vadaparru shales of middle to late Eocene age which underlies Ravva Formation in the offshore region (fig. 1b). The Neogene environmental set up encompasses marginal marine, shelf and bathyal environments including early Miocene delta complexes. Venkatarengan *et al.* (1993) have classified Neogene sediments into four formations, viz., Rajahmundry Sandstone, Narsapur Claystone, Ravva Formation and Godavari Clay (table 1 and fig. 1b). These formations are facies variants and are partial equivalents in time.

It has been observed that a single group of microfossil does not provide any meaningful chronostratigraphic subdivision of the rock column because of varying lithofacies and biofacies. Moreover, zonal boundaries provided by a certain groups of microfossils do not correlate with the interpreted events of seismic stratigraphy. The aim of the present study is to define chronostratigraphic classification of an offshore Well G-2-D (fig. 1a) using calcareous nannoplankton and dinoflagellate cyst bio-events. The distribution of planktic foraminifera provides additional chronostratigraphic information.

STRATIGRAPHY

Most of the Neogene sediments are classified under four formations viz., Rajamundry Sandstone, Godavari Clay, Ravva Formation and Narsapur claystone grouped into Gowthami Group by Venkatarengan *et al.*

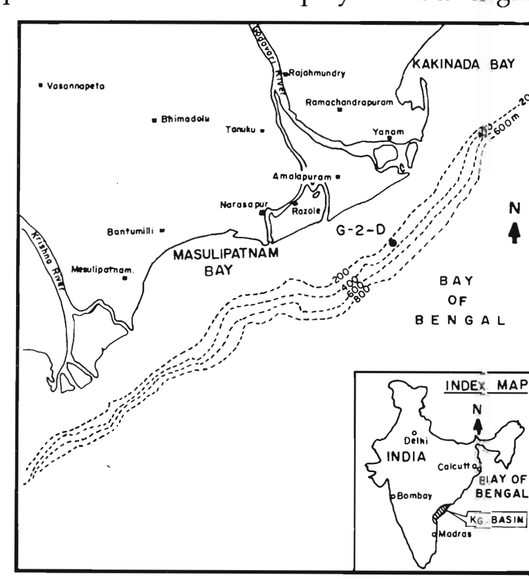


Fig. 1a. Location map.

Table 1: Lithostratigraphy of the Krishna-Godavari Basin (summarised by Venkatarangan *et al.*, 1993).

GROUP	FORMATION	LITHOLOGY	AGE	DEPOSITIONAL ENVIRONMENT
GOWTHAMI	Andhra Alluvium	Alluvium sandstone	Recent	Fluvial/Coastal
	Rajamundry Sandstone	Clay/Claystone Sandstone altering	Miocene-Pliocene	Lagoonal to shallow inner shelf
	Godavari Clay	with thick clay Claystone with	Miocene-Recent	Inner-Middle shelf
	Ravva Formation	minor sandstone	Miocene-Pliocene	Outer shelf
	Narsapur Claystone		Oligocene-Pliocene	Inner-Middle shelf
VASISHTA	Nimmakuru Sandstone	Sandstone with mionr claystone	Early Eocene-Early Miocene	Continental
	Matsyapuri Sandstone	Sandstone with streks of claystone	Late Eocene-Oligocene	Continental
	Bhimanapalli Limestone	Limestone with thin sand/shale	Middle Eocene	Inner Neretic
	Vadaparru Shale	alternation Sandstone and shale	Middle-Late Eocene	Outer Neretic
	Pasarlapudi Formation	alternations Dark grey shale Basalts	Late Palaeocene to Early Eocene	Outer Neretic
	Pallakollu Shale	and intertrappean clay	Late Cretaceous-Palaeocene	Middle Neretic
	Razole Formation		Late Cretaceous-Early Palaeocene	Submarine volcanism
GUDIVADA	Chintalapalli Shale	Shale with siltstone	Late Cretaceous	Inner Neretic
	Tiruparti Sandstone	Sandstone	Late Cretaceous	Continental
	Raghavapuram Shale	Shale	Early Cretaceous	Inner Neretic
NIZAMA PATNAM	Kanukollu Sandstone	Sandsone with claystone	Albian	Lagoonal to Inner Neretic
	Gajulpadu Shale	Dark grey shale	Albian	Middle Neretic
	Golapalli Formation	Grits and Ferrugenous sandstone	Pre-Albian	Fluvial
	Pennar Shale	Shale	Pre-Albian	Continental
	Bapatla Sandstone	Sandstone	Pre-Albian	Fluvial
	Nellore Claystone	Reddish Claystone	Neocomian-Aptian	Fluvial to marginal marine
LOWER GONDWANA	Mandapeta Sandstone	Sandstone with minor shale	Permian	Fluvial
	Kommugudem Formation	Alternating sandstone with shale	Permo-Carboniferous	Fluvial
	Raksharama Argillite	Greyish Black shale	Early Permian	Fluvial with marine incursions

PRECAMBRIAN METAMORPHIC COMPLEX

(1993). Table 1 shows the generalised stratigraphy of the KG Basin from early Permian to Recent sediments.

MATERIAL AND METHODS

A total of 231 samples generally at 10 m interval were studied of which five are conventional cores (CC1 to CC5) and the rest are cutting samples (860-3175 m). Two slides were prepared using standard palynological techniques and the residue was stained with Safranin O for better observation of thin walled dinoflagellate cysts. Two more slides of 94 samples were made for nannoplankton studies using standard procedure. The results are based on the study of these four slides.

RESULTS

42 species belonging to 34 genera of dinoflagelate cysts and 10 species belonging to 9 genera of acritarchs and other algal remains are identified. Most of the identifications are at the species level, however, few of the specimens are identified only at the generic level since they could not be related to any know species.

Fig. 2 shows the stratigraphic distribution of dinoflagellate cysts using LADs (Last Appearance Datum or extinction/disappearance level). The important bio-events recorded are as follows, while other bio-events are not considered in the present study.

910 m-	LAD-	*Multispinula quanta* Bradford, 1975 *Votadinum* sp.
950 m-	LAD-	*Polysphaeridium zoharyi* (Rossignol) Bujak *et al.*,1980
1060 m-	LAD-	*Apteodinium australinum* (Deflandre and Cookson) Williams, 1978
1120 m-	LAD-	*Trinovantedinium capitatum* Reid, 1977; *Omanodinium alticinctum* Bradford, 1975.
1170 m-	LAD-	*Heteraulacacysta campanula* Drugg and Loeblich, 1967
1350 m-	ACME-	*Tuberculodinium vancampoae* (Rossignol) Wall, 1967
1370 m-	LAD-	*Selenopemphix selenoides* Benedek
	ACME-	*Spiniferites* spp./*Achomosphaera* spp.
1430 m-	LAD-	*Operculodinium* sp.
1470 m-	LAD-	*Selenopemphix armata* Bujak in Bujak *et al.*, 1980.
1540 m-	LAD-	*Morkalacysta* sp.
1931 m-	CC3 LAD-	*Dapsilidinium pseudocolligerun* (Stover) Bujak *et al.*, 1980

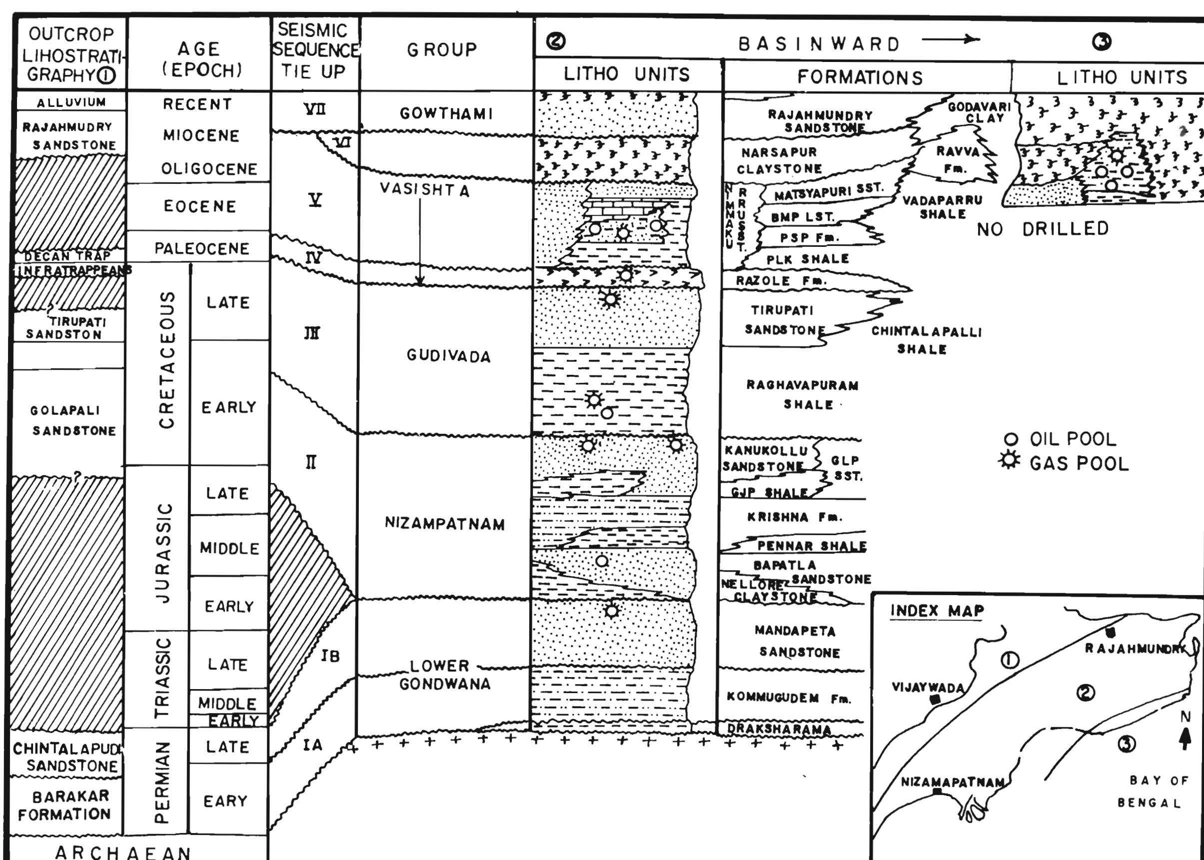
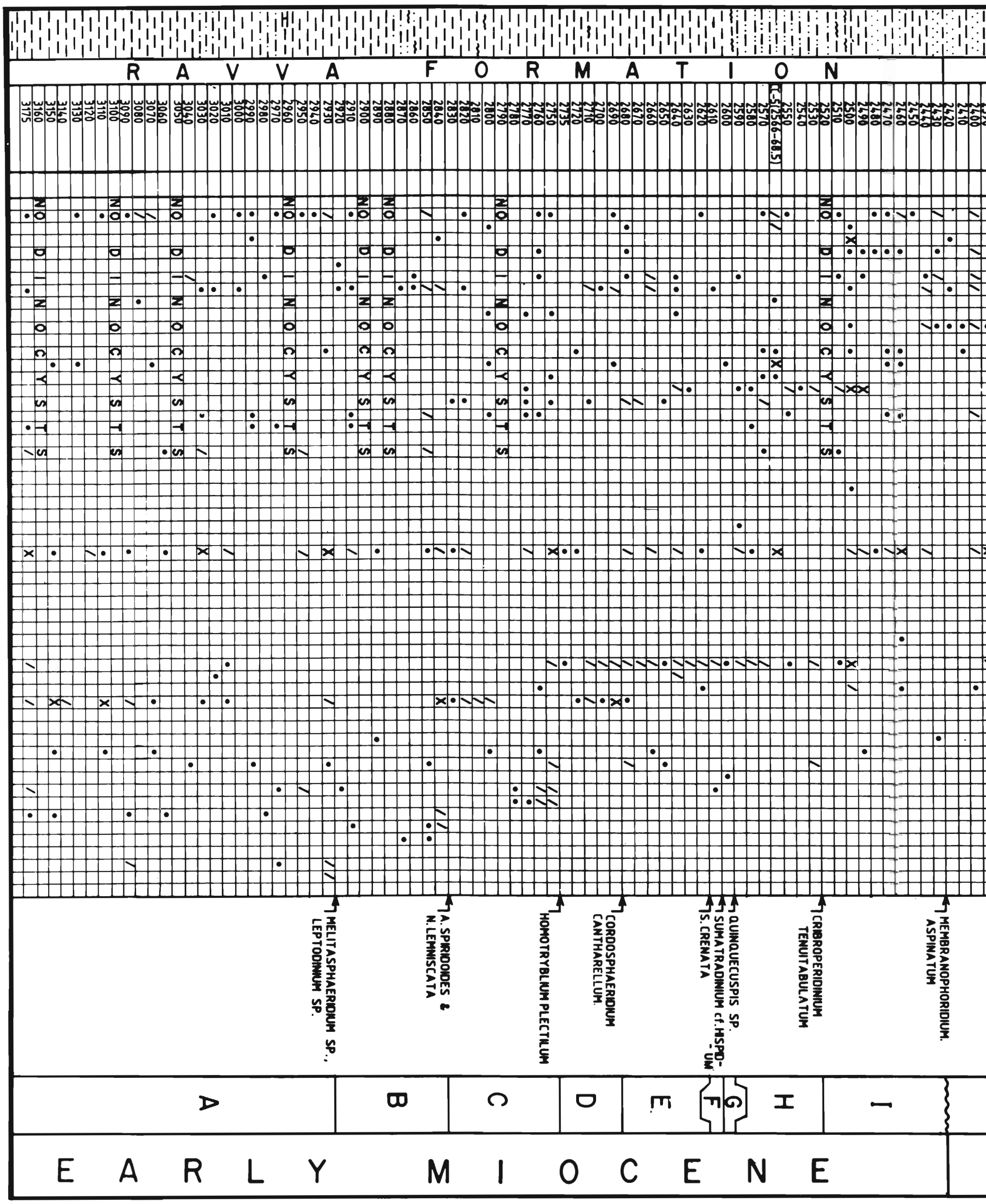


