Mahasagar–Bulletin of the National Institute of Oceanography, **18**(2), 1985, 163–177.

LONGSHORE CURRENTS AND ASSOCIATED SEDIMENT TRANSPORT IN THE NEARSHORE AREAS OF KERALA AND GOA, WEST COAST OF INDIA

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ABSTRACT

The field observations on the longshore currents at selected locations along the coasts of Goa and Kerala on the western seaboard spanning over a period of five years revealed high variability in their direction and speed. The currents and the associated circulation of water derived from wave refraction diagrams for these regions indicated the near closed cellular patterns of flows for waves of near normal incidence while meandering flows either in an upcoast or downcoast direction have been found to result in for waves approaching the shore from extreme deep-water directions. The sediments of this zone brought into suspension through turbulence generated by wave breaking processes have been found to get recirculated in the area under the influence of these circulations. Under some favourable environments these currents and the associated circulation of water help in maintaining the shoals in the vicinity of river mouths or in stabilising the shores.

Key-words : *Longshore currents, sediment transport, Kerala, Goa.*

INTRODUCTION

In the coastal zone two current systems may be identified which are important from the point of view of sediment transport — (i) those within the surf zone and (ii) those beyond the surf zone. Of these, the currents in the surf zone are by far the most important in the transfer of sediments and these derive their energy from the breaking waves. On the other hand, the momentum (or mass transport) in the sea, the wind and tide govern the currents seaward of the surf zone and these currents could become effective for transporting sediments only when the latter are carried beyond the surf zone. The structural aspects of these currents have been presented by Murty, Das and Varadachari (1972) and dealt in considerable detail by Longuet-Higgins (1972; 1972a) and Bowen and Inman (1974).

The longshore current measurements being spot observations, are very transitory in character and represent the conditions prevailing at that moment and at that point making it difficult to extrapolate and/or interpolate for the entire stretch of the beach. Thus, while these form an important data set, much reliance cannot be placed on them to derive advective transport in the surf zone. Realising these problems, several investigators have attempted, both in the field and in the laboratory, to obtain a quantitative measure of the field of motion in relation to the breaker characteristics (see Galvin, 1968 for a review). Based on the momentum and energy considerations, the observed field of motion was sought to be explained by these authors and their results show varying degrees of success. More recently, utilising the concept of radiation stress (Longuet-Higgins and Stewart, 1962), several theoretical and field studies were initiated to derive the nature of circulation in the surf zone (Bowen, 1969; Sonu, 1972; Noda, 1974). Bowen's studies provide an explanation for the development of rip currents along a plane beach when the wave approach is normal to the shore. Sonu's field experiments brought to light the importance of bathymetric features in the surf zone in the development of these current systems. His study also emphasises the importance of the topographic features along with the variations in the radiation stress along the beach to derive the field of motion in a realistic manner. The interaction of the incoming waves, the bottom topography and its influence on the nearshore currents have been examined by Noda (1974). All these studies showed the occurrence of discrete circulation cells (Bowen and Inman, 1969; Inman and Brush, 1973) for normal incidence of wave rays and meandering flows when waves break at an angle to the shoreline.

It may be pointed out that as waves approach shallow water, the wave rays curve in such a manner that they will become perpendicular to the shoreline at the 'zero depth' of the water near the beach. While this condition is not generally fulfilled since the waves of higher amplitude break sooner (i.e., in deep water) in nearshore, one may expect the wave rays tend to be nearly normal at the breaker zone except for waves approaching from extreme deep-water directions. Thus, more often, along an open beach, cellular current patterns are likely to prevail. When the angle of incidence of the breakers is considerable the resulting flow pattern is likely to show a meandering character. Associated with these currents, the beach material brought into suspension is transported in either closed cells or along the beach in a meandering pattern. When this material gets transported beyond the surf zone, then only, the coastal currents would be effective in transporting it farther.

In this paper the currents prevailing within the surf zone based on the field measurements and the field of motion derived from wave refraction studies are presented for the coasts of Goa and Kerala (Figs. 1A and 1B). These results have been utilised to explain the probable sediment transport in the nearshore areas of these two regions.

DATA AND ANALYSIS

The data on the drift measurements made during the various field surveys at various locations along the coasts of Kerala and Goa have been summarised and presented in Tables I to III. Based on wave refraction diagrams for different wave periods and directions of approach, the wave height distribution maps are prepared for the Goa region assuming unit deep water wave height undergoing refraction and typical examples are presented in Figs. 2A and 3A. From the wave heights evaluated, wave orbital velocities

