

niche in the Digha beach and is harboured in astronomical numbers. This sensitive ecological factor, in turn, leads to spatial variations in degree of bioturbation.

The plots of coastal profile-linked average *Ocypode* burrow lengths (Figure 1d) indicate that the Digha burrows all over the coastal profile are longer than those noticed for other areas. This suggests that the bioturbated top layer in Digha is thicker than that of the other areas.

The Digha beach has a few looped segments which provide ideal protected shelter for the burrowing crabs. These parts are found totally reworked during each low tide. The measured burrow concentrations even increase up to 80/m². The degree of bioturbation in the top layer is so intensive that the sedimentary structures are totally obliterated (Figure 2c).

It is illustrative from the above data that the upper half of the Digha beach suffers extraordinarily higher and deeper bioturbation in comparison to adjoining beaches. Underground burrowing is also accompanied by surficial excavations in the form of scratching, pitting and pellet making which are prominently seen in the swarf zone. These processes also help in prompt loosening of the bioturbated layer.

While hydrodynamic and other environmental factors remain nearly common to the studied areas, the Digha beach, in particular, experiences the highest degree of bioturbation genetically related to decapods. The most adversely affected backshore and upper foreshore areas are selectively subjected to diurnal erosion owing to the formation of unstable bioturbated top layer. Repetition of this process over decades has overall degradational effects on the Digha beach. The bioturbational force in the neighbouring beaches has not crossed the threshold to bring about instability. This example carries the unequivocal message that the nature of bioturbation acts as major agency in deciding the stability of coastal landscapes.

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Pteropods as bathometers: A case study from the continental shelf off Kerala coast, India

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There are several biological parameters commonly used for determining water depth related to past sea level changes. An attempt is made here to assess the indicative value of pteropods in paleobathymetric determination based on the quantitative analyses of 13 surface samples from the shelf off north Kerala. This study reveals a significant bathymetric control over distribution of certain pteropod species, viz. *Limacina inflata*, *Creseis acicula*, *C. virgula* and *C. chierchiae*. Relative response of these species to the changing water depth is examined in terms of abundance ratio of *L. inflata* (mesopelagic) and epipelagic *Creseis* spp. (*acicula*, *virgula*, *chierchiae*). Comparison of the *L. inflata*/*Creseis* spp. vs water depth curves obtained for the two transects running across the shelf indicates compliant consistency in relationship between their abundance and depth. Thus, the limited depth range of these pteropod species with their greater sensitivity to the bathymetric changes make them excellent bathometers. The data on the modern distribution–depth relationship of these bathometers can be used for deciphering paleodepth in core sections.

OVER the last decade, there has been an increase in interest among the Quaternary researchers to study the pattern of past sea level changes on the global, regional and local scales. The biotic components of the marine sediments have been commonly used as tools for deciphering oceanographic and climatic history of the recent past. Several biological criteria adopted for this purpose were established based on the clear understanding of various environmental and ecological factors (including depth habitat, relevant in the present context) controlling the modern distribution of fauna and flora in the sea. The main criteria for the selection of any microfauna as bathymetric indicator are its limited range of depth habitat and high sensitivity to the water depth variation. Previous studies on the modern distribution of pteropods reveal that certain species have restricted depth range^{1,2}. Another important peculiarity which promotes the utility of pteropods in paleodepth

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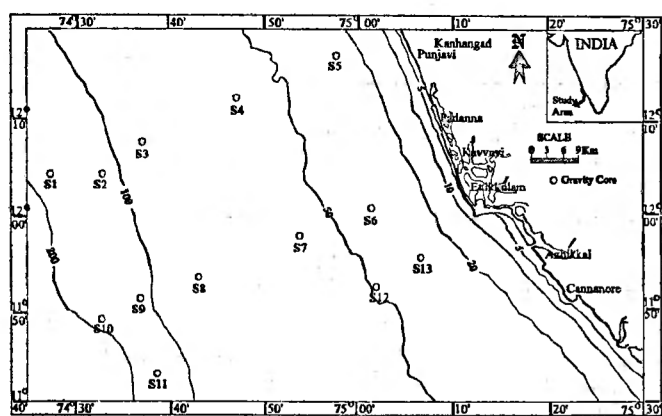


Figure 1. Map showing bathymetry and sampling locations.

