STUDIES ON THE LITTORAL PROCESSES IN RELATION TO STABILITY OF BEACHES AROUND COCHIN

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By

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CERTIFICATE

This is to certify that the thesis bound herewith is an authentic record of the research carried out by Shri S. Sathees Chandra Shenoi, M.Sc., under my supervision and guidance in the School of Marine Sciences, in partial fulfilment of the requirement for the Ph.D. Degree of the University of Cochin and that no part thereof has been presented before for any other degree in any University.

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DECLARATION

I hereby declare that the thesis entitled 'STUDIES ON THE LITTORAL PROCESSES IN RELATION TO STABILITY OF BEACHES AROUND COCHIN' is an authentic record of the research work carried out by me under the supervision and guidance of Dr.P.G.Kurup, Reader, School of Marine Sciences, University of Cochin, in partial fulfilment of the requirement for the Ph.D. Degree of the University of Cochin and that no part of it has previously formed the basis for the award of any degree, diploma or associateship in any University.

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CONTENTS

PREFACE

The coastal and nearshore areas find varied uses and play important role in the socio-economic development of nations. The beaches along the Kerala coast are barrier type backed by a series of lagoons, and along certain reaches sheltered from wave action by the mud banks which are regions of calm water appearing close to the shore during the rough southwest monsoon season. The barrier beaches of Kerala are migratory in nature and subjected to severe erosion and accretion. Heavy mineral deposits of monozite and ilmenite, ranked as world's largest and richest, are present along this coastal stretch. Planned development of our coastal areas calls for systematic studies to understand the nearshore processes that govern the stability of the beaches along this coastline. The purpose of the present study is to examine the nature and effect of various physical parameters operating in the shoreline processes along the beaches around Cochin.

The thesis is presented in seven chapters. A brief discussion on the available environmental parameters along with the physiography and history of shoreline changes of the region is presented in Chapter 1. Chapter 2 presents the deep water wave climate off the region under study and the results of the investigations on wave refraction as these deep water waves propagate towards the shore. A comparison of the nearshore wave characteristics obtained from wave refraction studies with the observed breaker characteristics has been made with special reference to the damping of waves inside the mud banks. After discussing the pattern of littoral currents as obtained from wave refraction studies and field observations in Chapter 3, the spatial and temporal variations of the characteristics of beach material have been presented in Chapter 4 and discussed in relation to the environmental parameters operating along the coast. Chapter 5 presents the longshore drift of beach material as derived from the longshore component of wave energy and discusses it in relation to the availability of material along the shore under study. The morphological changes of the beaches exposed to the incoming waves and those subjected to the sheltering effect of mud banks are presented in Chapter 6. The dynamics of the beaches has been analysed in the light of the various littoral processes taking place along this shore. The summary and conclusions are presented in Chapter 7.

CHAPTER 1

INTRODUCTION

The coastal and nearshore areas have played vital role in the trade and economic development of coastal nations since ancient times. In recent years, the demands for utilization of these areas have increased for purposes of navigation, setting up of offshore structures for oil industry, exploitation of the available fishery and mineral resources, and to provide recreational facilities along the coast as a part of the coastal zone management. It is in this context the studies on nearshore processes receive greater priorities.

The nearshore and littoral processes comprise the effects of waves, currents, tides and the direct and indirect influences of winds and their mutual interactions. The dynamical effects of these environmental parameters on shoreline processes have been well documented (Wiegel, 1964; Zenkovich, 1967; King, 1972; Horikawa, 1978). At any given shoreline, a detailed examination of these process variables helps in understanding the transport of sediments and the stability of the coast and adjoining beaches. A beach may suffer from large scale erosion or accretion temporarily but the long-term conditions of the beach stability depend on the rates of supply and loss of sedimentary material.

Along the southwest coast of India (Kerala coast), various reports exist on the severe erosion of some of the beaches leading to large scale recession of the shoreline. This coast oriented in the NNW-SSE direction extends over a distance of 560 km. About 25% of this stretch experiences severe erosion. Shore protection structures such as sea-walls and groynes have been constructed to prevent the alarming or large scale recession of some sections of the shoreline. This large scale erosion posing threat to the human settlements and the economically important heavy mineral deposits on these beaches demands an indepth investigation on the various physical processes operating in the environment controlling the stability of the beaches and the shoreline. More so, with the growth in population, the coastal zone of Kerala would undergo greater developments in future. Systematic studies aimed at understanding the various factors and the nearshore processes operating in this environment would be beneficial for better management and planning of this coastal zone.

This thesis presents the studies carried out on the geomorphology and the stability of the beaches at selected locations along Kerala coast in relation to the various environmental process variables. A brief account of the available environmental parameters has been detailed below .

before presenting the observational findings of the current investigations.

1.1. PHYSIOGRAPHY OF THE COAST

The coast of Kerala (Fig.1) extends from $8^{o}15'N$ to $12^{o}50'N$ latitude and lies between $74^{o}50'E$ and $77^{o}30'E$ longitude, spanning nearly 560 km with a maximum width of 120 km. The coast is bordered on the eastern side by western ghats which are composed mainly of horizontally bedded Creto-Eocene basalts rising to heights of about 2000 m (Krishnan, 1968). From the low-lands adjoining the western sea-board, the land scape ascends steadily towards east to the mid-lands and further on the high lands sloping from the western ghats. The mountain ranges that form a natural wall separating Kerala from the adjoining states have an average elevation of 1 km with peaks exceeding 2 km.

The western slopes of the hills and mountains at the eastern border of Kerala receive considerable amount of precipitation during the rainy season and nourish a large number of rivers ($\sim$ forty). These rivers together with their numerous tributaries cut across the mainland to join the Arabian Sea directly or through the backwater systems separated by a barrier on the seaward

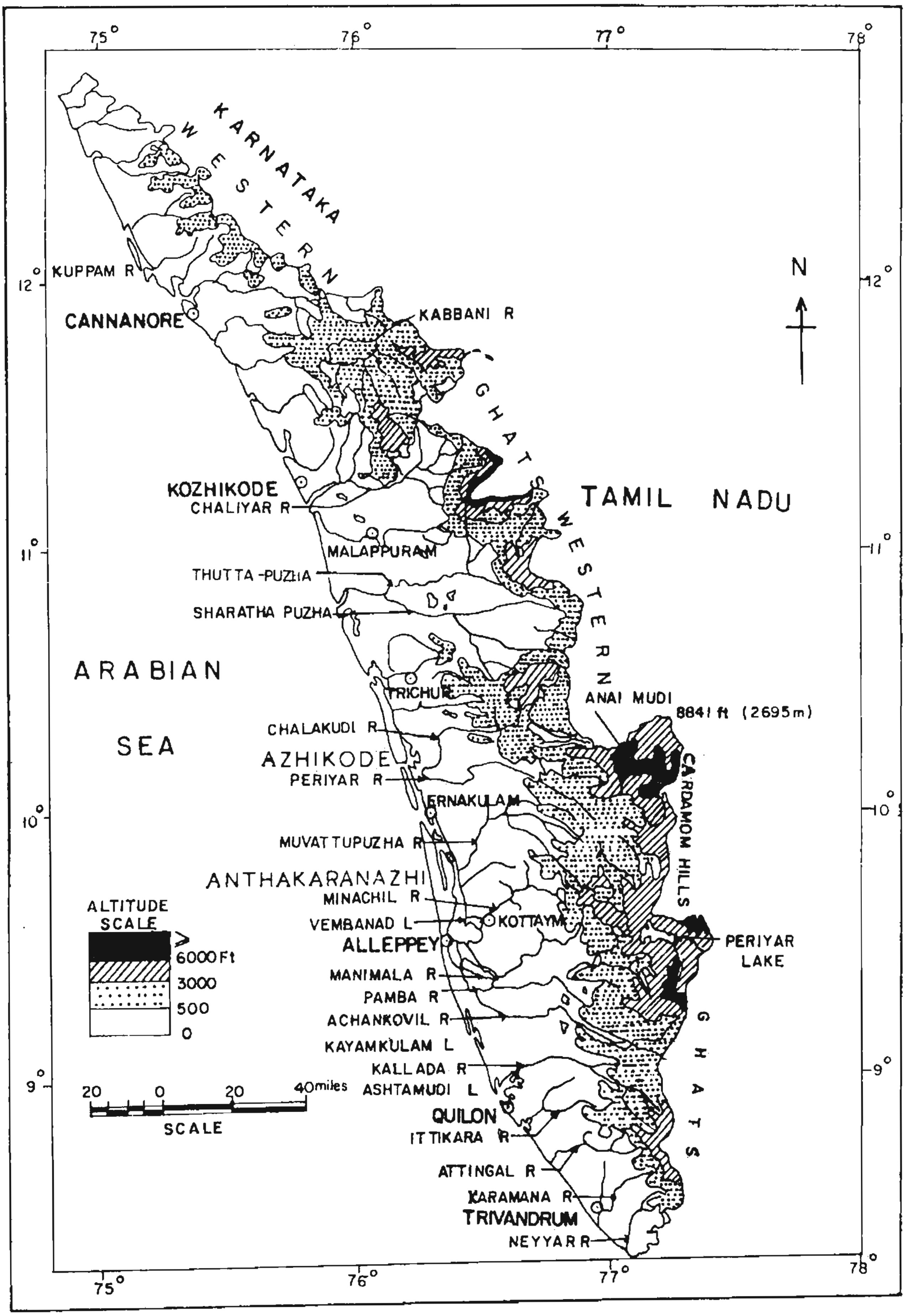

Fig. 1. Physical map of Kerala

end. These backwaters or lagoons, known locally as 'Kāyals' with intermittent islands are inter-connected by artificial and natural canals and possess variable widths. They act as filters to the sediments brought by various river systems. Vembanad lake - the major backwater system - with an area of 80 sq km opens into the Arabian Sea at Cochin and at Azhikode. Six major rivers - Periyar, Pamba, Manimala, Achenkovil, Meenachil and Muvattupuzha - discharge the sediment laden fresh water into this lake and the discharge increases considerably during the southwest monsoon season.

1.2. COASTAL AND NEARSHORE SEDIMENTS

The sedimentary formations of Kerala coast are of recent and sub-recent origin except for the miocene formations of Quilon and Varkala beds. Sandstones, sands and clays with thin beds of lignite occur in the cliffs on the sea-shore on the southern portions of the coast (Rao, 1968). The beaches of Kerala can be classified as barrier beaches following the definitions of Zenkovich (1967). The coastline between Alleppey and Cannanore has a low, sandy relief fringed with coconut palms and housing large population. Heavy mineral deposits like monozite and ilmenite, ranked as world's largest and richest, occur in this area, particularly between Kayamkulam and Neendakara.

The very nearshore sea bottom of this region has unconsolidated sediments mainly sands and occupy a narrow zone parallel to the shore. The sediments exhibit a well-marked zonation in regard to their spatial distribution. Silty clays or clayey silts occupy the inner shelf while silty or clayey sands cover the rest of the shelf and slope regions (Nair and Pylee, 1968). Broadly, these sediments could be classified as (1) sandy deposits in the nearshore region upto 3.5 m isobath, (2) muddy deposits with small quantities of sand between 3.5 m and 18.0 m isobaths from Mangalore to Quilon barring the region off Cochin where these grey mud deposits extend upto 35 m, (3) sandy zone between 18 m and 100 m or 120 m isobath, and (4) hard bottom zone between 100 m and 260 m isobath (Kurian, 1969).

1.3. MUD BANKS

Along this coast, patches of calm, turbid water with high loads of sediment in suspension, commonly known as mud banks, have been reported to be active during the southwest monsoon season (Bristow, 1938). Their formation has been considered as unique phenomenon along this coast (Shepard, 1973). The results of the studies on sediments from these mud banks by various authors (Nair *et al.*, 1966; Nair and Murty, 1968; Dora *et al.*, 1968; Nair, 1976; Kurup, 1977) indicate that they are essentially clays

(45 - 60% $w/_w$) or silty clays with very little sands. These sediments, mostly unconsolidated, have moisture contents varying from 60 - 80% (Damodaran, 1973; Gopinathan and Qasim, 1974). These banks have been reported to be non-stationary in nature (Kurup, 1972). They may disappear completely due to the dispersal of their constituents or through their deposition as a result of flocculated settlement during the post-monsoon season (Kurup, 1977). These mud banks, although formed only during southwest monsoon season, serve as storehouses for littoral sediments and provide a buffer to wave attack. These depositional forms in the coastal zone affect the dynamics of the beaches significantly.

1.4. CLIMATE, WINDS AND RAINFALL

1.4.1. Climate

Monsoons control the climate in this region. From the standpoint of weather and climate the following four seasons can be identified:

(1) Winter (January - February)
(2) Hot weather (March - May)
(3) Southwest monsoon (June - September)
(4) Northeast monsoon (October - December).

1.4.2. Winds

The mean resultant winds (Fig.2) show variations from month to month over this region with a complete reversal during the year. During February and May, the wind direction shows a gradual change from north to west through northwest. From June to September, these directions vary between west and west-north-west with high constancy and magnitude. From October to November, variable winds between north-west and west-north-west prevail over this region. From December to January, light or moderate north-easterly winds prevail. Though these are the mean directions for different months for the area as a whole, significant variations in their directions can occur from location to location.

Apart from this, the diurnal coastal air circulation characterized by alternate sea and land breezes, though poorly studied for this area,constitutes an important form of energy supply for nearshore and coastal processes (Sonu *et al.*, 1973). The predominant wind directions recorded at four shore stations - Calicut, Cochin, Alleppey and Trivandrum - have been shown in Table 1 (Anonymous, 1966). In this region the land-sea breezes are experienced almost throughout the year and merge with the general wind systems during the monsoon season (Fig.3).

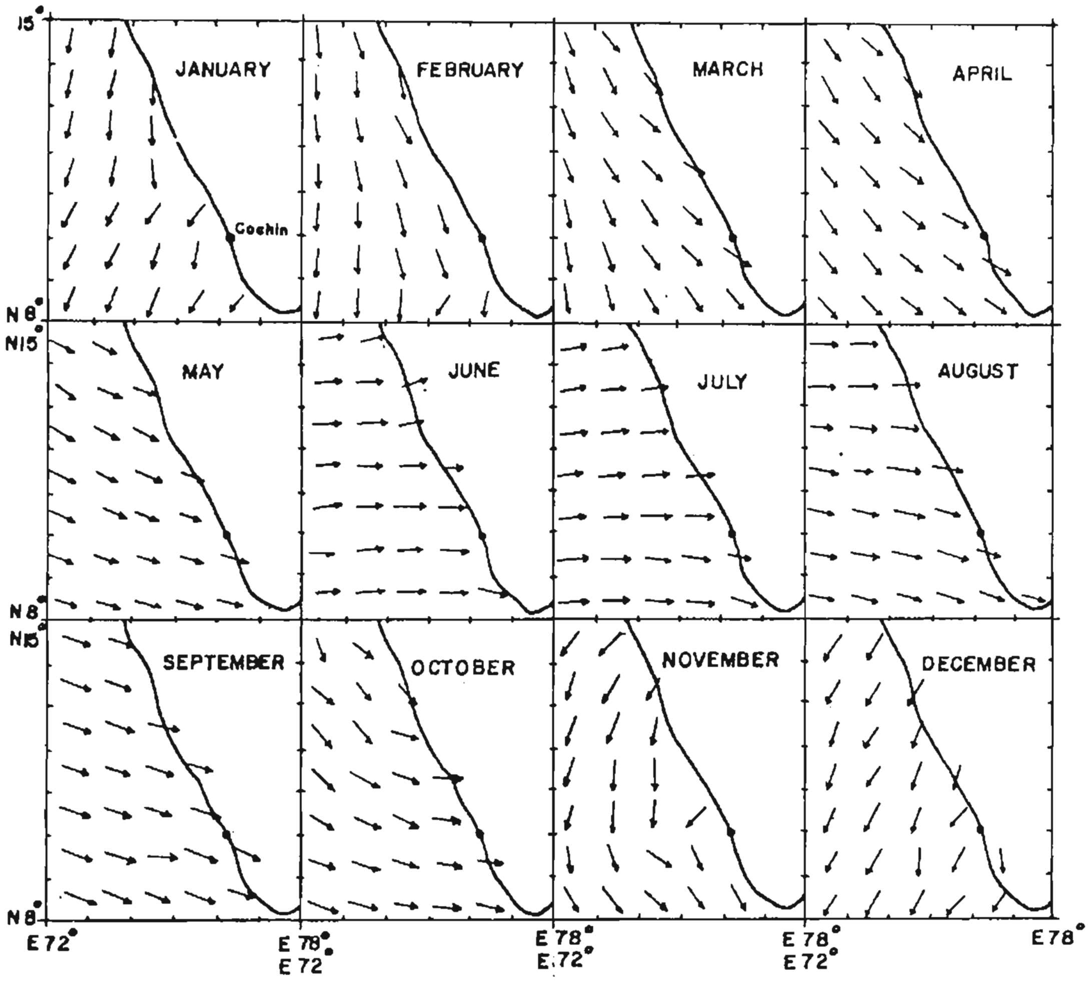

Fig. 2. Direction of monthly mean resultant wind over south east Arabian sea (after Hastenrath and Lamb, 1978)

TABLE 1

The predominant wind directions prevailing at certain coastal stations along the coast of Kerala

Month		Calicut	Cochin	Alleppey	Trivandrum
January	FN	E	NE	E	NE
	AN	W	W	W	SW
February	FN	E	NE	E	NE
	AN	W	W	W	SW
March	FN	E	NE	E	NE
	AN	W	W	W	SW
April	FN	NE	NE	E	N
	AN	W	W	NW	W
May	FN	NE	NE	E	N
	AN	W	W/NW	NW	NW
June	FN	NE	E	NW	NW
	AN	W/NW	W/NW	NW	NW
July	FN	NW	W	NW	NW
	AN	NW	NW/W	NW	NW
August	FN	NW	NW	NW	NW
	AN	NW	NW/W	NW	NW
September	FN	NW	NE	NE/NW	NW/N
	AN	NW	NW	NW	NW
October	FN	E	E/NE	E	N
	AN	W	W	W	NW
November	FN	E	E	E	NE
	AN	W	W	W	SW
December	FN	E	NE	NE	NE
	AN	W	W	W	SW

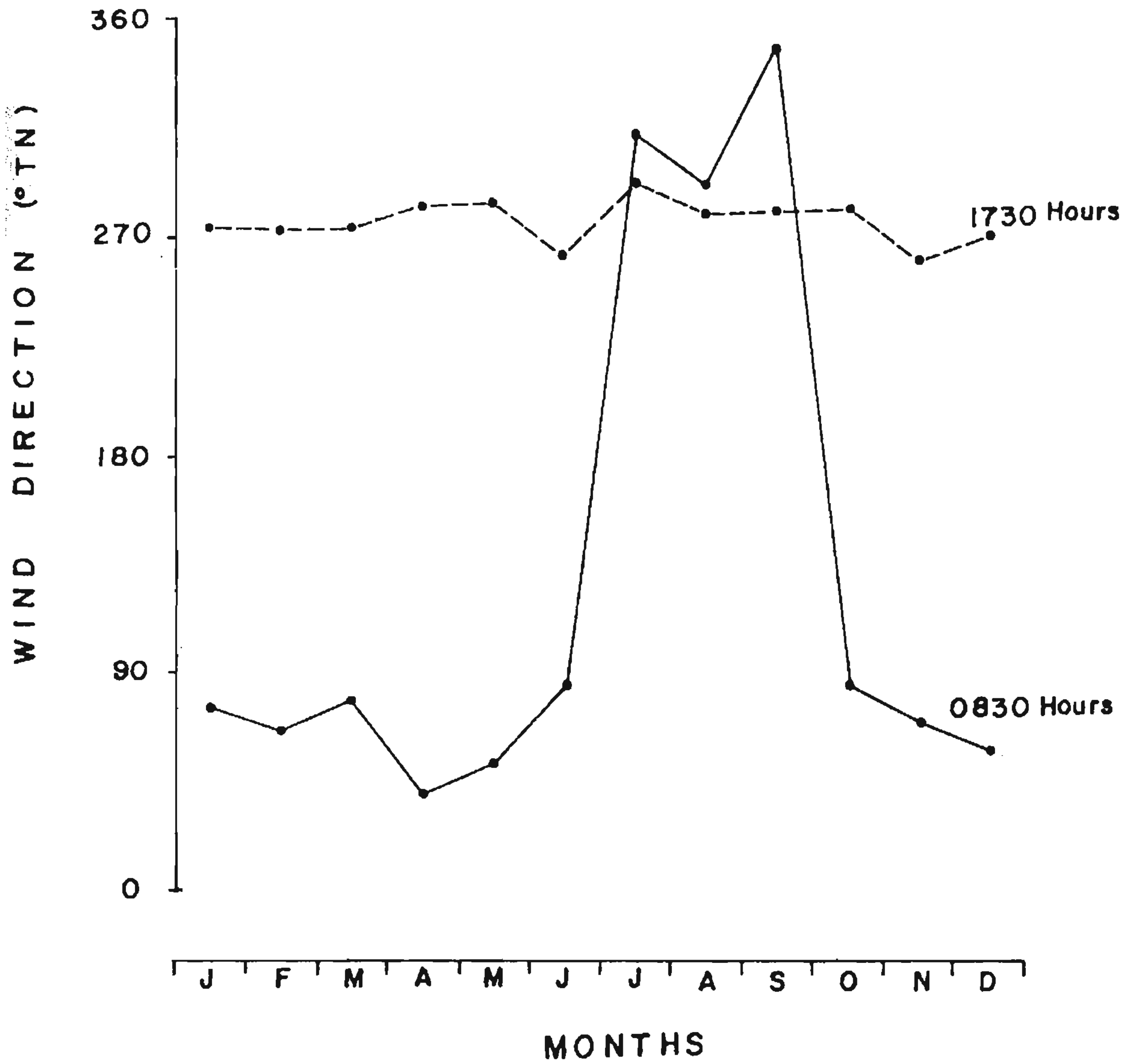

Fig. 3. Monthly variation of wind direction at Cochin at 0830 and 1730 hours

The onshore/offshore components dominate the alongshore component (mostly northerly) all through the year. The strength of sea breeze occasionally attains speeds as high as 15 km/hr as could be seen from Figure 4 prepared using data from the Indian Daily Weather Reports of the India Meteorological Department. These prevailing strong and well defined onshore/offshore components of winds may have a significant effect on the local seas and the incoming swells.

1.4.3. Rainfall

Yet another important factor controlling the coastal processes - the rainfall - over this area, determines the freshwater discharges into the Arabian sea through various river systems. Associated with heavy rainfall concentrated during southwest monsoon season, the detritus from the hill tops and low-lands collected and transported to coastal areas through these river systems nourish the adjoining beaches to some extent.

The coastal belt from and near about Cochin to south of Kozhikode receives an annual rainfall of about 300 cm. The monthly distribution exhibits bimodality with two maxima (Ananthakrishnan et al., 1979) corresponding to the southwest and northeast monsoon seasons.

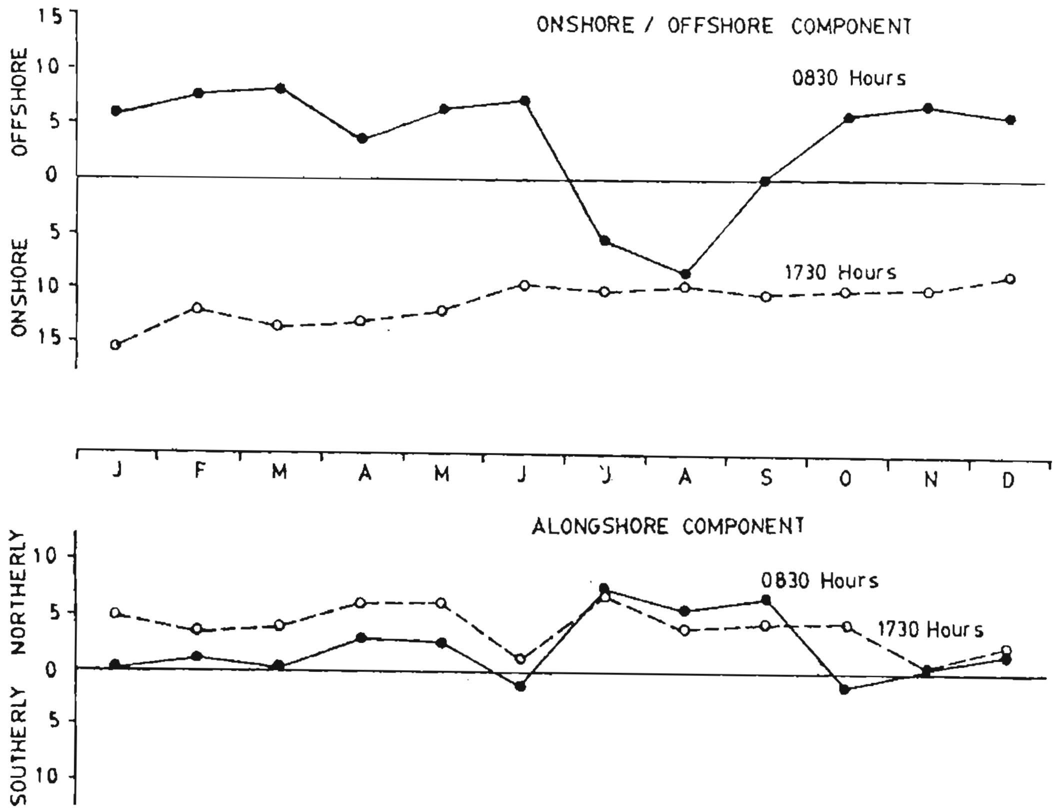

Fig. 4. Monthly variation of the onshore/offshore and alongshore components of winds at Cochin at 0830 and 1730 hours

1.5. WAVES, TIDES AND CURRENTS

1.5.1. Waves

Owing to the variability of winds from month to month and a complete reversal during the year as mentioned earlier, variable fetches occur in this region from time to time. The fetches on the southwest and west are fairly infinite compared to those on the northwest. Considering the orientation of the shoreline, waves approaching the shore from directions varying between 170° and 350° TN only will be of considerable significance in shore processes. The predominant periods of the swell waves approaching the coastline under study lie between 5 and 14 sec with deep water directions between 240° and 320° TN. These waves have their predominant heights from 0.5 to 1.5 m during non-monsoon months and attain as much as 3 m during southwest monsoon months. During the southwest monsoon season, the predominant direction of wave approach falls between west-southwest and west-northwest (Anonymous, 1949; Hogben and Lumb, 1967; Srivastava *et al*., 1968; Varkey *et al*., 1982).

1.5.2. Tides

Tides play an important role in shoreline dynamics by shifting the breaker zone landward and seaward with the rise and fall of water level. The reversing currents associated with the tides - mostly conspicuous in the vicinity of river mouths - will help in transporting the bottom sediments in conjunction with the currents due to mass transport of waves (Johnson, 1966).

Mixed semidiurnal tides with a maximum range of 1.25 m and falling within the micro-tidal range occur in this area. The diurnal variation in mean sea level has been found to be normally low during the monsoon season compared to the post and pre-monsoon periods (Rama Raju and Hariharan, 1967).

