Journal of Coastal Research | 9 | 4 | 934-943 | Fort Lauderdale, Florida | Fall 1993

Quantification of Changes in Seabed Topography with Special Reference to Hansthal Creek, Gulf of Kachchh, India

S.S. Pattanshetti, Onkar S. Chauhan and K.M. Sivakholundu

National Institute of Oceanography
Dona Paula
Goa 403 004, India

ABSTRACT

PATTANSHETTI, S.S.; CHAUHAN, O.S., and SIVAKHOLUNDU, K.M., 1993. Quantification of changes in seabed topography with special reference to Hansthal Creek, Gulf of Kachchh, India. *Journal of Coastal Research*, 9(4), 934-943. Fort Lauderdale (Florida), ISSN 0749-0208.

Variations in the bathymetry in macrotidal Hansthal Creek between 1984 and 1950, along 14 closely spaced lines, are used to quantify the volumetric changes in seabed topography in terms of erosion/accretion. Two surfaces from the bathymetric data of 1984 and 1950 have been modelled. The profile wise comparison along the transects indicates a dynamic deformation due to distinct alteration in the shoreline and a shift in the channel course. The shoreline has retreated 650 and 450 m on the northern and southern banks respectively.

The studies suggest scouring of horizontally deposited fine sediments (clays deposited in an antecedent depositional phase) in the Hansthal Creek due to existing dynamic equilibrium among (a) influence of physiography in amplifying the tidal range, (b) increased efflux due to contribution through inter-creek water movements, and (c) high magnitude currents. Magnitude of erosion in the creeks, particularly on the flanks, is much more than in the axial channel. The degree of the erosion reduces from the Hansthal Creek mouth to inland (area in the close vicinity of Little Gulf of Kachchh). During the last 34 years about 71.5 × 10^6 m^3 of sediments were eroded from Hansthal Creek, of which 12.9 × 10^6 m^3 were redeposited leading to a net loss of 58.6 × 10^6 m^3 from this creek during the course of the present study. Offshoreward movement of scoured sediments and their redeposition in the outer gulf as a fill in the paleo-channel is observed.

ADDITIONAL INDEX WORDS: *Gulf of Kachchh, Hansthal Creek, shoreline changes, bathymetry, erosion, accretion.*

INTRODUCTION

Macrotidal environments characterized by high energy systems significantly influence the physiography and sedimentary dynamics of an area, and often lead to resuspension and distribution of surficial sediments. These processes are, however, very complex. Migration of large quantities of sediment, particularly in the form of sandwaves and megaripples, and associated physiographic modifications signify the importance and magnitude of this morphodynamic agent (EVAN, 1982; STRIDE, 1982; PALLETIER and MCMULLEN, 1972).

Determination of long term sediment budgets and associated physiographic changes in a macrotidal body are essential to better understand its dynamic characteristics and to provide a data base for future offshore projects such that might include, for example, optimum use of tidal channels for navigation purposes or utilizing the tidal energy for power generation. The Gulf of Kachchh is one of three promising sites in India for tidal power generation. In addition, its tidal channel is used for navigation at several ports on both banks of the Gulf. These considerations require the compilation of a database to assist efforts to determine the influence of the macrotidal regime on the physiographic evolution of the area, sediment dynamics and quantification of sediment exchanged in this complex environment.

The present study utilizes data collected in the Gulf of Kachchh by the National Institute of Oceanography (NIO) during 1984 and compares this with bathymetric data from 1950. This comparison was made by surface modelling and computation of volumetric changes in the study area. An estimation of the changes in bottom topography associated with dynamical factors and volumetric changes that have occurred within the channel, is made. Attempts are made to quantify the shoreline change, shifts in the channel course, as well as estimate the magnitude of erosion and accretion, together with the factors responsible for these changes in Hansthal Creek.

STUDY AREA

The Gulf of Kachchh (Kutch) is a large tidal water body (area 7,325 km^2) situated in a seis-

---

91097 received 30 October 1991; accepted in revision 6 September 1992.