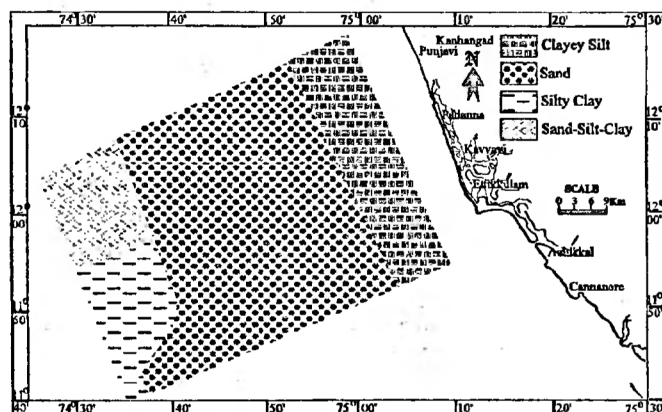


Figure 2. Sediment distribution map of the study area.

construction is their deposition close to the natural habitat because of the larger size³. Thus, the distribution patterns of pteropods in the sediments are considered to be representative of the depth habitats of their living counterparts, in contrast to the other planktic micro-organisms. Pteropods have been reported earlier from the marginal seas and areas of tropical continental shelves^{1,2,4-9}. It has been observed that the western continental shelf of India is ideal for the investigations on the Quaternary pteropods, as they constitute one of the major biotic components in the sediments^{1,10}. Although paleodepth determinations using pteropods were suggested long back in 1969 by Herman and Rosenberg based on their preliminary investigations on the surface samples from the northwestern continental shelf of India, surprisingly no attempt has been made thereafter to evaluate the potentiality of pteropods as paleobathymetric indicators.

Thirteen gravity cores from the shelf off north Kerala were collected along the two transects covering inner-shelf to outer-shelf areas (30 to 151 m water depth) on-board FORV Sagar Sampada cruise No. 119 (Figure 1). Core top samples were treated with 5% H_2O_2 and washed through 125 μm sieve and dried. The entire pteropod and foraminifera populations were analysed both qualitatively and quantitatively in 1 g of the dry sediment $>125 \mu m$ of each sample. The bathymetric

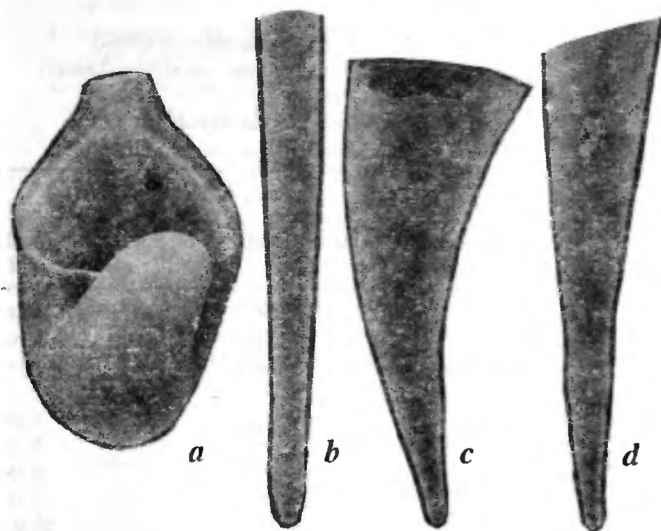


Figure 3. SEM photographs of pteropod species considered as bathymetric indicators. a, *Limacina inflata* (d'Orbigny) Apertural view $\times 63$; b, *Creseis acicula* (Rang) $\times 85$; c, *Creseis virgula* (Rang) $\times 65$; d, *Creseis chierchiae* (Boas), $\times 55$.

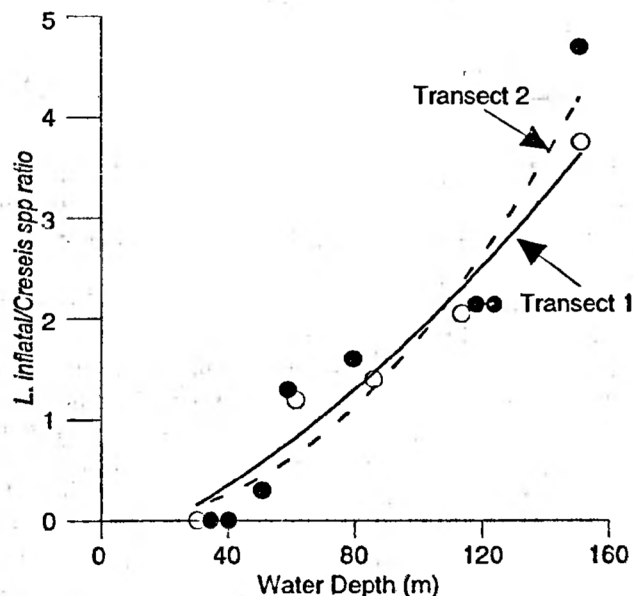


Figure 4. Variation in the *Limacina inflata*/*Creseis* spp. ratio with water depth (Open circles: transect 1 and closed circles: transect 2).