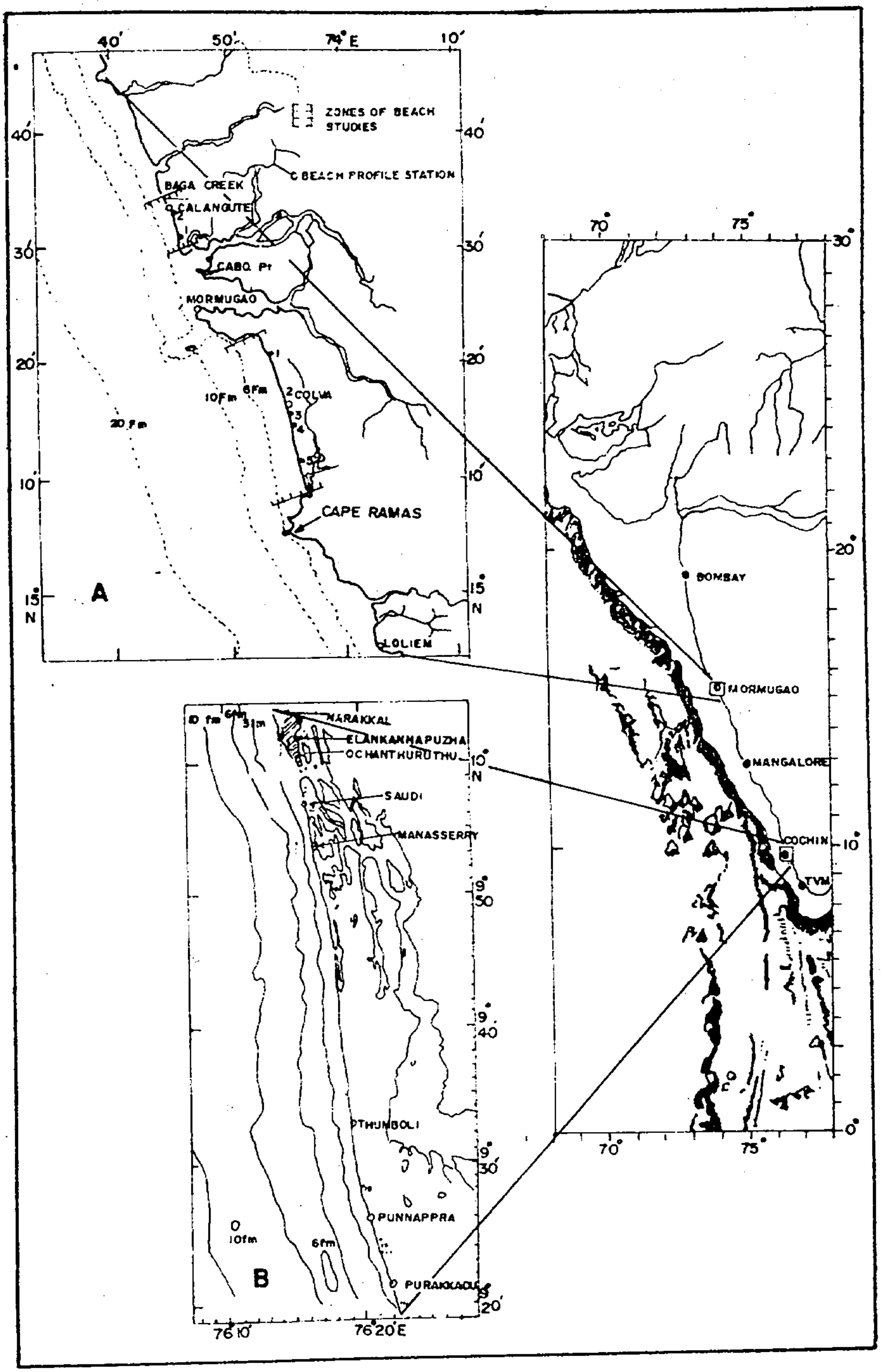


Fig. 1. Location map showing the west coast of India, its continental shelf and the adjacent sea. (A) Coast of Goa and (B) part of the shoreline along Kerala coast where the studies were carried out.

Table I. Observed littoral flows at various locations shown in Fig. 1B during November 1964 to November 1968 along the coast of Kerala.

Month	Narakkal		Elankan-napuzha		Ochanth-ruthu		Saudi		Manassery		Thumboli		Punnappra		Purakkad	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Jan.	N	W											S	W		
Feb.											N	W	S	W	S	W
Mar.	N	W	S	W			N	W			N	M	N	W	N	W
Apr.	N	W	S	W			N	W	S	W	S, N	M			N	W
May			S	W			N	W			N, S	M			N	W
June	S	W					N	W					S	M	N	M
July							S	W	S	W	N, S	W	S	W	N, S	W
Aug.									N	W			S	W	S	W
Sept.									N	W	S	W	S	W		
Oct.	N	W					N	W	N	W	N	W	N	W	N	W
Nov.							N	W	N	W	N	W	N	W	N	W
Dec.									N	W	N	W				

1. **Direction**

N— Northerly or upcoast flow.

S— Southerly or downcoast flow.

2. **Speed**

W— Weak ($<$ 30 cm/sec)

M— Moderate (30-60 cm/sec)

S— Strong ($>$ 60 cm/sec)

Table II. Observed littoral flows at various locations shown in Fig. 1A during September 1969 to April 1973 along the coast of Goa.