Fig. 1b. Generalised stratigraphy, Krishna-Godawari Basin.


RAVVA FORMATION
3175 3160 3150 3140 3130 3120 3110 3100 3090 3080 3070 3060 3050 3040 3030 3020 3010 3000 2990 2980 2970 2960 2950 2940 2930 2920 2910 2900 2890 2880 2870 2860 2850 2840 2830 2820 2810 2800 2790 2780 2770 2760 2750 2735 2720 2710 2700 2690 2680 2670 2660 2650 2640 2630 2620 2610 2600 2590 2580 2570 C-5 (2566-68.5) 2550 2540 2530 2520 2510 2500 2490 2480 2470 2460 2450 2440 2430 2420 2410 2400 2390
NO DINOCYSTS
MELITASPHAERIDIUM SP., LEPTODINIUM SP.
A. SPIRIDOIDES & N. LEMNISCATA
HOMOTRYBLIUM PLECTILUM
CORDOSPHAERIDIUM CANTHARELLUM
S. CRENATA
SUMATRADINIUM cf. HISPIDUM
QUINQUECUSPIS SP.
CRIBROPERIDINIUM TENUITABULATUM
MEMBRANOPHORIDIUM ASPINATUM
A
B
C
D
E
F
G
H
I
EARLY MIOCENE

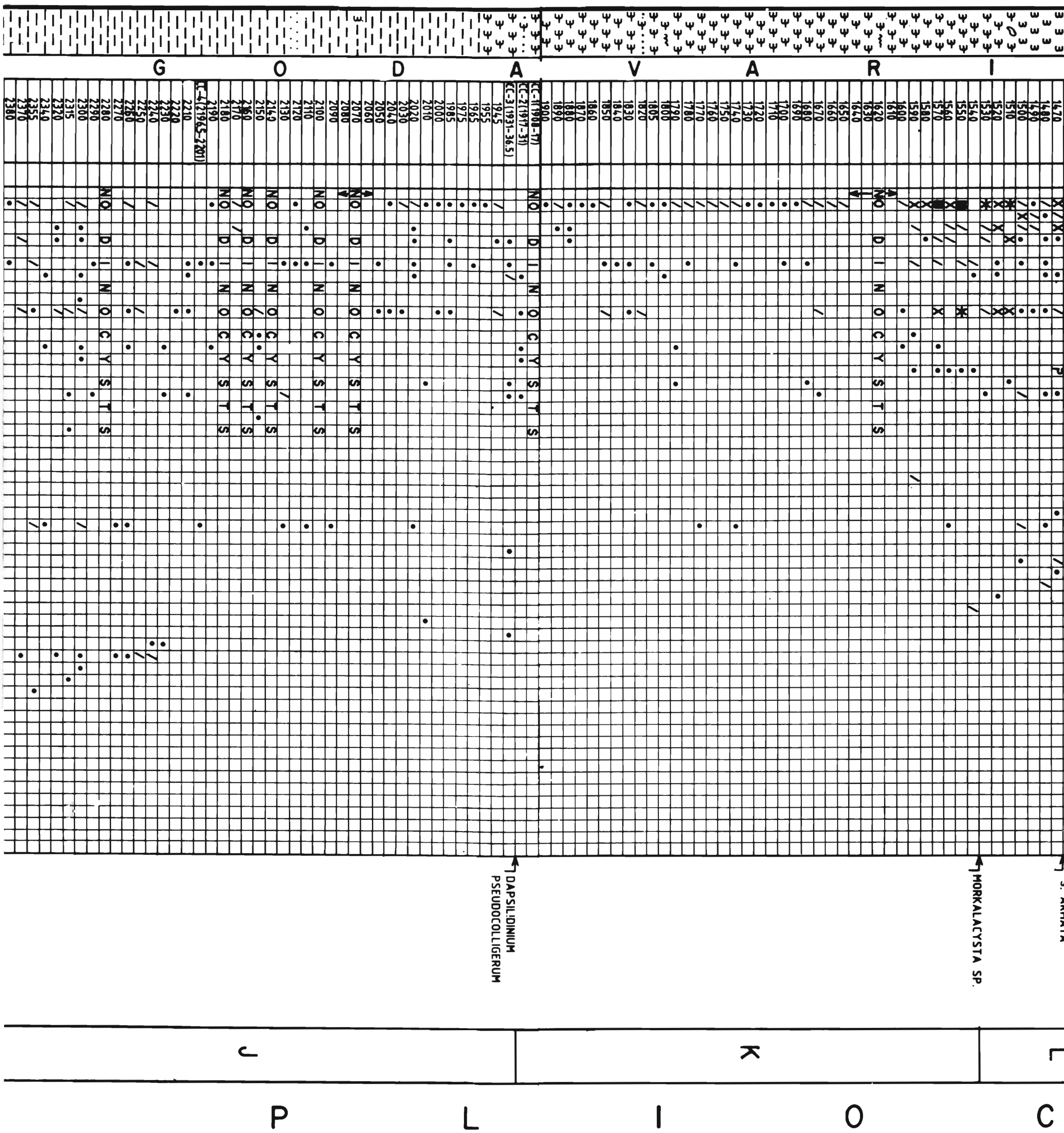
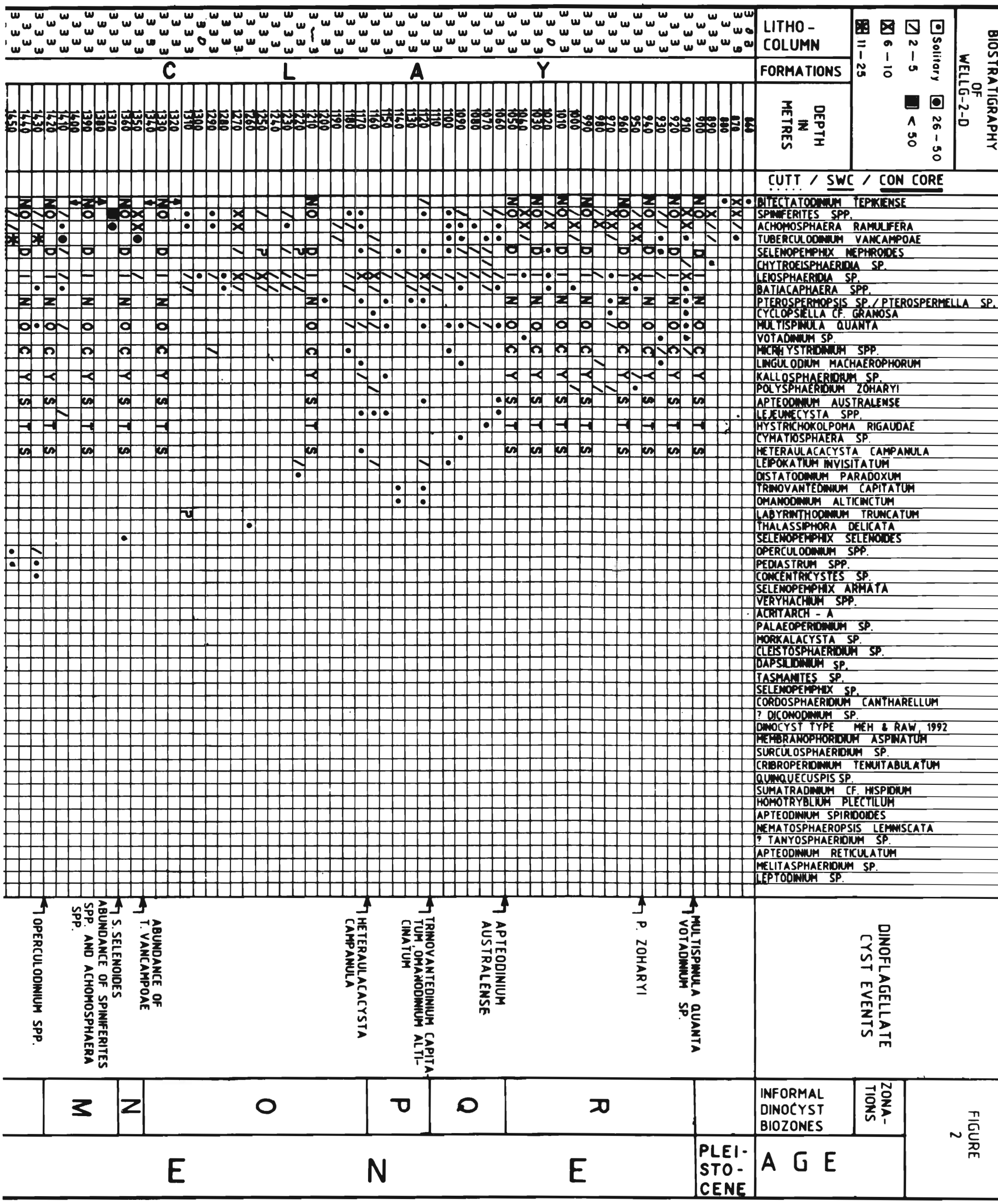


Fig. 2. Distribution of dinoflagellate cyst in the offshore well G-2-D, Krishna-Godawari Basin, India.