distribution of each pteropod species was recorded transect-wise to test for uniformity in the response of species to changing water depth in the study area. The distribution patterns of benthic/planktic foraminifera, pteropods/planktic foraminifera abundance ratios were also recorded. Grain size analysis was also performed with conventional wet sieving and pipette method¹¹. Sediment classification was made based on the descriptive scale proposed by Shepard¹².

Table 1. A checklist of recorded pteropod species in the core top samples of the continental shelf off north Kerala

<i>Cavolinia longirostris</i> (De Blainville)	<i>Creseis chierchiae</i> (Boas)
<i>Cavolinia</i> sp.	<i>Diacria quadridentata</i> (De Blainville)
<i>Clio pyramidata</i> Linne forma <i>convexa</i> (Boas)	<i>Diacria trispinosa</i> (De Blainville)
<i>Clio pyramidata</i> (Linne) forma <i>lanceolata</i> (Lesuer)	<i>Hyalocylis striata</i> (Rang)
<i>Creseis acicula</i> (Rang)	<i>Limacina inflata</i> (d'Orbigny)
<i>Creseis virgula</i> (Rang) forma <i>virgula</i> (Rang)	<i>Limacina bulimoides</i> (d'Orbigny)
<i>Creseis virgula</i> (Rang) forma <i>conica</i> Eschscholtz	<i>Limacina trochiformis</i> (d'Orbigny)

Table 2. Ratio of benthic/planktic foraminifera, pteropods/planktic foraminifera and *L. inflata*/*Creseis* spp. in 1 g of washed samples with >125 µm

Location	Water depth (m)	Benthic/planktic Foraminifera	Pteropods/planktic Foraminifera	<i>L. inflata</i> / <i>Creseis</i> spp.
Transect 1				
S1	151.0	1.49	1.37	3.76
S2	113.5	1.36	1.16	2.05
S3	86.0	0.30	1.43	1.40
S4	61.4	2.18	0.73	1.20
S5	30.2	20.93	0.13	only <i>acicula</i>
Transect 2				
S10	150.5	1.26	1.40	4.71
S11	123.6	1.86	1.39	2.14
S9	118.1	0.98	1.85	2.14
S8	79.7	1.50	1.48	1.60
S7	59.0	2.88	0.74	1.30
S12	50.7	3.07	0.20	0.30
S6	40.0	10.22	0.03	only <i>acicula</i>
S13	34.5	10.11	0.11	only <i>acicula</i>

Textural attributes of the surface sediment samples are presented in Figure 2. Three major sedimentary units can be identified on the shelf. The innershelf region is dominated in clayey silt, which is restricted to the 40 m isobath. In the mid-shelf, a wide expanse of sharply contrasting sediment composition rich in sand is observed. The steeper outershelf is abundant in clay with both silty clay and sand-silt-clay textural grades distributed over it. Though the sediments in the mid-shelf are surmised as transgressive and still stand Holocene sand sheet, it contains around 13% mud, which is clearly attributable to the modern process of sedimentation. Moreover, the deposits in mid-shelf region are below the effective depth of wave erosion. However, the diametrical composition of CaCO₃ and organic matter in the surficial sediments indicate *in situ* depth dependent modern physical and biological processes.