1.5.3. Surface currents

The surface currents in the Arabian Sea are characterised by seasonal reversal due to the reversing monsoonal circulations. The general circulation of the surface waters is clockwise during the southwest monsoon season with maximum speeds of the order of 50 cm/sec and anti-clockwise with speeds less than 15 cm/sec during the northeast monsoon season (Varadachari and Sharma, 1967). Along the coast during November to January, the coastal currents flow northward and by the end of January they show a reversal with varying strengths (Anonymous, 1975). These coastal currents are much stronger during southwest monsoon season and weaker during northeast monsoon season.

1.6. HISTORY OF SHORELINE CHANGES AND COASTAL PROTECTION STRUCTURES ALONG THE COAST

The barrier beaches of Kerala came into existence only during the last 2000 to 3000 years. The present coast with its net-work of lagoons and estuaries and the rich heavy mineral deposits on the beaches appears to have been built up on earlier mud-flats (Rao, 1968). The coastal areas have been subjected to annual erosion and accretion. Consistant recession of shoreline from 1850 to 1968 ($\sim$ 120 years) at many places have been reported based on detailed examination of the survey maps (Ravindran et al., 1971). Figure 5 shows the shoreline changes along the Cochin - Chellanam region during the period from 1850 to 1969. Table 2 shows the average yearly rates of erosion at different places. Accretion has been noticed at Vypeen during the last 60 - 70 years. This may be the reason for naming this area as Puthuvypu, meaning locally newly deposited area, after the construction of the approach channel at Cochin (1920-1929).

Shore protection works have been carried out at various locations experiencing erosion. The earliest constructions probably have commenced at Varkala and which comprised of large size blocks of naturally occurring rocks in the form of a sea wall. More coastal protection works are said to have been made in connection with the development

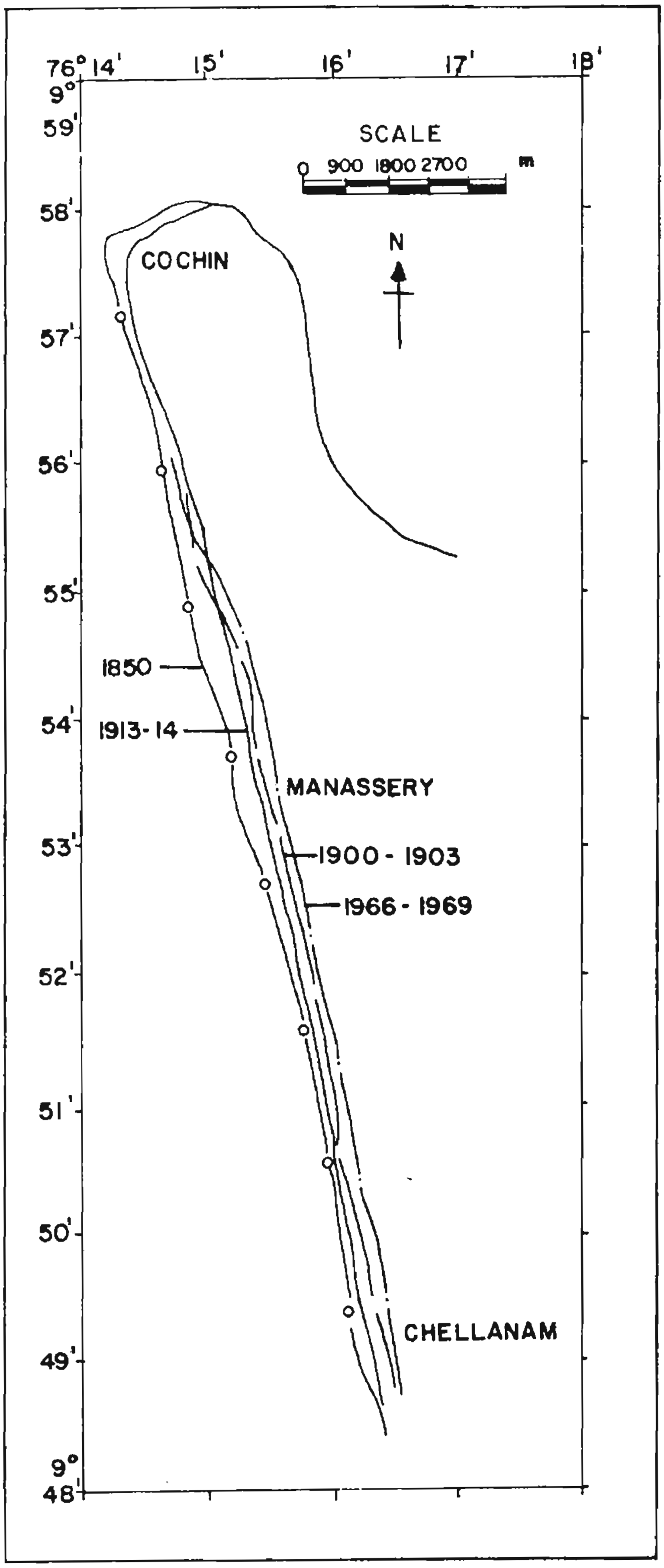

Fig.5. Shoreline changes from 1850 to 1969 along Cochin-Chellanam region (after Ravindran et al., 1971)

TABLE 2

Rate of erosion and accretion at various locations along Kerala coast (after Ravindran *et al.*, 1971)

District	Location	Years of comparison	Period (years)	Accretion (+)/ Erosion (-) (m) during the period	Accretion/ (+) Erosion(-) (m/year)
Cannanore	Mattul (2)	1935-68	33	-277.20	-8.40
	Mattul (1)	1935-68	33	-138.40	-4.20
	Azhikkal	1935-68	33	-138.40	-4.20
	Dharmadham	1934-68	34	- 19.80	-0.84
Calicut	West Hill	1935-67	32	+ 95.00	+2.96
	Calicut	1935-67	32	- 12.00	-0.38
Trichur	Eriyad	1901-69	68	-198.00	-2.91
	Azhikode	1901-69	68	-453.00	-6.65
Ernakulam	Vadakkekara	1901-69	68	-316.0	-4.65
	Pallipuram	1913-69	56	-652.00	-11.65
	Edavanakkad	1903-69	66	-453.00	-6.85
	Kuzhipilly	1913-69	56	-605.00	-10.80
	Vypeen	1920-60	40	+138.00	+34.50
	Manassery	1900-66	66	-138.60	-2.31
	Cheriyakadavu	1903-67	64	-217.20	-3.39
	Chellanam	1903-69	66	-198.20	-3.00
Alleppey	Anthakaranazhi	1896-69	73	- 99.00	-1.33
	Ambalapuzha	1913-69	56	+316.00	+4.63
	Purakkadu	1906-66	60	-138.60	-2.31
	Thrikkunnapuzha	1906-66	60	-150.48	-1.60
Quilon	Chavara	1882-67	85	- 79.20	-0.93
	Neendakara	1882-67	85	+217.80	+2.55
	Sakthikulangara	1889-66	77	+217.80	+2.55
	Marathady	1889-66	77	- 59.40	-0.77

of Cochin harbour. During the first stage of this developmental work, a series of parallel groynes were constructed on either sides of harbour entrance. Later, combination of seawalls and groynes have been constructed at various other locations experiencing severe erosion. Though these structures have shown some effectiveness initially, failures have been reported subsequently, apart from their adverse effects on the nearby beaches. Spectacular evidences of such adverse effects could be seen south of Cochin harbour at Saudi, Manassery and Chellanam (Murty et al., 1980). Of late, the protection method adopted to most of the parts of Kerala coast is the construction of seawalls alone.

1.7. SCOPE OF THE PRESENT STUDIES

Earlier investigations pertaining to beach processes along this coast include: (i) studies on wave refraction (Das et al., 1966; Varma, 1971; Reddy and Varadachari, 1972; Shenoi and Prasannakumar, 1982), (ii) the beach morphological changes (Murty, 1977), (iii) the shoreline deformations in relation to shore protection structures (Erathupuzha and Raman, 1970; Moni, 1972; Murty et al., 1980) and (iv) the estimation of littoral drift (Prasannakumar et al., 1983).

The present study aims to examine the cause and effect of the shoreline processes in relation to the stability of the beaches around Cochin. These investigations include studies on nature and extense of the role of waves, littoral currents and beach characteristics in deciding the changes as observed on the shoreline sector from Azhikode to Anthakaranazhi. The results of this study would provide the basic information required for selection of the most appropriate and effective beach protection systems from the available ones.

1.8. AREA UNDER INVESTIGATION

A stretch of about 57 km of shoreline from Azhikode to Anthakaranazhi has been investigated (Fig.6). The shoreline is oriented in a NNW-SSE direction and varies in its width from place to place. The beaches consists of sediments in the medium to fine sand-size class. On the northern end of this stretch, river Periyar opens out into the Arabian Sea at Azhikode. Midway between Azhikode and Anthakaranazhi lies the entrance to Cochin harbour. The width of the continental shelf off this part of the coast varies from 50 to 60 km with somewhat even bottom contours. The bottom topography on the northern side of the Cochin harbour channel presents gentle offshore slopes in contrast to steep slopes on the southern side of the channel. Very near to the shore, the bottom consists of sand and shell fragments upto 3 m isobath with silty-clays.

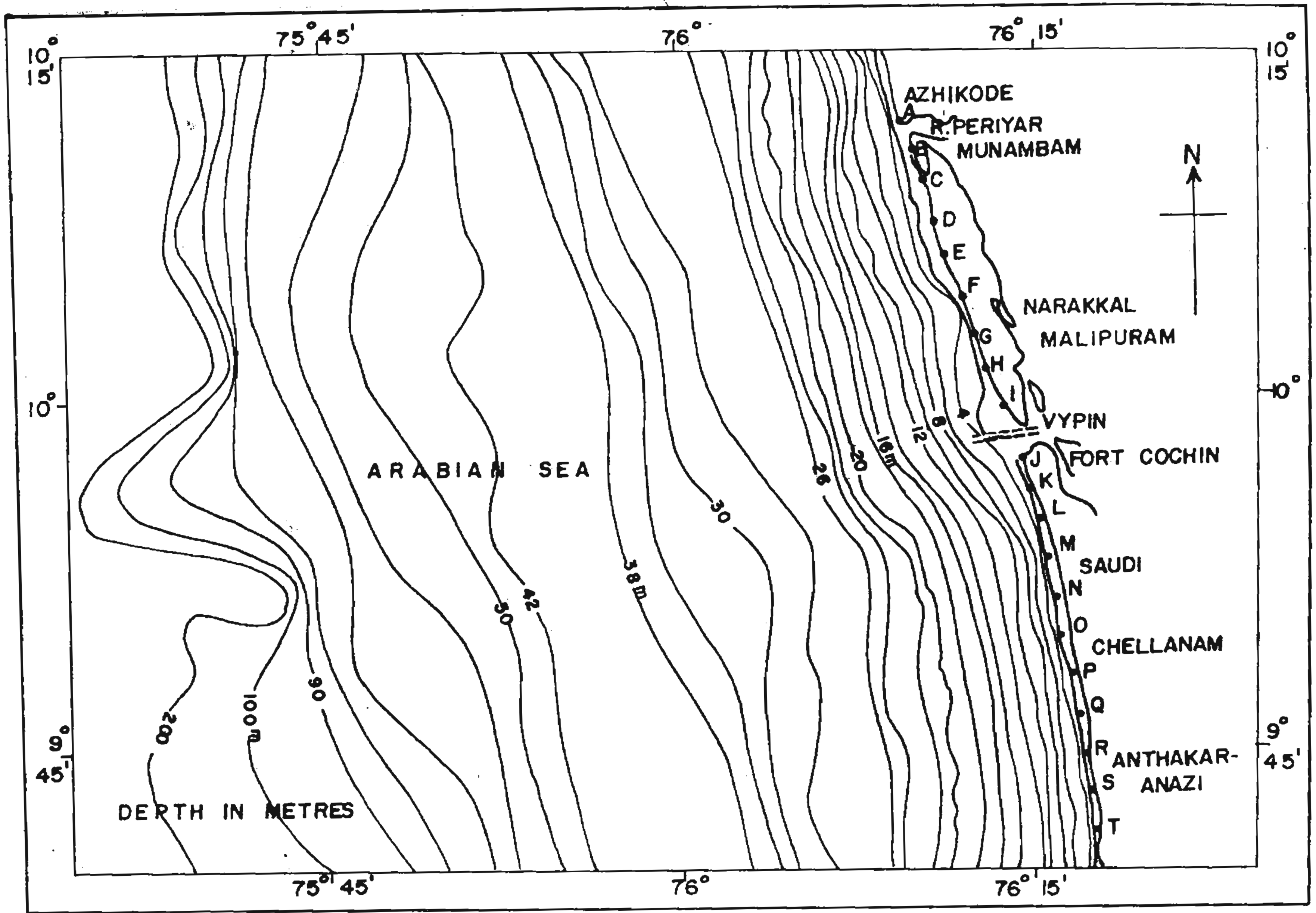

Fig. 6. Shoreline and offshore bathymetry of the area under study showing location of stations A to T

or clays beyond that (Nair and Pylee, 1968). At Narakkal and Malipuram the shore receives protection provided by the mud banks during the southwest monsoon season when they become active.

Four regions namely Narakkal and Malipuram on the northern side of the Cochin harbour entrance channel and Fort Cochin and Anthakaranazhi on the southern side of the Cochin harbour entrance channel have been chosen for this detailed study. The beaches at Narakkal and Malipuram have been selected to study the effect of nearshore mud deposits on the littoral processes and the adjoining beaches. The southern most beach at Anthakaranazhi has been selected to gain a better understanding of the littoral processes when the environmental parameters are nearly similar to those of the beaches on the northern side but free from the influence of mud banks.

Narakkal and Malipuram are two fishing villages situated on the 23 km long and 2 km wide Vypeen Island. At Malipuram, artificial shore protection structures exist well behind a wide, low backshore. The beach at Narakkal has been protected by a seawall-groyne assembly. These groynes, constructed during the early 60's have almost either collapsed or got burried.

The width of the beach at Fort Cochin varies from 70 to 120 m with seawalls constructed during late sixties far behind the effective foreshore.

At anthakaranazhi, about 24 km south of the Cochin harbour entrance channel, the low and sandy beach has been protected by seawalls. A small seasonal opening (called 'Azhi' in Malayalam) about 200 m wide, exists at this location and remains open throughout the southwest monsoon season.

Sixteen stations (Fig.7; Table 3) have been fixed for collection of data on beach profiles and other field observations at Narakkal (stations 1 to 3), Malipuram (stations 4 to 8), Fort Cochin (stations 9 to 12) and Anthakaranazhi (stations 13 to 16). The method of data collection and the results have been presented in the subsequent chapters.

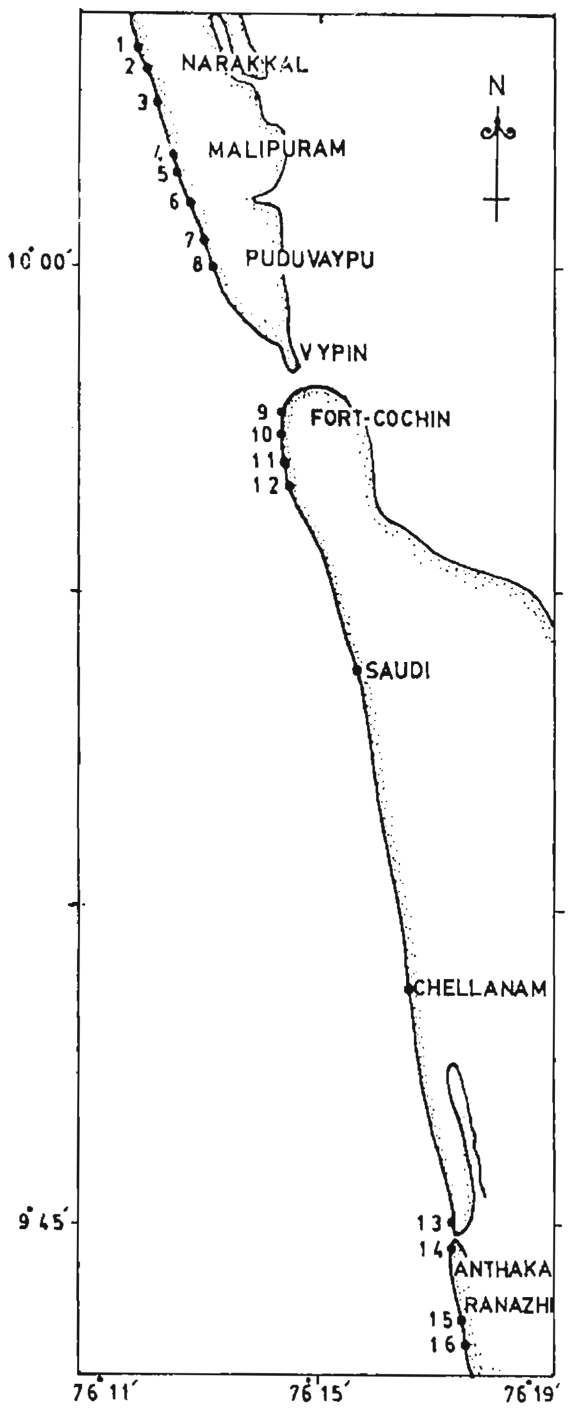

Fig. 7. Location of stations 1 to 16 selected for field observations.

TABLE 3

Location of stations 1 - 16 along the beaches around Cochin

Station No.	Station position		Region
	Latitude	Longitude	
1	$10^{\circ}03.41'$N	$76^{\circ}12.25'$E	
2	$10^{\circ}03.08'$N	$76^{\circ}12.33'$E	NARAKKAL
3	$10^{\circ}02.50'$N	$76^{\circ}12.50'$E	
4	$10^{\circ}01.75'$N	$76^{\circ}12.75'$E	
5	$10^{\circ}01.50'$N	$76^{\circ}12.83'$E	
6	$10^{\circ}00.94'$N	$76^{\circ}12.83'$E	MALIPURAM
7	$10^{\circ}00.44'$N	$76^{\circ}13.25'$E	
8	$10^{\circ}00.00'$N	$76^{\circ}13.42'$E	
9	$9^{\circ}57.75'$N	$76^{\circ}14.33'$E	
10	$9^{\circ}57.42'$N	$76^{\circ}14.41'$E	FORT COCHIN
11	$9^{\circ}57.00'$N	$76^{\circ}14.49'$E	
12	$9^{\circ}56.67'$N	$76^{\circ}14.58'$E	
13	$9^{\circ}45.00'$N	$76^{\circ}17.30'$E	
14	$9^{\circ}44.67'$N	$76^{\circ}17.28'$E	ANTHAKARANAZHI
15	$9^{\circ}43.50'$N	$76^{\circ}17.33'$E	
16	$9^{\circ}63.25'$N	$76^{\circ}17.33'$E	

CHAPTER 2

WAVE REFRACTION AND NEARSHORE WAVE CHARACTERISTICS

2.1. INTRODUCTION

Waves generated due to the direct effects of winds propagate radially outwards from their generating areas in the form of swells and expend considerable amount of energy within a shallow and narrow zone close to the beach through breaking. This wave energy has a paramount importance in the shoreline dynamics as it determines the beach profile and its constituent sediments. The variations in the distribution of energy along the shoreline and the resulting movement of water within the surf zone cause transport of sediments alongshore and away from the shore.

As waves propagate shoreward, part of their energy gets dissipated through bottom friction and percolation (Putnam and Johnson, 1949) in addition to breaking due to the development of caustics. The type of wave breaking and the depth at which breaking of waves occur near the shore depend largely on the wave steepness (ratio of wave height to wave length) and the slope of the nearshore bathymetry (Wiegel, 1964).

A wave moving from deep water into shallow water decreases in its length and speed continuously while its height increases (Kinsman, 1965). In shallow water (relative water depth $\frac{d}{L} < \frac{1}{25}$) the wave celerity depends only on depth and is proportional to the square root of the depth. Thus a wave moving over a variable topography possesses greater velocity in deep water as against shallow water. This leads to bending of waves commonly known as 'wave refraction' (O'Brien, 1942; Pierson et al., 1955; Wiegel, 1964). Waves may also be refracted by currents (Unna, 1942; Johnson, 1947; Barry, 1981).

The study of wave refraction enables one to understand how the deep water waves eventually propagate towards the shore and helps in identifying areas of divergence and convergence of wave energy along the shoreline. The areas of divergence and convergence, in turn, are important in demarcating the areas of accretion/ erosion and in the design of coastal structures. Following two basic methods - (i) graphical (Johnson et al., 1948; Munk and Aurther, 1951; Aurther et al., 1952; Saville and Kaplan, 1952), and (ii) numerical (Mehr, 1962; Griswold, 1963; Harison and Wilson, 1964; Wilson, 1966; Keulegen and Harison, 1970) - one could gain a better understanding of the refraction processes.

In addition to refraction, waves may experience either partial or total reflection from a barrier. Diffraction also may occur when a regular train of waves is interrupted by a barrier (Bretschneider, 1966a).

In the present Chapter, the distribution of wave energy along the shoreline has been obtained through a study of wave refraction and discussed along with the observed littoral wave characteristics.

2.2. MATERIAL AND METHODS

2.2.1. Deep-water wave characteristics

Information on wave climate off west coast of India is scandy. There have been very few attempts either to record the ocean waves (Dattatri, 1973) or to forecast them (Dattatri and Renukaradhya, 1971). Data pertaining to deep water wave climate obtained through visual observations have been utilised in this study as the data recorded with the help of wave recorders is very limited. Swell wave data in the neighbourhood of Cochin between latitudes 8°30'N and 11°30'N and longitudes 73°30'E and 76°30 E published by India Meteorological Department in the Indian Daily Weather Reports have been collected for the years 1974 to 1980. This data have been grouped according to periods, directions of wave approach and wave heights to compute their percent of occurrences for different months. The monthly percentage frequency of swell periods (Table 4) and the monthly percentage occurrence of swell directions and heights (Fig.8) have been obtained.

TABLE 4

Monthly percentage frequency of swell periods between Lat. 8°30'N and 11°30'N and Long. 73°30'E and 76°30'E

Month	Period (sec)									
	$\leq$5	6	7	8	9	10	11	12	13	$\geq$14
Jan	43.4	19.7	5.3	2.6	1.3	11.8	2.6	2.6	4.0	6.6
Feb	53.3	19.5	3.9	3.9	5.2	1.3	0	2.6	6.5	3.9
Mar	23.3	30.0	6.7	15.0	5.0	3.3	5.0	8.3	0	3.3
Apr	44.8	20.9	13.4	14.9	1.5	3.0	1.5	0	0	0
May	28.9	23.1	14.4	12.5	1.9	2.9	4.8	3.9	2.9	4.8
Jun	18.7	28.0	13.1	14.0	5.6	14.9	0	0	1.9	3.7
Jul	23.7	19.5	19.5	16.1	7.6	5.9	0.9	0.9	2.5	3.4
Aug	12.4	24.0	23.3	16.3	7.0	7.8	5.4	1.6	1.6	0.8
Sep	24.8	23.0	20.4	7.1	4.4	6.2	0	1.8	5.3	7.1
Oct	36.5	22.2	12.7	9.5	9.5	6.4	0	0	0	3.2
Nov	39.0	12.9	12.9	9.1	2.6	3.9	2.6	1.3	1.3	14.3
Dec	59.4	21.7	4.4	5.8	0	2.9	0	0	2.9	2.9

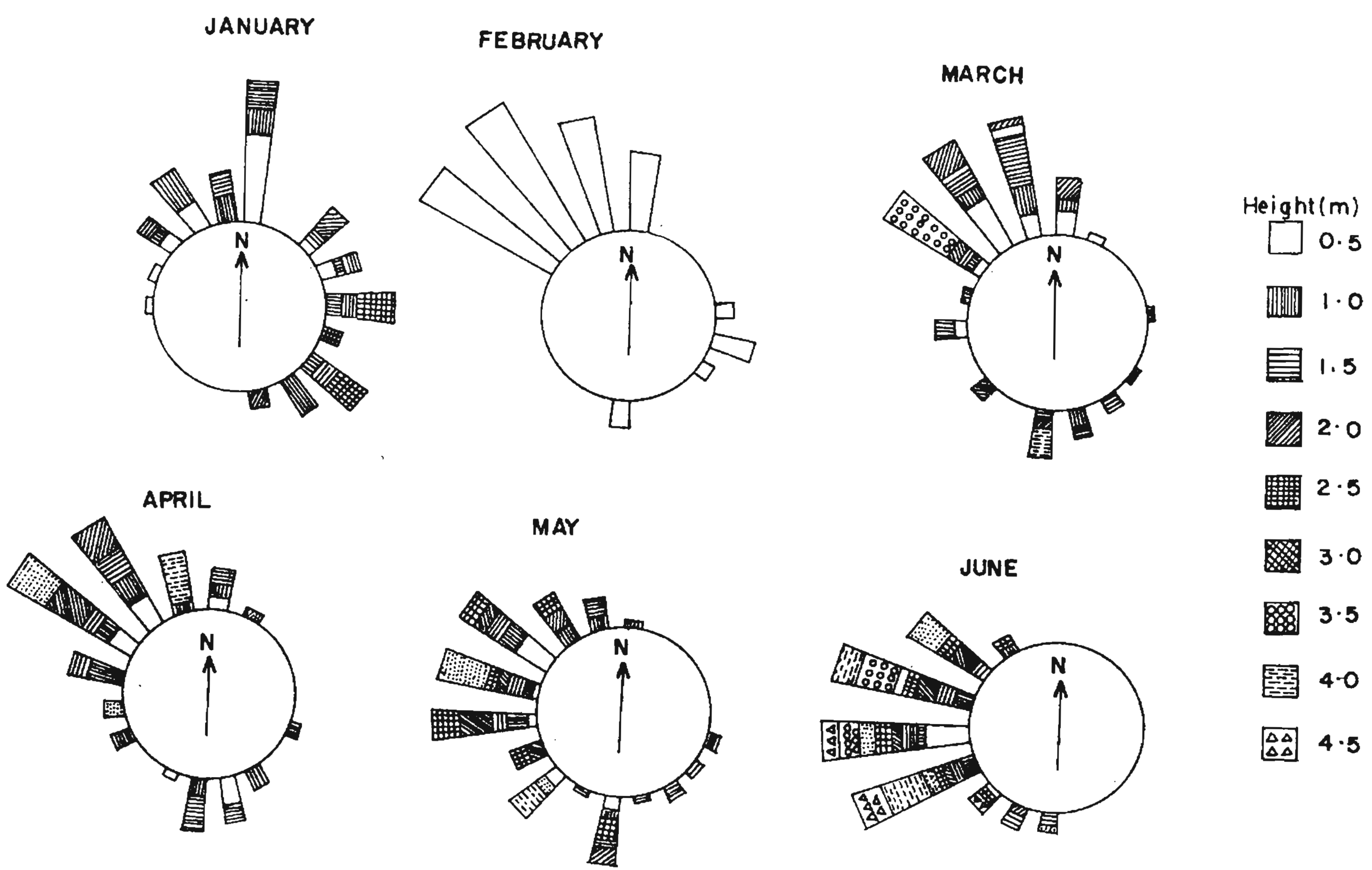

Fig. 8. Monthly percentage occurrence of swell directions and heights

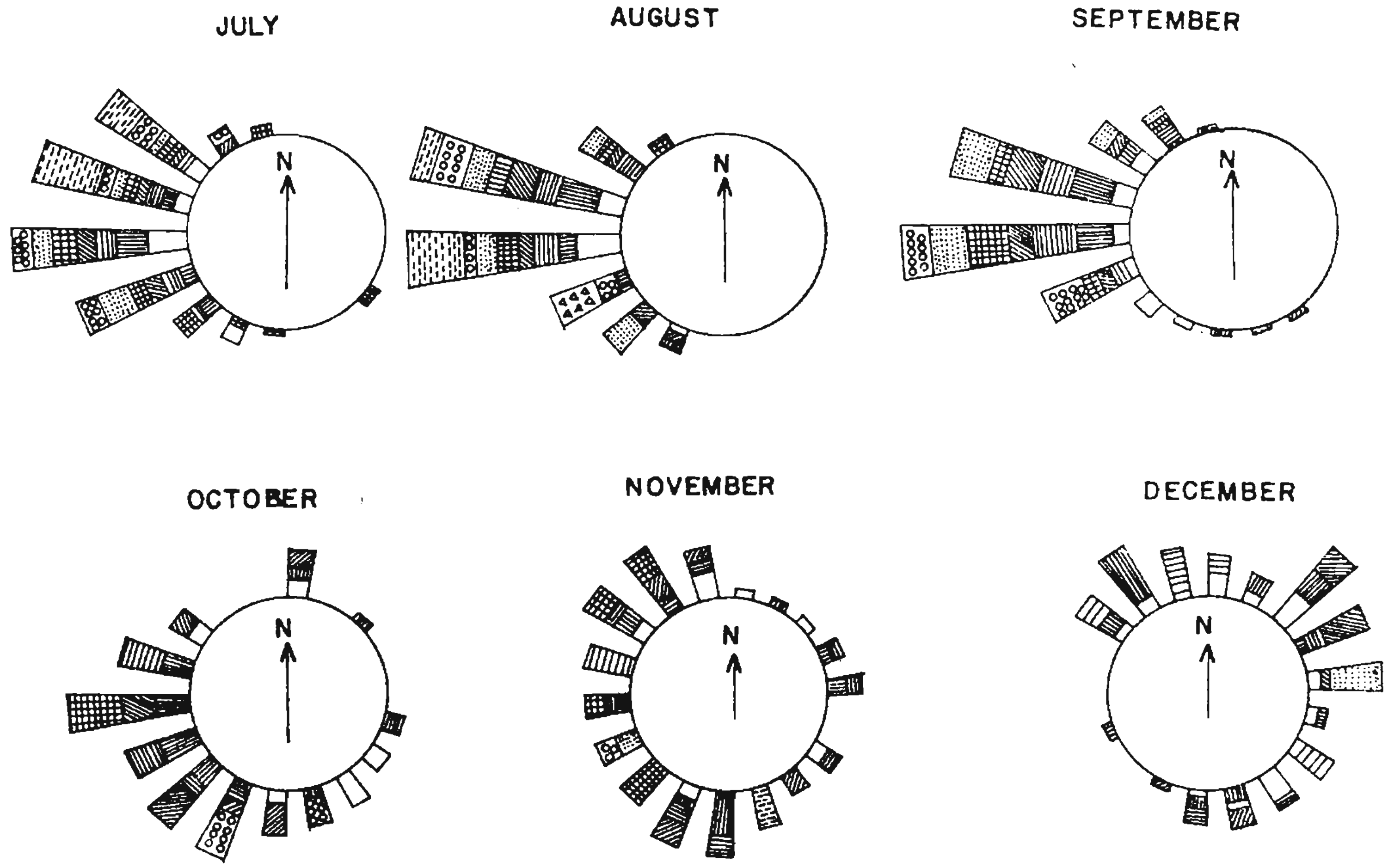

Fig. 8. (Contd.)

