ANIMAL-SEDIMENT RELATIONSHIP OF THE TWO BENTHIC COMMUNITIES [CRUSTACEAN AND POLYCHAETES] IN THE INTERTIDAL ZONE AROUND MANDVI, GULF OF KACHCHH, GUJARAT

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Animal-Sediment Relationships of the crustaceans and polychaetes - benthic communities were studied in the intertidal zone of the Mandvi taluka in the Gulf of Kachchh, Kachchh district. The study area is falls in the Survey of Indian Topographic Sheet No. 41 F/5 on scale 1:50,000, and it stretches from 22^0 50' and 22^0 46' N latitude and 69^0 18' and 69^0 30' E longitude and includes Mandvi, Salaya, Rawal Pir, Modwa, and Gundiyali villages.

Kachchh coastline, particularly studied on microfaunal and geomorphic aspects but as far as animal-sediment relationship investigation is concerns, first time attempt has been made. This area provides ideal sites investigation in Gulf of Kachchh because the open sea and gulf sea environments influence it. The objective of the study was to observe behaviours of the organisms in the natural flow conditions and collect systematic samples of sediments, animals and bioturbational structures. This entire study is field based with supporting laboratory data.

To achieve this goal author carried out intensive biological and sedimentological investigations in the intertidal zone of the Mandvi area. The author has discussed his investigation in details in nine chapters.

Chapter one deals with significance of the animal-sediment relationships and broad methodology used for investigation. It also provides general information on Kachchh, regional setting, Mesozoic and Tertiary stratigraphy in tabular form geomorphology of the Gulf of Kachchh and previous works. Brief geographic description is given for the three sites (Wind Farm, Rawal Pir and Modwa Spit) of the study area.

The prime objective of the study was to collect systematic samples and observed the behavior of the animals (Crustaceans and Polychaetes) from the different geomorphic units of the intertidal zone. The study is entirely field based with supporting laboratory studies. Animal-sediment relationship was studied with the help of photographs of different biogenic structure in the field by trenching, radiography, casting, peeling, methods, which were further analyzed in the laboratory.

To achieve this goal author has followed the methodology as under.

- Two types of benthic communities (Crustaceans and Polychaetes) were collected from the various geomorphic settings in the intertidal zone and were preserved in formalin and later identified in the laboratory.
- For detailed analysis of physical and biogenic sedimentary structures, oriented, undisturbed rectangular box-cores as well as relief peels were collected from different geomorphic units of the intertidal zone. The box cores were subsampled for textural analysis.
- Behavior of the crabs and polychaetes were observed on surface and subsurface. Lateral variations along and across intertidal zone were recorded and monitored in two seasons (April/May and November/December).
- Length, diameter and penetration of the burrows in sediments were studied applying modern techniques such as wax or resin cast.
- Replicas of burrows were obtained by pouring molten wax through burrow openings only during the low tides when lower surface gets partially dried up.
- Morphological features of the biogenic sedimentary structures were analyzed in the light of trace makers, substrate consistency and hydrodynamic conditions.
- Various biogenic sedimentary structures were studied in detail and were classified based on their ethology and trophic types.
- Shapes and sizes of the biogenic sedimentary structures and their relative abundance and diversity along the Mandvi coast were used for reconstructing a depositional model in the present day intertidal zone.

The second chapter deals with techniques used for studying animal-sediment relationships. Since the study is altogether field based, the method of studying the behavior of the organisms, sediments, etc needs to be modified accordingly. Various methods were developed or modified, like relief peel technique; X-ray radiograph etc.. Animals were collected and preserved in formalin for later species level identification. The behavioral activities were observed and noted with the help of various photographic techniques, like time lapse photography.

