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"PTEROPOD PRESERVATION SPIKE" AND ITS SIGNIFICANCE IN THE ANDAMAN SEA

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ABSTRACT

A rich occurrence of pteropod is noted in some gravity cores collected between 525 m and 1259m water depth around the Narcondam Island in the Andaman Sea. Eighteen species of pteroped belonging to eight genera are identified and studied in detail from top to bottom of the gravity cores. They belong to three families of two suborders namely Pseudothecosomata and Euthecosamata under the order Thecosomata. A considerable variation in abundance of pteropod and their assemblages along the core length marks the area. Their abundance is moderate in the upper part and remarkably high in the lower part of the cores. An acme zone of pteropod is established at about 90-120 b.s.f. High diversity of pteropod taxa and their good preservation in the acme zone points to variation in the carbonate chemistry of the sea water during the late Quaternary time.

Two distinct assemblages of pteropods are recognised in the studied cores that occur above and below the acme zone. The upper assemblage is dominated by *Limacina inflata, Limacina bulimoides, Creseis virgula, Clio convexa, Cavolinia inflexa*, while the lower one comprises mainly *Limacina trochiformis, Creseis acicula, Clio pyramidata, Peraclis reticulata*. The acme zone corresponds to the pteropod preservation spike of the Tropical Belt all over the world. Analogous observation is reported from the Equatorial Pacific and the Atlantic Oceans. This study additionally determines the aragonite compensation depth (ACD) in this part of the Andaman Sea during Late Quaternary.

INTRODUCTION

During the last two decades, numerous palaeoceanographic studies had been made on pteropods of the deep-sea cores from the Gulf of Mexico, Red Sea, Caribbean Sea, Mediterranean Sea, Equatorial regions of the Atlantic and the Pacific Oceans. These studies attempted correlation between the occurrence of pteropods and various physicochemical parameters of the environments. The result of the studies reveals that pteropods can be used as a faithful indicator of specific ecological conditions. Biekart (1989) observed that this group of pelagic molluscs provides a very useful tool in establishing palaeoenvironments. He proposes the Quaternary Mediterranean pteropod zonation (Q.M.P.Z.) on the strength of variation of pteropod taxa with the palaeocenograpic milieu. Work on the Late Quaternary pteropod in the Andaman Sea is still in a preliminry stage and the present work attempts to study the late Quaternary pteropod in the northern part of the Andaman Sea around the Narcondam Island.

PREVIOUS LITERATURE

Pteropod studies of the Indian Ocean include the works of Pelseneer, (1888), Meisenheimer, (1905), Stubbings, (1938), Tesch, (1948) and Taki and Okutani, (1962) on the sea bed samples collected by 'Challenger', 'Valdia', 'John Murray', 'Dana' and 'Umika Maru' respectively. Sakthivel, (1969) studied the pteropods of the Arabian Sea, the Bay of Bengal and the southwestern parts of the Indian Ocean (sea bed samples collected by 'R.V. Argo' and 'R.V. Antan Brutun' in the I.I.O.E, 1964).

Berner (1977) prepared the pteropod ooze distribution map of the world oceans compiling data from Murray and Chumley (1924), Chen (1971) and Herman (1971). The noteworthy places of their distribution are the Persian Gulf, the Carribbean Sea (Chen, 1968), the Mediterranean Sea (Chen, 1968), the Gulf of Aqaba and the Red Sea (Almogi-Labin, 1982), Aegean Sea (Aksu *et al.*, 1995), the Gulf of Mexico (Chen, 1968), the Bermuda Pedistal (Chen, 1964), the rift valleys of the Mid-Atlantic Ridges, the Black and the Azores Plateau (Melkert *et al.*, 1992), the Rio Grande Rise, the Sargasso Sea (Wormuth, 1981), etc. Distribution of pteropod in the Andaman Sea was not shown in that map. The pteropod distribution map around the Andaman-Nicobar Islands was first published by Bhattacharjee and Ghosh (1993) and the data base was from the cruises of 'R.V. Samudra Manthan' of the Geological Survey of India.

A brief account of the Late Quaternary pteropod studies and its past environmental significance is presented in table 1.

MATERIALS AND METHODS

The present work is based on the studies of four gravity cores collected during the three GSI cruises (SM-36A, 44 &61) by 'R.V. Samudra Manthan' in the An-

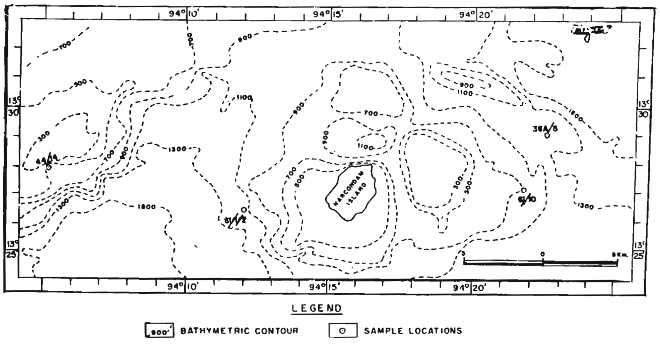

Fig. 1. Sample location map.

