Surf zone dynamics along the south Karnataka coast between Bhatkal and Ullal, west coast of India

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Field study between Bhatkal and Ullal from June 1989 to May 1990 indicated that the beaches along this segment of coastline are essentially stable showing only seasonal fluctuations. Beaches after being subjected to erosional phase during southwest monsoon season, were found to regain their profiles by January or February. The erosion observed at the river mouths can be attributed to the readjustment of the river mouths during monsoon season when the river flow was highest. Longshore currents were stronger in June, and relatively low and steady during the rest of the year. Coast between Padubidri and Ullal experienced relatively stronger longshore currents than the coast between Maravanthe and Malpe. Longshore sediment transport rate was relatively low at Maravanthe and Ullal compared to Malpe and Padubidri.

The waves while propagating towards the coast would steepen and break on the shore, expending their energy. The hydrodynamic process in the surf zone is quite complex due to wave breaking, presence of longshore and onshore-offshore currents, littoral sediment transport, erosion/deposition of beach sediments, etc. Responding to the various forces acting in the surf zone, the coast re-adjusts itself and tends to be in a dynamic equilibrium. Longshore current plays a predominant role in transporting the sediment in the surf zone. The longshore current velocity varies across the surf zone, attaining the maximum value close to the wave breaking point[1-3]. For practical purposes, the average longshore current measured in the surf zone would be sufficient for estimating the sediment transport rate. The longshore sediment transport is in general estimated using the semi-empirical equations, which are mostly based on laboratory data[4]. The sediment transport equation calibrated with the field data would however, be more reliable for field application. In the present study, various parameters in the surf zone have been measured for 1 y along the coast between Bhatkal and Ullal, and they are discussed in relation to various coastal processes.

Study area

Coastline between Bhatkal and Ullal is a stretch of open beach, intermittently interrupted by the west flowing rivers (Fig.1). The continental shelf is relatively wide, varying from 120 km off Bhatkal to 75 km off Mangalore. The surficial seabed sediments[5] consist of clayey silt till 50 m water depth, sand between 50 and 100 m water depth, and silty sand between 100 and 200 m depths. Beach erosion is observed almost at all estuarine mouths and sea walls have been constructed along these stretches. The