Geomorphology of the study area is dealt in detail in third chapter. The coastal area is a cuspate foreland complex with numerous ridges and spits. The Wind Farm sites generally consist of beaches, raised beach and dunes. In addition to these landforms, the Rawal Pir site comprises of four to five sets of ridge-runnel systems, lagoon, raised mud

flats and patchy exposures of the shore platforms. While the Modwa Spit site comprises more diverse land form units which includes beaches, ridge-runnel systems, lagoon, berm, raised mud flats, shore platforms, tidal mud flats, dunes and supratidal flats. These landforms are result of intense tectonic activity in the region on account of the stress accumulation along the E-W directed major faults of the Kachchh peninsula and differential uplift of the various Kachchh coastal blocks along the Median High. The manifestations of which can be seen as well developed asymmetrical ravines, abrupt widening of the river valley, sudden N-S turn of the rivers after entering coastal plains and development of fan deltas. In intertidal zone, the tectonic signatures can be seen as paleo dewatered, mud flats, with pre-omission traces of subtidal nature like *Ophiomorpha/ Thalassinoides* association overprinted by omission traces of intertidal area like *Gastrochaenolites*. These Pre-omission/omission suites are today exposed in the supratidal zone. Moreover, the raised beach contains lower intertidal traces like *Skolithos* and *Ophiomorpha.* Their insitu natures suggest a tectonic effect in evolution of these deposits rather than the normal sea level change.

The fourth chapter deals with sedimentological aspects of the study area. The intertidal area is classified according to the exposures it receives, during the tidal variations. The five critical tidal limits (CTL's) 1, 2, 3, 4 and 5 are defined. According to which, the dunal zone and the supratidal zone falls in CTL's 1. The beach, falls in 2 CTL's while the ridge and runnel falls in 3 and 4. Fifth CTL is the region of the lower intertidal zone, rarely exposing during a day. The sediments are further classified in the form of variation of gravel, sand, silt, and plotted on sediment trigons for Wind Farm, Rawal Pir and Modwa Spit sites. Wind Farm site shows dominance of the coarse sand particles. While the sediments of the Rawal Pir site are more sandy and silty in nature. Muddy gravel and silty mud type of sediments are encountered in Modwa spit site. Physical sedimentary structures are diverse in the intertidal zone, it includes structures like plane bed laminations, cross laminations, flaser bedding, etc. The bedforms include various kind of ripple marks, rill marks, 2D and 3D subaqueous dunes, nascent dunes, megaripples, antidunes etc. Taking into consideration all these factors, five intertidal subfacies were described include; beach subfacies, ridge subfacies, runnel subfacies, lagoon subfacies, and supratidal subfacies. The information based on intertidal subfacies distribution has been further used advantageously in the studies pertaining the biogenic structures and their distribution in-space. Four different type of sediments substrate

(Soup ground substrate, Soft ground substrate, Firm ground substrate and Hard ground substrate) were identified and described in relation to feeding types.

Systematic of crustacean and polychaetes and their trophic analysis are dealt in fifth chapter. In the crustaceans, braychuryans are the most dominating and are represented by nine Species viz. *Ocypoda ceratopathalma* (Pallas), *Ocypode platytarsis* (Milne-Edward) *Ocypoda roundata* (Miers) *Uca annulipes* Latreille, *Uca marionis* Desmarest, *Matuta lunaris* (Forskal), *Matuta planipes* (Fabricus), *Portunus tenuipes* (De Hann), *Plagusia depressa* Var. Squamosa (Herbst). Anoumara crustaceans are represented by one species, *Clibanarus infraspinatus.* In Shrimp *Penaeus (Marsupenaeus) japonicus* Bate. Stomatopod are represented by two species *Oratosquilla striata* Manning (1978), *Oratosquilla hindustanica* Manning (1978). Likewise the polychaete are represented by fifteen species, viz. *Diopatra, Onuphis, Lumbriconereis, Nereis, Lycastis, Nephtys, Serpula, Clymene, Heteromastus, Amphinome, Chloeia.* Unsegmented worm species Nemertea *Cerebratulus marginatus* is found in the lagoon. Abundant species of Bivalvia (*Macoma, Solen, Ostrea, Bernea, Arca, Cardita* etc.) and Gastropods (*Murex, turetilla, Cerithium, Telescopium, Natica, Voluta, Archeotectonica* etc.) are also found in the intertidal zone.

