

Littoral Processes and their relevance to the submergence of ancient ports along Andhra Coast, India.

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The study of environmental parameters along the coast of Andhra Pradesh, India reveals that the area during December to March experiences mild waves ($H_s \approx 1$ m, $T_s \approx 6$ sec) predominantly from N.E. Modification of wave parameters takes place in April and high waves ($H_s > 2$ m, $T_s > 8$ sec, dir. 180-270) prevail during May - September. Qualitative picture of littoral currents also vary with the changes in the prevalent wave parameters. These currents were from NE for the waves from 90° and from SW for 120° - 210° wave approaches. Rip currents were also observed in these patterns. The observed currents were from NE (intensity 0-40 cm sec) in February whereas they were from SW (magnitude 20 - 70 cm sec⁻¹) in September.

Based on sediment budget between February 1981 to September 1982, it is found that about 117 m sediment deposits in a storm to swell cycle. The average rate of sediment deposition was 58 to 65 m for swell to storm profile transformation. The bivariate plots of size measures suggest that the source of the sediments is through river source. The dominance of depositional processes leading to the accretionary nature of the coast and their relationship with the submergence of ancient harbours in this region is discussed.

INTRODUCTION

The sediment dynamics in the littoral zone is governed by the prevalent environmental conditions of an area and sediment input (Chauhan 1986, 5; Anamymous, 1977). The prevalent morphodynamic processes which are the net result of sediment input and intensity of geomorphic agents thus determine the nature of a coast. The dominance of accretionary processes over a long period of time would lead to emergent type of coast and tend to migrate the coast line seawards. Higher input of sediments in a favourable physiography may lead to the dominance of accretionary processes. Magnitude and direction of the littoral currents determine the quantum of sediment transfer along a coast and in depth knowledge of this process is essential for understanding the nature of a coast.

Condition of navigational channel of any harbour determines its utility. A deep unobstructive natural channel is *sine qua non* for the efficient movement of the vessels. The maintenance of navigational channel, to a large extent, depends upon silting of channels and this in turn is related with the sediment dynamics in the littoral zone.

The littoral currents generated within and beyond the surf zone are the most important sediment transporting agents and state of a beach (Wright 1984, 93-118) at any given time represent a dynamic equilibrium among various prevalent morphodynamic processes and sediment input. As "Present is the key to the past" and the nature of a beach is the reflection of the morphodynamic nature of an area, the study of sediment dynamics along a coast will help in understanding the physiographic evolution an area has under gone in the recent past.

Present work has been carried out at Machilipatnam (Fig.1) and aimed at determining the nature of the coast. To establish this, the prevalent wave parameters (based on over 10 years of ship borne observations) has been obtained. Patterns of littoral currents based on wave refraction studies for most prevalent wave approaches and wave periods have been obtained. These patterns have been validated by the field measurements. Sediment budget, based on the profile measurements in time and space, has been obtained and source of the sediments to the area is determined based on bivariate plots (Friedman, 1977, 3-32).

AREA

The study area is constituted of sandy beaches which are bordered landwards by some creeks (Fig. 1). The Machilipatnam harbour is located deep inland, and the creek acts as its navigational channel. The beaches are open and directly exposed to the Bay of Bengal. The detailed physiography of the area based on the Naval Hydrographic chart Number 355 is shown in Figure 1.

METHODOLOGY

About 25 km area of Machilipatnam coast has been monitored between February 1981 - September 1982. Five transects extending from berm to 2 m water depth below low tide level were monitored. The location of each transect is shown in Figure 1. To obtain the variations in the beach profiles under different environmental conditions, observations were made in February of 1981 and 82, April of 1981 and September of 1981 and 82. The variations in the beach profiles in

time and space have been utilized to obtain beach states⁵ and to determine sediment budget in time and space under different environmental conditions, i.e. swell to storm cycles, following the methods described by Chauhan. The net sediment budget between February 1981 to September 1982 has been obtained. The details of beach profile measurements, determination of wave steepness (H_w/L_w), wave energy (\bar{E}) and beach slope have been described in Chauhan (1988, 60).

The wave parameters for the study area have been obtained from daily published weather reports of the India Meteorological Department, based on shipborne observations between 1978-1985. The percentage occurrence of swell wave parameters, i.e. wave height (H_w), period (T_w) and prevalent directions were obtained after statistical analyses of these data (Kenny p.348).

The qualitative picture of coastal circulation was obtained by wave refraction studies following the numerical methods on the ND 570 computer based on the detail assumptions.

(Anonymous 1977). Bathymetry for the wave refraction studies has been obtained from the Naval Hydrographic Chart Number 355. Wave orthogonals were drawn at 50 m intervals so as to obtain detailed refraction patterns. As the coast has NE-SW orientation, the wave approaching from 90-210° only will influence the coast directly, and hence, wave refraction patterns were observed for these directions for wave periods 6,8,10 and 12 sec. The patterns of littoral currents were also obtained in February of 1981, 82 September of 1981 and April of 1981 following the standard methods i.e. release of Rhodamine B dye and float observations methods.

About 150 sediments samples were collected from the upper 5 cm of beach surfaces, along and across the beach profiles, and were analysed for various size measures following standard method¹⁵ on the ND 570 computer. The bivariate plots for the size measures¹³ were obtained to demarcate the environment of deposition.