Colva region :

Location :	Location 1		Location 2		Location 3		Location 4		Location 5	
Month	1	2	1	2	1	2	1	2	1	2
Jan.	N	W	N, N, S	M, S	N, N, N, Off	W	N, S	M, W	N, N	M
Feb.	N, N	W	N	W	N	W	N	W	N	W
Mar.	Off	S	N, N, N	M	N, N, N	W	N, N	W	N	W
Apr.	N, N, N	W	N	M	N, N	M	Off	W	N, S, N	M
May	N, N, N, S	W	N, S, Off	M	S, N, S, Off	W	N, N, S	W	N, N, S, Off	W
June	N	M	Off	M	N	W	S	S	S	W
July	S, S	M, M	N, S, N	M, W	S	M	N, S	W	N, S, N, Off	W
Aug.	N, S, S	M, S	S, Off	W	S	M	S, N	W	N, N	W
Sep.	S, S, N	M	S, V	M	Off	W	N, N	W	N, N, N	W
Oct.	S, N	M	S	W	N	W	N, N	M	N, N	M
Nov.	—	—	S	W	S	M	S	M	S	W
Dec.	N	W	N, Off	W	N	M	N	W	N	M

1. **Direction**

N— Northerly or upcoast flow.
S— Southerly or downcoast flow.
Off— Offshore flow.
V— Variable

2. **Speed**

W— weak (< 30 cm/sec)
M— moderate (30 — 60 cm/sec)
S— strong (> 60 cm/sec)

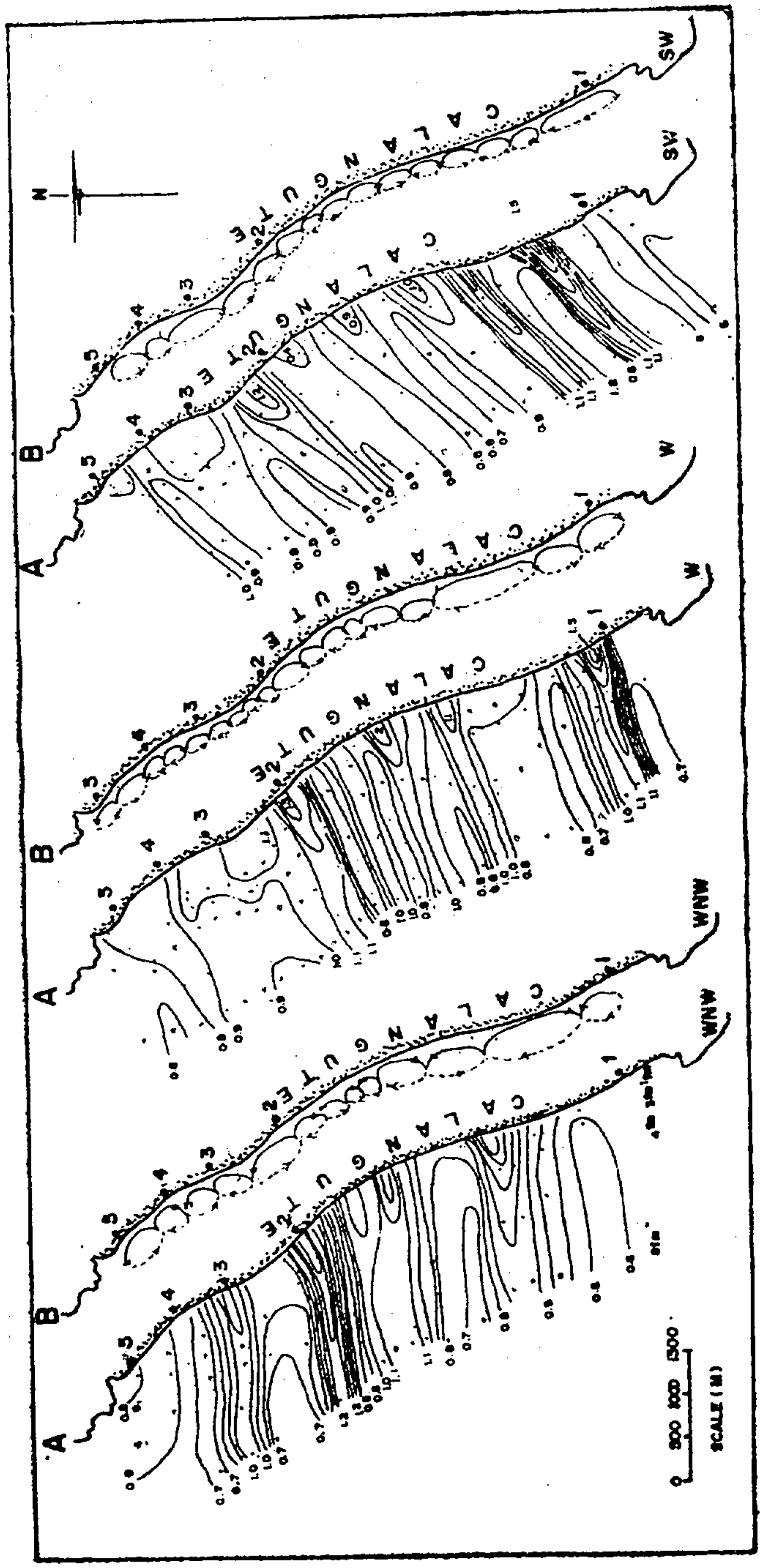


Fig. 2. Wave height distribution (A) and flow patterns in the surf zone (B) associated with waves of 8 sec period from WNW, W and SW for Calangute area, Goa.