BIOSTRATIGRAPHY OF WELL G-2-D
LITHO-COLUMN
FORMATIONS
C L A Y
DEPTH IN METRES
Solitary
2 – 5
6 – 10
11 – 25
26 – 50
< 50
CUTT / SWC / CON CORE
BITECTATODINIUM TEPIKIENSE
SPINIFERITES SPP.
ACHOMOSPHAERA RAMULIFERA
TUBERCULODINIUM VANCAMPOAE
SELENOPEMPHIX NEPHROIDES
CHYTROEISPHAERIDIA SP.
LEIOSPHAERIDIA SP.
BATIACAPHAERA SPP.
PTEROSPERMOPSIS SP./PTEROSPERMELLA SP.
CYCLOPSIELLA CF. GRANOSA
MULTISPINULA QUANTA
VOTADINIUM SP.
MICRHYSTRIDINIUM SPP.
LINGULODIUM MACHAEROPHORUM
KALLOSPHAERIDIUM SP.
POLYSPHAERIDIUM ZOHARYI
APTEODINIUM AUSTRALENSE
LEJEUNECYSTA SPP.
HYSTRICHOKOLPOMA RIGAUDAE
CYMATIOSPHAERA SP.
HETERAULACACYSTA CAMPANULA
LEIPOKATIUM INVISITATUM
DISTATODINIUM PARADOXUM
TRINOVANTEDINIUM CAPITATUM
OMANODINIUM ALTICINCTUM
LABYRINTHODINIUM TRUNCATUM
THALASSIPHORA DELICATA
SELENOPEMPHIX SELENOIDES
OPERCULODINIUM SPP.
PEDIASTRUM SPP.
CONCENTRICYSTES SP.
SELENOPEMPHIX ARMATA
VERYHACHIUM SPP.
ACRITARCH - A
PALAEOPERIDINIUM SP.
MORKALACYSTA SP.
CLEISTOSPHAERIDIUM SP.
DAPSILIDINIUM SP.
TASMANITES SP.
SELENOPEMPHIX SP.
CORDOSPHAERIDIUM CANTHARELLUM
? DICONODINIUM SP.
DINOCYST TYPE MEH & RAW, 1992
MEMBRANOPHORIDIUM ASPINATUM
SURCULOSPHAERIDIUM SP.
CRIBROPERIDINIUM TENUITABULATUM
QUINQUECUSPIS SP.
SUMATRADINIUM CF. HISPIDIUM
HOMOTRYBLIUM PLECTILUM
APTEODINIUM SPIRIDOIDES
NEMATOSPHAEROPSIS LEMNISCATA
? TANYOSPHAERIDIUM SP.
APTEODINIUM RETICULATUM
MELITASPHAERIDIUM SP.
LEPTODINIUM SP.
OPERCULODINIUM SPP.
S. SELENOIDES
ABUNDANCE OF SPINIFERITES SPP. AND ACHOMOSPHAERA SPP.
ABUNDANCE OF T. VANCAMPOAE
HETERAULACACYSTA CAMPANULA
TRINOVANTEDINIUM CAPITATUM, OMANODINIUM ALTICINATUM
APTEODINIUM AUSTRALENSE
P. ZOHARYI
MULTISPINULA QUANTA VOTADINIUM SP.
DINOFLAGELLATE CYST EVENTS
M N O P Q R
INFORMAL DINOCYST BIOZONES
ZONATIONS
E N E
PLEISTOCENE
AGE
FIGURE 2

2430 m-	LAD-	*Membranophoridium aspinatum* Gerlach ex Gocht, 1969
2530 m-	LAD-	*Cribroperidinium tenuitabulatum* (Gerlach) Helenes, 1961
2600 m-	LAD-	*Quinquecuspis* sp., 1984
2610 m-	LAD-	*Sumatradinium* cf. *hispidum* (Drugg) Lentin and Williams, 1976
2620 m-	LAD-	*Selenopemphix crenata* Matsuoka dn Bujak, 1980
2690 m-	LAD-	*Cordosphaeridium cantharellum* (Brosius) Gocht, 1969
2750 m-	LAD-	*Homotryblium plectilum*
2840 m-	LAD-	*Apteodinium spiridoides* Bebedek, 1972
		Nematosphaeropsis lemniscata Bujak, 1984
2930 m-	LAD-	*Melitasphaeridium* sp. *Leptodinium* sp.

Based on the above listed bio-events, eighteen informal biozones are proposed. A through I are of early Miocene and the rest nine (J throgh R) are of upper late Miocene to Pliocene (figs. 3 and 4). All these biozones are informal and are based mostly on LADs and only two on the basis of abundance (Acme zones). Such boundaries could demarcate facies changes and could be controlled by the changes in depositional environments rather than extinction levels of individual species. Future work on the Neogene sections of other wells will demonstrate the usefulness of a few of these proposed biozones in case they are identifiable across the facies boundaries. Formal biozones based on dinoflagellate cysts would be proposed once the zones across the facies are identified.

The LAD of *Membranophoridium aspinatum* at 2430 m is very important since the LAD of this species is in the early Miocene (Haq *et al.*, 1987). This datum is taken here to mark the top of early Miocene and the boundary between early Miocene and upper late Miocene. Thus, this boundary also represents a major unconformity in this well section. The LADs of *Cor- dosphaeridium cantharellum*, *Homotryblium plectilum* and *Cribroperidinium tenuitabulatum* are also within early Miocene.

List of the dinoflagellate cysts recorded in this study

Genus *Achomosphaera* Evitt, 1963

A. ramulifera (Deflandre, 1937) Evitt, 1963 (pl. 1/3/; 1/13)

Genus *Apteodinium* Eisenack, 1958 emend. Sarjeant, 1985 emend. Lucas -Clark, 1987

A. australense (Deflandre and Cookson, 1955) Williams, 1978 (Not illustrated)

A. spiridoides Benedek, 1972 (pl. 5/3)

Genus *Batiacasphaera* Drugg, 1970

Batiacasphaera spp. (pl. 1/5; 1/8; 3/13; 3/16; 4/1)

Genus *Brigantedinium* Reid, 1977

cf. *B. simplex* (Wall) Reid, 1977 (pl. 4/10)

Genus *Cordosphaeridium* Eisenack, 1963 emend, Davey, 1969

C. cantharellum (Brosius, 1963) Gocht, 1969 (pl. 4/6; 4/18)

Genus *Cribroperidinium* Neale and Sarjeant, 1962 emend. Davey, 1969 emend. Sarjeant, 1982 emend. Helenes, 1984

C. tenuitabulatum (Gerlach, 1961) Helenes, 1984 (pl. 4/5; 5/12)

Genus *Dapsilidinium* Bujak *et al.*, 1980

Dapsilidinium pseudocolligerum (Stover) Bujak *et al.*, 1980 (pl. 1/12; 4/11)

Genus *Distatodinium* Eaton, 1976

D. paradoxum (Brosius, 1963) Eaton, 1976 (Not illustrated)

Genus *Heteraulacacysta* Drugg and Loeblich, 1967 emend. Bujak in Bujak *et al.*, 1980

H. campanula Drugg and Loeblich, 1967 (pl. 4/17)

H. cf. *granulata* Jan du chene and Adediran, 1985 (pl. 4/8)

Genus *Hystrichokolpoma* Klumpp, 1953 emend. Williams and Downie, 1966

H. rigaudae Deflandre and Cookson, 1955 (Not illustrated)

Genus *Impletosphaeridium* Morgenroth, 1966

Impletosphaeridium sp. (pl. 2/9)

Genus *Kallosphaeridium* De Conick, 1969 emene. Jan du Chene *et al.*, 1985

Kallosphaeridium sp. (pl. 2/15; 5/10)

Genus *Labyrinthodinium* Piasecki, 1980

L. truncatum Piasecki, 1980 (pl. 2/7; 4/14; 5/15)

cf. *Labyrinthodinium* sp. (pl. 5/8)

Genus *Leipokatium* Bradford, 1975

L. invisitatum Bradford, 1975 (pl. 1/14; 3/8)

Genus *Lejeunecysta* Artzner and Dörhöfer, 1978

L. hyalina (Gerlach 1961) Artzner & Dörhöfer 1978 emend. Sarjeant, 1984

(pl. 3/8)

Genus *Leptodinium* Klement, 1960 emend. Sarjeant, 1966, emend. Wall, 1967, emend. Stover and Evitt., 1978, emend. Sarjeant, 1982

Leptodinium sp. (Not Illustrated)

Genus *Lingulodinium* Wall, 1967 emend. Wall and Dale in Wall *et al.*, 1973

L. machaerophorum (Deflandre and Cookson, 1955) Wall, 1967 (pl. 5/9)

Genus *Melitasphaeridium* Harland and Hill, 1979

Melitasphaeridium sp. (Not Illustrated)

Genus *Membranophoridium* Gerlach, 1961. emend. Stover and Evitt, 1978

M. aspinatum Gerlach, 1961, ex Gocht, 1969 (pl. 4/2)

Genus *Morkaleacysta* Harris, 1974

Morkaleacysta sp. (pl. 3/4; 3/6)

Genus *Multispinula* Bradford, 1975

M.quanta Bradford, 1975 (pl. 1/6; 2/1; 4/19; 5/1)

Genus *Nematosphaeropsis* Deflandre and Cookson, 1955 emend.