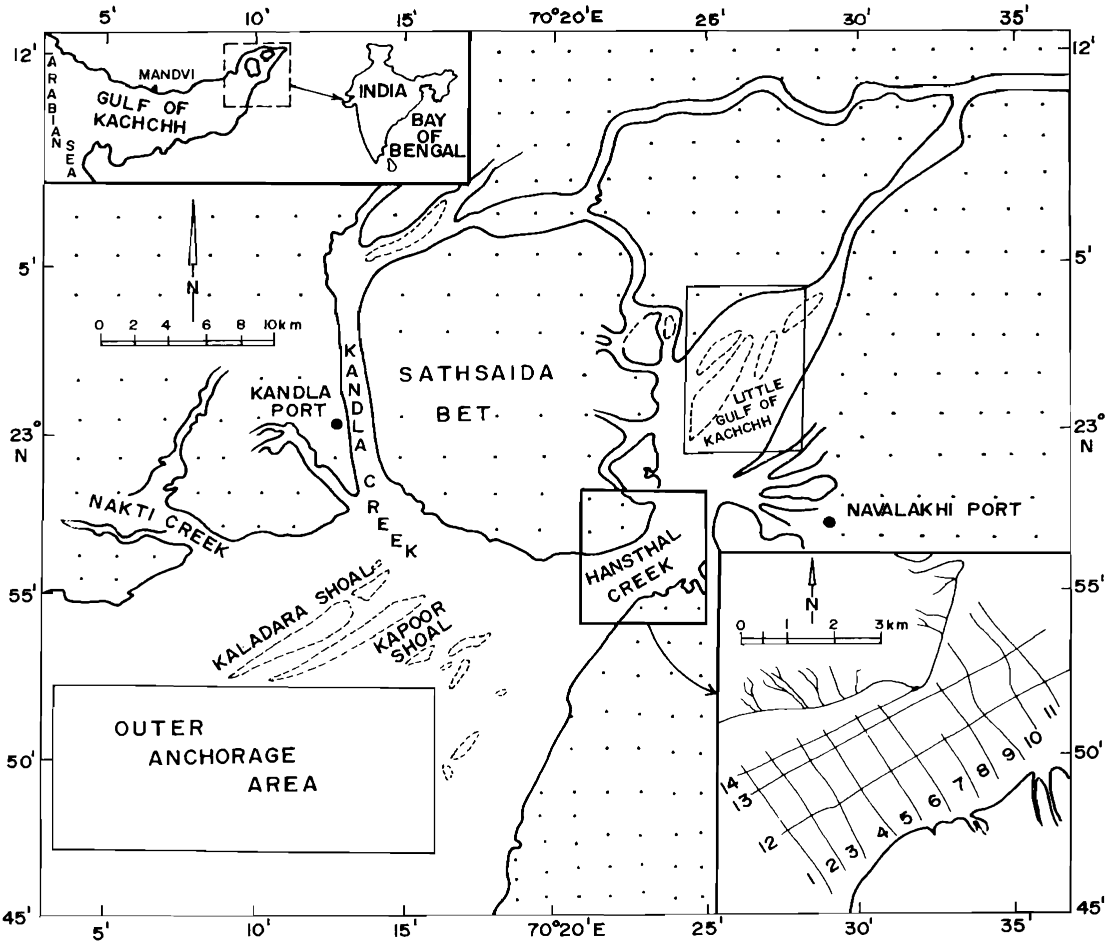

Figure 1. Study area and position of surveyed tracks.

mically active indentation in the Saurashtra Peninsula along the northwest coast of India (Figure 1). The gulf is about 170 km long and 75 km wide at the mouth, and narrows down to 18 km near Kaladara Shoal (Figure 1). At this location, it branches into three major creek systems, the most prominent among them is Hansthal Creek. The Gulf is situated in an arid zone (rainfall 50 cm yr^{-1}) and receives insignificant discharge from short, seasonal, and estuarine rivers (CHAUHAN and VORA, 1990). The detailed geomorphology, sedimentological parameters and shallow subbottom features of the Gulf are described by HASHIMI *et al.* (1978), WAGLE (1979), NAIR *et al.* (1982), RAO (1988), VORA and CHAUHAN (1988) and CHAUHAN and VORA (1990). The entire Gulf is tide dominated, semi-diurnal type with an average tidal range of 2.2 m at the open sea (Gulf mouth) which amplifies to 6.87 m in the study area (SHARMA and DEVASAHAYAM, 1988). These ranges are associated with 2.5–4.5 knot ebb and flood currents (GOKHALE and KANETKAR, 1988).

A current-scoured deep axial channel and indented shoreline on the southern flank are the conspicuous features of the Gulf. Two major and several minor ports are situated in the Gulf and the axial channel is used as navigational channel, particularly for Kandla and Navlakhi Ports situated 150 km inland of the Gulf mouth in the vicinity of the Hansthal Creek.

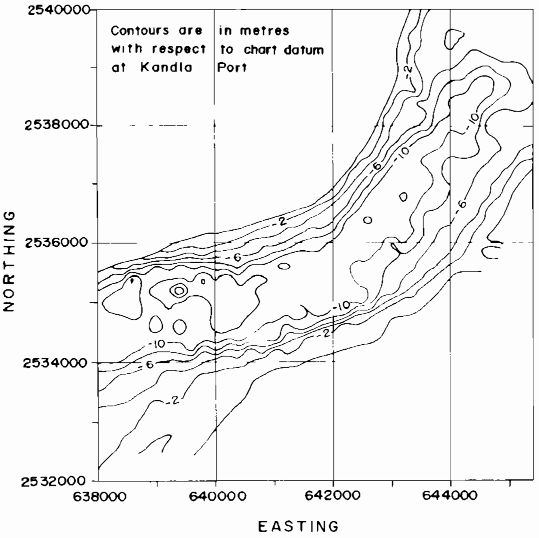

Figure 2. Observed bathymetry of the Hansthal Creek in 1950.

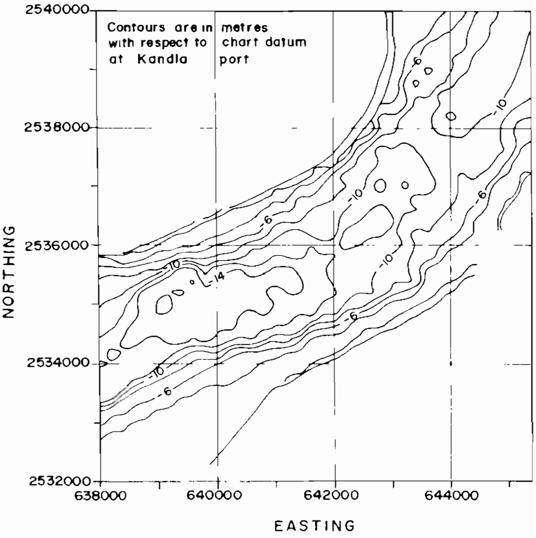

Figure 3. Observed bathymetry of the Hansthal Creek in 1984.