RESULTS AND DISCUSSIONS

The prevalent environmental conditions along A.P. coast vary within wide range. Table 1-3 present the wave parameters for the coast. The prevalent waves are generally mild and have low periodicity during December to February ($H_w \approx 1\text{m}$, $T_w 5\text{ sec}$). The most prevalent wave direction during this period is from NE (30-60°). The shift in the direction of wave approach takes place in March to April ($H_w 1-4\text{m}$, $T_w 5-10\text{ sec}$, direction 30-210°) and during May to September high wave environment prevails (Table 1) The general direction of wave approach also changes from NE to SW (180-270°, 210-240 for > 60% time) during this period. These parameters again change in October (Tables 1-3). The area experiences cyclonic storms/depressions in May and late October to early December. The frequency of their occurrence is high in November.

The detailed patterns of littoral currents and the area of wave energy concentration obtained through the wave refraction studies (utilising refraction and direction functions) are presented in Figures 2-3. The patterns of the littoral currents obtained based upon dye and float movements under different hydraulic conditions (Fig.4) validate the results of the refraction studies. The patterns of littoral currents appear to be more complex for the SW waves having high periodicity ($T_w > 10\text{ sec}$). The area prone to erosion has also been identified for different wave directions and periods (Figs. 5-6). The magnitude and directions of the measured littoral currents show contrasting changes. Mild to moderate currents (0-40 cm sec⁻¹) from NE prevail in February, whereas the moderate/strong (20 - 70 cm sec⁻¹) currents from SW were observed in September. In April, magnitude of the currents was mild to moderate and they have variable directions.

The beaches of the area respond to the changes in the prevalent environmental conditions (Fig. 7). The variations in the beach slope and other parameters of beach profile in time and space under different environmental conditions are presented in Table 4. The beach profile was "swell type"¹⁰ in February, 81 and 82. With changes in the prevalent hydraulic

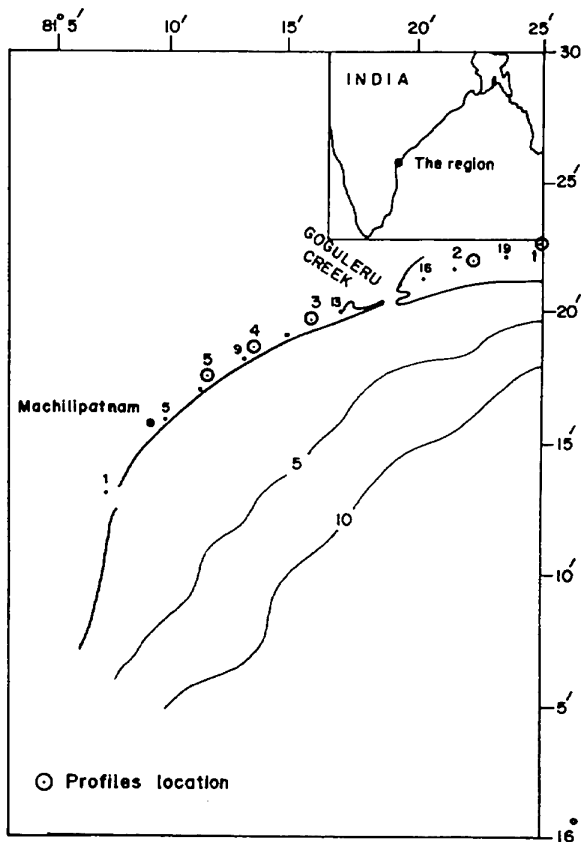


Fig. 1

Table 1. Deep water wave height H_w (PER CENT) for different months long the A.P. coast.

MONTHS	WAVE HEIGHT IN M						
	1	1.5	2.0	2.5	3.0	3.5	4.0
Jan	60.80	26.08	13.04				
Feb	71.40	07.14	07.14	14.28			
Mar	73.30	06.66	06.66	06.66	06.66		
Apr	88.88		11.11				
May	33.33	23.80	19.04	09.50	09.52		04.76
June	09.52	09.52	42.80	33.30		04.76	
July	22.70	31.80	18.18		18.18		09.09
Aug	06.25	25.00	25.00	12.50		87.00	12.50
Sep	12.50	25.00	25.00	25.00	12.50		
Oct	62.50	37.50					
Nov	55.55	33.33			11.11		
Dec	46.15	30.76	15.38		07.69		

Table 2. Deep water wave height (T_w) for different months long the A.P. coast. Values are in PER CENT.

MONTHS	WAVE PERIOD IN SEC								
	5	6	7	8	9	10	11	12	>12
Jan	85.71		04.76		14.28				
Feb	69.56	30.43							
Mar	78.57		07.14		07.14				07.14
Apr	55.55	11.11	11.11	11.11	11.11				
May	22.85	22.85	19.59	40.00	05.70				
June	20.00	15.00	20.00	30.00	05.00				10.00
July	08.00	20.00	12.00	36.00	12.00			04.00	08.00
Aug	15.09	15.09	32.07	15.09	07.54	15.09			
Sep	44.44	11.11		22.22	11.11	11.11			
Oct	73.68				10.52				15.78
Nov	80.95			09.52					09.52
Dec	76.92	07.69	15.38						

conditions in March, beach profiles modify and were characteristically "storm type" in September. The change in the direction of wave approach from NE to SW during this period had pronounced effects on the beach profiles. The concentration of wave energy due to wave refraction along the coast (Figs. 2-3) and high wave energy density of prevalent waves lead to the profound effects on the beach (Figs. 5-6).