Williams and Downie, 1966

N. lemniscata Bujak, 1984 (Not Illustrated)

Genus *Omanodinium* Bradford, 1975

O. alticinctum Bradford, 1975 (pl. 1/9)

Genus *Operculodinium* Wall, 1967

Operculodinium sp. (pl. 4/16)

Genus *Pentadinium* (Gerlach) Benedek *et al.*, 1982

Pentadinium sp. (pl. 4/7)

Genus *Polysphaeridium* Davey and Williams, 1966 emend. Bujak, *et al.*, 1980

P. zoharyi (Rossignol, 1962) Bujak *et al.*, 1980 (pl. 3/1; 5/14)

P. subtile Davey and Willams emend. Bujak *et al.*, 1980 (pl. 4.15)

Genus *Quinquecuspis* Harland, 1977

Quinquecuspis sp. (Not Illustrated)

Genus *Selenopemphix* Benedek, 1972 emend. Bujak in Bujak *et al.*, 1980

S. armata Bujak in Bujak *et al.*, 1980 (pl. 4/12)

S. coronata Bujak in Bujak *et al.*, 1980 (pl. 5/7)

S. crenata Matsuoka and Bujak, 1988)pl. 4/13)

S. nephroides Benedek, 1972 emend. Bujak in Bujak *et al.*, 1980 emend. *Benedek and Sarjeant*, 1981 (pl. 1/4)

S. selenoides Benedek, 1972 emend. Bujak in Bujak et al., 1980 emend. Benedek and Sarjeant, 1981 (pl. 3/9; 3/10; 3/11; 4/9)

Genus *Spiniferites Mantell*, 1850 emend. Sarjeant, 1970

Spiniferites sp. (pl. 2/8)

Genus *Sumatradinium* Lentin and Williams, 1976

S. cf. *hispidum* (Drugg, 1970) Lentin and Williams, 1976 (pl. 5/4; 5/5)

Genus *Trinovantedinium* Reid, 1977 emend. Harland, 1977 emend. Bujak, 1984

T. capitatum Reid, 1977 (pl. 2/2; 2/3; 3/5; 4/3; 5/6)

Genus *Tuberculodinium* Wall, 1967

T. vancampoae (Rossignol, 1962) Wall 1967 (pl. 1/15;4/4;5/11;3/13)

Genus *Votadinium* Reid, 1977

Votadinium sp. (pl. 2/13)

Genus *Xandarodinium* Reid, 1977

X. anthum Reid, 1977 (pl. 3/3)

Acritarchs and other Algal Remains

Genus *Concentricystes* Rossignol, 1962

Concentricystes sp. (pl. 2/14)

Genus *Cyclopsiella* Drugg and Loeblich, 1967 emend. Jain & Dutta in Dutta & Jain, 1980 emend. Head *et al.*, 1989

C. elliptica Drugg and Loeblich, 1967 (pl. 1/2)

Genus *Cymatiosp haera* O. Wetaxel, 1933 ex. Deflandre, 1954

Cymatiosphaera sp. (pl. 1/10; 2/11; 2/12; 3/15; 5/2)

Genus *Leiosphaeridia* Eisenack, 1958 emend. Downie and Sarjeant, 1963 emend. *Turner*, 1984

Leiosphaeridia sp. (pl. 1/11)

Genus *Micrhystridium* Deflandre, 1937 emend. Staplin, 1961 emend. Lister, 1970

Micrystridium sp. (pl. 2, Fig. 20)

Genus *Pediastrum* Meyen, 1829

Pediastrum sp. (Not Illustrated).

Genus *Pterospermella* Eisenack, 1972.

Petrospermella sp. (pl. 1/7)

Genus *Tasmanites* Newton, 1875

Tasmanites sp. (Not Illustrated)

Genus *Veryhachium* Deunff, 1954 emend. Downie and Sarjeant, 1963, emend. Turner, 1984.

Veryhachium sp. (Not Illustrated)

BIOCHRONOSTRATIGRAPHY OF CALCAREOUS NANNOPLANKTON

The stratigraphic distribution of calcareous nannoplankton species and biochronozones are shown in fig. - 3. Twenty five species belonging to 12 genera of calcareous nannoplankton are recorded in the section. The biochronostratigraphy of this well is attempted using standard nannoplankton events (Young *et al.*, 1984). The nannoplankton ;biochronozones are correlated with the scale of Haq *et al.*, (1987). The information is summarized in table 2.

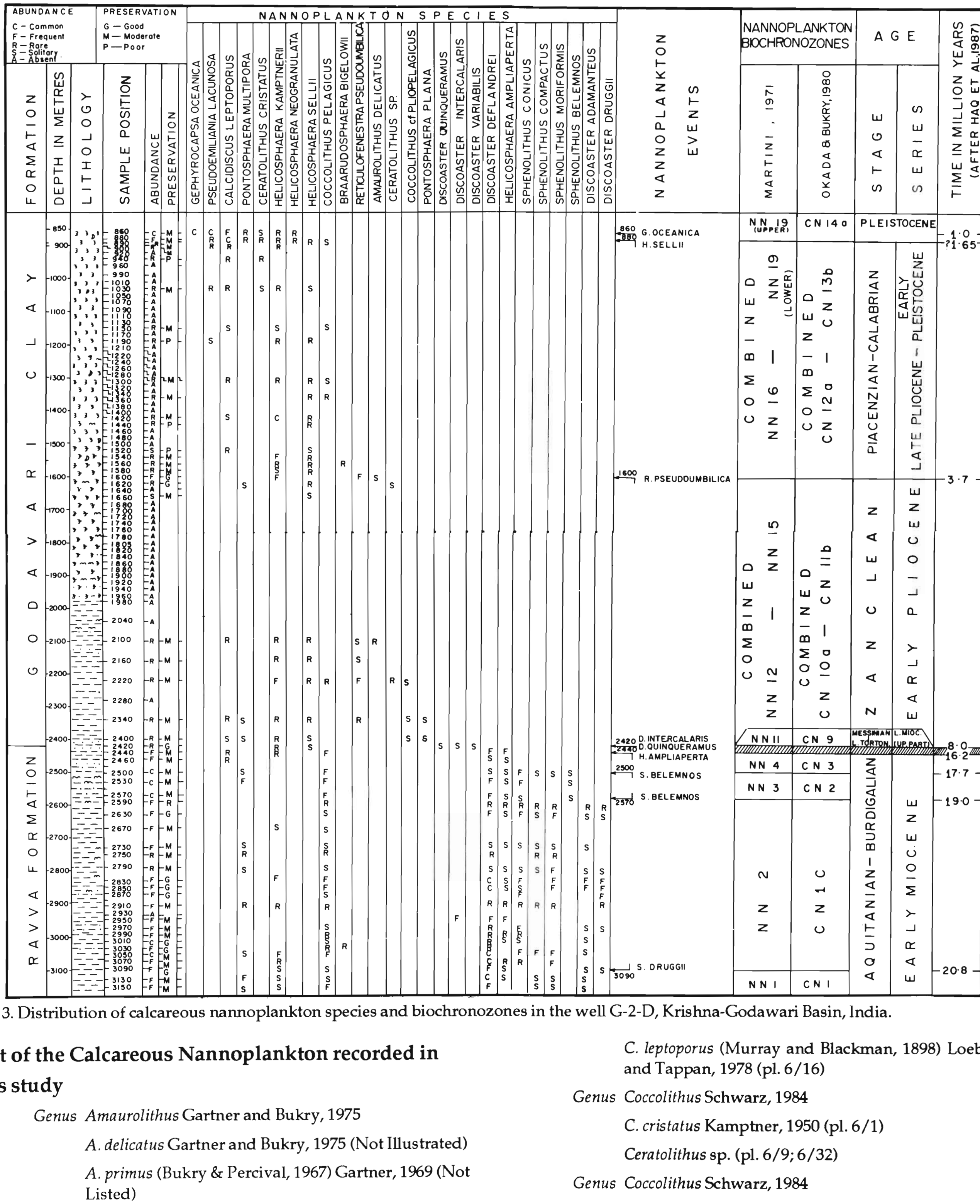


Fig. 3. Distribution of calcareous nannoplankton species and biochronozones in the well G-2-D, Krishna-Godawari Basin, India.

List of the Calcareous Nannoplankton recorded in this study

Genus Amaurolithus Gartner and Bukry, 1975

A. delicatus Gartner and Bukry, 1975 (Not Illustrated)

A. primus (Bukry & Percival, 1967) Gartner, 1969 (Not Listed)

Genus Braarudosphaera Deflandre, 1947

B. bigelowii (Gran and Braarud, 1935) Deflandre, 1947 (Not illustrated)

Genus Calcidiscus Kamptner, 1950

C. leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978 (pl. 6/16)

Genus Coccolithus Schwarz, 1984

C. cristatus Kamptner, 1950 (pl. 6/1)

Ceratolithus sp. (pl. 6/9; 6/32)

Genus Coccolithus Schwarz, 1984

C. pelagicus (Wallich, 1877) Schiller, 1930 (pl. 6/10; 6/11)

C. pliopelagicus Wise, 1973 (pl. 6/12)

Genus Discoaster Tan, 1927

Table 2: Stratigraphic distribution of nannofossil species using LADs and FADs and standard nannofossil biochronozones.

Depth (m)	Nanno event	Nannoplankton Species		Chronostratigraphy (NN Zone of Martini, 1971; CN Zone/Sub Zones of Okada & Bukry, 1980	
860	FAD	*Gephyrocapsa oceanica* Kamptner, 1943	NN 19 (Up): CN 14 a:	*Pseudoemiliania lacunosa* Zone Late Pleistocene *Emiliania ovata* subzone	1.0 Ma
880	LAD	*Helicosphaera sellii* Bukry & Bramlette, 1969	NN 19(Lr) : CN 13b (Lr) :	*Pseudoemiliania lacunosa* zone/Early Pleistocene *Gephyrocapsa caribbeanica* subzone (Calabrian)	1.5 Ma
880	FAD	*Helicosphaera neogranulatea* Gartner, 1977			
1030	FAD	*Ceratolithus cristatus* Kamptner, 1950			
1520	FAD	*Pseudoemiliania lacunosa* (Kamptner, 1963) Gartner, 1969			
1560	OCC.	*Braarudosphaera bigelowii* (Gran & Braarud, 1935) Deflandre, 1947			
1600	LAD	*Reticulofenestro pseudoumbilica* (Gartner, 1967)	NN 15: CN 11b :	*Reticulofenestra pseudoumbilica*/Early Pliocene *Discoaster asymmetricus* (Zanclean)	3.7 Ma
	LAD	*Amaruolithus delicatus* Gartner & Bukry, 1975			
1620	LAD	*Amaurolithus Primus* (Bukry & Percival, 1971) Gartner & Bukry, 1975			
	LAD	*Pontosphaera multipora* (Kamptner, 1948) Roth, 1970			
2220	LAD	*Coccolithus pliopelagicus* Wise, 1973	NN 11/CN 9:	*Discoaster quinqueramus* (L. Tortonian - Messinian) Late Miocene (Up. part) 8.0 MA	
2340	LAD	*Pontosphaera plana* (Bramlette & Sullivan, 1961) Haq, 1971			
	FAD	*Reticulofenestra pseudoumbilica* (Gartner, 1967) Gartner, 1969	NN 4/CN 3 :	*Helicosphaera ampliapertaa*/ Early Miocene	16.2 Ma
2400	FAD	*Pontosphaeraa plana* (Bramlette & Sullivan, 1961) Haq, 1971			
2420	OCC.	*Discoaster quinqueramus* Gartner, 1969			
	LAD	*Discoaster quinqueramus* Gartner, 1969			
	FAD	*Helicosphaera ampliaperta* Bramlette & Wilcoxn, 1967			
2440	LAD	*Discoaster deflandrei* Bramlette & Wilcoxon, 1967			
	LAD	*Helicosphaera ampliaperta* Bramlette & Wilcoxon, 1967			
2460	FAD	*Calcidiscus leptoprus* (Murray & Blackman, 1998) Loeblich & Tappan, 1978.			
2500	LAD	*Sphenolithus belemnos* Bramlette & Wilcoxon, 1967	NN 3:	*Sphenolithus belemnos* (Up. limit) Burdigalian	17.7 Ma
	LAD	*Sphenolithus conicus* Bukry, 1971			
2570	FAD	*Sphenolithus Belemnos* Bramlette & Wilcoxon, 1967	NN 3/ CN 2:	*Sphenolithus belemnos* (Lower limit) Burdigalian	19.0 Ma
2590	LAD	*Discoaster adamanteus* Bramlette & Wilcoxon, 1961			
	LAD	*Discoaster druggii* Bramlette & Wilcoxon, 1961			
3070	FAD	*Discoaster druggii* Bramlette & Wilcoxon, 1967	NN2/ CNIC :	*Discoaster druggii* Aquitanian - Burdigalian (Early Miocene)	20.8 Ma
3130	FAD	*Helicosphaera ampliaperta* Bramlette & Wilcoxon, 1967			