Majority of the organisms are classified according to the functional groups of Woodin and Jackson, (1979); I. Sediment destabiliser (a) Mobile destabiliser-Mobile burrowers organisms whose movements causes the sediment to be more easily resuspended and eroded. Also true for the deposit feeders. (b) Sedentary destabiliser-organisms whose activities (primary feeding and defecation) causes the sediment to be more easily suspended. (c) Sedentary destabiliser-organisms that project both above and below the sediment surface changing both local hydrodynamic regimes and rate of resuspension and erosion (at low and moderate density:- destabilizing effect). II. Sediment stabilizer. (a) Sedentary organisms that project both above and below the sediment surface changing both local hydrodynamic regimes and rate of resuspension and erosion (at high density Stabilizing effect). (b) Tube building organisms within the sediment can stabilize the sediment. (c) Do not appear to have any significant effect on the surrounding sediment.

Organism	Mobile/ Sedentar	1a	1b	1c	2a	2b	2c
Macropathalmus	M	#					
Uca	M	#	#				
Ocypode	M	#	#				
Plagusia	M	#					
Graspus	M	#	#				
Portunus	M						#
Scylla	M						#
Neptunus	M						#
Matuta	M	#					
Oratosquilla	M	#	#		#		
Squilla	M	#			#		
Diopatra	M				#	#	
Onuphis		#			#		
Lumbriconereis	M				#	#	
Nereis	M	#			#		
Lycastis	M	#			#	#	
Nephtys	M	#			#	#	#
Serpula	S				#		#
Clymene	S				#		#
Heteromastus	M	#			#		
Amphinome	M	#					
Chloeia	M	#					
Nemertea	M				#		
Clibanarus	M	#					
Gastropod	M	#			#		
Gastropod	M	#			#		
Bivalves	M				#		
Bivalves	M		#		#		
Holothuria	M				#		
Fat Innkeper	M			#			
Starfish and Feather star	M						#
Barnacle	S				#		#

Table:1 Functional groups of the organisms found in the Study area (Classified and modified after Woodin 1983, Woodin and Jackson 1979).

The trophic analysis of the intertidal organisms indicates that nearly 80% are deposit feeders, of which 42% account for interface deposit feeder, 25% account for shallow deposit feeders, 17% for middle deposit feeder, and 8% of the animals are surface and deep deposit feeders. Similarly observed feeding regions (i.e. feeding depth and height) at the sediment water interface (SWI) were plotted against standard organic matter curve, which indicates that nearly 90% of the animal feeding activity are at sediment water interface, which is site for high organic matter.

Detailed studies on biogenic sedimentary structures of the crustacean and polychaetes were incorporated in sixth chapter, which includes observation, identification and interpretation. Crustacean traces in the intertidal zone are represented as pellets

(faecal, feeding and burrowing), grazing (cheliped marking), crawling (appendage marking) and dwellings (lined and unlined burrows). The stomatopodean crustaceans burrows are thickly lined with nodose structure resemble to *Ophiomorpha.* The polychaete also makes abundant and lined branched or unbranched resembling to *Skolithos* or *Polykladichnus*. The most important burrow system dendritic pattern ramifying in upward direction is made by *Nephthys* species, similar to the ichnogenus *Chondrite*. *Oniphus* adapted to the anoxic conditions and modifies their burrows, to form group funnel burrows to ichnogenus *Balanoglossites*. The other important biogenic structures made by polychaetes agglutinated tubes identical to *Diopatrichnus.* Faecal strings and faecal mounds, agglutinated reefs and solitary calcitic tubes common in runnels and shore platform respectively.