(U_{max}) near the seabed in the nearshore region have been computed using the following equation (Lamb, 1945):

$$U_{max} = \frac{\pi H}{T} \frac{1}{\sinh \frac{2\pi h}{L}} \qquad \ldots\ldots (1)$$

where U_{max} is the maximum horizontal component of orbital velocity

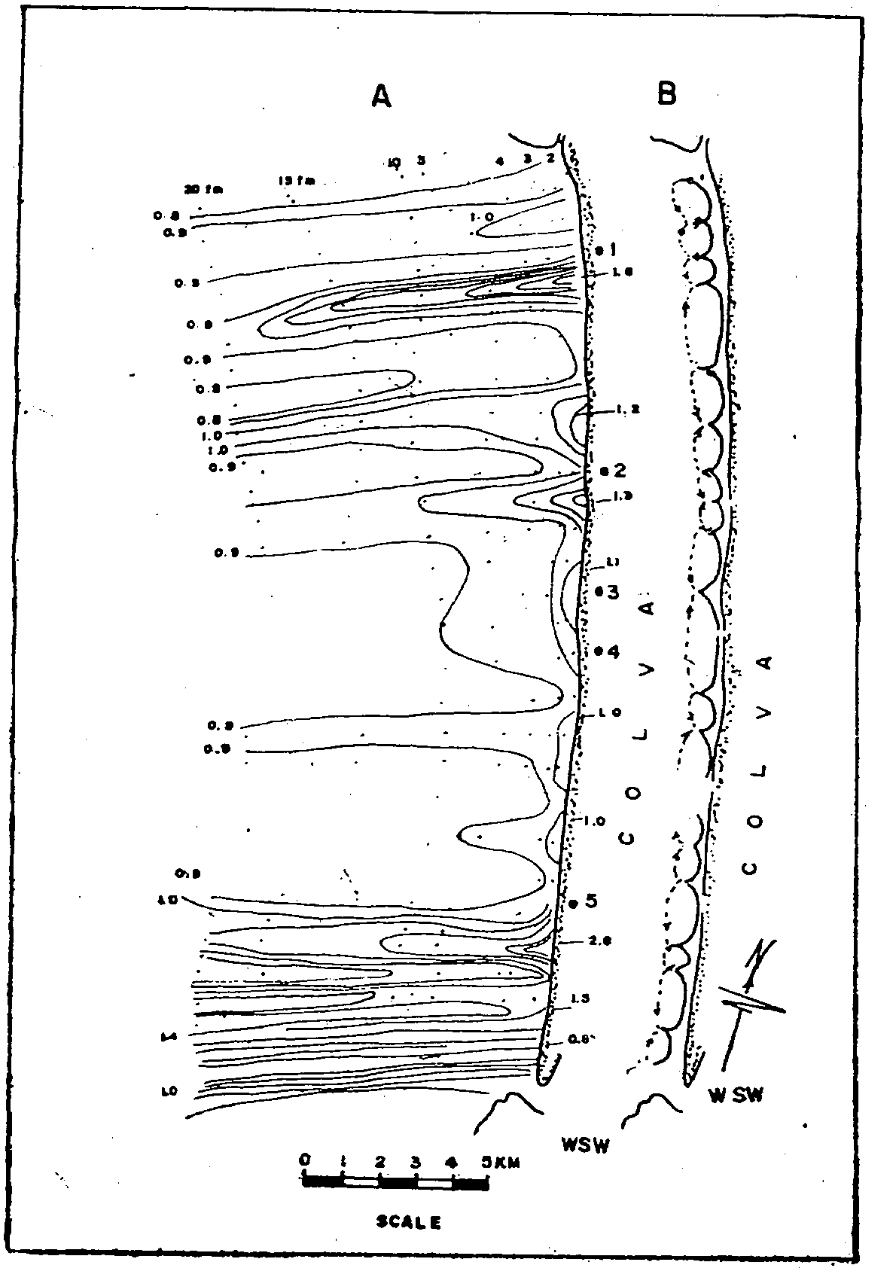


Fig. 3. Wave height distribution (A) and flow pattern in the surf zone (B) associated with waves of 10 sec period from WSW for Colva area, Goa.

Table III. Observed littoral flows at various locations shown in Fig. 1A during September 1969 to April 1973 along the coast of Goa.

