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TAXONOMIC STUDY OF PTEROPODS FROM THE SEABED SEDIMENTS IN THE CARLSBERG RIDGE AND ITS SIGNIFICANCE

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ABSTRACT

A good amount of Thecosomata, collected from the Carlsberg Ridge area of Indian Ocean, is systematically discussed in this work. Twenty pteropod species belonging to nine genera of three families and two suborders are described with their taxonomic remarks. Morphological characteristics of these pteropods were examined to interpret their ecological significance. Pteropod populations are of a tropical environment and their preservation is associated with well-known center of winnowing action. The pteropods (composed of *Cuvieirina columnella, Cavolina inflexa, C.longirostrics, C.globulosa, Diacria trispinosa. Limacina inflata, L.buliminoides, Clio pyramidata, C. convexa, Styliola subula* and *Creseis acicula)* are characteristic of a typical gyre Central Indian Ocean fauna.

Distribution pattern of pteropod in the seabed sediments indicates that aragonite compensation depth (ACD) falls at about 2400m. The deeper level of ACD below the general depth of 1500m in Central Indian Ocean is related to oligotrophic productivity and winnowing of pteropod-bearing sediments.

Key words : Pteropods, Thecosomata, Seabed Sediment, Carlsberg Ridge, Aragonite Compensation Depth (ACD).

INTRODUCTION

Pteropods form a group of pelagic mollusks which are widely distributed in the open oceans from the polar to the tropical regions (Bé and Gilmer,1977 and Berner, 1977). Their assemblage depends upon the physical, chemical and biological parameters of different water masses. They are more preserved in marginal seas, shelf and upper bathyal zone of the ocean, around the islands in open seas and over the physiographic high regions of the deep oceans (Berger, 1978). Because of highly fragile and solution prone nature of the aragonitic pteropod tests, their occurrence is restricted in the seabed sediments. Palaeontological studies of the ocean floor and mid-oceanic ridge sediment samples reveal the characteristic pteropod assembleage having a bearing on the enviornmental conditions. The Carlsberg Ridge represents an important structural domain of the Indian Ocean (fig. 1) and the distribution of the pteropod over the central part of the ridge gives an insight into the ACD level in this region. In the present work, taxonomy of pteropod assemblages from the Carlsberg Ridge area has been carried out. Systematic description of twenty speices is briefly discussed with their palaeoenvironmental significance.

PREVIOUS LITERATURE

Palaeoceanographic significane of pteropod was studied during the last few decades from the North Atlantic (Diester-Hass and van der Spoel, 1967; Pafort-van Iersel, 1986 and Cifelli and Mecloy, 1983), North Pacific (Grossman, Betzer, Dubley and Dunbar, 1986), Mediterranean sea (Herman, 1981), Red sea (Almogi-Labin, Luz and Duplessy, 1986; Reiss, Luz, Almogi-Labin, Halicz, Winter, Weld and Ross, 1980), Gulf of Mexico (Berger, 1977; Castillo, Sengupta and Herrera, 1998), Caribbean sea (Chen, 1966), Sargasso sea (Almogi-Labin, Hemleben and

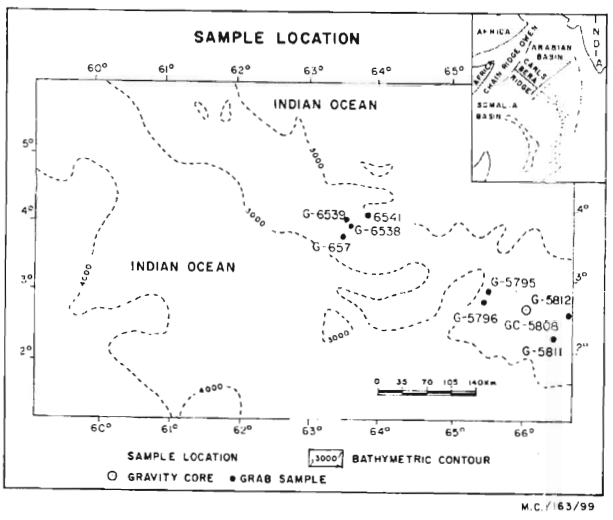

Fig. 1. Location map of the area of study.

Deuser, 1988; Winter, Almogi-Labin, Erez, Halicz, Luz and Reiss, 1983), China sea (Miao and Thunnel, 1993; Rottman, 1980) and rift valleys of the Mid-Atlantic Ridges (Melkert, Ganssen, Helder and Troelstra, 1992). Pteropods were studied by various researchers during several oceanographic expeditions, namely HMS Challanger (Pelseneer, 1888), John Murry (Stubbings, 1938), Dana (Tesch, 1946 and 1948), Antarctic (Taki and Okutani, 1962) and International Indian Ocean Expedition (Sakthivel, 1969). Palaeontological importance of pteropods in the Quaternary and late Neogene seabed sediments was established by scientific results of DSDP (Herman, 1973; Jung, 1973) and ODP (Droxler, Bruce, Sagar and Watkins, 1988; Droxler, Haddad, Mucciarone and Cullen, 1990). Seabed sediments collected by GSI research Vessel " R.V. Samudra Manthan" in the last fifteen years have recorded the occurrence of pterpods from Arabian sea (Bhatt and Adiga, 1993; Rao, Vaz, Vijay Kumar and Babu Rao, 1998), Bay of Bengal (Narasayya, Rao, Mahapatra and Hari Prasad, 1990; Bandyophadayya, 1992), Andaman sea (Saha, Rakshit, Mazumdar and Bhattacherjee, 1993; Saha, Sinha, Rakshit and Bhattacharjee, 1997; Bhattacharjee, 1996a; Bhattacharjee, Ghose and Bandopadhyay, 1998) and Indian ocean (Bhattacharjee, 1996b; Venkatesh, Sinha, Battacharjee and Ramchandra, 1998). These studies reveal that the occurrence of pteropods in the seabed sediments depends on the temperature, salinity, rate of sedimentation, biogenic productivity and alkalinity of the marine environment.

Table 1 : Showing relative abundance of pteropods.