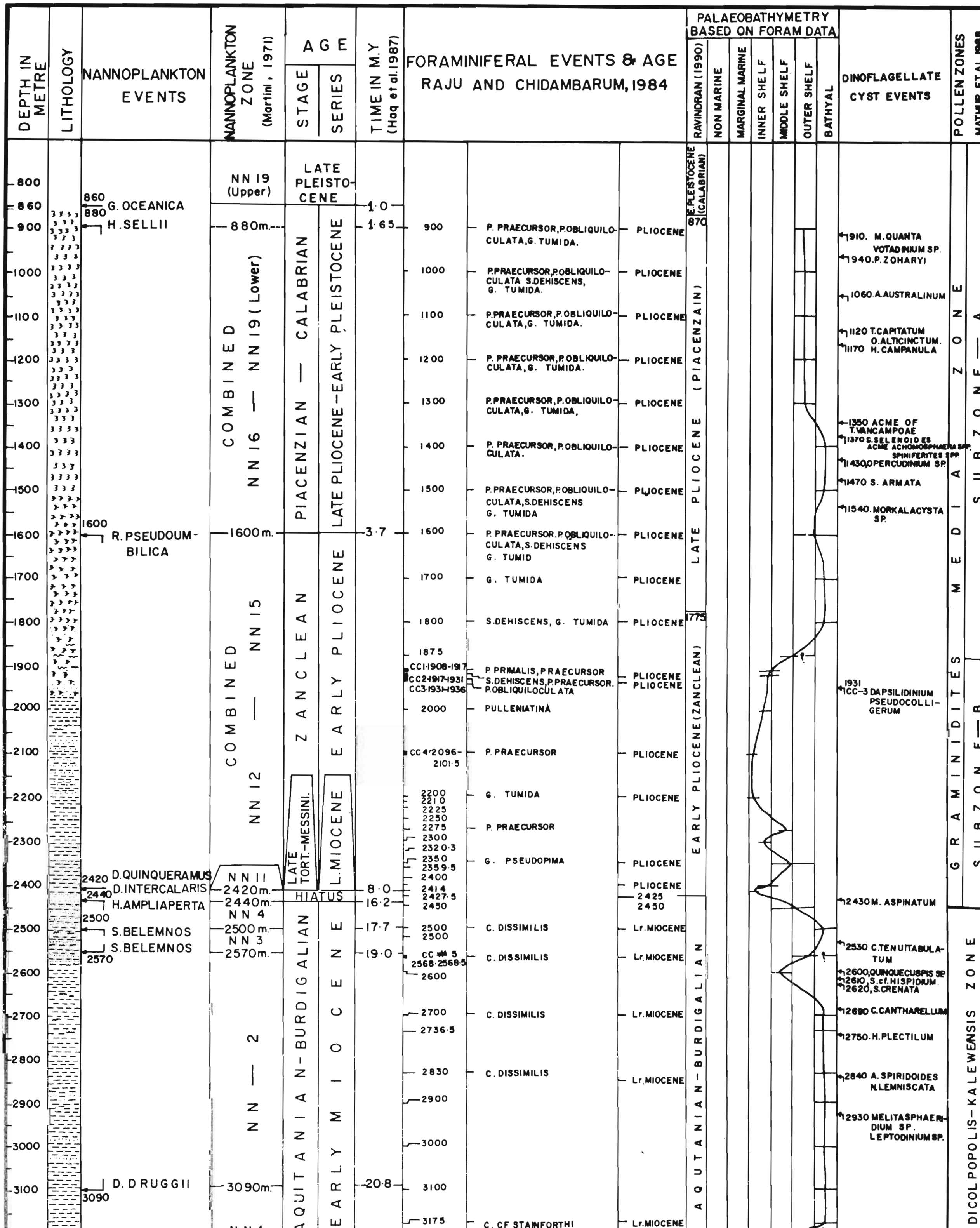


Fig. 4. Microfossil events and chronostratigraphy of the well G-2-D, offshore Krishna-Godawari Basin, India.

D. adamanteus Bramlette and Wilcoxon, 1967 (Not Illustrated)

D. deflandrei Bramlette and Riedel, 1954 (pl. 6/26)

D. druggii Bramlette and Wilcoxon, 1967 (Not Illustrated)

D. intercalaris Bukry, 1971 (pl. 6/20)

D. quinqueramus Gartner, 1969 (Not Illustrated)

D. variabilis Martini and Bramlette, 1963 (pl. 6/13)

Genus *Gephyrocapsa* Kamptner, 1943

G. oceanica Kamptner, 1943 (pl.6/14; 6/15)

Genus *Helicosphaera* Kamptner, 1954

H.ampliaperta Bramlette and Wilcoxon, 1967 (Not Illustrated)

H. kamptneri Hay and Mohler in Hay *et al.*, 1967 (pl. 6/2; 6/3; 6/4)

H.neogranulata Gartner, 1977 (Not Illustrated)

H.sellii Bukry and Bramlette, 1969 (pl.6/5; 6/6; 6/31)

Genus *Pontosphaera* Lohmann, 1902

P.multipora (Kamptner, 1948) Roth, 1970 (pl.6/21; 6/22)

P.plana (Bramlette and Sullivan, 1961) Haq,1971(pl. 6/17)

Genus *Pseudoemiliania* Gartner, 1969

P.lacunosa (Kamptner, 1963) Gartner, 1969 (pl.6/7;6/8)

Genus *Reticulofenestra* Hay, Mohler and Wade, 1966

R.pseudoumbilica (Gartner, 1967) Gartner, 1969 (pl. 6/18; 6/19)

Genus *Sphenolithus* Deflandre in Grasse, 1952

S.belemnos Bramlette and Wilcoxon, 1967 (pl.6/27; 6/28;6/29)

S. compactus Backman, 1900 (pl. 6/30)

S.conicus Bukry, 1971 (pl.6/23; 6/24; 6/25)

S.moriformis (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967 (Not Illustrated)

PLANKTIC FORAMINIFERAL CONTROL

Raju and Chidambaram (1984) have listed the occurrence of characteristic foraminifera at every 100m interval between 900-3200m depth. They consider 3200 to 2425m interval as early Miocene and interval from 2425 to 900 m as Pliocene. Ravindran (1990) also studied foraminifera from this well and dated the sediments of this well as follows :

860 - 870m Early Pleistocene (Calabrian)

870 - 1775m Late Pliocene (Piacenzian)

1775 - 2450m Early Pliocene (Zanclean)

2450 - 3200m Lower Miocene (Aquitanian-Burdigalian)

CHRONOSTRATIGRAPHY AND TIME BOUNDARIES

Fig. 4 shows a correlation between dinoflagellate cyst events, nannoplankton chronostratigraphic boundaries and planktic foraminiferal datums. Raju and Chidambaram (1984) mark the boundary between Lower Miocene and overlying Pliocene at 2425m, whereas this boundary is marked at 2450m by Ravindran (1990). Both of these studies are based on planktonic foraminifera. Mathur *et al.* (1988) demarcated this boundary on the basis of pollen and spore data at 2440m. The LAD of dinoflagellate cyst *Membranophoridium aspinatum* at 2430m marks this boundary. It seems that Early Miocene/Pliocene boundary is somewhere between 2425m and 2450m. The Pliocene-Pleistocene boundary is marked at 870m by Ravindran (1990) and 880 by Mathur *et al.* (1988).

Early Miocene calcareous nannoplankton events in this well range in age from NN1 to NN4 zones covering a time span of 4.6 Ma from 20.8 Ma to 16.2 Ma. The Late Miocene to Early Pleistocene covers NN 11 to lower part of NN 19 zones covering a time span of 6.5 Ma from 8.0 Ma to 1.5 Ma. Nannoplankton event *Discoaster quinqueramus* indicates the presence of Late Miocene (Late Tortonian-Messinian) sediments at 2420m depth. Thus, the time gap at 2440m is between the top of Early Miocene (16.2 Ma) and the base of Late Miocene (8.0 Ma) is 8.2 Ma, which is a major unconformity in this well section.

The Pliocene/Pleistocene boundary is marked at 880m based on the LAD of *Helicosphaera sellii* which marks Early Pleistocene (Takayama, 1993) and presence of *Helicosphaera neogranulata* which marks Pleistocene (Gartner, 1977). Here known LAD of *H. sellii* is considered to be significant whereas, presence of *H. neogranulata* supports the presence of Early Pleistocene in the section. The Plio-Pleistocene boundary falls at 880m tentatively because the absence of *H. neogranulata* at 890m and presence of *H.sellii* at 880m. The boundary does not match with Ravindran's(1990) boundary at 870m. This discrepancy needs to be further studied. Similarly, the boundary between Early and Late Pliocene is demarcated at 1775m by Ravindran (1990), whereas we put this boundary on the LAD of *Reticulofenestra pseudoumbilica* at 1600m. The dinoflagellate cyst events within this chronostratigraphic framework is useful and the time resolution of the order of 0.5 Ma can be achieved.

DEPOSITIONAL ENVIRONMENT

Almost all the studied samples contain fair to good assemblage of palynomorphs. However, few samples are almost barren of dinoflagellate cysts, though they have yielded pollen grains. Most of the assemblages are dominated by pollen-spores and dinoflagellate cysts form only a minor constituent of the assemblage. Generally, dinoflagellate cysts form 20% to 40% of the overall palynomorph assemblage which at times could be much less. This ratio does not show any trend in depositional environments in relation to the depth of water and distance from the shoreline. Raju and Chidambaram (1984) have interpreted the approximate palaeobathymetry using planktic foraminiferal data. The depth curve indicates that most of the Early Miocene and Pliocene section was deposited under outer shelf to bathyal environments. A shallowing is evident in the Early Pliocene part and depths have frequently varied from inner-shelf to bathyal environments during lower part of the early Pliocene and upper part of the Early Miocene section. Palynological data does not indicate any such trend, mainly because the shelf area is narrow and the rates of sedimentation have been fast coupled with the supply of enormous amounts of organic debris from land through large river systems.

