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RADIOLARIAN ZONATION AND VOLCANIC ASH LAYERS IN TWO QUATERNARY SEDIMENT CORES FROM THE CENTRAL INDIAN OCEAN BASIN

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ABSTRACT

Radiolarian abundance in two Quaternary sediment cores, collected from the Central Indian Basin, was studied and Nigrini's (1971) and Goll's (1980) zones are recognised. New radiolarian zones *Collosphaera orthoconus, Lamprocyrtis nigriniae, Lamprocyrtis neopheteroporos* and *Lamprocyrtis heteroporos* are proposed and described to modify Nigrini's (1971) and Goll's (1980)'s zonations. A hiatus of 0.2-0.3 M.Y., corresponding to *Pseudocubus warreni* zone (Goll, 1980) in core F-88 B, suggest the erosion and redistribution of Pliocene taxa by a bottom water current (probably Antarctic Bottom Water Current). Volcanic ash layers of apparently about 20,000; 30,000 - 40,000; 80,000; 340,000 and younger than 400,000 years are also recognised, which suggest suboceanic explosive volcanic eruptions durind late Quaternary in the area.

INTRODUCTION

Radiolaria are a major microfossil group in oceanic deposits below corbonate compensation depth, where siliceous microfossils are the only means of biostratigraphic studies. Quaternary radiolarian biostratigraphic studies in high latitudes (Hays, 1965; Hays and Opdyke, 1967), in middle latitudes (Hays, 1967; Kling, 1971 and 1973; Nigrini, 1970) and in the tropics (Nigrini, 1971; Petrushveskaya, 1972; Johnson and Knoll, 1975; Caulet, 1979; Goll, 1980) have established the well marked datum levels. First of all Nigrini (1971) proposed a four-fold classification for Quaternary radiolarian deposits and Johnson and Knoll (1975) have established the absolute dates for eight radiolarian events in two paleomagnetically dated (Hays, Saito, Opdyke and Burckle, 1969) Equatorial Pacific Cores. Later Goll (1980) divided East Pacific Rise Quaternary Radiolaria into two major zones and eight sub zones. Johnson (1974) found difficulties in applying Nigrini's zonation (1971) due to the poor preservation and low abundance of stratigraphically important taxa in the Eastern Indian Ocean. The principal objective of the present study was to recognise the Nigrini's (1971) and Goll's (1980) zones and other radiolarian events in the cores collected from the Central Indian Basin.

MATERIAL AND METHODS

The sediment cores (Boomerang core F - 88 B; 12°.43'S, 77°.03' E, depth 5427 m., core length 88 cm. and Boomerang core F-200 B; 12°.00'S, 76°.45' E, depth 5460 m., core length 86 cm.) were retrieved by the Boomerang corer in two cruises of M.V. Farnella, a chartered vessel for the survey of polymetallic nodules, from an almost flat topography in the Central Indian Basin (Figure-1). Onboard observation (faecal pellets on the top) of the retrieved core showed the top layer intact. The cores yielded well preserved Radiolaria and volcanic glass shards. The sediment cores were subsampled at 5 cm. interval,

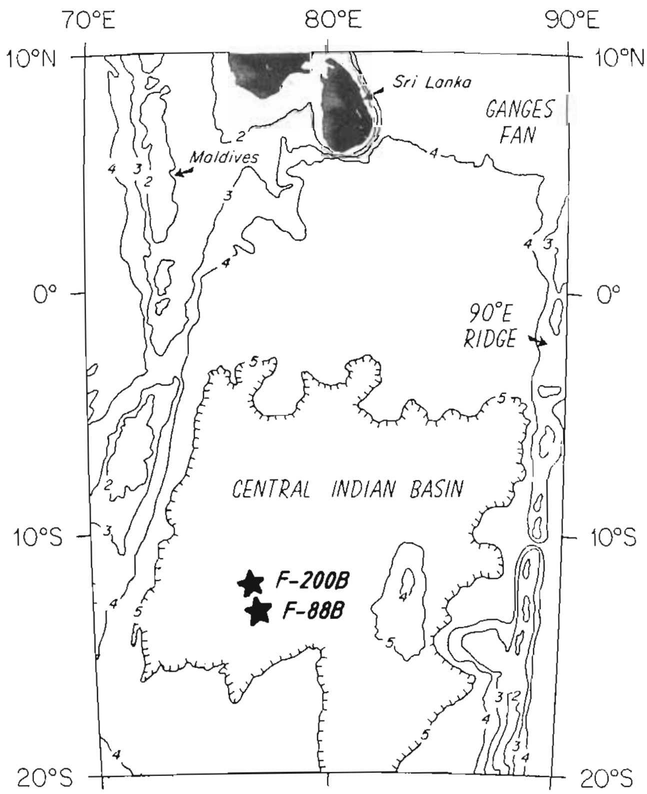


Fig. 1. Location of the Boomerang cores in the Central Indian Ocean Basin and physiographic setting (B = Boomerang cores, Depth in Kms.).

Table 1A. Distribution of stratigraphically important radiolarian taxa in core F-88 B.

Taxa	Sediment subsample interval (cm.)								
	0 - 6	11 - 16	21 - 26	31 - 36	41 - 46	51 - 56	61 - 66	71 - 76	81 - 80
Glass shards	Cb	—	Cb	Cb	—	—	—	—	—
Pterocanium prismatium	—	—	—	—	—	—	—	—	—
Sphaerozoum crossus	—	—	—	—	—	—	—	—	—
Theocorythium vetulum	—	—	—	—	—	—	—	—	—
Lamprocyrtis heteroporos	—	—	—	—	—	—	—	T	R
Lamprocyrtis neoheteroporos	—	—	—	—	—	—	T	R	C
Spongaster pentas	—	—	—	T	—	—	—	—	—
Lamprocyrtis nigriniae	F	F	F	F	F	R	R	—	—
Anthocyrtidium angulare	—	—	—	—	—	R	C	C	C
Nephrospyris renilla renilla	C	C	C	C	T	—	—	—	—
Nephrospyris renilla lana	—	—	—	T	T	R	C	C	C
Amphispyris roggentheni	—	—	—	—	T	F	F	F	F
Stylactractus universus	—	—	—	—	F	F	F	F	F
Androspyris fenstrata	—	—	—	F	F	F	F	F	F
Androspyris anthropiscus	—	—	—	R	R	R	R	R	R
Androspyris huxleyie	F	F	F	F	F	—	—	—	—
Amphirhopalum ypsilon	C *5,3,2	C *5,3,2	C *5,3,2	C *3,2,5	C *2,3,5	C *2,3,5	C *2,3	C *2,3	C *2,3
Theocorythium trachelium	C	C	C	C	C	C	C	C	C
Lithopera bacca	C	C	C	C	C	C	C	C	C
Sphearozoum punctatum	T	T	T	T	—	—	—	—	—
Collosphaera orthoconus	—	F	F	—	—	—	—	—	—
Collosphaera tuberosa	C	C	—	—	—	—	—	—	—
Collosphaera invaginata	F	—	—	—	—	—	—	—	—
RADIOLARIAN ZONES	COLLOSPHAERA INVAGINATA (Nigrini, 1971)	COLLOSPHAERA TUBEROSA (Nigrini, 1971)	COLLOSPHAERA ORTHOCONUS (Present pap	NEPHROSPYRIS RENILLA (Goll, 1980) HIATUS	AMPHISPYRIS ROGGENTHENI (Goll, 1980)	LAMPROCYRTIS NIGRINIAE (Present pap.)	LAMPROCYRTIS NEOHETEROPOROS (-do-)	LAMPROCYRTIS HETEROPOROS (-do-)	
SEDIMENT ACC. RATE SAR (Borole, in press)	← 0.8 mm/1000 yrs. →				(after Johnson & Knoll, 1975)	1.01MY	1.30MY		
EXTRA-POLATED AGE (in 1000 yrs., ±10,000 yrs.)		111	200	333					