Sample No.	Depth (m)	Recovery	Broken/ Whole Pteropod Ratio	Pteropod/ Planktic formas Ratio	Pteropod tests/gm. of dry sample
GC-5808	2742	Absent	—	0	—
G-5795	2242	Good	0.06	0.46	350-400
G-5796	2017	Moderate	0.36	0.26	180-200
G-5811	2123	Good	0.12	0.38	250-280
G-5812	2255	Good	0.10	0.41	200-220
G-6537	2571	Absent	—	0	—
G-6538	1958	Traces	1.42	0.19	4-6
G-6539	1958	Poor	0.24	0.10	40.50
G-6541	2386	Poor	1.21	0.08	20-30

Distribution pattern of pteropods from the Arabian sea reveals that certain pteropod species are also influnced by the upwelling intensity similar to planktic foraminifera (Singh and Rajaram, 1997) and they can be used as bathymetric indicators (Singh Rajaraman, Ramchandran, Suchindan and Samsuddin, 1998). Though occurrence of pteropods was reported from the Carlsberg area (Bhattarcharjee, 1996b and 1997) and their mode of preservatoin examined, little attention was paid to their taxonomic study. Hence, the present work was taken up for the systematic study of pteropods.

MATERIAL AND METHODS

About 10 gram dry seabed sediment samples (eight grab samples and six subsamples of a gravity core) collected during the GSI cruises by its research Vessel "R.V. Samudra Manthan" 1 (fig. 1, sample location), were processed following the standard methods of pteropod sampling techniques. The weight percentage of the coarse fractoin was calculated and the processed samples (>63mm size) were split with a microspliter in order to obtain a suitable aliquot that contains about 2000 specimens. Relative abundance of pteropod specimens in different seabed samples is shwon in table 1. The pteropod specimens belonging to the three families of two suborders Pseudothecosomata and Euthecosomata were identified under binocular microscope and counted. It was not possible to identify the broken fragments of pteropod specimens but the ratio of total broken pteropod to the whole pteropod tests in each sample was calculated, as this parameter is a common and reliable indicator of degree of pteropod (aragonite) dissolution. Pteropod to planktic foraminifera ratio was also measured to get an idea about the degree of aragonite versus calcite preservation in seabed samples (table 1). Pteropod test size was measured under binocular microscope. The grain counts of 20 species of 9 genera were taken by hand picking and fixing them up on the micropalaeontological trays. The whole mounted specimens were classified following the standard taxonomic literature (Tesch, 1946; Bé and Gilmer,1977; Almogi-Labin, 1982; Hodgkinson Garvie and Bé, 1992; Ujihara, 1996).

OBSERVATION AND RESULTS

Quantitative study of the sediments reveals that

crests and inter-ridge depressions of the Carlsberg Ridge are mainly floored by calcareous ooze. The ooze mainly comprises planktic foraminifera and radiolaria. Over the peaks of the ridge, the ooze contain some amount of pteropod, diatom, sponge spicules, dinoflagellate with few bryozoa, ostracod and echinoid spines. In the intra-ridge depression regions, the occurrence of pteropod is very rare to absent. On the basis of preservation, pteropod tests can be divided into the follwing three groups:

1. *Well-preserved tests*. Mostly opaque-white or pale-brown to dark brown in colour. Some of the specimens show minute specks on their surface. In some specimens the colour coating obliterates partly or completely the surface ornamentation.

2. *Poorly preserved tests*. Highly corroded tests showing prominent dissolution effects. Partial staining of yellowish brown material visible on the surface of some specimens.

3. *Milky white to white, fragmented tests* of highly fragile nature. Generic level identification is not possible in some cases due to intense fragmentation.

TAXONOMIC DESCRIPTION

Twenty Pteropod species belonging to nine genera of three families have been identified. These pteropods belong to two subroders, Pseudothecosomata and Euthecosomata under the order Thecosomata. Sixteen SEM photomicrograhps of fifteen species are given (Pls. I & II). Coiled specimens are illustrated with apex up (dorsal) and aperture below. Uncoiled or tubular species are described with aperture up and protoconch down (dorsal). Brief systematic description of the studied pteropod species is given below.

Suborder **Euthecosomata** Meisenheimer, 1905

Family **Cavolimiidae** Fischer, 1883

Genus ***Creseis*** Rang, 1828

Creseis virgula concia (Rang, 1828)
(Pl, I, fig.1)

Test elongated, conical, cross-section expanding rapidly and aperture circular. (Length: 2.3 to 2.5 mm; max. diameter : 0.55 to 0.65mm).

It is found in good number and shows moderate preservation.

Remarks : Some of the specimens are similar to *Creseis virgula constrica* (Sakthivel, 1974) due to the constriction near the protoconch.

Occurrence: It is a warm tropical species. occuring in Bermuda waters (Chen and Bé, 1964) and in the Mediterranean Sea (Menzies,1958).

Creseis virgula virgula (Rang, 1828)
(Pl.I, fig.2)

Test strongly flexed dorsally to an angle about 40^0 to 50^0, transverse diameter increasing rapidly in the beginning and gradually in the adult stage, aperture rounded. (Length: 4 to 4.5 mm; maximum width: 1.4 to 1.8 mm.).

Remarks : It shows the characterisitic curvature along the length of the test. Its number is reduced due to its more fragile nature.

Occurrence : It is a tropical species, more stenothermal with a temperature range from 15°C to 27.5°C.

Common occurrence is noticed off the Somali coast, Bay of Bengal, Gulf of Oman (Sakthivel 1969); Northern Arabian Sea (Stubbings, 1938) and Off Great Barrier Reef (Russell and Colman, 1935).

Creseis acicula (Rang, 1828)
(Pl.I, fig.3)

Test elongated, gradually increasing in diameter and with circular aperture. It is initially extremely white but the posterior part is less white and opaque. (Length: 3.8 to 4 mm, max. diameter: 0.5 to 0.6 mm)

Remarks : It shows characteristic pencil-like shape and smooth test. Found in good number with moderate preservation.

Occurrence : Warm-water, cosmopolitan but abundant in tropical and subtropical regions (Meisenheimer, 1905; Tesch, 1946 and van der Spoel, 1967). Observered in South Atlantic and Central Indian Ocean (McGowan,1960; Sakthivel, 1969).

Genus ***Clio*** Linne, 1767

Clio pyramidata Linne, 1767
(Pl. I, fig. 4)

Test triangular and conical, diameter of the shell increasing uniformly. Three prominent longitudinal ridges on dorsal side of the test. (Length: 8 to 7 mm; max. trans. diameter : 4 to 4.5mm).