Calangute region:

Location:	Location 1		Location 2		Location 3		Location 4	
Month	1	2	1	2	1	2	1	2
Jan.	N, S, S	W	S, S, N, N	W	Off, S, S, S	S	Off, S, S	S
Feb.	S, S, S, N	M	S, S	S	Off	M	S, S, Off	M
Mar.	N, N, N	W	S, S, N, Off	W	S, S, N, Off	M	N, N	W
Apr.	S, S, N, N, N	M, W	S, Off, N	M	S, N, Off	M	S, S, N, Off	W
May	Off, N, S	W	N, S	M	N, S, S, S	M, S	Off, S, N	M, W
June	N, Off	M	Off, N, S	M	N, Off	W	Off	M
July	N, Off	W	Off, N, N	M	Off	M	S, S, S	M
Aug.	N, S, Off	M	S, S	M	N, N, S	W	N, N	M
Sept.	N, Off	W	N, N, Off	M	N, N	M	N, N	M
Oct.	Off, N, S	S	Off, N	M	N, N, N	M	N	S
Nov.	N	M	N	W	N, Off	M	N	M
Dec.	S, N, Off	M	N, N, N	W	Off, N, N	W	N, N, N	W

1. **Direction**

N— northerly or upcoast flow
S— southerly or downcoast flow
Off— Offshore flow.

2. **Speed**

W— Weak ($<$ 30 cm/sec)
M— Moderate (30-60 cm/sec)
S— Strong ($>$ 60 cm/sec)

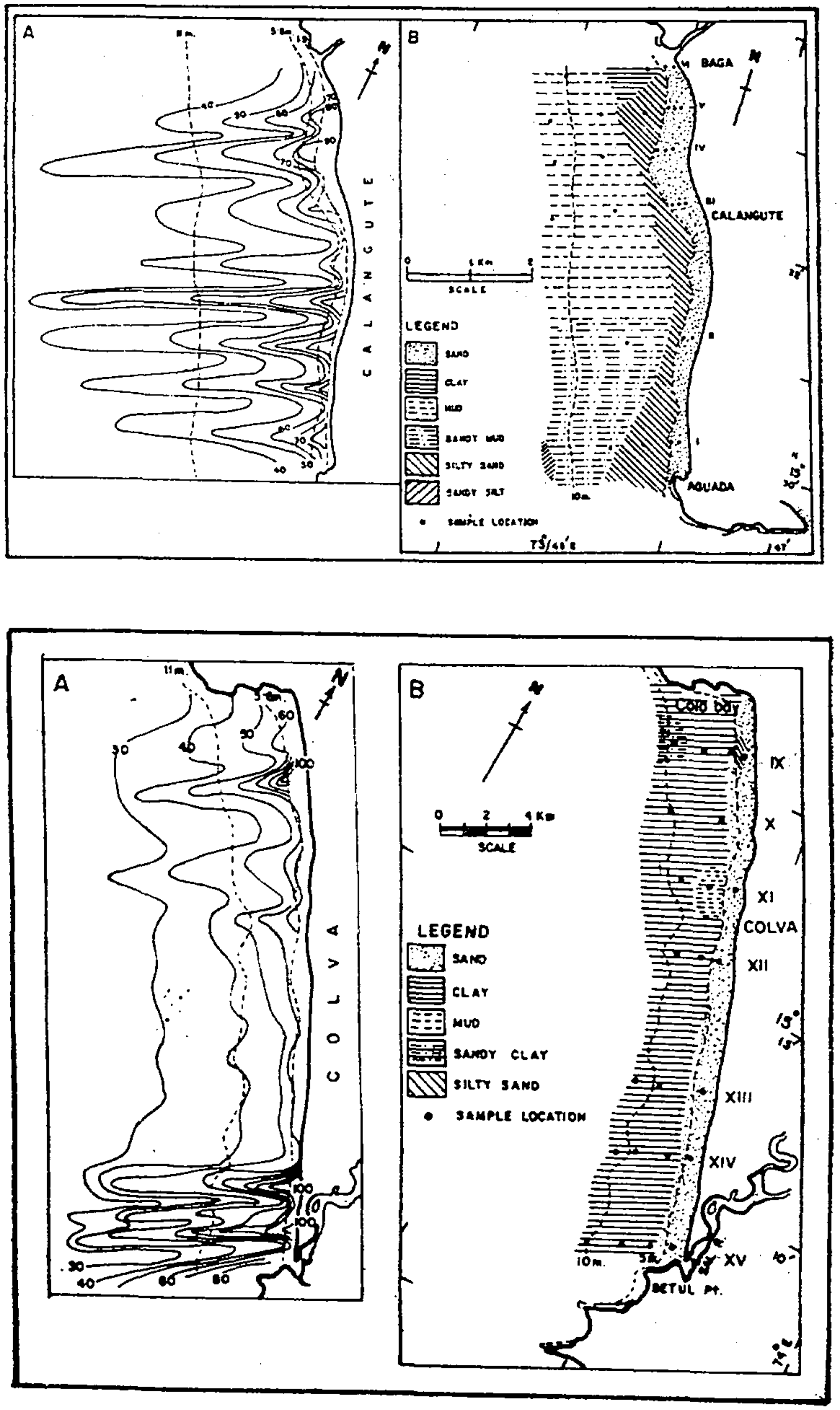
of the near-bottom orbital motions, H is the wave height at the depth of water considered, T is the wave period in sec (approximately constant from beyond the surf zone into deep water), h is the water depth and L is the wave length at the depth of water considered (approximately constant from well beyond the surf zone into deep water) and their distribution patterns are shown in Figs. 4A and 5A. The derived flow patterns are shown in Figs. 2B and 3B.