METHODOLOGY

Soundings along 11 transects spaced about 500 m apart, across the creek, and along three longitudinal lines were collected (Figure 1). The depths along the survey tracks were obtained using an Atlas Deso 10 dual frequency (30 and 210 kHz) echosounder. An ORE Mud Profiler (frequency 3.5 kHz), an EG & G side scan sonar, (frequency 1.05 kHz) and an EG & G uniboom (power 0.4 k Joule) were used to delineate sub-bottom features and the plan view along selected lines to supplement sounding data. A Miniranger MRS III radio electronic position-fixing system (accuracy ±3 m) was used to obtain positions along the survey tracks.

The side scan sonar data were applied using slant range corrections. Shallow seismic reflection data were used to determine the seabed characteristics, to measure the depth to the acoustic basement, and to delineate the nature of sediments and the zones of deposition and erosion. Tidal corrections for the sounding data were applied using co-tidal charts of the Survey of India and observed tide at Kandla Port to reduce the bathymetry with respect to chart datum at Kandla Port. Maps were prepared on a scale of 1:25,000.

Bathymetric data of the Hansthal Creek for the year 1950 were extracted from the hydrographic chart published at the Naval Hydrographic Office (NHO) on a scale of 1:25,000. Bathymetry data based upon the 1984 survey were compared with those of the 1950 year chart. Since the data points collected in 1984 and the data available in 1950 charts were randomly distributed, the chart of 1950 was digitized on a high resolution digitizer and the entire area was transformed into a set of XYZ coordinates (X = Easting, Y = Northing and Z = Depth). Similarly, the survey data from 1984 were also made into a similar file containing randomly distributed XYZ coordinates. In addition to this, a zero level contour line adopted from the NHO chart (1981) was also merged to define the channel boundary in the 1984 data set. The random data of both the charts were grided separately with a spacing of 200 m along X and Y axes using the software package SURFER, and Z coordinate (depth) at each grid node was interpolated based on the random XYZ input data. These grid files were then used to create a perspective view and contour map of the study area to determine shoreline and channel geometry modifications and quantification of sediment exchanged between years 1950 and 1984.

RESULTS AND DISCUSSIONS

The bathymetry of the study area in 1984 and 1950 is presented in Figures 2 and 3. Transverse sections showing variations in the seabed of 1984

Table 1. *Physical parameters of the channel during 1984 and 1950. (1950 data is shown within parentheses.)*

Sr. No.	Channel Width Changes in m	Present Depth Against 1950 Reference		Shift of Present H.W.L. as Compared to 1950 (in m)		Gradient of Profile Across Channel Flanks	
		N.B.	S.B.	N.B.	S.B.	N.B.	S.B.
1	3,625 (3,125)	+1.6	+1.1	+25	+325	1:27 (1:23)	1:153 (1:138)
2	3,350 (2,750)	+1.2	+1.5	−190	+375	1:50 (1:57)	1:120 (1:85)
3	2,975 (2,450)	+1.7	+2.5	−150	+425	1:76 (1:80)	1:66 (1:87)
4	2,975 (2,425)	+1.5	+1.7	00	+450	1:91 (1:83)	1:56 (1:33)
5	2,800 (2,400)	+2.7	+1.6	+100	+325	1:106 (1:68)	1:43 (1:44)
6	2,850 (2,425)	+2.6	00	+40	+360	1:76 (1:76)	1:42 (1:44)
7	2,775 (2,375)	+4.3	+1.4	+650	+350	—	1:49 (1:32)
8	2,875 (2,450)	+2.7	—	+500	+200	1:61 (1:57)	—
9	3,125 (2,875)	+3.2	+0.5	+300	+50	1:90 (1:69)	1:125 (1:95)
10	3,175 (2,775)	+2.4	+2.0	+125	+50	1:145 (1:110)	1:164 (1:108)
11	3,350 (2,950)	+0.7	+1.3	+100	+75	1:125 (1:125)	1:94 (1:92)

N.B. = Northern Bank. S.B. = Southern Bank

and 1950, together with the sediment distribution map of the study area, are shown in Figures 4–6.

The picture that emerged on the basis of the above results is that the Hansthal Creek has rugged topography (Figure 5) with parallel horizontal reflectors down to 18 m on the flanks and a rugged deep axial channel (Figure 7b). The sloping flanks show a high gradient (Table 1). The scouring of horizontally deposited clays which is observed at the flanks only (Figure 7b) appears to have produced the present deep axial channel.

The comparison of cross-sections along all transects based upon 1984 and 1950 data shows contrast in the degree of erosion (Figure 5). On profiles 1–3, the flanks have higher gradients (1:30) and the depth of the axial channel is also greater (Table 1). The flanks at profiles 5–11, however, have a much gentler gradient (1:125). The depth of the creek is reduced between profiles 5–11 and is the least at profile 11. The degree of erosion, in general, is observed to be the smallest in the axial part with the flanks showing higher erosion. The process of channel widening is more dominant than deepening leading to loss of clays from the flanks. When the flanks are compared, the northern flank has more erosion than the southern flank (Figure 4); and at a few locations, deposition is also observed (profiles 1, 2, 9 and 14; Figure 4). These results further suggest that erosion of the flanks and the deepening of the channel are more dominant at the mouth of the creek than at the head. These processes attest to the fact that the channel has yet to attain equilibrium under the present hydrodynamic regime.