The palaeoichnological chapter deals with fossil and semi fossilized burrows found in intertidal zone, either in raised beach, or in raised tidal mudflats or in shells of various bivalves. Ichnologically these deposits are characterised by abundant but ethologically less diverse groups of ichnospecies. Systematic of the *Skolithos, Ophiomorpha, Polykladichnus, Thalassinoides, Gastrochaenolites and Monocraterion* were described in details. The shell borings are represented by *Entobia, Talpina, Meandropolydora, Cliona, Oichnus* etc.,

Combining all the biogenic structures found in the different geomorphic units of the present day intertidal zone six ichnocoenoses are proposed and described in chapter eight. These include *Faecichnia* ichnocoenosis, *Entobia-Meandropolydora* ichnocoenosis, *Chondrite* ichnocoenosis, *Skolithos* ichnocoenosis, *Psilonichnus* ichnocoenosis, *Ophiomorpha* ichnocoenosis and *Balanoglossites* ichnocoenosis. These ichnocoenoses were interpreted in the light of the ecological interpretations. has been identified and described from the recent intertidal zone. While from the paleo-raised beach and Tidal flat, three ichnocoenoses, viz. *Glossifunguites* ichnocoenosis, *Skolithos* ichnocoenosis, *Ophiomorpha* ichnocoenosis have been identified and described. These paleo ichnocoenosis are strong indicative of lower intertidal/subtidal transition exposed as exhumed surfaces in upper intertidal zone.

Finally all the information collected is incorporated in working out ichno-sedimentologic models of Beach, Ridge, Runnel and lagoon of the Mandvi intertidal zone.

A large number of trace-making organisms inhabit in intertidal zone of the Mandvi area. Many of these organisms occupy particular niches, thus the biogenic structures they produce are characteristics of particular depositional environments. Further more this intertidal zone is composed of dynamic spacio-temporal landform units. Each landform is constantly modified and provides temporal hospitality to the crustaceans and polychaetes with some opportunistic animals. In constantly changing environmental conditions the biogenic sedimentary structures of these animals in the intertidal zone helps in understanding distribution of the different kind of population of crustaceans and polychaetes. In intertidal zone, within an assemblages of biogenic structures is often more important environmentally rather than presence of a single kind of biogenic structures. Certain types of biogenic sedimentary structures are found on more than one habitat because stress tolerant animals adapts wide range of variation (i.e. geomorphic settings, substrate preference, food resources and fluctuation in temperature, salinity and oxygen contents) in subaerially exposed.

The important observations are as follows.

⇒ The study area is situated on junction of the open sea and gulf sea, for convenience it is laterally divided in to three units: Wind Farm, Rawal Pir and Modwa Spit sites.

⇒ This intertidal zone experiences moderate wave and current energy, which progressively decreases from Wind Farm site to Modwa Spit site. Intertidal zone is narrow, sloping $>10^0$ at Wind Farm sites and broadens (>1 km) with gentle slope at Modwa Spit.

⇒ The intertidal animals, sediments and biogenic structures have been subjected to grain size analysis, relief peels, coring, x-ray radiography, burrow cast, collecting and, preserving animals, water and substrate analysis and photographic documentation.

⇒ Various micro-geomorphic landforms identified in the Mandvi intertidal zone are beaches, berms, ridge-runnel systems, cuspate foreland, spits, lagoons, shore platforms, dunes, tidal flats and coastal plains.

⇒ Raised beaches and raised tidal mud flats of Holocene time are the tectonically influenced landforms.

⇒ The grain size analysis reveals well sorted, mature, clean, medium to coarse grain sand size particles at Wind Farm site, whereas Modwa Spit shows poorly sorted fine-grained sediments.

⇒ Each landform is characterised by distinct sedimentary structures.

⇒ Different intertidal sub-facies has been recognized: Beach sub facies, Ridge sub facies, Runnel sub facies, Supratidal sub facies, and Lagoonal facies.

⇒ Four different types of ground are identified based on substrate consistency includes Soup ground substrate, Soft ground substrate, Firm ground substrate and Hard ground substrate.

⇒ Crustacean and Polychaetes under study have shown preference of habitation implying responses to changing physical, chemical and biological conditions.

⇒ 19 species of crustaceans, 15 species of polychaetes and 2 species of unsegmented worm Nemertea have been identified and documented.

⇒ Crustacean *Ocypode platyrsis* and *Portunus tenuipes* are recorded for the first time from the Western Indian coast. Abnormal behavior (Trauma condition) of the Stomatopod species *Oratosquilla striata* have been recorded in relation to the 26th January 2001 Kachchh earthquake. These observations have potential of relating biogenic sedimentary structures with paleoseismicity.