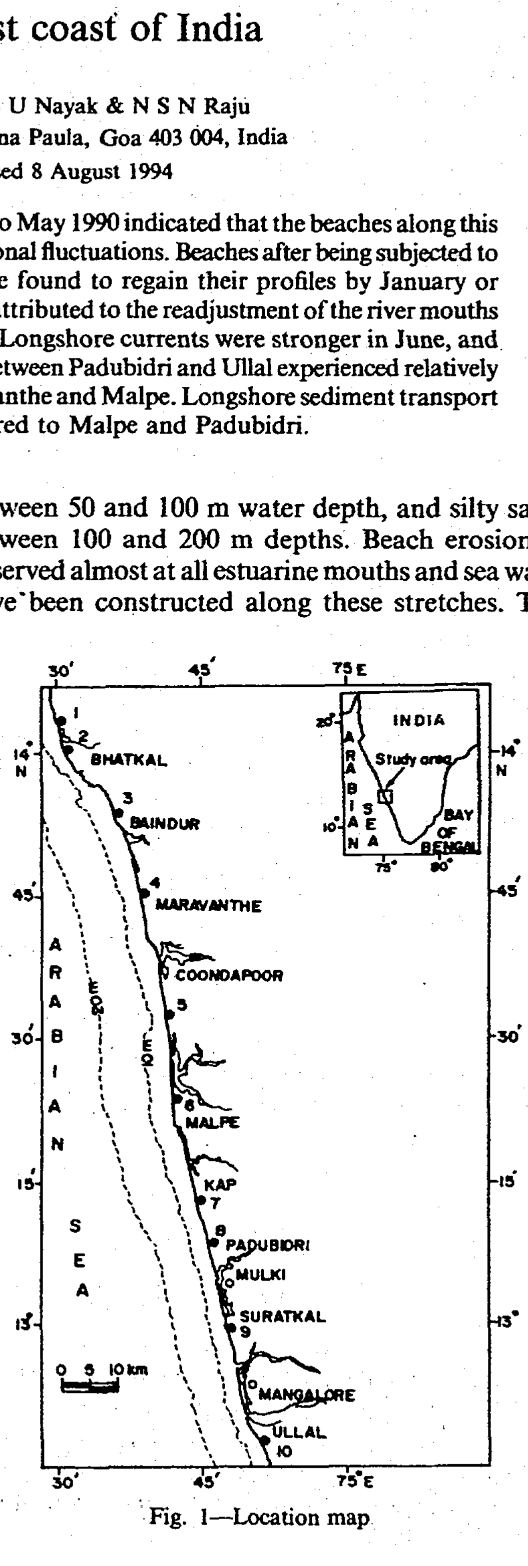

Fig. 1—Location map

study region is dominated by southwest monsoon during June to September. According to the ship observed wave data[6], the swells predominantly vary between 1 and 3.5 m during June to September, and 0.5 and 1 m during October to January. The swell periods predominantly vary between 5 and 8 sec during June to September, and between 5 and 12 sec during October to May. During June to August, the monsoon waves approach the coast predominanty from the sector between southwest and northwest. The tides in this region are characterized by a mixed type, predominantly semi-diurnal. Based on the predicted tide for New Mangalore Port, the average tidal range is about 0.25-1.54 m.

Materials and Methods

Ten base stations were established along the shoreline between Bhatkal and Ullal (Fig.1). Monthly (June 1989 to May 1990) changes in beach levels were measured at each station at every 5 m interval along a transect from backshore dune, seaward till 1 m water depth during the low tide. Surveyor's dumpy level and a graduated staff were used for measuring the beach levels. Observations on breaking wave characteristics, longshore current velocities and directions were made daily for 1 y at sts 4, 6, 8 and 10. Heights of 10 consecutive breakers were visually measured and the average of them was noted as significant wave height at breaking. Total time required for 10 waves to break was noted using a stop watch and the average was considered as breaking wave period. Longshore current velocity and direction were measured by releasing neutrally buoyant floats in the surf zone and by measuring the distance covered in 2 minutes. Beach sediment samples were collected at each station every month close to mid tide line and the sieve analysis was carried out to study the grain size distribution. Based on the data collected the longshore sediment transport rates at sts 4, 6, 8 and 10 were computed using the Walton's equation[7],

$$Q = \frac{1290\ \rho\ g\ H_b\ W\ v\ C_f}{0.78\ (5\ \pi/2)\ (v/v_0)}$$

where, Q is annual longshore sediment transport rate in $m^3.y^{-1}$; $\rho = 1025\ kg.m^{-3}$; $g = 9.81\ m.sec^{-2}$; $C_f = 0.01$; H_b = breaking wave height in m; W = surf zone width in m; v = longshore current velocity in $m.sec^{-1}$; and (v/v_0) = theoretical dimensionless longshore current velocity[8].

Results and Discussion

Beach studies — Typical variations in monthly beach levels at sts 1 and 6 are shown in Fig.2. Beach level variations at other stations are presented earlier[9]. The trend in beach level changes indicates the influence of seasonal erosion and accretion conditions prevailing during the southwest monsoon and fair weather periods. Relative changes in the volume of sediment per metre length of the beach up to 1 m water depth at each station were estimated and are presented in Fig.3. Volume changes per metre length of the beach over an annual cycle were estimated as 138, 55, 80, 115, 115, 87, 49, 151, 173 and 103 m^3 from sts 1 to 10 respectively. The beach levels were lowest in November at sts 1, 2, 3 and 7, in October at st. 4, in August at st 5, and in July at sts 6, 8-10. Highest beach levels were observed in January at sts 2 and 4, in February at sts 1, 3, and 5 to 10. It is interesting to note that though it is expected for the west coast to reach lowest beach levels during the southwest monsoon period, the beaches near sts 1 to 4, and at st 7 were found to continue their erosion processes during the northeast monsoon period also. The variation of beach levels over an annual cycle showed that the beaches mostly recovered their original profiles at all places thereby indicating that they are stable.