Remarks : Protoconch is medium to small in size. Test well preserved.

Occurrence : It is a cosmopolitan, eurythermic species and shows good abundance in this area.

It is well observed in Indo-Pacific Ocean and in equatorial Atlantic (Tesch, 1946, 1948).

Clio convexa (Boas, 1886)
(Pl.I, fig. 5)

Shell triangular-elongated, posterior side slightly curved ventrally, very little ornamentation. Double-lined lateral ribs present on the surface. Protoconch short with a blunt cusp (Length: 2.2 to 2.8 mm; max. trans. diameter: 1.25 to 1.5 mm).

Remarks : The protoconch of *Clio convexa* has double-lined lateral ribs but in *Clio pyramidata* it has a single-lined lateral rib.

Occurrence : It occurs frequently in this area. It is predominantly a tropical species restricted to the Indo-Pacific region (Bé and Gilmer, 1977). It is also reported from eastern and western Pacific Ocean (van der Spoel, 1967).

Clio cuspidata (Bosc, 1802)
(Pl.I, fig.6)

Test conical, posterior end curved dorsally, protoconch teardrop-shaped with sharp point. (Length: 3.5 to 4 mm; max. diameter: 1.4 to 1.6 mm).

Remarks : Teardrop shaped protoconch is very characteristic of this species. It shows close similarity with the warm water cosmopolitan species of the Indo-Pacific region.

Occurrence : Frequency is poor in this area but it is a widespread warm-water cosmopolitan species.

Tesch (1946) found it as a common taxon in Central Indian Ocean and Indo-Pacific Ocean.

Genus ***Diacria*** Gray, 1850

Diacria trispinosa (de Blainville, 1827)
(Pl. I, fig. 7, 8)

Test biconvex, faint concentric growth lines are present on the both sides of the test, dorsal side less convex than the ventral side. Prominent three longitudinal ridges on the dorsal side of the shell and two lateral spines. (Length: 6 to 7 mm; width: 6 to 5 mm, thickness: 2 to 3 mm).

Remarks : The lateral spines are not perpendicular to shell axis but slightly oblique. It shows strongly curved dorsal apertural rim. Shell size is slighlty larger than the general ocurrences.

Occurrence : A warm-water, comopolitan species, it occurs in good number in subtropical seas but found in low frequency in this area. Good occurrence reported from Caribbean Sea. Mediterranean Sea (Chen, 1971 and Meinsenheimer. 1905), Arabian Sea, Bay of Bengal and Pacific Archipelagoes (Tesch, 1946 and Sakthivel, 1969).

Diacria quadridentata (de Blaniville, 1827)
(Pl.II, fig.1)

Shell biconvex, ventral side more convex than the dorsal side, well ornamented, five longitudinal ridges on the dorsal side, distinct marginal striation on the apertural face. (Length: 2.75 to 3.25; thickness: 2 to 2.5mm).

Remarks : Small spherical protoconnch and absence of lateral ribs. It shows moderate frequency and good degree of preservation.

Occurrence : It is found particularly in the equatorial Indian Ocean. High abundance is reported in equatorial boundary currents in Pacific and Indian Oceans (Tesch, 1948; Sahthivel, 1969).

Genus ***Cavolinia*** Abildgard, 1791

Cavolinia longirostris de Blaninville, 1821
(Pl.II, fig. 2)

Shell inflated, well ornamented, prominent ridges on the dorsal side and distinct growth lines on the apertural face of the ventral side. (Length: 7 to 7.5 mm; width: 4 to 5mm; thickness: 4 to 5mm).

Remarks : Test is posteriorly truncated and the dorsal apertural lip has channel-like fold. Frequencey is poor but mode of preservation is good. Shell dimension is slightly alrger than normal size of this taxon.

Occurrence : It is a warm water, cosmopolitan species. It shows patchy distribution in the tropical ocean (Bé and Gilmer, 1977). It is common in tropical Indian Ocean (Sakthivel, 1969) and found in good numbers in Arabinan Sea (Stubblings, 1938).

Cavolinia globulosa (Gray, 1850)
(Pl.II, fig.3)

Shell inflated, biconvex, surface smooth, ventral side more rounded, small but with spherical protoconch. (Length: 4.8 to 5.2 mm; width: 4 to 5 mm; thickness: 4.5 to 4 mm).

Remarks : It is found in low numbers but tests are well ornamented and well preserved.

Occurrence : It is centrered at the equator (10^0 N to 10^0 S). It is generally confined to the tropical belt of the Indo-Pacific region (Tesch, 1948). Also recodred from Bay of Bengal, eastern part of Indian Ocean and Arabian Sea (Stubbings , 1938; Sakthivel, 1969).

Cavolinia tridentata Niebühr, 1775

Shell inflated, test moderately ornamented, posterior section straight, ventral apertural margin curved. (Length: 9 to 8 mm; width: 7 to 6.5 mm; thickness: 5 to mm).

Remarks : Rarely observed and tests are generally fragmented.

Occurrence : This species has greater preference for subtropical water than that of the tropical region (Tesch, 1948; McGowan, 1960). It occurs in higher latitudes (20^0 S to 40^0 S) in Indian Ocean and Indonesian Archipelago (Meisenheimer, 1905; Stubbings, 1938).

Cavolinia inflexa (Lesueur, 1813)

Shell flattened, the lateral portion of the aperture is narrower than the middle part. The ventral surface is bulged. Posterior end slighlty curved. (Length : 4.5 to 5 mm; max. width : 3 to 3.5 mm).

Remarks : The specimens are much fragmented, mode of preservation is moderate to poor and frequency is low.

Occurrence : In the Indian Ocean, it is generally observed to the south of the equator. This is known from the cooler part of the tropical zone and enriched in some places by the Somali current (Sakthivel, 1969) and from subtropical Atlantic (Herman, 1971).

Genus ***Cuvierina*** Boas, 1886

Cuvierina columnella (Rang, 1827)
(Pl.II, fig.4)

Test slender, subcylindrical, dorsal side weakly convex but ventral side more convex. Aperture bean shaped. Apertural end of the test is slightly compressed and blunt (Length: 7 to 8 mm; width: 2.8 to 3.2mm).

