

**Geomorphic processes in the vicinity of the Venkatapur River mouth, Central West Coast of India: Implications on Estuarine Sedimentation**

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**ABSTRACT**

Geomorphic processes in the vicinity of river mouths of the Central West Coast of India have been discussed in this paper with the Venkatapur River as the representative. Multidate satellite image analyses, wave refraction pattern, time series beach section study and sediment characteristics have been used to understand the geomorphic processes operating in the region. Multi-date image analyses indicated a significant re-adjustment of mouth configuration as well as shoal features; spit growth northward across the river Venkatapur and other rivers of the region- the Gangavali, the Sharavati, and the river mouth shifting northward; narrowing of the river mouths; development of submerged bars across the river mouths, etc., are observed. The beaches to the north of the Venkatapur river mouth showed erosion (retreated landward) where as the beaches on the southern side of the river mouth accreted (grown seaward/ alongshore). In general, the beaches showed accretion during post monsoon and pre monsoon, and erosion during monsoon. Sediments on the beach are medium to very fine-grained (1.38 -3.45  $\phi$ ), moderately to poorly sorted ( $\sigma = 0.3$  to 0.81), suggesting low energy conditions of their deposition. During pre monsoon, there is re-suspension of sediments, which move landward and into the estuary especially during high tide. Wave refraction pattern shows wave divergence in the mouth of the river and wave convergence away from the river on either side during Pre-monsoon (March to May) leading to wave shadow area in front of the river mouth. These processes lead to sedimentation in the estuary and dynamic changes in the vicinity of the river mouth.

**ADDITIONAL INDEX WORDS:** *Central West Coast of India, Morphodynamic processes, Multidate images, Beach profile, Sedimentation, Wave refraction.*

## **INTRODUCTION**

Coastal regions, in particular the regions around the river mouths are the important habitats. Geomorphic process in these regions is complex, and is the net result of inland geology, shoreline configuration, tectonics, sea level rise and fall, near-shore wave climate and sediment influx. In addition to the aforesaid factors, anthropogenic activities also influence the near shore geomorphic processes, which increase with time and development of civilization (c.f Frihy, Dewidar and El-Banna, 1998a). In the tropical region, influx of sediments is highly variable with season, and sediment circulations in the near shore as well as in the vicinity of the river mouth also vary with the seasons. In response to the variation in the sediment influx, beaches in the vicinity of the river mouth and mouth configuration of the rivers undergo rapid changes and create management problems, especially, when sediment influx is modified either by damming of river (c.f. Bittencourt et al., 2007) or if current pattern is modified by construction activities in the mouth region (c.f. Abadie et al., 2008). Sedimentation in the river mouth, narrowing of river mouths, shoreline erosion, and rapid changes of the mouth configurations are the common problems observed along the Central West Coast of India. Sedimentation in old Mangalore port is related to suspended sediment load and bed loads of the rivers along-with the littoral drift due to wave action (Reddy, Hariharan and Kurian, 1979). In New Mangalore port, it is mainly due to deposition of seabed material brought into suspension by the monsoon waves (Dattatri and Kamat, 1997), whereas in the Sharavati estuary, sedimentation is related to the offshore source brought by tidal currents, and interaction of waves and river processes in the channel (Hegde et al., 2004). Multiple sources and processes are also observed elsewhere (c.f. Damietta harbor by Frihy, Badr Abd El and Mohammad, 2002).

There are a number of river mouths along the Central West Coast of India being developed into fishery and general harbors, where sedimentation in the navigational channel is a major problem. The Central West Coast of India is becoming a center of

developmental activities due to National High way and Konkan railway facilities; growing tourism at Murdeshwar and Gokarna; Karwar sea board project; many power related projects such as Kaiga nuclear project (not shown in the map), Kadra Hydro electric project, the proposed thermal project at Tadadi etc. As a result of these anthropogenic activities, natural geomorphic processes are influenced leading to a significant modification in the coastal configuration, in particular around the river mouths. In the present study, the Venkatapur river mouth is investigated as representative to understand the geomorphic processes occurring around the river mouths of the Central West Coast of India.

## **STUDY AREA**

Based on tidal conditions, shorelines have been classified into micro-tidal (tidal range  $<2$  m), meso-tidal (tidal range 2-4 m) and macro-tidal (tidal range  $>4$ m) (Short, 1991). As per these criteria, in the area under investigation near Bhatkal, Central West Coast of India (Fig.1) mesotidal conditions prevail. Where micro-tidal conditions prevail, waves are the dominant forces, whereas in macro -tidal condition tides are the dominant forces in sediment movement in the near shore region (Hayes, 1979). Therefore, it implies that in the meso-tidal condition waves as well as tidal currents are important. Waves cause landward transport of sand whereas ebb tides result in seaward transport of sands (Dean and Walton, 1975). However, in coastal regions where high wave energy prevails, tidal condition becomes insignificant (Short and Hesp, 1982). Although, in the study area wave height (0.75 -1.25 m) defines low energy conditions during pre-monsoon and post-monsoon, high wave energy prevails during monsoon and transition from pre-monsoon to monsoon.

The case-study area stretches to about ten km- six km north and four km south from the Venkatapur river mouth. Parallel to the coast, approximately at 2m depths and at the confluence of the river mouth of the Venkatapur, concentric submerged bar is developed. Similar features are also developed at the confluence of the river Sharavati and the Gangavali also (Fig. 2). There are islands in the near-shore region in front of

the Venkatapur, the Sharavati, and Kali, which appear to modify the wave characteristics particularly when approaching from the west. Murdeshwar, a tourism center, which was an island, but got connected to the mainland by tombolo effect, lies to the north of the Venkatapur river mouth. To the south of the Murdeshwar Island there was coastal erosion and a sea wall is constructed.

### **Climate of the study area**

The area experiences tropical monsoonal climate (Am) as per the classification of Koppen (*In: Kottek et al., 2006*), high rainfall (around 300 cm,) and 85% of the rainfall is received during the southwest monsoon (June to September) and there is variation in both river discharges as well as sediment influx into the near-shore region. Wind direction is from southwest during the southwest monsoon season and during the winter the winds are from northeast and from west during March to May. The tidal range is between 1- 3m (meso tidal condition) and tidal currents are dominant especially in the vicinity of the river mouth during low tide. Wave energy in the study area is moderate to high. Wave heights are less than 1 m during pre monsoon, 1 to 2m during post monsoon and 2 to 4 m during monsoon.

### **Geology and Geomorphology of the study area**

Archaean granitic rocks of tonalite- trondhjemite- granodioritic composition dominate in the coastal regions of Uttara Kannada district (Hegde, 1992). Towards the interior, Precambrian meta-sediments like greywackes dominate the area. Owing to the tropical monsoonal climate, there is intense weathering of the hinterland, and as the area is well dissected by drainage and monsoon is strong, transportation of weathered materials to the coastal environment is a common feature.

The coastal features of the West Coast of India are the result of long-term changes in sea level and climate, besides factors like lithology, structure and local tectonic movements (Wagle, 1991). In particular, the Coast under study is unique in nature,

owing to geomorphic set ups like spit, headland, cliffed shoreline, lagoons, river mouth beaches etc. These processes have been overprinted the tectonic processes. They have left their signatures in the form of various geomorphic features along the coast such as beach ridges, wave cut platform, palaeo-river channels, terraces in the lower part of the river, migration of river channels and abandoned channels, shifting of river mouth, coast perpendicular faults and embayment leading to sediment trap, and backwater-lagoon systems.