⇒ Crustacean and polychaetes activities were observed in the form of pellet making, burrowing, feeding and crawling traces.

⇒ Dune and beach zone have favoured the adult *Ocypode* species, visible high proportion is observable in the in the beach zone as compared to dunal zone. While, high level fluctuation of water levels created harsh environmental conditions for polychaetes.

⇒ Young and juvenile species of crabs are found on the ridges and runnels, their proportion increase in seaward direction. Stomatopodean species *Oratosquilla striata* are found in runnels and lower reaches of the ridges.

⇒ Motile deposit feeder polychaetes are abundant on the ridges and occasionally found on lower reaches of the beaches, while suspension and filter feeders are abundant in the runnels. The sessile filter feeder polychaetes are abundant on the rocky shore platforms. Rawal Pir lagoon consist of suspension feeders *Chloeia flava* and *Onuphis*, while Modwa Spit lagoon consist of unsegmented worms *Cerebratulus marginatus*.

⇒ Five burrows and six boring structures have been identified in raised beach and paleo tidal mud flats sections.

⇒ Dunes and beaches are characterised by I, Y, J shaped dwelling burrows of adult *Ocypodes*. The crustacean burrows of the dunes are characteristically large, widely spaced and occur as mono-dominant, while on the beach burrows are large but densely populated and often marking their territory with sand mound. The opening of burrows on the beach markedly oriented towards the sea, while it is randomly oriented in the dunal area. They are identical to ichnogenus *Psilonichnus*.

⇒ Ridges represent deposit-feeding burrows of young and juvenile crustaceans while the surfaces are completely studded with feeding, burrowing and faecal pellets. The pellet making activity leads to complete obscuring of the freshly deposited sediment layer. *Nephtys inermis* and *Nephtys diabranchis* make characteristic multi-ramifying tunnel system in the lower part of the ridges identical to ichnogenus *Chondrites*.

⇒ Runnels consist of three dimensional pelleted walled burrow system of *Oratosquilla striata,* which is identical to ichnogenus *Ophiomorpha*. Flow oriented structures of polychaetes are dominated in the runnels they includes agglutinated tubes of *Diopatra*. U-shaped tubes of *Arenicola* and mucus bound dwelling burrows of *Heteromastus* and multi-ramifying tunnel system of *Nephtys* are also abundant.

⇒ Lagoons consist of mainly grouped funnel systems, branched burrows of *Oniphus* and *Chloeia flava*, identical to ichnogenus *Balanoglossites*. U-shaped burrows with funnel opening of *Arenicola* and straight simple dwelling burrow of Nemertea. These are opportunistic and have exploited restricted neiches for dwelling-feeding purposes.

⇒ The shore platform consists of cemented calcareous tubes of filter feeding *Serpula* along with symbiotic encrusters like *Oystrea* and Barnacles.

⇒ Trophic categories (Deposit feeders, Interface feeders, Surface deposit feeders, Shallow tier deposit feeders, Middle tier deposit feeders, Deep tier deposit feeders and Suspension feeders) are characterised by considering the functional groups, feeding guilds and location of food resources.

⇒ For ecological interpretation of the intertidal zone seven ichnocoenoses (*Faecichnia* ichnocoenosis, *Entobia-Meandropolydora* ichnocoenosis, *Chondrite* ichnocoenosis, *Skolithos* Ichnocoenosis, *Psilonichnus* ichnocoenosis, *Ophiomorpha* ichnocoenosis, *Balanoglossites* ichnocoenosis) have been described and interpreted.

⇒ For palaeoecological interpretation three ichnocoenoses (*Glossifunguites* ichnocoenosis, *Skolithos* ichnocoenosis, *and Ophiomorpha* ichnocoenosis) have been described and interpreted.

⇒ Based on data of the Mandvi intertidal zone, three-dimensional ichno-sedimentologic model of the Beach, Ridge, Runnel, and Lagoon were reconstructed, indicates that it experiences low to moderate wave and current energy.