Remarks : This species could be compared with *Cuvierina miyazakiensis* (Ujihara, 1996) but is comparatively more inflated and has the maximum width of the test situated towards the posterior side.

Occurrence : It has widespread distribution in the tropical and subtropical waters between 5°N and 5°S and in the Somali current (Sakthivel, 1959). It is common in Mediterranean Sea (Rampal, 1968; Tesch, 1946) and along the west coast of Africa (Meisenheimer, 1905).

Genus ***Styliola*** Gray, 1850

Styliola subula Quoy & Gaimard, 1827
(Pl.II, fig. 2)

Test conical, elongated and gradually increasing in diameter. Prominent longitudinal groove running slightly oblique to the long axis of the test. Aperture circular. (Length: 7 to 8 mm; max. diameter: 2 to 1.8mm).

Remarks : Shell surface is smooth, without ornamentation except the elongated longitudinal rib. Proloculus is very small. (Length: Max. diameter ratio varies from 3.5 to 4.3. It occurs in good number in this area).

Occurrence : This species avoids very warm water. It is a gyre centric species and is reported from east Mediterranean and subtropical Atlantic (Herman, 1971) and also from the western equatorial Indian Ocean (Sakthivel, 1969).

Genus ***Hyalocylis*** Fol, 1875

Hyalocylis striata (Rang, 1828)

Test transparent to white but delicate in nature. Shell conical, slightly curved dorsally, faintly ornamented by numerous growth increments. (Length: 2 to 2.5 mm, Max. diameter: 1.5 to 1.8 mm).

Remarks : It shows slight curvature towards the posterior end and has more width in comparison of the specimens shown by Ujihara (1996). This difference, however, might be interspecific variation.

Occurrence : Typical tropical species. Frequency of this species is low due to its fragile nature. It is common in Caribbean Sea, Equatorial

Atlantic (Chen and Bé, 1964 and Boltovoskey, 1971). Good occurrence is also noticed in the western Indian Ocean, Arabian Sea, Bay of Bengal and in north equatorial current in Indian Ocean (Sakthivel, 1969).

Family **Limacinidae** Gray, 1847

Genus ***Limacina*** Bosc, 1817

Limacina inflata (d'Orbigny, 1836)
(Pl.II, fig.6)

Shell sinstral, slightly trochoid, smooth aperture rounded, umbilicus broad and deep. (Width: 1.1 to 1.2 mm; height; 1.6 to 2.0 mm).

Remarks : It occurs in good number with good preservation. Height: Width ratio varies from 1.7 to 1.9.

Occurrence : It is the most common species of the warm water belt including the tropics of the Central Indian Ocean. It is common in Sargasso Sea (Almogi-Labin *et al.*, 1988), Caribbean Sea, Equatorial Atlantic (Chen and Bé, 1964; Boltovosky, 1971). Good occurrence is noticed in the western Indian Ocean, Arabian Sea, Bay of Bengal and in north equatorial current (Sakthivel, 1969).

Limacina trochiformis (d'Orbigny, 1836)
(Pl.II, fig.8)

Shell equals the maximum diameter, smooth with little ornamentation. Umbilicus constricted and aperature oval. (Width: 2 to 2.5 mm; height: 2.4 to 2.6 mm).

Occurrence : It is a common and widespread species in Indian Ocean. Reported from subtropical Atlantic, Mediterranean Sea, Northwest Indian Ocean (Herman, 1971), Red Sea (Almogi-Labin, 1986) and Northen Indian Ocean (Sakthivel, 1969).

Limacina bulimoides (d'Orbigny, 1836)
(Pl.II, fig.7)

Shell medium sized, elongated, high spired, trochispiral, umbilicus closed to very narrow, columella arched. (Height: 2.5 to 3.5 mm; width: 1.5 to 1.8 mm).

Remarks : Short discontinuous longitudinal striations on the surface of the test.

Occurrence : Subtropical region. Sakthivel (1969) reported this species from tropical Indian Ocean between 10^0 S to 12^0 S Latitude.

Limacina lesueuri (d' Orbigny, 1836)

Shell translucent, whorls expanding rapidly, umbilicus narrow and deep. Transversely lined callus deposit on the inner side of the aperture. (Height: 2.0 to 2.5 mm; width: 2.2 to 2.8m).

Remarks : It shows low frequency and moderate preservation.

Occurrence : Essentially subtropical. Subtropical Altantic (Herman, 1971), Arabian Sea and Northern Indian Ocean (Sakthivel, 1969).

Suborder **Pseudothecosomata** Meisenheimer, 1905.

Family **Peraclididae** Tesch, 1913

Genus ***Peraclis*** Forbes, 1844

Peraclis reticulata (d'Orbigny, 1836)

Test trocospiral, low spired, whorl rapidly and uniformly increasing in size. Aperture elongated and large. Surface ormamentation with the hexagonal reticulate outline. Columella twisted with prolonged pointed rostrum. (Height: 4 to 5 mm; width: 3.0 to 3.5mm).

Remarks : Height is always greater than the maximum width of the test. Height : max. diameter ratio varies from 1.4 to 1.6. It is found in moderate frequencey, with preservation of the test.

Occurrence : Tropical region of the Indian Ocean. Wide distribution over the whole tropical Indo-Pacific region, off New Zeland (Tesch, 1948).

PTEROPOD DISTRIBUTION

It is observed that the degree of pteropod dissolution in seabed sediments depends on the aragonite compensation depth (Berger, 1978; Berner, 1977). Distribution of pteropod and ACD in different parts of the world ocean was studied by various workers (Bener and Morse, 1974; Byrnetal, 1984 and Peterson and Prell, 1985) during the last few decades. These studies suggest that the ACD is nearly at 1500 m in the low latitude regions of Indian Ocean. The presence of pteropod in good amount in sediments up to 2400 m depth and their absence

beyond, suggests that ACD lies approximately at 2400 m isobath. The ratio of broken to whole pteropods and pteropod to planktic forminifera are found directly proportional to the number of pteropod tests per gram of dry sediment sample (table-1). In general, the higher the number of pteropod tests per gram sample, higher the pteropod/ planktic foram ratio and lower the broken/whole pteropod ratio. The low pteropod to planktic formainifera ratio (0.08 to 0.46) suggests an advance stage of pteropod dissolution in sediments above 2400 m depth. In contrast, sediments showing higher pteropod dissolution have a higher broken to whole pteropod ratio.

