

# Wave refraction patterns and their role in sediment redistribution along South Konkan, Maharashtra, India

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## Abstract

Wave refraction studies were undertaken for the nearshore sediments of four bays, Wada Vetye, Ambolgarh, Rajapur and Vijaydurg along the Konkan coast, Maharashtra, Central west coast of India, to understand the effect of wave dynamics in sediment redistribution. From the wave refraction patterns, wave convergent zones are identified at Wada Vetye North end, Ambolgarh promontory and Vijaydurg southern end, which are marked by strong erosional activities. In contrast, Ambolgarh, Vijaydurg and Wada Vetye bays are dominantly influenced by wave divergent conditions most of the time, leading to the formation of depositional land forms like tombolo at Ambolgarh bay, sand bar at Vijaydurg bay and accumulation of mangroves in the estuarine mouth of Vagotan river. The wave convergent zones are marked by cliffed rocky coastline. Erosional processes by wave convergence at various headlands have led to the deposition of sediments removed from the promontories in Vijaydurg, Ambolgarh and Wada Vetye bays.

*Keywords:* Wave refraction, Erosion, Deposition, Konkan, West coast of India

## Introduction

Waves are the principal source of energy available in the nearshore zone. This process is responsible for the sediment movement along any open coast. Depending upon bottom topography, water depth, configuration of the coastline, nature of wind, tide and several other factors, there is a possibility of waves being modified to increase or to dissipate their energy in any particular coastal region. Variations in wave velocity cause the wave crest to bend towards the alignment of the contours. Such bending effect is called 'refraction' and mainly depends on the relationship of the water depth with wave amplitude. As a result of wave refraction, the waves tend to become parallel to the coast, but they break at a slight angle to it, resulting in the formation of littoral currents, which are the prevalent type among many other nearshore currents, contributing to the movement of nearshore sediments (Horikawa, 1978; Komar, 1998; Masselink and Hughes, 2003). One of the important effects of littoral currents is the movement of sand as a littoral drift along the coast. The calculated quantum of gross littoral drift in the west

coast of India about 1.28 million cubic metres/year, (Moni, 1972) with an annual discharge of sediments to the sea along the Indian coast of the order of  $1.2 \times 10^{12}$  kg (Chandramohan et al., 2001).

The angle between the crest of the breaking wave and the shoreline face determines the direction of the long shore component of water motion in the surf zone and also the long shore transport direction. The wave refraction phenomenon is also an important process responsible for changes in coastal morphology. In the world, these studies are mainly used for investigating wave effects on various offshore installations and seasonal changes in the sediment transport and deposition (Wright et al., 1979; Daily, 2001; Masselink and Parttitaratchi, 2001; Bittencourt et al., 2002; Parttitaratchi and Harris, 2003; Ranasinghe and Parttitaratchi, 2003). In India, wave refraction studies in the nearshore were undertaken along its west and east coast, mainly to understand the distribution patterns of placer-rich sediments (Rajamanickam et al., 1986; Chandramohan, 1988; Chandrasekar, 1992; Jena, 1997; Angusamy et al., 2000; Anil, 2003). In the present study, an attempt has been made to understand

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the wave dynamics along the Konkan coast, south Maharashtra and its role in sediments redistribution.

### Study area

The Konkan coast in Maharashtra (about 500 km long) is marked by several bays. However, only four southern bays have been taken into account for the present study. These bays, with Wada Vetye in the north and Vijaydurg in the south (Fig. 1), are bounded by a submergent type of coastline on the east and a wide open Arabian Sea on the west. In the south and north they are bounded by cliffs and headlands. The coastline between Wada Vetye to the north and Vijaydurg to the south is very irregular and indented, and is attributed to a submergent type (Ahmed, 1972; Wagle, 1989; Sukthankar, 1995). The area is characterized by the presence of wave cut terraces, headlands, stacks, tombolos, tidal flats, cliffs and abandoned cliffs (Fig. 2). Northeast of Wadavetye, the beach at the point of the foothills of the cliff is characterized by boulders and basaltic rock formations, whereas in the south the beach is a straight, narrow and sandy, with steep gradient.