subsamples were dried and dispersed in 10% Sodium hexametaphosphate, then treated with 30% Hydrogen peroxide for four hours and afterward sieved on 62 micron mesh. From each subsample two permanent strewn slides (Nigrini, 1967) and two smear slides were made in Canada balsam. Radiolaria are studied under a Carl Zeiss Jena optical microscope, at 200 X for identification and 80 magnification for faunal counting and transmitted light photomicrographs are used for illustrations.

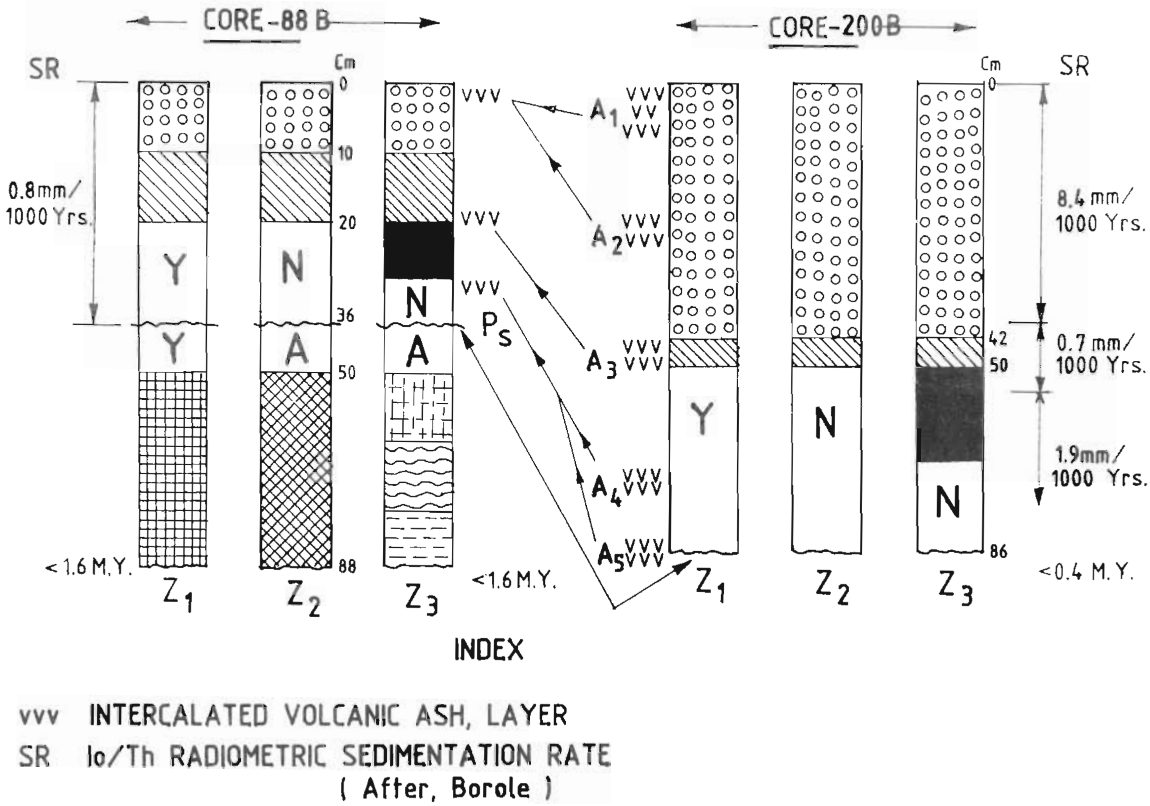
RESULTS

Identification of stratigraphically important species is done (Taxonomic appendix) and their abundance

Table 1B. Distribution of stratigraphically important radiolarian taxa in core F-200 B.

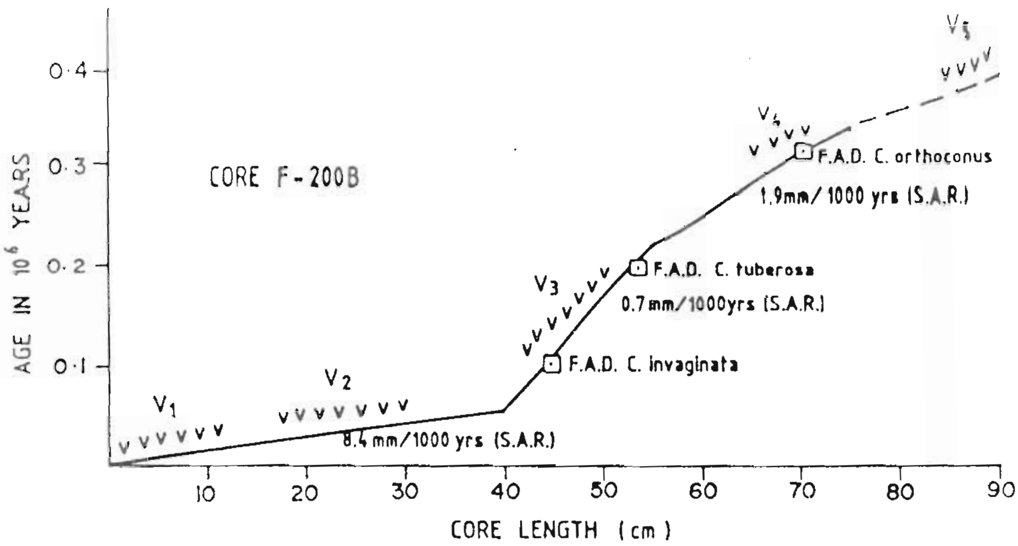
Index to table - 1A & 1B: — = Nil; T = Traces 1-3 specimen/slide; R = Rare, 3.5 specimens/slide; F = Few, more than 5 specimens/slide; C = Common, 10 specimens/slide; A = Abundant, 15 specimen/slide.
* = number of chambers in order of abundance, before bifurcation of the forked arm of *A. yepsilon.*
Glass shards: Ab = Abundant, broken bubble type; Ac = Abundant bubble and pumiceous type, Cb = Common bubble type; Cc = Common bubble and pumiceous type.