CONCLUSIONS

1. An offshore well G-2-D was studied with an objective to demarcate dinoflagellate cyst events and to provide biochronzones based on calcareous nannoplankton.

2. An unconformity of 8.2 Ma duration is marked between Early Miocene and Late Miocene at depth 2440m based on nannoplankton biochronzones, whilst dinoflagellate event suggests unconformity at 2430m between Early Miocene and Pliocene.

3. Eighteen dinoflagellate cysts events, nine in Early Miocene and nine in Pliocene are demarcated, based mainly on LADs.

4. Calcareous nannoplankton biochronozones provide a time framework for this well section which have been correlated with Haq *et al.* (1987).

5. These sediments were deposited under outer-shelf to bathyal environments.

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EXPLANATION OF PLATES

Plate I

(Magnification : x approx. 700)

1. cf. *Bitectatodinium tepikiense*, 880 (2): 67.3 x 110.7
2. *Cyclopsiella elliptica*,910(2): 69 x 98.2
3. *Achomosphaera ramulifera*,870 (1) :60.5 x 98.0
4. *Selenopemphix nephroides*, 1070 (1): 59.9 x 99
5. *Batiacasphaera* sp, 1000 (2): 56 x 108.2
6. *Multispinula quanta*, 1060 (2); 66.5 x 95.5
7. *Pterospermella* sp.,910(1):28.3 x 96.7
8. ? *Bitectatodinium* 890 (1): 38.2 x 99

9. *Omanodinium alticinctum*, 1040 (2) 50.1 x 104.2
10. *Cymatiosphaera sp.*, 1070 (2): 28.9 x 95.5
11. *Leiosphaeridia* sp., 950 (2): 36.8 x 96.3
12. *Dapsilidinium pseudocolligerum*, 970 (1) : 56 x 92
13. *Achomosphaera ramulifera*, 970 (1): 53.2 x 96.5
14. *Leipokatium invisitatum*, 1100(1):36.4x 111
15. *Tuberculodinium vancampoae*, 950 (1):46.1x106.8

Plate II

(Magnification : x approx. 700)

1. *Multispinula quanta*, 1090 (1): 50.6 x 110.8
2. *Trinovantedinium capitatum*, 1140 (1):4.5 x 97
3. *Trinovantedinium capitatum*, 1120 (1):37.5 x98.2
4. *Bitectatodinium tepikiense*, 1120 (1):37.5 x98.2
5. *Labyrinthodinium* sp.,1230(2): 46.2 x 110.2
6. *Batiacasphaera* sp.,1000 (1): 58.5 x 96.8
7. *Labyrinthodinium truncatum*, 1200 (1): 34.3 x 92
8. *Spiniferites ramosus ramosus*, 1370 (1) : 62 x 108.8
9. cf. *Impletosphaeridium* sp., 950 (2); 52.3 x 98.2
10. *Micrhystridum* sp., 1160 (1):34 x 109.6
11. *Cymatiosphaera* sp.,1370 (1): 34 x 109.6
12. *Cymatiosphaera* sp.,1230 (2):27x 100.5
13. ?*Votadinium*sp., 1020(2):64.3 x102
14. *Concentricystes* sp., 950(1): 61.8 x 94.5
15. *Kallosphaeridium* sp., 1150 (1): 50.3 x 98

Plate III

(Magnification : x approx. 700)

1. cf. *Polysphaeridium zoharyi*, 2390(2) : 59x106.8
2. *Apteodinium* type, (x250) 1410(2) : 51.2x94.6
3. *Xandarodinium xanthum*, 2400(1) : 33.5x102.8
4. *Morkallacysta* sp., 2130(1) : 36.8x103.8
5. *Trinovantedinium capitatum*, 2315(2) : 53.8x94
6. *Morkallacysta* sp., 1540(2) : 58.5x102.7
7. *Multispinula quanta*, 2000(1) : 36.8x103.6
8. *Leipokatium invisitatum*, 1160(1) : 26.4x92.9
9. *Selenopemphix selenoides*, 2250(1) : 47.2x96.8
10. *Selenopemphix selenoides*, 2300(1) : 46.7x101.5
11. *Selenopemphix selenoides*, 2240(2) : 57.5x98.7
12. *Cyelopsiella cf. granosa*, 2300(2) : 35.2x108.2
13. *Batiacasphaera* sp., 1460(1) : 32.3x94.3
14. *Acritarch* - A, 1480(2) : 32x96.4
15. *Cymatiosphaera* sp., 1200(2) : 67x99
16. *Batiacasphaera* sp., 1540(1) : 38.5x100.1
17. *Multispinula quanta*, 1410(1) : 62.1x106.8
18. *Lejeunecysta hyalina*, 1410(1) : 62x107.8

Plate IV

(Magnification : x approx. 700)

1. *Batiacasphaera* sp., 1400(1) : 51.4x106.4
2. *Membranophoridium* cf. *aspinatum*, 2430(2) : 43.7x105.5
3. *Trinovantedinium capitatum*, 2500(1) : 54.6x96
4. *Tuberculodinium* cf. *vancampoae*, 2500(1) : 61.4x101.5
5. *Cribroperidinium tenuitabulatum*, 2530(1) : 44.7x101.11

6. *Cordosphaeridium cantharellum*, 2930(1) : 66.4x103.5
7. *Pentadinium* sp., 3070(1) : 37.6x108
8. *Heteraulacacysta* cf. *granulata*, 3030(2) : 38.6x105.8
9. *Selenopemphix selenoides*, 2500(1) : 62x103
10. cf. *Brigantedinium simplex*, 1520(2) : 65x102.5
11. *Dapsilidinium pseudocolligerum*, 1160(1) : 44.3x110.8
12. *Selenopemphix armata*, 2750(1) : 51x103.7
13. *Selenopemphix crenata*, 2640(2) : 36.3x99.5
14. ?*Labyrinthodinium truncatum*, 1310(1) : 28x94.6
15. cf. *Polysphaeridium subtile*, 2300(1) : 48.4x101.6
16. ? *Operculodinium* sp., 3060(1) : 55.9x104.4
17. *Heteraulacacysta campanula*, 3175(1) : 22.7x101.2
18. *Cordosphaeridium cantharellum*, 3150(1) : 42.5x95.6
19. *Multispinula quanta*, 1470(2) : 44.8x106.7

Plate V

(Magnification : x approx. 700)

1. *Multispinula quanta*, 1160(1) : 52.3x98.2
2. *Cymatiosphaera* sp., 930(1) : 37x101
3. *Apteodinium spiridoides*, 3060(1) : 49x104.2
4. *Sumatradinium* cf. *hispidum*, 3175(1) : 40.3x103.2
5. *Sumatradinium* cf. *hispidum*, 2750(2) : 59x103.7
6. *Trinovantedinium capitatum*, 1780(1) : 41.5x100.8
7. *Selenopemphix coronata*, 2640(1) : 29.4x99.4
8. cf. *Labyrinthodinium* sp., 1310(1) : 29.9x101.6
9. *Lingulodinium machaerophorum*, 3175(1) : 67.5x103.6
10. *Kallosphaeridium* sp., 2570(1) : 30.7x98.6
11. *Tuberculodinium vancampoae*, 1460(2) : 29.3x109.9
12. *Cribroperidinium* cf. *tenuitabulatum*, 2930(1) : 67.1x103.8
13. *Tuberculodinium vancampoae*, 1350(1) : 40.7x98.8
14. *Polysphaeridium zoharyi*, 2750(2) : 57.9x103.2
15. *Labyrinthodinium truncatum*, 1170(1) : 55.5x102.8

Plate VI

(Magnification : x approx. 1600)

1. *Ceratolithus cristatus*, G-2-D, 940m, 7.9/110.1, In x-nicols

2-4. *Helicosphaera kamptneri*, G-2-D, 2220m, 2.6/116.02. In normal light,3-4. In x-nicols

5-6. *Helicosphaera sellii*, G-2-D, 1560m., 9.1/100.1 5. In normal light 6. In x-nicols

7-8. *Pseudoemiliania lacunosa*, G-2-D, 860m, 7.8/110.1 7. In normal light 8. In x-nicols

9. *Ceratolithus* sp. G-2-D, 1620m, 7.7/110.2, In x-nicols

10-11. *Coccolithus pelagicus*, G-2-D, 2220m,11.1/114.9 10. In normal light 11. In x-nicols

12. *Coccolithus pliopelagicus*, G-2-D, 2400m, 7.1/115.5. In x-nicols

13. *Discoaster variabilis*, G-2-D, 2440m, 10/115, In x-nicols

14-15. *Gephyrocapsa oceanica*, G-2-D, 860m, 8.1/110.3,14. In normal light 15. In x-nicols

16. *Calcidiscus leptoporus*, G-2-D, 860m, 8.1/110.3, In x-nicols

17. *Pontosphaera plana*, G-2-D, 2340m, 7.2/114.4, In x-nicols

18-19. *Reticulofenestra pseudoumbilica*, G-2-D, 2100m,10.0/111.2,18. In normal light 19. In x-nicols

20. *Discoaster intercalaris*, G-2-D, 2420m, 6.9/115.1, In normal light

21-22. *Pontosphaera multipora*, G-2-D, 860m, 7.8/109.0,21. In normal light 22. In x-nicols

23-25. *Sphenolithus conicus*, G-2-D, 2850m, 7.1/113.3, In x-nicols 23. In 90 ° 24. In 45 ° 25. 7.2/104.4, In x-nicols, 45 °