Considering the orientation (NNW - SSE) of the coast under study, the waves approaching from deep water directions between 170^{o} - 350^{o} TN are of significant influence in the littoral processes. Under random sea conditions, continuity could be noticed from the distribution of values for wave period and direction. However, to perform wave refraction analysis, representative set of wave periods (6,8,10,12 and 14 sec) and directions (220,240,260,280 and 300^{o}) have been selected.

2.2.2. Wave refraction

Wave refraction diagrams have been constructed graphically following Aurther *et al.* (1952). Bathymetric map (Chart No.220) prepared and published by the Naval Hydrographic Office, Government of India, Dehra Dun with corrections based on soundings upto 1971 have been utilized for this purpose. Refraction functions have been computed at 20 arbitrarily fixed points A to T covering the entire 57 km of the shore under study (Fig. 6) for five directions and five periods using the formula of Pierson *et al.* (1955).

$$K\,(f,\,\theta)^2 = \frac{b_o/b}{\frac{C}{C_o} + \frac{4\pi d}{L_o}\left(\mathrm{Sinh}\,\frac{4\pi d}{L_o}\,\frac{C_o}{C}\right)^{-1}}$$

where b_o and b are the distances of separation of wave rays in deep and shallow water, C_o and C are the speeds in deep and shallow waters, d is the water depth and L_o is the deep water wave length.

The wave heights at 2 m isobath have been calculated using the relation (Bretschneider, 1966b):

$$\text{i.e. } H = H_o \left[\frac{L_o}{L}\right]^{1/2} \left[\frac{b_o/b}{1 + \dfrac{4\pi d/L_o}{\text{Sinh}\,\dfrac{4\pi d}{L_o}}}\right]^{1/2} = H_o K^{1/2}$$

where the subscript 'o' stands for deep water parameters unaffected by refraction.

Of the 25 refraction diagrams constructed, the diagrams for waves with period 10 sec approaching from 260°TN and those with period 8 sec approaching from 280° TN have been presented in Figure 9 A and B. The angle θ (angle subtended by the wave orthogonal to the shore normal), taken from the refraction diagrams have been presented in Table 5. The magnitude of refraction function 'K' at each of the stations A to T at 2 m isobath has been indicated in Figure 10 A-E for various periods and directions of wave approach. The directions of the wave energy gradients along the shore for these periods and directions are also presented in the same diagrams. The wave heights computed along the 2 m isobath from the refraction functions have been shown in Table 6.

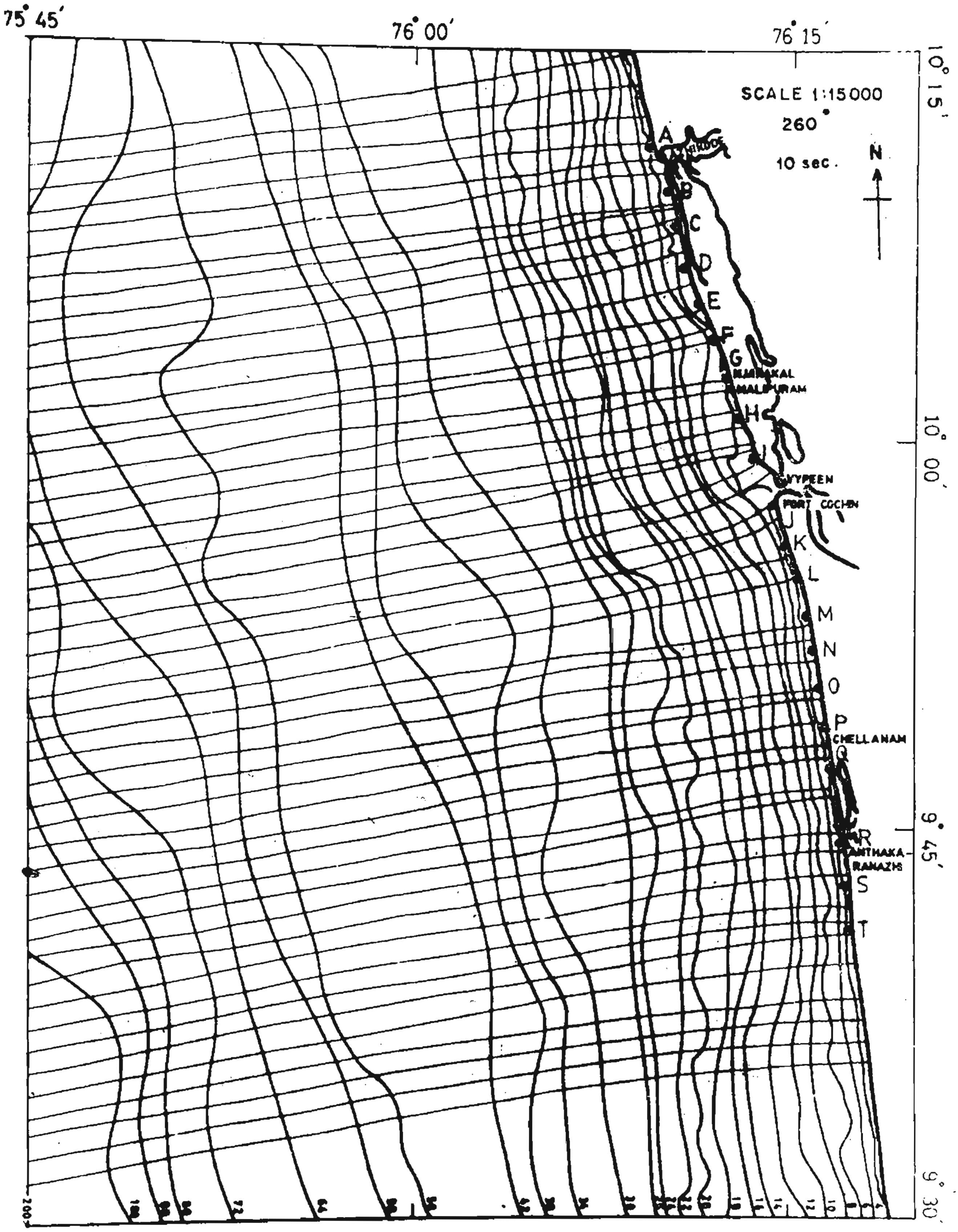

Fig. 9 A. Refraction diagram for waves with period 10 sec approaching from 260°

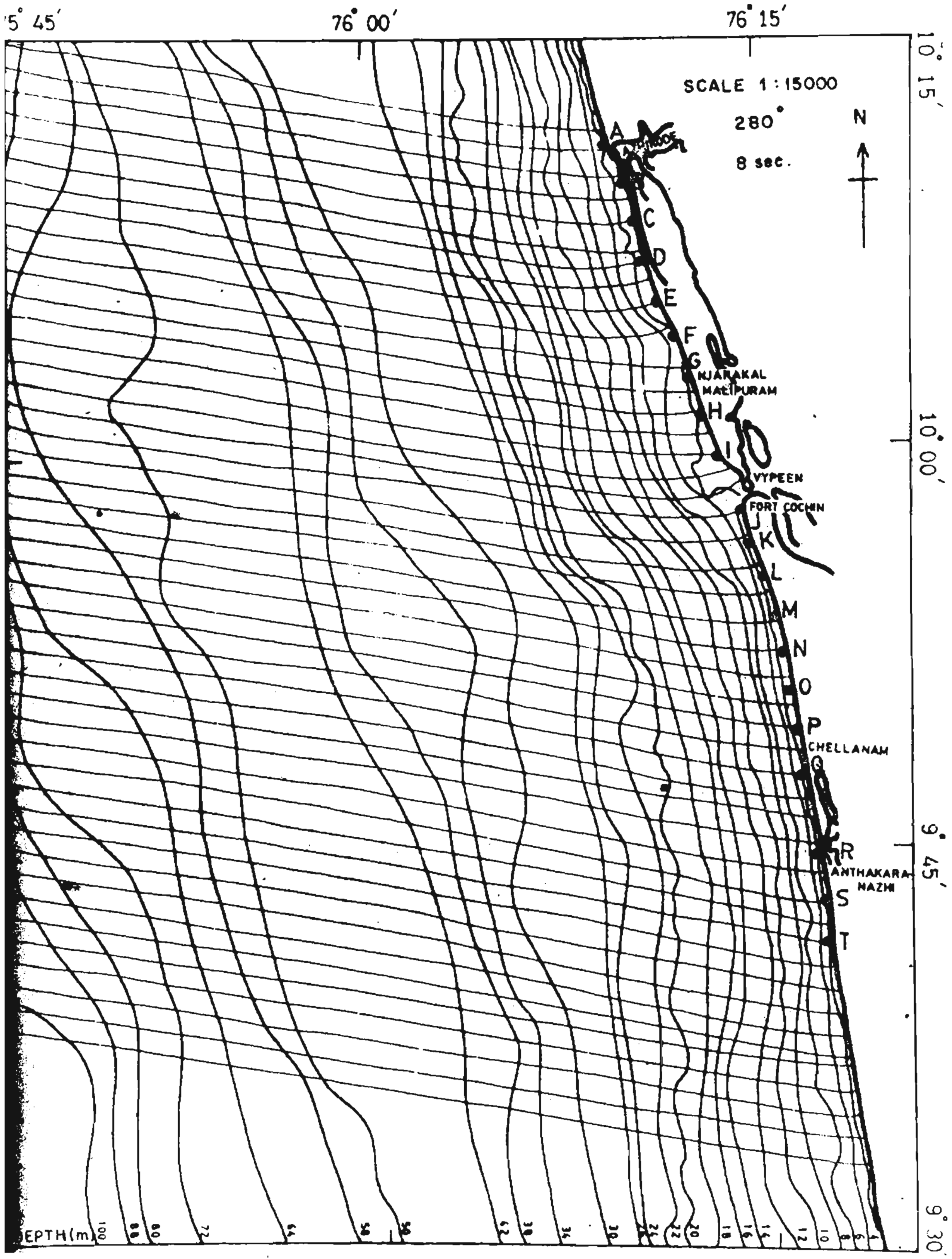

Fig. 9 B. Refraction diagram for waves with period 8 sec approaching from 280°

TABLE 5

Angle 'θ' for different directions of approach and periods at stations A to T

Stations	Period (sec)					Period (sec)				
	6	8	10	12	14	6	8	10	12	14
	Direction 220°TN					Direction 240°TN				
A	-15.0	- 7.0	-10.0	- 5.0	- 3.0	- 2.0	0	0	- 1.0	0
B	-20.5	-15.5	- 9.0	- 8.0	-13.0	- 4.5	- 3.5	1.0	- 4.0	- 3.5
C	-20.5	-15.5	- 9.0	-12.5	-18.5	- 7.0	- 2.0	- 2.0	- 7.5	- 5.0
D	-21.5	12.5	-13.0	-11.0	-12.0	- 6.2	- 5.0	- 4.0	- 5.0	- 5.5
E	-21.0	-19.0	-15.0	-15.0	-18.5	-10.5	- 8.5	- 6.0	- 8.0	- 7.0
F	-21.5	-12.5	- 8.0	- 7.5	-18.5	- 7.5	- 5.0	- 1.0	- 5.0	2.0
G	-14.5	-10.0	- 1.0	- 4.5	- 5.0	- 2.0	2.5	4.0	1.0	3.5
H	-17.5	-14.0	- 9.5	- 9.0	-11.5	- 4.5	0	1.0	- 2.0	- 3.0
I	-22.0	-23.0	- 6.0	-17.0	-18.5	-11.5	- 7.0	- 8.0	-11.0	- 9.0
J	-24.0	-14.0	- 6.0	-20.5	-23.0	-14.0	-15.0	-13.0	-10.0	-13.0
K	-23.0	-15.5	-13.0	-10.5	-13.5	-10.5	- 9.5	- 8.0	- 8.0	- 6.0
L	-23.5	-19.0	-13.0	- 9.5	-11.0	-13.0	- 7.0	-10.0	- 8.5	- 8.0
M	-21.5	-13.0	- 8.5	- 9.5	- 6.0	- 7.5	- 3.5	- 2.5	- 6.0	- 2.5
N	-25.5	-17.0	-11.0	-11.5	-10.0	-12.0	- 6.5	- 4.0	- 5.0	- 3.5
O	-25.6	-17.5	-12.0	-14.5	-12.0	-14.5	- 7.0	- 6.5	- 8.5	- 5.5
P	-25.0	-18.0	-15.5	-14.5	-13.5	+13.0	- 7.5	- 7.0	- 7.5	- 7.0
Q	-25.5	-19.5	-14.5	-15.0	-14.0	-13.5	-11.5	- 9.0	-11.0	- 7.5
R	-	-14.0	-10.5	-13.0	-18.0	-13.0	- 5.5	- 6.0	- 8.0	- 6.0
S	-	-20.0	-13.0	-14.5	-11.0	-15.0	- 9.0	- 8.0	- 9.0	- 7.0
T	-	-14.0	-12.0	-	-	-14.0	- 6.5	- 5.5	- 5.0	- 4.5

+ indicates angle measured towards north
- indicates angle measured towards south

TABLE 5 (Contd.)

Stations	Period (sec)					Period (sec)				
	6	8	10	12	14	6	8	10	12	14
	Direction 260°TN					Direction 280°TN				
A	8.0	12.0	11.0	12.0	5.0	20.0	19.0	19.0	10.0	13.0
B	7.0	8.0	8.0	4.5	5.5	23.5	20.0	15.0	11.5	11.5
C	4.0	8.0	6.0	2.5	5.5	21.0	19.0	16.0	9.0	11.0
D	2.5	5.0	2.5	-1.0	1.0	21.5	16.0	13.0	7.5	6.5
E	1.0	7.0	3.5	-1.0	2.0	16.5	12.0	8.0	2.5	4.0
F	0.5	3.5	1.0	-0.5	0.5	11.5	6.0	18.0	1.0	8.0
G	8.0	12.0	11.0	11.0	15.0	24.5	23.0	19.0	17.5	17.0
H	7.5	11.5	9.0	3.0	5.0	22.0	22.0	16.0	13.0	12.0
I	3.5	8.0	7.0	-2.0	-2.5	22.0	20.0	13.5	8.5	6.0
J	-4.0	-3.0	-5.5	-9.0	-12.5	8.5	12.5	1.5	-7.0	-2.0
K	-0.5	-2.0	-4.0	-4.0	-6.5	13.0	10.0	1.5	-1.0	-5.0
L	0	-1.0	-4.5	-4.0	-4.5	-10.0	2.0	-1.5	1.0	-1.5
M	3.0	6.5	4.0	3.5	3.5	18.5	12.5	11.5	7.5	7.0
N	2.0	6.0	4.5	3.0	4.0	17.0	9.0	11.0	8.0	7.0
O	0	2.0	1.0	0	-3.0	15.0	10.0	11.5	5.0	6.5
P	0	4.5	1.0	-1.5	0	13.0	8.0	8.0	4.5	3.5
Q	-1.5	1.0	-2.5	-2.0	-4.0	12.5	8.5	5.0	2.5	0.5
R	-1.0	1.0	1.0	-3.0	-1.0	13.5	11.0	10.0	6.0	3.5
S	-3.5	2.5	0	-2.5	-3.0	11.0	9.5	6.5	4.5	5.0
T	-1.0	4.5	0.5	-0.5	0	11.5	15.0	10.0	7.0	8.5

TABLE 5 (Contd.)

Stations	Period (sec) 6	8	10	12	14
			Direction 300°TN		
A	29.0	22.0	22.0	29.0	25.0
B	30.0	27.5	19.0	15.5	18.5
C	32.5	26.5	19.0	14.5	12.5
D	30.0	25.0	18.5	11.5	13.0
E	21.5	19.0	17.5	9.0	7.0
F	23.0	21.5	16.0	18.5	7.5
G	30.0	28.0	23.5	21.0	26.5
H	32.0	27.5	16.0	18.0	26.0
I	32.5	24.5	20.0	9.5	11.0
J	24.5	9.5	1.5	0	-2.5
K	24.5	13.5	12.5	4.5	2.0
L	18.5	11.5	13.0	4.0	2.0
M	25.0	21.5	15.0	8.5	12.0
N	26.0	22.5	15.0	10.0	10.0
O	24.5	18.5	15.5	7.0	10.0
P	24.5	21.0	17.0	11.5	8.5
Q	22.5	17.0	12.5	8.0	6.5
R	20.0	19.5	18.0	5.0	6.5
S	20.0	14.0	13.5	10.0	10.0
T	27.0	21.5	16.0	10.5	11.5

TABLE 6

Wave height (H) calculated along 2 m isobath for unit deep water wave height (H_o) for different directions and periods of wave approach

Stations	Period (sec)					Period (sec)				
	6	8	10	12	14	6	8	10	12	14
	Direction 220°TN					Direction 240°TN				
A	1.15	1.41	1.17	1.46	1.48	1.21	1.22	1.66	1.14	
B	1.31	1.61	1.51	1.53	1.52	1.15	1.45	1.35	1.71	1.80
C	0.96	1.26	1.18	1.57	1.34	1.15	1.57	1.51	1.66	1.60
D	1.19	1.33	1.33	2.05	1.32	1.21	1.08	1.11	1.38	1.12
E	1.08	1.69	1.58	1.46	1.84	1.22	1.65	2.06	1.48	
F	0.89	1.01	1.09	1.73	1.32	1.04	1.03	1.02	1.35	
G	1.43	1.54	1.26	1.87	1.84	1.02	1.34	1.52	1.96	2.47
H	1.18	1.14	1.25	1.70	1.23	1.08	1.29	1.37	2.05	1.41
I	1.35	1.43	1.58	1.67	1.13	1.43	1.85	2.26	1.66	2.53
J	1.12	0.98	0.96	1.45		1.01	1.08	1.25	1.25	1.32
K	1.10	0.98	1.42	1.12		1.10	0.96	1.09	1.25	0.99
L	1.31	0.96	1.41	1.07	1.31	1.08	1.34	1.22	1.28	1.37
M	1.03	1.55	1.54	1.60	1.64	1.06	1.07	1.18	1.25	1.46
N	1.01	1.09	1.59	2.45	1.77	1.22	1.40	1.45	2.05	1.94
O	1.15	1.38	1.35	1.42	1.68	0.98	0.98	1.52	1.73	1.32
P	1.11	1.03	1.10	1.08	2.11	1.14	1.36	1.17	1.33	1.43
Q	1.05	1.34	1.18	1.38	1.22	1.16	1.06	1.41	1.64	1.94
R		0.93	0.91	1.29	1.55	1.08	1.15	0.90	1.31	1.69
S		1.34	1.66	1.57	1.46	0.99	1.19	1.46	1.08	1.12
T		0.95	1.35			1.05	0.95	1.37	1.27	1.67

TABLE 6 (Contd.)

Stations	Period (sec)					Period (sec)				
	6	8	10	12	14	6	8	10	12	14
	Direction 260^{o}TN					Direction 280^{o}TN				
A	1.03	1.36	1.30	1.56	2.33	1.05	1.12	1.16	1.48	1.43
B	1.01	1.26	1.49	1.62	1.86	1.11	1.16	1.30	1.46	1.84
C	1.14	1.38	2.98	1.87	2.11	1.11	1.26	1.09	1.33	1.40
D	1.01	1.16	1.54	1.25	1.25	1.17	0.99	1.37	1.71	1.34
E	1.05	1.85	1.17	1.57	1.18	1.11	1.23	1.22	1.20	
F	0.96	1.01	1.89	1.42		0.88	0.86	1.02	1.25	
G	1.09	1.43	0.96	1.80		1.01	1.14	1.30	1.53	1.56
H	1.08	1.14	1.37	1.55	1.16	1.08	1.19	1.17	1.35	1.22
I	1.06	1.19	1.35	1.84	1.56	1.26	1.37	1.37	1.79	1.74
J	0.89	1.07	1.25	1.39	1.44	0.95	1.03	1.24	1.71	1.29
K	1.02	1.43	1.23	1.19	1.12	0.99	0.98	1.16	1.41	
L	0.95	1.03		1.23	1.28	0.92	0.88	0.84	1.18	
M	1.08	1.01		1.32	1.52	0.88	0.99	1.17	1.12	
N	1.04	1.16	1.12	1.46	1.31	1.08	1.01	1.60	1.11	
O	1.18	1.38	1.25	1.71	1.86	0.98	0.98	1.25	1.31	
P	0.97	1.02	1.54	1.14	1.75	1.10	1.39	1.07	1.26	1.37
Q	1.08	1.26	2.11	1.58	1.32	1.06	1.19	1.57	1.41	1.16
R	1.01	1.04	1.41	1.60	1.32	1.03	1.19	1.11	1.15	1.36
S	1.04	1.11	1.04	1.67	2.95	1.06	1.11	1.19	1.46	1.55
T	0.96	1.11	1.66	1.64	1.19	1.26	1.26	1.45	1.32	1.88

TABLE 6 (Contd.)

Stations	Period (sec)				
	6	8	10	12	14
			Direction 300°TN		
A	0.98	1.07	1.21	2.29	1.60
B	1.10	1.23	2.36	1.42	1.49
C	0.91	1.69	0.81	1.35	1.43
D	1.05	1.12	1.39	1.45	1.94
E	1.03	1.14	1.66	1.46	1.46
F	0.79	0.91	0.90	0.89	1.01
G	0.88	1.19	1.15	1.23	1.15
H	1.06		1.01	1.25	1.22
I	1.16	1.08	1.30	1.16	1.20
J	0.86	0.88	1.32	1.15	1.80
K	0.89	0.91		1.57	1.09
L	0.75	0.89		1.38	
M	0.89	1.12	1.23	1.16	
N	1.01	0.99	1.39	1.45	1.09
O	1.07		0.87	1.16	0.93
P	1.07		1.32	1.18	1.86
Q	0.94	1.37	1.51	1.57	1.49
R	0.97	1.07	1.80	1.10	1.18
S	1.10	1.55	1.19	1.15	1.09
T	0.99	0.89	0.89	0.93	1.75

2.2.3. Observations of breaker characteristics

Data on mean monthly breaker characteristics observed along the beaches during the field surveys around Cochin have been presented in Tables 7 a to d. These have been arrived at based on measurements of breaker height, period and angle between the shoreline and breaking wave. Though the quality and quantity of this data do not justify any statistical analysis, they provide valuable information on the characteristics of breakers along the area under study.

Visual estimates of nearshore wave parameters were made at 16 stations (Fig.7) once in a week during the time of low tides. Wave period was obtained from the time taken for 11 wave crests to pass an arbitrary fixed point in the surf zone. The heights of ten consecutive breakers have been measured with the help of a graduated pole. The angle of wave approach at breaking has been determined using a planimeter compass.