Taxa / Sample	Subsample interval (cm) 0 - 1	6 - 7	10 - 11	14 - 15	20 - 21	30 - 31	40-41	43-44	46-47	49-50	51-52	61-62	71-72	81-82	85-86
Glass shrads	Ac	Ac	Ac	Ac	Ab	Ab	—	—	Ab	Ab	—	—	Cb	—	Cb
Phytoliths	A	A	A	A	—	—	C	C	C	C	—	—	—	C	C
S. pentas	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
L. nigriniae	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
A. angulare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N. renilla	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
N. renilla lana	—	—	—	—	—	—	—	—	—	—	—	C	C	C	C
A. roggentheni	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S. universus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A. fenestrata	—	—	—	—	—	—	—	F	F	F	F	F	F	F	F
A. anthropiscus	—	—	—	—	—	—	F	F	F	F	F	F	F	F	F
A. huxleyie	F	F	F	F	F	F	F	F	—	—	—	—	—	—	—
A. ypsilon	C * 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3	C 5, 3
T. trachelium	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
L. bacca	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
C. orthoconus	—	—	—	—	—	F	F	F	F	F	F	F	F	—	—
C. tuberosa	C	C	C	C	C	C	C	C	F	F	F	—	—	—	—
C. invaginata	F	F	F	F	F	F	F	F	—	—	—	—	—	—	—
RADIOLARIAN ZONES	COLLOSHAERA INVAGINATA (Nigrini, 1971)								COLLOSPHAERA TUBEROSA (Nigrini, 1971)			COLLOSPHAERA ORTHOCONUS		NEPHROSPYRIS RENILLA (Goll, 1980)	
SEDIMENT ACCUMULATION RATE. (Borole, in press)	← 8.4 mm/1000 yrs. →						40 cm.		← 0.7 mm/1000yrs →		54 cm.	← 1.9 mm/ 1000yrs. →	76 cm.		
EXTRAPOLATED AGE OF THE SECTIONS							48,000		57,000		52 cm. 114,000		120,000		
AGE AT DATUM LEVELS (in yrs. ± 10,000)									1,05,000		2,19,000		3,40,000		



Z1 NIGRINI (1971) INDEX		Z2 GOLL (1980)	INDEX	Z3 PRESENT WORK	INDEX	AGE IN M.Y. JOHNSON & KNOLL (1975)	GOLL (1980)	HEREIN
(circles)	BUCCINOSPHAERA INVAGINATA	COLLOSPHAERA INVAGINATA	(circles)	COLLOSPHAERA INVAGINATA	(circles)			
(hatched)	COLLOSPHAERA TUBEROSA	COLLOSPHAERA TUBEROSA	(hatched)	COLLOSPHAERA TUBEROSA	(hatched)	0.21	0.1	0.10
Y	AMPHIRHOPALUM YPSILON	NEPHROSPYRIS RENILLA	N	COLLOSPHAERA ORTHOCONUS	(black)	0.37	0.2	0.20
				NEPHROSPYRIS RENILLA	N			0.35
		PSEUDOCUBUS WARRENI	Ps	PSEUDOCUBUS WARRENI	~HIATUS~		0.4	0.40
		AMPHISPYRIS ROGGENTHENI	A	AMPHISPYRIS ROGGENTHENI	A		0.6	
(grid)	ANTHOCYRTIDIUM ANGULARE	ACROSPHAERA TREPANATA	(cross-hatched)	LAMPROCYRTIS NIGRINIAE	(crosses)	0.9	0.9	
				LAMPROCYRTIS NEOHETROPOROS	(wavy)	1.1		
		NEOSEMANTIS HOFFERI		LAMPROCYRTIS HETROPOROS	(dashed)	1.3	1.3	
		SIPHANOSPHAERA TENARA		NOT FOUND			1.6	
							1.8	

Fig. 2. Quaternary radiolarian zones and volcanic ash layers in core F-88 B and core F-200 B.