Maximum changes in beach width and beach elevation during the annual beach process cycle at

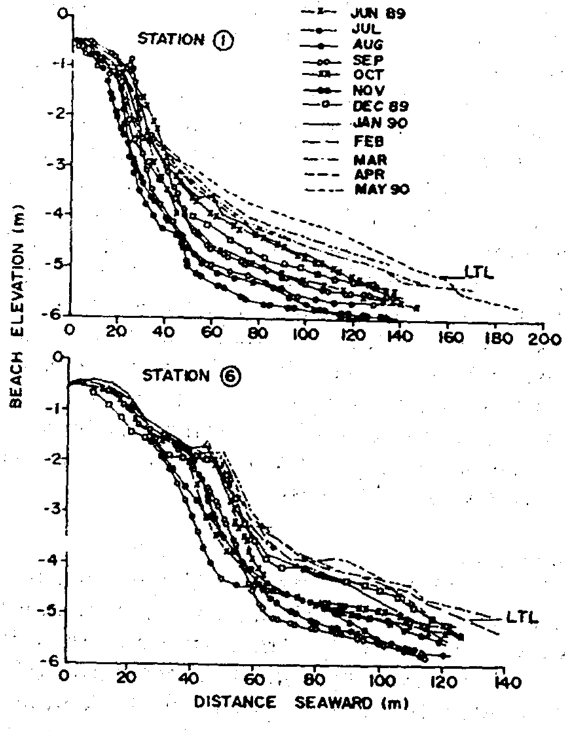

Fig. 2—Beach level variation at sts 1 and 6

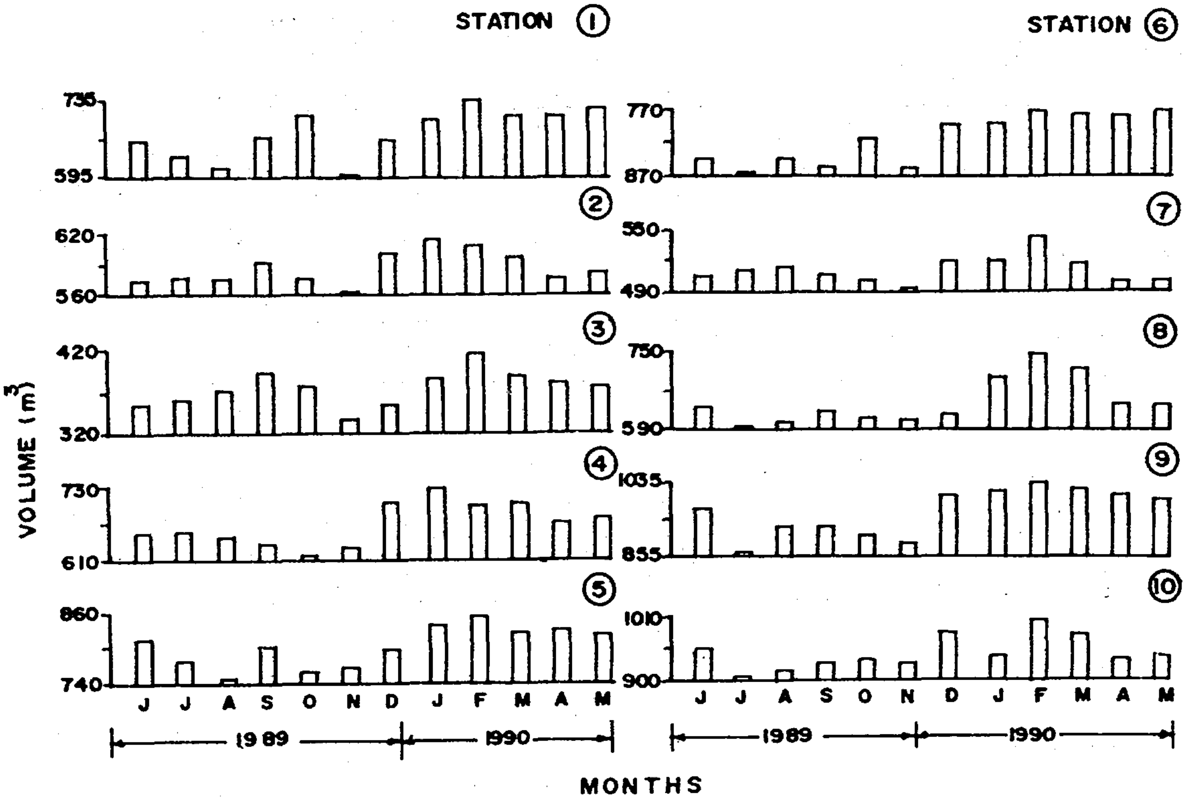

Fig. 3—Monthly changes in beach sediment volume

each station were estimated and presented in Table 1. Maximum change in the beach width of the order 80 m at st. 1 and minimum change of 10 m at st. 4 were observed. Maximum vertical change in beach level was about 3.1 m at st. 9 and the minimum was about 1.3 m at st. 2.