## **METHODOLOGY**

The present study is based on the multi-date temporal and spatial data analyses in ERDAS Imagine software (8.5 versions); observation of the river mouth configuration using Global Positioning System (GPS), wave refraction analyses, time series beach elevation studies in the vicinity of the Venkatapur river mouth and beach sediment characteristics. Survey of India toposheet (1979) in the scale of 1:25000, LISS III imageries of November 1989, March 2002 and May 2003, Indian Remote Sensing (IRS)-ID, PAN 2004 and Google Earth 2006 constitute the database for the analyses of long-term changes in configuration of the estuarine beach. Based on the changes observed from the imagery of 1989 and Survey of India toposheet (1979), two sites were selected for beach profile study on the northern side of the Venkatapur river mouth. Beach profiles have been monitored at seasonal intervals following stake and horizon method, and during the survey beach sediments have been collected from the microenvironments (low, mid and high water line) for sedimentological investigations. Sediment samples have been washed thoroughly, desalted and heated in hydrogen peroxide solution to remove the organic contents (Ingram, 1970). After coning and quartering, a portion of the sample has been subjected to sieve analysis for 15 minutes on a Ro Tap sieve shaker and American Society for Testing Material sieves at a quarter Phi interval. Textural parameters of the sediments have been calculated following Folk and Ward (1957). Wave refraction analyses have been carried out following Snell's law. "TARANGAM" wave refraction program (Chandramohan, 1988) has been used to

estimate the near shore wave characteristics from given deep water wave characteristics (wave height-  $H$ , wave period- $T$ , the angle of wave approach-  $\theta$ ) and nearshore bathymetry. Wave characteristics at any intermediate depth using linear wave theory are computed incorporating refraction, shoaling, bottom percolation, bottom friction and dissipation.

## **RESULTS AND OBSERVATIONS**

### **Long term shoreline changes**

Multidate spatial data analyses of the regions around the Venkatapur river mouth indicates reduction in the width of the Venkatapur river mouth, and the river mouth from 100.30 m to 42.30m in the last 105 years (in 1900 it was 100.30m; in 1978- 60.60m; 2003- 49.80m and in 2005, it was 42.30m) and the river mouth has been shifted northward. There is erosion to the north of B3 location (south of Murdeshwar island)(Fig. 3a); but insignificant erosion or deposition at B3, less deposition at B4 (Fig. 3b) and deposition to the immediate south of the river mouth (Fig.3c), but erosion farther south of the river mouth (Fig. 3b and 3d). During 2002-2003, there was deposition to the north of B3 and less deposition at B3 although there was erosion to the south of Murdeshwar-island (Fig.3c). Similar features of erosion on the northern side and growth on the southern side have been observed in the vicinity of the Gangavali (Chavadi et al., 1989), and the Sharavati River mouth beaches (Hegde et al., 2009). The Venkatapur river mouth configuration mapped using GPS on either side of the river mouth during January 2003 and May 2005 showed redistribution of materials and dynamic changes in the mouth configuration (Fig.3d). To the north of the river mouth however, there is no change, which could be due to a sea wall, that was constructed during 2003. There is a large-scale change in the mouth configuration of the Venkatapur River in the last 105 years (Fig. 3a; Fig. 3b; Fig. 3c; Fig. 3d). Beach portion shadowed by an island in the southern side of the river mouth is growing seaward in the form of a tombolo (Fig. 4).

### **Wave Refraction analyses**

As waves propagate from deep water to shallow water, they undergo modifications in their height, speed and direction in response to the bottom topography and shoaling. This process of wave transformation is called wave refraction and can be expressed as

$$\frac{\sin \theta_2}{C_2} = \frac{\sin \theta_1}{C_1} = \text{Constant}$$

Where,  $\theta_1$  = angle of wave crest with the bottom contour over which it is passing

$\theta_2$  = a similar angle when it passes over the next contour

$C_1$  = wave velocity at the depth of first contour

$C_2$  = wave velocity at the next contour

$C = (gD)^{1/2}$  in shallow water

$C = gT/2\pi$

$D$  = depth of water,  $T$  = wave period,  $g$  = acceleration due to gravity.

Along the Central West Coast of India, the principal direction of wave approach is from North West during November to February (Fig.5a); from West during March to May (Fig.5b) and from Southwest during June to October (Fig.5c). The predominant wave periods range from 6 to 12 seconds. Therefore, wave refraction analysis is carried out for waves approaching from North West, West and Southwest and wave periods 6, 8, 10 and 12 seconds. All the above wave periods show nearly similar wave refraction pattern and hence wave refraction pattern for 10 seconds is presented.

During November to February, waves approaching from Northwest generate southerly alongshore current due to North-Northwest orientation of the coast. These southerly long shore currents remove sediments from the beaches of the northern side of the river mouth and transport them southward. When they meet the river, the drift is diverted towards the sea due to obtuse angle between the shoreline and the river flow (against direction of the current). When wave approach is from West, wave divergences occur in the mouth region and wave convergence away from the mouths. These features are common along the Central West Coast of India and observed by other workers also (Veerayya and Pankajakshan, 1988; Rajamanickam, Vethamony and Gujar, 1986). Presence of an island in front of the Venkatapur river mouth may also aid to this effect. These divergence and convergence of waves generate circulation cells in the surf zone (Murthy and Veerayya,

1985). Due to a slight change in the angle of incidence of the waves, the zones of convergence that are away from the mouth shift their positions in time and space. As a result of these, the materials removed from the foreshore are caught in the circulation cells and re-circulated locally, which provide stability to the beaches during the season (Murthy and Veerayya, 1985). During monsoon to early post monsoon, southwesterly approaching waves generate along-shore current northward. Estimated net northerly drift per year in the mouth region is  $4217 \text{ m}^3$ . As the energy of the waves is high during this season compared to the pre monsoon and late phase of post-monsoon, net northerly drifts dominate over the southerly drift (cf. Kunte and Wagle, 2001). These northerly drifts are arrested by the river due to “groin effect of the river” (acute angle between the river flow direction and the shoreline orientation in the direction of the current) favoring its deposition and spit growth towards north.

### **Beach profile studies**

Beach profile studies carried out at two representative locations B3 and B4 from November 2001 to September 2003 indicated accretion both at B3 and B4 (Fig.6) during post monsoon, (superimposition of October-December; December-April profiles) and erosion during monsoon (May-July). However, during pre-monsoon (December-May) and early post monsoon (October) it is highly variable along the coast. Erosion is seen at B3 whereas deposition is observed at B4 during pre monsoon (Southerly drift). However, during early post monsoon (September-October) it is vice versa. Accretion is observed at B3 and erosion at B4 (Northerly drift). Similar features are also observed for the beaches in the vicinity of the Gangavali river mouth (Chavadi et al., 1989), the Sharavati river mouth (Hegde et al., 2009). In general, monsoonal erosion and post monsoonal accretion followed by a minor cycle of erosion during December/January is a common feature along the Central West Coast of India (Chavadi et al., 1999; Bhat et al., 2003). However, in the vicinity of the river mouths it is highly variable especially during the transitional period (monsoon to post monsoon and pre-monsoon to monsoon). Similar depositional and erosional processes are observed along the beaches in the vicinity of the Kali River (Nayak, 1986). During monsoon, erosion is



observed both at Sadashivagad and Kodibag, but during pre monsoon when Sadashivagad beach experienced erosion, Kodibag experienced accretion and vice versa during post monsoon (Nayak, 1986).