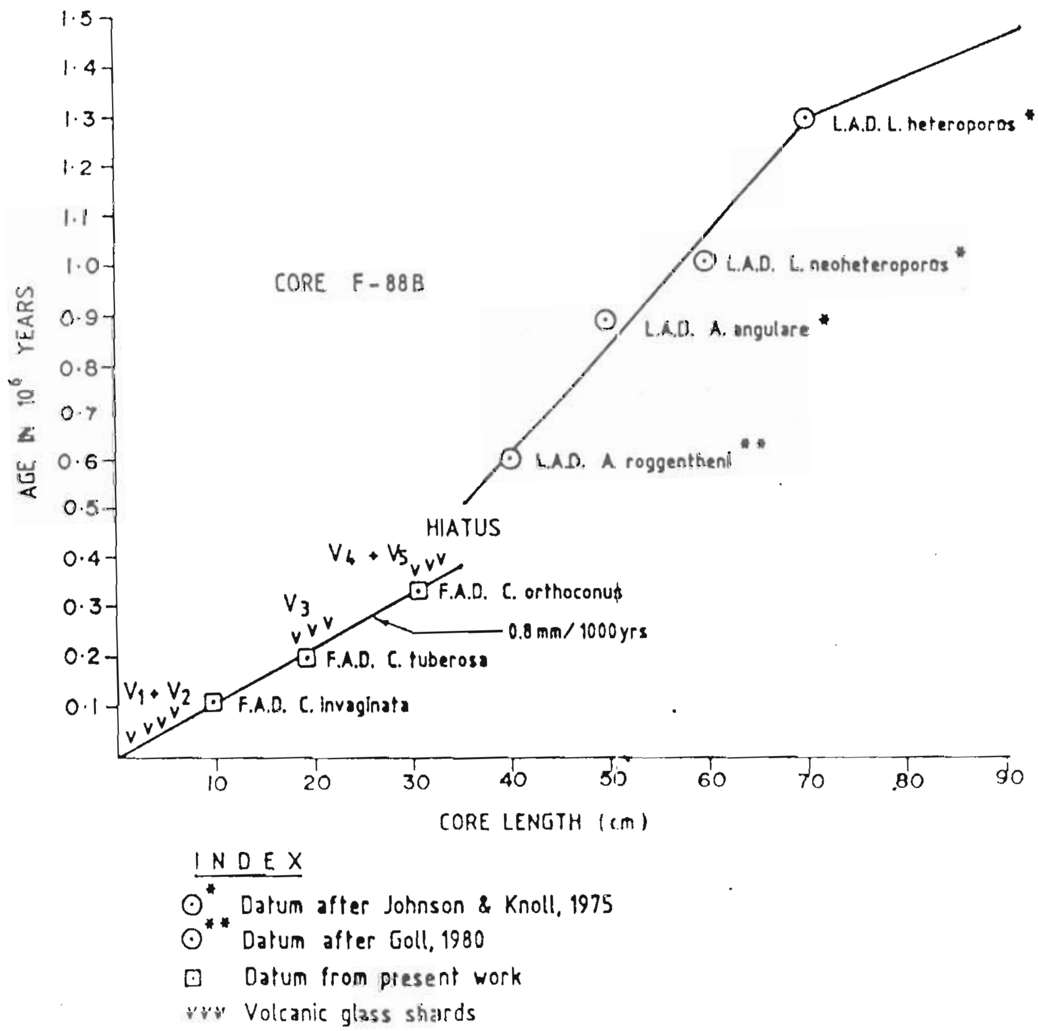


Fig. 3. Radiolarian events and Volcanic ash layers in cores F-88 B and core F-200 B.

(Table-1A, 1B) in the cores is worked out. The Quaternary radiolarian events (Johnson and Knoll, 1975) in the cores are recognised (Figures-2 & 3 and Tables-1A & 1B). The Quaternary zones *Collosphaera invaginata, Collosphaera tuberosa, Amphirhopalum ypsilon, Anthocyrtidium angulare* zones (Nigrini, 1971) and *Nephrospyris renilla, Amphispyris roggentheni, Acrosphaera trepanata* zones (Goll, 1980) are recognised. *Collsphaera orthoconus, Lamprocyrtis nigriniae, Lamprocyrtis neoheteroporos* and *Lamprocyrtis heteroporos* zones are described. Three to five intercalated layers of volcanic glass shards at 0-15 cm, 20-30 cm, 47-50 cm, 70-75 cm, and 82-86 cm in core F - 200 B and at 1-5 cm, 20-25 cm and 30-35 cm, in core F - 88 B are also recognised. Zone *Pseudocubus warreni* (0.4 - 0.6 M.Y., Goll, 1980) is totally missing in core F - 88 B and Pliocene taxa *Spongaster pentas* are found at that horison.

STRATIGRAPHIC CONTROL

Earlier sub sampling of core at 5 cm interval was done for the radiolarian zonation. When Dr. D.V. Borole (in press) provided Io/Th radiometric sedimentation rates of these cores, finer sub sampling at the core sections, where the sediment accumulation rates changes abruptly, (40-54 cm in core F - 200 B) was done at 2 cm interval to check the further extent of *Collosphaera invaginata, Collosphaera tuberosa* and newly proposed *Collosphaera orthoconus* zones. Comparison of radiolarian data and sediment accumulation rates (Borole, in press) and its extrapolated ages for the sections are given in Tables 1A & 1B and result is summarised in Figure 2. It resulted in Io/Th radiometric dates for First appearence datum level (F.A.D./Advent) of *Collosphaera invaginata* (0.11 ± 0.01 M.Y.) and *Collosphaera orthoconus* (0.34 ± 0.01 M.Y.), which are used to define the late Quaternary radiolarian zones.

COLLOSPHAERA INVAGINATA ZONE

Range zone (Nigrini, 1971)
Top: Present day sea floor
Base: Advent of *Collosphaera invaginata* (0.1 M.Y.)

Collosphaera invaginata, Collosphaera tuberosa, Amphirhopalum ypsilon, Lithopera bacca and *Theocorythium trachelium* are common in this zone. *Amphirhopalum ypsilon* with 5 proximal chambers before the bifurcation of forked arm, is dominent, followed by three chambered and 2 chambered specimens. This zone is 0-10 cm. in core F-88 B and 0-42 cm. in core F-200 B. Apparent age of these sections (Borole, in press) is about 0.1 M.Y., which is well in agreement to Goll (1980), but differ from Johnson & Knoll (1975), in a magnitude of 0.1 M.Y.

COLLOSPHAERA TUBEROSA ZONE

Concurrent range zone (Nigrini, 1971)
Interval zone (Sanfilippo, Westberg and Riedel, 1985)
Top: Advent of *Collosphaera invaginata* (0.1 M.Y.)
Base: Advent of *Collosphaera tuberosa* (0.2 M.Y.)

Absence of *Collosphaera invaginata* and common abundance of *Collosphaera tuberosa* and rare to common *Collosphaera orthoconus* in the core represent this zone. It is from 10-20 cm, in F-88 B and 44-52 cm, in core F-200 B. Apparent age of these sections is about 0.2 M.Y., which is well in agreement to Goll (1980) but differ from Johnson and Knoll (1975) in magnitude of 0.17 M.Y.

COLLOSPHAERA ORTHOCONUS ZONE (NEW ZONE)

Interval zone (described herein)
Top: Advent of *Collosphaera tuberosa* (0.2 M.Y.)
Base: Advent of *Collosphaera orthoconus* (0.34 M.Y.)

In this zone *Collosphaera tuberosa, Collosphaera invaginata* are absent. Zone is identified on the basis of rare to common occurence of *Collosphaera orthoconus*. This zone is 21-30 cm in core F-88 B and 52-76 cm in core F-200 B. Apparent radiometric age (Borole, in press) of these horizons is about 0.3-0.34 M.Y. (Figure-2 & 3, Table-1A & 1B). Johnson and Knoll (1975) have dated F.A.D. for *Collosphaera sp. A*, the same species at about 0.6 M.Y. in Equatorial Pacific, but in present case it is quite younger (0.3 - 0.34 M.Y.).

AMPHIRHOPALUM YPSILON ZONE

Assemblage zone (Nigrini, 1971)
Interval zone (Sanfilippo *et al*, 1985)
Top: Advent of *Collosphaera tuberosa* (0.2 M.Y.)
Base: Extinction of *Anthocyrtidium angulare* (0.9 M.Y.)

The absence of *C. invaginata, C. tuberosa, C. orthoconus* and *A. angulare* and common occurence of *A. ypsilon, L. bacca, T. trachelium* represents the *A. ypsilon* zone. *A. ypslon* with 3-2 proximal chambered specimens are common. This zone is 21-50 cm in Core F-88 B and of age about >0.9 to >0.2 M.Y. B.P. In core F-200 B this zone is from 44-88 cm. However this zone has been further divided in several finer zones by Goll (1980) and in present paper (see above) also by including a new zone *Collosphaera orthoconus* (Figure-2; Table-1A and 1B).