Longshore current — Daily variations of longshore current velocity and direction measured at sts 4, 6, 8 and 10 are shown in Fig. 4. At sts. 4 (Maravanthe), the average longshore current velsocity persisted at about 0.3 $m.sec^{-1}$ in June and between 0.1 and 0.15 $m.sec^{-1}$ during the rest of the year. At st. 6 (Malpe), it persisted at around 0.25 $m.sec^{-1}$ in June, and around 0.1 $m.sec^{-1}$ during the rest of the year. At st. 8 (Padubidri), the longshore current velocity prevailed at around 0.5 $m.sec^{-1}$ in June, 0.4 $m.sec^{-1}$ in July and 0.25 $m.sec^{-1}$ rest of the year. At st. 10 (Ullal), it remained around 0.4 $m.sec^{-1}$ in June and 0.25 $m.sec^{-1}$ in the rest of the year. It is noticed that relatively strong longshore currents prevailed in June along the entire study region. Further, throughout the study period, relatively stronger currents prevailed at sts 8 and 10 when compared to those at sts 4 and 6.

Table 1—Changes in beach width and elevation

St. no.	Beach width (m)	Beach elevation (m)
1	80	1.8
2	55	1.3
3	35	1.9
4	10	1.5
5	20	2.5
6	40	2.5
7	20	1.8
8	30	1.9
9	40	3.1
10	30	3.0

At st 4, longshore current was predominantly northward in April, June, and September, and it was southward in May and August. The direction was variable on either side during the rest of the year. At st 6, the longshore current was northward during June, July, and September to December, and southward during the rest of the year. At st. 8, the direction of longshore current was northward from September to February and southward during the rest of the year.