Presence of brown to dark brown stains, made of Fe-Mn on some pteropod tests within the major white to milky white assemblage indicates the evidence of some lag deposition. Bottom current could concentrate the pteropod shells into a lag deposit by winnowing of the uppermost sediments. Similar phenomenon of lag deposition has been invoked to explain the the pteropod rich sediments in the Rio Grande Rise in Atlantic Ocean (Price *et al.*, 1985).

SUMMARY AND CONCLUSION

Detailed taxonmic study of pteropod species from the central part of the Carlsberg ridge reveals their close similarity with the faunal assemblages of the Indo-Pacific region. The characteristic pteropod assemblage of *Cuverina columnella, Cavolina inflexa, Diacria trispinosa, Cavolina globulosa, Limacina inflata* and *Creseis virgula* indicates an assemblage of a typical gyre fauna of Central Indian Ocean.

Mode of preservation of the pteropod tests are moderate to good and some of them show Fe-Mn stains along with other associated biota. The occurrence of ACD is recorded at about 2400 m isobath level which is nearly 900 m below the reported depth of 1500m. Oligotrophic productivity of pteropod and the concentration of pteropod tests over the Carlsberg Ridge by the winnowing phenomenon are the possible reasons for the presence of ACD below the expected depth in this part of Central Indian Ocean.

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REFERENCES

Almogi-Labin, A., Luz, B., and Duplessy, J.C. 1986. Quaternary Paleo-oceanography, pteropod preservation and stable-isotope record of the Red Sea. *Palaeogeogr., Palaeclimatol., Palaeoecol.* **57**:195-211.

Almogi-Labin, A. 1982. Stratigraphic and Paleoceanographic significance of Late Quaternary pteropods from deep sea cores in the Gulf of Aqaba (Elat) and Northernmost Red Sea, *Mar. Micropal.* **7:** 53-72.

Almogi-Labin, A., Hemleben, C.H and Deuser, W.G. 1988. Seasonal variation in the flux of euthecosomatous pteropod collected in deep sediment traps in the Sargosso sea. *Deep Sea Res.* **35** (3) : 441-464

Bandyopadhyay, R.R., Bandyopadhyay, A., Bhattacharjee, D., Gupta, S. and Ghosh, S.K. 1992. Seabed survey off Andaman Island in Bay of Bengal (SM-69). *GSI Record*, **125**(2): 111-112.

Be, A.W.H and **Gilmer, W.R.** 1977. A zoogeographic and taxonomic review of euthecosomatous pteropod, p.733-808. In: *Oceanic Micropalaentology* (Ramsay, A.T.S Ed.), V.1, Academic Press.

Berger, W.H. 1977. Deep-sea carbonate and the deglaciation preservation spike in pteropods and foraminifera. *Nature*, **263:** 301-308.

Beger, W.H. 2978. Deep-sea carbonate: Pteropod distribution and the aragonite compensatoin depth. *Deep Sea Res.* **25:** 447-452.

Berner, R.A. 1977. Sedimentation and dissolution of pteropods in the ocean., p.243-260. In : *The fate of fossil fuel* C02 *in the Oceans.* Eds. Anderson, N.R. and Malahaff, A., Plenum Press, New York.

Berner, R.A. and Morse, J.W. 1974. Dissolution kinetics of calcium carbonate in sea water. I-IV. Theory of calcite dissolution. *Amer. Jour. Sci.* **274:** 108-134.

Bhatt, K.K and Adiga, K.S. 1993. Late Pleistocene-Holocene transition study of core from Lashadeep Sea. *News Letter, MW,* G.S.I., **14**(1): 6-7.

Bhattacharjee, D. 1996a. Distribution of pteropods off Andaman-Nicobar Archipelago. *News Letter, MW*, G.S.I. **12** (1) : 11-13.

Bhattacherjee, D. 1996b. Pteropods in Carlsberg Ridge, its significance. *News Letter, NW*, G.S.I., **12**(2) : 10-11.

Bhattacharjee, D. 1997. Micropalaentological evidences of possible hydrothermal activities in Carlsberg Ridge, Indian Ocean. *News Letter, MW*, G.S.I. **13**(1): 6-7.

Bhatterjee, D., Ghosh, S.K. and Bandopadhyay, R.R.. 1998. Carbonate compensation depth. A clue from biotic study around the Batti Malv and Tillanagchang Islands, Andaman sea. *News Letter, Marine Wing, G.S.L.* 14(1) : 6-7.

Boltovoskoy, D. 1971. Pteropods Thecosomados del Atlantic studocidental. *Malaeologia*, **11**(1): 121-140

Byrne, R.H., Acker, J.G. Betzer, P,R. Feely, R.A. and Cates, M.H. 1984. Water column dissolution of aragonite in the Pacific Ocean. *Nature*, **312:**321-2326.

Castillo, M-L., Sengupta, B.K and Alcala Herrera, J.A. 1998. Late Quatenary change in deep bathyal and abyssal water of the Gulf of Mexeco: Preservation record of the formainifera *Bilocculina irrergulairs, Jour. For. Res.* **28** (2): 95-101.

Chen, C 1966. **Calcareous Zooplankton** in the Scotia Sea and Drake Paaage. *Nature*, **212**(5062):678-681.

Chen, C. 1971. Occurrence of pteropods in pelagic sedinments.,p. In: *Micropalaeontology of Oceans*. (Eds. Funnel, B.M. and Riedal, W.R.), Cambridge University Press, London.

Chen, C. and Be, A.W.H. 1964. Distribution of pteropods in Western North Atlantic sediments. *Bull. Amer. Assoc. Petrol. Geol.* **48**(4-6): 520-521.

Cifelli, R and Mecloy, C. 1983. Planktonic formainifera and euthecosomatous pteropods in the surface waters of the North Atlantic. *Jour. Foram. Res.* **13** (2) : 91-107.

Diester Hass, L and Van der Spoel, S. 1978. Late Pleistocene pteropod rich sediment layer in the norheast Atlantic and Protoconch variation in *Clio pyramidata Linnge*. 1767. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **24:** 70-85.