NEPHROSPYRIS RENILLA ZONE

Interval zone (Goll, 1980)

Top: Advent of *Collosphaera tuberosa* (0.2 M.Y.) Goll

Top: Advent of *Collosphaera orthoconus* (0.34 M.Y.) emended herein

Base: Extinction of *Stylatractus universus* (0.4 M.Y.)

In this zone *C. tuberosa, C. invaginata* are absent and *C. orthoconus* is rare. *Androspyris anthropiscus, Androspyris fenestrata* and *Androspyris huxleyi* are rare to common in transitional stages. *Nephrospyris renilla lana* is comparatively abundant than *Nephrospyris renilla renilla*. This zone is 21-35 cm in core F-88 B and from 76-86 cm in core F-200 B (Figure 2).

PSEUDOCUBUS WARRENI ZONE

Interval Zone (Goll, 1980)

Top: Extinction of *Stylatractus universus* (0.4 M.Y.)

Base: Extinction of *Amphispyris roggentheni* (0.6 M.Y.)

This zone is missing in the core F-88 B and in core F-200 B. In core F-88 B, it is represented by a hiatus, which is confirmed by presence of older taxa *Spongaster pentas* (Pliocene age). This hiatus represents roughly a period of 0.7-0.4 M.Y. (0.2-0.3 M.Y. time) and probably is caused by the erosion and redistribution of Pliocene sediments by an abyssal current (probably Antarctic Bottom Water Current) during glacial time. At this section fairly substantial % of subtropical and subpolar species are present, which represent a glacial stage (detailed study is in progress).

AMPHISPYRIS ROGGENTHENI ZONE

Interval zone (Goll, 1980)

Top: Extinction of *Amphispyris roggentheni* (0.6 M.Y.)

Base: Advent of *Lamprocyrtis nigriniae* (0.9 M.Y.)

Absence of *C. invaginata, C. tuberosa, C. orthoconus, Sphaerozoum punctatum* and occurence of *S. universus, A. roggentheni, Lamprocyrtis nigriniae* represent this zone. The presence of mutilated specimens of *Spongaster pentas*, a reworked taxa of early Pliocene age at 31-36 cm of the core F-88 B, is observed.

Remarks: The presence of mutilated specimens of Pliocene taxa in between *A. ypsilon/A. roggentheni* zones and absence of *Pseudocubus warreni zone* (roughly a period of 0.7-0.4 M.Y. B.P.) suggest a hiatus of about a period of 0.3 M.Y. in core F-88 B (Table-1A, Figure-2).

ANTHOCYRTIDIUM ANGULARE ZONE

Concurrent range zone (Nigrini, 1971)

Interval zone (Sanfilippo *et al*, 1985)

Top: Extinction of *Anthocyrtidium angulare* (0.9 M.Y.)

Base: Extinction of *Pterocanium prismatium* (1.8 M.Y.)

The rare occurence of the *Anthocyrtidium angulare* in 51-56 cm. interval and its increasing number in down core and rare occurence of *Lamprocyrtis nigriniae* and its increasing number in upper part of the core F-88 B, represent the top of Nigrini's fourth lowermost zone. In this zone *C. invaginata, C. tuberosa, C. orthoconus, Sphaerozoum punctatum* are absent. Goll (1980) further divided this zone into *Acrosphaera trepanata, Neosemantis hofferi* and *Siphanosphaera tenara* zones. In present paper this zone is proposed to be replaced by *Lamprocyrtis nigriniae, Lamprocyrtis neoheteroporos* and *Lamprocyrtis heteroporos* zones.

ACROSPHAERA TREPANATA ZONE

Interval zone (Goll, 1980)

Top: Advent of *Lamprocyrtis nigriniae* (0.9 M.Y.)

Base: Extinction of *Sphaerozoum crossus* (1.3 M.Y.)

In this zone *C. invaginata, C. tuberosa* and *C. orthoconus* and *Sphaerozoum punctatum* are absent. *Lamprocyrtis neoheteroporos* and *Lamprocyrtis nigriniae* co-occur at 61-66 cm of core F-88 B. *Lamprocyrtis heteroporos* (Extiction 1.3 M.Y.) is rare to common below 71-76 cm and absent above 71 cm in core F-88 B. *Sphaerozoum crossus* is totally absent in these cores. This zone could not be found in core F-200 B.

Lithopera bacca, A. ypsilon become relatively rare in this zone and *A. ypsilon* represented only by 2 chambered specimens. The base of the Nigrini's fourth zone could not be found as *Pterocanium prismatium* is totally absent in the core F-88 B and F-200 B. The species *Sphaerozoum crossus, Neosemantis hofferi, Acrosphaera trepanata, Theocorythium vetulum, Pterocanium prismatium,* though searched, are not found in the cores. So the base of *A. trepanata* zone is not certain, but as the extinction of *Lamprocyrtis heteroporos* (1.3-1.4 M.Y.) represented in 71-76 cm. interval, is almost equal to the extinction of *Sphaerozoum crossus* (1.3 M.Y.), a doubtful base of this zone can be assumed. Due to absence of *Sphaerozoum crossus* and *Neosemantis hofferi* in the cores studied (probably due to poor preservation or their absence), a phylogenetic evolutionary lineage: *Lamprocyrtis heteroporos-Lamprocyrtis neoheteroporos-Lamprocyrtis nigriniae* (Kling, 1973) and their datum (Johnson and Knoll, 1975) are used for the further and finer stratigraphy of the core F-88 B. New zones are proposed by using this evolutionary lineage.

LAMPROCYRTIS NIGRINIAE ZONE

Range zone (Riedel and Sanfilippo, 1978),
(*Lamprocyrtis haysi* and *Lamprocyrtis nigriniae* are synonym)
Interval zone. (emmended herein)
Top: Extinction of *Anthocyrtidium angulare* (0.9 M.Y.)
Base: Extinction of *Lamprocyrtis neoheteroporos* (1.1 M.Y.)

This zone is recognised on the basis of absence of *Lamprocyrtis neoheteroporos* and presence of *Lamprocyrtis nigriniae*, at the place of Goll's (1980) *Acrosphaera trepanata zone*, due to absence of *Sphaerozoum crossus* in the core F-88 B. The event dates are after Johnson and Knoll (1975) and are interpreted in Figures 2 & 3. This zone is from 51-60 cm. in core F-88 B.

LAMPROCYRTIS NEOHETEROPOROS ZONE (NEW ZONE)

Lineage segment/Interval zone. (described herein)
Top: Extinction of *Lamprocyrtis neoheteroporos* (1.1 M.Y.)
Base: Extinction of *Lamprocyrtis heteroporos* (1.3 M.Y.)

