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

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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 hydrodynamic preconditions[1-3] 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.

Bioerosion[4] is an important process in marine sedimentation and benthic ecology[5]. 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 agencies[5]. 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 flats[6] is comparable to that of the Digha beach.

The present neoichnological study has focused attention on the burrowing activities of the predominant decapod crustaceans along the coastal profiles developed at Digha, Shankarpur, Junput and Bakkhali areas from west to east on the Bay of Bengal coast (Figure 1 *a*). 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 method[7].

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 Shankarpur. The statistical beach orientation is azimuthal 75°–255°.

The areas experience maximum 40°C to minimum 22°C 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°–85°.

Crabs, namely *Ocypode ceratophthalma* (pallas), *O. cardimana* (Desmarest), *O. macrocera* (Edwards), *O. stimpsoni* (Ortmann), *Uca marionis* (Desmarest) and *Ilyoplax 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, multibranched 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

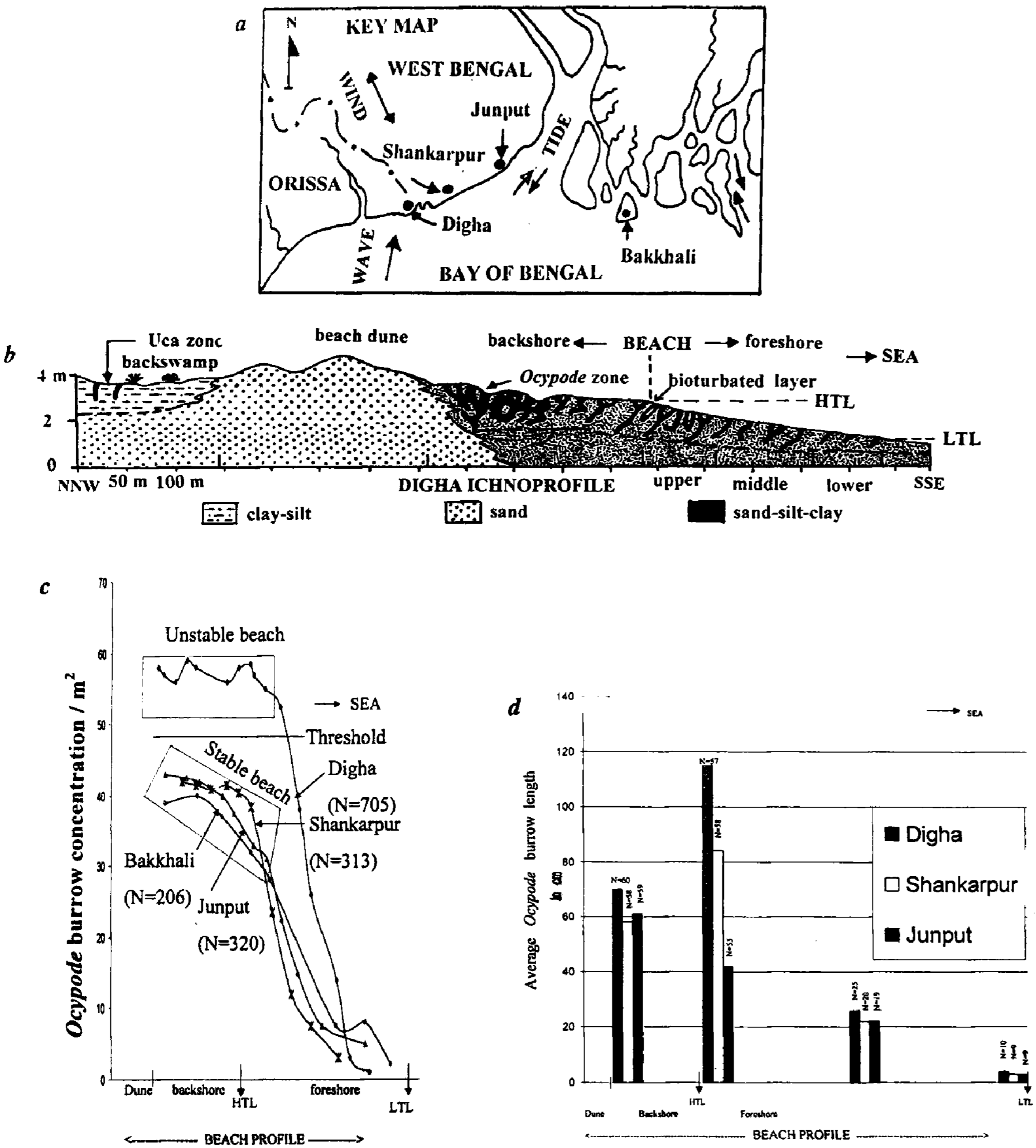

Figure 1. ***a***, Key map showing positions of Digha, Shankarpur, Junput and Bakkhali beaches on the Bay of Bengal Coast, West Bengal; ***b***, Nature of geomorphic profile, sediments, *Ocypode* spp. burrow forms, burrow zones and burrow concentrations across the Digha beach. ***c***, *Ocypode* spp. burrow concentration curves for Digha, Shankarpur Junput and Bakkhali beach profiles. ***d***, Plots of coastal profile linked average *Ocypode* 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 subvertical 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 