The magnitude of sediment budget in time and space along the coast shows marked variations (Table 5). The study of erosion - depositional cycles during the course of the present study suggest the dominance of accretionary processes over the erosional component. The budget of sediment at different profiles clearly demonstrate that from swell to storm profile,

i.e. between February to September, on an average 58-65 m² sediments were eroded. Average rate of deposition from storm to swell transformations (September to February) was about 117 m².

At each beach profile the rate of sediment exchange was also found to be variable. Northern end (Profiles 1-2) has higher deposition compared to the southern portion of the study area (Profiles 3-5, Table 5).

Bivariate plots obtained on the sediments of this beach show that majority of the sediments of the beach fall in the area designated for "river" (Fig.8). Earlier study² has shown that the sediments of this beach are predominantly bimodal and have high silt contents. These results confirm that the sediments to the beach are contributed through fluvial sources.

SUBMERGENCE OF ANCIENT PORTS ALONG ANDHRA COAST, INDIA

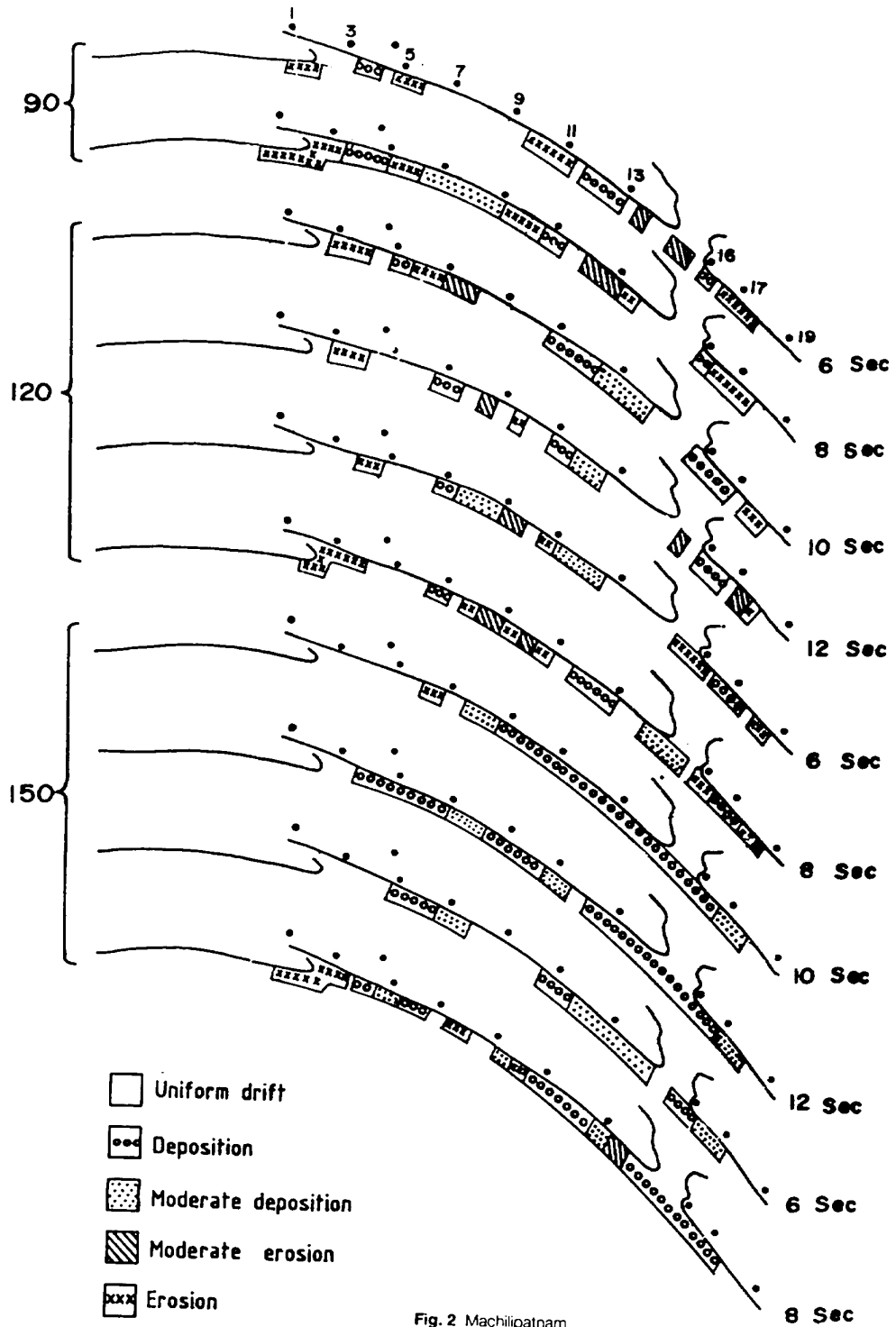


Fig. 2 Machilipatnam

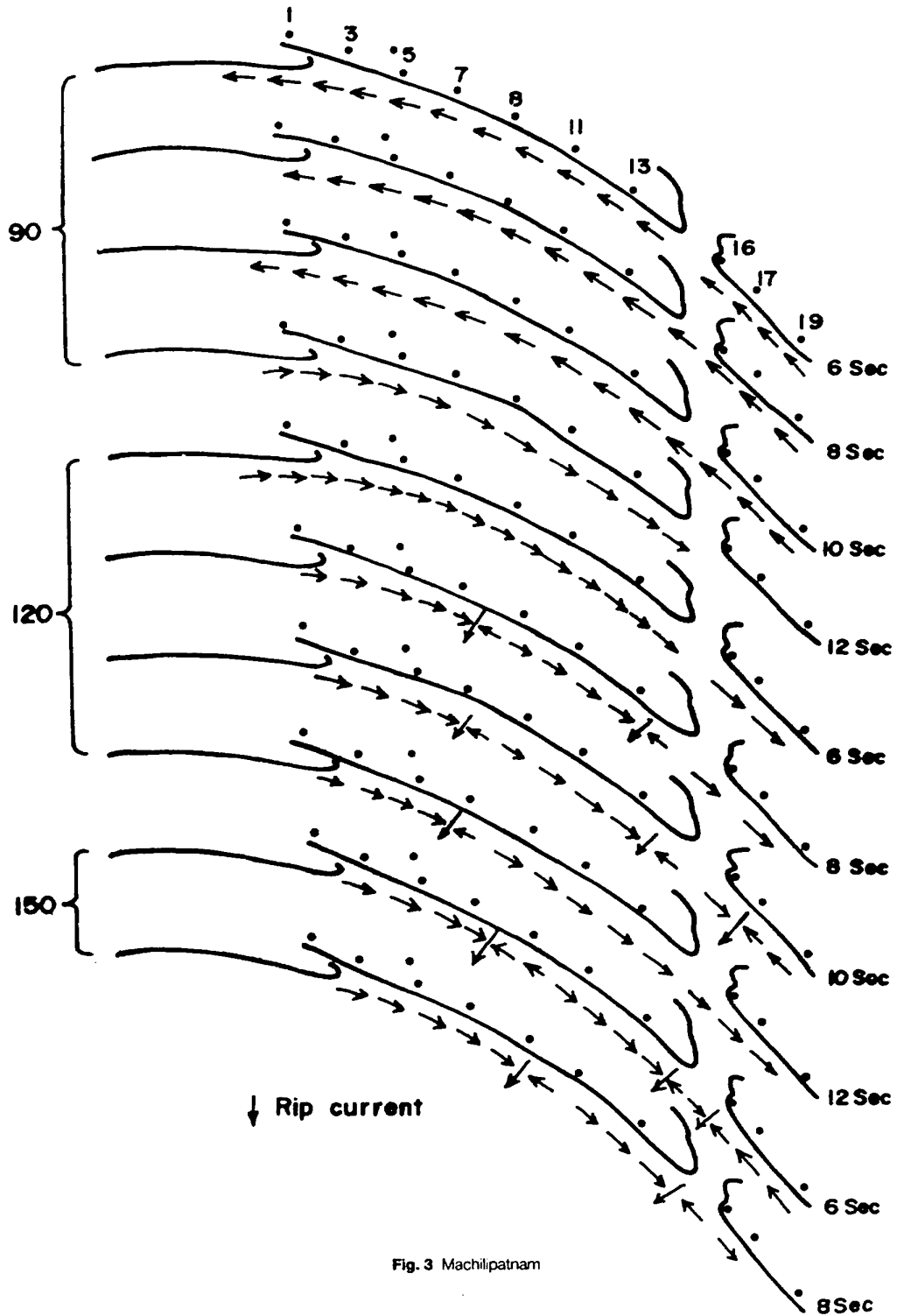


Fig. 3 Machilipatnam

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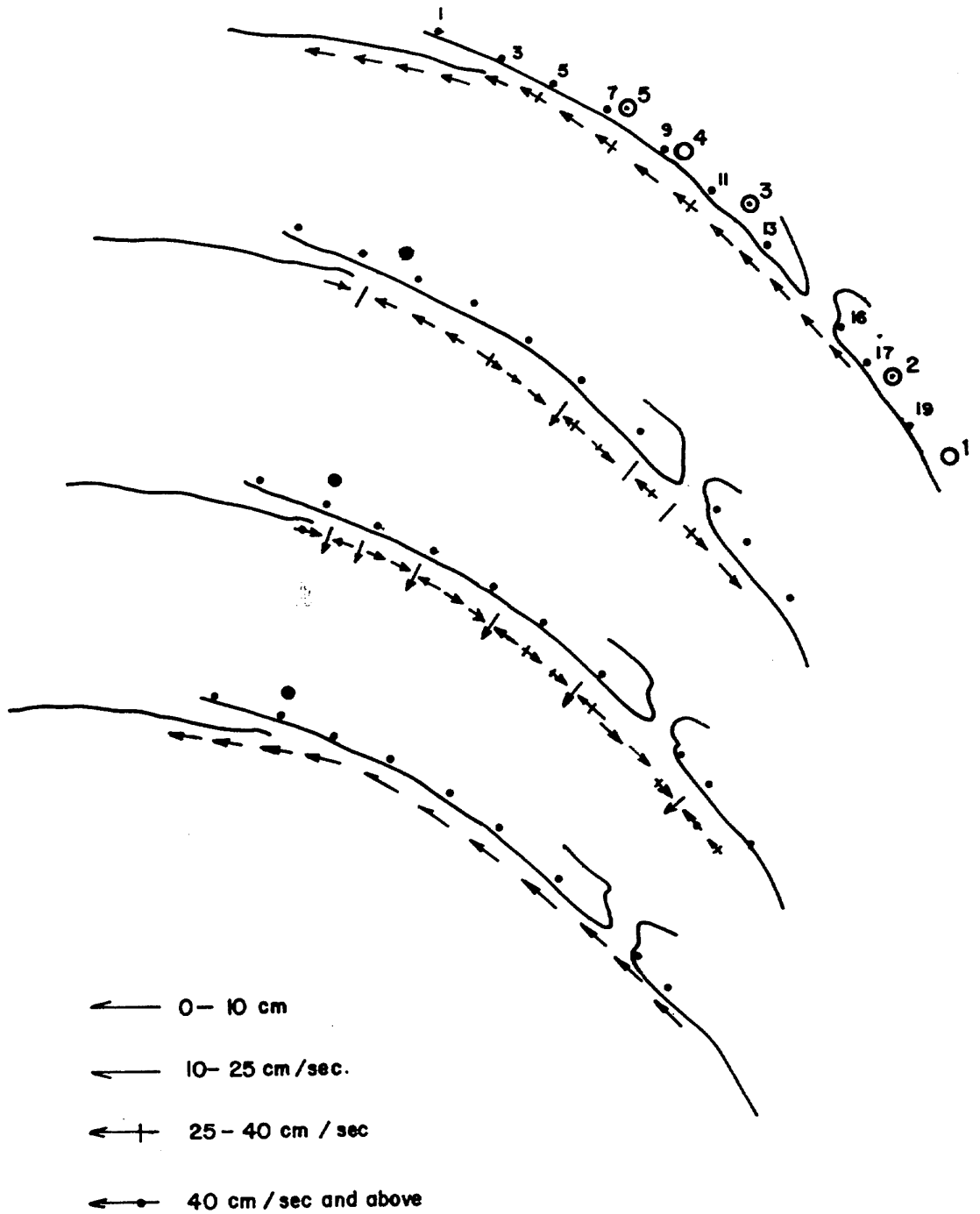