Substantial changes in the position of the low and high water lines have been observed on both sides of the banks along the Hansthal Creek (Figure 4). Considering the horizontal shift in the shoreline, it is seen that there is a maximum retreat of about 650 m along the northern bank and 450 m along the southern bank. Maximum scouring is, however, recorded on the northern bank close to transect 14 and 7 (Figure 4). Further, the shoreline has accreted as much as 190 m along the northern bank in the western section near transects 2–3 only.

Volume difference in the seabed was determined by superimposing the 1984 and 1950 sea-

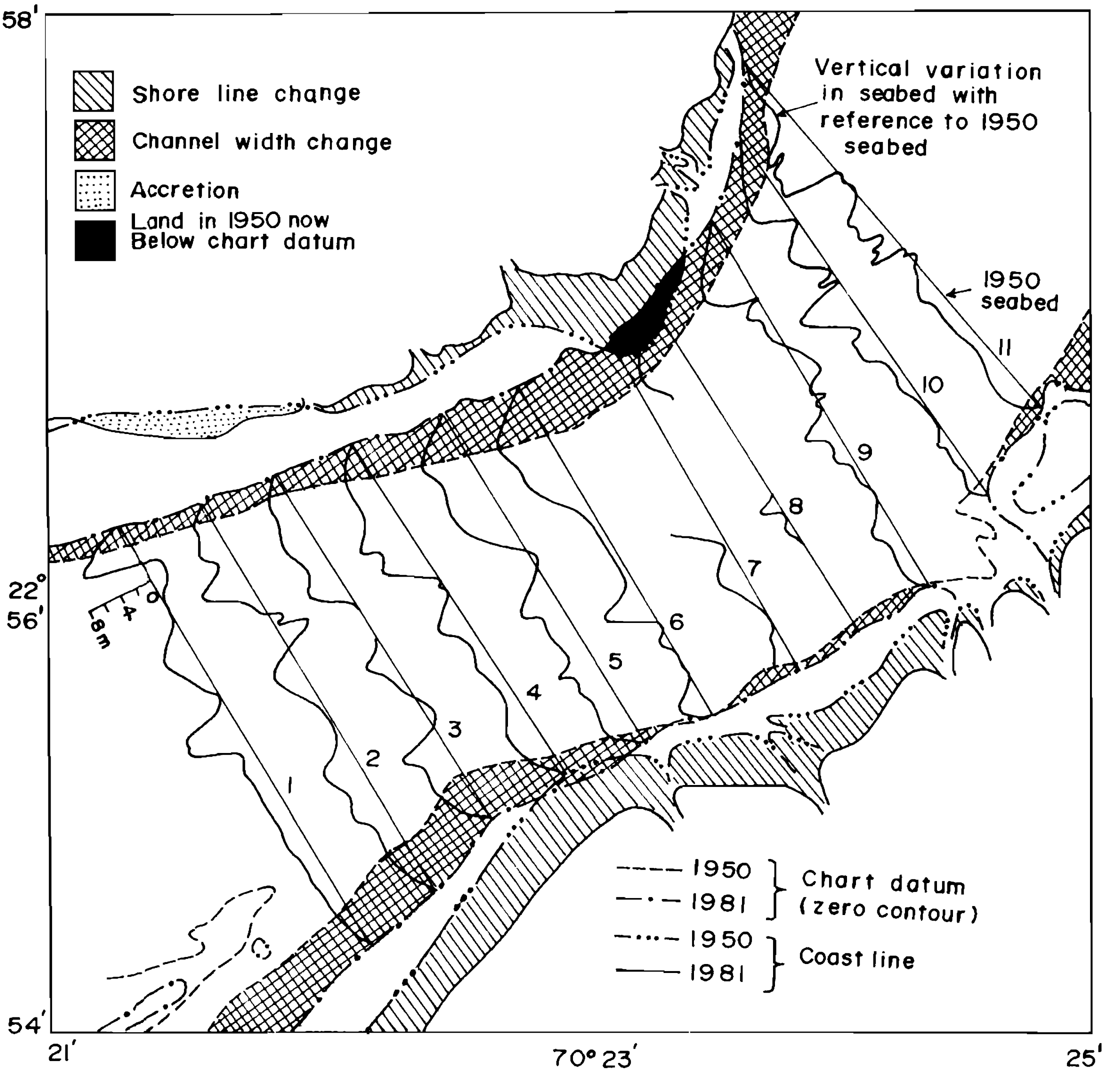

Figure 4. Difference between 1950 and 1984 surfaces showing shoreline and channel width changes, and variations in erosion/accretion in the Hansthal Creek.

floor maps in terms of erosion/accretion. Based upon comparisons of the surfaces of 1950 and 1984, the volume of the seabed eroded is found to be 71.5 × 10^6 m^3 in the Hansthal Creek. These studies also suggest that out of these eroded sediments about 12.9 × 10^6 m^3 have been redeposited inside the study area resulting in a net loss of 58.6 × 10^6 m^3 of sediments during the course of the present study.