The Ambolgarh beach is gently arcuate to semi-arcuate in shape. The Rajapur bay has a small pocket beach behind the promontory, whereas the Vijaydurg bay is surrounded by an arcuate beach (Table 1). Development of berms and dunes are noticed in Ambolgarh, Rajapur and part of Vijaydurg areas. The dunes are found to be stabilized by thick vegetation. Both Vijaydurg and Wada Vetye are larger compared to the other bays. The Vijaydurg bay has one river (Vagotan) and one small stream, Rajapur has one river (Kodavil) and the Wada Vetye has one small stream. Ambolgarh bay does not have any river or stream source. Rivers Kodavil and Vagotan reflect a dominant tectonic control, and have steep graded profiles. These rivers display deep V-shaped cut valleys and include pebbles and boulders in their river bed, particularly in their upstream parts. The coastline is flanked by flat topped hills and headlands made up of Deccan trap basalt, capped by lateritic units of variable thickness.

### Waves, currents and tides

The study area is under tropical climatic zone and is dominantly attacked by waves, with short period and high amplitude during monsoon (June-October), whereas the reverse is true in the non-monsoonal months. These waves break offshore, thereby widening the surf zone. The predominant wave directions in the study area are SW, WSW, W and WNW, with periods ranging from 6 to 12 seconds (Chandramohan and Nayak, 1992; Rajamanickam et al., 1986). The south-westerly waves move the sediment northwards, whereas the WNW waves transport the sediment southwards.

### Materials and methods

Wave refraction studies can be done by either graphical or numerical methods. The numerical method is comparatively more accurate and less time consuming (Harrison and Wilson, 1964). This method was employed in the present study using a wave refraction model, (Chandramohan, 1988). The common assumptions as included in the Shore Protection Manual (Anon, 1977) were adopted for wave refraction calculations. Wave period, wave direction and water depth are the three major parameters used in the present study, and given as inputs in the wave refraction model. The offshore area, starting from 200 m water depth, was divided into 1:25 inch square grids. The interpolated depths from the naval hydrographic charts at the intersection of gridline were taken for the purpose of input depth. The starting depth of each orthogonal was always maintained at half the wave length. Wave periods 6, 8, 10, and 12 seconds (Reddy, 1976), and wave directions SW, W, WSW and WNW were taken into account for computation.

### Results and discussion

Wave refraction diagrams are presented for SW, W, WSW and WNW directions of the waves and for 6, 8, 10 and 12 seconds (Figs. 3a and b). The dominant waves are from SW and W. In the refraction pattern of 6 s of W direction, Wada Vetye north, Wada Vetye, Ambolgarh, Rajapur, and Vijaydurg bay show divergence, whereas Ambolgarh Promontory, Vijaydurg promontory

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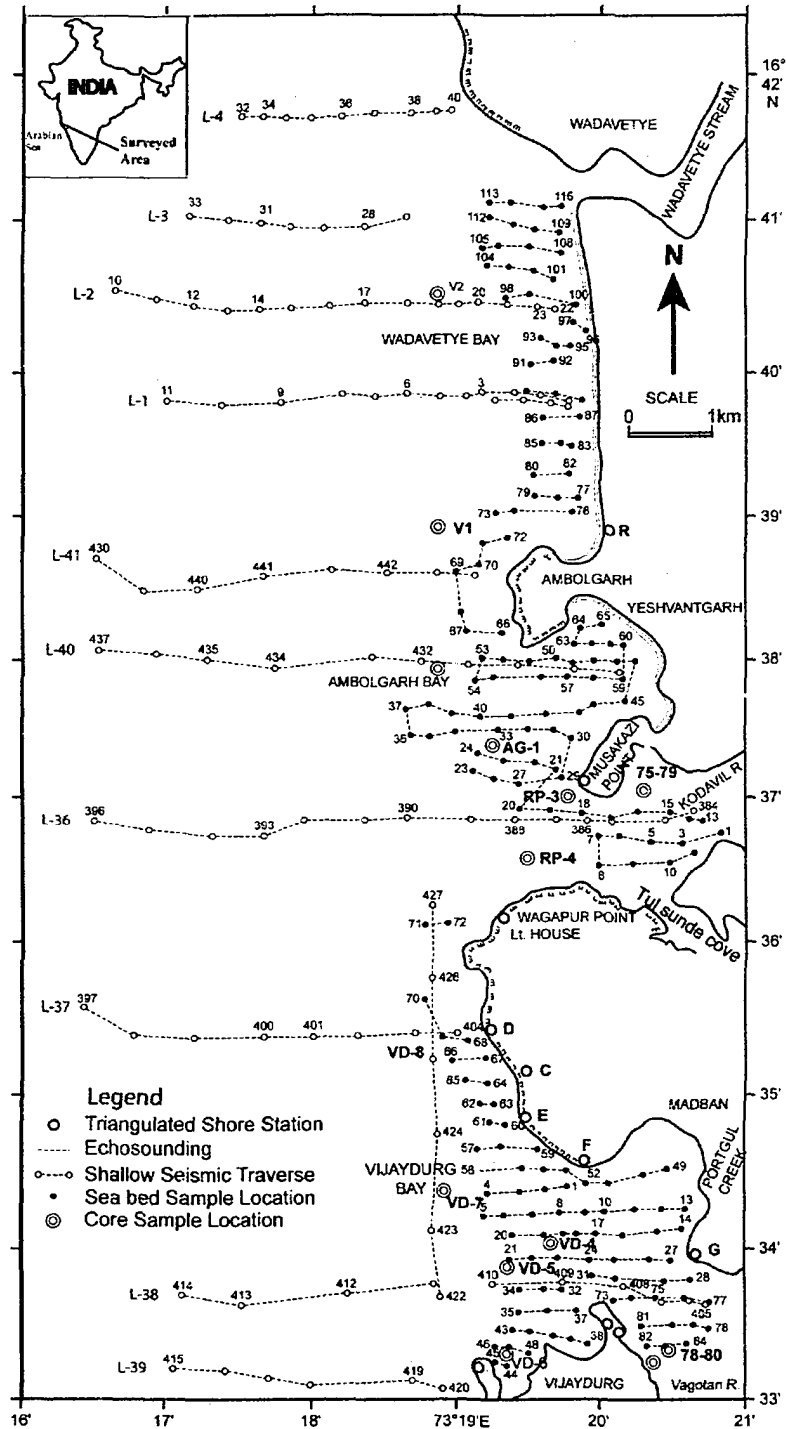