Table 1: Previous Literature.

Authors	Study area	Studies on
Sakthivel, M. 1969	Arabian Sea & Indian Ocean	Distribution of Euthecosomata.
Herman, Y. (1971, 1981)	Pacific & Indian Ocean	Palaeoclimatic studies of pteropod.
Junk, P. (1973)	DSDP Site-147	Pleistoene pteropods.
Diester-Hass, L. and Van der Spoel, S. (1978)	NE Atlantic	Late Pleistocene pteropods.
Reiss, Z. *et al* (1980)	Gulf of Aqaba (Red Sea)	Palaeocenographic studies of pteropods.
Wormuth, J.H. (1981)	NW Sargasso Sea	Vertical distribution of Euthecosomata.
Almogi-Labin, A. *et al.* (1986)	Red Sea	Palaeocenographic studies, pteropod preservation & isotope records.
Bucheri, G. (1984)	Cava Puleo (Ficarazzi, Italy)	Pleistocene pteropods.
Lahiri, A. and Sanyal, S.K. (1990)	Arabian Sea	Ecology of pteropods.
Bhattacharjee, D. (1995)	Andaman Sea	Distribution & ecology of pteropods.
Aksu, A.E. *et. al.* (1995)	Aegean Sea	Palaeoclimatic & isotope studies of pteropods and foraminifera.

daman Sea. The cores vary from 123 cm to 187 cm in length and were collected in water depths between 525m and 1259 m (fig. 1, table 2). Clay silt, silt, biogenic sand, fine sand, silty clay and clay are recorded from top to bottom of the same cores (fig. 2). About 10 to 12 gm dry subsamples were taken at 15 to 20cm intervals from the top to the bottom of the cores following the lithological variation of the sediment column. A total of 34 subsamples were selected from the said cores for this work. The samples were processed in 6% H_2O_2 solution, washed through a +230 ASTm sieve and dried in room temperature. The weight percentage of the coarser fraction (>63 µm size) was calculated (fig. 3).

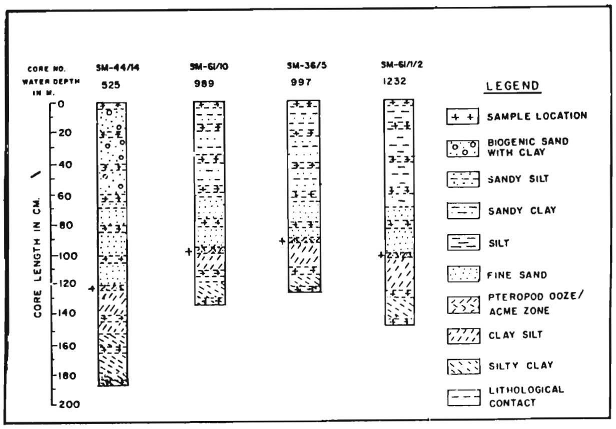

Fig. 2. Lithologs & sample location of gravity cores.

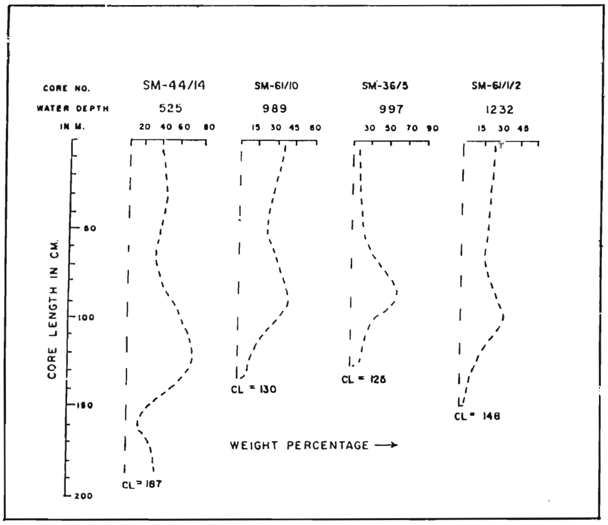

Fig. 3. Weight percentage of coarser fraction (>63 µm size)

The processed samples with high number of pteropods were again split with a microspliter in order to obtain a suitable aliquot that contains about 250 specimens. The whole pteropod assemblage was classified following the taxonomic works of Junk (1973), Be

Table 2: Core length, location and water depth (sample particulars).

Core No.	Latitude (N)	Longitude (E)	Water depth in m	Core length in cm
SM-36A/5	$13^{0}12.9'$	$94^{0}22.7'$	997	123
SM-44/14	$13^{0}28'$	$94^{0}05'$	525	186
SM-61/1/2	$13^{0}26.4'$	$94^{0}11.9'$	1259	143
SM-61/10	$13^{0}27'$	$94^{0}22'$	989	130

and Gilmer (1977), Almogi-Labin (1982) and Hodgkinson *et al.* (1992). All the pteropod specimens belonging to three families of two suborders, namely, the pseudothecosomata and Euthecosomata were identified under the binocular microscope. Grain counts of 18 species of 10 genera were taken by hand picking and fixing them up on the micropalaentological tray for check lists (tables 3A, B,C &D). The palaeoceanographic interpretation of the pteropod taxa was attempted after Berger (1977), Reiss *et al.* (1980), Buccheri (1984), Cramp *et al.* (1988), Melkert *et al.*, (1992) and Aksu *et al.* (1995).