Fig. 4 Machilipatnam

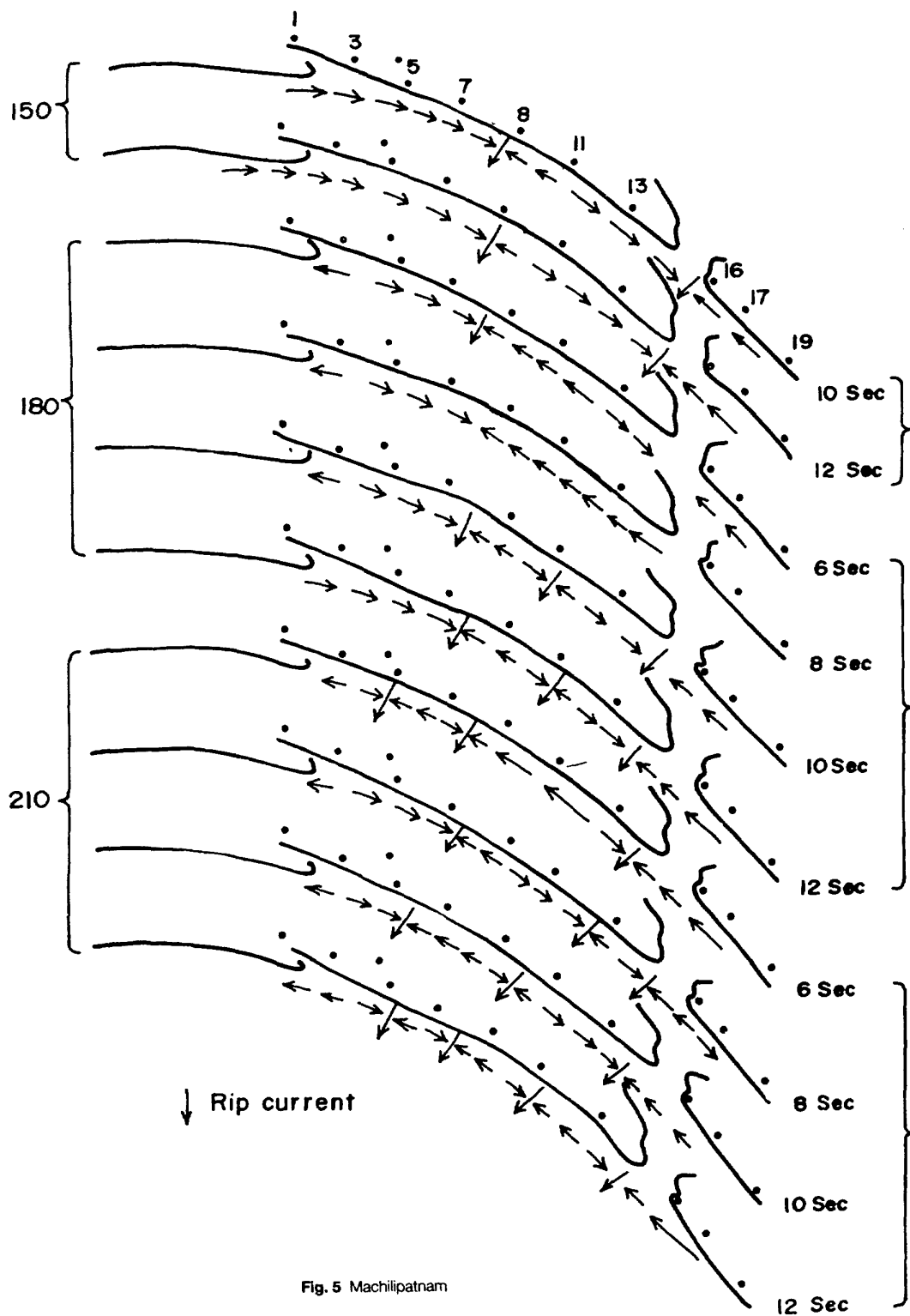


Fig. 5 Machilipatnam

SUBMERGENCE OF ANCIENT PORTS ALONG ANDHRA COAST, INDIA

Table 3. Deep water wave approaches for different months along the A.P. coast.

MONTHS	DIRECTION OF WAVE APPROACH IN DEGREE												
	0	30	60	90	120	150	180	210	240	270	300	330	
Jan		31.81	36.36	18.18	09.09								04.54
Feb			57.14	28.57			14.28	28.57					
Mar		14.28		14.28	14.28			42.85		14.28			
Apr		11.11		11.11		11.11	33.33	22.22	11.11				
May						10.00	35.00	30.00	25.00	05.00			
June						04.76		38.50	47.61	144.28			04.76
July			04.54			04.54	27.27	31.81	31.81	31.81			
Aug						06.25	12.50	31.75	31.50	06.25	06.25		
Sep						12.90	50.00	02.50	12.90				
Oct			25.00		12.90			27.50	25.00				
Nov			44.44	44.44		22.22							
Dec		30.00	70.00										

Table 4. Beach profile characteristic at different stations along the Machilipatnam Coast based on the beach profile measurements during February 1981 – September 82.

PROFILE NO.	PROFILE LENGTH (m)		BEACH SLOPE (Degree)	
	NE MONSOON/ Fair Weather	SW MONSOON/ rough Weather	NE MONSOON/ Fair Weather	SW MONSOON/ rough Weather
1	150 – 155	120 – 130	3.01 – 3.6	6 – 6.5
2	150 – 160	136	2.21 – 2.3	4 – 4.5
3	– 145 – 150	110 – 115	2.07 – 3.07	4.6 – 5.9
4	155 – 165	145 – 150	2.3 – 3.1	4.3 – 4.9
5	140 – 145	110 – 120	2.3 – 3.2	4.09 – 4.62

The area undertaken for this study lies between the rivers Godavari and Krishna, two major rivers of the penninsular India and they have high TSM¹⁴ (1845 & 1158). The location of this area with respect to these fluvial sources makes it a favourable site. The sediments of the river Godavari are contributed to the area through currents from NE in October – April, and the drift from SW carrying the sediments of the river Krishna provides nourishments to the beach during SW monsoon. This continual contribution of the sediments to coast keeps the rate of erosion low during transformation of swell profile to storm profile (Table 5). The SW currents are strong ($\approx 70 \text{ cm sec}^{-1}$), and are capable of transporting the sediments for longer distances, and thus, the coast of Andhra Pradesh located south of these rivers receives very high sediments due to combined drift from these two rivers, i.e., rivers Krishna and Godavari. The sediment input of these rivers is also at peak at this time due to heavy rains in the catchment

area of these rivers during SW monsoon. The prevalent waves and currents are very high and their intensity is reduced in December only. The suspended sediments discharged by these rivers therefore, remain in suspension even after SW monsoon.

The above discussion, thus, suggests that the Machilipatnam beach is dominantly accretionary. The frequent silting problem of the Machilipatnam Harbour (located deep inland in a creek and the channel located in the creek is navigational during high tide only) also appears to be due to the influence of the fluvial sources. Similar situation might have been prevalent in the recent past and due to high accretionary environment at the coast, the coast line might have advanced seawards. The high suspended matters transported along A.P. coast which remain in suspension for a long time have adversely affected the navigational channels of the ports located along this portion of the coast. This has affected severely