Fig. 1 - Study area and survey tracks.

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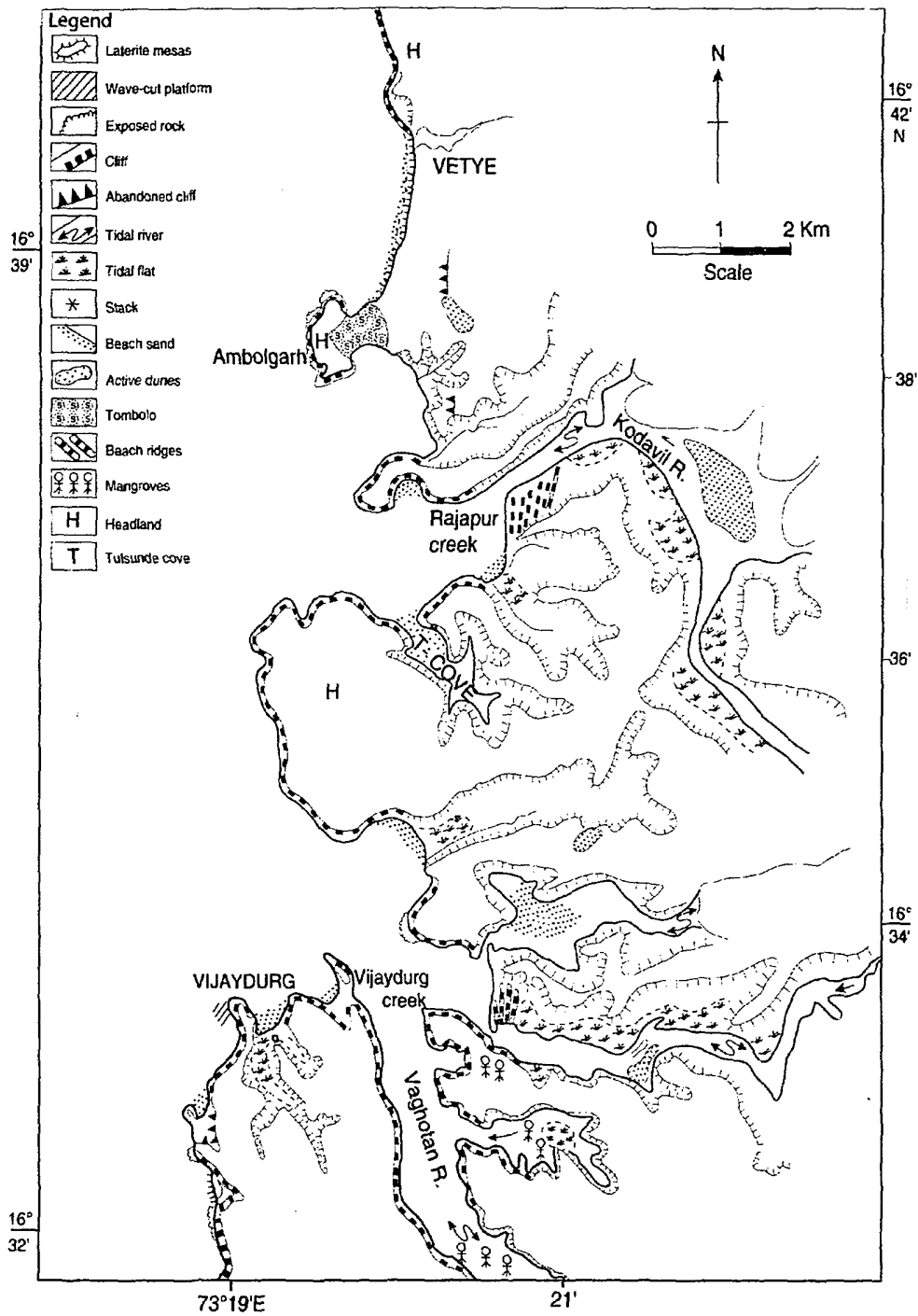