This zone is recognised on the basis of absence of *Lamprocyrtis heteroporos, Lamprocyrtis nigriniae* and presence of *Lamprocyrtis neoheteroporos* and its transitional stages to *Lamprocyrtis nigriniae* in 61-70 cm. of F-88 B (Figure 2).

LAMPROCYRTIS HETEROPOROS ZONE (NEW ZONE)

Interval zone. (described herein)
Top: Extinction of *Lamprocyrtis heteroporos (1.3 M.Y.)*
Base: Extinction of *Theocorythium vetulum* (1.6 M.Y.)

This zone is recognised on the basis of presence of *Lamprocyrtis heteroporos, L. neoheteroporos* and absence of *Lamprocyrtis nigriniae* and *Theocorythium vetulum*. This zone is from 71-88 cm in core F-88 B. Absolute dates for the lineage used in determining the boundaries between these new zones (Figure-2 & 3) are after Johnson and Knoll (1980), which may slightly vary for the Indian Ocean.

DISCUSSION

Io/Th radiometric sediment accumulation rates (Borole, in press) for the core F-88 B (0.8 mm/1000 yrs) and for core F-200 B (8.4 mm/1000 yrs from 0-40 cm; 0.7 mm/1000 yrs, from 41-55 cm and 1.9 mm/1000 yrs from 55-76 cm), when extrapolated and compared to the recognised Pacific radiolarian datum levels (Johnson and knoll, 1975; Table-1A & 1B and Figures 2 & 3), resulted in recognision of probable diachroniety in radiolarian events, of the magnitude of 0.1 to 0.3 M.Y. to that of Pacific, in the Indian Ocean Basin and a hiatus in core F-88 B.

Johnson and Nigrini (1985) have mentioned the inconsistencies in Neogene radiolarian events in the Indian Ocean and concluded that most of the extinctions have about 0.1 M.Y. differences, whereas Advent levels have differences of magnitude 1.0 M.Y. from the Pacific Ocean. Similarly there may be diachroniety in late Quaternary radiolarian events like Advents of *C. invaginata, C. tuberosa* and *C. orthoconus* in Indian Ocean Basin, compared to the Pacific.

Presence of volcanic glass shards (Tables 1A & 1B; Figures 2,3,4) from abundant to common in certain horizons A_1, A_2, A_3, A_4 and A_5) in studied cores is also recorded. Volcanic glass shards have typical gas vesicles, bubbles and broken bubble walls (Figure 4). The bursting of bubble walls of the gas vesicles suggest the sudden cooling of glass from very high temperature. This phenomenon happens when high temperature glass comes in contact of cooler media like ice, cold water or Ice and is termed as *Hyloclastics* (Nayadu, 1964; Kennett, 1981). Characterstic broken walls of vesicles suggest the suboceanic explosive volcanic eruptions in the vicinity in Central Indian Basin. Hyloclastites or submarine volcanic

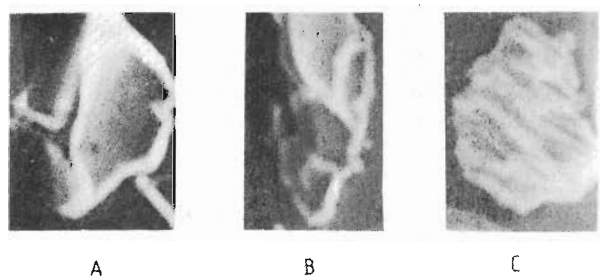


Fig. 4. SEM photomicrographs of typical volcanic glass shards.
A. Broken bubble wall glass shards (Cuspate) X 200
B. and C. Pumiceous shards. X 200.

debris generally do not spread beyond 400 Kms from the volcanic source (Kennett, 1981). Suboceanic volcanism might have caused toxicity at the sediment water interface, which might have facilitated the preservation of such fine stratigraphic record from the destruction by the benthic mixing due to bioturbation.

CONCLUSION

(1) Radiolarian zonation (Nigrini, 1971 and Goll, 1980) and events (Johnson and Knoll, 1975) for the Quaternary Equatorial Pacific are applicable to the Central Indian Basin with slight modification by including zones like *Collosphaera orthoconus, Lamprocyrtis nigriniae, Lamprocyrtis neoheteroporos* and *Lamprocyrtis heteroporos*. The apparent age of the radiolariian events after Io/Th radiometric sedimentation rates (Borole, in press) are well in agreement to Goll (1980). The data made possible to recognise a hiatus in core F-88 B. Hiatus starts just before the end of *A. roggentheni* zone (0.7 M.Y. B.P.), through *Pseudocubus warreni* zone (0.4 M.Y.), which is missing and *Nephrospyris renilla* zone directly overlies the *Amphispyris roggentheni* zone. This datum level is marked by the reworked specimens of *Spongaster pentas* (lower Pliocene fauna at 31-36 cm.) and conforms to erosion and redistribution of the older sediment in the area by a bottom water current (probably Antarctic Bottom Water Current). However, confirmation of these results need detailed study of more longer cores covering larger geographical area in Equatorial Indian Ocean.

(2) Futhermore, the boundary of *Collosphaera invaginata / C. tuberosa* zones is 0.1 M.Y. and of *Collosphaera tuberosa/N. renilla* is 0.2 M.Y. B.P., which is well in agreement to that of Goll (1980).

(3) Three to five volcanic ash-layers of roughly 0-20,000; 30-40,000; 80-000; 340,000 and younger than 400,000 yrs in cores are also recognised. Intercalations of ash layers in the cores suggest suboceanic volcanic eruption in late Quaternary time in the Central Indian Basin.

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TAXONOMIC APPENDIX

Subclassk : Radiolaria Muller 1858.
Order : Polycystina Ehrenberg 1875.
Sub order : Spumellaria and Nasselaria

Buccinosphaera invaginata. Haeckel (Pl. 1, Fig. 1,2)
B. invaginata Haeckel, 1887, p. 99, pl. 5, fig. 11. —do—Haeckel; Nigrini, 1971, p. 445, pl. 34.1, fig.2.
Collosphaera invaginata Bjorklund and Goll, 1979, p. 1305, 1317, pl. 3 fig. 1-9.

Anthocyrtidium angulare Nigrini (Pl. I, Fig. 8; Pl. II, Fig. 8)
Anthocyrtidium angulare Nigrini, 1971, p. 445, pl. 34.1, figs. 3a, 3b.; Dinkelman. 1973, pl. 10, fig. 5; Johnson and Knoll. 1975. pl. 1, fig. 3a, 3b.