### **Textural characters**

Sediments of the beach in the vicinity of the Venkatapur river mouth are medium to fine grained (1.38 to 3.45  $\phi$ ) and moderately to poorly sorted ( $\sigma = 0.35$  to 0.95). Temporal and spatial variation in the grain size characteristics is evident from the table 1. The sediments are bimodal to poly modal during post monsoon and pre monsoon, and unimodal to bimodal during monsoon. The bimodal to poly modal nature suggests either different sources or it may be due to different mode of transport. The Coarsest first percentile versus median diameter (C-M) plots for the sediments of the beaches indicates uniform graded suspension (Fig.7). During November, sediments on the region B3 are medium grained, while on the B4 it is fine grained and less sorted suggesting that sediment transport is towards south. During post monsoon (December), once again fine grained less sorted sediments dominate the beach, suggesting addition of fines on to the beach environment. During March, a similar trend is observed, but during May, sediments in both the locations show an insignificant difference in their grain size characteristics. During monsoon, sediments on the B3 and B4 showed medium grained, (coarsening compared to pre monsoon) and suggest selective removal of fines from the foreshore. Similar features are also observed in the vicinity of the Gangavali river mouth (Chavadi and Hegde, 1989; Bhat, Chavadi and Hegde, 2002); the Sharavati river mouth (Hegde et al., 2009); and the Kali river mouth (Nayak, 1986). Such a winnowing action generally results in the improvement of sorting, but in the present case the sorting decreased. Such features could be due to the river input. Bi-variant plots constructed for sediments of the Venkatapur river mouth beaches suggest significant river input in the Venkatapur river mouth (Fig.8). These grain size variations correlate well with the bimodal and poly modal nature observed in different seasons.

## **DISCUSSION AND IMPLICATIONS ON ESTUARINE SEDIMENTATION**

Integration of the morphological features, both short term and long-term changes along with the sediment natures, suggest the importance of wave refraction and the resulting littoral currents in the observed geomorphic processes. Wave divergence occurring for waves approaching from west and West-southwest; create a low energy zone in front of the river mouth. Because of the interaction of high waves prevailing during monsoon and the river flow due to monsoon effect, sediments brought by the river are deposited on either side of the river mouths. Away from the mouth, high waves cause seaward movement of the beach sand resulting in erosion of the beach. These eroded materials are deposited seaward, and a wide surf zone is developed. Due to the interaction of swash and strong backwash, material deposited in the form of a ridge at the breaker zone develops into a submerged bar. By late September to November wind speed decreases, which facilitates long-period swell waves to prevail, and waves start approaching from Southwest and South-southwest which generate northerly drift. With long period swell waves, net shoreward pulse of the sand dominates (Cook and Gorsline, 1972). Breaking waves sweep over the crest of the bar, transfer the materials from the seaward side of the bar to the landward side resulting in the migration of the bar shoreward. The northerly drift removes the material from the south and transports it towards the north. But alongshore drift ceases in the river mouth due to obstruction and groin effect by the river flow resulting in the deposition of the material at the northern end of the southern side of the river mouth. This favors the spit growth across the river mouth from south to north. During December to February, waves approaching from North-Northwest and Northwest generate southerly drift causing spit growth to develop from north to south across the river Venkatapur leading to the narrowing of the river mouth. However, the northerly drift is dominant over the southerly drift and during monsoon the north side of the river mouth experiences more severe erosion than the southern side. Hence, the net spit growth is towards north. Due to weak post monsoonal flow, the river is unable to washout neither the bar nor the narrowing of the mouth, and the bars start trapping the river fed materials resulting in the bar growth.

From March to May, wind starts blowing from West-Northwest and West with higher velocity and higher waves are generated in the sea, and the sea gets agitated. The net result is re-suspension of bed materials (both fine sand and silt) a common feature along the Central West Coast of India (Shankar and Manjunath, 1997; Dattatri, 2001). These re-suspended sediments move landward during high tide. When the silt fractions mix with fresh water in the estuary, they are deposited in the channel due to flocculation caused by the mixing of high and low salinity water where as, velocity check due to river and wave interaction caused fine sand to deposit in the bar. Sediments in the Venkatapur river estuary up to 6 km landward from the mouth is dominated by silt whereas the bar materials are sand. These features support our interpretation. Such onshore migration of materials is especially common in the vicinity of the river mouth (Shankar and Manjunath, 1997). Rajamanickam, Vethamony and Gujar (1986), also observed similar bar dynamics along the Konkan coast, and Murthy and Veerayya (1985) in Augunda bay, Goa. The depositional environment of the foreshore sediments in the vicinity of the Sharavati river mouth also supports similar geomorphic processes (Hegde et al., 2009). Therefore, it can be inferred that sedimentation in the estuary is due to bar formation and narrowing of the river mouth due to spit growth.

Minor differences in the deposition and erosion pattern at B3 and B4 could be due to the wave refraction caused by islands which result in the sheltered effect to the portion of the beaches around B4 where as they remove sand from B3 towards offshore. During March-April, the westerly approach of waves develops wave divergence and convergence causing redistribution of materials on the beach and short-term beach rotation process in response to a shift in the incident wave direction (c.f.Klein, Lindino and Delamar, 2002).

From the long-term shoreline changes occurring in the study region it can be visualized that there was wave divergence at Murdeshwar due to the island effect and wave convergence to the south and north of the island causing erosion there. Because of wave divergence and the resulting low energy zone, deposition occurred behind the Murdeshwar Island resulting in tumbolo formation, and the Murdeshwar Island got connected to the main land. On the other hand, erosion continued on either side of the

Murdeswar Island. To prevent erosion, a sea wall is constructed both on the north and south of the island. Sediment starved waves started erosion of the beaches towards further south of the Murdeswar Island resulting in the shifting of the zone of erosion to the vicinity of the northern part of the Venkatapur river mouth. To check erosion, here also a sea wall is constructed. Although erosion is prevented to the north of the river mouth, the zone of erosion is now being shifted towards the south of the river mouth, which was experiencing deposition so far. However, this appears to be a temporary phenomenon because the northerly drift is bringing materials and compensating the loss. Spit and beaches are showing growth once again.

## **CONCLUSION**

From the foregoing account it can be concluded that due to interaction of high monsoonal waves and river flow, sediments get deposited in and around the mouth. During post monsoon as the wave height decreases and direction of wave approach also change condition is favorable for the sediment deposition in the mouth leading to bar formation. Similar wave set up, tropical monsoonal climate and geomorphic processes are observed in the other river mouths in this region. Submerged bar formation in front of the river mouth (e.g. the Gangavali, the Sharavati and the Venkatapur) causes the wave divergence and low energy in the mouth region. By March-April wave energy further decreases favoring deposition in the mouth leading to bar growth. Alongshore drift is responsible for the spit growth and the narrowing of the river mouths. Since northerly drift dominate in the region, spit grows northward across the river mouths. The combined effect is narrowing of the mouth and sedimentation in the river mouth. Re-suspension of sediments caused by the wave and their movement landward, and their deposition in the estuary is favored by low energy condition. This is added by the flocculation process caused by the mixing of fresh and saline water. Sedimentation is also favored by obstruction due to narrowing of the river mouth due to spit growth.

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**Table 1. Textural characteristics of the beach sediments of**

Table 1. Textural characteristics of the beach sediments of Shirali  
Near the Venkatapur river mouth.