fig. 2- Geomorphological features of the study area.

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<b>Bays</b>	<b>Vijaydurg</b>	<b>Rajapur</b>	<b>Ambolgarh</b>	<b>Wada Vetye</b>
Shape	Arcuate	Arcuate	Arcuate to Semi-Arcuate	Straight
Coastline Configuration	NNE-SSW	E - W	NE-SW	N-S
Promontories	N and S	N and S	S	S
Beach	Sandy	Sandy	Sandy	Bouldery and coarse sand
Wind	Partially protected	Partially protected	Protected	Open condition
Landforms	Sandbar-Mudflats and Mangroves	Sandy beach	Tombolo	Bouldery beach (N)

Table 1 - Characteristic features of the bays

Directions	W				WNW				SW				WSW			
	6	8	10	12	6	8	10	12	6	8	10	12	6	8	10	12
Wada Vetye N.	D	D	I	D	C	C	D	I	C	C	C	C	C	D	D	C
Wada Vetye	D	C	I	D	D	D	C	D	D	D	D	D	D	D	D	C
Ambolgarh (promontory)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	D
Ambolgarh	D	D	C	D	D	C	D	C	D	D	D	D	D	D	C	D
Rajapur	D	0	C	C	D	D	D	D	D	D	C	D	D	D	C	D
Vijaydurg (Promontory)	C	C	D	D	C	C	C	C	C	C	D	C	C	C	D	C
Vijaydurg Bay	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Vijaydurg S.	C	C	C	C	C	C	C	I	C	C	C	C	C	C	C	C

D - wave divergence      C - wave convergence      T - inept conditions

Table 2 • Energy conditions prevailing in the study area for different wave directions and periods