Stylatractrus universus Hays (Pl. I, Fig. 9a & b)
Stylatractus universus Hays, 1970, p. 215, pl. 1, figs. 1,2; Kling, 1971, p. 1086, pl. 1, fig. 7; Dinkelman, 1973, pl. 10 figs. 6,7; Johnson and Knoll, 1975, pl. 1, fig. 5.

Collosphaera tuberosa Haeckel (Pl. I, Fig. 3,4; Pl. II, Figs. 1,2)
Nigrini, 1971, p. 445, pl. 34.1, fig. 1; Johnson and Knoll, 1975, pl. 1, fig. 1.

Collosphaera orthoconus (Haeckel) (Pl. I, Fig. 5)
Collosphaera irregularis Haeckel, 1887
Collosphaera orthoconus Haeckel, 1887, p. 221, pl. 12, fig. 2
Collosphaera sp. A Johnson and Knoll, 1975, pl. I, fig. 1;
Collosphera orthoconus Goll, 1980, pl. 1, fig. 10-11.

Lamprocyrtis neoheteroporos Kling, (Pl. II, Fig. 13)
Lamprocyrtis neoheteroporos Kling, 1973, p. 639, pl. 5, figs. 17-19; Sanfilippo and Riedel, 1974, pl. 3, fig. 11.

Lamprocyrtis heteroporos (Hays) (Pl. II, Figs. 10 & 12)
Hays, 1965; Goll, 1980, pl. 3, figs. 12, 13.

Theocorythium trachelium Ehrenberg (Pl. I, Fig. 14, 15; Pl. II, Fig. 9)
Theocorythium trachelium Nigrini, 1971, pl. 34.1, fig. 5

Spongaster pentas Riedel & Sanfilippo (Pl. I, Fig. 10).
Spongaster pentas Riedel and Sanfilippo, 1971.

Lithopera bacca Enrenberg. (Pl. II, Figs. 3,4)
Nigrini, 1971, pl.-34.1, figs. 11, 12.

Amphirhopalum ypsilon. (Haeckel) (Pl. I, Figs. 6, 7)
Nigrini, 1971, pl.-34.1, figs. 11, 12.

Androspyris fenestrata Haeckel (Pl. 1, Fig. 12)
Goll, 1980, pl. 4, fig. 1.

Androspyris anthropiscus Haeckel (Pl. I, Fig. 11)
Goll, 1980, pl. 4, figs. 2, 3.

Androspyris huxleyi Haeckel (Pl. I, Fig. 13)
Goll, 1980, pl. 4, figs. 4, 5.

Lamprocyrtis nigriniae Caulet (Pl. II, Fig. 14, 15)
Caulet, 1971, Goll, 1980, pl. 3, fig. 10.

Nephrospyris renilla renilla Haeckel (Pl. II, Fig. 11)
Goll, 1980, pl. 5, fig. 2.

Nephrospyris renilla lana Goll (Pl. II, Fig. 7)
Goll, 1980, pl. 5, fig. 1.

Amphispyris roggentheni Goll (Pl. I, Fig. 16)
Goll, 1980, pl. 6, figs. 1, 3, 4, pl. 7, figs. 4, 6.

Sphaerozoum punctatum (Muller) (Pl. II, Fig. 6)
Goll, 1980, pl. 1, fig. 1, 2.

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EXPLANATION OF PLATES

All specimens unless otherwise mentioned are at 80 magnification and from core F-88 B.

PLATE I

1. *Collosphaera invaginata* (Haeckel) Figured specimen from 1-5 cm.
2. *Collosphaera invaginata* (Haeckel) X 200.
3. *Collosphaera tuberosa* (Haeckel) Figured specimen from 11-15 cm.
4. *Collosphaera tuberosa* (Haeckel) X 200.
5. *Collosphaera orthoconus* (Haeckel) Figured specimen from 21-25.

6, 7. *Amphirhopalum ypsilon* with 5 and 3 chambers respectively before the bifurcation of forked arm.

8. *Anthocyrtidium angulare* Nigrini Figured specimen from 51-55 cm.

9a. *Stylatractus universus* Hays X 40 Figured specimen from 41-45 cm.

9b. *Stylatractus universus* Hays X 100.

10. *Spongaster pentas* Riedel and Sanfilippo Figured specimen from 31-35 cm.

11. *Androspyris anthropiscus* (Haeckel) Figured specimen from 41-45 cm.

12. *Androspyris fenestrata* Haeckel Figure specimen from 61-65 cm.

13. *Androspyris huxleyi* Haeckel Figured specimen from 61-65 cm.

14, 15. *Theocorythium trachelium* Ehrenberg.

16. *Amphispyris roggentheni.* Goll Figured specimen from 41-45 cm.

17. *Lamprocyclas martalis polypora* Nigrini.

PLATE II

1. *Collosphaera tuberosa* X 200.

2. *Collosphaera tuberosa* X 80.

3,4. *Lithopera bacca.* Ehrenberg.

5. *Sphaerozoum sp.*

6. *Sphaerozoum punctatum* (Muller) Figured specimen from 31-35 cm.

7. *Nephrospyris renilla lana* Goll Figured specimen from 41-46 cm.

8. *Anthocyrtidium angulare* Nigrini Figured specimen from 61-66 cm.

9. *Theocorythium trachelium* Ehrenberg Figured specimen from 51-56 cm. X 200.

10. *Lamprocyrtis heteroporos* Hays Figured specimen from 71-15 cm.