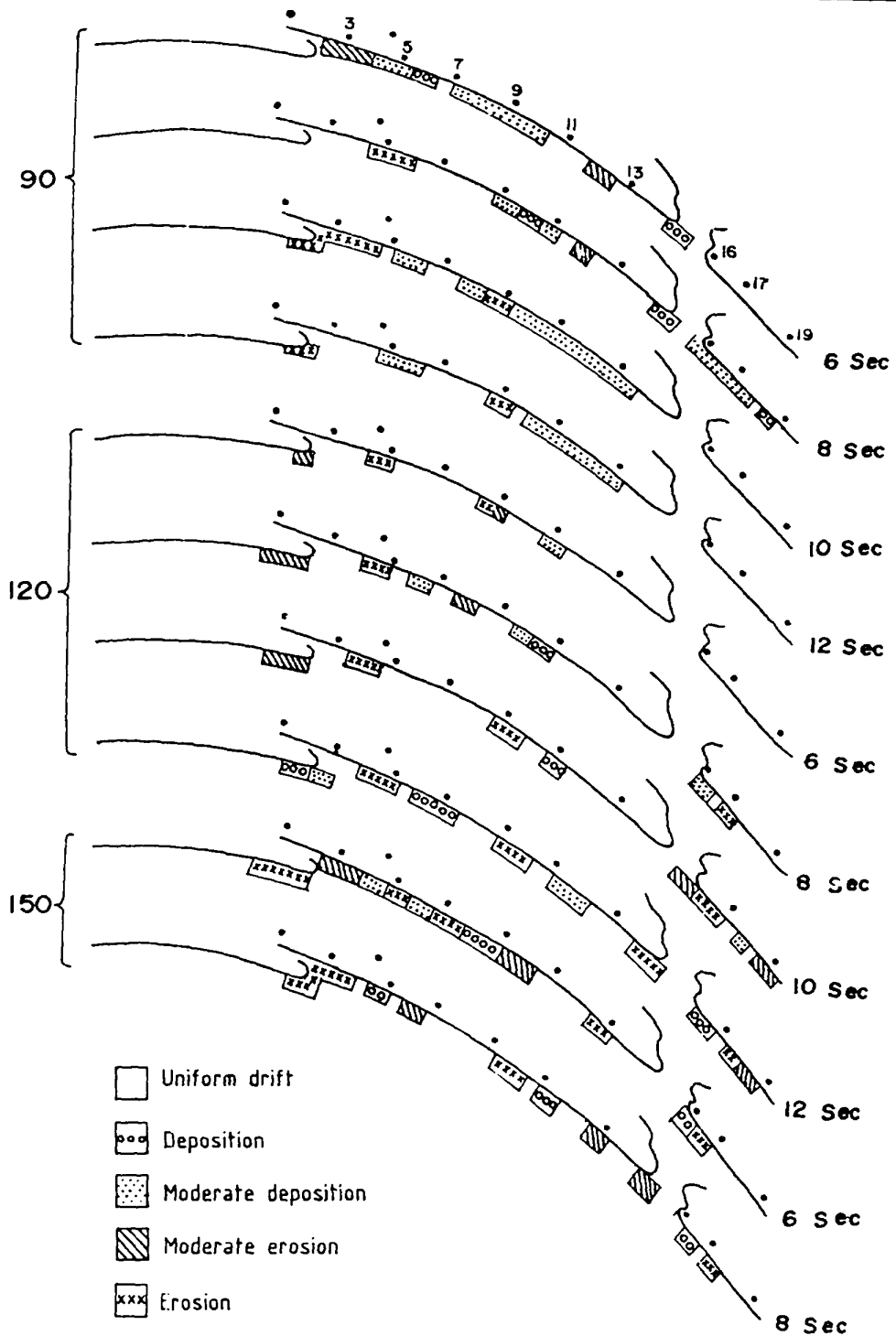


Fig. 6 Machilpatnam

SUBMERGENCE OF ANCIENT PORTS ALONG ANDHRA COAST, INDIA

Table 5. Budget of sediment exchange at different stations along the Machilipatnam Coast obtained from the comparison of beach profiles in time and space during 1981 - 1982 (Values are in m²).

PERIOD	AVERAGE LENGTH OF BEACH PROFILE (m)	PROFILE NUMBERS					AVERAGE
		1	2	3	4	5	
Feb.81 - Apr.81	150	+ 14.117	+ 11.72	+ 19.05	+ 17.21	+ 24.64	+ 15.15
Feb.81 - Sep.81	110	- 67.35	- 68.50	- 59.57	- 60.18	- 74.06	- 65.93
Sep.81 - Feb.82	150	+136.72	+121.73	+ 98.69	+109.10	+120.15	+117.27
Feb.82 - Sep.82	110	- 78.82	- 70.21	- 52.73	- 41.45	- 47.50	- 58.16
Range of Sediment deposition in one cycle		(+)57-69	+51-52.8	+39-45	+48-67	+6-72	+51-59.11