Seismic sections from the Little Gulf of Kachchh (inland of the study area) and from the outer anchorage area (offshore of the study area; Figure 7a and c) demonstrate that in the Little Gulf of Kachchh, the physiography is uneven and that four horizontal reflectors (clays) down to 15 m are present. Isolated scouring, cutting through these reflectors, are observed at a number of locations (Figure 7c). The Outer Anchorage Area, on the contrary, has evenly deposited clays with three horizontal and parallel reflectors down to 18 m

(Figure 7a). These reflectors have a maximum thickness in the axial region, but thin down at the flanks. The seabed is characteristically even and no ruggedness is observed. Below these reflectors, an undulating reflector is interpreted as a paleo-channel and overlying sediments seem to be recent fill in this paleo-channel.

For determination of the probable cause and the dynamics of these scoured sediments and their possible redeposition in the study area (an area that is submerged at high tide only and has a low lying land form) necessitated a reevaluation of waves, sea level rise, current and tide data, and high resolution seismic reflection sections. Based upon the deployment of wave rider buoys in the study area, NAYAK *et al.* (1988) reported significant wave heights (H_s) 0.2–1.6 m during March–May. The wave heights were higher in April only (H_s 0.23–2.75 m). As these waves have low energy (following $E = \rho g H^2$) and the study area mostly remains above chart datum and submerged during high tide only, the erosional influences of these waves on the study area appear to be rather insignificant. The reported sea level rise in the study area is 1.22 mm yr^{-1} (SURVEY OF INDIA REPORT, 1992), and is rather insignificant in trying to account for erosion of this magnitude in the creek.

The sub-bottom profiles in Little Gulf of Kachchh (Figure 7c) depict isolated V-shaped cutting extending through horizontally deposited clays. The presence of these clays (down to 15 m) and the nature of the reflectors in this region apparently attest to a low energy environment prior to present phase of erosion. This suggests that the existing erosion in this region is fairly recent and is superimposed over an antecedent depositional phase due to a reversal in the environment of deposition. This led to the dominance of an erosional component under the existing hydrodynamic regime. The outer anchorage area, on the contrary, has even physiography. The thick clays (18 m) deposited over the entire region (Figures 6–7), over the erosional surfaces are observed in this area. This sequence clearly depicts existing dominant depositional phase superimposed over an antecedent erosional phase in this area. Further, the Gulf of Kachchh lies in an arid region and has insignificant sediment input from its small estuarine rivers. The deposition of 18 m thick clays in a 23 km wide channel, in the absence of any sediment input, is intriguing, and probable reasons for this may lie in the contrasting changes in the physiography of the area and magnitude of morphodynamic agents within the study area. An evaluation of the parameters for observed erosion in the Hansthal Creek and deposition in the outer Gulf follows:

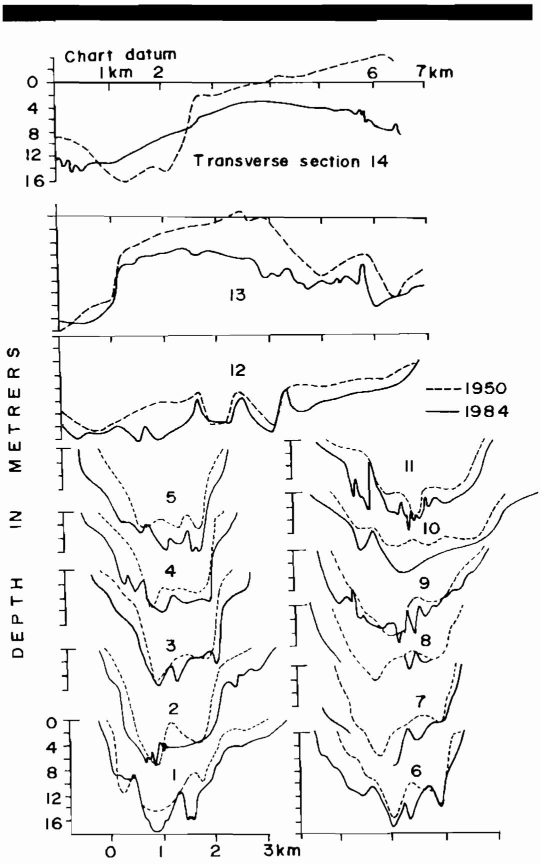

Figure 5. Transverse sections along the transects showing variations in the seabed in 1984 and 1950. For location of the transects see Figure 1.

1. The Hansthal Creek lies close to the junction of three major creek systems (Figure 1). At this point, the broader Gulf narrows down landwards. As the tide propagates from the wider outer gulf to the narrow Hansthal Creek due to width and depth factors in the creek, the tide evidently amplifies during flood tide. The relation between magnitude of current and tidal range in the study area (Figure 8) also suggests an increase in the magnitude of currents (1.67 m sec^{-1}) associated with this increase in the tidal range in the area. These high magnitude currents have high erosive power and

