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**Biological reworking of sediments by crabs: A cause for erosion of the Digha beach, West Bengal**

C. De

Geological Survey of India, 15 Kyd Street, Calcutta 700 016, India

Beach erosion in and around Digha, West Bengal, a perennial problem for developmental work, is related to exceptionally high rate of organic reworkings of backshore to upper foreshore soft sediments. Extensive burrowing activities, especially by typical sandy beach crab *Ocypode* spp., produce a characteristic bioturbated top layer (1–1.5 m thick) having very high concentration (55–80 m⁻² area) of interconnected complex burrow cavities, which weaken and divide the coherent layer into numerous small sediment blocks amenable to quick erosion by wave and tidal actions. Repetition of this process over the years has been significantly enhancing long-term erosion of the Digha beach.

EROSION of the Digha beach, West Bengal, has been a matter of serious concern over the years for developmental work of the area including its tourism industry. The erosional process has so far been interpreted to be solely related to some critical physical and hydrodynamical preconditions¹ such as beach orientation, angle of wave approachability, tidal current velocity and so on. Construction of gravel barriers and mangrove plantation has been used as remedial measure to check coastal decay which, however, remains unabated. After a brief pause of three to four years, severe erosion of coastal tract by no less than 20 m in width and 10 km in length was recorded in 1997 at Digha.

Biocorrosion⁵ is an important process in marine sedimentation and benthic ecology. No less than 12 animal phyla, several plant groups and protozoans are important agents in marine bioerosion. Of these, fungi, algae, sponges, worms, gastropods, crustaceans, echinoids and fishes are most active. Vast supratidal and intertidal flats of the Digha coast harbour a myriad of burrowers and borers. A majority of the crustaceans and gastropods are found to be burrowers. Relative importance of bioeroders may in some cases be greater than other erosive agencies³. The Digha beach like many other tropical to subtropical soft beaches, is inhabited by decapods in huge numbers. Most of them possess sharp hard parts like pincers, walking legs, chela and mouth for excavation of sediments. Decapod bioerosion of California tidal flats⁴ is comparable to that of the Digha beach.

The present neochronological study has focused attention on the burrowing activities of the predominant decapod crustaceans along the coastal profiles developed at Digha, Shankapur, Junput and Bakkhali areas from west to east on the Bay of Bengal coast (Figure 1a). Of these, the Digha beach is being gradually eroded while others are stable. Size, shape and concentration of burrows *vis-à-vis* their environmental zonation have been studied and compared. The burrow cavities are replicated by white paraffin wax casting method⁶.

The selected four areas exhibit development of comparable geomorphic profiles which include wide back swamps with salt marshes (clays and silts), mobile beach dunes (medium to fine sands), supratidal backshore (intercalated sands, silts and clays) and intertidal foreshore (sands and silts with little clays, MZ 2.75 phi to 1.4 phi) from land (north) to sea (south). The width of the beaches varies from 750 m at Junput to 1.25 km at Shankapur. The statistical beach orientation is azimuthal 75⁰–255⁰.

The areas experience maximum 40⁰C to minimum 18⁰C annual range of temperature, 1480 cm to 2400 cm of annual rainfall, 25% to 38% of salinity range, pH variation 7.6–8.5, maximum spring tidal range 6.5–7.6 m, maximum neap tidal range 2–2.5 m, north-south both ways wind actions, seasonal premonsoon cyclonic storms (southeast to northwest) and wave action approaching the beach at 70–85⁰.

Crabs, namely *Ocypode ceratophthalma* (pallas), *O. cardimana* (Dcsmarest), *O. macrocera* (Edwards), *O. stimpsoni* (Ortmann), *Vca marioni* (Dcsmarest) and *Hyaleus pusillus* (De Hann), are found to burrow habitually in immense numbers all over the coastal profiles of the studied areas. *Ocypode* spp., being the most abundant in number, produces characteristic I, J, U, Y, multibranch Y and complex network burrow systems on the backshore and foreshore areas defining a conspicuous burrow zone running all along the Bay of Bengal coast. The old individuals produce short and thick (45 cm long and 10–25 cm circumference) burrows selectively in the backshore depressions. The burrows eventually join together, forming huge and complex systems.
Figure 1. a, Key map showing positions of Digha, Shankarpur, Junput and Bakkhali beaches on the Bay of Bengal Coast, West Bengal; b, Nature of geomorphic profile, sediments. Ocyopode spp. burrow forms, burrow zones and burrow concentrations across the Digha beach. c, Ocyopode spp. burrow concentration curves for Digha, Shankarpur Junput and Bakkhali beach profiles. d, Plots of coastal profile linked average Ocyopode spp. burrow lengths for different beaches.