26. *Discoaster deflandrei*, G-2-D, 2850m, 8.5/110.5. In normal light

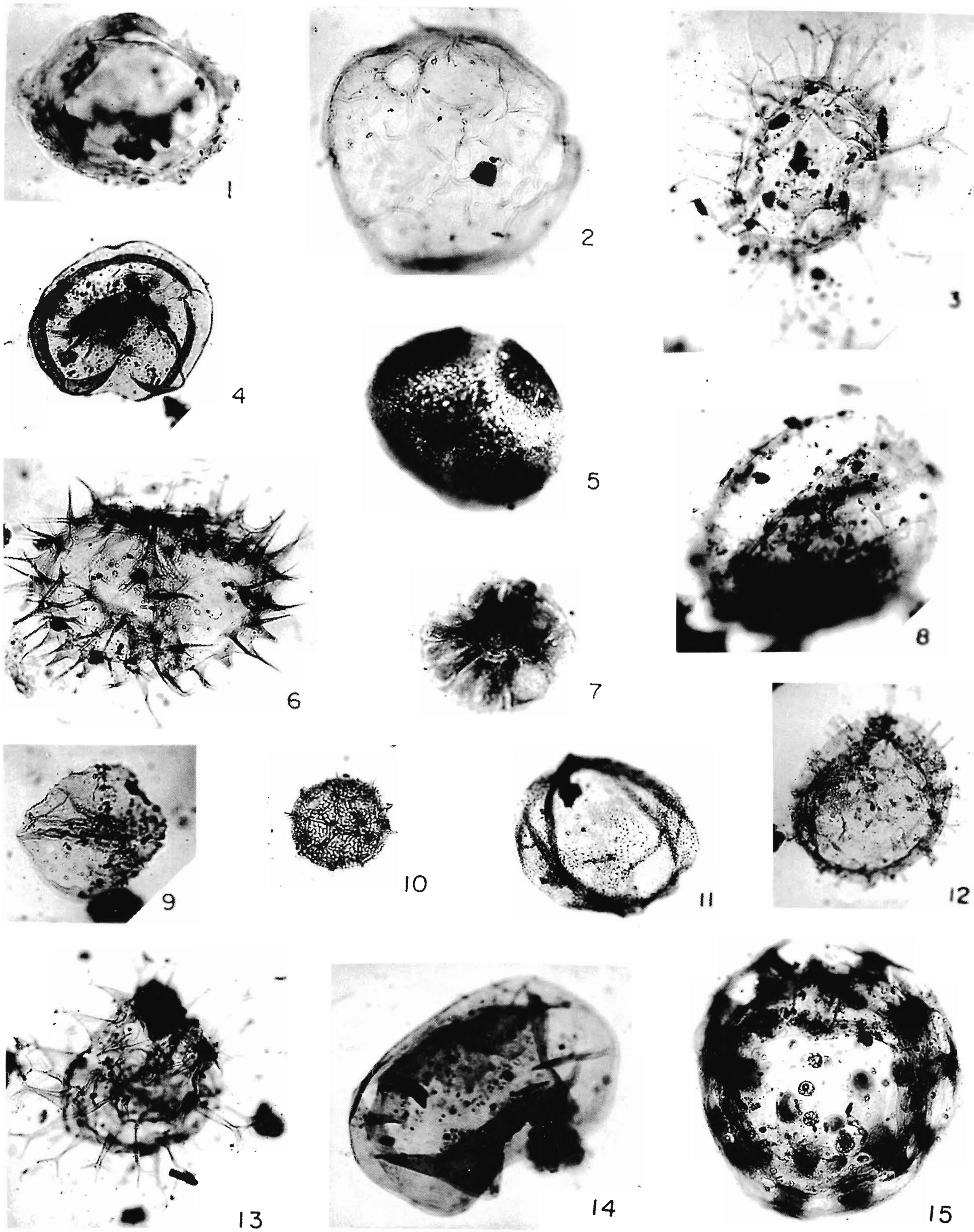
27-29. *Sphenolithus belemnos*, G-2-D, 2500m, 6.1/111.6, In x-nicols, 27. In 90 ° 28. In 45 ° 29. 2570m, In x-nicols, 45 °

30. *Sphenolithus compactus*, G-2-D, 2500m, 10.1/116.4. In x-nicols, 90 °

31. *Helicosphaera sellii*, G-2-D, 1190m, 14.1/115.9, In x-nicols

32. *Ceratolithus* sp., G-2-D, 1620m, 10.2/116.2, In x-nicols

33. *Reticulofenestra* sp., G-2-D, 2970m, 11.3/110.5, In x-nicols



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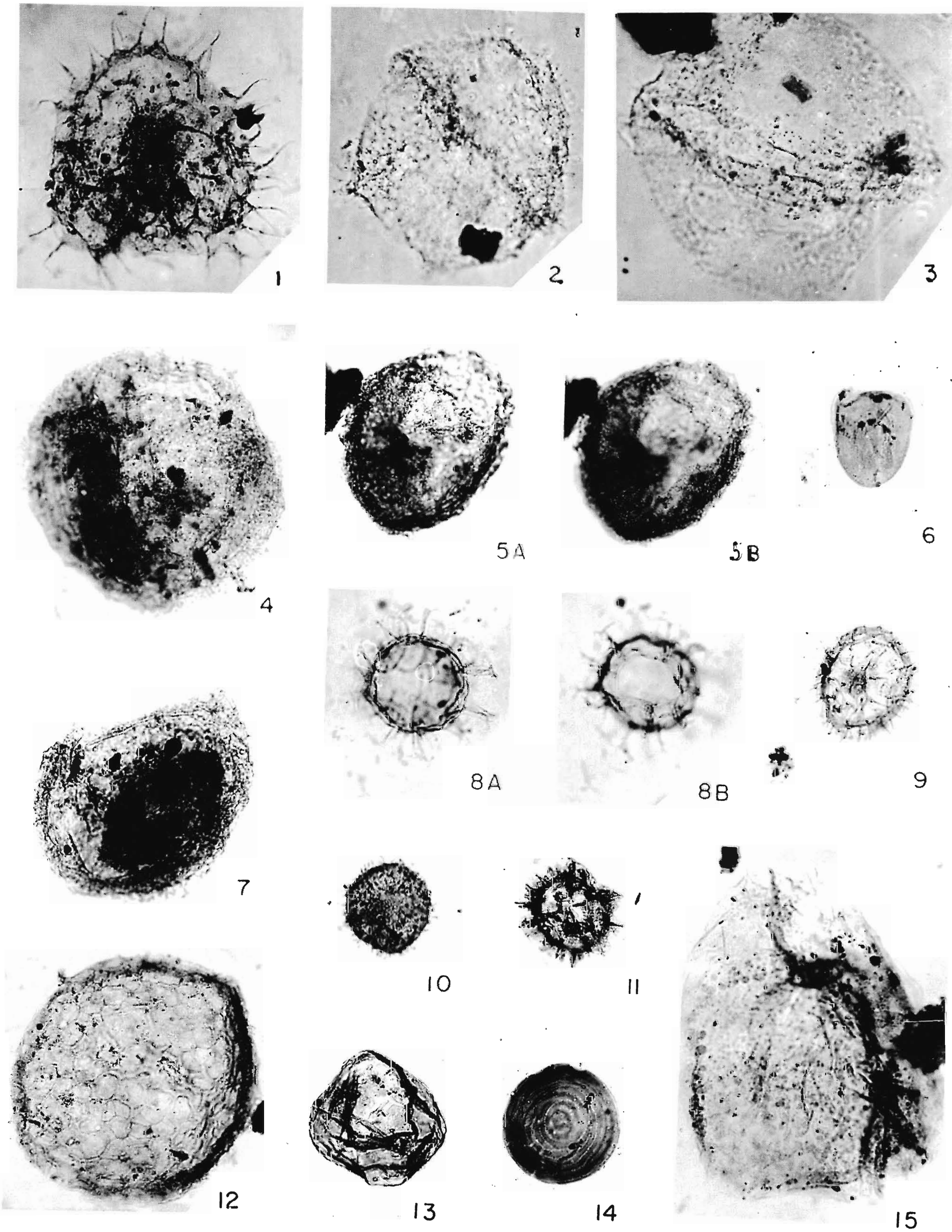

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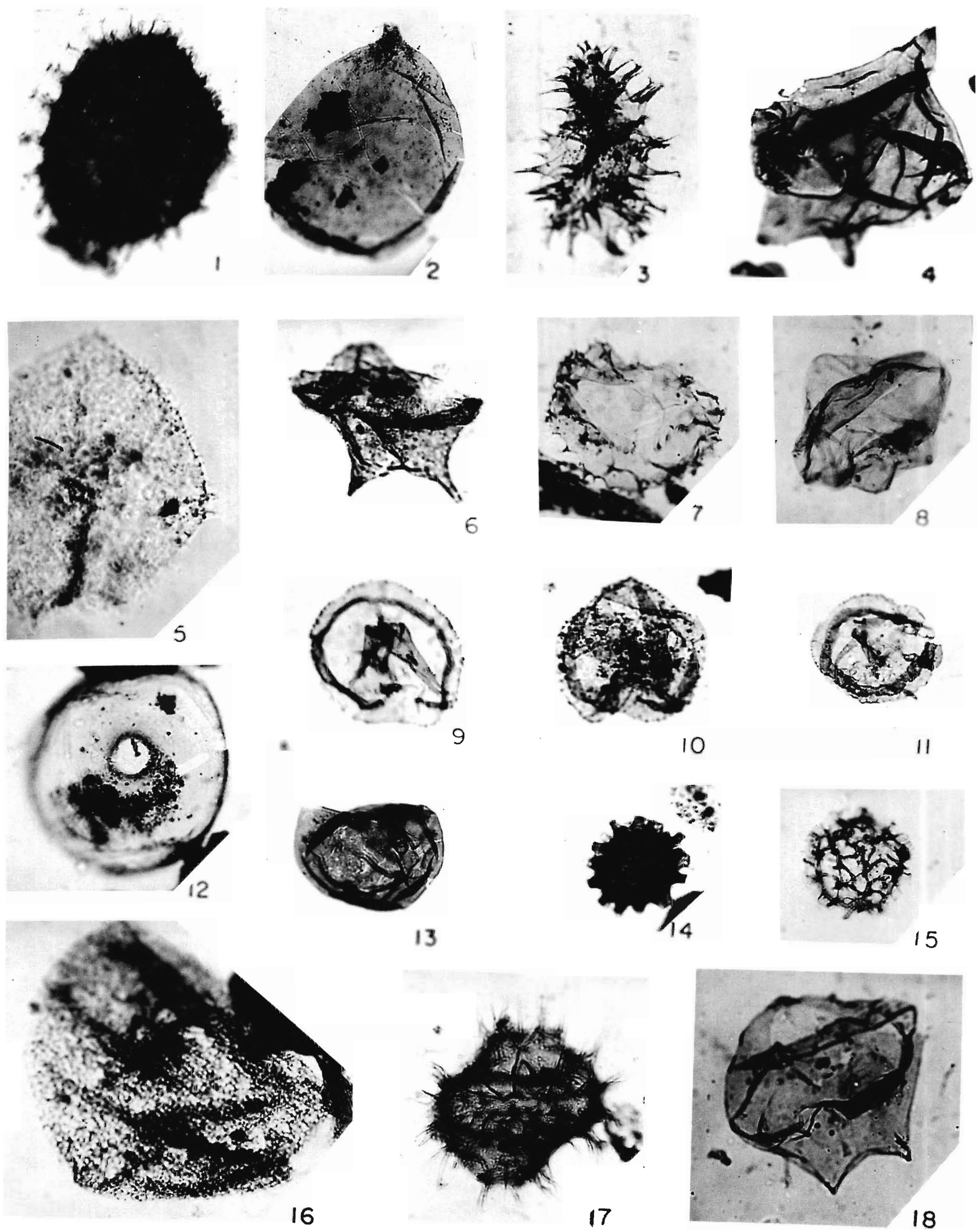
Plate III