OCCURRENCE OF PTEROPODS IN CORE SAMPLES

Maximum abundance of pteropods is recorded at 120 to 125 cm, 95-100cm, 90-95 cm and 100-105 cm b.s.f. in cores respectively (Pl.-III). The increase in the weight percentage of the coreser fraction has always been found due to increase of the incidence of pteropods and benthic foraminifers. Such a rise in the weight percentage of the coareser fraction almost invariably marks a depositional event and, as such, may be construed as an event marker.

The abundence of the dominant taxa in 34 subsamples of 4 cores are presented in table (3A, B, C & D). The frequency of only twelve important species is quantitatively shown from top to bottom of the cores. These tables indicate that there is a considerable variation in the abundance of pteropod and their assemblages along core length. Their abundance is moderate in the upper part and pronounced in the lower part of the cores. As already mentioned, maximum abundance is recorded at 4 subsurface levels of the cores. These levels represent the peak or acme zone of pteropod occurrence and may be marked as "Pteropod preservation spikes." These typial pteropod rich levels compare well with the so-called pteropod preservation spikes of Berger (1977) and Broecker and Peng (1982). These spikes were reported from the sediment cores collected in the North Atlantic (Bramlette and Bradley, 1940), the Caribbean and the-Mediterranean Sea, the Gulf of Mexico, from the continental slope off Portugal, Morocco, Spanish Sahara and Senegal in the Equatorial Atlantic Ocean (Kudrass, 1973 and Diester-Hass *et al.*, 1978).

It is noted that the frequencies of *Limacina inflata, L. bulimoides, Creseis virgula,* and *Cilo convexa* are relatively conspicuous in the upper part of the acme zone than the lower part of the core. On the other hand, the occurrence of *Creseis acicula, Clio pyramidata* and *Peraclis reticulata* are higher below the acme zone than in the upper part of the cores. Frequency of *Diacria quadridentata, D. trispinosa, Styliola subula* considerably increases around the acme zone and wanes towards both the upper and the lower part of the 'pteropod preservation spike'.

The diversity of the pteropod assemblage is low in the core sample except in the acme zone in comparison with the Northwest India Ocean (Sakthivel, 1969). Mode of preservation of the pteropod shells are generally

Table 3a: Abundance of Pteropod taxa in the Core (gc-sm 44/14). Water depth: 525m.

Depth down the Core Samples in cm.	0-5	20-25	4-45	60-65	80- 85	100-105	120-125	140-145	160-165	180-185.
Dominant Species										
Limacina inflata (d'Orbigny, 1936)	C	C	A	A	C	P	A	C	P	F
L. bulimoides (d'Orbigny, 1836)	R	R	R	R	F	F		C	C	P
L. trochiformis (d'Orbigny, 1836)	R	R	R	F	F	F	C	P	P	F
Creseis chierchiae (Boas, 1886)	P	P	P	F	F	F	C	P	P	F
Creseis virgula Rang, 1828	P	P	P	P	P	F	C	P	F	F
C.acicula Rang, 1828	R	R	F	F	P	P	A	C	P	P
Clio convex (Boas, 1886)	R	R	R	F	F	F	C	P	F	F
Clio pyramidata Linne, 1767	F	F	F	F	P	P	C	P	P	P
Diacria quadridentata (de Blainville, 1827)	R	R	R	R	F	P	C	P	F	P
Peraclis reticulata (d'Orbigny, 1836)	R	R	R	F	F	P	C	P	P	F
Cavolinia inflexa (Lesueur, 1813)	R	R	F	F	F	P	C	P	P	P
Styliola subula (Quoy & Gaimard, 1827)	R	R	F	F	F	P	C	P	P	P

Legend : No of Specimens	Abbreviation	Terminology
01-05	R	Rare
05-15	F	Few
15-40	P	Present
40-60	C.	Common
60-85	A	Abundant

Table 3b : Abundance of Pteropod taxa in the core (gc-sm/61/10). Depth : 989 M.