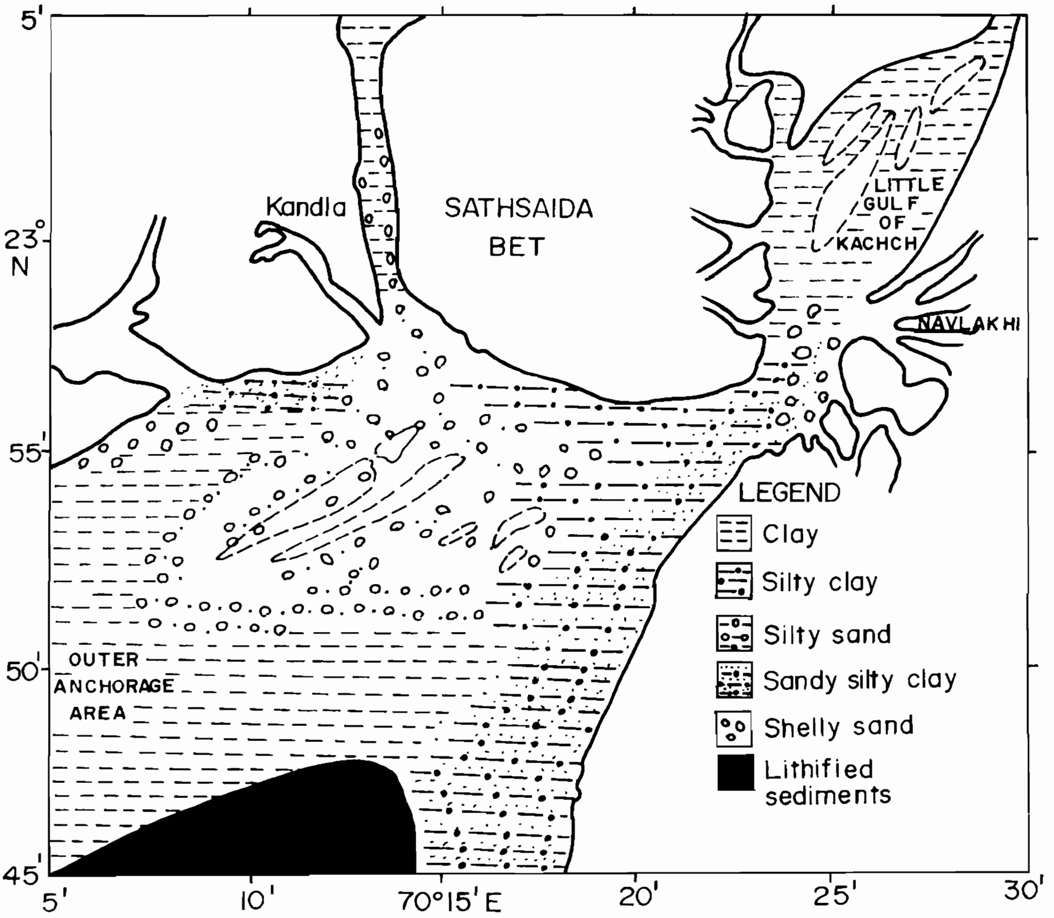

Figure 6. Sediment distribution map of the Hansthal Creek and adjacent area.

scour the sediments within the creeks and the area adjacent to it.

2. The Hansthal Creek which branches out towards the east draws more tidal influx than the Kandla Creek. During flood tide, about 864 × 10^6 m^3 and 320 × 10^6 m^3 of water enters the Hansthal and Kandla Creeks respectively. During the ebb tide, however, 918 × 10^6 m^3 returns through the Hansthal Creek, whereas 280 × 10^6 m^3 water returns from the Kandla Creek (GOKHALE and KANETKAR, 1988). This means, Hansthal Creek receives an additional efflux of water mass (about 40 × 10^6 m^3) through intercreek water exchange which augments the ebb flow. This augmented ebb flow in the Hansthal Creek induces erosion in the creek.
3. The difference between the rise and fall at the mouths of the three creeks and the rise and fall about 27 km up the creeks in the upper Gulf (innermost Gulf) is +3 to 3.5 m (U.S. NAVY, 1942). This difference in level causes the ebb currents in the Hansthal Creek to flow longer than the flood with their duration being about 8 and 4 hours, respectively. The ebb currents in the Hansthal Creek owing to the large shallow area which covers and uncovers attains a rate of 6 to 7 knots at its mouth (U.S. NAVY, 1942). This means the strong ebb flows much longer than the flood in the region with the high magnitude currents.