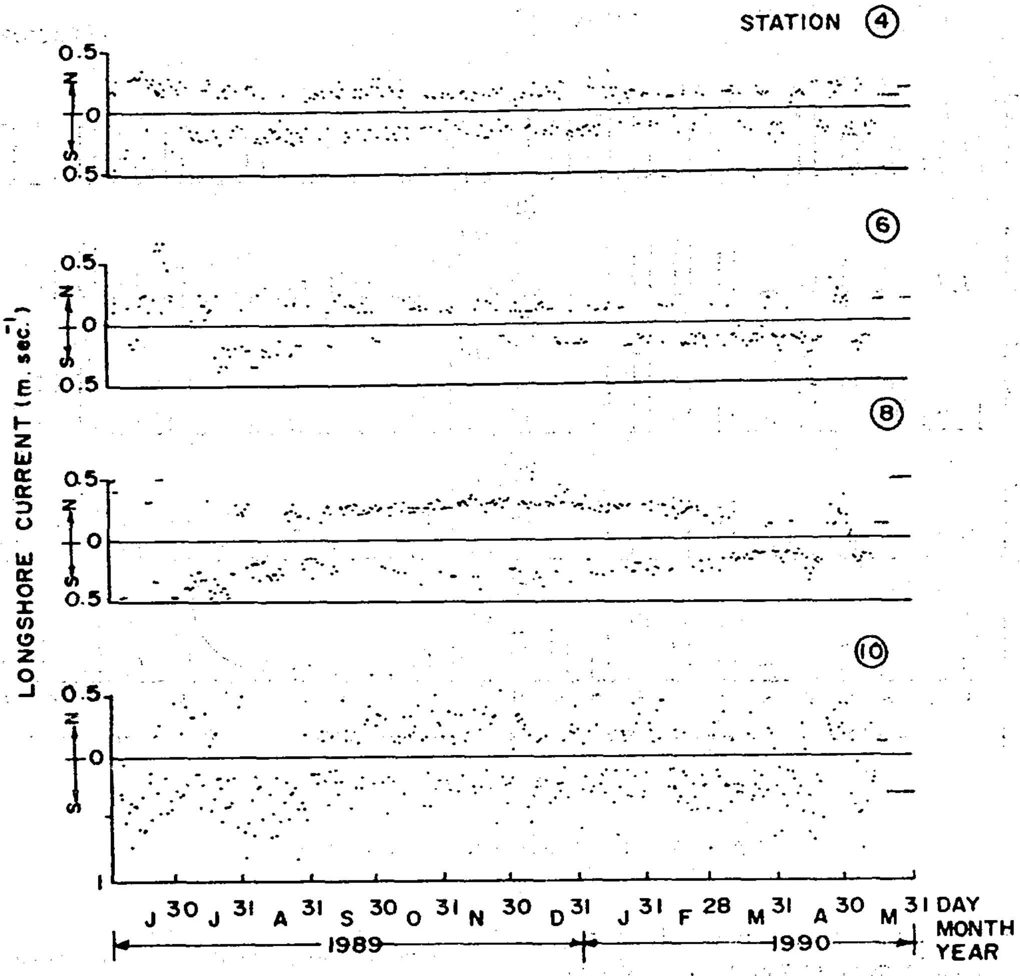

Fig. 4—Daily variation of longshore current velocity and direction

At st. 10, the longshore current was northward from October to December and southward during the rest of the year. It is observed that at sts 8 and 10, during the northeast monsoon period, the longshore current direction was predominantly north, and during southwest monsoon and fair weather period, it was southward. Station 6 showed northerly current during southwest monsoon and northeast monsoon periods. The direction was quite inconsistent at st. 4. The study shows that the distribution pattern of longshore current direction is not uniform along the study region. The difference in the distribution of longshore current direction would influence the redistribution of littoral sediment within the study region, leading to stability of the coast over an annual cycle.

Breaker characteristics — Daily variation of breaking wave height, wave period and surf zone width measured at sts 4, 6, 8 and 10 are presented in Figs 5 and 6. At sts 4, 6 and 8, the average breaking wave height persisted at about 1 m during June and July, and at about 0.6 m during the rest of the year. At st. 10 the breaking wave height persisted at about 0.6 m in June and July, and 0.4 m during the rest of the year. Wave height were higher at st.4 and were lower at st. 10. Wave period persisted between 4 and 8 sec at sts 4 and 6, and 8-10 sec at sts 8 and 10. The surf zone width was larger during June to August being about 25 m at sts 4 and 10, 40 m at st. 6, and 100 m at st. 8. During the rest of the year, the surf zone width was only about 10 m at st. 4 and 10, 20 m at st. 6 and 50 m at st. 8.

Longshore sediment transport — The longshore sediment transport rates estimated using Walton's equation at sts 4, 6, 8 and 10 are presented in Table 2.

At Maravanthe (st.4), longshore sediment transport rate was relatively high, about 0.22×10^5 $m^3.month^{-1}$ in June, and low, $< 0.01 \times 10^5$ $m^3.month^{-1}$ during the rest of the year. Sediment transport direction was always towards north except