Depth down the Core Samples in cm.	0-5	15-20	35-40	55-60	75-80	95-100	110-115	120-135
Dominant Species								
Limacina inflata (d'Orbigny, 1936)	F	F	P	P	C	A	C	P
L. bulimoides (d'Orbigny, 1836)	R	R	P	F	P	C	F	F
L. trochiformis (d'Orbigny, 1836)	F	P	F	F	P	C	P	P
Creseis chierchiae (Boas, 1886)	P	P	P	F	P	C	C	P
Creseis virgula Rang, 1828	P	P	F	F	C	C	P	P
C. acicula Rang, 1828	F	F	F	P	C	C	P	P
Clio convex (Boas, 1886)	R	R	F	F	P	C	P	F
Clio pyramidata Linné, 1767	R	F	F	C	C	A	P	P
Diacria quadridentata (de Blainville, 1827)	R	R	R	F	F	C	C	P
Peraclis reticulata (d'Orbigny, 1836)	R	R	R	F	F	C	P	P
Cavolinia inflexa (Lesueur, 1813)	R	R	F	F	P	C	F	F
Styliola subula (Quoy & Gaimard, 1827)	R	F	F	P	C	C	F	F

Legend : No of Specimens	Abbreviation	Terminology
01-05	R	Rare
05-15	F	Few
15-40	P	Present
40-60	C	Common
60-85	A	Abundant

Table 3c : Abundance of Pteropod taxa in the core (GC-SM/36A/5). Depth : 997 m.

Depth down the Core Samples in cm.	0-5	15-20	35-40	55-60	75-80	95-100	110-115	120-135
Dominant Species								
Limacina inflata (d'Orbigny, 1936)	F	F	P	C	C	A	C	P
L. bulimoides (d'Orbigny, 1836)	R	R	F	F	C	C	P	P
L. trochiformis (d'Orbigny, 1836)	R	R	R	F	F	P	P	F
Creseis chierchiae (Boas, 1886)	P	P	P	F	F	P	C	P
Creseis virgula Rang, 1828	P	P	P	P	P	R	P	F
C. acicula Rang, 1828	F	F	F	P	P	C	C	P
Clio convexa (Boas, 1886)	R	R	F	F	P	C	P	F
Clio pyramidata Linne, 1767	F	F	F	P	P	A	C	P
Diacria quadridentata (de Blainville, 1827)	R	R	R	F	F	C	P	F
Peraclis reticulata (d'Orbigny, 1836)	R	R	R	F	F	C	P	P
Cavolinia inflexa (Lesueur, 1813)	F	f	P	P	C	C	P	P
Styliola subula (Quoy & Gaimard, 1827)	F	P	P	P	P	P	F	F

Legend : No of Specimens	Abbreviation	Terminology
01-05	R	Rare
05-15	F	Few
15-40	P	Present
40-60	C	Common
60-85	A	Abundant

Table 3D : Abundance of pteropod Taxa in the Core (GC-SM/61/1/2). Depth: 1259.

Depth down the Core Samples in cm.	0-5	30-35	40-45	60-65	80-85	100-105	120-125	145-148
Dominant Species								
Limacina inflata (d'Orbigny, 1836)	F	F	P	P	P	A	C	P
L. bulimoides (d'Orbigny, 1836)	R	R	R	R	F	C	P	P
L. trochiformis (d'Oribigny, 1836)	F	F	F	F	P	C	P	F
Creseis chierchiae (Boas, 1836)	P	P	P	F	F	C	C	F
Creseis virgula Rang, 1828	F	P	P	F	F	A	P	P
C. acicula Rang,1828	R	R	R	R	F	A	C	C
Clio convexa (Boas, 1886)	R	R	R	F	F	P	C	P
Clio pyramidata Linne, 1767	F	F	F	F	P	A	C	P
Diacria quadridentata (de Blainville, 1827)	R	F	R	R	F	C	P	F
Peraclis reticulata (d'Orbigny, 1836)	R	R	F	R	P	C	F	F
Cavolinia inflexa (Lesueur, 1813)	F	F	R	F	P	P	C	F
Styliola subula (Quoy & Gaimard, 1827)	R	R	F	F	F	C	P	P

Legend : No. of Specimens	Abbreviation.	Terminology
01-05	R	Rare
05-15	F	Few
15-40	P	Present
40-60	C	Common
60-85	A	Abundant

good. The tests of *Limacina inflata, L. bulimoides, L. trochiformis, Diacria quadridentata, Clio pyramidata, Cavolinia gibbosa* and *Creseis acicula* are well presrved. Moderate to good mode of preservation is seen in the test of *Diacria trispinosa, Cuvierina columnella, Creseis virgula, Peraclis reticulata* and *Cavolinia inflexa*. However, the test of *Hyalocylis striata, Styliola subula, Cavolinia tridentata, Creseis virgula, C. acicula* and *Creseis chierchiae* are poorly preserved in this area.

TAXONOMIC NOTES

All the pteropods studied in this area belong to three families (Limacinidae, Peraclididae and Calvoliniidae) under the one order thecosomata. Seven genera are identified from the family Calvoliniidae. They are *Creseis, Clio, Cuvierina, Styliola, Cavolinia, Hyalocylis* and *Diacria*. The Limacinidae family is represented by the only genus *Limacina* with rich population. The Peraclididae family has only one genus represented by *Peraclis* which shows moderate abundance.

Eighteen species of pteropods were identified in the cores and they are systematically presented to show their taxonomic position. Sixteen scanning electron microscopic photographs of pteropod specimens are given in plates I,II and III to illustrate the taxonomic details. A brief description of some important specimens are detailed below.