Droxler, A.W., Bruce, C.H., Sagar, W.W. and Watkins, D.H. 1988. Pliocene-Pleistocene variations in aragonite content and planktonic oxygen-isotope record in Bahamian Periplatform ooze, Hole 633 A. *Proceedings of ODP, Scientific Results.* **101 :** 221-236.

Droxler, A.W., Haddad, G.A., Mucciarone, D.A. and Cullen, J.L. 1990. Pliocene-Plistocene aragonite cycle variation in Holes 714A and 716B (The Maldives) compared with Hole 633A (The Bahamas). *Proceedings of ODP Scientific Results.* **115 :** 539-567.

Grossman, E.L., Betzer, P.R., Dubley, W.C. and Dunber, R.B. 1986. Stable isotopic variation in pteropods and Atlandis from North Pacific sediment traps. *Mar. Micropal.* **10 :** 9-22.

Herman, Y. 1971. Vertical and Horizontal distribution of Pteropods in Quaternary sequences, p. 463-486. In: *Micropalaeontology of Oceans* (Eds. Funnel, B.M. and Riedel, W.R.), Cambridge University Press, London.

Herman, Y. 1973. Preliminary pteropod results from the Mediterrancean Sea. Leg. 13, pt.2, p. 9930-1001. In : *Initial Rep. DSDP Drilling Project* 13, USGP Office, Washington D.C.

Herman, Y. 1081. Paleoclimatic and paleohydrologic record of Mediterranean deep-sea cores based on pteropods, planktonic and benthic foraminifera. *Rev. Esp. Micropal.* **13**(2): 171-200.

Hodgkinson, K.A, Garvie, C.L and Bé, A.W.H. 1992. Eocene euthecosomatus ptreropods (Gastropoda) of the Gulf and eastern coasts of North America. *Bull. Amer. Palaent.* **103** (341): 5-35.

Jung, P. 1073. Pleistocene pteropods, Leg. 15, Site 147, p. 753-767. In: *Initial Rept. DSDP Drilling Project* 15, USGP Office, Washington D.C.

McGowan, J.A. 1960. The systematics, distribution and abundance of the Euthecosomata of the North Pacific. *Unpublished Ph. D. dissertation, University of California, San Diego.*

Meisenheimer, J, 1905. Pteropod Wiss Ergebn. deutschen Tiefsee Exped. 1898-95, IX, P.1-314, pls.i-xxvii, test figs. 1-35,9 charts.

Melkert, M.J, Ganssen, G, Helder, W and Troelstra, S.R. 1992. Episodic preservation of pteropod ooze in the deep Northeast Atlantic Ocean: climatic changes and hydrothermal activities. *Mar. Geol.* **103:** 407-422.

Menzies, R.J. 1958. Shell-bearing pteropod gastropods from Mediterranean plankton (Cavolinidae) Pubbl *Staz. Zool. Napoliv.* **30:** 381-401.

Miao, Q and Thunnel, R.C. 1993. Recent deep sea benthic foraminiferal distributions in the South China and Sulu seas. *Mar. Micropal.* **22:**1-32.

Narassayya, B.L., Rao, B.L, Mahapatara, G.P., and Hari Prasad, M. 1990. Seabed sampling of Pondicherry in the EEZ of Bay of Bengal (SM-47). *GSI Record,* **122**(2): 188-189.

Pafort-van Iersel, T. 1986: Contribution to pelagic zoogeopgraphy of the Mid North Atlantic Ocean, Part-1. Distribution of pteropods, heteropods and silver hatchfishes. *Plankton News Letter, Rep. Ser,* **1**:1-57,

Pelseneer, P. 1888: Report of the pteropoda. Report on the scientific results of the voyage of H.M.S "Challenger" 1873-1876. *Zoology,* **Part. 65**(23): 1-132.

Peterson, L.C and Prell, W.L. 1985. Carbonate dissolution in recent sediments of the Eastern Equatorial Indian Occean: Preservation pattern and carbonate loss above the lysocline. *Mar. Geol.* **64:**259-290.

Price, B.A., Killingley, J.S and Berger, W.H. 1985. On the pteropod pavement of the Eastern Rio Grande Rise. *Mar. Geol.* **64:**217-235.

Rampal, J. 1968. Les Pteropodes thecosomes en Mediterrancee. Com,. *Int. Expd. Sci. Mer. Medit. Monaco.*:1-142.

Rao, B.R., B.L., Vaz, G.G., Vijay kumar, P and Babu Rao, M. 1998. Search for phosphorite and lime mud occurenes off Gujrat coast (SM-98). *G.S.I. Records*, **129**(2): 156-157.

Reiss, Z., Luz. B., Almogi-Labin, A., Halicz. E., Winter. A., Wolf. A and Ross, D.A. 1980. Late Quaternary paleoceanogeaphy of the Aqaba (Elat). Red sea. *Quat. Res.* **14:** 294-308.

Rottkman, M.L. 1980: Net tow and surface sediment distribution of pteropods in the South China sea region: comparison and oceanographic implications. *Mar. Micropal.* **5:** 71-110.

Russell, F.S. and Colman, J.S. 1935. The zooplankton IV. The occurrence and seasonal distribution of the Tunicata, Mollusca and coelenterata (Siphonophora). *Sci. Rep. of the Great Barrier Reef Exp.* 1928-1929. **2**(7):203-276.

Saha, B.K., Rakshit, S., Mazumder, S. and Bhattacharjee, D. 1993. Quaternary sedimentation around Narcondam Island. Andaman Sea. Workshop on Evolution of East Coast of India, IGCP-274. *Tamil Univer.*:41-42.

Saha, B.K., Sinha, J.K., Rakshit, S and Bhattacharjee, D. 1997. Morphology and sediment character of seamounts and undersea Ridges in Andaman Sea. *Ind. Min.* **50**(4):339-360.

Sakthivel, M. 1969. A preliminary report on the distribution and relative abundance of Euthecosomata with a note on the seasonal variation of *Limacina* species in the Indian Ocean. *Bull. Nat. Inst. Sci. India.* **38:**700-717.

Sakthivel, M. 1874. A new species of *Creseis* (Gastropods, Mollusca) from the Laccadive sea. *Curr. Sci.* **43:** 619-620.