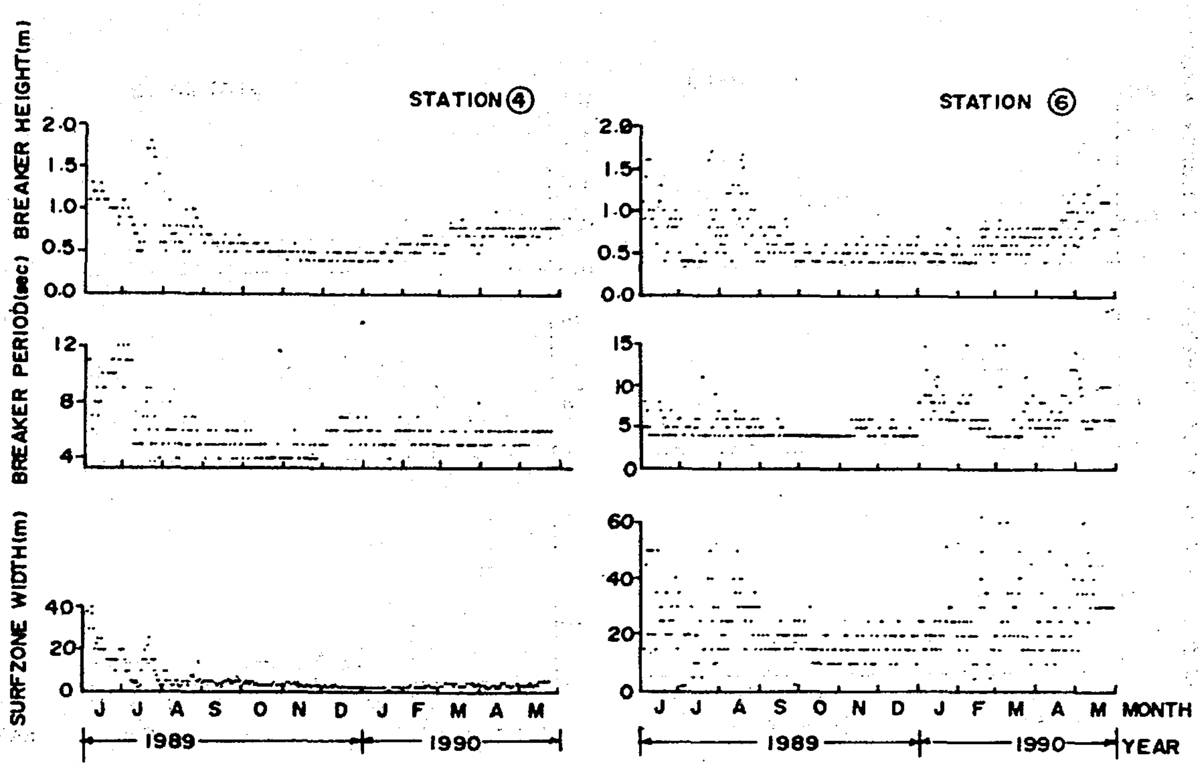

Fig. 5—Variation of breaker height, breaker period and surf zone width at sts 4 and 6

Table 2—Longshore sediment transport rate (m³.month⁻¹)

Month	Station no.			
	4	6	8	10
June 1989	22836	37125	−8801	−11763
July	2523	−12321	−180537	−9325
Aug.	−1477	−14768	−25173	−12050
Sept.	1059	4262	16879	−199
Oct.	116	1039	18544	698
Nov.	217	2152	36388	356
Dec.	81	1657	42274	−160
Jan. 1990	177	−2247	22310	−699
Feb.	12	−4206	11659	−408
March	266	−10755	−9374	−1136
April	316	−1171	−1475	−717
May	−755	−14938	−12053	−764
Net ($m^3.y^{-1}$)	25372	−14169	−89358	−36165
Gross ($m^3.y^{-1}$)	29836	106641	385469	38273

(−) transport towards south; (+) transport towards north

in May and August. At Malpe (st.6), sediment transport rate was relatively high, about 0.37 × 10^5 $m^3.month^{-1}$ in June and < 0.02 × 10^5 $m^3.month^{-1}$ during October to January and April. The sediment transport direction was northward in June and September to December, and southward during the rest of the year. Padubidri (st.8) showed relatively high rate of sediment transport during the southwest monsoon period, when compared to that at sts 4, 6 and 10. Maximum transport of 1.8 × 10^5 $m^3.month^{-1}$ was observed in July and a minimum of 0.01 × 10^5 $m^3.month^{-1}$ in April. Sediment transport direction was southward from March to August and northward during the rest of the year. Low rate of longshore sediment transport was observed at Ullal (st.10), highest being about 0.12 × 10^5 $m^3.month^{-1}$ only during June and August. Sediment transport was southward from December to September, and northward in October and November.

Annual net transport was 0.25 × 10^5, 0.14 × 10^5, 0.89 × 10^5 and 0.36 × 10^5 $m^3.y^{-1}$ at sts 4, 6, 8 and 10 respectively. Annual net transport was northward at st.4, and southward at sts 6, 8 and 10. Annual gross transport ($m^3.y^{-1}$) was relatively high, about 3.85 × 10^5 at sts. 8 and 1.06 × 10^5 at sts. 6 and relatively low, about 0.3 × 10^5 and 0.38 × 10^5 at sts 4 and 10 respectively.

Sediment size distribution — Chemical analysis of beach sediment collected on July 1989 shows that the percent of calcareous sediments were 11, 4, 17, 13, 6, 7, 13, 9, 3 and 1 by weight at sts 1 to 10 respectively.

Variation of median size (d_{50}) of beach sediment at each station, in different months is shown in Table 3.