2.3. RESULTS AND DISCUSSION

2.3.1. Offshore wave climate

Table 4 indicates that a considerable percentage of waves have periods $\leq$ 5 sec especially during October to April. Waves with periods greater than 11 sec have comparatively low percentage of occurrence during all the

TABLE 7a

Observed breaker height, period and breaker angle at Narakkal region

Month	Breaker height (m)			Breaker period (sec)			Breaker angle (°)		
	Stn.1	Stn.2	Stn.3	Stn.1	Stn.2	Stn.3	Stn.1	Stn.2	Stn.3
Nov '80	0.30	0.30	0.50	10	10	10	- 15	- 20	- 20
Dec	0.20	0.20	0.20	10	10	10	- 12	- 10	- 12
Jan '81	0.20	0.20	0.20	10	11	10	+ 15	+ 15	+ 15
Feb	0.20	0.20	0.20	8	8	-	+ ≤ 5	+ ≤ 5	-
Mar	0.40	0.40	0.35	8	8	8	+ 10	+ 12	+ 15
Apr	0.20	0.20	0	12	12	-	- 10	- 10	-
May	0	0	0	-	-	-	-	-	-
Jun	0.18	0	0	8	-	-	- 8	-	-
Jul	0.20	0.20	0.20	12	12	12	+ ≤ 5	+ ≤ 5	+ ≤ 5
Aug	0.10	0.10	0.10	15	15	15	-	-	-
Sep	0.18	0.20	0.22	9	9	8	+ 9	+ 8	+ ≤ 5
Oct	0.16	0.17	0.10	10	10	10	+ 10	+ 8	+ 8
Nov	0.35	0.35	0.40	10	10	10	- ≤ 5	- ≤ 5	- ≤ 5
Dec	0.10	0.10	0.10	10	10	11	+ 12	+ 10	+ 10
Jan '82	0.30	0.32	0.32	10	10	10	+ 9	+ 12	+ 10
Feb	0.45	0.45	0.40	8	8	8	+ 8	+ 10	+ 13

+ waves from north - waves from south

TABLE 7b

Observed breaker height, period and breaker angle at Malipuram region

Month	Breaker height (m)					Breaker period (sec)					Breaker angle (°)				
	Stn.4	Stn.5	Stn.6	Stn.7	Stn.8	Stn.4	Stn.5	Stn.6	Stn.7	Stn.8	Stn.4	Stn.5	Stn.6	Stn.7	Stn.8
Oct.'80	-	0.10	0.10	0.10	0.10	-	13	13	13	13	-	+≤ 5	+≤ 5	+≤ 5	+≤ 5
Nov	0.10	0.10	0.15	0.15	0.10	13	13	13	-	-	-15	- 15	- 12	- 10	- 10
Dec	0.10	0.10	0.10	0.08	0.08	12	12	13	-	-	-10	- 12	- 13	- 10	- 15
Jan '81	0.15	0.12	0.12	0.10	0.10	11	10	-	-	-	+10	+ 12	+ 10	+ 10	+ 12
Feb	0.10	0.10	0.08	0.10	0.10	10	9	10	11	11	+ 8	+ 8	+ 15	+ 10	+ 11
Mar	0.16	0.11	0.15	0.15	0.15	9	9	10	9	9	+≤5	+ 7	+≤ 5	+≤ 5	+ 10
Apr	0.10	0.	0	0.17	0	11	-	-	10	-	-≤5	-	-	-≤ 5	-
May	0	0	0.10	0.10	0.10	10	-	-	-	10	-	-	- 12	-≤ 5	-≤ 5
Jun	0	0	0.10	0	0.18	-	-	-	-	8	-	-	-	+≤ 5	-
Jul	0	0	0	0.11	0.15	-	-	-	12	12	-	+≤ 5	-	+≤ 5	+≤ 5
Aug	0.08	0.08	0.10	0.13	0.15	--	15	15	15	15	+≤5	+≤ 5	-≤ 5	-≤ 5	-≤ 5
Sep	0.20	0.20	0.10	0.15	0.15	8	8	8	8	8	+ 8	+ 7	- 10	- 10	- 10
Oct	0.30	0.20	0.20	0.20	0.20	11	11	11	11	10	+10	+ 10	-≤ 5	- 10	- 10
Nov	0.25	0.15	0.15	0.12	0.10	12	13	12	12	12	+11	+ 13	+ 8	+ 8	+≤ 5
Dec	0.10	0.10	0.10	0.10	0.08	11	11	12	11	10	+≤5	+ ≤5	+ 10	+≤ 5	+ 8
Jan '82	0.15	0.18	0.15	0.15	0.15	11	10	10	10	10	+≤5	+ 6	+ 8	+≤ 5	+≤ 5
Feb	0.15	0.15	0.20	0.20	0.20	9	9	9	9	9	+ 8	+ 10	+ 12	+ 12	+ 10

+ waves from north — waves from south

TABLE 7c

Observed breaker height+ period and breaker angle at Fort Cochin region

Month	Breaker height (m)				Breaker period (sec)				Breaker angle (°)			
	Stn.9	Stn.10	Stn.11	Stn.12	Stn.9	Stn.10	Stn.11	Stn.12	Stn.9	Stn.10	Stn.11	Stn.12
Nov '80	0.75	0.80	0.65	0.65	10	10	10	10	+≤ 5	+ 9	+ 9	+ 11
Dec	0.65	0.65	0.45	0.15	10	10	10	10	+ 8	+ 9	+ 8	− 10
Jan '81	0.95	0.80	0.55	0.15	9	9	10	10	+≤ 5	+ 12	+ 12	+ 13
Feb	0.73	0.55	0.35	0.25	10	10	10	9	+ 12	+ 8	+ 10	+ 14
Mar	0.43	0.45	0.20	0.19	9	9	9	9	+ 13	+ 11	+ 14	+ 13
Apr	0.65	1.00	0.87	0.69	10	10	10	10	+ 12	−≤ 5	+ 15	+ 11
May	0.63	0.69	0.40	0.40	8,9	9	8,9	8,9	+ 12	+ 10	+≤ 5	+ 10
Jun	0.23	0	0.10	0.20	6,7	−	−	6	+≤ 5	−	+≤ 5	+≤ 5
Jul	0.30	0	0.10	0	5,6	−	6	−	+ 7	−	+ 10	−
Aug	0.30	0	0	0	7	−	−	−	+ 10	−	−	−
Sep	0.50	0.50	0.40	0.30	8	7,8	8	8	+ 10	+ 10	+ 15	+ 15
Oct	0.45	0.45	0	0	8	8	8	−	+ 12	+ 10	−	−
Nov	0.20	0.25	0.20	0	8,10	8,10	8	−	+ 12	+ 10	+ 10	−
Dec	0.65	0.50	0.50	0.20	9	9	9	9	+ 10	+ 8	+ 8	+ 8
Jan '82	0.80	0.75	0.55	0.20	10	10	9	9	+≤ 5	+≤ 5	+ 10	+≤ 5
Feb	0.80	0.70	0.45	0.35	10	10	10	10	+ 11	+ 10	+ 9	+ 12

+ waves from north − waves from south

TABLE 7d

Observed breaker height, period and breaker angle at Anthakaranazhi region

Month	Breaker height (m)				Breaker period (sec)				Breaker angle (°)			
	Stn.13	Stn.14	Stn.15	Stn.16	Stn.13	Stn.14	Stn.15	Stn.16	Stn.13	Stn.14	Stn.15	Stn.16
Nov '80	0.90	0.85	0.85	0.85	10	10	10	10	0	0	$+\leq 5$	$+\leq 5$
Dec	0.85	0.85	0.85	0.90	10	10	10	10	$-\leq 5$	$-\leq 5$	$-\leq 5$	$-\leq 5$
Jan '81	0.50	0.40	0.55	0.55	10	10	10	10	0	$-\leq 5$	0	0
Feb	0.82	0.82	0.82	0.82	10	10	10	10	0	0	0	0
Mar	1.00	1.00	1.00	0.82	9	9	9	9	+ 12	+ 10	+ 12	+ 10
Apr	1.25	1.25	1.20	1.25	10,11	10	10	10	0	0	$+\leq 5$	$+\leq 5$
May	1.50	1.50	1.50	1.50	8	8	8	8	- 10	- 10	- 8	$-\leq 5$
Jun	2.00	2.10	2.25	2.80	5,6	5,6	5,6	5,6	$-\leq 5$	$-\leq 5$	$-\leq 5$	$-\leq 5$
Jul	2.25	2.35	2.25	2.25	6,7	6,7	6,7	6,7	$-\leq 5$	$-\leq 5$	- 8	- 8
Aug	0.92	0.82	0.82	0.82	7	7	7	7	+ 7	+ 8	- 7	- 8
Sep	1.75	1.60	1.75	1.75	8	8	8	8	$+\leq 5$	$+\leq 5$	0	$+\leq 5$
Oct	0.35	0.50	0.40	0.40	10	10	10	10	$+\leq 5$	$+\leq 5$	$+\leq 5$	$+\leq 5$
Nov	1.00	1.00	1.00	1.00	10	10	10	10	$+\leq 5$	$+\leq 5$	$+\leq 5$	$+\leq 5$
Dec	1.25	1.25	1.00	1.10	11	11	11	11	$+\leq 5$	$+\leq 5$	$-\leq 5$	$-\leq 5$
Jan '82	0.60	0.50	0.55	0.60	10	10	10	10	$-\leq 5$	$-\leq 5$	$-\leq 5$	$-\leq 5$
Feb	0.70	0.75	0.70	0.70	8,10	8,10	8,10	8,10	$-\leq 5$	0	0	0

+ Waves from north — waves from south

months. Amongst this, waves with 14 sec period have highest frequency of occurrence (14.3%) during November. During the southwest monsoon season (June - September) waves with periods 5,6 and 7 sec have the highest frequency of occurrence. In general, the higher period waves have greater percentage of occurrence during the fair weather season (October - May) than during the southwest monsoon season.

During October - February the predominant wave heights have been in the range 0.5 m to 1.0 m but during the southwest monsoon season (June - September) the waves attain heights of about 2.0 m. During this season nearly 70% of the waves have heights in the range of 1 to 3 m though values of 0.5 m to 4.5 m also occupy the spectrum (Fig. 8).

The prevailing waves have their predominant directions of approach between 300° to 10° TN during January to March. This shifts to 290° and 300° TN during April and May and then to 260°-290° TN by June. During October to December, the wave directions exhibit greater variability in contrast to the low variability during June - September.

These wave parameters show greater dependence on the wind distribution over the region. During the southwest monsoon season comparatively strong winds with higher constancy from W to NW blow over the Arabian Sea (Fig. 2), leading to the generation of the observed low period waves. During the northeast monsoon season the prevailing northeast winds, though not strong, produce fully developed seas. The waves from southwest with long periods during October to November probably have their source in the southern Indian Ocean.

A closer examination made with the use of wave records off Mangalore (Dattatri, 1973; Sundara Raman et al., 1974) and the data published in IDWRs reveal that the latter could be considered representative for studies of this nature.

The energy spectra of the waves recorded at Mangalore (Sundara Raman et al., 1974) shows biomodality in frequency during all the months except June and July. The energy spectra indicate two peaks at 7 sec and 12 sec during December to February, sharp peaks at 7 sec and 13 sec during March to April, almost uniform curve with mode around 10 sec during May through August, and two peaks during October and November. That is in general, the energy spectra show two peaks, one at lower period and one at higher period during October to May and a single peak during June to September. During the fair weather season, more than 90% of the time, the wave heights are less than 0.8 m but during the southwest monsoon period the wave heights are conspicuously more and for about 20% of the time they exceed 3.2 m, with 5.4 m being the recorded maximum (Dattatri, 1973).

In the present study the wave rose (Fig. 8) shows a considerable amount of waves approaching from directions other than 170^o to 320^o, especially during January and December. Eventhough these waves may not affect the area under study directly they do affect it indirectly. These waves moving offshore, opposing the incoming swell waves may lead to the development of short-crested, diamond shaped waves which give a glossy appearance in the nearshore regions through wave-wave interactions.

Furthermore, the high frequency waves generated by the land-sea breeze system (Chapter 1) contribute significantly during November to April as against the transient effect on incoming waves during transition periods. Sonu et al. (1973) found an increase in the wave heights and in the frequency of incoming waves during the periods of sea-breeze along the coast of Gulf of Mexico.

2.3.2. Wave energy distribution along the coast

The refraction function (K values) computed at all the 20 stations A to T (Fig. 6) could be taken as an index of probable incoming wave energy. The distribution of K values for various wave periods and deep water directions of wave approach along this stretch of the coast is discussed in detail in the following paragraphs.

Waves approaching the coast from 220° TN with periods of 12 sec show high energy concentrations at most of the stations with maximum values of 6.0 and 4.2 at stations N and D respectively. From the point of view of wave energy distribution, the second highest concentrations observed at most of the stations are associated with waves having 14 sec period. Comparatively low values of K could be noticed at stations P, L, K, J and A and higher values at stations S, O, M, I, G, E and B irrespective of wave period. Stations H, F and C show low values of K for all periods except 12 sec. In general the waves approaching from 220° have been found to be associated with higher energy concentrations along the coast north of Cochin harbour entrance channel (Stations I to A) compared to the stations (J to T) south of it (Fig. 10A). Thus when the direction of approach is 220°, the wave at 2 m isobath presents greater

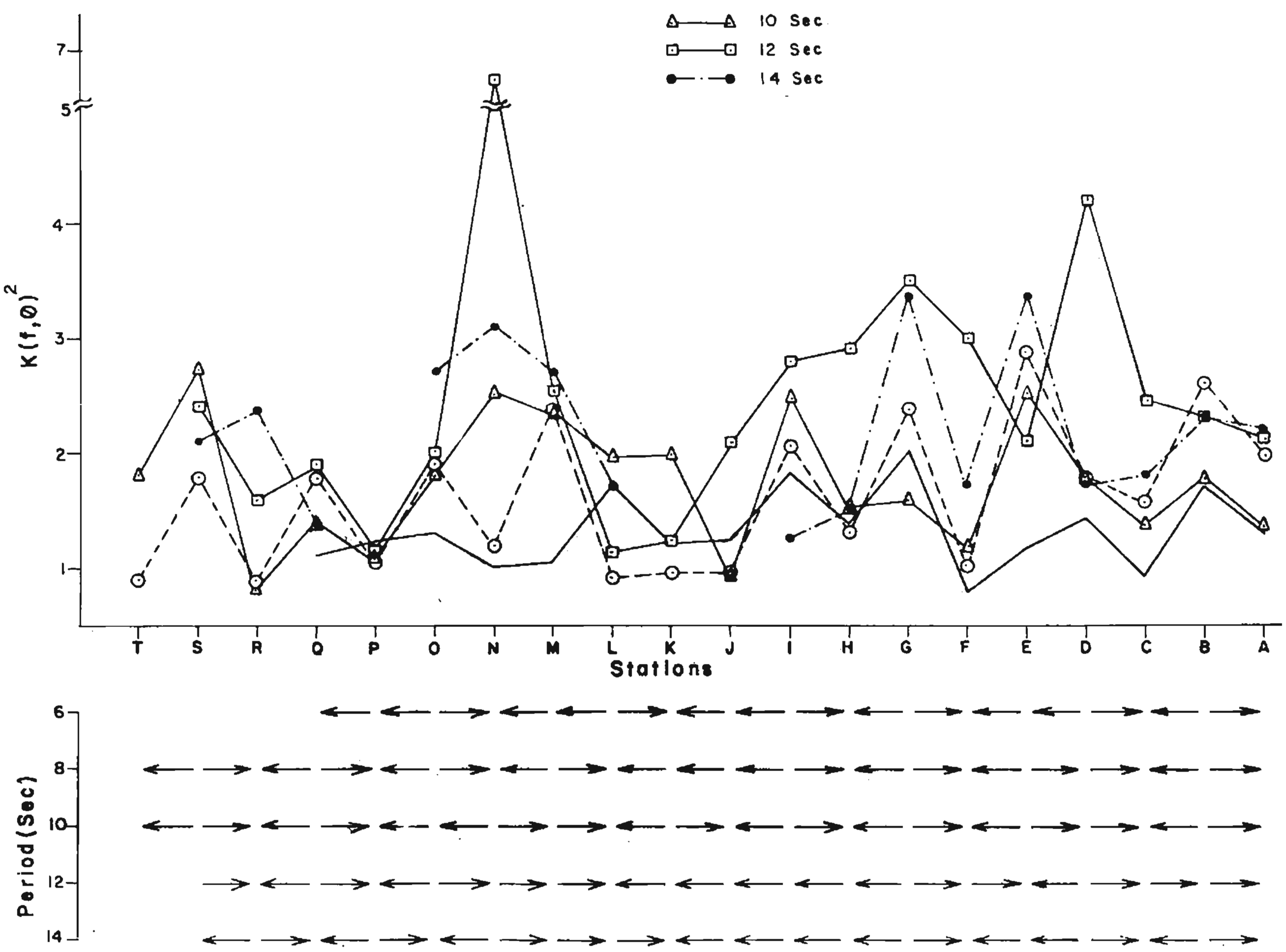

Fig. 10 A. Distribution of refraction function (K) along the shore

amplifications on the northern part of Cochin harbour compared to the southern part.

More zones of energy concentration with higher K values could be identified along 2 m isobath when waves approach the coast from 240^{o}. For this direction of approach, waves with periods 12 and 14 sec show very high energy concentrations at most of the stations (Fig. 10B).

Large K values have been found to be associated with waves approaching from 260^{o} TN at most of the stations. The refraction functions show general increase in K values from 6 sec to 14 sec at most of the stations. Stations Q, O, I and C have been identified as zones of higher energy concentration irrespective of the periods. From Figure 10 C it can be seen that K values are maximum at both northern and southern parts and minimum in the central part of the shore under study.

Comparatively low K values have been obtained for the waves from 280^{o} at most of the stations. The waves having 12 sec period seems to have the maximum K values at most of the stations. For this direction of wave approach, higher K values have been obtained on the northern side than that on the southern side of the Cochin harbour entrance channel (Fig. 10 D). Stations I and B are identified as zones of higher energy concentration whereas stations L and F are identified as low energy zones for all periods.

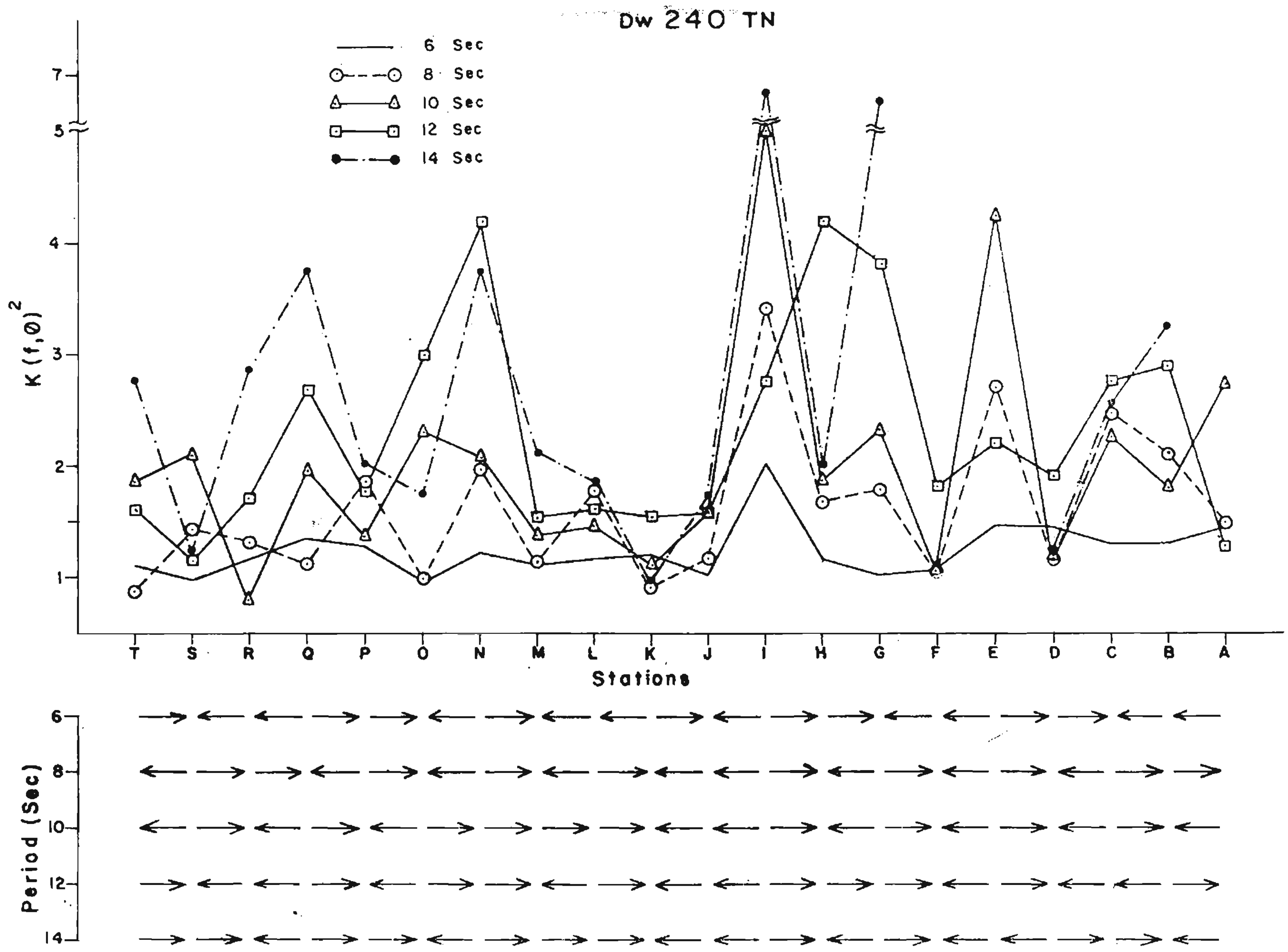

Fig. 10 B. Distribution of refraction function (K) along the shore for waves approaching from 240° TN (arrows indicate the

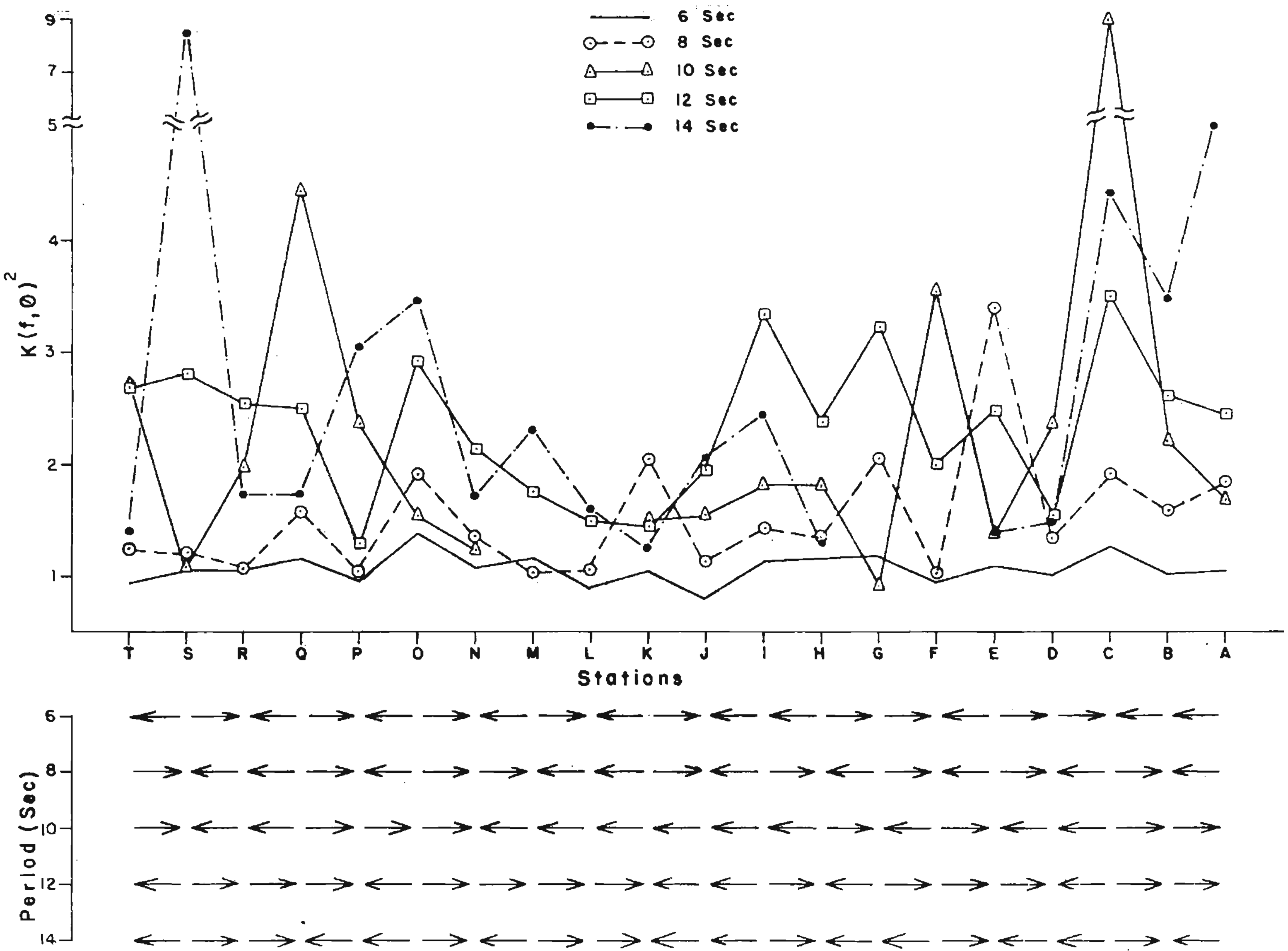

Fig. 10 C. Distribution of refraction function (K) along the shore

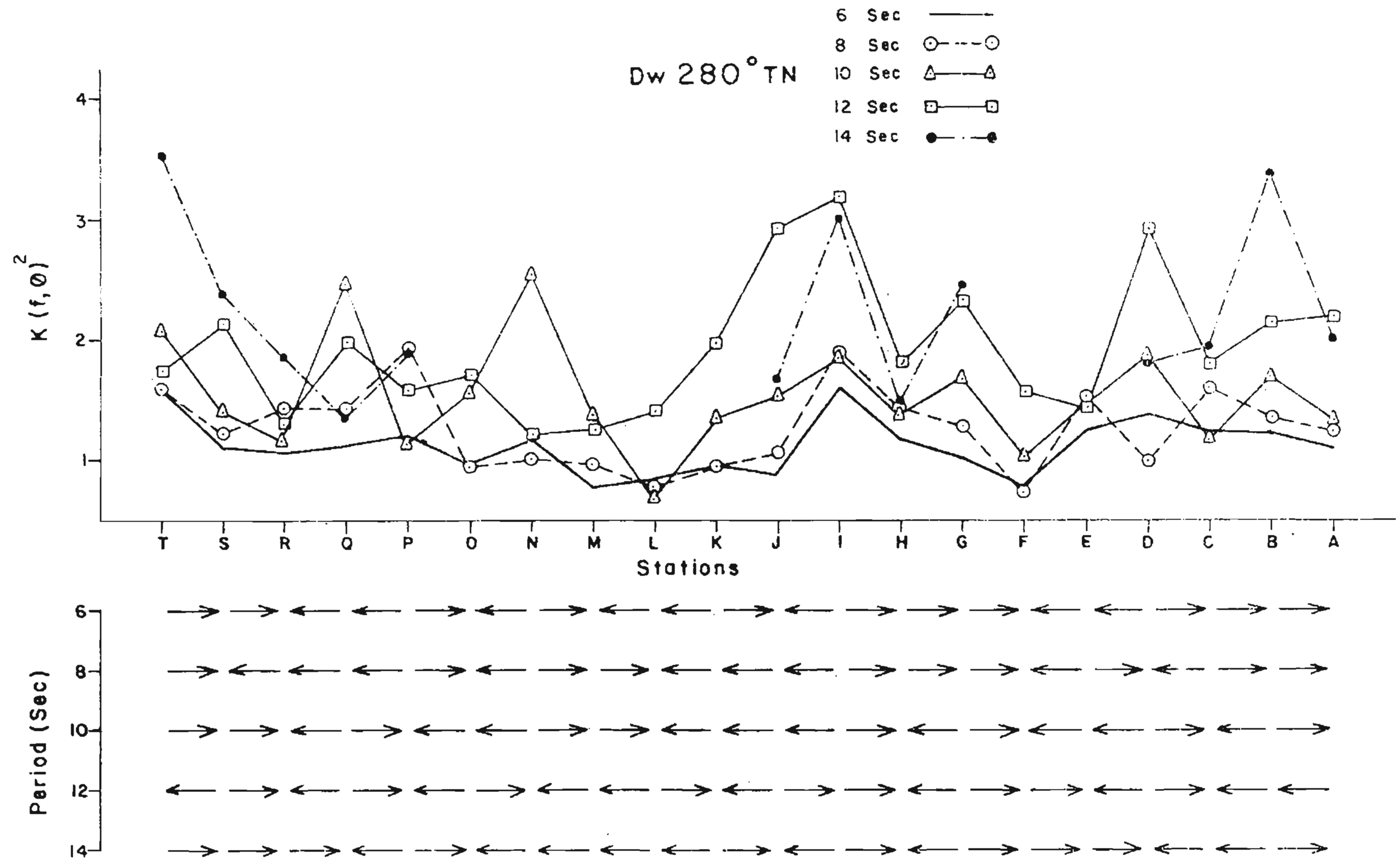

Fig. 10 D. Distribution of refraction function (K) along the shore for waves approaching from 280° TN (arrows indicate the directions of the wave energy gradients)

The K values obtained for waves from 300^{o} vary between the values obtained for 280^{o} and those obtained for other directions of wave approach. As seen from Figure 10 E, there exist alternate peaks and troughs of K values with maximum values at northern stations. The areas between stations A to E and P to S can be identified as zones of higher energy concentrations for this direction of wave approach. The K values at most of the stations show an increase with increase in the period.