Limacina inflata (d'Orbigny, 1936)
(Pl. I, figs. 1-2)

Test smooth without ornamentation, trochoid to nearly planispiral, closely whorled, last whorl 1/2 to 4/5 of the entire shell. Aperture wide, rounded, prolonged at the base. Umbilicus broad and deep. Shell apex depressed by subsequently greatly expanding whorls.

Limacina trochiformis (d'Orbigny, 1836)

Shell low spired, height smaller than the maximum diameter, smooth with little ornamentation. Umbilicus constricted, aperture oval.

Limacina bulimoides (d'Orbigny, 1836)
(Pl. I, fig. 3-juvenile, fig. 4-adult)

Shell medium sized, elongated, high spired, trochispiral, umbilicus closed to very narrow, short discontinuous, columella arched and aperture oval.

Creseis chierchiae (Boas, 1886)
(Pl. II, fig. 4)

Test elongated, conical and gradually increasing in size. More than 2/3 of test length is covered by finer transverse grooves. The grooves are nearly equidistant from each other. Aperture circular.

Creseis acicula (Rang, 1828)

Shell long and conical, pencil-like, without longtudinal groove and ornamentation. Initially extremely white, posterior portion white but opaque, aperture circular.

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

Test conical, strongly flexed dorsally to an angle of about 50^0, transverse diameter increasing uniformly, surface smooth, aperture circular.

Creseis virgula (Rang, 1828)

Test elongatd, conical, slightly curved shell, cross section expanding more rapidly, aperture circular.

Cuvierina columnella (Rang, 1827)

Test flask to fat cigar shaped, widest near middle of shell length. Oval in cross-section except tqwards the aperture. Apertue oval to bean shaped.

Diacria quadridentata (de Blainville, 1827)
(Pl. III, figs. 1-3)

Shell inflated, biconvex, ventral side more convex than dorsal side, well ornamented. Prominent longitudional ridges on the dorsal side, distinct marginal striation on the apertural face, spherical protoconch.

Diacria trispinosa (Lesueur, 1821)

Large flattened shell, elongated with two prominent lateral spines, concentric growth lines are present on both the ventral and dorsal sides.

Cavolinia inflexa (Lesueur, 1813)

Shell flattened, greatest shell width between two lateral spines in the middle of the shell. The lateral portion of the aperture is narrower than the middle part. The ventral surface is bulged. Posterior end slightly curved to straight.

Cavolinia gibbosa (d' Orbigny, 1836)

Ventral side protruding and slightly angular. Test inflated, well ornamented, narrow posterior end but dorsal side convex.

Clio pyramidata Linnaeus, 1767

Test triangular, smooth to very little ornamented, transverse diameter increasing gently and uniformly. Three longitudinal ridges on dorsal side.

Clio convexa (Boas, 1886)
(Pl. III, fig. 4)

Shell elongated, posterior side curved ventrally and double lined lateral ribs present on the surface.

Styliola subula (Quoy and Gaimard, 1827)
(Pl. III, fig. 5; Pl. II, fig. 3).

Test conical, elongated, and nearly smooth. Longitudinal groove running slightly obliquely along dorsal length. Cross-section nearly circular.

Hyalocylis striata (Rang, 1828)

Shell conical, slightly curved dorsally, very faintly ornamented by numerous growth increments.

Peraclis reticulata (d'Orbigny, 1836)

Test sinistrally coiled, short spired, bulging whorls rapidly increasing towards the very large and elongated aperture. Columella twisted with a prolonged pointed rostrum. Surface ornamented with the raised hexagonal reticulated surface.

PALAEOCEANOGRAPHIC INTERPRETATION

The occurrence of the pteropods in the world oceans indicate that their distribution pattern changes with climatic condition. A considerable change in the occurrence of the pteropods during the warmer and the cooler climatic conditions has been noted in the Mediterranean, the Caribbean, the Equatorial Atlantic, the Pacific and the Indian Ocean by various workers (Kennett and Huddlestum, 1972; Buccheri, 1984; Gaby and Sengupta, 1985; Aksu *et al.*, 1995). Traits of such changes have been used as a tool for demarcating the Holocene (warmer) from the latest Pleistocene (cooler) sequences of the sea bed. On the basis of maximum abundance of pteropods at certain levels of the core samples, 'pteropod preservation spikes' have been identified by various workers in

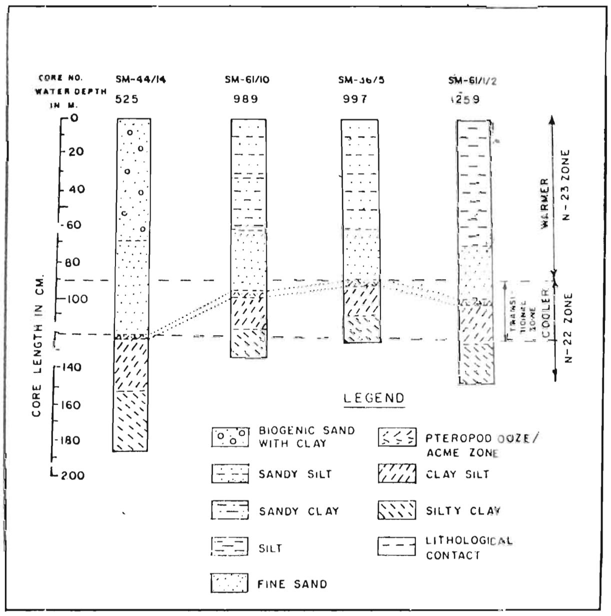

Fig. 4. Correlation of gravity cores.

different parts of the world oceans. Though this preservation spike may occur at different subsurface levels, it draws the attention of many micropalaentologists for its stratigraphic position just below the Pleistoene-Holocene boundary. This event mark has great palaeoceanographic signifiance for correlating the late Quaternary sediment columns intersected at various cores.