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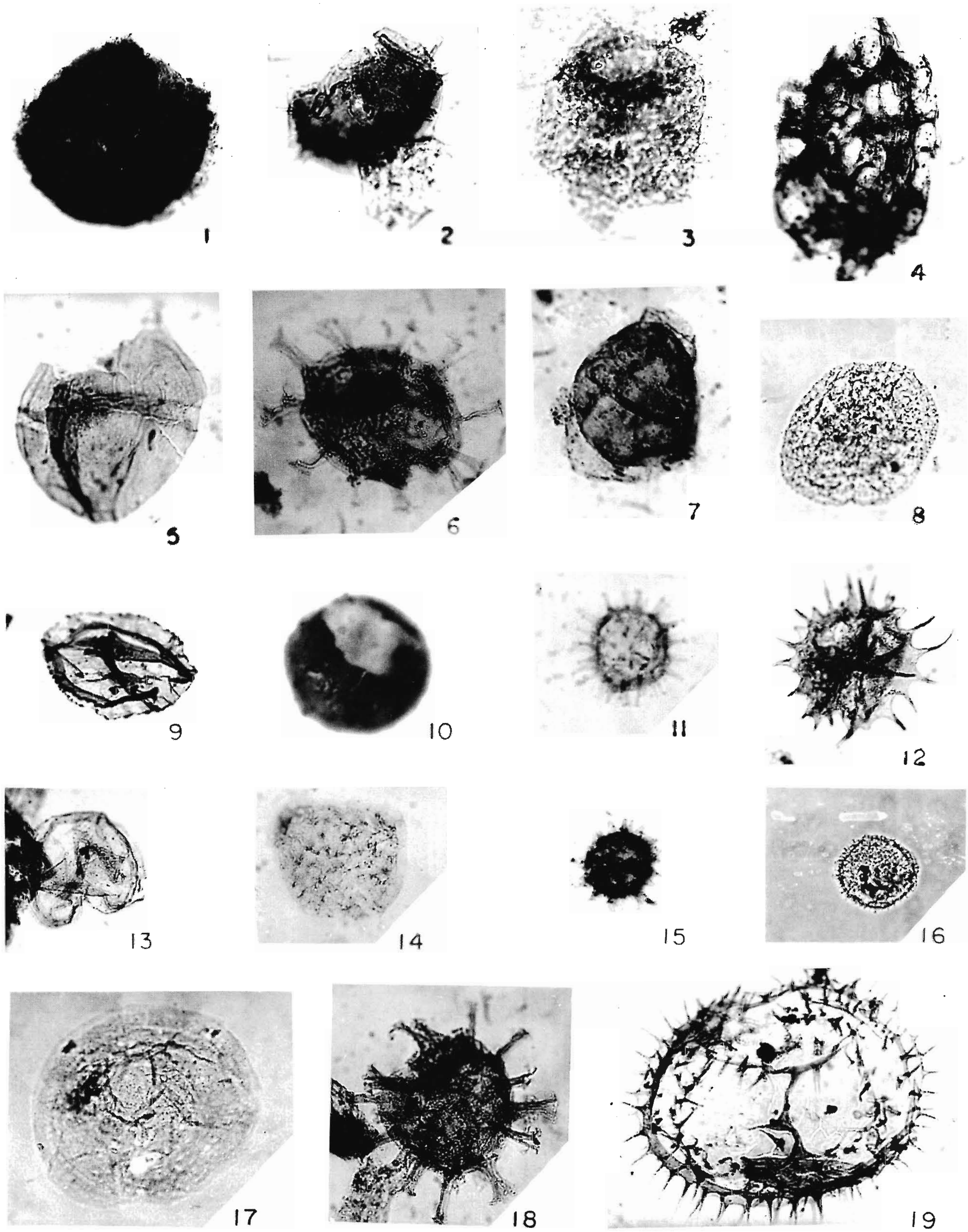

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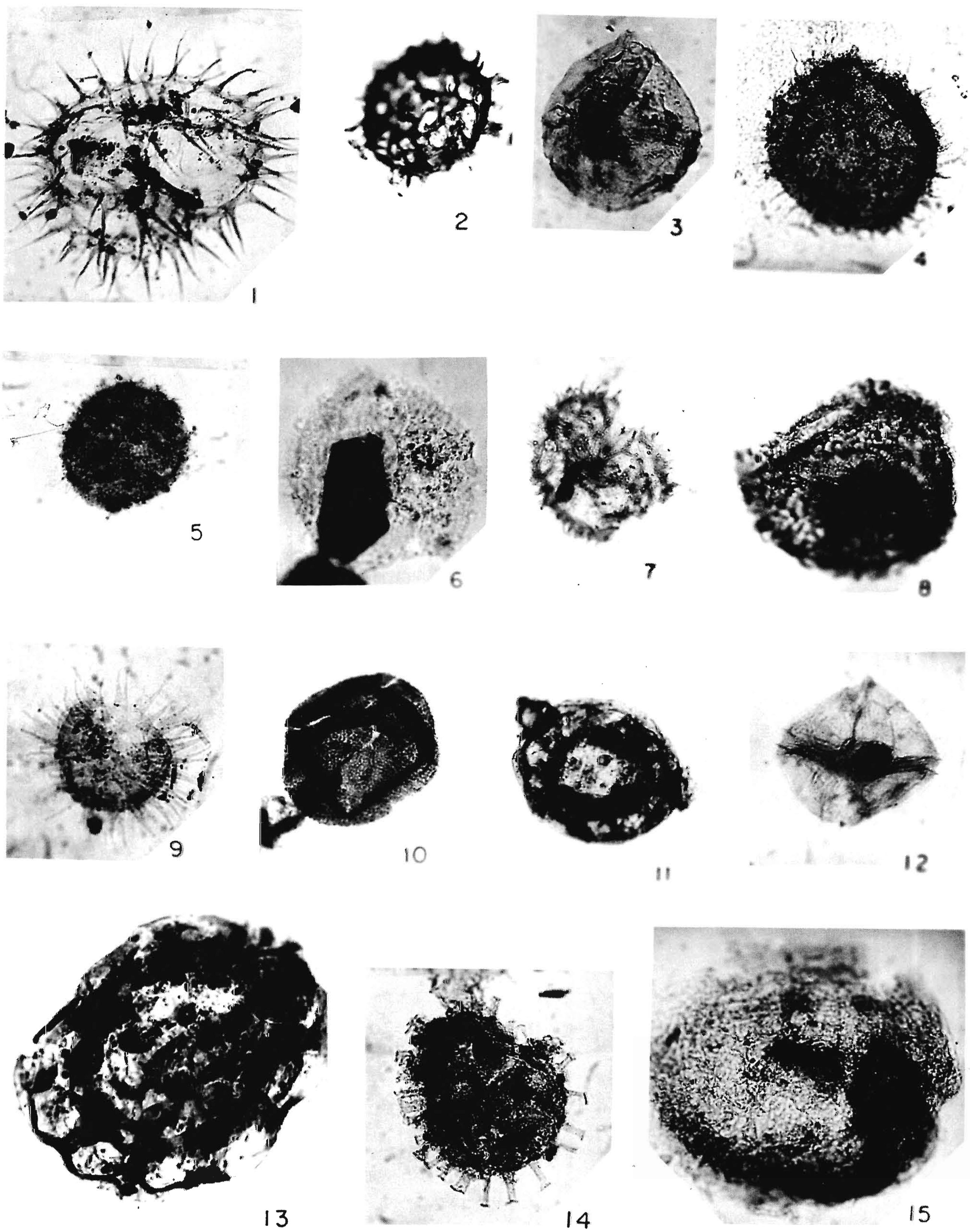
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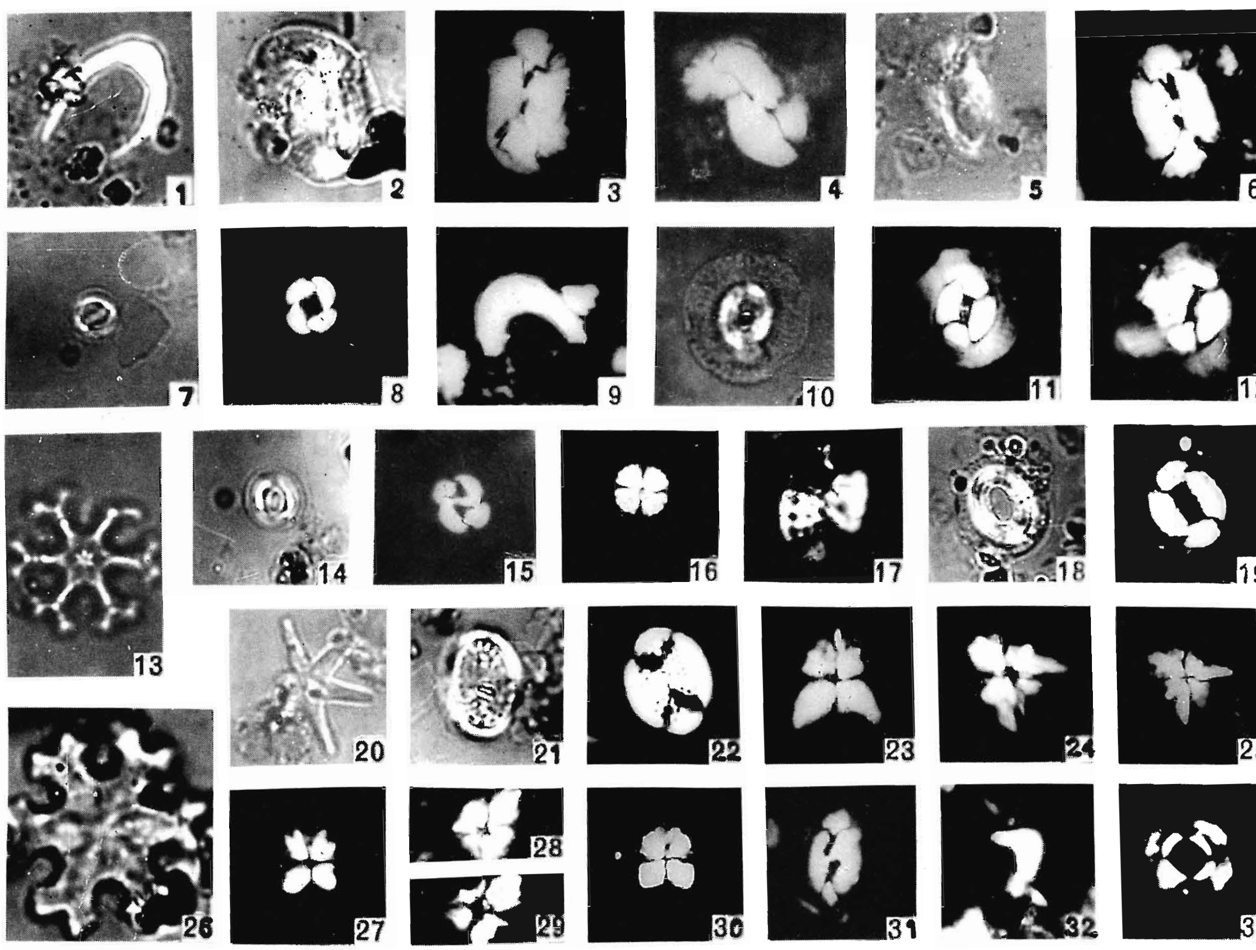

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