RESULTS AND DISCUSSION

Based on the drift measurements and the circulation patterns of the waters within the nearshore zone, the basic features of sediment transport are presented below.

Transport along the Kerala coast:

The wave refraction diagrams (Das, Hariharan and Varadachari, 1966; Reddy and Varadachari, 1972) indicate that waves from SW, W and WNW undergo considerable refraction, while those from WSW have nearly normal incidence. As such,waves from WSW, even though predominant, do not seem to have much effect on the beaches. On the other hand, these refraction diagrams indicate northerly flows associated with waves from SW (Fig. 6) and southerly flows for waves from W and WNW. For example south of Purakkadu (Fig. 1B) the wave refraction studies indicate possible differential refraction. For waves from WSW, a diverging flow pattern and hence a probable zone of erosion is indicated. Waves from W and WNW though show a southerly drift,



Figs. 4 and 5. Distribution pattern of (A) near bottom orbital velocities [(cm/sec) D_w = WSW, P_w = 10 sec)] and (B) different sediment types off Calangute (4) and Colva (5).

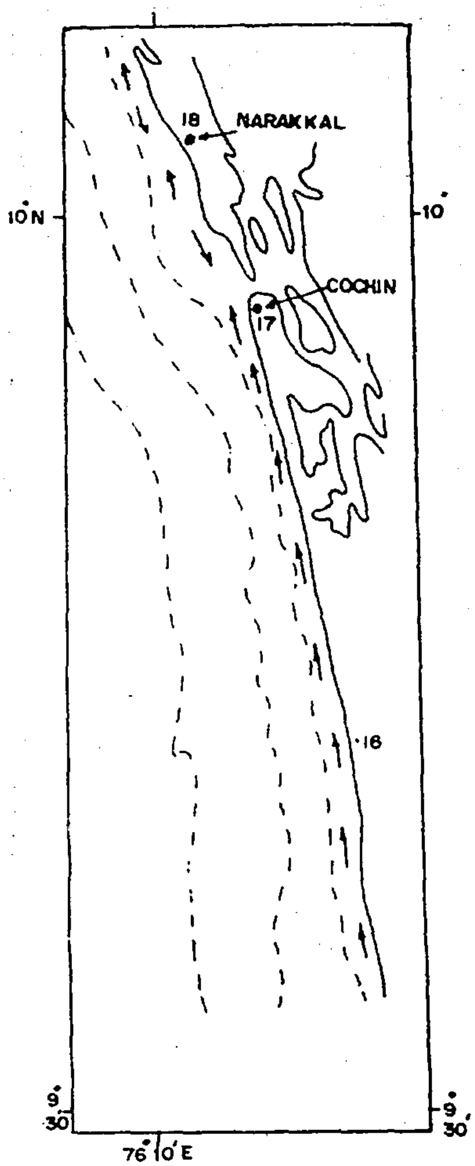


Fig. 6. Littoral current patterns along a part of the Kerala coast (modified from Das, Hariharan and Varadachari, 1966 and Reddy and Varadachari, 1972).

because of large differences in the direction function one may expect a zone of accretion. Waves from these directions may also give rise to meandering flows along the coast.

The data (Table I, columns 7 and 8) show consistently that at Punnappra, except during the transition periods, the direction is southerly whereas at Purakkadu the predominant direction is northerly indicating littoral drift to converge at Nircunnam. This, in fact, has been observed and the beach at this location has shown features of progradation by about 50 m while at the same time, the beaches at Purakkadu and Punnappra have undergone erosion (Murty, 1977).

The observed flows at Thumboli exhibit variation with the changing wave conditions. The littoral currents here are generally alternating. Further north, at Narakkal and Elankannapuzha, the littoral flows show a diverging current pattern. At Elankannapuzha, the drift is mostly southerly whereas further south, at Saudi, the alongshore drift is northerly. At Ochanthuruthu, located between Elankannapuzha and Saudi, the breaker activity is significant throughout the year. Thus the converging flows from Elankannapuzha and Saudi result in an accumulation of material at Ochanthuruthu though a part of this material finds its way into the entrance channel of Cochin harbour.

Transport along the Goa coast:

The Tables II and III indicate the variability in the direction of longshore currents conspicuously. This could be attributed to the width of the surf zone which varies considerably as this region experiences tides having a maximum range of 2.2 m. Further, the width of the continental shelf is much more off Goa. Thus the deep water waves have to travel larger distances while undergoing refraction and it seems more probable that they attain a nearly normal incidence along this part of the coast. Another factor that would contribute to the observed variability in the littoral current direction is the fairly well developed land-sea breeze local air circulation.