In this area, the pteropod preservation spikes are recorded at four levels of 120-125 cm, 95-100cm, 90-95cm and 100-105 cm b.s.f. in the gravity core of SM-44/14, 61/10, 36A/5 and 61/1/2 respectively. The overall pteropod assemblage in the upper part of the preservation spike is dominated by *Limacina inflata*, *L. bulimoides*, *Creseis virgula*, *Clio convexa* and *Cavolinia inflexa*. The lower part below the preservation spike is mostly represented by *L. trochiformis*, *Creseis acicula*, *Clio pyramidata* and *Peraclis reticulata* While the former assemblage mostly represents warmer environment, the latter indicates a cooler condition of deposition heralding the Holocene and the Pleistocene sequence respectively. Here, the preservation spike defines a marker that separates the Holoene from the Pleistocene.

Thus, gravity cores collected from different sea bed regimes around the Narcondam Island (fig. 1) are correlatable with the help of the pteropod preservation spikes. The Holocene - Pliestocene boundary in this part of Andaman sea appears to lie at a level of 0.9m to 1.2m b.s.f. (fig. 4).

The pteropod distribution records of the gravity cores indicate that the pteropod preservation spikes were formed due to reduced dissolution of pteropods over some period of time when the aragonite compensation depth was lowered. Such a condition may have been induced by changes of surface and bottom water circulation or by a sudden rise in alkalinity of the sea water as a whole.

High supply of organic carbon during the period of deposition of the pteropod preservation spikes is indirectly related to the rise in the alkalinity of the depositional milieu which is evident from the remarkable flourishing of the benthic foraminifera in the acme zone as mentioned in the preceding section. Rise of alkanity further favours the chances of a greater degree of preservation of foraminiferal tests.

CONCLUSION

On the basis of the pteropod assemblage and the pteropod preservation spikes, the Holocene-Pleistocene boundary was demarcated at 0.9-1.2 m.b.s.f. in four gravity cores around the Narcondam Island in the north Andaman sea. The four sediment cores are correlated by an event marker defined by the pteropod preservation spikes. Incidentally, this marker horizon has been established at other tropical seas all over the world and corrosponds to transition from Stage-2/1 of the Oxygen isotopic stage of Emiliani (1955) and the upper part of the Ericson's 'Y' zone (14,000 years ago) known at present as the Deglaciation period.

Venkatachala *et al.* (1992) carried out palynological studies and 14_{C} dating of one core that was incidentally collected from the same locality of the present study (location of core SM- 61/1/2). According to their work, the pteropod preservation spike as demarcated by the author comes at 1-1.05m b.s.f. that dates 15,000-16,000 years BP by 14^{C} dating. These two dates - one on the strength of biotic studies and the other on the basis of abiotic dating (14^{C}) - are strikingly close. Banerji *et al.* (1992) are also of the view that a remarkable closeness is evident between the biotic dating based on planktic foraminiferal assemblages and the 14^{C} dating in the late Quaternary sediments of the Andaman sea around the Narcondam Island.

It appears quite plausible that the pteropod preservation spike recorded in the late Quaternary sediments is a good palaeoceanographic indicator in the North Andaman Sea as in other marginal seas of the world. It may be used as an effective tool for the biozonation of the late Quaternary marine sequences.

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EXPLANATION OF PLATES

Plate I

1. *Limacina inflata* (d' Orbigny). Apical view showing prominant 'tooth' at the last whorl.
2. *Limacina inflata* (d' Orbigny). Apertural view showing wide and large aperture and smooth test without ornamentation. Umbilicus is on the left side of the specimen.
3. *Limacina bulimoides* (d'Orbigny). Apertural view shows short spired test, quadrangular aperture with a rectilinear collumellar margin, a juvenile specimen.
4. *Limacina bulimoides* (d' Orbigny). Apertural view showing elongated, high spired, oval shaped test. Umbilicus closed and aperture nearly rounded.