Singh, A.D. and Rajaraman, K.N. 1997: Distribtion of pteropods in surface sediments from the continental shelf North Kerala. *Jour. Geo. Soc. India*, **49:** 81-84.

Singh, A.D., Rajaranman, K.M, Ramachandran, K.K., Suchindan, G.K and **Samusddin, M.** 1998. Pteropod and bathymeters: A case study for the continental shelf off Kerala coastal India. *Curr. Sci.* **75**(6) : 620-623.

Stubbings. H. G. 1938. Pteropod., p. 3-33. In : The **John Murry** Expedition 1933-34.

Taki, I. and Okutani, T. 1962. Planktonic grastropoda collected by the training vessel "Umitaka Maru" from the Pacific and Indian Oceans in the course of her Atlantic expedition, 1956. *Jour. Fac. Fish. Anim. Hiroshima Univer.* **4:** 81-97.

Tesch, J.J. 1946. The Thecosomatous Pteropods (The Atlantic). the Carlsbarg Foundation's Oceanographical Expedition Round the world, 1928-1930 and previous "Dana" Expedition. *Dana Report.* **28:** 1-85.

Tesh, J.J. 1948. The thecosmatous pteropods: In Indo-Pacific. Dana *Report (Carlsberg Foundation, Copenhagen),* **30 :** 1-45.

Ujihara, A. 1996. Pteropods (Mollusca, Gastropoda) from the Pliocene Miyazaki Group, Miyazaki Prefecture, Japan. *Jour. Pal.* **70**(5): 771-788.

van der Spoel, S. 1967. *Euthecosomata, a group with remarkable development stages (Gastropoda, Pteropods).* J. Norrduyu en Zoon Gorinchen.

Venkatesh, K.V, Sinha, J.K., Bhattacharjje, D and Ramachandran, K.K. 1997. "Seabed survey in the Indian Ocean around Carlsberg Ridge". (SM-101) *G.S.I. Records* **129** (2): 166-167.

Winter, A., Almogi-Labin, A., Erez, Y., Halicz, E., Luz, B and Reiss, Z. 1983. Salinity tolerance of marine organisms deduced from Red Sea Quarternary record. *Mar. Geol.* **53:** M17-M22.

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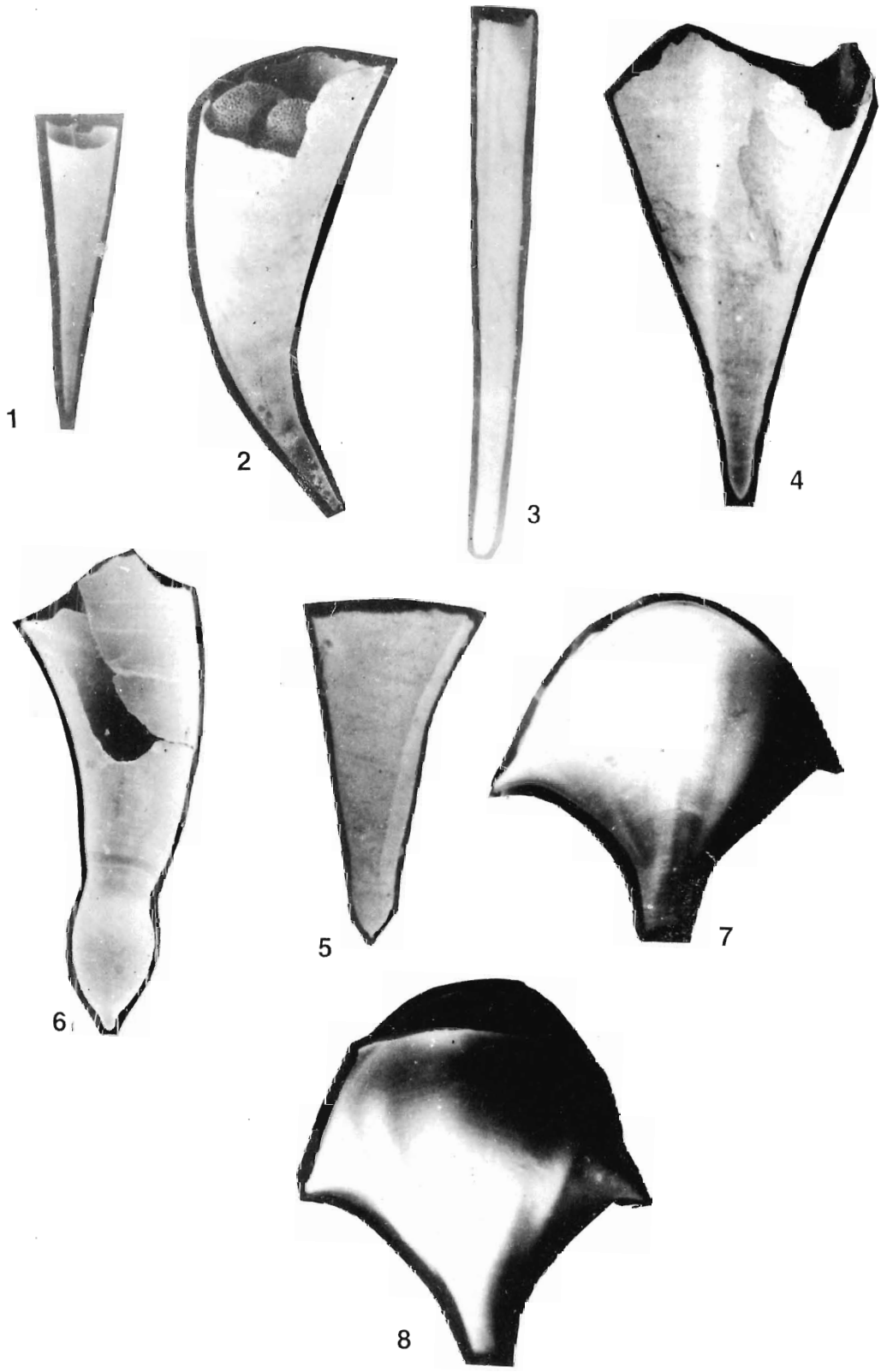
EXPLANATION OF PLATES