Thus, it is apparent that Hansthal Creek ex-

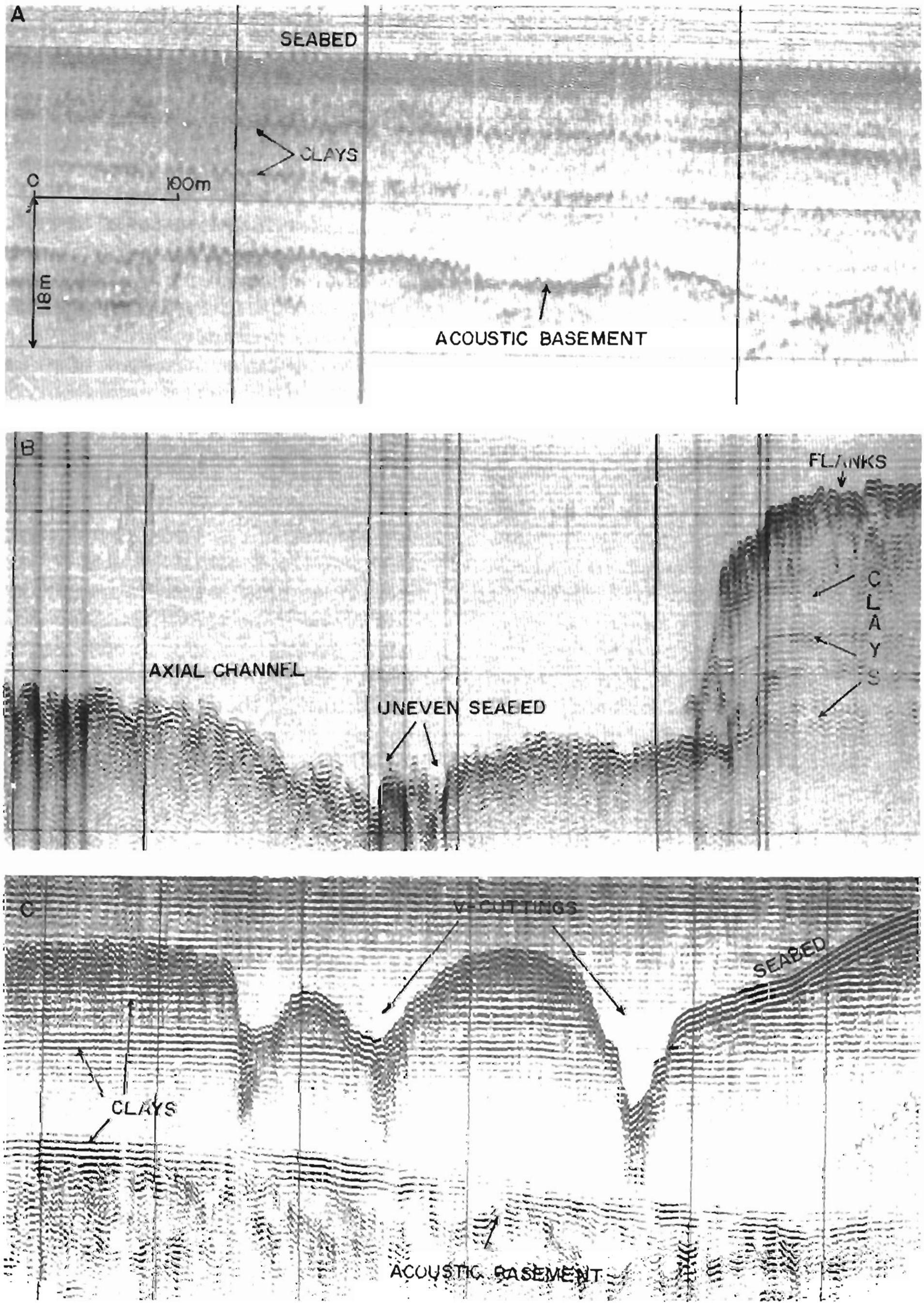

Figure 7. High resolution seismic reflection records (a) from a portion of the outer Gulf depicting horizontally bedded clays over undulating acoustic basement; (b) uneven bed in the Hansthal Creek resulting due to scouring of horizontally bedded clays at the flanks; (c) the Little Gulf of Kachchh with isolated scouring extending through parallel reflectors (clays).

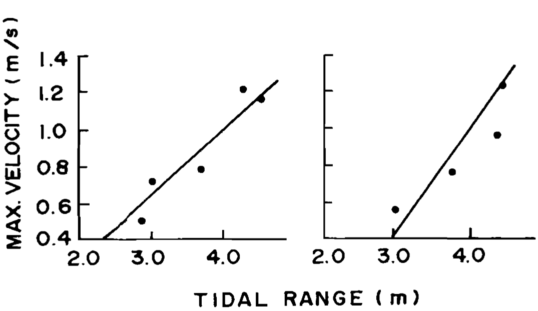

Figure 8. Relationship between current speed and tidal range for the study area (modified from GOKHALE and KANETKAR, 1988).

periences stronger currents, higher tidal range and higher efflux due to inter creek transfer of water mass and amplification of tide due to physiography and associated high magnitude currents. All the above factors suggest an erosion-dominant environment in the creek, and are reflected in the scouring of sediments from the flanks. The channel geometry of Hansthal Creek (Figures 5 and 7) also suggests that the channel development is in an advanced stage, and the widening of the channel is more dominant than the deepening. Due to this, evenly deposited sediments (clays) are transformed into rugged topography (Figures 4 and 5) and huge amounts of sediments are scoured (of the order of 71.5 × 10^6 m^3) from this creek.

The observed depositional phase at the outer Gulf in the absence of any sediment input to area is apparently due to deposition of these scoured sediments in the outer Gulf region. The deposition of the sediments in this area scoured from the creeks appears to be due to changes in the magnitude of tide and associated currents and a physiographic factor. Due to change in the physiography from the narrow creek (width 3 km) to the wider outer Gulf (18–75 km wide) during ebb, the flow emanates from the narrow creeks and fans out to the wider outer Gulf. This fanning out leads to a reduction in the magnitude of the tide in the outer Gulf (tidal range 6.87 m in the Hansthal Creek and 3.67 m in the outer Gulf at Mandvi) (SHARMA and DEVASAHAYAM, 1988). Also, there is a two-fold reduction in the magnitude of currents which is associated with a reduction in the tidal range (Figure 8), and is related to retardation in speed (4–7 knots hr^{-1} compared to 2–3 knots hr^{-1} in the outer Gulf) (U.S. NAVY, 1942) due to a fanning out of the flow. As these ebb flows are highly charged within the sediments scoured from within the creeks, the retardation in the magnitude of currents and tide lead to deposition of these sediments in the outer Gulf region. The observed 18 m thick clays and an even physiography of this area (Figures 6 and 7a) are supportive of our above contention. The observed offshoreward migration of sediments in wave forms in an earlier study of creeks in the Gulf of Kachchh (CHAUHAN and VORA, 1990) also confirm our proposed offshoreward migration. Studies by EVAN (1982) from the Bay of Fundy and FRIHY *et al.* (1991) from the Nile Delta suggesting movement of sediments in rhythmic wave forms in macrotidal environments are in line with our proposition of large scale mass movements and sediment redistribution in the macrotidal environment.