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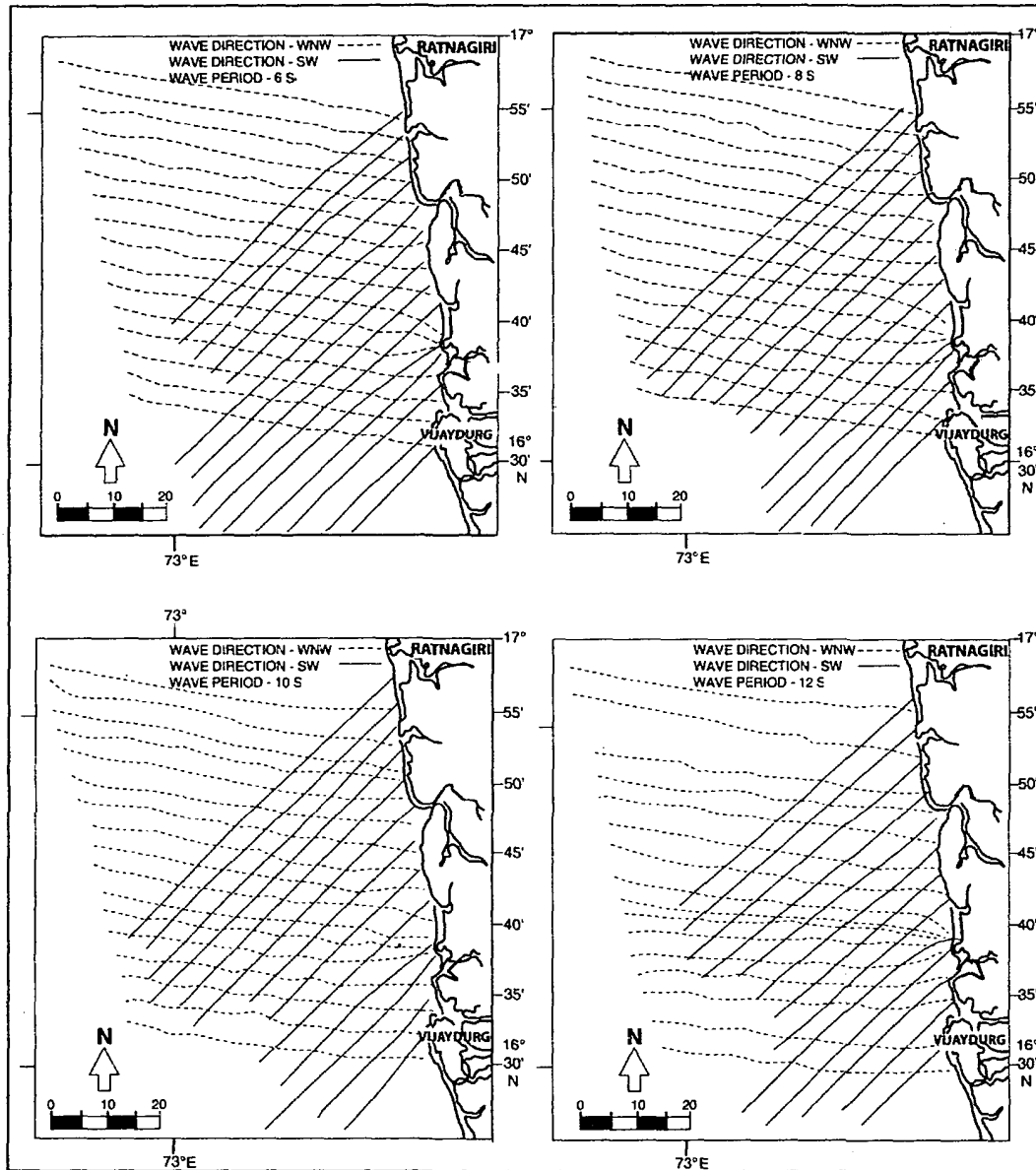


Fig. 3a - Wave refraction patterns for WNW and SW waves of different (6, 8, 10 and 12 seconds) period.

and Vijaydurg show wave convergence (Fig. 3b). While Ambolgarh and Vijaydurg point show a wave convergence for all the wave periods of 6, 8, 10, and 12 s of W direction, Vijaydurg promontory becomes wave divergent for 10 and 12 sec of W

direction, whereas Rajapur becomes wave convergent for the same wave periods (Fig. 3b). The other stations maintain either wave divergent or inept wave conditions (Table 2).