In all, 14 species were recorded (Table 1). The assemblage is characterized by both the epipelagic (*Creseis acicula*, *C. chierchiae*, *C. virgula* and *Limacina trochiformis*) and mesopelagic (*Limacina inflata*, *L. bulimoides* and *Clio pyramidata*) forms. At the shallow locations (S5, S6 and S13), the pteropod assemblage comprises only single species *Creseis acicula*, whereas at deeper sites (S1 and S10), *Limacina inflata* dominates (~75%) in the assemblage. From 40 to 120 m depth, a

gradual variation in assemblages is recorded, showing a decreasing trend in relative abundance of *Creseis* (*C. acicula*, *C. chierchiae* and *C. virgula*) and increasing trend of *L. inflata*. The other species do not show any definite trend of variation in their abundance with water depth. This observation suggests that *Creseis* spp. and *L. inflata* are water depth-dependent and hence are potential bathymetric indicators, useful for inferring the paleobathymetry from the core sections (Figure 3). An attempt has been made to document the relationship between *L. inflata*/*Creseis* spp. abundance ratio and water depth variations. *L. inflata*/*Creseis* spp. ratio vs water depth plots were made separately for the two transects (transect 1: S1, S2, S3, S4, S5; transect 2: S10, S11, S9, S8, S7, S12, S6, S13) (Figure 4). Polynomial curve fitting of second order was performed on the data sets. The fitted curves show similar relationship between the *L. inflata*/*Creseis* spp. ratio and water depth for both the transects, suggesting a definite correlation of the change of abundance ratio of these species to the bathymetric variations (Figure 4). The different values of *L. inflata*/*Creseis* spp. ratio with corresponding present water depth can be utilized confidently for paleodepth determinations in core sections. The variations in the microfaunal assemblages have also been found to be influenced by other factors such as geographical

location and oceanographic conditions of the area¹³. Therefore, any such model established from an area will be mainly applicable to determine the paleobathymetry from the sediment cores of the same region.

The foraminiferal and pteropod data of the examined samples also indicate a depth control on the variation of benthic/planktic foraminifera (BF/PF) and pteropods/planktic foraminifera (Pt/PF) abundance ratios (Table 2). The usefulness of BF/PF ratio in paleodepth determination has been studied for the Arabian sea by Nigam and Henriques¹⁴. Therefore BF/PF and Pt/PF ratios can also be considered as additional tools for the bathymetric determinations.

Our studies reveal that *L. inflata* and *Creseis acicula*, *C. virgula* and *C. chierchiae* of the pteropod assemblages are highly depth sensitive and they can be considered as important bathometers. The data on the relationship of abundance ratio of *L. inflata* (mesopelagic)/*Creseis* spp. (epipelagic) and water depth can be used effectively for inferring the paleobathymetry of the area from the core sections. The pteropods/planktic foraminifera abundance ratio in the assemblages has also been found to be an additional useful tool for paleodepth determinations. We suggest similar studies to be conducted in other parts of the western continental shelf of India for evolving a regional model useful in the reconstruction of paleobathymetry, which in turn would provide history of past sea level changes.

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Surface deformation related to the 1819 Kachchh earthquake: Evidence for recurrent activity

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Field observations from the deformation zone of the 1819 Kachchh earthquakes are discussed in this paper. The results suggest segmented nature of the fault zone, operated by multiple earthquakes.

THE Kachchh earthquake of 16 June 1819 in northwest India (Figure 1) is considered to be a unique event of the stable continental regions (SCR) because of the extensive attendant surface deformation^{1–4}. It is believed to rank second in size to the 1810–11 ($M=8$) New Madrid earthquakes^{5,6}. A remarkable feature of this earthquake was the creation of a long elevated tract of land. This fault trace offers a rare opportunity to constrain the source of a large SCR event in a region otherwise known for sparse occur-

rence of surface ruptures. This paper presents some salient features of the deformation zone which indicate unmistakable presence of multiple scarps, marked by characteristic slips along two of its segments, generated by large earthquakes ($M \geq 7.5$) including the 1819 earthquake.

The 1819 fault scarp (known as 'Allah Bund' – dam of God) is located in the Runn of Kachchh, close to the international border between India and Pakistan (Figures 1a and b). Geologically, the Runn occurs within a failed Mesozoic rift, comprised of tilted fault blocks, horsts and grabens⁷. Presently a tidal flat connected to Arabian Sea through the Kori Creek, most parts of the Runn are inaccessible due to its marshy conditions⁸. The Allah Bund strikes in an east-west direction along its northern margin and rises against the salt-encrusted surface for a distance of ~95 km (Figure 2). The emergent land is composed of moist dark brown layers of silty clay, interspersed with lenses of fluidized silty sands and ferruginous tubes (Figure 2b).

A false colour composite of the study area generated from the Landsat TM (thematic mapper) bands 2, 4, 7 is shown in Figure 2a. The 95-km-long and 16–20-km-wide deformation zone can be clearly demarcated, sandwiched between desert dunes (white) in the north and the salt-