network of underground burrow cavities with numerous surficial openings (4–12 cm in diameter). Very thin (0.5–0.8 cm wide) juvenile shafts and tunnels intervene with the network burrows and make them more complicated. Young and adults, on the other hand, produce discrete but very long and slender burrows with one or two openings over greater width of the intertidal foreshore areas. Uca marionis, producing I-shaped subverti-
cal to vertical burrows of variable dimensions (0.5–70 cm long and 0.9–1.3 cm wide), defines a separate burrow zone in the backswamp — saltmarshes parallel to the Ocypode burrow zone (Figure 1b). Concentration of Uca burrows is maximum (20/m²) in the clay-dominated moist areas. The Ilyoplax burrow concentration varies from 90/m² in the backshore to 5/m² in the middle foreshore in all the beaches. Ocypode and Ilyoplax together define a common burrow zone. The Ocypode burrow zone is absent in the middle intertidal foreshore beach of Bakkhal and replaced by Charybdis rostrata (crab) boring zone developed in exposed woody substrates.

The burrowing activities are confined to the top 1 m to 1.5 m thick layer of beach sediments. This layer is referred to here as bioturbated layer. After the recession of each high tide, this layer is produced by the crabs within three to four hours on the intertidal beach. The coherence and rigidity of this layer depend on the degree and nature of bioturbation which vary with time and place. High concentration of interconnected shafts and tunnels with surficial openings weaken and divide the top layer into innumerable interlocked sediment blocks which, at times, when subjected to hydrodynamic pressures of onrushing waves and tidal currents collapse heterogeneously. Individual burrow cavity having volumetric range from a few cubic centimetres to even 30 litres collapses under water producing circular depression (Figure 2a) on the beach. In thickly-populated areas, collective or en masse burrow collapse leads to uneven sagging or subsidence and even slumping (Figure 2b) in the creek and runnel banks. Cumulative effects of biogenic reworkings and following hydrodynamism decide to a great extent the rate of beach erosion. Since the hydrodynamic and other environmental factors remain nearly common to all the studied beaches, the biological factors become decisive in determining the beach stability.

The geomorphic profiles, sediment characters, burrow zones and variations of the produced burrow forms of the Digha beach (Figure 1b) are more or less similar to those of the other beaches studied, excepting burrow concentrations. It is evident that the burrow complexities attain maximum in the backshore to upper foreshore areas.

When relative courses of Ocypode burrow concentration curves for the four beaches are compared (Figure 1c), it is interestingly evident that the backshore–upper foreshore burrow concentration at Digha (55–60/m²) is much higher than the corresponding values (35–42/m²) of other areas. There is clear separation of fields for backshore-upper foreshore burrow concentration for Digha and that for other three areas. In this sense the Digha beach occupies a unique place characterized by highest ever counted burrow concentration. There is slight but supersensitive increase in clay content of the beach sediments from Digha to Bakkhal, a factor governing crab concentration which visibly diminish from Digha to Bakkhal with increase in clay content. Ocypode spp., being sand dweller, thus, finds ecological

Figure 2. a, Circular depression around individual burrow opening on Digha beach depicting gradual burrow collapse after recession of high tide. Bar scale = 5 cm; b, Nature of bioerosion on backshore-upper foreshore beach of Digha. Note circular areas (foreground) undergoing subsidence and slumping owing to en masse collapse of burrows underground. Bar scale = 5 m; c, Highly bioturbated looped beach part of Digha showing enormously high (80/m²) burrow concentration and total obliteration on sedimentary structures. Bar scale = 1 cm.
niche in the Digha beach and is harboured in astro-
nomical numbers. This sensitive ecological factor, in,
turn, leads to spatial variations in degree of bioturba-
tion.

The plots of coastal profile-linked average Ocyopode
burrow lengths (Figure 1d) indicate that the Digha bur-
rrows all over the coastal profile are longer than those
noticed for other areas. This suggests that the biotur-
bated 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, pit-
ting and pellet making which are prominently seen in the
swash 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 une-
quivocal message that the nature of bioturbation acts as
major agency in deciding the stability of coastal land-
scrapes.

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

A. D. Singh†, K. N. Rajarama,
K. K. Ramachandran*, G. K. Suchindan* and
M. Samsuddin*

Department of Marine Geology and Geophysics, Cochin University of
Science and Technology, Fine Arts Avenue, Cochin 682 016, India
*Centre for Earth Science Studies, Akkulam, Thiruvananthapuram
695 031, India

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, Crectes acicula, C. virgula and
C. chierchia. Relative response of these species to
the changing water depth is examined in terms of
abundance ratio of L. inflata (mesopelagic) and
epipelagic Crectes spp. (acicula, virgula, chierchiae).
Comparison of the L. inflata/Crectes 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 spec-
ies 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 paleo-
depth in core sections.

Over the last decade, there has been an increase in in-
terest 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 deci-
phering 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) control-
ling the modern distribution of fauna and flora in the
sea. The main criteria for the selection of any micro-
fauna 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 range1,2. Another important peculiarity which
promotes the utility of pteropods in paleodepth

†For correspondence.