In the wave period of 6 and 8 s of WNW di-

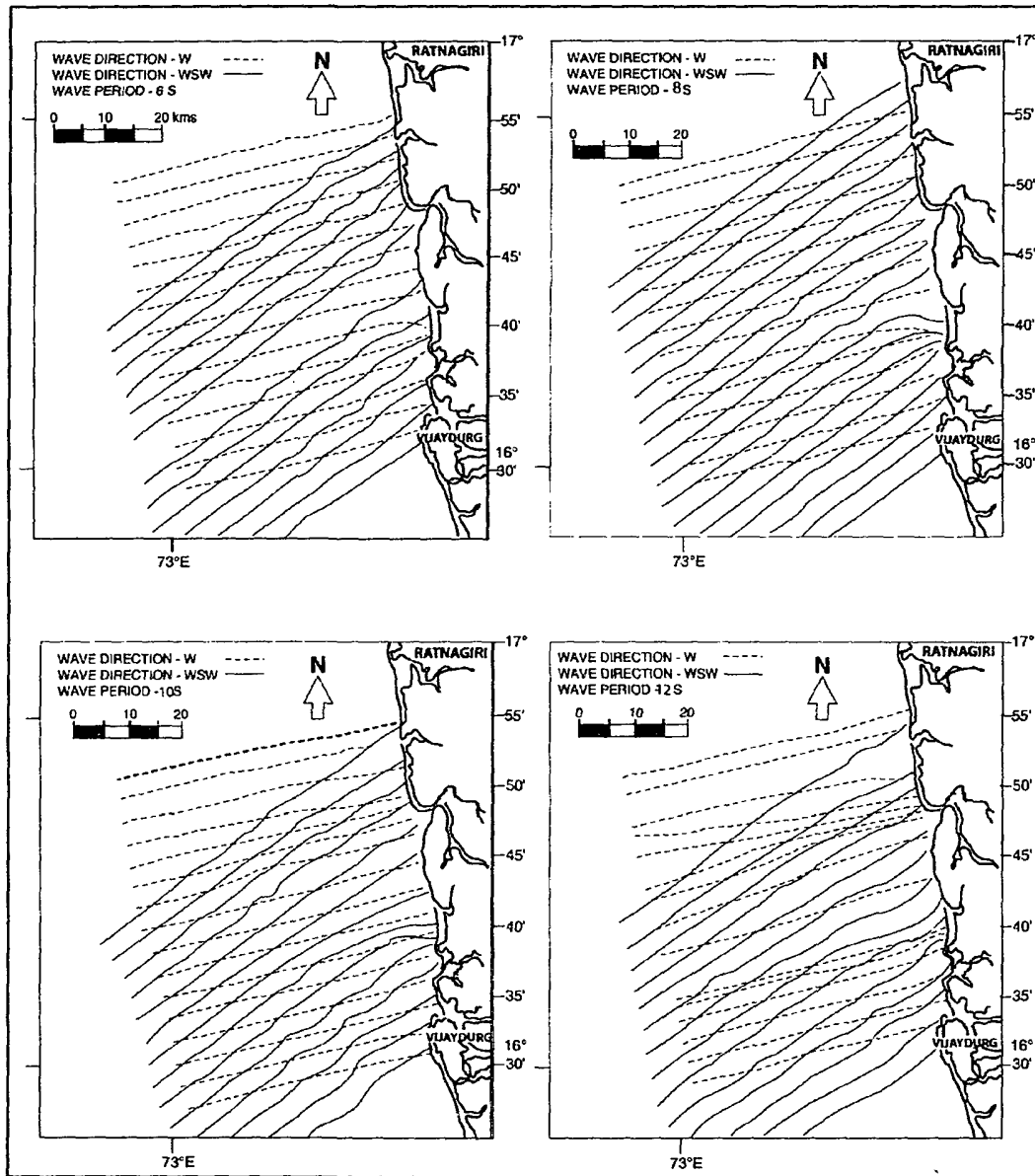


Fig. 3b - Wave refraction patterns for WJ and WSW waves of different (6, 8, 10 and 12 seconds) period.

rection Wada Vetye becomes convergent and Ambolgarh, Vijaydurg promontory, and Vijaydurg point keep wave convergent high-energy conditions in the above periods in addition to 10 and 12 s (Fig. 3a).

In the refraction pattern of 6, 8, 10, and 12 s of SW, Wada Vetye north shows a reversal from the earlier pattern, showing convergence persistently. This indicates that Wada Vetye north is more influenced by SW wave directions of all the wave

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periods (Fig. 3a). In this wave direction Ambolgarh promontory, Vijaydurg promontory and Vijaydurg point keep wave convergence of higher-energy conditions for these four periods.

Similarly, in WSW direction of 6, 8, 10 and 12 s, the above three stations indented with promontories show high wave-energy conditions, indicating convergence of wave orthogonals (Fig. 3b).

The overall results of wave refraction patterns of the present study indicate that Wada Vetye North end, Ambolgarh promontory and Vijaydurg southern end act as wave convergence points due to the projection of promontories/headlands into the sea and bay, while Wada Vetye (partly), Ambolgarh, Rajapur and Vijaydurg bay act as a zone of divergence. In these areas, characterized by cliff and promontories, lack of sedimentation is noticed up to 10 m water depth. This is due to the wave convergence of orthogonals which help to winnow away the finer sediments offshore. At points of convergence there is more turbulence due to the high energy and removal of material caused by strong wave action. Sand deposition was not observed off Wada Vetye north, Ambolgarh, promontory, Musakazi point in Rajapur, and Vijaydurg promontory (Fig. 4). This is probably due to the high near bottom currents generated as a result of wave convergence around these locations (near bottom currents - 26-47 cm/s at Musakazi, - 29-37 cm/sec at Vijaydurg promontory - Anon, 1990). The rocky or boulder sea beds in these areas are directly overlain by silty-sandy clays. The sand off Wada Vetye is slightly coarser and shelly, compared to the sands of the other bays. Because of the convergence of wave energy at Wada Vetye north, Ambolgarh promontory, Musakazi point, and Vijaydurg promontory, removal of sediments, especially lighter materials, takes place. This conclusion is supported by rocky sea bed even up to 10 m water depth in front of Vijaydurg promontory and lack of sedimentation at Ambolgarh and Wada Vetye north (Fig. 4).