Month		Mean Size $\Phi$			Sorting $\sigma$		
		HWL	MWL	LWL	HWL	MWL	LWL
November 2001	B3	2.83	1.81	2.06	0.40	0.62	0.47
	B4	2.45	2.76	2.98	0.58	0.50	0.68
January 2002	B3	2.85	1.71	2.06	0.39	0.71	0.45
	B4	2.3	2.58	2.88	0.52	0.83	0.70
March 2002	B3	2.82	2.73	2.23	0.36	0.37	0.36
	B4	2.61	3.34	3.45	0.23	0.37	0.47
May-2002	B3	3.25	3.18	2.81	0.35	0.34	0.38
	B4	3.18	3.25	2.63	0.46	0.35	0.52
July-2002	B3	2.53	1.38	2.53	0.44	0.49	0.61
	B4	2.23	1.77	-	0.71	0.37	
December 2002	B3	3.01	2.75	2.90	0.49	0.57	0.66
	B4	2.13	2.37	2.63	0.56	0.86	0.95
Average	South	1.69			0.99		
	North	2.12			0.65		

Fig.1

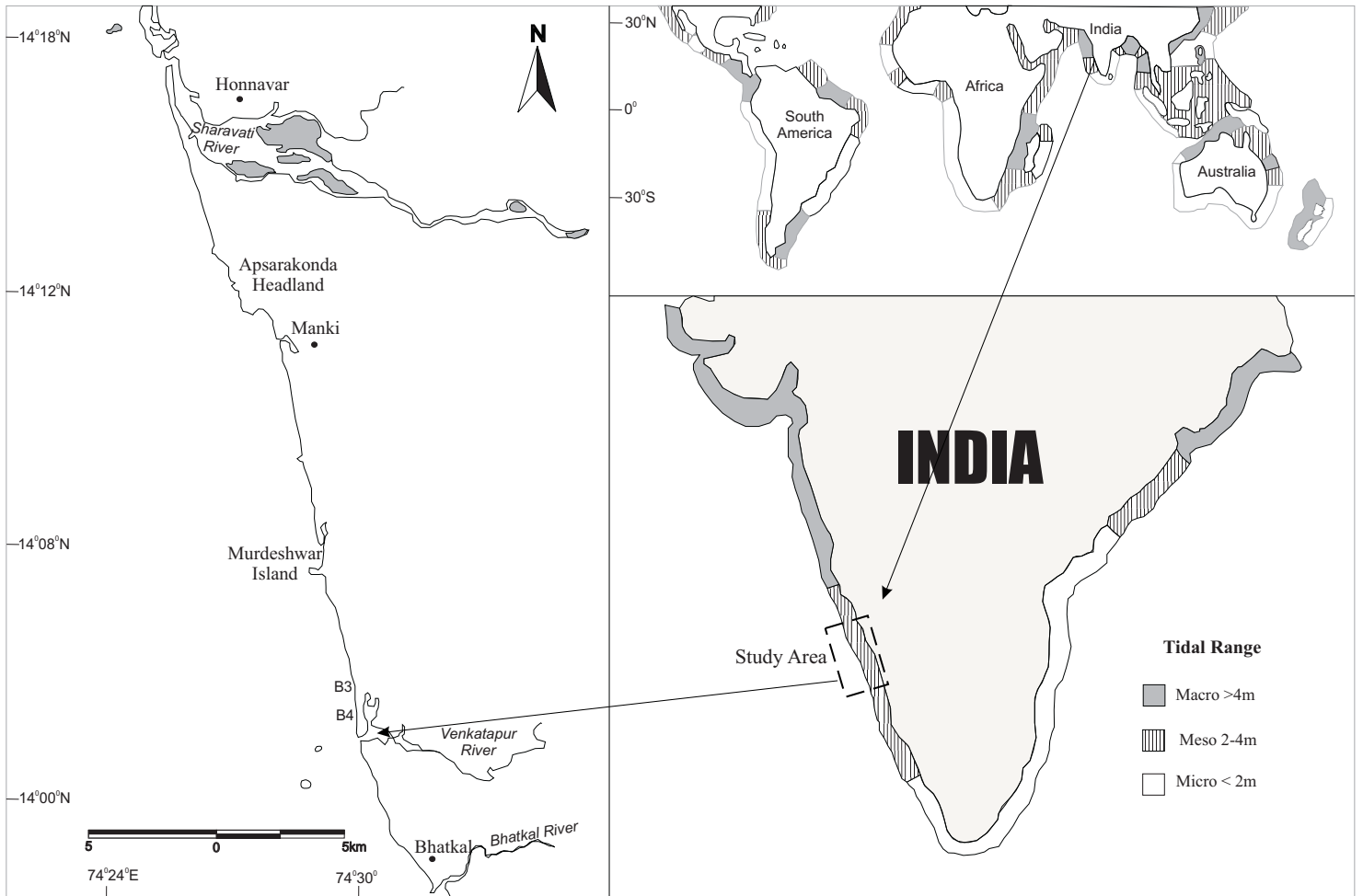


Fig.2.

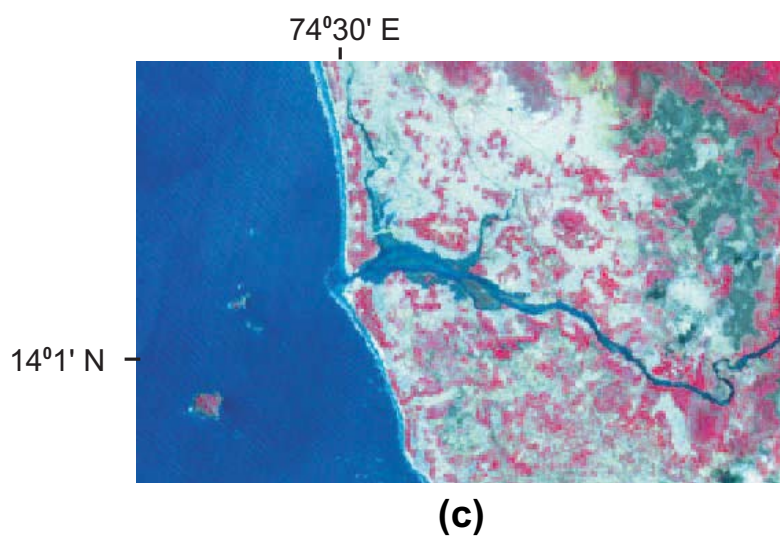
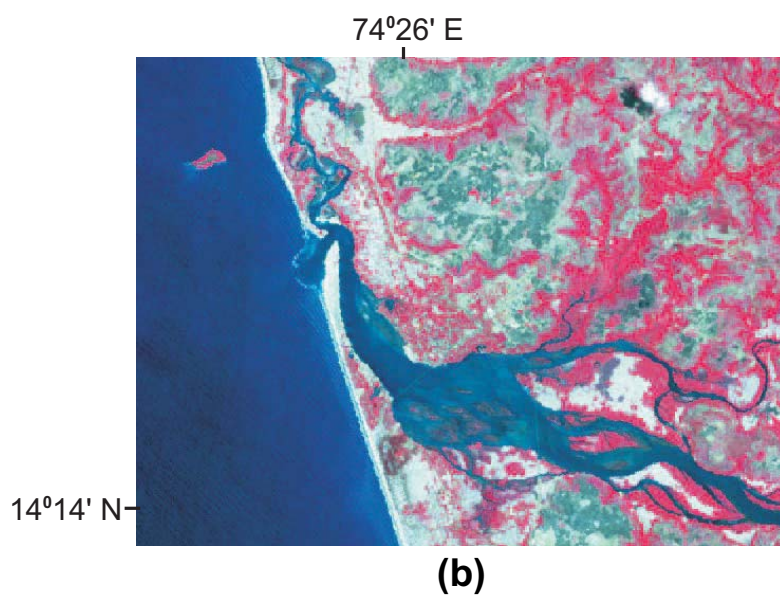
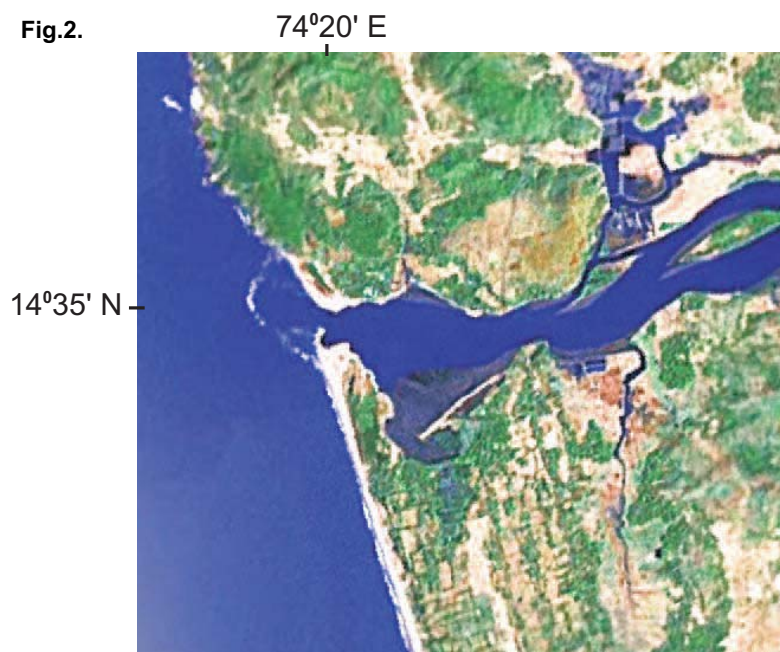