The K values greater than 1.12 for 6 sec, 1.44 for 8 sec, 1.78 for 10 sec, 2.10 for 12 sec and 2.44 for 14 sec, corresponding to unit b_o/b, indicate convergence of wave energy due to wave refraction at different stations along the coast. The K values obtained in this study exceed by far these limits indicating strong convergences. It is also seen that higher the wave periods, greater is the intensity of energy convergence. More such areas of convergence for higher period waves along the beaches around Cochin have been reported by Das et al. (1966).

In general the K values seem to be higher when the waves approach the coast from southern quadrant than when the approach is from the northern quadrant, in addition to a general increase in the value of K with increasing wave period. Eventhough a shift in the zones

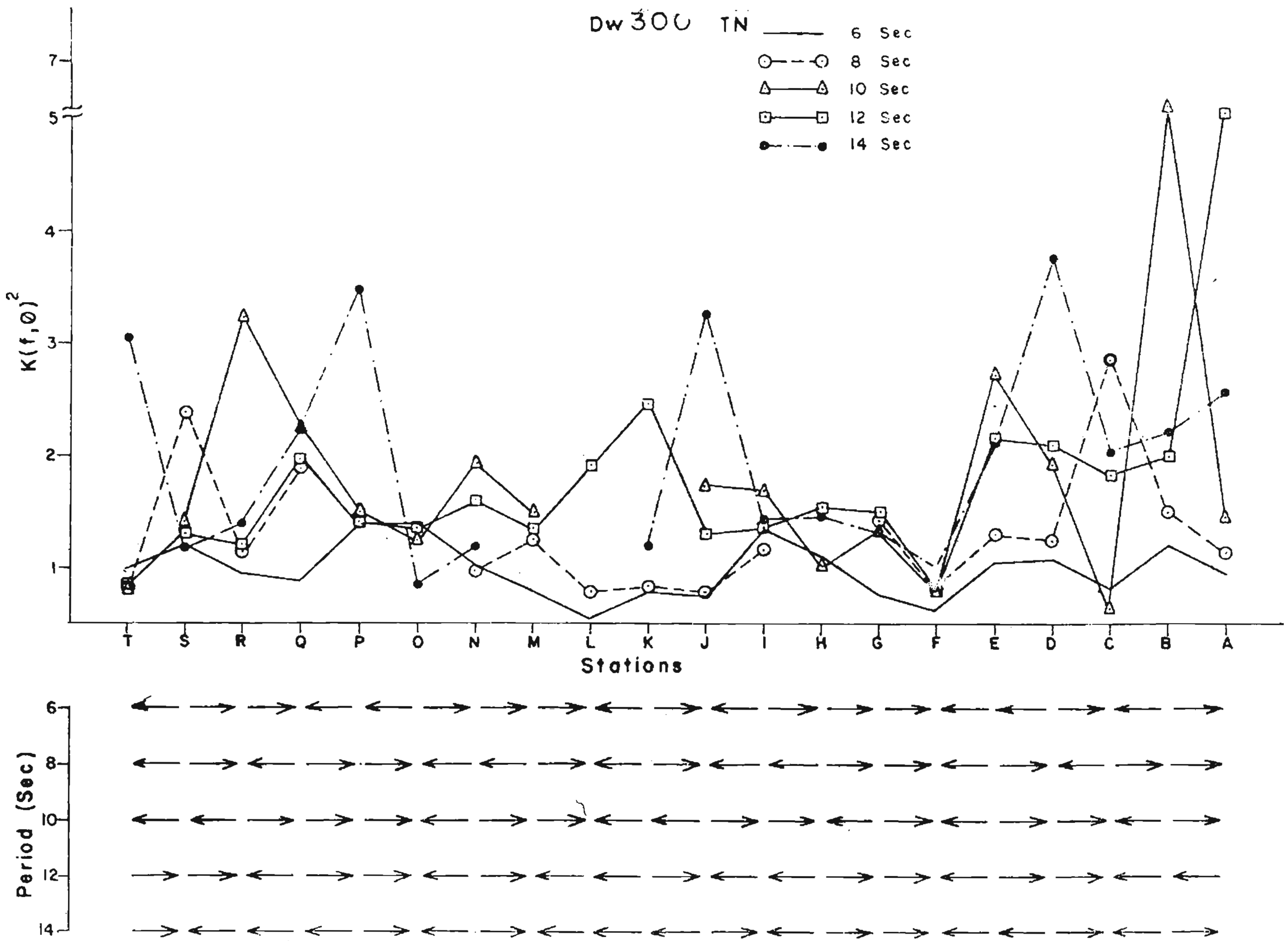

Fig. 10 E. Distribution of refraction function (K) along the shore for waves approaching from 300° TN (arrows indicate·

of convergence and divergence with changes in period and direction have been observed, certain stations exhibit energy concentration irrespective of periods for most of the directions. As seen from the Figures 10 A to E, a number of peaks exist on the southern and northern parts of the area under study indicating higher energy concentration at both parts. This is more so when the waves approach from 260°. The anomalous peaking up of K values observed at certain stations could be due to the concave nature of offshore bathymetry. These waves which peak up break prior to reaching the 2 m isobath.

The distribution of K values for different wave periods and approaching from various directions indicates the divergences and convergences of wave energy near the shore. The divergence of energy causes reduction of wave height and convergence leads to amplification of wave height. To ascertain this aspect, computations have been made on the ratio of the wave heights at 2 m isobath to unit deep water wave height (Table 6) using the relation $\frac{H}{H_o} = \sqrt{K}$. From this, it could be seen that for some zones with higher concentration of wave energy, the wave heights have been amplified by 2 to 3 times the deepwater wave heights. At many stations this ratio is greater than one indicating amplification due to wave refraction. This amplification in wave heights is more for waves approaching from 220, 240 and 260^{0} compared to waves approaching from 280^{0} and 300^{0} along many parts of the shore under study. As mentioned earlier, the wave refraction caused a very high convergence at certain locations. But these waves experiencing greater amplification might result in breaking before reaching the 2 m isobath through instabilities or caustics. Following the limiting wave height H = 0.83 d (Longuet-Higgins, 1972) the maximum height of the wave at 2 m isobath could be only 1.66 m. Thus, waves exceeding this limit would collapse prior to reaching the shore and subsequently expend the energy over a wider nearshore zone through spilling or multiple breakers. For 6 and 8 sec period waves, the nearshore wave heights are less than the limiting wave height of 1.66 m at 2 m isobath. Similar feature has been observed for 10 sec waves also. For higher periods, the wave height exceeds this optimum value at most of the stations. Thus the total effect due to the higher period waves may vary much from that expected from the action of lower period waves.

The angle 'Θ' made by the wave ray with the normal to the 2 m isobath gives an idea about the direction of the longshore currents generated due to the oblique approach of waves to the shoreline. The angles measured towards north and south of the normal to the 2 m depth contour are indicated with positive (+) and negative (-) sign respectively and zero indicates normal approach (Table 5). Comparatively larger angles were obtained for 6 sec period waves at most of the stations than for higher period waves. Das et al. (1966) also reported higher values of angle θ for lower period waves along this shoreline. Maximum breaker angles have been obtained at H and G for 300° waves with 6 sec period. The values of angle θ reported at these locations by Das et al. (1966) are in good agreement with the present values. For waves approaching from 220° and 240°, the angles measured are towards south of the normal, while the angles measured for waves approaching from 280° to 300° are towards north of the normal at most of the stations. The angles measured for waves of approach from 260° vary in direction at many stations.

A comparison of these predicted nearshore wave characteristics based on refraction diagrams with the observed breaker characteristics are presented in the following paragraphs.

2.3.3. Observations on breaking waves

Mean monthly breaker heights, periods and angles at 16 observation stations along the four beaches around Cochin are as presented in Tables 7 a to d. The observations at stations 1 to 3 along the Narakkal beach indicated maximum breaker heights of 0.5 m during November 1980 and practically negligible or calm conditions during southwest monsoon period. The breaker periods along this beach varied from 12 sec (April 1981) to 6 sec (September 1981). Large breaker angles (upto 20^{o}) were observed during November 1980, whereas during monsoon months, June - August, the breakers, whenever present, were more or less normal to the shore (Table 7 a). The monthly mean breaker heights observed along Malipuram beach (stations 4-8) varied from 0 to 0.30 m (Table 7 b). Breaker heights at station 4 were slightly more compared to other stations during any particular month. Monthly mean breaker angles were comparatively higher during non-monsoon months than during monsoon months.

Along the Fort Cochin beach during southwest monsoon season more or less calm conditions prevailed off stations 10, 11 and 12. Monthly mean breaker heights observed were generally higher at station 9 than those at the other stations. For a particular month the monthly mean period was found to be the same at all the stations. Breaker angles varied from $\leq 5^{o}$ to 15^{o}. The positive values of breaker angles show that most of the breakers approach the coast from northern quadrant. Monthly mean breaker heights along the beach in the vicinity of Anthakaranazhi (stations 13-16) varied from 0.40 m during the non-monsoon months to 2.5 m during the southwest monsoon season. The breaker heights did not show much variation from station 13 to 16 during any particular month. Breaker angles showed much lesser values along this beach compared to other beaches under study.

During the period of observation the beaches at Narakkal and Malipuram were protected by mud banks during the southwest monsoon season. During the other seasons the nearshore bottom was covered by unconsolidated mud deposits of varying thickness. The beach at Fort Cochin also was under the influence of mud banks (not so active like the mud banks at Narakkal and Malipuram) during June - August. A comparative study of the wave heights predicted from wave refraction diagrams and the observed breaker heights near the coast (Table 7) presents large anomalies, along the beaches sheltered by mud banks. At Anthakaranazhi where the shore was not protected by mud bank, higher breaker heights were observed compared to other beaches. These heights are comparable to the heights obtained from refraction studies. To understand the above anomalies in greater detail, maps (Fig. 11 A-C) showing the wave height distribution based on refraction diagrams

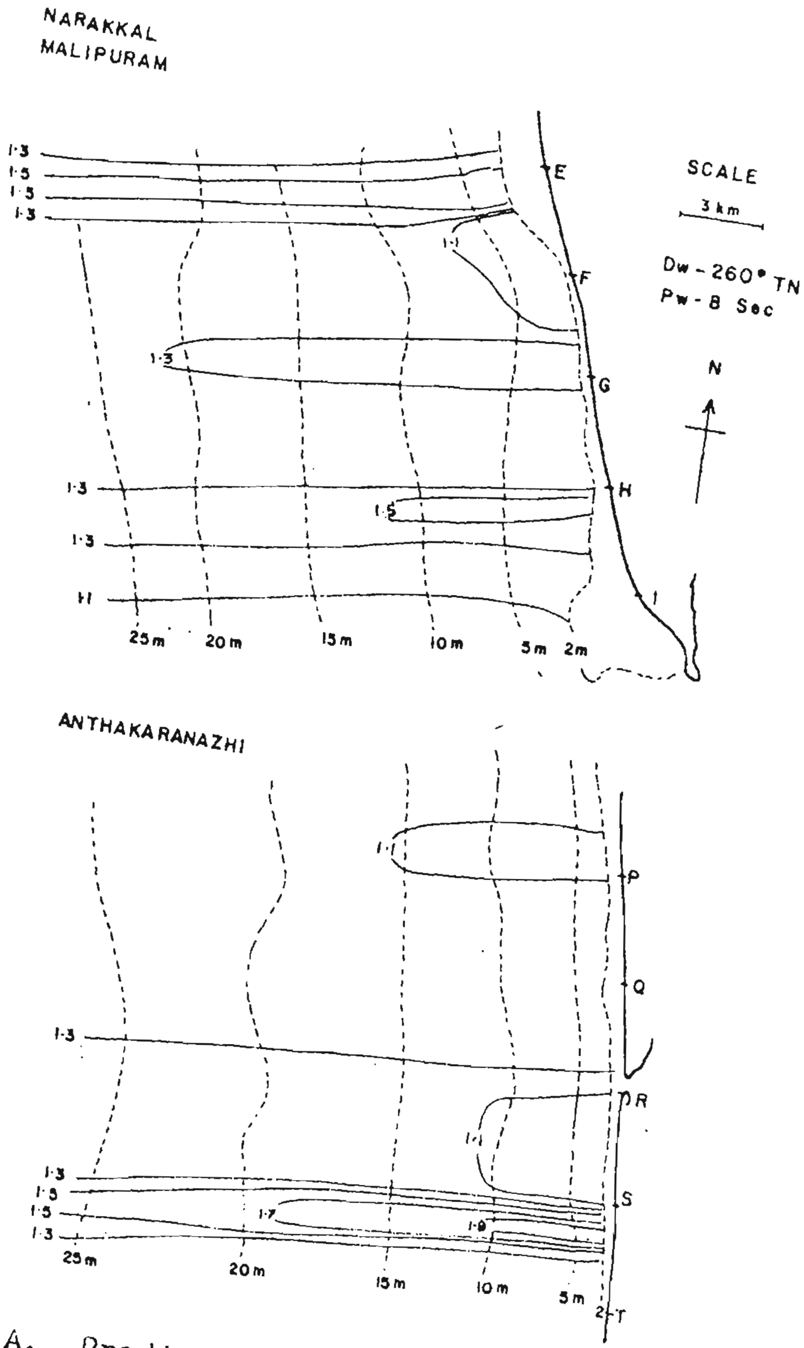

Fig. 11 A. Predicted wave height distribution in the Narakkal-Malipuram and Anthakaranazhi regions for waves of 8 sec approaching from 260° TN

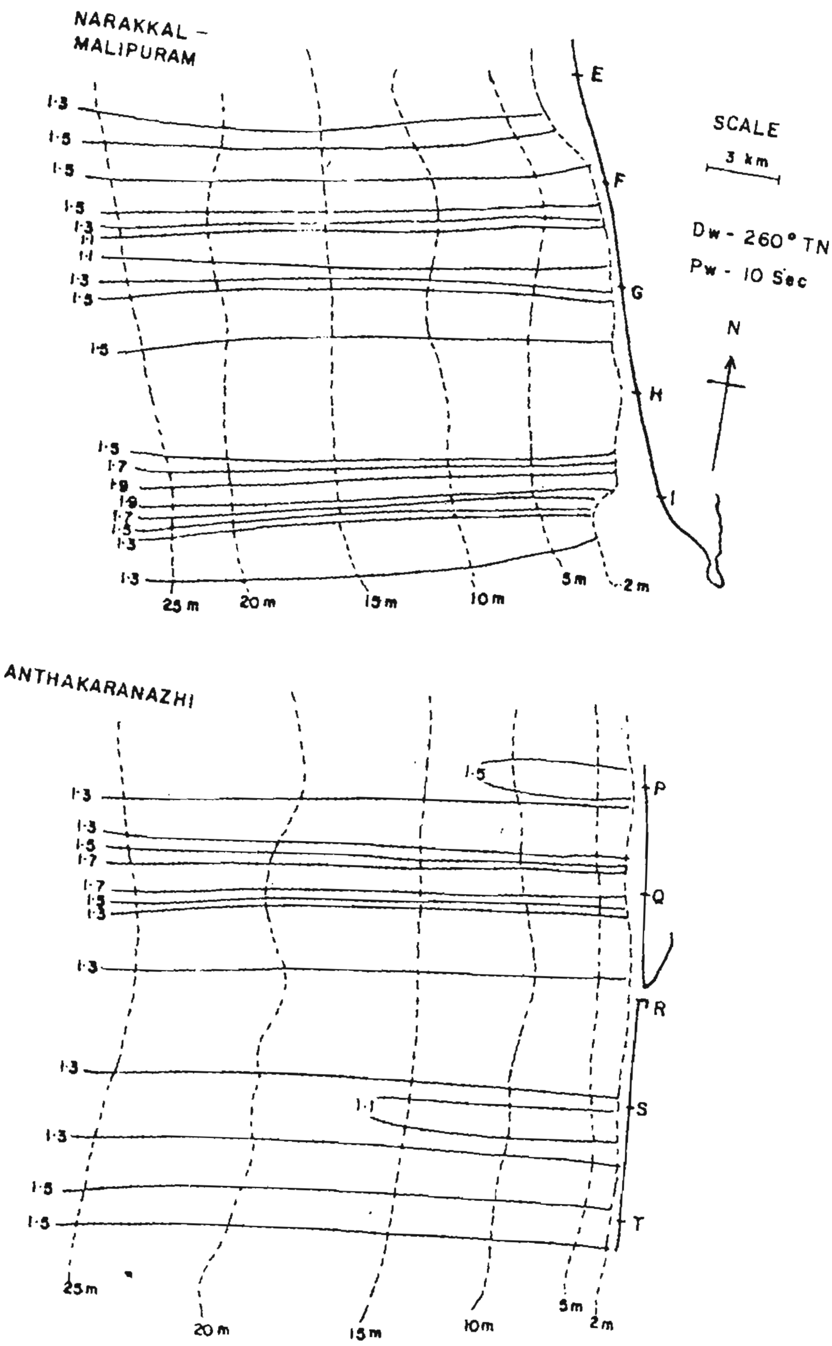

Fig. 11 3. Predicted wave height distribution in the Narakkal-Malipuram and Anthakaranazhi regions for waves of 10 sec approaching from 260° TN

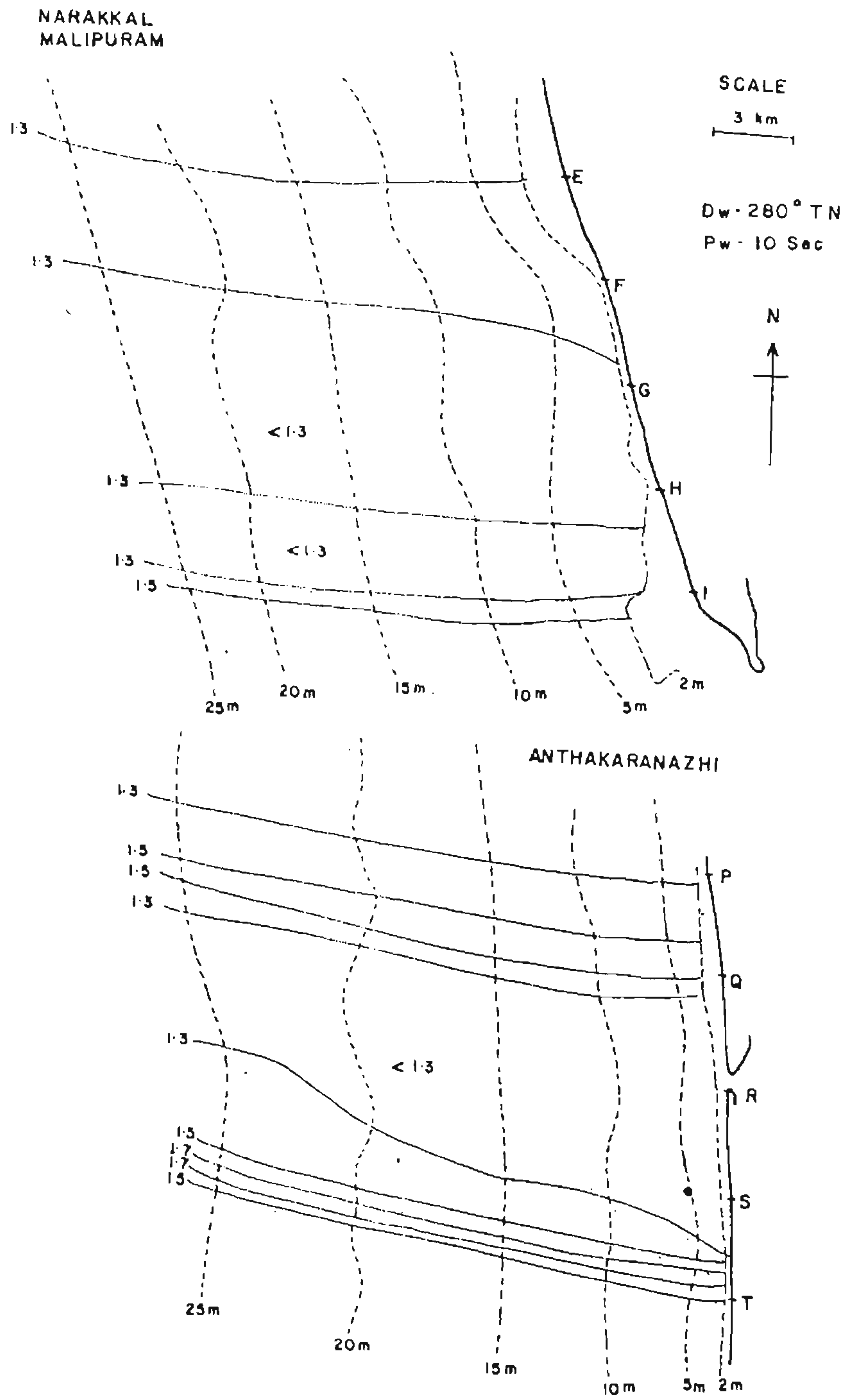

Fig. 11 C. Predicted wave height distribution in the Narakkal-Malipuram and Anthakaranazhi regions for waves of 10 sec approaching from 280° TN

have been constructed for the regions sheltered by mud banks (Narakkal-Malipuram) and for the region exposed directly to the incoming wave intensities (Anthakaranazhi). From these figures, an increase in wave height with decreasing water depth could clearly be observed as expected from the equations that govern the wave motion over a rigid bottom for inviscid fluids. But in the regions covered by mud banks the bottom is non-rigid and the fluid is highly viscous due to increased sediments in suspension. Under such conditions it will be interesting to see the fate of these waves having heights of about 1.3 m or more at the periphery of the mud bank at a depth of 7.5 m and about 5-6 km away from the shore as they propagate shoreward through the region of mud banks.

The effect of a fluid-mud bottom on waves has been noted for more than two centuries (Bristow, 1938). The periodic motion of the fluid produces in the first place boundary layers at both bottom and free surface. These oscillatory boundary layers have thickness of only few millimeters under normal conditions. The distribution of the mass transport associated with these waves are strongly influenced by the viscous boundary layers (Longuet-Higgins, 1953). Thus the high viscosities of the media and a fluid-mud bottom such as the one prevailing at Narakkal-Malipuram mud bank area may be to enlarge the boundary layer thickness expressed as

$$\delta = 5 \left(\frac{2\nu}{\omega} \right)$$

where ν is kinematic viscosity and $\omega = \frac{2\pi}{T}$, the radian frequency. With the increase of kinematic viscosity in the range of 1 to 10 cm^2/sec for 10 sec waves, the boundary layer thickness increases to 9 - 28 cm. However, ν values as high as 450 cm^2/sec have been reported by Keen (1938) for these mud banks. The thin vertical streaks obtained in the echograms from mud bank areas due to muds in suspension (Gopinathan and Qasim, 1974) show the possible existence of such high viscosities. Table 8 gives the boundary layer thickness for various viscosities and wave periods. The increased thickness of boundary layers would help transfer of wave energy to the interior of the fluid column. From the moment of starting the waves, the second order vorticity developed at the free surface would get transported into the fluid by viscous conduction, convection and by viscous diffusion (Longuet-Higgins, 1960). This energy transport into the fluid keeps the mud in suspension with increased viscosities. Thus the vorticity transported into the interior of the fluid

TABLE 8

Boundary layer thickness 'δ' (cm) for different wave periods and kinematic viscosities

ν (cm^2/sec) \ Period (sec)	6	8	10	12	14
0.001	0.22	0.25	0.28	0.31	0.33
0.01	0.69	0.80	0.90	0.98	1.06
0.10	2.19	2.52	2.82	3.09	3.34
1.00	6.91	7.98	8.92	9.77	10.56
10.00	21.85	25.23	28.21	30.90	33.38
100.00	69.10	79.79	89.21	97.72	105.56
450.00	146.59	169.26	189.23	207.30	223.91

dampens the waves through increased viscosities. This increased viscotity in turn transfers energy from the surface wave into the interior where it is dissipated through internal friction more rapidly. As such this mechanism appears to be a feed back system causing rapid decay of waves and maintain the mud bank active during the southwest monsoon season.

Wells (1977) observed that the incoming swells change their form from sinusoidal to solitary-like while propagating over fluid-mud. So, the theoretical rate of loss of energy owing to viscous shear beneath a solitary wave over a smooth horizontal surface (Keulegan, 1948) could be used to determine the rate of loss of energy. Dean and Eagleson (1966) have shown that the amplitude attenuation of wave manifested by the rate of energy loss could be written as

$$\frac{dH}{dx} = -0.334 \left[\frac{\nu}{\sqrt{gd}.d}\right]^{1/2} \left[\frac{H}{d}\right]^{5/4}$$

where H is the wave height at depth d and x is the horizontal distance travelled by the wave.