On the other hand, along the bay, *ie.* in the zone of divergence, which signifies low energy environment, deposition of finer sediments takes place. Sediments in the bay consist mainly of sand, silt, silty sand and silty clay (Fig. 4). Sand covered areas are up to 11-12 m water depth and extend across for about 1.3 km in Vetye, 2.0 km in Ambolgarh, 1.5 km in Rajapur, and 23 km in Vijaydurg bay. These are overlain by acoustically transparent clays (Gujar, 1996). The effects of this deposition are noticed in the siltation of Vijaydurg

(9.0 mm/year) and Musakazi (7.1 mm/year) harbours, and in the development of landforms (tombolo) in the Ambolgarh and Vijaydurg bay (sand bar and mangroves). In the case of Wada-vetye bay, the observed convergence of orthogonals is probably responsible for removal of finer sediments from the bay sediment, especially in its northern half (Fig. 2). Change of wave energy in a particular area at different wave periods can be attributed to the change of quantum of sediment movement from one convergent point to another (Angusamy et al., 2000).

The convergence point (Ambolgarh promontory and Vijaydurg southern end) acts as a barrier to sediment movement, and the net effect observed is accretion on the updrift side and erosion on the downdrift side. Nevertheless, the presence of distinct promontories might have also aided the restrictions caused by the convergence, because if an artificial or a natural barrier is present perpendicular to a straight beach, relative effects will be observed even with the same direction of incident wave according to the size of the material, wave energy, length of the barrier etc. (Le Mahaute and Brebner, 1961; Rajamanickam et al., 1986; Hanamgond and Chavadi; 1993)" In such circumstances, accretion would result on the updrift side and erosion on the downdrift side (Brun and Nayak, 1980). In the present case, Ambolgarh promontory and Vijaydurg southern end are natural barriers affecting the littoral drift considerably. Due to the presence of natural barrier, the coast south of Ambolgarh promontory (Ambolgarh bay) and Vijaydurg promontory (Vijaydurg bay) undergoes deposition, whereas the coast on the north side undergoes erosion. The extent of deposition south of Vijaydurg is around 12.7 mm/year based on <sup>210</sup>Pb geochronology (Gujar, 1996; Gujar et al., 2005). Erosion tends to remove mainly the light minerals and flaky constituents. Hence, the enrichment in heavy minerals in Ambolgarh (Gujar, 1996) and at Vijaydurg appears to be related to such erosion. Rajamanickam et al. (1986) have reported a similar enrichment in heavy minerals in the zones of wave convergent orthogonals along the north central Konkan coast. Similarly, the enrichment of heavies at selective pockets of Kanyakumari coast is reported by Angusamy and Rajamanickam (2000), where convergences of waves winnow away the coarser light minerals.

Likewise, the area north of Ambolgarh head suffers erosion by losing light and heavy miner-