Fig.3

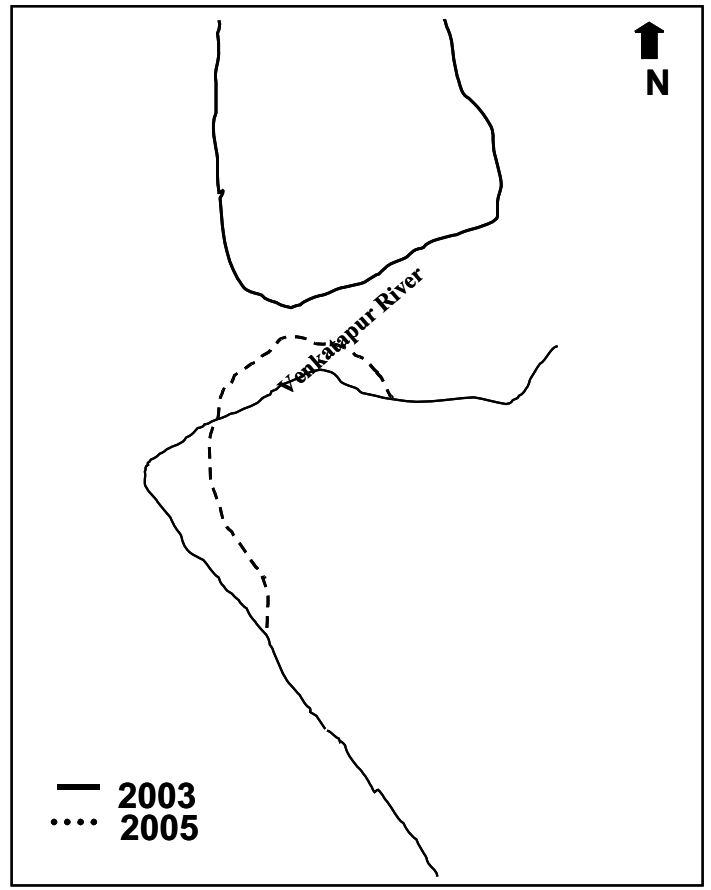
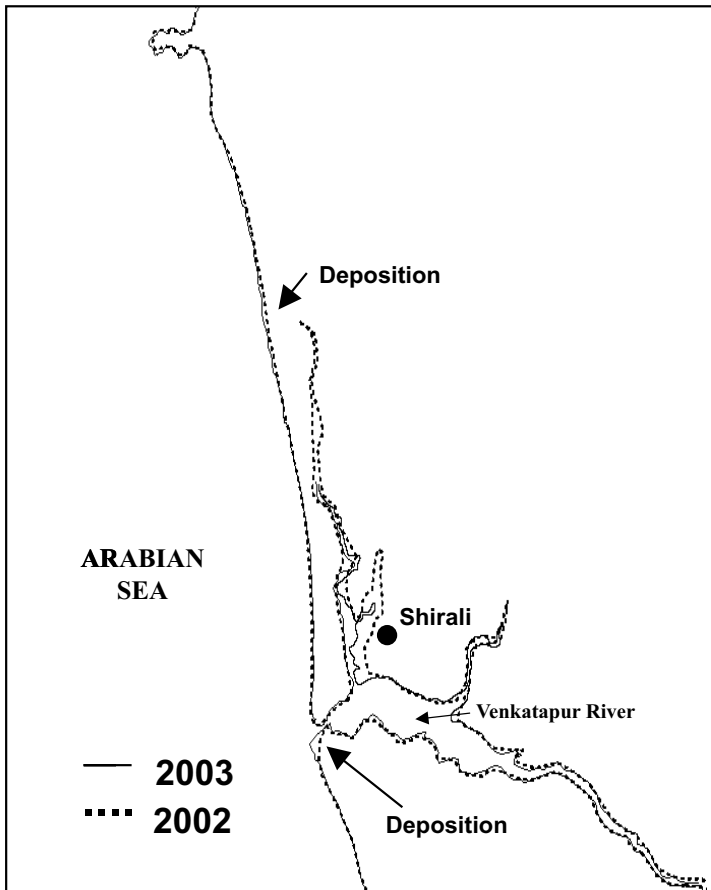
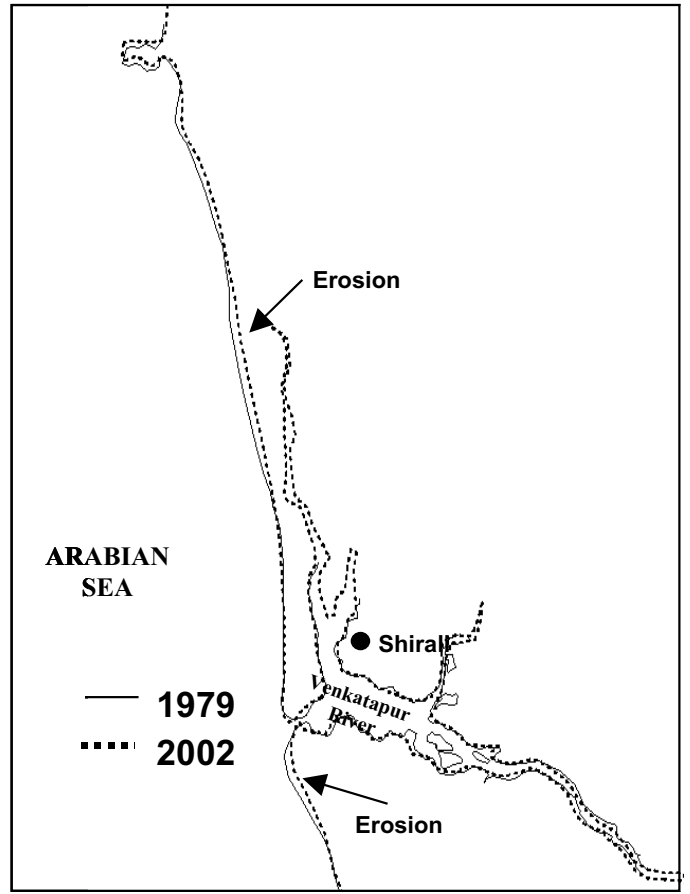
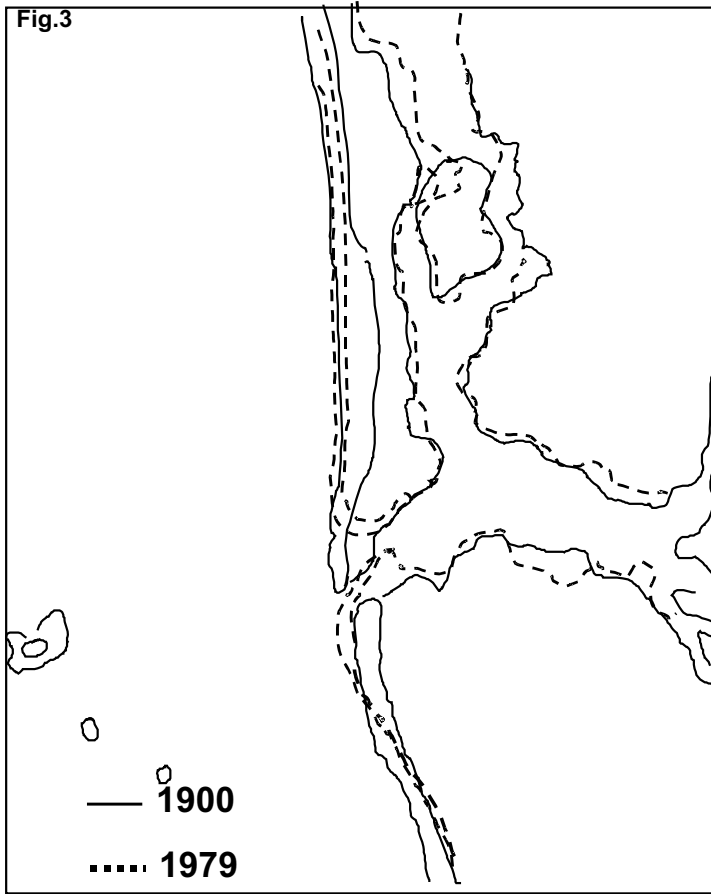