Assuming an average depth of 3 m for Narakkal-Malipuram mud bank (Gopinathan and Qasim, 1974), it could be seen that a wave having a height of 1.5 m at the outer periphery (Fig. 12) of the mud bank looses 50% of its total energy over a distance of about 1.5 km and nearly 100% over a distance of about 4 km, for ν = 1 cm^2/sec. If ν = 0.1 cm^2/sec, the waves have to travel a distance of about 4 km for 50% dissipation of its energy. This indicates that kinematic viscosities in the range 0.1 - 1.0 cm^2/sec within the boundary layer could significantly attenuate the waves as they propagate through the mud banks.

Figure 13(A) shows the decrease in wave height with increase of viscosity for different wave heights at the outer periphery of the mud bank with all other conditions being same as above. When ν <0.01 cm^2/sec, there is no significant reduction in the wave height. But when ν increases to 0.1 cm^2/sec the decrease in wave height is considerable and the rate of change increases abruptly with further increase in ν to 1 cm^2/sec. When ν = 0.8 cm^2/sec, the wave height is about 15 cm irrespective of the initial wave height. This indicates that for a mud bank having a width of 5 km and average depth 3 m, whatever may be the wave height at the periphery the wave height near the shore will be constant ($\sim$15 cm) when ν = 0.8 cm^2/sec. This value of kinematic viscosity may be considered as critical value for a mud bank of the above descriptions. This critical ν value increases with

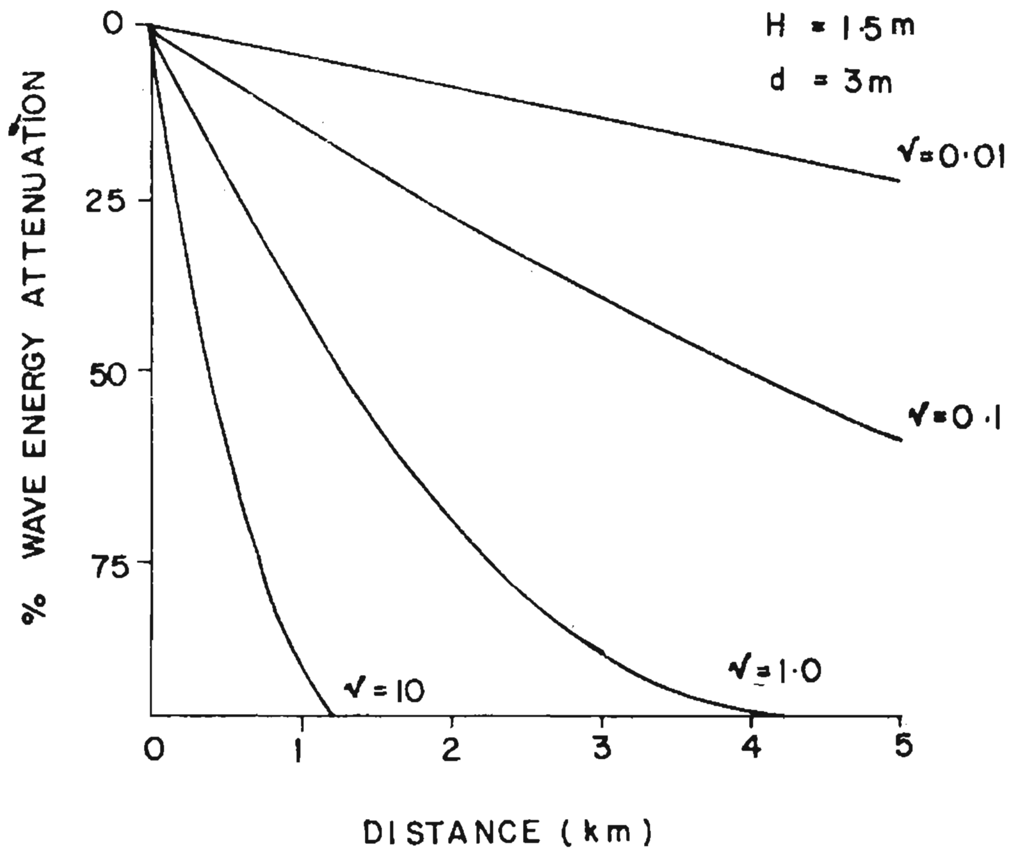

Fig. 12. Percentage wave energy attenuation for different kinematic viscosities of the fluid

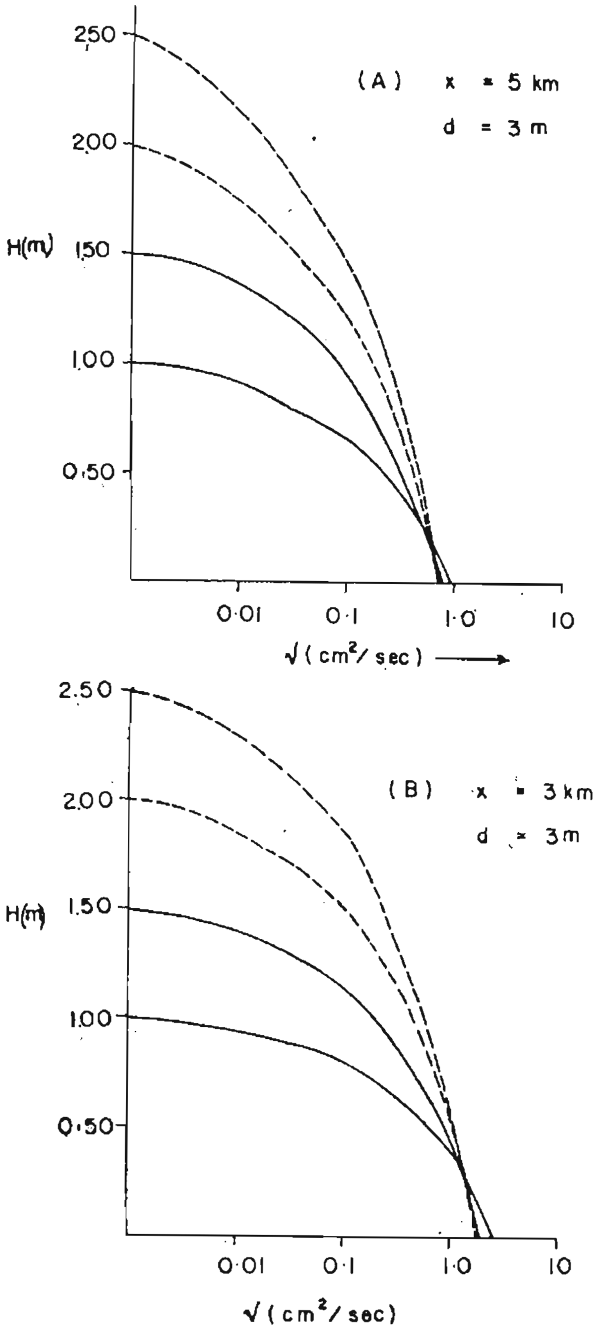

Fig. 13. Variation of wave height (H m)- with kinematic viscosity over a mud bank of width (A) 5 km and (B) 3 km

the decrease in the width of mud bank. For example, $\nu = 1.4\ cm^2/sec$ is required to reduce all the waves to $\sim$ 25 cm over a distance of 3 km (Fig. 13 (B)). Thus, over a particular distance, for a given ν and depth d, the higher waves will dissipate much faster than the waves having lower wave heights.

It must be kept in mind that the wave attenuation as discussed above will be valid if the bottom is smooth and horizontal. The soft muddy bottom may be considered as physically and hydraulically smooth as suggested by Wells (1977) for the nearshore region of Surinam coast. In the present study the bottom slope differs from zero and the water depth does not remain constant over the mud bank. Thus additional energy must be dissipated by higher near-bottom viscosities in the boundary layer or by other mechanisms.

Gade (1958) developed a theoretical model for a non-rigid, impermeable bottom and found that 2.0 ft high wave of 8 sec period travelling in 4 ft of water over a bottom with a layer of mud that is 1.5 ft thick and 1000 ft long, will be only 37% as high at the end of the stretch of mud as at the start. If the bottom is purely elastic there is zero decay when waves propagate over it (Mallard and Dalrymple, 1977; Mac Pherson, 1980). Dalrymple and Liu

(1978) developed a two layer fluid model to explain the damping of waves over soft muds. In this model they included a viscous upper layer and a more viscous lower layer. The results indicated extremely higher rates of wave attenuation when the thickness of the lower layer approached that of the internal boundary layer. Mac Pherson (1980) proposed a viscoelastic bed to develop a theoretical model for mud banks. He found peak energy dissipation occurring for the viscous bed than the energy dissipation for viscoelastic bed. Mac Pherson and Kurup (1981) developed a model similar to Gade's model to explain the wave damping at the Kerala mud banks. The process of wave damping using the above theory involves the generation of progressive oscillations in the soft fluid-like sea bed and as a result the waves are damped through viscous dissipation with the sea bed. Tubman and Suhayda (1976) have shown that an oscillating bottom can dissipate energy at a rate at least an order of magnitude greater than that resulting from bottom friction alone. But it is not known whether fluid mud over the mud banks oscillates vertically while maintaining its cohesive structure (Wells, 1977).

Varma and Kurup (1969) explained the disappearance of mud banks as due to the flocculated settlement of mud during the post-monsoon season when the salinity increases. This settlement of mud floccules will certainly provide a soft muddy bottom during the non-monsoon period also. If this is the case, there must be considerable wave damping as observed during southwest monsoon season in these areas, if the wave energy can dissipate over the soft muddy bottom as expalined in some of the models discussed earlier. But the fact is that in these areas the wave heights observed during the non-monsoon period are comparatively higher than that during southwest monsoon season (Table 7 a-b), eventhough the incoming waves are low compared to rough southwest monsoon. This type of behaviour of mud bank areas can also be explained if the wave damping through the boundary layer as explained earlier is taken into consideration.

The comparatively higher period waves observed at these mud banks during the southwest monsoon season when they are active may be due to higher rates of attenuation of high frequency waves with the increase in sediment concentration. When viscosity of water is increased significantly with the addition of sediment particles, internal friction may become important, especially for high frequency waves (Wells, 1977). On the west coast of Malaysia, Silvester (1974) has observed total attenuation of low period waves of around 4 sec over a distance of few wave lengths.

CHAPTER 3

LONGSHORE CURRENTS

3.1. INTRODUCTION

The complex nearshore processes change continually and derive their energy mainly from waves and currents. In the earlier chapter, the refraction of waves and wave energy distribution along the coast have been presented. The present chapter deals with the advective processes namely, the littoral currents generated by wave breaking near the shore.

Nearshore current system may be broadly classified into coastal currents and littoral currents. The coastal currents flow roughly parallel to the shore (tangential to the isobaths) beyond the surf zone (Inman and Bagnold, 1963; Wiegel, 1964). These include tidal currents, transient wind driven currents and those associated with the distribution of mass. Littoral currents are predominantly wave-induced motions confined to the surf zone. This chapter deals with such flows within the surf zone which have greater importance in the transport of sedimentary material. These currents and their associated circulation provide continuous exchange of waters of the surf zone to those of the offshore zone and act as distributing mechanisms for nutrients, land runoff, and other materials injected into the surf zone (Inman et al. 1971).

There are two types of wave induced current systems contributing to the water movements within the surf zone in addition to the to-and-fro oscillatory (orbital) motions associated with the wave. These are (1) longshore currents produced by the oblique approach of waves to the shoreline, and (2) a cellular circulation system comprising of rip currents and their feeders.

Several investigators have attempted to obtain a quantitative measure of the circulation pattern and arrived at a number of empirical solutions relating the magnitude of longshore currents to the wave parameters (Putnam et al., 1949; Inman and Quinn, 1952; Bruun, 1963; Galvin and Eagleson, 1965). The existing theories and their limitations have been reviewed by Galvin (1967). Subsequently, the generation of longshore currents in terms of longshore momentum flux (radiation stress) has been successfully described by Bowen (1969a) and Longuet-Higgins (1970 a and b). Later, on the basis of extensive field observations of the wave induced nearshore circulation cells and the meandering flows, Sonu (1972) stressed the importance of nearshore bathymetric features in the development of these current systems. Considering the interaction of an incoming system of uniform waves with a variable bottom topography, Noda (1972;1974) developed an analytical model for wave induced nearshore circulation. Later models, such as those by James (1974), Liu and Dalrymple (1978) and Ostendorf and Madson (1979), assumed arbitrary incident wave angles and longshore current strengths.

Converging longshore currents lead to the development of rip currents. The longshore currents which feed these rip currents have been investigated theoretically and experimentally by Bowen (1969b) and Bowen and Inman (1969) who found the alongshore variations in the height of incoming waves to be the principal driving force. These variations in wave height may be due to wave refraction or due to the interactions between the incoming waves with edge waves trapped within the nearshore region (Bowen and Inman, 1969). All these studies stress the importance of longshore variations in the breaker height or the oblique wave approach to the shoreline or a combination of both in the occurrence of longshore currents. Komar (1975) has presented an analytical equation that combines both the above generating mechanisms.

The nearshore current systems are very complicated and field observational data are at present scanty. The 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. The flow characteristics based on wave refraction and drift observations at selected locations (Fig. 7) along the present study area have been presented below.

3.2. METHOD OF STUDY

The direction of longshore currents from Azhikode to Anthakaranazhi (Fig. 6) has been determined from wave refraction diagrams by measuring the angle between the wave orthogonal and the normal to the shoreline assuming the beach to be more or less straight at all the stations following the method of Putnam _et al_. (1949). The points where the longshore currents are found to converge have been marked as probable zones of rip currents.

Field measurements of the longshore currents have been made by timing the movement of spherical surface floats released into the surf zone. These have been repeated thrice at each location to obtain representative mean flows. These measurements have been carried out once in a week at stations 1-16 (Fig. 7) and their monthly means have been presented in Figure 14 A-D. This data include the currents generated due to (i) oblique approach of waves to the shoreline (ii) wave height variations along the shore and (iii) alongshore wind components.

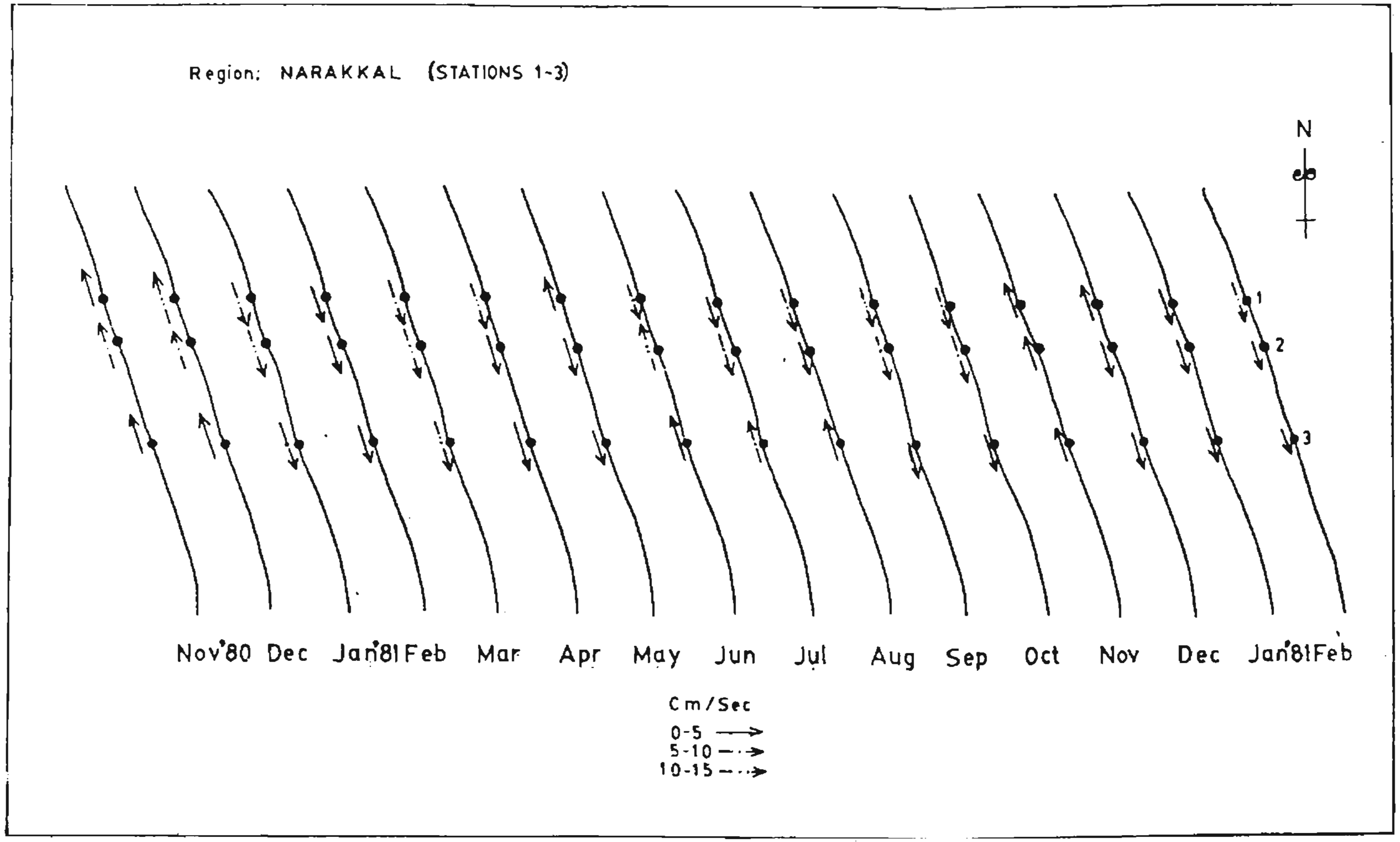

Fig. 14 A. Mean observed speed and direction of longshore currents at Narakkal (stations 1 to 3)

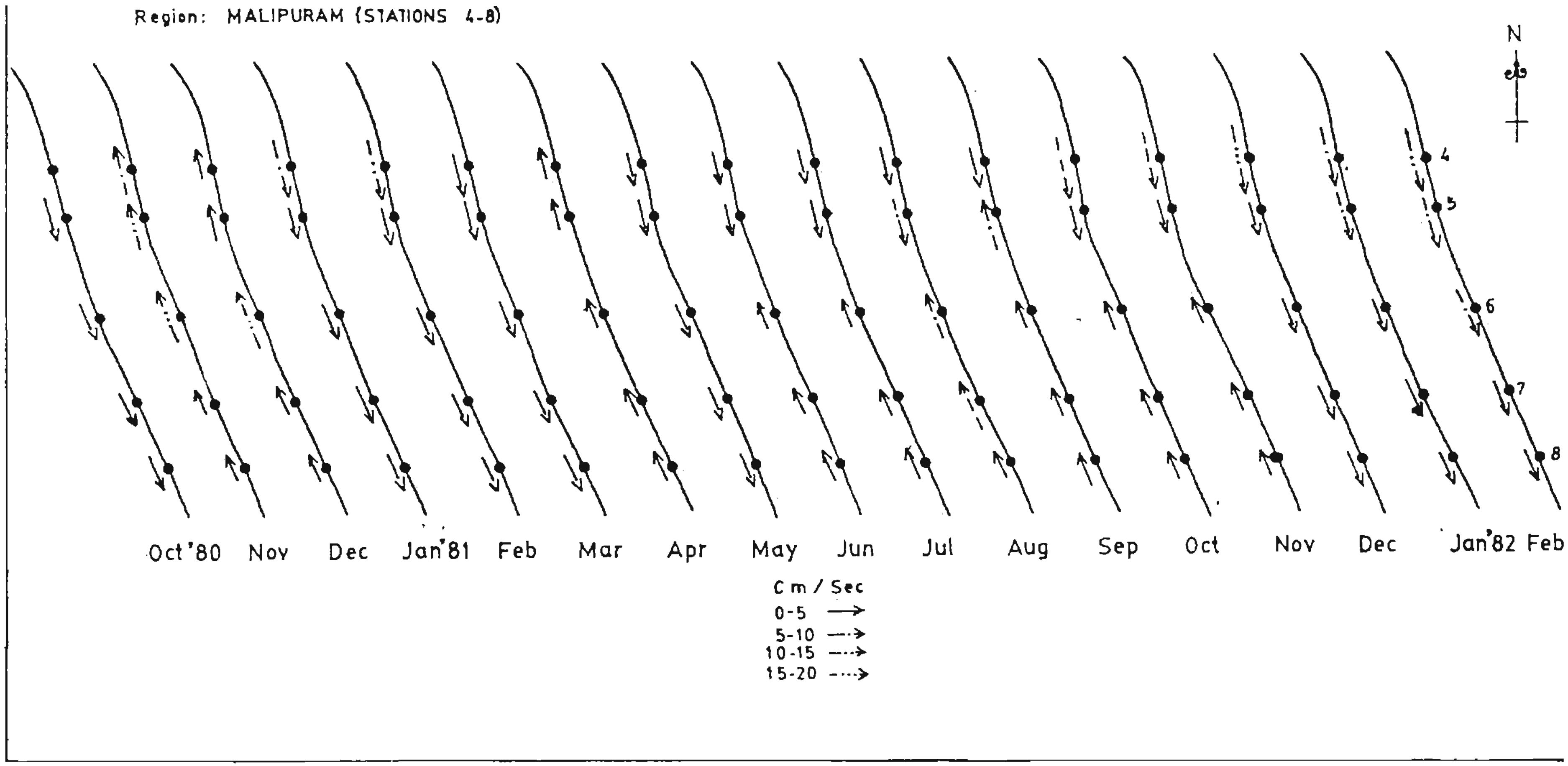

Fig. 14 B. Mean observed speed and direction of longshore currents at Malipuram (stations 4 to 8)

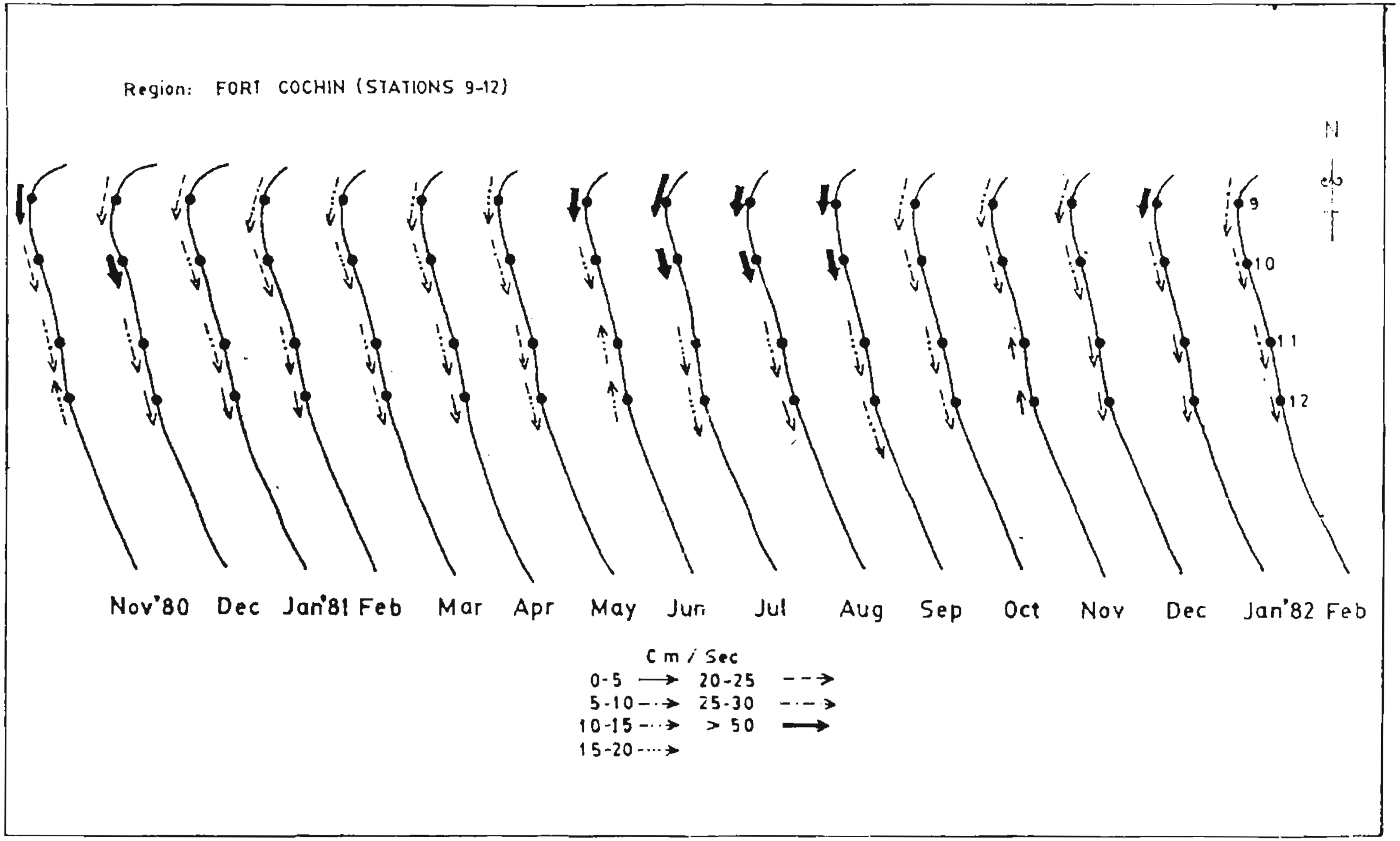

Fig. 14 C. Mean observed speed and direction of longshore currents at Fort Cochin (stations 9 to 12)

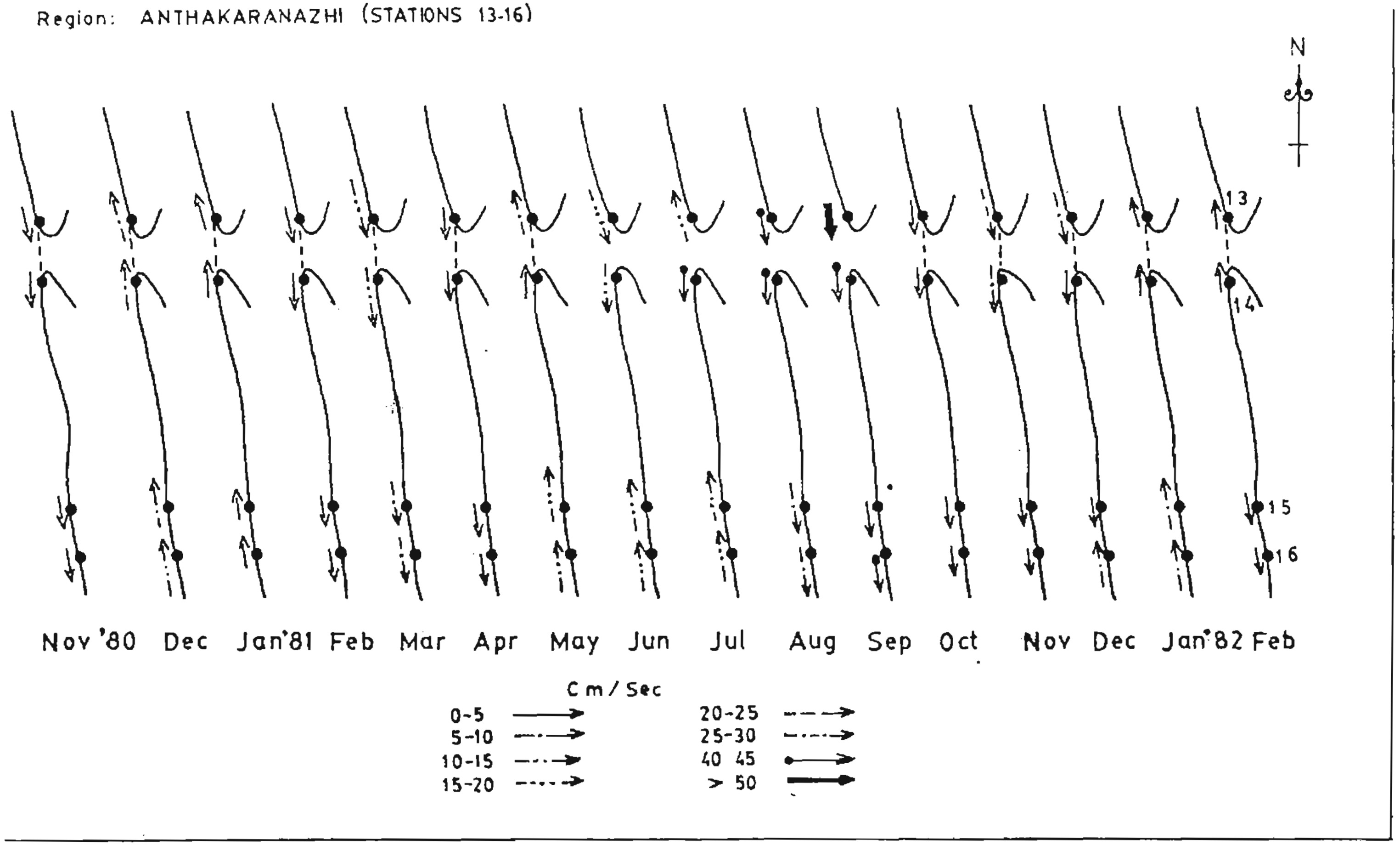

Fig. 14 D. Mean observed speed and direction of longshore currents at Anthakaranazhi (stations 13 to 16)