Plate I

1. *Creseis virgula conica* (Rang, 1828) X 20. Lateral view showing straight conical test and rapidly expanding diameter.
2. *Creseis virgula virgula* (Rang, 1828) X 20. Slide view showing strongly flexed conical test. Transverse diameter increasing rapidly in the beginning and gradually in the adult stage.
3. *Creseis acicula* (Rang, 1828) X 20. Lateral view showing elongated straight test expanding gradually in diameter.
4. *Clio pyramidata* Linne, 1767. X 20. Lateral view showing conical and triangular test. Prominent longitudinal ridges visible on the dorsal side.
5. *Clio convexa* (Boas, 1886) X 10. Test conical and triangular test. Double lined lateral ribs along the elongation of the test.
6. *Clio cuspidata* (Bosc, 1802) X 10. Test conical, posterior end slightly curved, protoconch teardrop-shaped with sharp point.
7. *Diacria trispinosa* (de Blainville, 1827) X 10. Dorsal view showing prominent longitudinal ribs, faint concentric growth lines and lateral spines.
8. *Diacria trispinosa* (de Blainville, 1827) X 10. Ventral view showing arch shaped aperture, convex ventral part of the test and faint concentric growth lines.

Plate II

1. *Diacria quadridentata* (de Blainville, 1827) X 20. Side view showing inflated, biconvex and well ornamented test. Longitudinal ridges of the dorsal side of the test is also visible.
2. *Cavolina longirostris* de Blainville, 1821. X 10. Apertural view showing enlarged arch shaped aperture and prominent growth lines on the apertural face of the ventral side.
3. *Cavolina globulosa* (Gray, 1850) X 10. Apertural view showing inflated test, smooth surface, large aperture and rounded ventral side.
4. *Cuvierina columnella* (Rang, 1827) X 10. Lateral view showing subcylindrical test and bean shaped aperture.
5. *Styliola subula* Quoy and and Gaimard, 1827.X 10. Side view showing conical test with a longitudinal groove runing slightly obliquely along the dorsal length.
6. *Limacina inflata* (d'Orbigny, 1836) X 30. Apertural view showing wide and lare aperature and smooth test without ornamentation.
7. *Limacina bulimoides* (d'Orbigny, 1836) X 25. Apertural view showing elongated, high spired, oval shaped test with nearly rounded aperture.
8. *Limacina trochiformis* (d'Orbigny, 1836) X 20. Apertural view showing low spired, nearly smooth test and oval shaped aperture.



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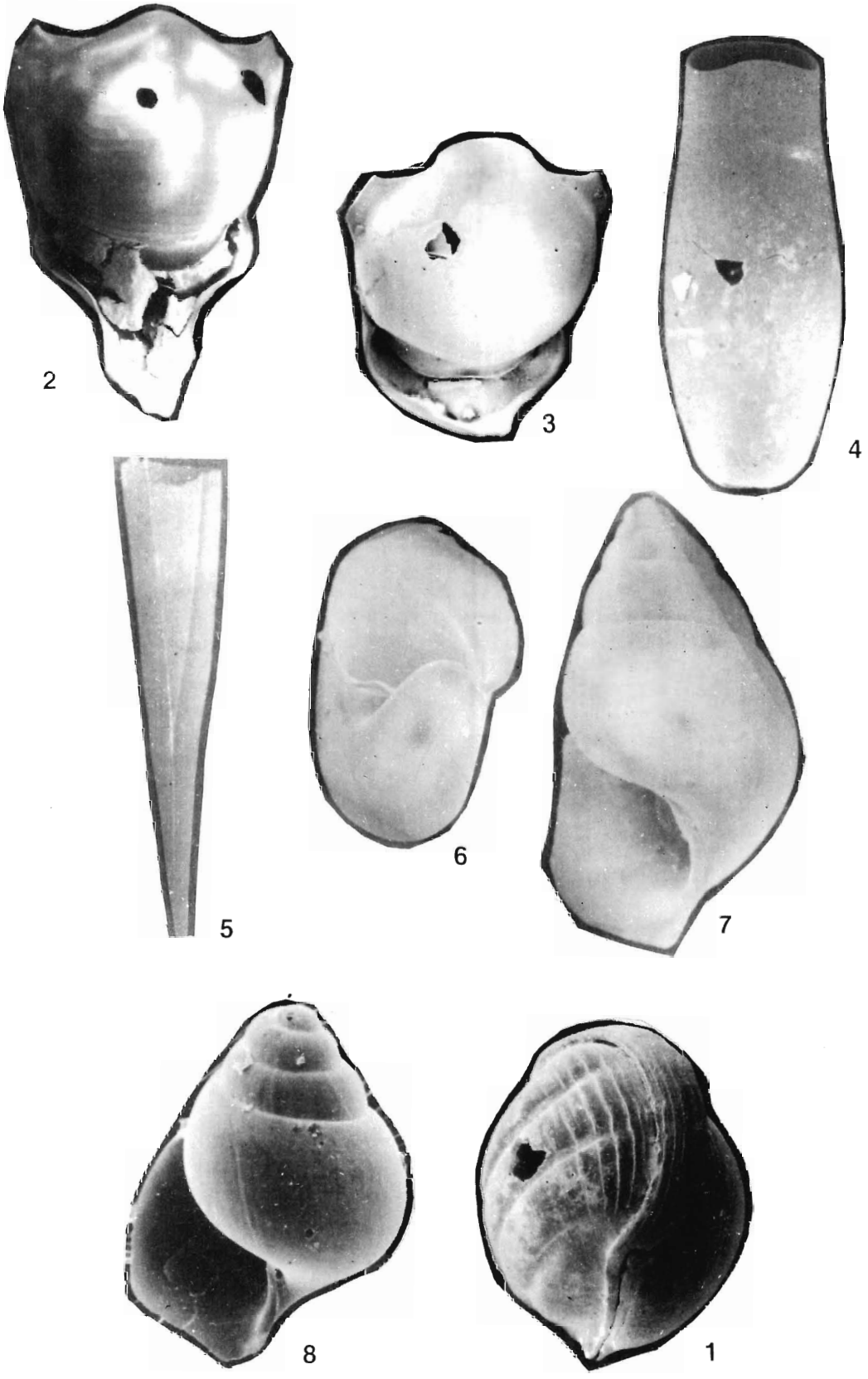
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