Fig.4

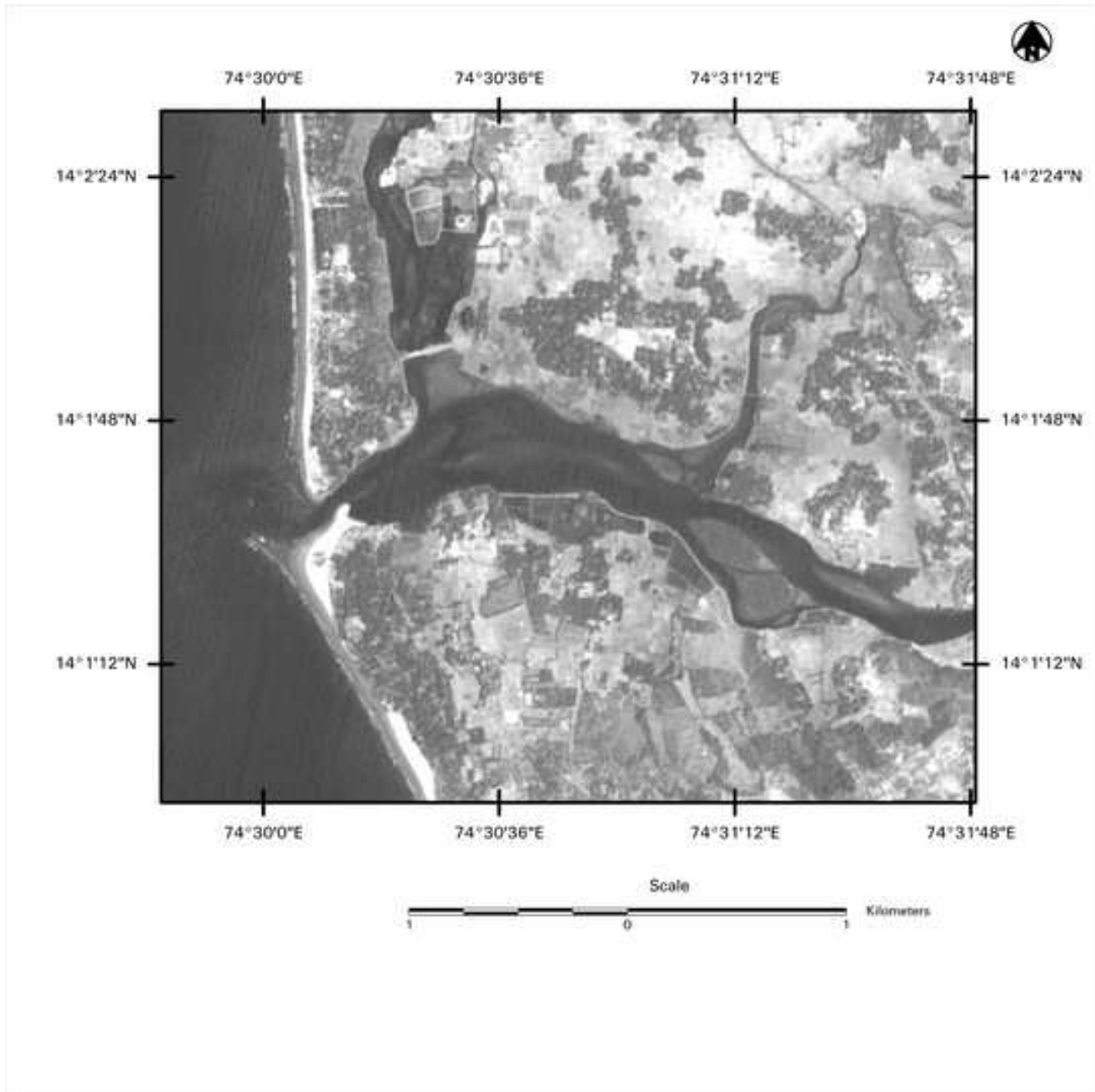
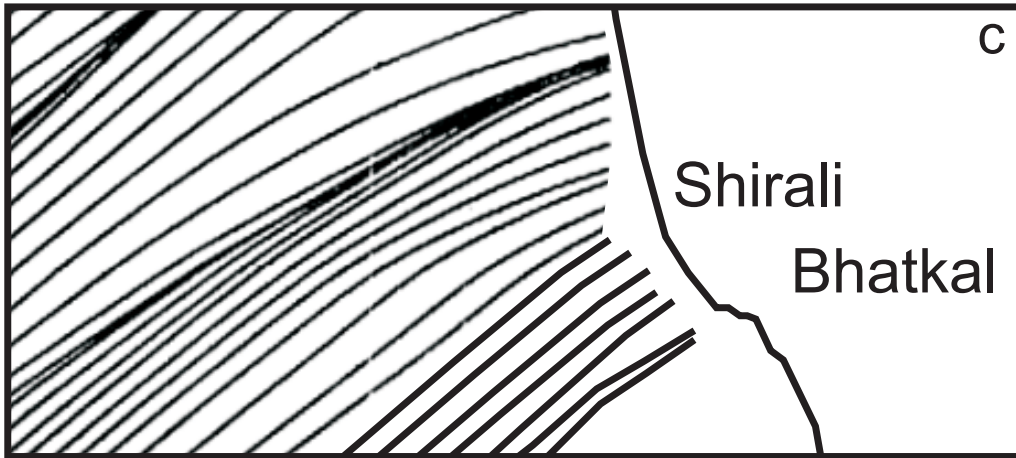
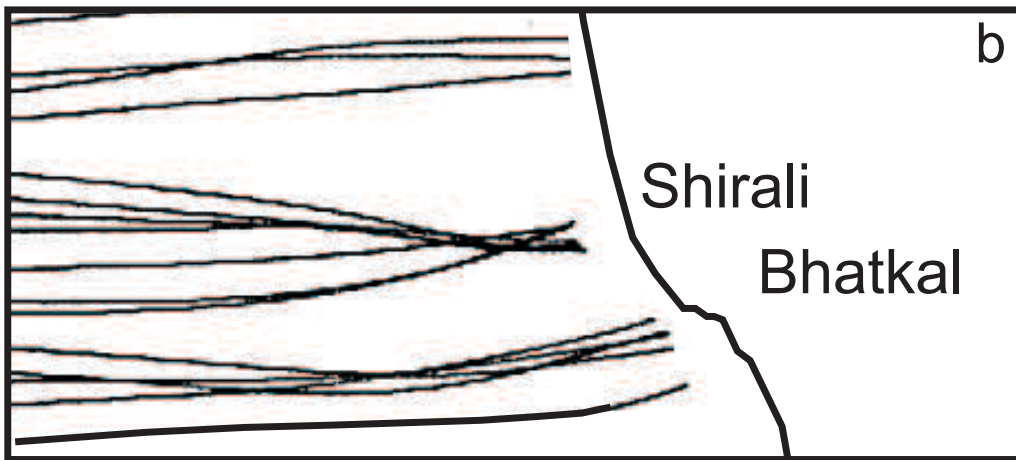