3.3. RESULTS AND DISCUSSION

3.3.1. Longshore currents as obtained from wave refraction studies

The littoral flows evaluated from refraction diagrams are presented in Figure 15 A-E. The arrows near the shoreline indicate the direction of flow due to oblique approach of waves and the cellular circulation patterns show the probable flow as derived from alongshore wave energy gradients. For all periods, waves from 220°TN give rise to northward drift at all the stations A to T. For waves approaching from 240° also, the general direction of flow is northerly, though opposing longshore flows leading to the cellular circulation patterns can be seen between stations A-B, B-C and G-H for different wave periods. Similarly, the general direction of longshore currents generated by waves approaching the shore from 280° and 300° is southerly all along the coast except between stations I-J and J-K. However, differences exist in the littoral current patterns for waves approaching from 260°. More zones of opposing longshore currents can be identified for this direction of wave approach. For these waves, a prominent cell circulation between stations J-K for 6 sec waves and extending upto station L for 8, 10 and 12 sec waves and further upto station M

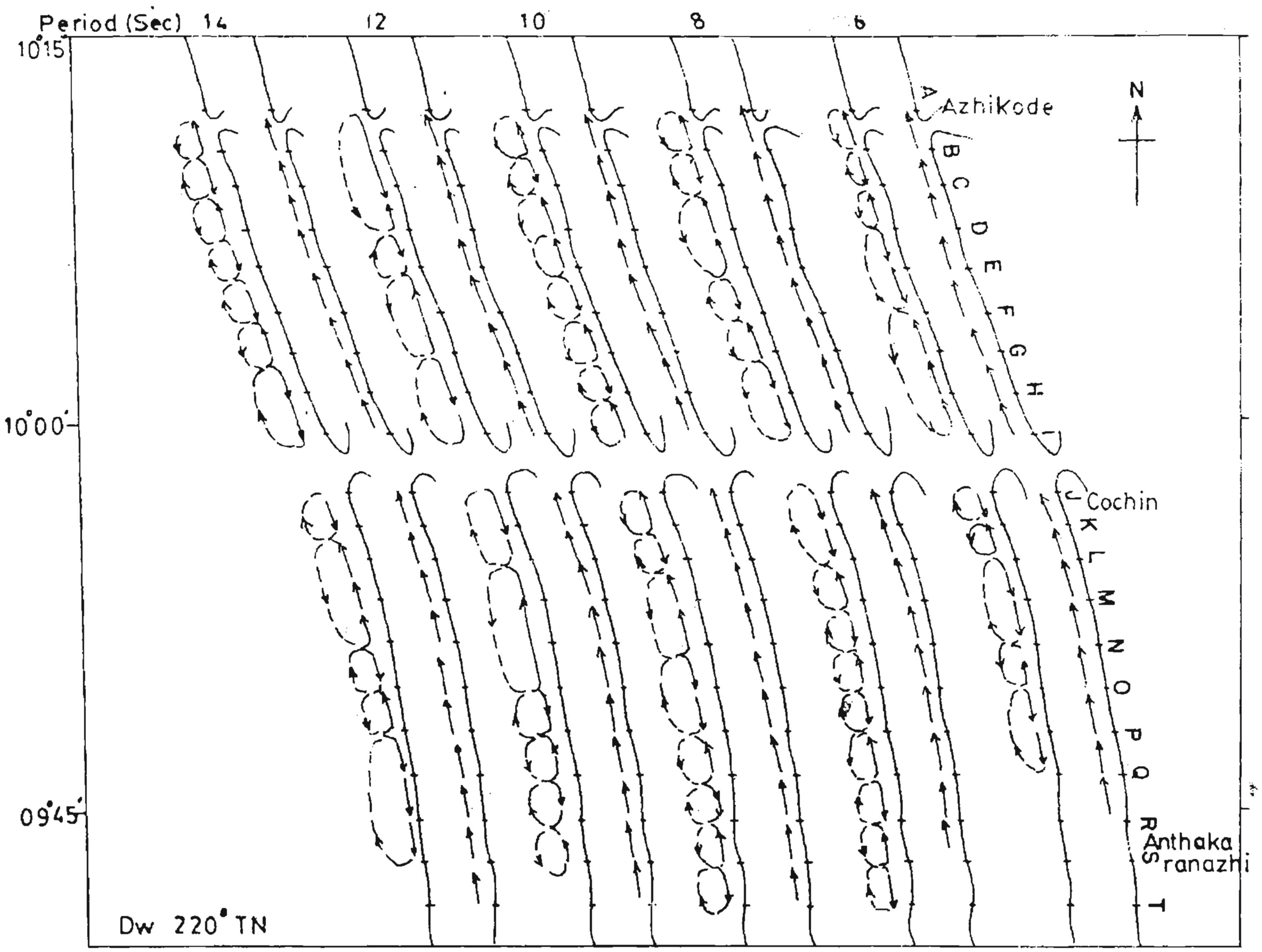

Fig. 15 A. Variation of the pattern of littoral flows with period for waves approaching from 220° TN

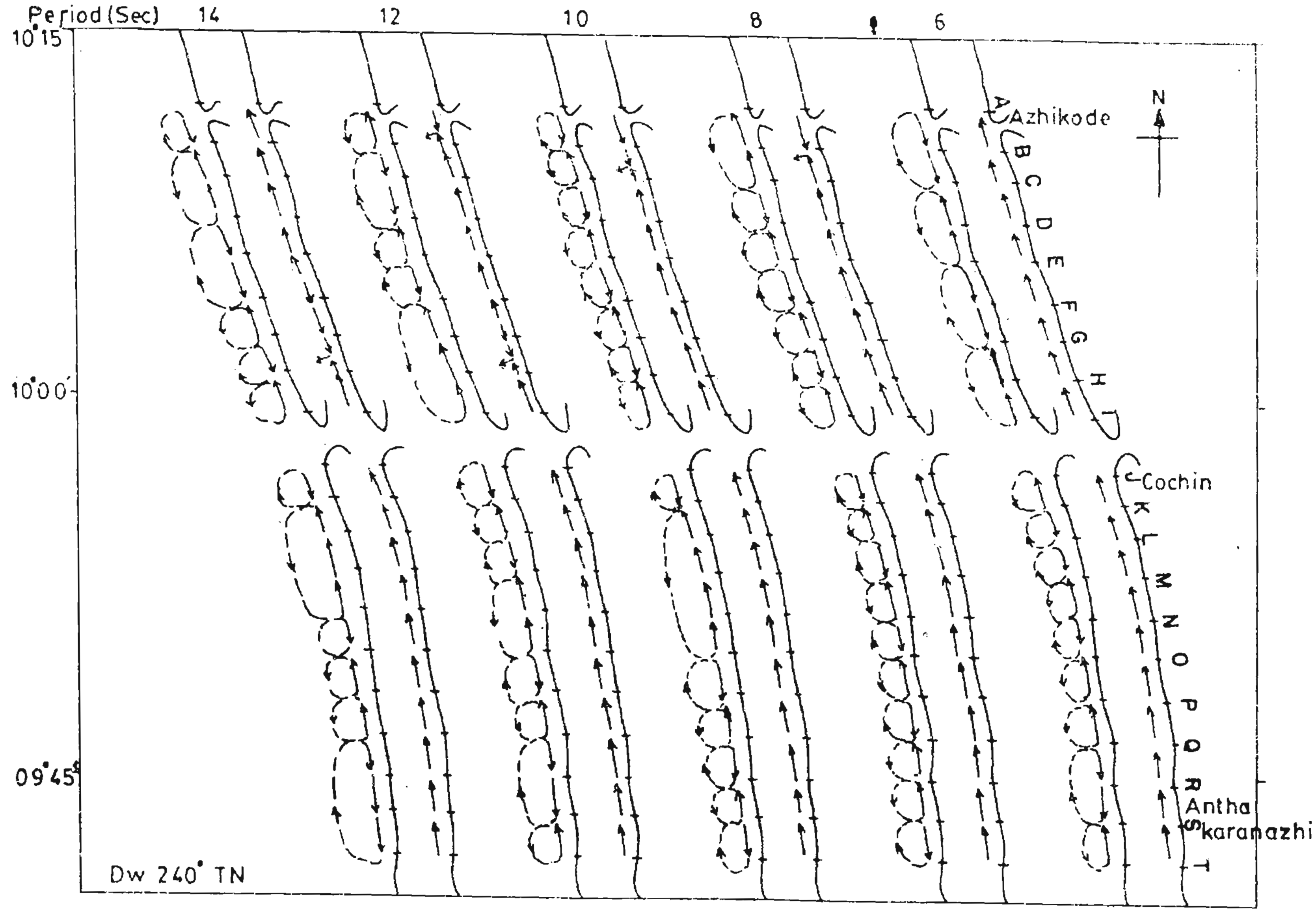

Fig. 15 B. Variation of the pattern of littoral flows with period for waves approaching from 240° TN

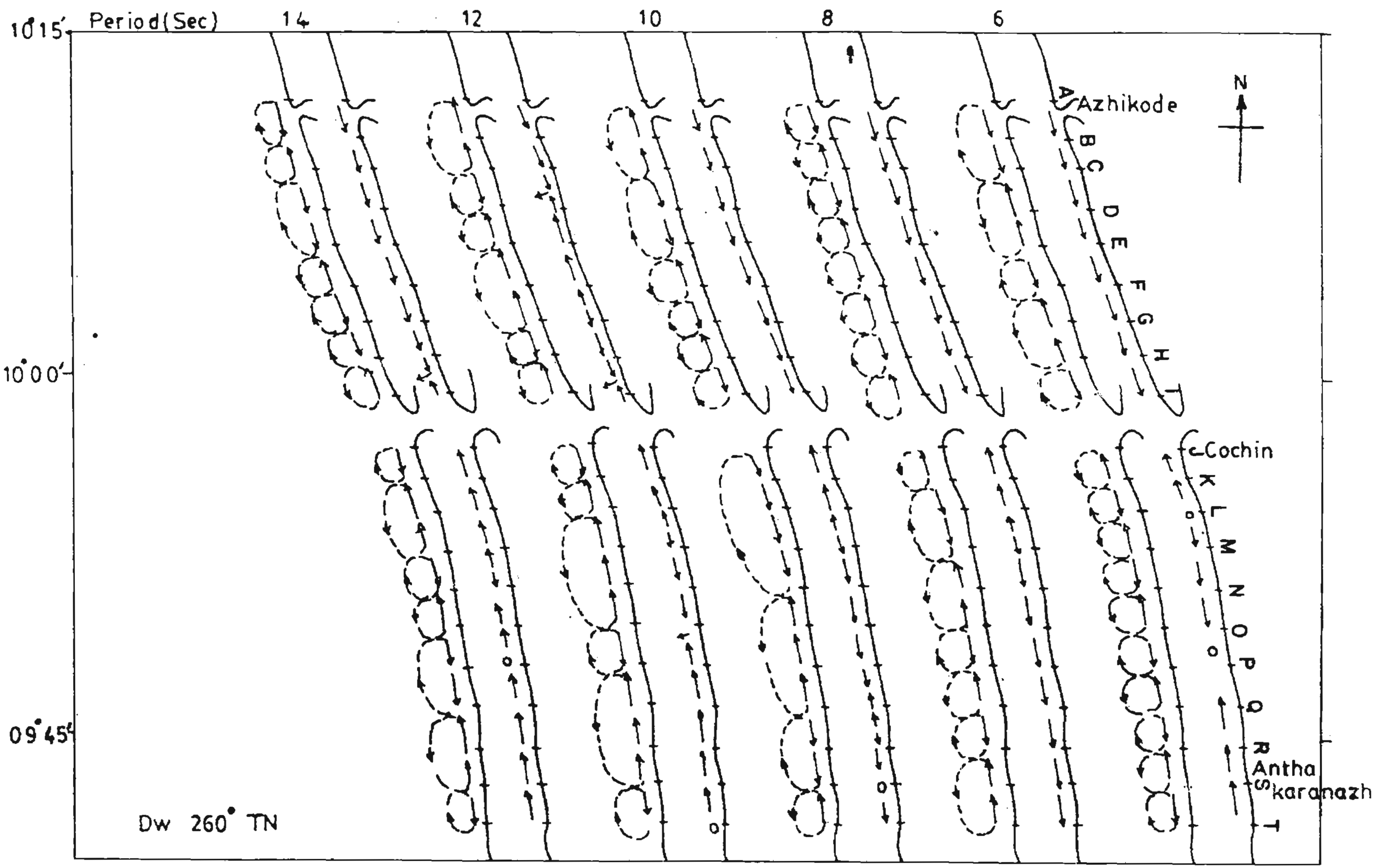

Fig. 15 C. Variation of the pattern of littoral flows with period for waves approaching from 260° TN

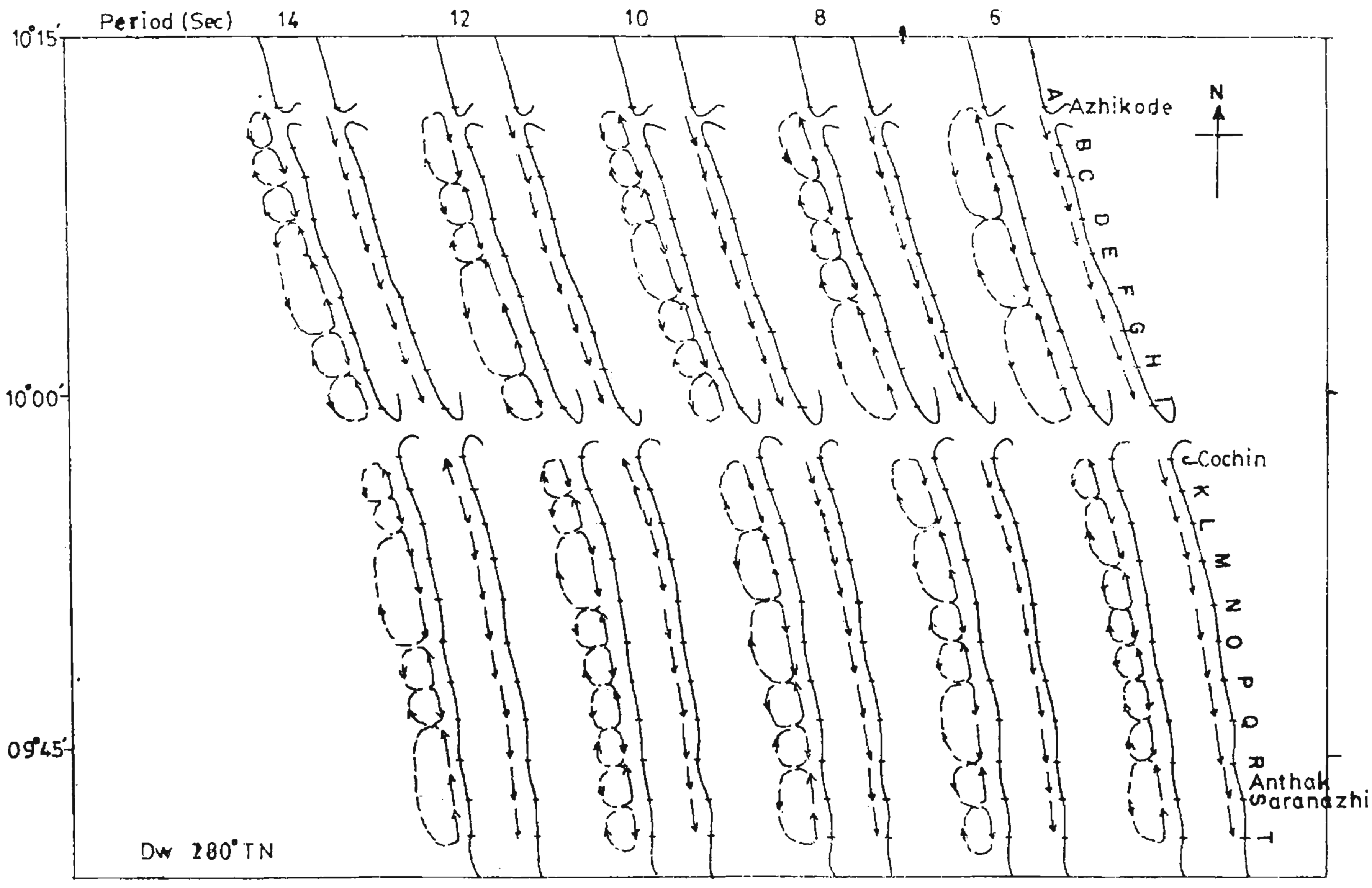

Fig. 15 D. Variation of the pattern of littoral flows with period for waves approaching from 280° TN

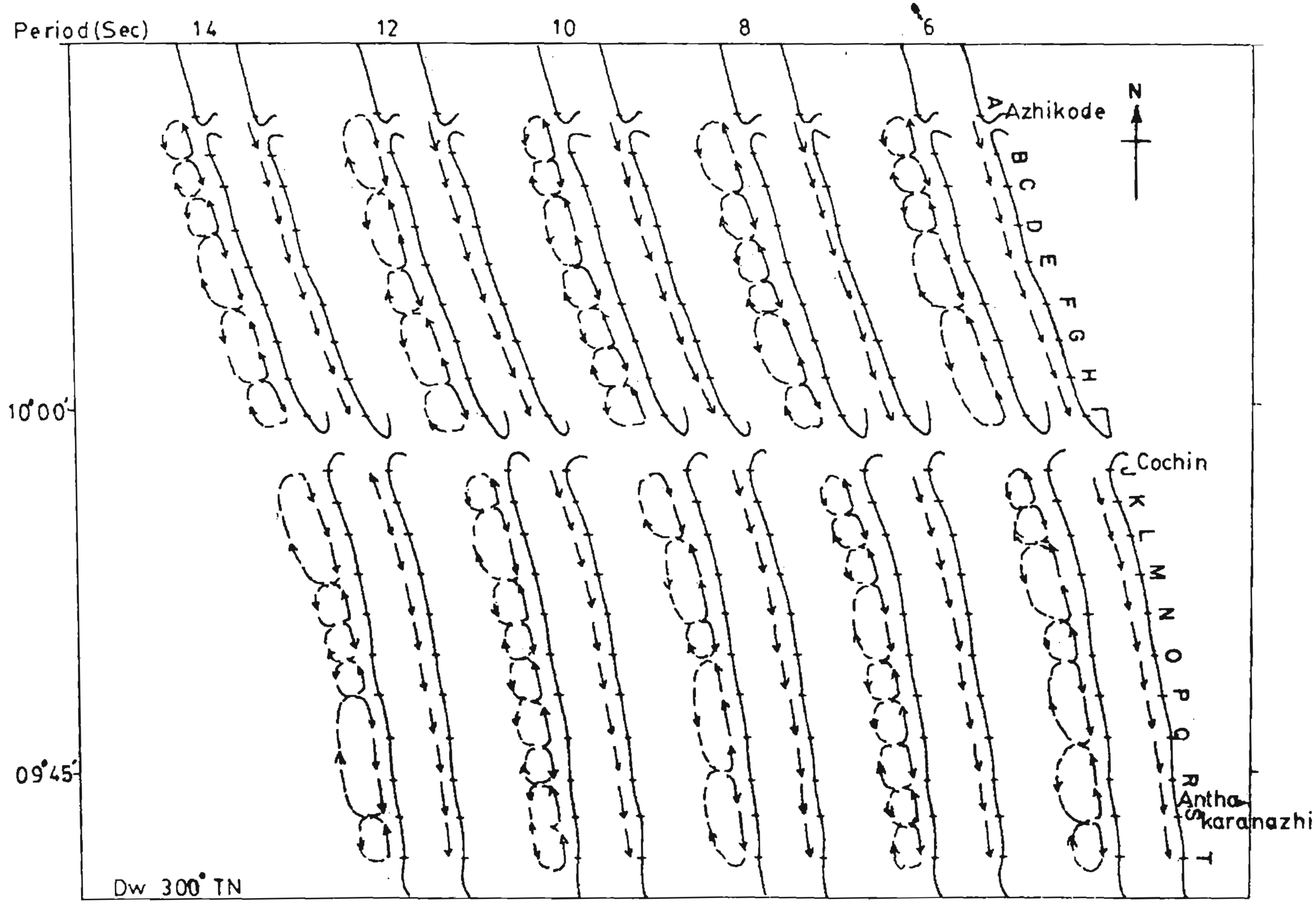

Fig. 15 E. Variation of the pattern of littoral flows with period for waves approaching from 300° TN

for 14 sec waves can be identified. For waves with period 12 and 14 sec, similar pattern of flows between stations M and O also could be clearly noticed. The angle θ for this direction of approach (260^{o}TN) has been very low ($< 5^{o}$) for waves of different periods (Table 5). This can be considered as a near-normal approach to the coast-line with a possibility of onshore-offshore flows in the littoral zone.

Thus, longshore currents are directed towards north for waves from southerly quadrant and are southerly for waves from northerly quadrant along the entire coast from Azhikode to Anthakaranazhi except at few stations. During the southwest monsoon season (June - September) with predominant direction of wave approach being 260^{o} to 270^{o}, one expects a large number of cellular patterns in the nearshore areas and southerly longshore currents. During the year, since more than 70% of the waves approach the coast from directions between 260^{o} and 320^{o} (Fig. 8), a net southerly longshore current along the coast could prevail except during October and November. But the resultant longshore current direction may be southerly even during these months due to the waves from the northerly quadrant. Thus it may be concluded that the predominant direction of longshore currents generated due to the oblique incidence of waves is southerly along the coast from Azhikode to Anthakaranazhi for major part of the year.

The differential height distribution (presented in Chapter 2) indicates the presence of zones of convergence of wave energy at some stations with higher wave heights and zones of divergence of wave energy at others with lower wave heights. This gives rise to alongshore gradients in wave energy which would provide the necessary forcing for the longshore flows. This may also get up a circulation cell with return flows from areas of convergence. The nearshore flow directions generated due to these energy gradients have been shown in Figures 15 A-E. As seen from these figures, the circulation pattern derived from the distribution of wave heights results in the formation of alternate converging and diverging flows along the shoreline and favour the formation of cellular flows for all wave periods and directions of approach.

Thus the circulation pattern within the surf zone, is due to the combined effects of the oblique approach of incoming waves and the variation in the wave heights along the shore. The resulting flow structure is governed by these two with the net direction being dependant on their relative strengths. When the angle of incidence of the breakers becomes considerable, the resulting flow pattern might show a meandering character due to the combination of southerly/northerly flows generated by the oblique incidence of waves and cell circulations generated by the energy gradients. On the other hand, when the waves approach normal to the shoreline closed cellular current patterns are maintained.

It must be noted that the above discussion represents ideal condition but in reality the field of motion would be more complex when one considers the effect of local seas superimposed on the swells with varying periods and directions. Moreover, the effects of mud banks reported along these beaches should also be taken into account while discussing the nearshore flow patterns. The distribution of nearshore wave energy along these beaches is controlled largely by mud banks, since the accumulation of fluid-mud has an attenuating effect on waves (Chapter 2). The results of the field observations on longshore currents made at selected stations will be discussed in the ensuing paragraphs.

3.3.2. Observed longshore currents

The speed and directions of longshore currents observed during November 1980 to February 1981 at stations

1-16 along the coast from Narakkal to Anthakaranazhi (Fig. 7) have been presented in Figures 14 A-D. At Narakkal (Fig. 14 A), currents directed towards south could be noticed during most of the months. Reversal of their directions occur during November 1980, December 1980 and November 1981. Current speeds vary from less than 5 to 15 cm/sec during the study period. Converging flows leading to offshore flows have also been observed between stations 1 and 2 during June 1981 and between stations 2 and 3 during August 1981. At Malipuram (Fig. 14 B) southerly currents are observed during most of the time except during November 1980, December 1980 and April 1981. The presence of rip currents can be noticed between stations 5 and 6 during June, July, August, October and November of 1981. The longshore current speeds varied generally between 5 and 25 cm/sec. Flows with negligible magnitudes have been observed during April to July in regions sheltered by mud banks.

In the Fort Cochin area (Fig. 14 C), these currents are directed towards south predominantly at most of the stations during the period of observation. Rip currents have been observed between stations 11 and 12 during November 1980 and between stations 10 and 11 during June 1981. The longshore current speeds vary from 5 to 50 cm/sec.

The higher velocities observed at station 9 may be due to the effect of the ebb water through Cochin harbour entrance which increased during June - September due to the increase in the monsoonal discharge. At Anthakaranazhi (Fig. 14 D), the longshore currents have been directed towards south. Northerly currents have been observed during December 1980, January 1981, May 1981 and January 1982. During June to July, southerly currents at station 14 and northerly currents at stations 15 and 16 have been observed. The speed of the longshore currents vary between 5 and 50 cm/sec along this beach.

These observations show that the predominant direction of longshore currents along the shore under study is towards south during most of the time and this corresponds well with the longshore current directions derived through wave refraction studies. During certain months, the converging flows observed at certain locations indicated that the currents may not be entirely two dimensional. According to Longuet-Higgins (1972) the pattern of longshore currents need often not be completely two dimensional, but broken up by rip currents into a sequence of circulating cells. A comparison of longshore flow directions and observed breaker angles (Table 7 a-d) indicates that the current directions are largely influenced.

by the breaker angles. A comparison of longshore current directions with breaker heights (Table 7 a -d) also reveals the dominance of differential breaker heights in contributing to the flows during most of the time. Thus the field observations on wave parameters and littoral currents show that the variations in current directions are induced partly by the oblique wave approach and partly by the longshore variations in wave height.