1 *b*). Concentration of *Uca* burrows is maximum (20/m^2) in the clay-dominated moist areas. The *Ilyoplax* burrow concentration varies from 90/m^2 in the backshore to 5/m^2 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 Bakkhali 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 2 *a*) on the beach. In thickly-populated areas, collective or *en masse* burrow collapse leads to uneven sagging or subsidence and even slumping (Figure 2 *b*) 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 1 *b*) 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 1 *c*), it is interestingly evident that the backshore–upper foreshore burrow concentration at Digha (55–60/m^2) is much higher than the corresponding values (35–42/m^2) 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 Bakkhali, a factor governing crab concentration which visibly diminish from Digha to Bakkhali with increase in clay content. *Ocypode* spp., being sand dweller, thus, finds ecological

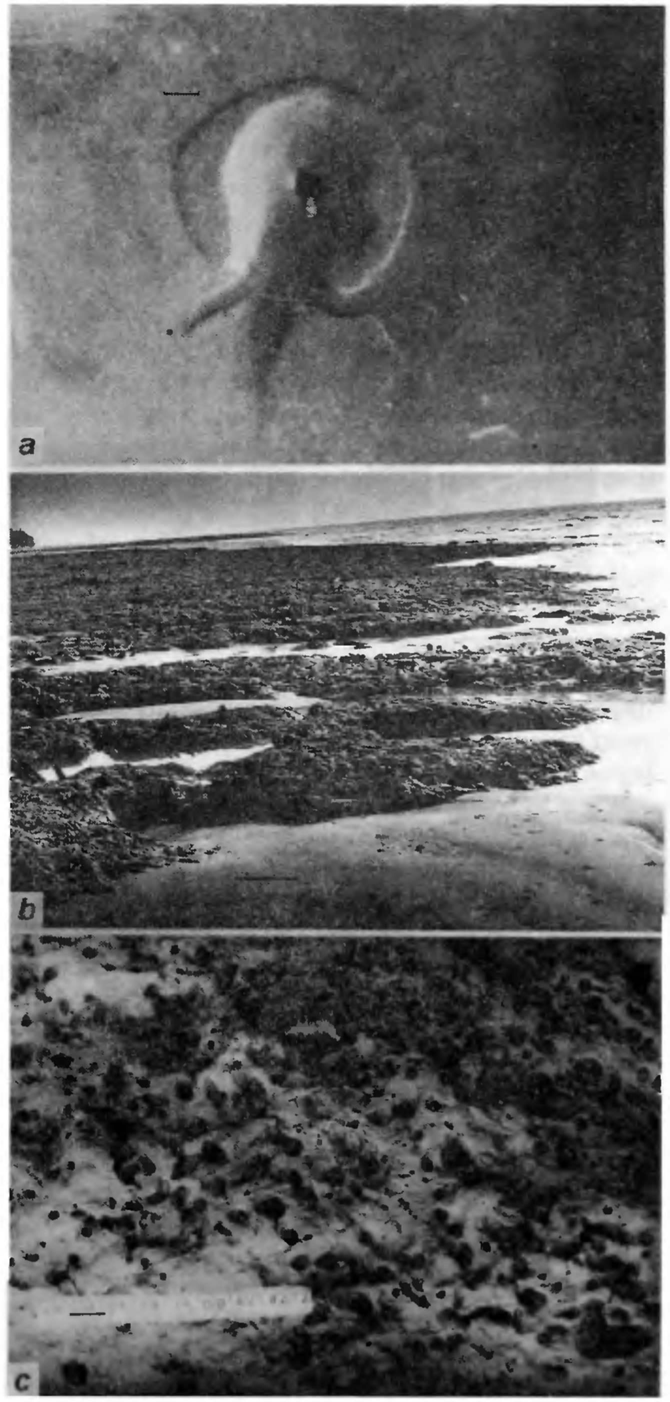

Figure 2. *a*, Circular depression around individual burrow opening on Digha beach depicting gradual burrow collapse after recession of high tide. Bar scale = 5 cm; *b*, Nature of bioerosion on backshore–upper foreshore beach of Digha. Note circular areas (foreground) undergoing subsidence and slumping owing to *en masse* collapse of burrows underground. Bar scale = 5 m. *c*, Highly bioturbated looped beach part of Digha showing enormously high (80/m^2) burrow concentration and total obliteration on sedimentary structures. Bar scale = 1 cm.

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 1 *d*) 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 $80/m^2$. The degree of bioturbation in the top layer is so intensive that the sedimentary structures are totally obliterated (Figure 2 *c*).

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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