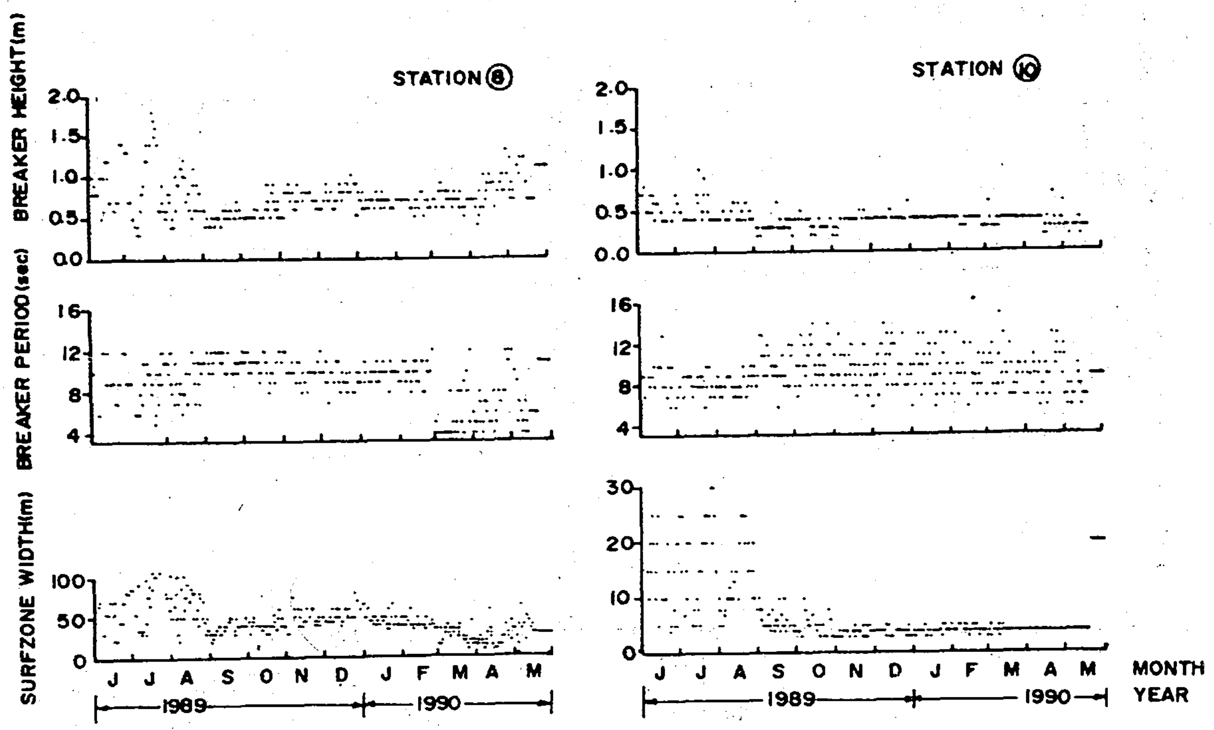

Fig. 6—Variation of breaker height, breaker period and surf zone width at sts 8 and 10

Table 3—Median size of beach sediments (mm)

St no.	1989							1990				
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
1	0.0600	0.1978	0.1633	0.2774	0.2488	0.1063	0.0691	0.0748	0.0692	0.0676	0.0769	0.0809
2	0.1300	0.2298	0.2583	0.2651	0.2555	0.2476	0.2148	0.2865	0.0748	0.0727	0.0586	0.0686
3	0.3306	0.3006	0.2525	0.2021	0.2430	0.4773	0.3485	0.3829	0.0805	0.0810	0.3451	0.2137
4	0.1657	0.2803	0.4351	0.3827	0.2355	0.2212	0.1747	0.1837	0.1693	0.1709	0.2184	0.2180
5	0.1590	0.1555	0.1650	0.2963	0.2086	0.1883	0.1534	0.1483	0.1168	0.1940	0.1471	0.1113
6	0.1970	0.2290	0.0967	0.2737	0.2553	0.2588	0.0931	0.1327	0.0901	0.1562	0.0830	0.0707
7	0.2141	0.3778	0.3074	0.3073	0.2434	0.2030	0.2332	0.2331	0.1419	0.2295	0.2230	0.2002
8	0.1301	0.2316	0.2757	0.1960	0.1733	0.2298	0.1268	0.1946	0.1725	0.1885	0.1784	0.1500
9	0.1282	0.2646	0.1645	0.2221	0.1004	0.2169	0.1498	0.1642	0.1479	0.1777	0.1647	0.1544
10	0.3482	0.3188	0.2746	0.3221	0.2536	0.2406	0.1878	0.2905	0.3480	0.3501	0.2492	0.3250

In general, the study region consists of fine sand to medium sand.

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