Figure 5

Wave period 10 Second  
Wave Direction SW



Wave Direction W



Wave Direction NW

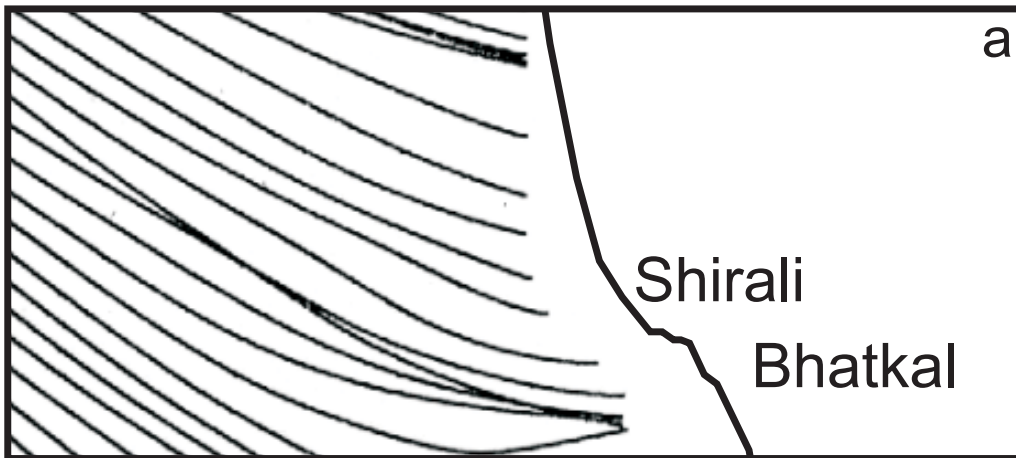


Fig.6

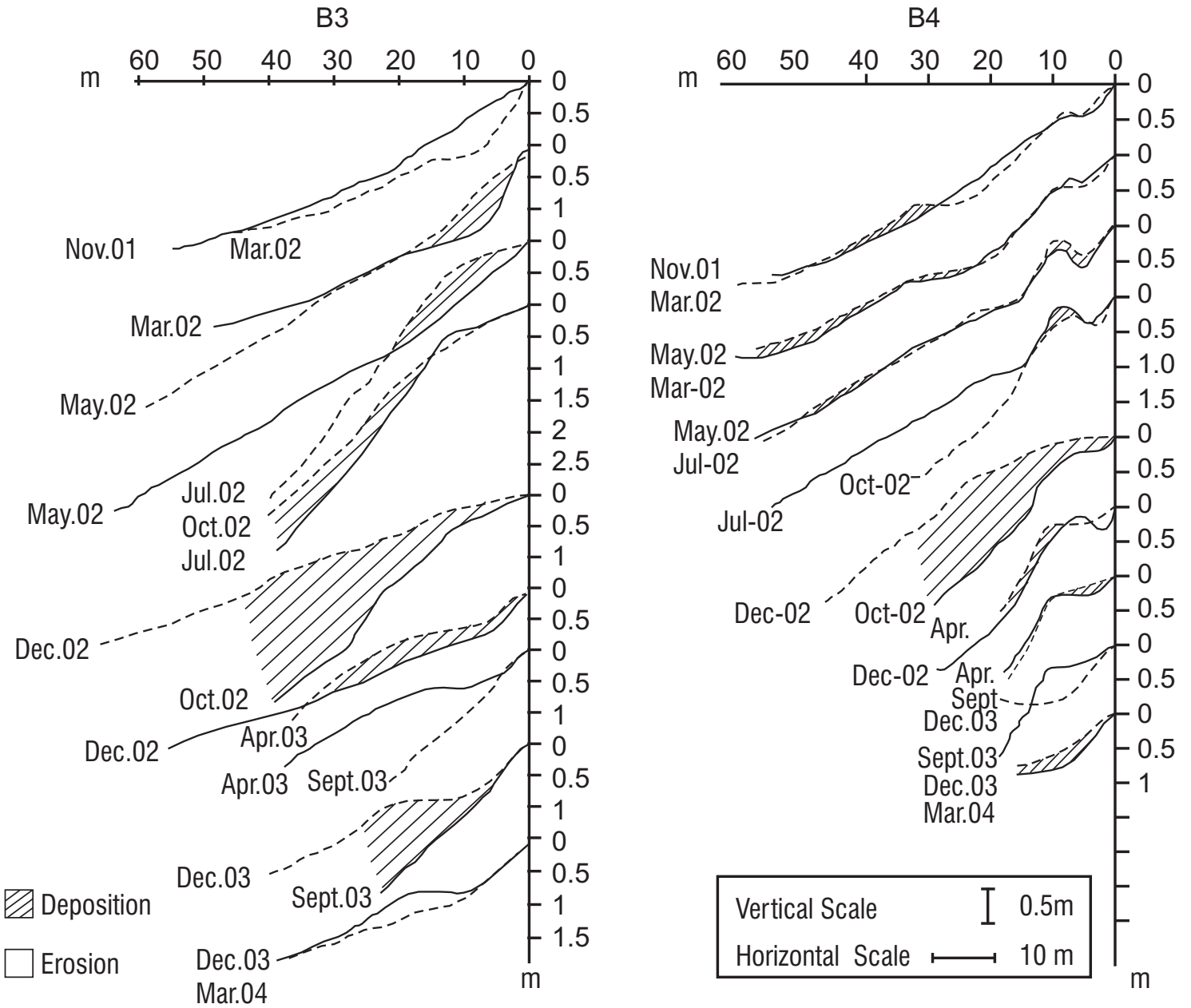


Fig.7

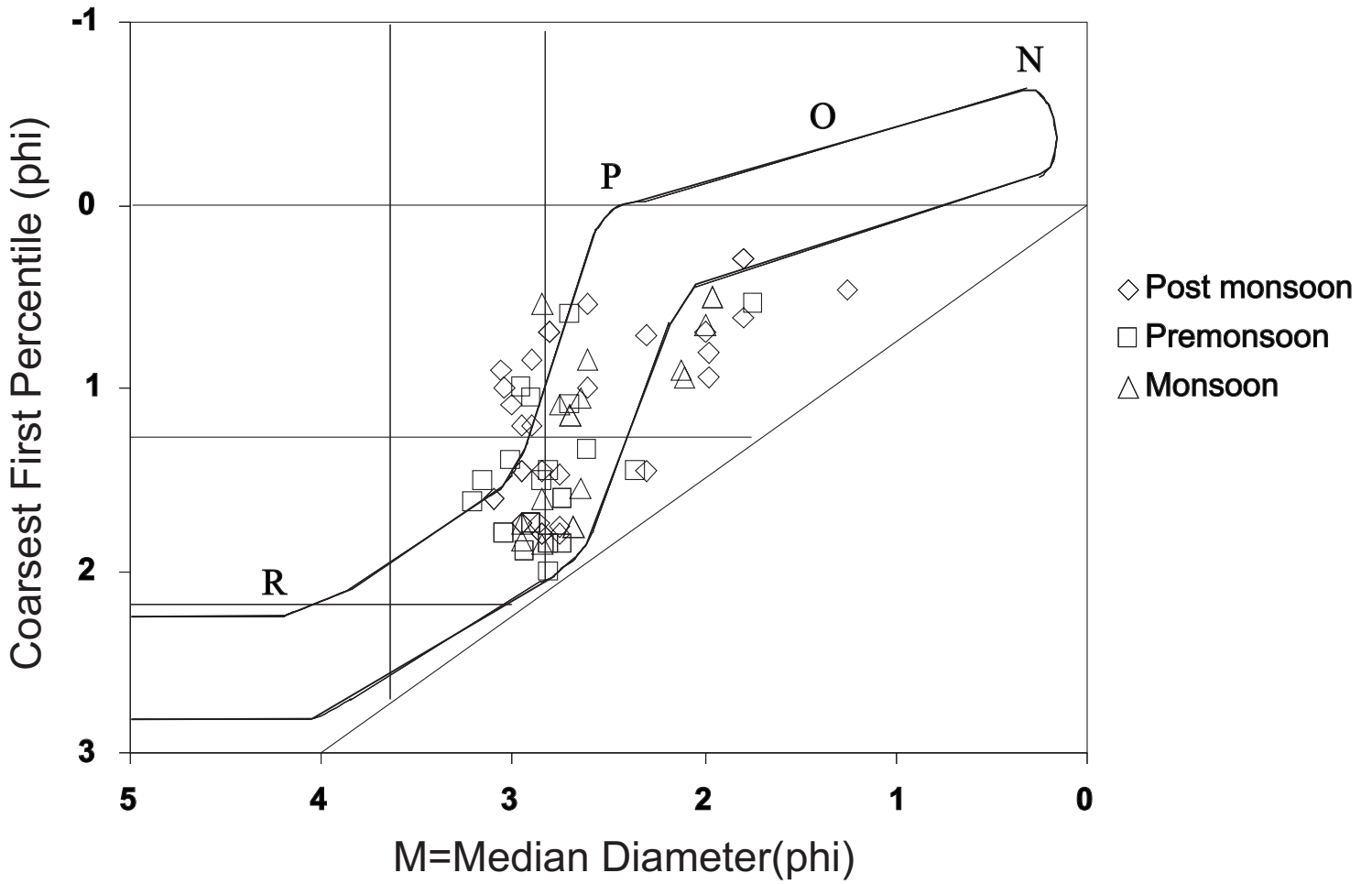
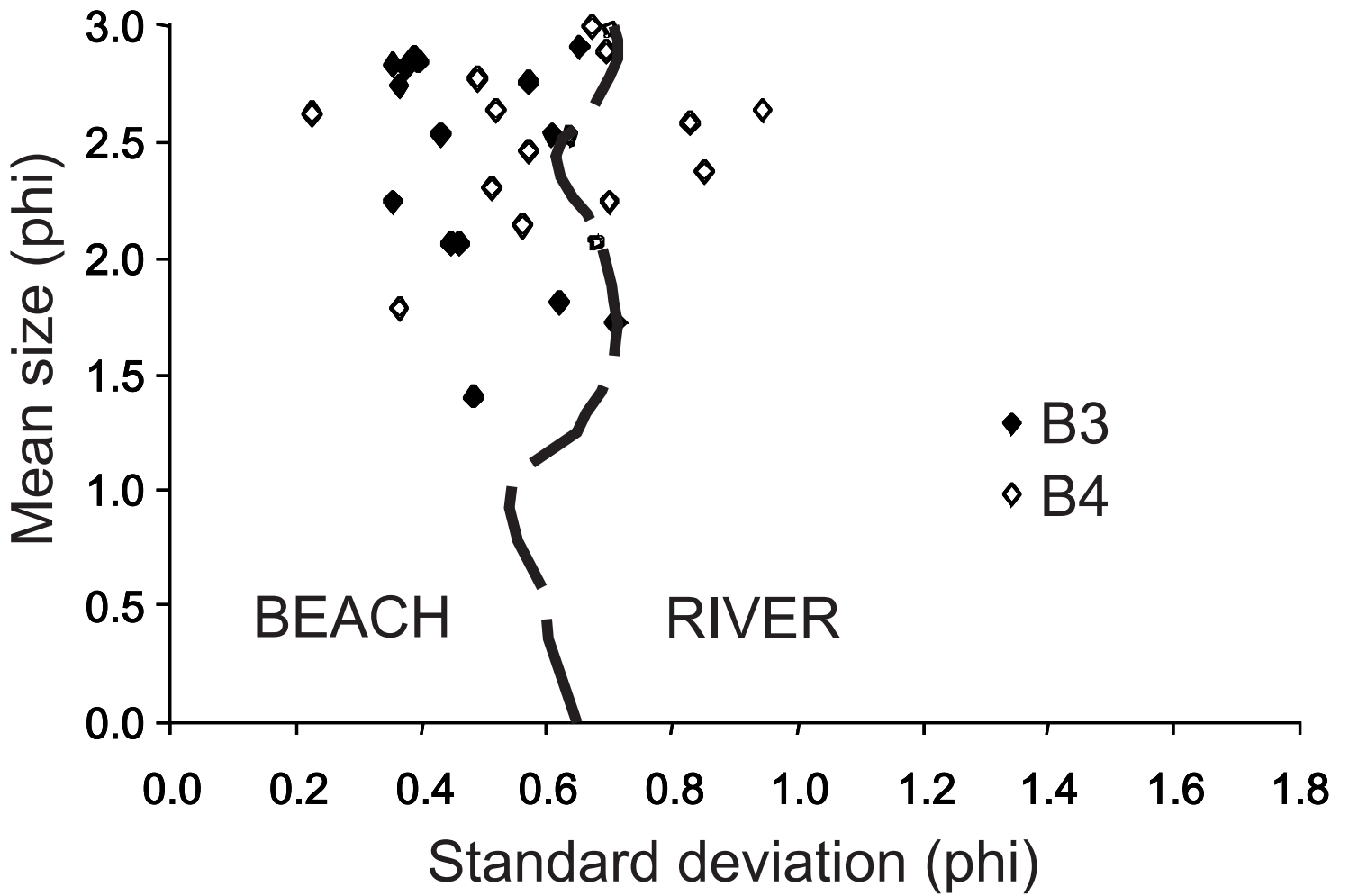




Fig. 8



## Figures Captions

Fig.1. Location map of the study area, showing the Venkatapur River mouth and the beaches and locations of the beach profile study

Fig.2. LISS III image (March 2002) showing crescent shaped submerged bar in-front of the Venkatapur, the Sharavati, and the Gangavali river mouths, Central west Coast of India.

Fig.3. Shore line changes in the vicinity of the Venkatapur river mouth.  
a) 1900-1979; b) 1979-2002; c) 2002-2003; d) 2003-2005

Fig.4 PAN Data of the Venkatapur river mouth region showing tumbolo –like beach growth behind the island.

Fig.5. Wave refraction pattern in the Study area for different season.

Fig.6. Seasonal variations in the Beach profiles to the north of the river mouth at Shirali

Fig.7. Coarsest first percentile versus Median diameter for the beach sands of the Central west coast of India.

Fig.8. Bi-variant plot of mean size versus standard deviation of the beach sediments of the study area.