(+) indicates deposition, (-) indicates erosion

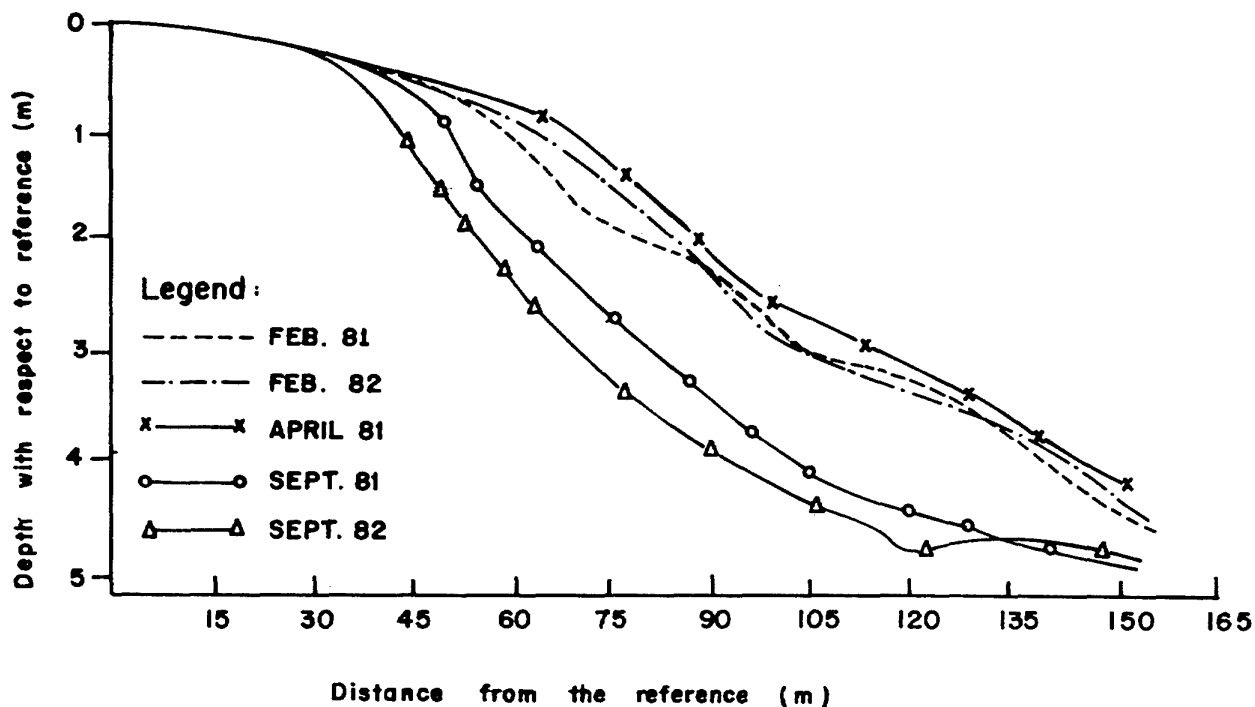


Fig. 7

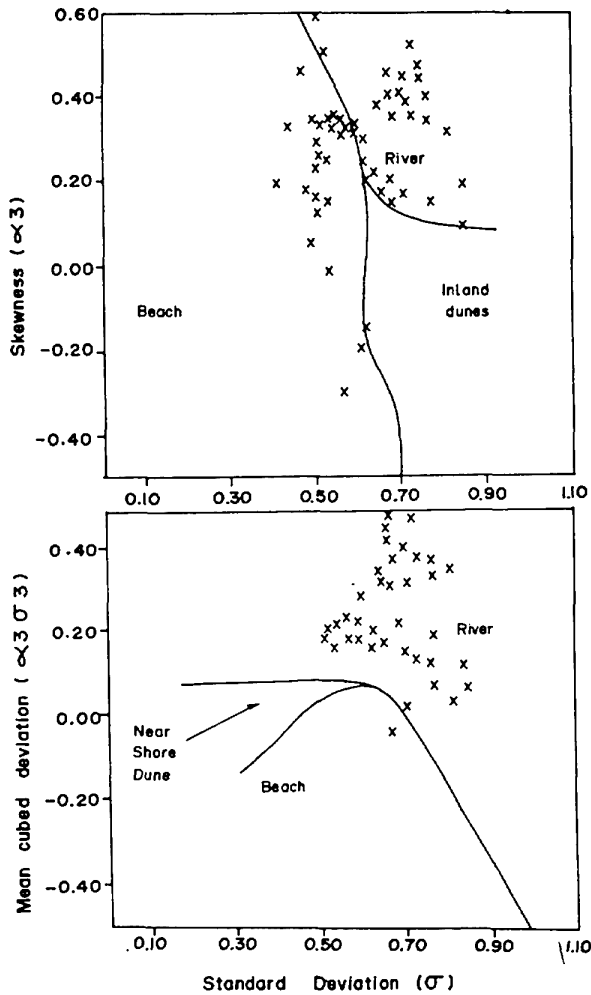


Fig. 8

ancient harbour leading to the abandoning of many minor ports or shifting the trade to more favourable alternatives, leading to sharp reduction in their numbers.

CONCLUSIONS

The results of the present study lead to the following conclusions:

1. The Andhra Pradesh Coast experiences high wave environment associated with strong currents during SW monsoon. The waves are mild during NE monsoon. The direction of littoral currents is reversed from SW to NE during this period.
2. Sediment budget along the coast and the characteristics of sediments in the bivariate plots confirm a high input of sediments to the area. The northern portions get very high input due to combined contributions by two major rivers.

3. The high input of the sediments leading to either migration of coast line or silting of navigational channels of ports, appears to be contributing factor for abandoning of ancient harbours.

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