Variations in the magnitude of erosion within the study area, evidenced by the variations in the gradient of the flanks at profiles 1–3 and 6–11 (Figure 5) and the reduced intensity of erosion inland of the Hansthal Creek (isolated channels scouring extending through underlying layers in the Little Gulf of Kachchh), compared to a deep axial channel in the Hansthal Creek (Figure 7b and c) also attest to the contrast in the intensity of erosion within the creeks. The ebb flows which are gradually augmented due to (a) the contribution of efflux from inter creek water mass movements from Kandla Creek system, through the Little Gulf of Kachchh, to the Hansthal Creek mouth (40 × 10^6 m^3), and (b) a 3 to 3.5 m water level difference in the upper Gulf. These parameters suggest a gradual increase in the erosive power from the inner most Gulf, *e.g.*, from the Little Gulf of Kachchh to the Hansthal Creek, and explain the variations in erosion within the creek.

CONCLUSIONS

Based upon the comparison of two bathymetric charts from 1950 and 1984, it has become possible to quantify the difference in volume of the seafloors in the study area. These results clearly show the widened channel and volumetric variations at different locations in the channel. Over a period of 34 years, net shoreline retreat, shift of contours, and a sharp increase in erosion at the flanks of channel were detected with a net loss of 58.6 × 10^6 m^3 of sediments.

The axial part of the creek was deep during

1950 and, at present, deposition is observed at only a few locations near the western part of the northern bank. This suggests that the channel development in the Hansthal Creek is in an advanced stage and that the widening of the channel is more dominant than the deepening.

The eroded sediments from the creeks are getting transported offshoreward (Outer Anchorage Area). The presence of shoals and the depositions of recent origin as thick reflectors (18 m in 18–23 km wide gulf) suggest deposition of this eroded material in this area.

Since there is no availability of a hard bottom down to 18 m depth (Figure 7a and c), the existing erosional trend may continue until channel geometry becomes stabilized in the landwards portion and the flow pattern becomes more moderate.

ACKNOWLEDGEMENTS

The authors are thankful to the Director, N.I.O., Goa, for providing the facilities. Thanks are also due to Dr. R.R. Nair and Dr. P. Chandramohan for comments on the manuscript. Thanks are also due to the anonymous referee, Dr. Charles W. Finkl (Jr.) and to Dr. Donald Forbes for improvements to the manuscript.

LITERATURE CITED

CHAUHAN, O.S. and VORA, K.H., 1990. Reflection seismic studies in the macrotidal Gulf of Kachchh India: Evidence of physiographic evolution. *Continental Shelf Research*, 10, 385–396.

EVAN, C.D.R., 1982. Surficial Sediments of the Inner Bristol Channel and Severn Estuary. *Severn Barrage.* London: Thomas Telferd, pp. 35–43.

FRIHY Y, O.E.; NASAR, S.M.; AHMED, M.H., and ELRAEY, M., 1991. Temporal shoreline and bottom changes of the inner continental shelf off the Nile Delta, Egypt. *Journal of Coastal Research,* 7, 465–475.

GOKHALE, D.P. and KANETKAR, C.N., 1988. Field data collection for currents, sediment and salinity for Kachchh Tidal Power Project. *Proceedings of the International Symposium on Tidal Power Development,* pp. 9–12.

HASHIMI, N.H.; NAIR, R.R., and KIDWAI, R.M., 1978. Sediments of the Gulf of Kachchh—A high energy tide dominated environment. *Indian Journal of Marine Sciences,* 7, 1–7.

NAYAK, B.U.; MANDAL, S., and CHANDRAMOHAN, P., 1988. Wave studies for tidal power project of Gulf of Kachchh. *Proceedings of the International Symposium on Tidal Power Development,* pp. 39–43.

NAIR, R.R.; HASHIMI, N.H., and RAO, P.C., 1982. On the possibility of high velocity tidal stream as dynamic barrier to the longshore transport. *Marine Geology,* 47, 77–86.

PALLETIER, B.R. and MCMULLEN, R.M., 1972. Sedimentation patterns in Bay of Fundy and Minas Basin. *In:* GRAY, T.J. and GASHUS, O.K. (eds.), *Tidal Power.* New York: Plenum, pp. 153–187.

RAO, D.G., 1988. A shallow seismic reflection study of Gulf of Kutch—Observation on its structural evolution. *Marine Geology,* 82, 277–283.

SHARMA, H.R. and DEVASAHAYAM, R., 1988. Field Investigations for Kachchh Tidal Power Project. *Proceedings of the International Symposium on Tidal Power Development* (New Delhi), pp. 13–19.

STRIDE, A.H., 1982. *Offshore Sand Process and Deposits.* New York: Chapman and Hill, 222p.

UNITED STATES NAVY DEPARTMENT, HYDROGRAPHIC OFFICE, 1942. *Sailing Directions for the West Coast of India—Third Edition.* Washington, D.C.

VORA, K.H. and CHAUHAN, O.S., 1988. Surficial geology of the environs of the Kachchh Tidal Power Project India. *Proceedings of the International Symposium on Tidal Power Development* (New Delhi), pp. 29–33.

WAGLE, B.G., 1979. Geomorphology of the Gulf of Kachchh. *Indian Journal of Marine Sciences,* 8, 123–136.