Realising the various causes that can lead to the observed variability, nearshore circulation patterns and the wave orbital velocities near the seabed (Figs. 2B and 3B; 4A and 5A) were computed to examine the nature of sediment movement. It was shown experimentally (Vincent, 1958) and theoretically (Longuet-Higgins, 1953) that a mass-transport velocity (U_b) occurs in shallow water near the bed in the direction of wave propagation and is given by

$$U_b = \frac{1.25\ L\ U_{max}}{T} \qquad (2)$$

where U_b is the mass transport velocity, L is the wave length and T is the wave period.

The linear relationship between U_{max} and U_b in the above expression indicates that the pattern of U_{max} presented in Figs. 4A and 5A is an index of the relative distribution pattern of mass transport velocity near the bed in the areas of study. Thus, U_{max} can be used as a general gauge of the bed disturbance capabilities of oscillatory waves (Vincent, 1958). It could be seen from Figs. 2B. and 3B for near normal incidence of waves, the circulation derived from wave height and mass transport distribution results in the formation of alternate converging and diverging flows along the shore zone associated with cellular patterns. These cells appear to be of varying scales from a few metres to more than 200m. Deep-water waves approaching from WNW direction give rise to a meandering flow pattern. The distribution pattern of mass transport velocities show that close to the breaker zone, the velocities increase considerably (Figs. 4A and 5A). These figures are ideal representations and in reality the field of motion would be much more complex when one considers the superimposed local seas on the swell waves. Nevertheless, a comparison of mass transport velocity distribution (Figs. 4A and 5A) with the sediment distribution (Figs. 4B and 5B) indicates that higher percentages of coarse grain-size material ($< 8 \phi$) is found where the Umax values are appreciably high (Veerayya, Murty and Varadachari, 1981).

The sediments that are brought into suspension are trapped in these littoral flows. Depending upon the prevailing wave characteristics and the angle of incidence of waves in the breaker zone the material is likely to be caught in the cells which may go on shifting from place to place as a result of slight variations in the angle of incidence. Under such cases, the sedimentary material would get recirculated locally with constant readjustment of the material. On the other hand, when the angle of incidence is considerable, the beach material shows a tendency to move along the beach in a meandering pattern. As the beaches of this coast are located within promontories and as the available material for longshore flows of this type is limited, bypassing of sediment beyond the promontories is unlikely. In either case, the sedimentary material is neither lost from the beach zone nor gets accumulated. These cellular flows are likely to provide stable conditions for the beaches bordering this coast (Murty, 1977; Veerayya, 1978; Murty, Veerayya and Varadachari, 1982) in constrast to the linear flows along the coast of Kerala which may lead to transportation of beach material to distant places along the coast except at few locations where significant changes in the shoreline stability prevail under the influence of mud banks (Fig. 7); Murty, Sastry and Varadachari (1980)

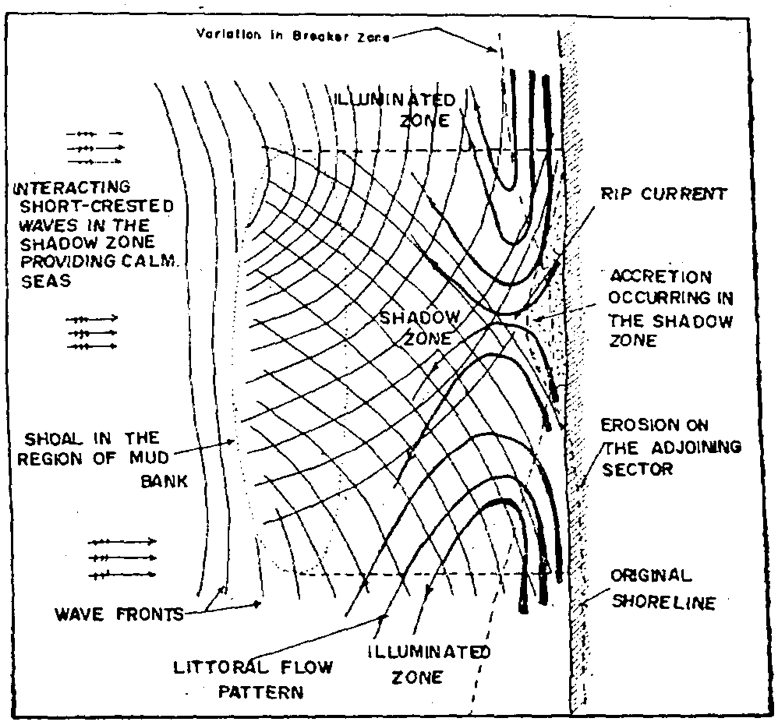


Fig. 7. Schematic diagram showing the effect of shoal in the near-shore regions on the adjoining shoreline.