Plate II

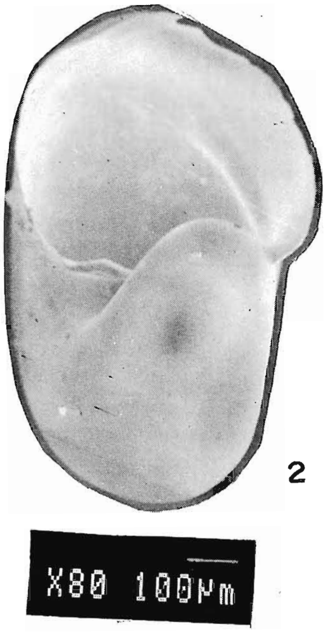
1. *Creseis acicula* (Rang). Side view showing straight, elongated and smooth shell with gradually increasing size.
2. *Creseis virgula virgula* (Rang). Side view showing conical test expanding rapidly in size.
3. *Styliola subula* (Quoy & Gaimard). Juvenile shell. Side view showing elongated, conical test and circular cross-section.
4. *Creseis chierchiae* (Boas). Side view showing conical test, slightly curved, densely and very thin ornamentation.

Plate III

1. *Diacria quadridentata* (de Blainville). Apertural view showing distinct marginal striation on the apertural face, thickened apertural margin and broad arch-shaped aperture.
2. *Diacria quadridentata* (de Blainville). Dorsal view showing prominant wide longitudinal ridges and two small lateral spines.
3. *Dicria quadridenta* (de Blainville). Side view showing the inflated, biconvex and well ornamented test.
4. *Clio convexa* (Boas). Side view showing conical and triangular test, prominent protoconch and transverse diameter increasing gently and uniformly.
5. *Styliola subula* (Quoy & Gaimard). Side view showing conical smooth test with a longitudinal groove running slightly obliquely along the dorsal length.

Plate I

1



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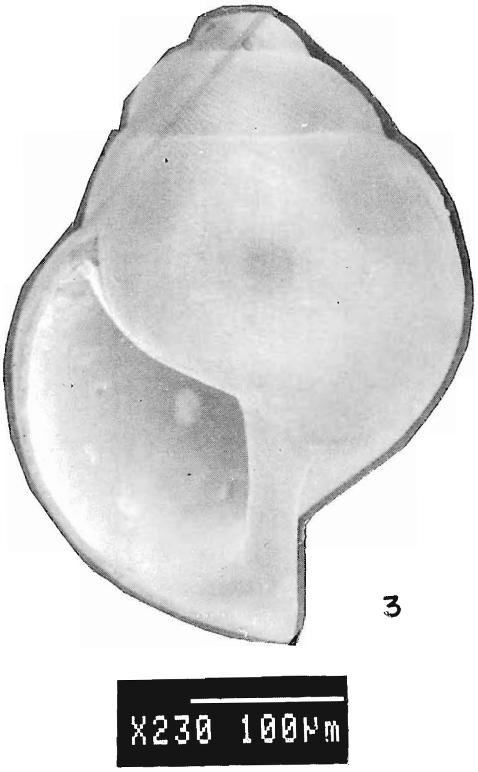

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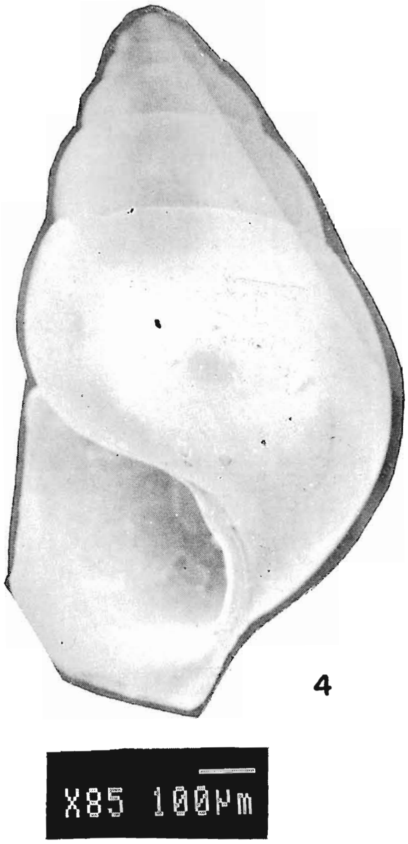

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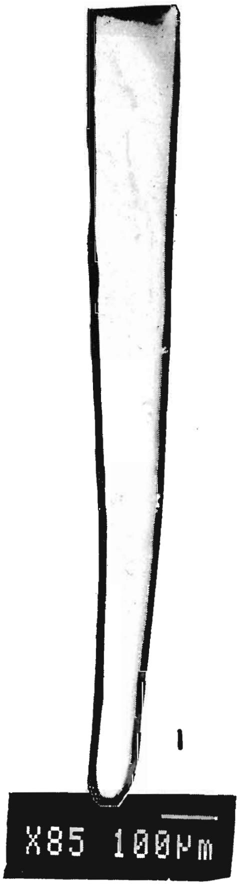

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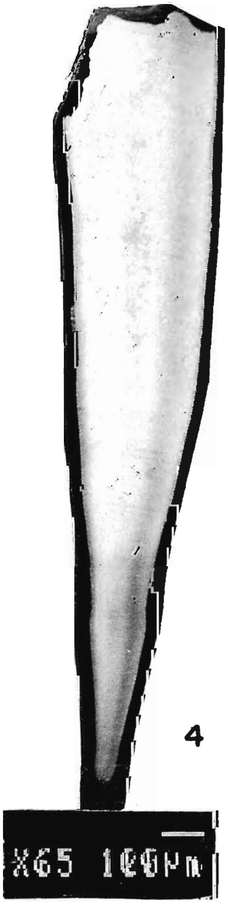