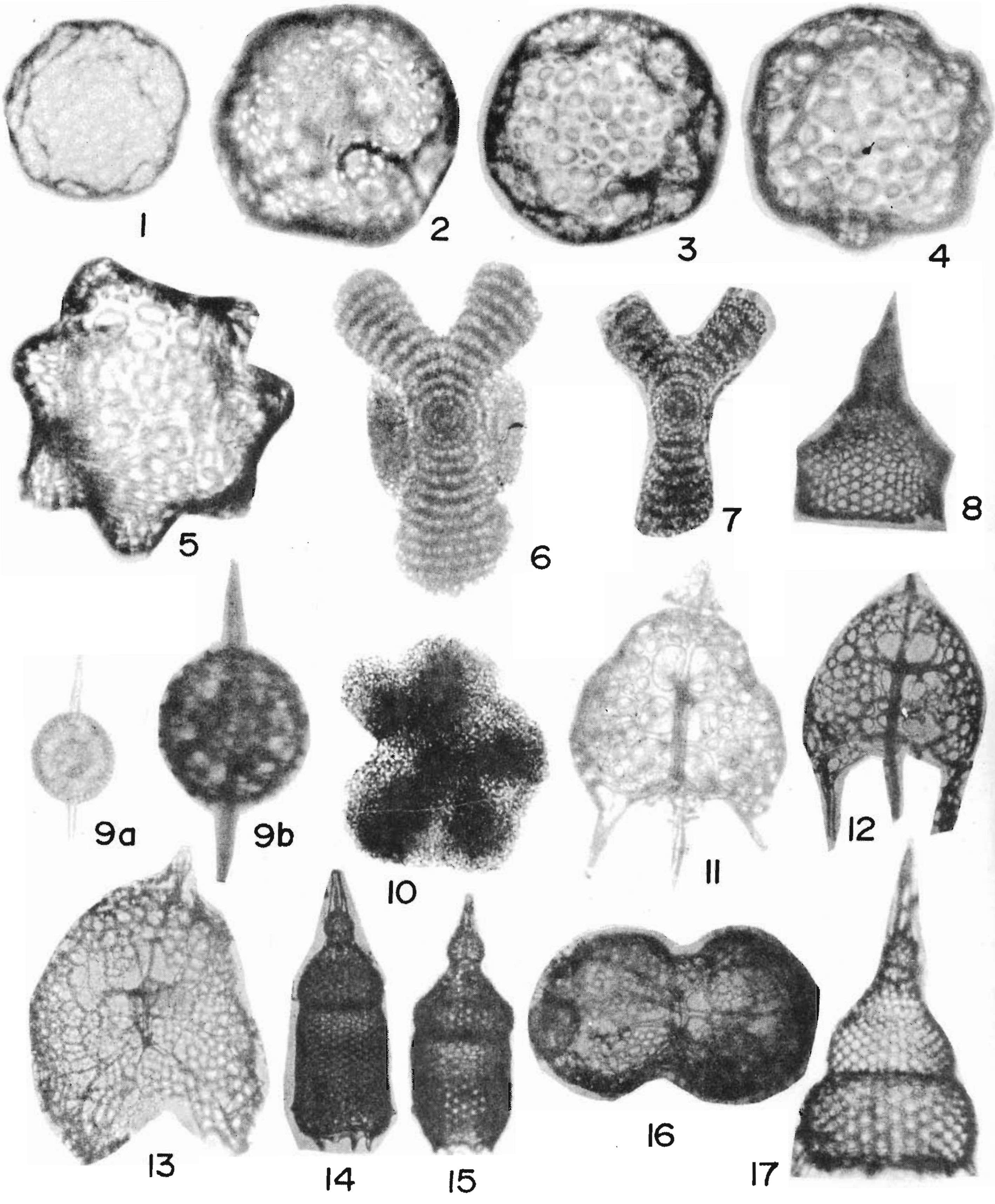
11. *Nephrospyris renilla renilla* Haeckel Figured specimen from 81-85 cm.

12. *Lamprocyrtis heteroporos* Hays Figured specimen from 81-85 cm.

13. *Lamprocyrtis neoheteroporos* Kling Figured specimen from 61-65 cm.

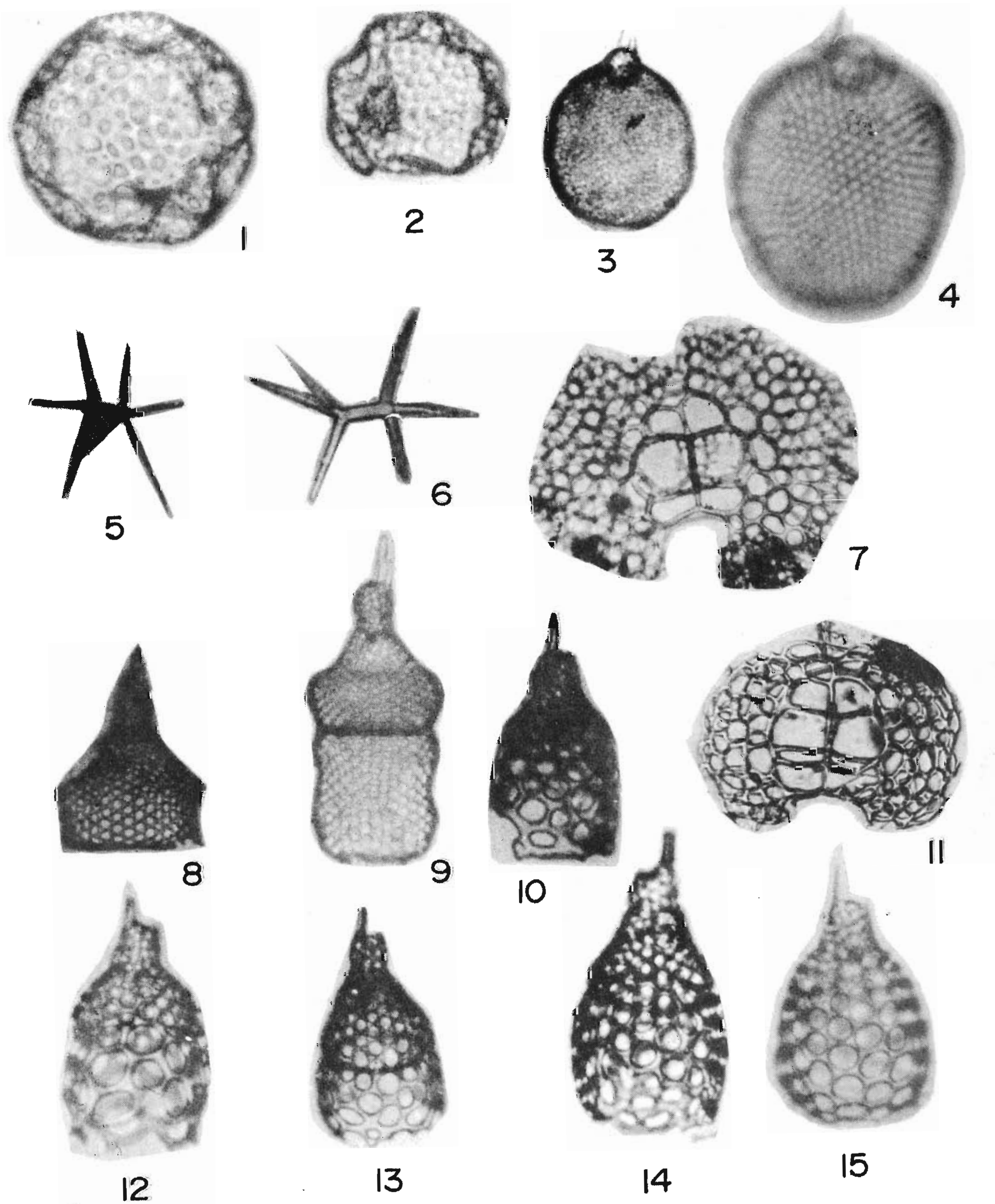
14, 15. *Lamprocyrtis nigriniae* Caulet Figured specimen from 51-56 cm.

Plate I



GUPTA

Plate II



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