In the vicinity of river inlets circulation patterns of similar nature probably help in the maintenance of the shoals normally encountered at such outlets, as for example the formation of Aguada bar and its maintenance at the entrance to the river Mandovi (Fig. 8). The implications of the existing circulation in this environment have been explained in detail by Murty, Das, Nair, Veerayya and Varadachari (1976).

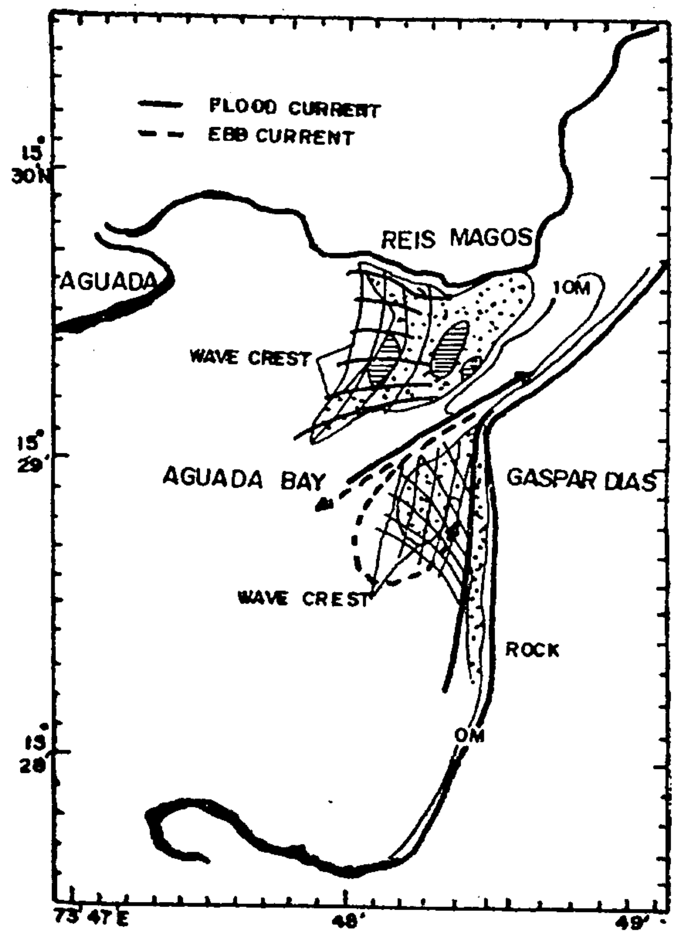


Fig. 8. Schematic representation of waves over shoals and the flood, and the ebb currents around the Aguada bar, Goa (From Murty, Das, Nair, Veerayya and Varadachari, 1976).

While within the surf zone these littoral flows help in the transportation of sediments and affect the stability of shores, beyond the surf zone one finds that the currents are mostly dominated by tides as could be seen from Fig 9 which depicts the float trajectories off Bombay during the months of February, April and May. The impact of the tide and the growing phase of winds and wave set-up as the monsoon conditions set in could be clearly seen from the increased strength of the flows from February to May. These currents may play a major role in the dispersal of pollutants discharged into the nearshore

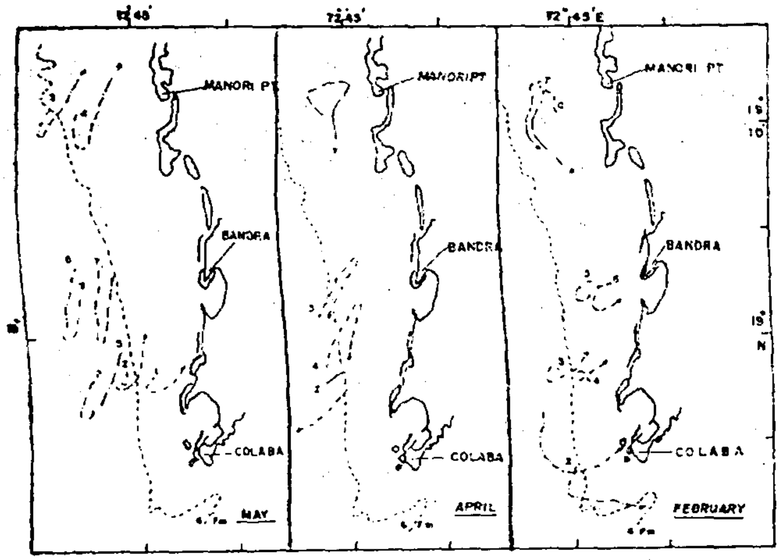


Fig. 9. Float trajectories off Bombay.

environment, though their contribution towards the sediment transport may be less significant, probably due to the nature of bottom sediments prevailing in the area.

ACKNOWLEDGEMENTS

The authors take this opportunity to convey their gratitude to Dr. V.V.R. Varadachari, Director, National Institute of Oceanography, Goa, in whose honour this special volume is being brought out. The results presented here have largely been derived from the investigations carried out during the past one decade under the leadership of Dr. Varadachari and form part of the studies on Coastal Zone Management Programme of the Institute.

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