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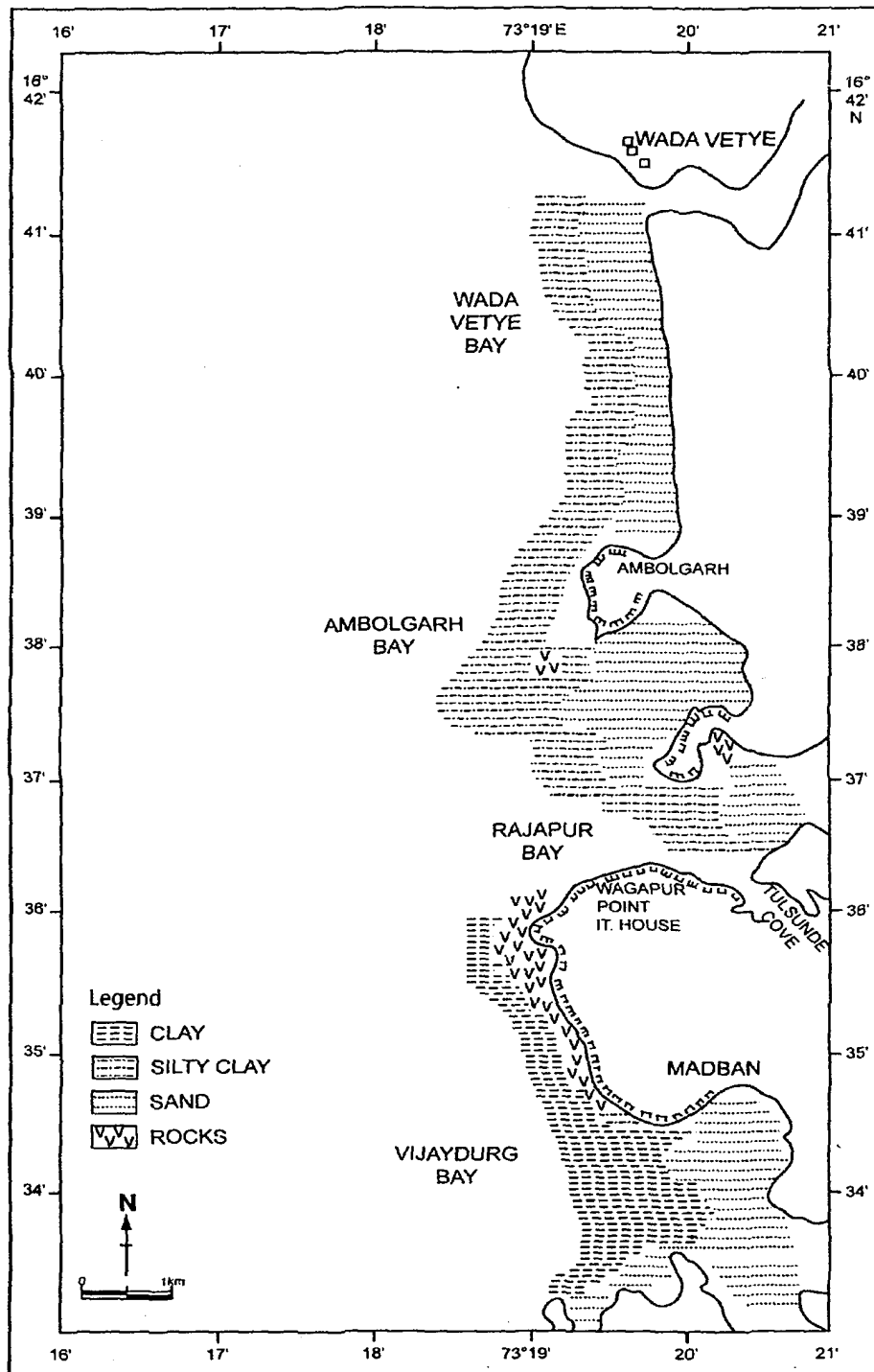


Fig. 4- Sediment distribution in the bays.

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als, which are deposited in southern part of Wada Vetye bay at a rate of 8.1 mm/year (Gujar, 1996) due to the presence of Wada Vetye cliff to the north. Similar observations are also reported from the east coast of India (Raja Ganesh Rama, 1987; Subramaniam and Mohan, 1989; Angusamy and Rajamanickam, 2000). At Ambolgarh bay, the presence of a tombolo testifies the prevalence of low-energy conditions leading to the formation of this landform in an undisturbed environment. Similarly, Angusamy et al. (2000) and Angusamy and Rajamanickam (2000) have reported development of the spit at Tuticorin in the updrift direction, because of the construction of artificial jetties which have acted as barriers.

## Conclusions

The study of Konkan coast has revealed the following features:

- Wave convergence zones are delineated at

Wada Vetye North end, Ambolgarh promontory and Vijaydurg southern end.

- Wave divergence conditions are identified at Vijaydurg, Rajapur, Ambolgarh and Wada Vetye bays.

- Due to strong erosion in the bays, the sediments removed from the promontories are deposited in the updrift direction of the littoral currents.

- The bays are characterized predominantly by sands and clays, whereas promontories by rocks and silty sands, indicating removal of sands from promontories with subsequent deposition in the adjacent bays.

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