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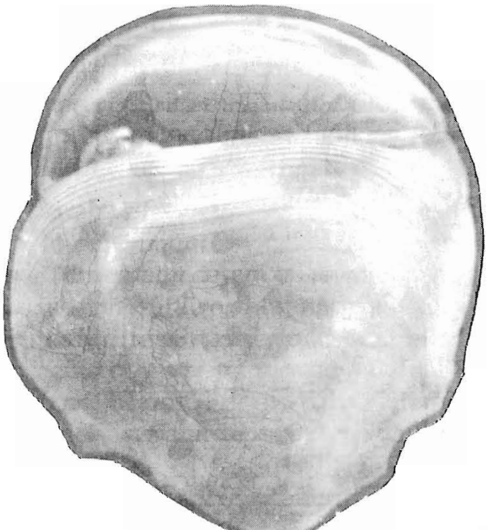

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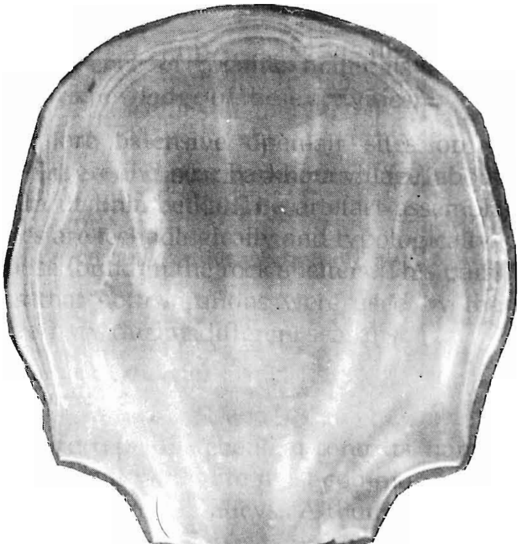

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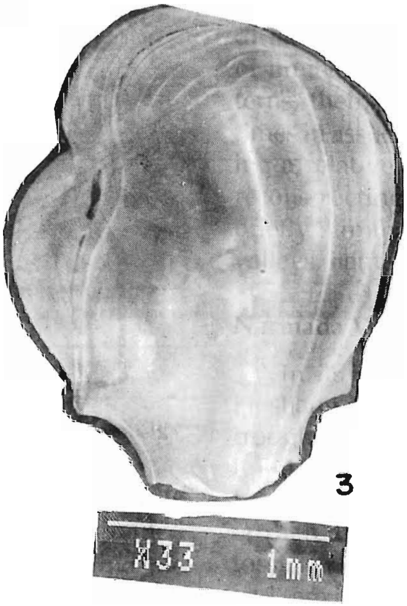

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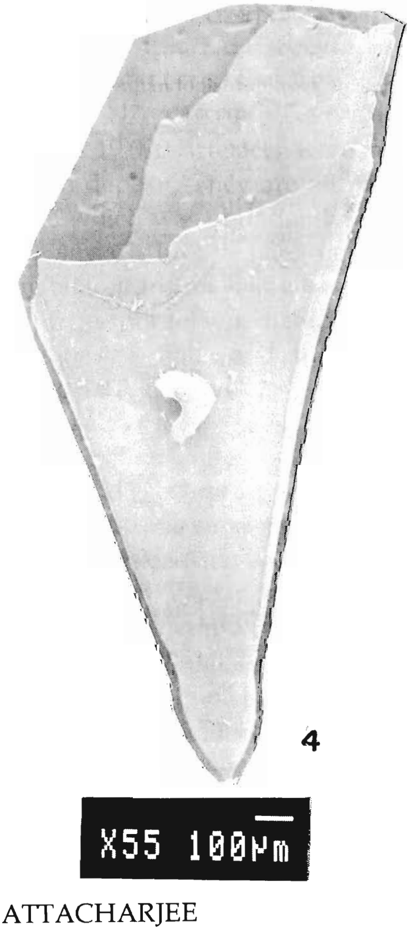

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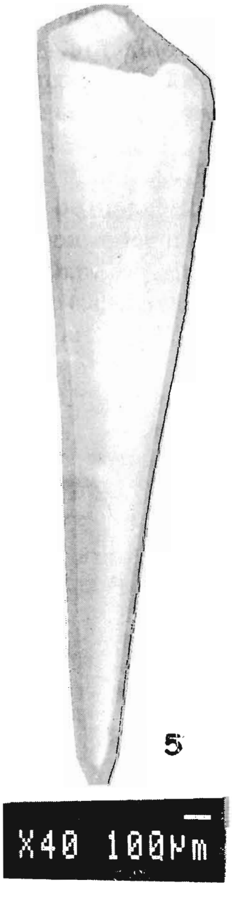

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