The observed lower magnitudes of littoral flows at Narakkal and Malipuram in contrast to higher magnitudes at Fort Cochin and Anthakaranazhi may be due to the considerable reduction in the incoming wave energy caused by the attenuating effect of the mud banks. Longuet-Higgins (1972) suggested that no littoral currents could be generated unless there were some dissipation by breaking. The higher magnitude of flows at Fort Cochin beach which comes under the influence of mud bank during southwest monsoon season may be due to the increased ebb flows from the Cochin harbour entrance channel.

In the mud bank areas - Narakkal and Malipuram - the longshore currents are directed towards south on the northern side of the mud bank and towards north on the southern side of the mud bank during June to August, when the mud bank is active. Similar observations have been reported by Kurup (1972,1977) at Purakkad mud bank. These flows on the northern and southern side of the mud bank may be due to the higher breaker activities on the periphery of the mud bank compared to the calm conditions on the leeward areas. This condition can provide energy gradients which will give rise to flows towards lower energy zones. This, in turn, may set up a circulation cell so that return flow takes place within the mud bank areas.

CHAPTER 4

BEACH SEDIMENTS

4.1. INTRODUCTION

The nature of the beach material plays an important role in modifying the characteristics of incoming waves and it is a matter of prime concern in regard to the character of the beach. The resistance of the beach sands towards the erosive forces depends on particle size. The general beach dynamics can be understood by a study of the size characteristics of the material vis-a-vis the beach profile data.

Littoral materials are masses of unconsolidated solid materials (mainly sedimentary) in the littoral zone on which the waves and currents act. The three main factors that control the mean grain size of the beach sediments are (i) the sediment source, (ii) the wave energy level, and (iii) the general offshore slope on which the beach is formed (Komar, 1976). The largest sand particles at any beach are found at the plunge point just seaward of the backwash, which, observation indicates, is the point of maximum turbulence (Bascom, 1951).

The statistical description of various grain size parameters would help the comparison of sediment samples. The importance of grain-size parameters of sediments has been well established (Folk, 1966). Such descriptions of sediment characteristics are a primary input to any coastal engineering design. Structures like seawalls, groynes etc. are often constructed along the coastline to stabilize the coast and to prevent further erosion. The knowledge of the nearshore sediments becomes important in the design of coastal structures.

Along the Kerala coast no extensive study has been carried out on the grain size parameters of beach sediments. In the present chapter, the temporal and spatial variations of grain size parameters along the beaches around Cochin are presented. These changes have been discussed in relation to the physical processes operating in this area.

4.2. MATERIAL AND METHODS

4.2.1. Collection of sediment samples

Samples were collected along the profile lines (Fig. 7) across the beach. Systematic sampling was performed by taking samples from pre-defined positions in segments of length 10 m following the sampling procedure given by Krumbein (1954). Four hundred and eighty three samples were collected from the 15 profile lines at bimonthly intervals. Each sample weighing about 150 gms collected from the sampling points along the profile line represents the upper few centimetre column of the beach deposits.

4.2.2. Laboratory methods of analysis

The beach sediments collected from various locations during different months contain size fractions ranging from sand to mud, especially in the samples from Narakkal and Malipuram. Therefore, two different methods were adopted for the size analysis as follows:

(i) Mechanical analysis for sand samples

Sand samples were sieved for 10 minutes on a ILM Labour Sieve-Shaker using $\frac{1}{2}$ ϕ interval Endecotts test sieves. The retent on each sieve was weighed on a physical balance with an accuracy of $\pm$0.01 gm, and fractions smaller than 1 gm were weighed to an accuracy of $\pm$0.001 gm. Before sieving the sand samples, they were washed and oven dried a about 50 to 75 gms were removed for sieving by coning and quartering of the entire sample.

(ii) Pipette analysis for mud samples

Pipette analysis was performed for the mud samples following the method given by Krumbien and Pettijohn (1938) A known quantity of sodium hexametaphosphate was used as dispersing agent. The mud sample was dried (not in the oven) and 10 gm of it were used for pipette analysis. All the materials coarser than 4ϕ (62μ) were removed from the sample by wet sieving before the sample was subjected to pipette analysis.

4.2.3. Statistical analysis of the sample parameters

In order to compare sediment samples quantitatively it is necessary to adopt precise measures of mean size, sorting and other frequency distribution properties. Thes properties may be determined either mathematically by the method of moments or graphically by reading selected percentiles of the cumulative curves. Both these methods have been summarised by Krumbien and Pettijohn (1938). In the present study, graphic measures (Folk and Ward, 19 were calculated for each sample from the cumulative frequency curve with the help of a computer. The compute output gave the cumulative percentage curve and the vario statistical parameters.

To determine the overall size of the grains in a particular sample, graphic mean size (M_z) was calculated. As a measure of sorting inclusive graphic standard deviat and to know how closely the grain size distribution approaches the normal Gaussian probability curve, skewnes and kurtosis were calculated. The extremities in the values of skewness and kurtosis give the non-normality of the size curve. While skewness gives the asymmetry of the curve, kurtosis gives the peakedness of the size curve. A perfectly symmetrical curve will have skewness equal to zero and kurtosis equal to unity. The formulae used to calculate these parameters have been given by Folk and Ward (1957). The advantages and disadvantages in the use of these formulae to calculate various grain size parameters have been discussed by Folk (1966).

Figures 16 A-O show the mean grain size of individual sample along with the elevation at each profile line. Table 9 gives the mean and standard deviation of grain-size parameters of all the samples collected during the period of study at each profile line. Figure 17 shows the scatter plots of mean grain size versus standard deviation (A) and skewness (B).

Student's t test (Griffiths, 1967) was applied to estimate the statistical significance of the spatial and temporal variations in the mean grain size of these sediment samples.

TABLE 9

Means ($\bar{x}$) and standard deviations (σ_n) of grain size parameters for different stations

Stations	Total No. of samples	Mean grain size (M_z Ø)	Standard deviation ($\sigma_Ø$)	Skewness (Sk)	Kurtosis (K_G)
1	26	2.6650 0.5582	0.7262 0.2231	0.0632 0.4374	1.0334 0.3496
2	21	2.8601 0.7079	0.6515 0.4527	0.2457 0.4392	0.9485 0.3693
3	19	2.7813 0.5991	0.7168 0.3362	0.1465 0.2158	1.0721 0.1412
4	48	2.8042 0.6701	0.7119 0.4531	0.1595 0.4545	1.0459 0.1886
5	33	3.0947 0.8940	0.9961 0.5640	0.2572 0.4387	1.1055 0.1655
6	31	3.2425 0.5483	0.7445 0.3213	0.2133 0.3612	1.1720 0.1879
7	23	2.7970 0.5270	0.7308 0.3232	0.2199 0.4448	1.2081 0.2142
9	44	2.1930 0.4444	0.7828 0.1788	-0.0598 0.0929	1.0316 0.2002
10	34	2.4232 0.4003	0.7563 0.1743	0.0404 0.1644	0.9218 0.1487
11	55	2.4268 0.5435	0.7542 0.1594	0.0536 0.1493	0.9962 0.1541
12	28	2.4698 0.6725	0.7538 0.2598	0.0586 0.3077	1.0315 0.2436
13	37	2.4111 0.4805	0.7555 0.2280	-0.0008 0.1801	1.0652 0.3114
14	31	2.4201 0.3846	0.7924 0.2682	-0.0656 0.1969	1.1889 0.2861
15	33	2.5133 0.3591	0.7228 0.2574	-0.1333 0.1775	1.0771 0.2772
16	20	2.7123 0.4191	0.6714 0.1017	-0.0316 0.2918	1.1255 0.2799

4.3. RESULTS AND DISCUSSION

4.3.1. Variations of sediment characteristics along the profile lines

The mean diameter of the samples along the profiles transverse to the beach are presented in Figure 16 A-O. The transverse profiles represent four beaches namely Narakkal (stations 1-3), Malipuram (stations 4-7), Fort Cochin (stations 9-12) and Anthakaranazhi (stations 13-16) (Fig. 7). Means and standard deviations of grain size parameters of all the samples collected at each profile line during the period of study are presented in Table 9. Values of students' t and the significance of the difference in the mean grain size (M_z ϕ) of the sediments between different months but from the same profile line are presented in Table 10. Scatter plots drawn to elucidate the relations, if any, existing between mean grain size, sorting and skewness are presented in Figures 17 A and B for different beaches.

(a) Narakkal (station 1 to 3)

The mean grain size does not show any definite trend along the profile line (Fig. 16 A-C). However, the mean grain size shows large variations towards the seaward

TABLE 10

Values of student's t test and significance for the differences in mean grain size parameters between different months at each Station

(a) Region : Narakkal

Months	Mar '81	May	Jul	Sep	Nov
Station 1					
Jan '81	1.785 (4)	2.220 (4)	0.181 (5)	0.776 (4)	1.472 (4)
Mar		0.623 (4)	0.075 (5)	1.419 (4)	2.014 (4)
May			0.076 (5)	1.387 (4)	1.864 (4)
Jul				0.109 (5)	0.870 (4)
Sep					1.577 (4)
Station 2					
Jan '81	0.648 (4)	1.981 (5)	0.832 (5)	3.065 (5)*	0.635 (4)
Mar		2.099 (5)	0.984 (5)	2.644 (5)*	0.489 (4)
May			0.453 (6)	0.201 (6)	2.212 (5)
Jul				0.412 (6)	0.741 (5)
Sep					2.934 (5)*
Station 3					
Jan '81	1.861 (7)	1.383 (9)	1.084 (7)	0.025 (7)	1.452 (6)
Mar		0.786 (8)	1.619 (6)	1.498 (6)	0.150 (5)
May			1.279 (8)	1.130 (8)	0.516 (7)
Jul				0.113 (6)	1.266 (5)
Sep					1.163 (5)

*Significant at 5% level   ( ) Degree of freedom

TABLE 10 (Contd.)

(b) Region : Malipuram

Months	Jan '81	Mar	May	Sep	Nov
Station 4					
Nov '80	0.260(10)	0.895(13)	1.193(13)	1.357(14)	1.186(12)
Jan '81		1.066(13)	1.723(13)	1.521(14)	1.402(12)
Mar			0.740(16)	0.479(17)	0.034(15)
May				0.423(17)	0.775(15)
Sep					0.565(15)
Station 5					
Nov '80	0.313 (8)	0.237(10)	1.117 (7)	0.637 (9)	0.588 (9)
Jan '81		0.503(10)	1.282 (7)	0.849 (9)	0.800 (9)
Mar			1.025 (9)	0.462(11)	0.051(11)
May				0.564 (8)	0.597 (8)
Sep					0.043(10)
Station 6					
Nov '80	1.673 (9)	0.733 (9)	1.488 (9)	1.998(10)	1.062 (8)
Jan '81		1.125 (8)	0.416 (8)	0.465 (9)	0.745 (7)
Mar			0.890 (8)	1.438 (9)	0.452 (7)
May				0.851 (9)	0.696 (7)
Sep					1.059 (8)
Station 7					
Nov '80	0.333 (6)	0.453 (7)	1.144 (5)	0.894 (5)	0.905 (6)
Jan '81		0.618 (7)	0.770 (5)	0.305 (5)	0.158 (6)
Mar			0.730 (6)	1.305 (6)	1.442 (7)
May				1.500 (4)	2.086 (5)
Sep					0.283 (5)

( ) Degree of freedom

TABLE 10 (Contd.)

(c) Region : Fort Cochin

Months	Jan '81	Mar	May	Jul	Sep	Nov
Station 9						
Nov '80	0.174(10)	0.460(10)	1.654(12)	0.347(11)	0.502(10)	0.201 (
Jan '81		0.253(10)	1.238(12)	1.266(11)	0.265(10)	0.371 (
Mar			1.063(12)	1.132(11)	0.016(10)	0.720 (
May				0.597(13)	1.467(12)	2.603(1
Jul					1.576(11)	2.630(1
Sep						1.393 (
Station 10						
Nov '80	0.670 (6)	1.028 (7)	0.321 (7)	0.159 (8)	0.271 (8)	1.173 (
Jan '81		1.600 (7)	1.909 (7)	0.913 (8)	1.048 (8)	1.605 (
Mar			0.464 (8)	0.896 (9)	0.881 (9)	0.234 (
May				1.282 (9)	1.335 (9)	0.257 (
Jul					0.241(10)	1.028 (
Sep						1.053 (
Station 11						
Nov '80	0.803(11)	0.965(13)	1.492(12)	0.654(13)	1.565(12)	1.507(1
Jan '81		0.024(14)	0.864(13)	0.032(14)	0.980(13)	0.886(1
Mar			0.981(15)	0.019(16)	1.111(15)	1.005(1
May				0.697(15)	0.160(14)	0.025(1
Jul					0.803(15)	0.715(1
Sep						0.135(1
Station 12						
Nov '80	0.530 (6)	0.702 (6)	1.025 (5)	0.794 (6)	0.392 (7)	1.972 (
Jan '81		0.343 (6)	0.405 (5)	0.472 (6)	0.236 (7)	0.750 (
Mar			0.415 (5)	0.011 (6)	0.526 (7)	0.137 (
May				0.713 (5)	1.154 (6)	0.611 (
Jul					0.650 (7)	0.230 (
Sep						0.874 (

*Significant at 5% level ( ) Degree of freedom

TABLE 10 (Contd.)

(d) Region : Anthakaranazhi

Months	Mar '81	May	Jul	Sep	Nov	Jan '82
Station 13						
Dec '80	0.450(10)	1.697(8)	1.406 (9)	2.087 (7)	1.190 (8)	0.294 (8)
Mar '81		2.479(10)	*2.254(11)	*3.213 (9)	*2.006(10)	0.022(10)
May			0.705 (9)	0.175 (7)	0.863 (8)	1.777 (8)
Jul				0.731 (8)	0.244 (9)	1.538 (9)
Sep					1.095 (7)	1.961 (7)
Nov						1.314 (8)
Station 14						
Dec '80	0.768(10)	0.596(10)	-	0.073 (6)	0.249 (8)	1.246 (7)
Mar '81		1.511(12)	-	0.731 (8)	0.259(10)	1.880 (9)
May			-	0.443 (8)	0.691(10)	1.146 (9)
Sep					0.242 (6)	0.946 (5)
Nov						1.175 (7)
Station 15						
Dec '80	0.873(10)	0.908(10)	1.293 (7)	0.824 (7)	0.366 (9)	-
Mar '81		1.833(12)	1.982 (9)	1.586 (9)	1.424(11)	-
May			0.183 (9)	0.157 (9)	0.441(11)	-
Jul				0.551 (6)	0.702 (8)	-
Sep					0.289 (8)	-
Station 16						
Dec '80	0.847 (9)	1.609 (6)	0.799 (7)	0.923 (8)	-	-
Mar '81		1.873 (9)	-	0.389(10)	0.934 (7)	-
May			-	0.802 (7)	0.748 (6)	-
Sep					0.623 (7)	-

*Significant at 5% level   ( ) Degree of freedom

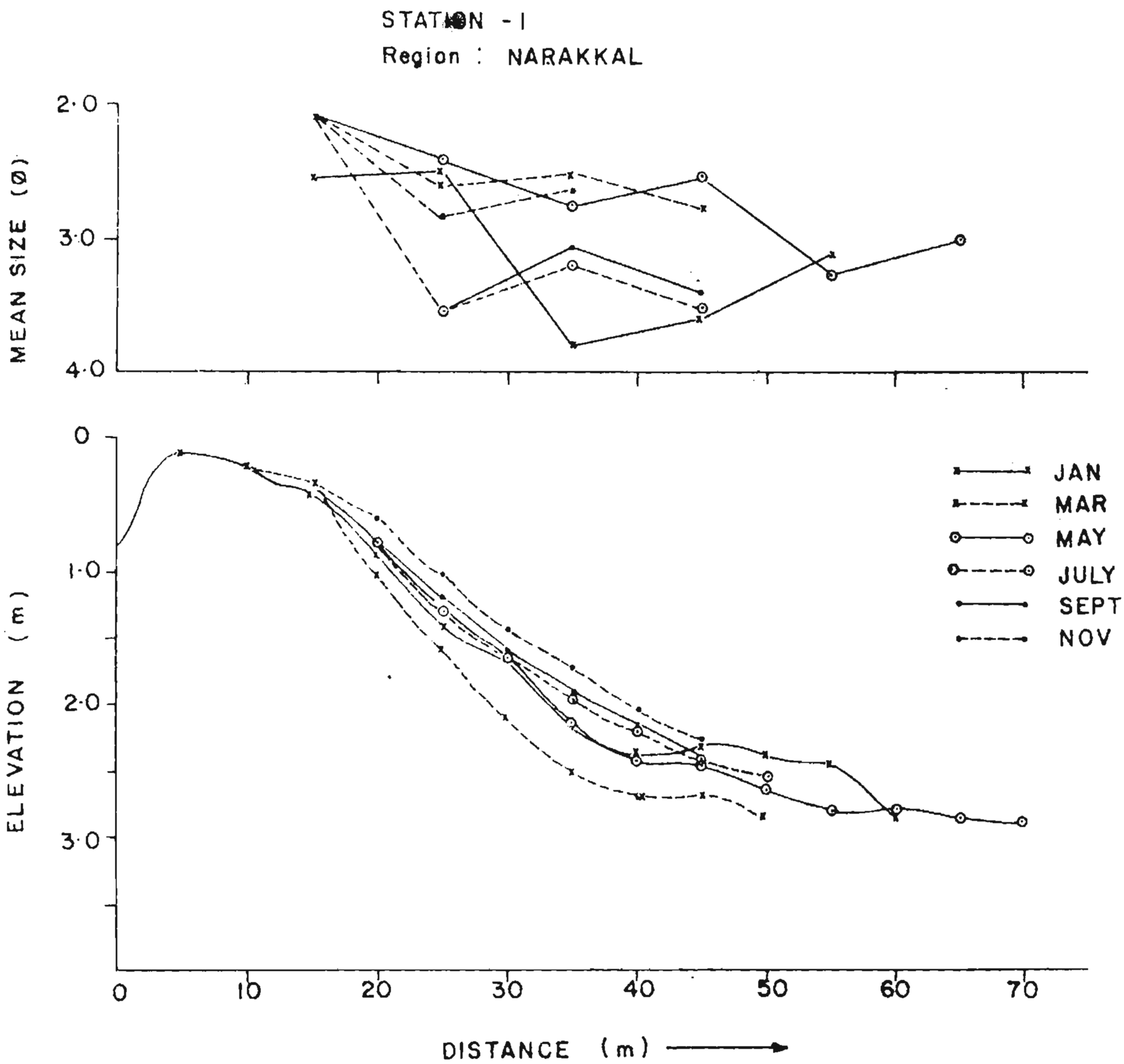

Fig. 16 A. Variation of mean grain size with elevati
along the profile line at station 1

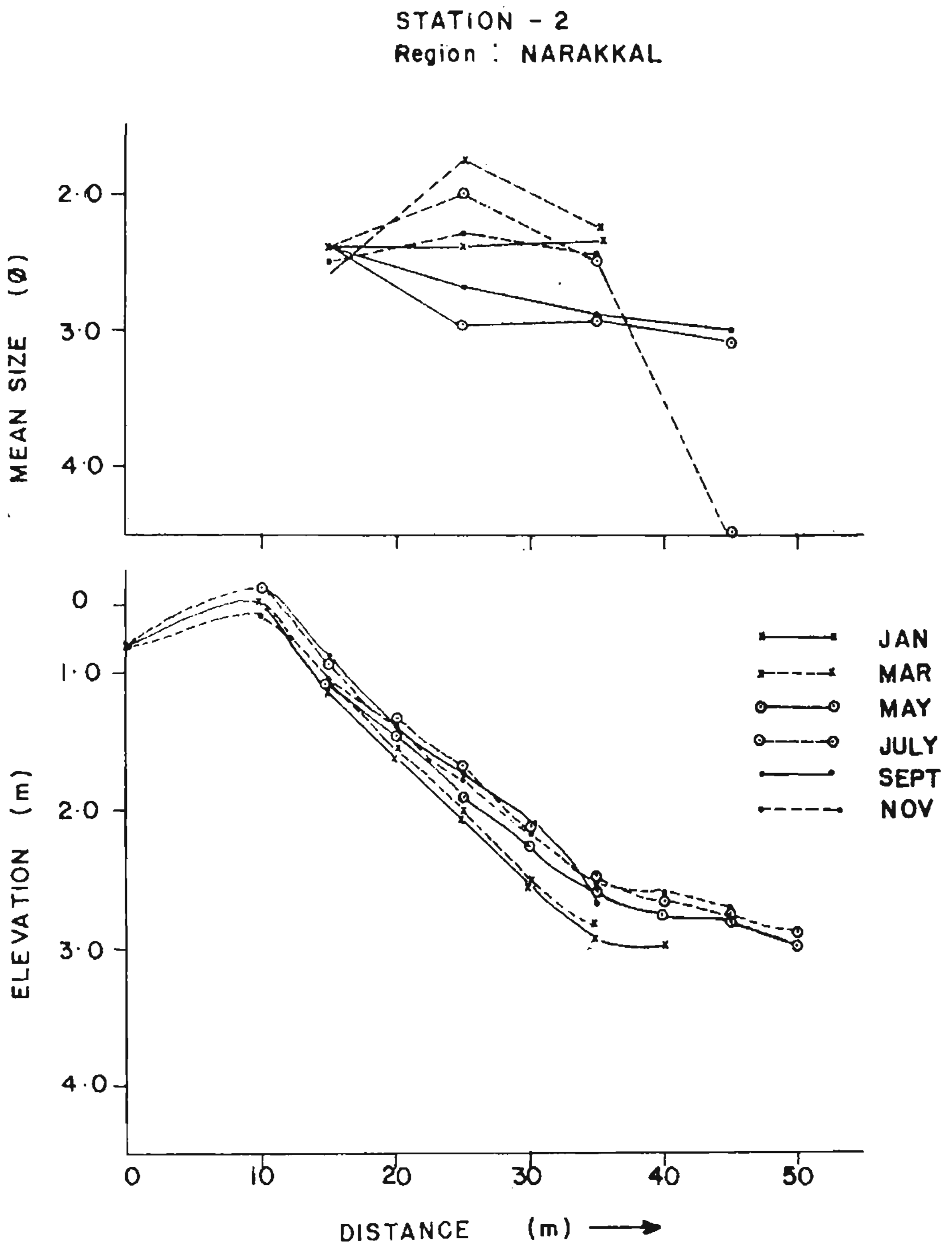

Fig. 16 B. Variation of mean grain size with elevation along the profile line at station 2

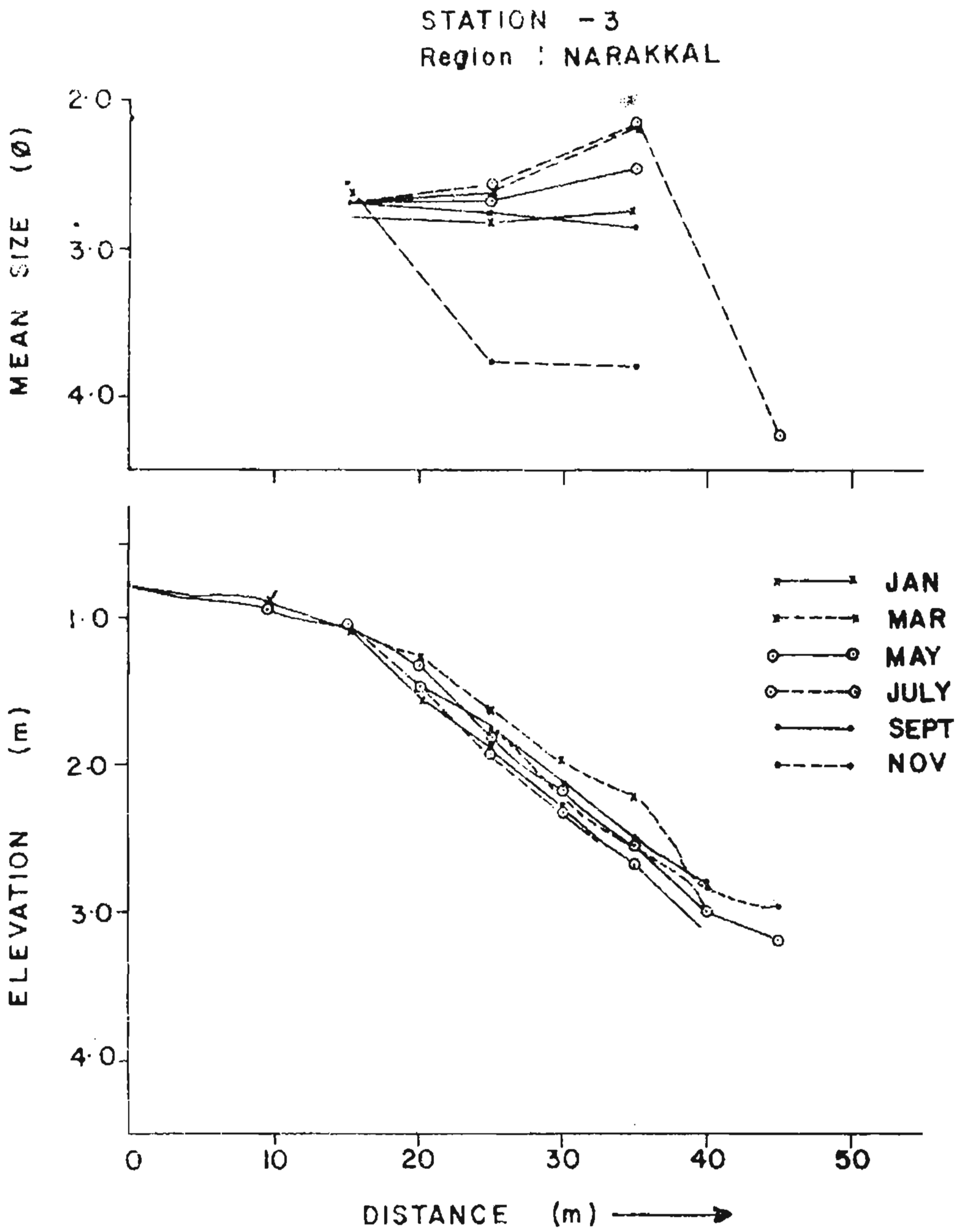

Fig. 16 C. Variation of mean grain size with elevation along the profile line at station 3

side during different months. The mean grain size varies between very fine to fine sand (3.8 Ø to 2.1 Ø) at station 1, silt to medium sand at station 2 (4.3 Ø to 1.8 Ø) and at station 3 (4.5 Ø to 1.8 Ø). Most of the sediment samples from this beach are moderately sorted eventhough the range varies from very well sorted to very poorly sorted. The scatter plots made between mean grain size versus standard deviation do not show any marked trend, while the scatter plots between mean grain size and skewness show a sinusoidal trend. The mean grain size of the samples collected during different months along a particular profile line does not show any significant difference (Table 10), except along profile line 2 where the samples collected during January, March and November show significant difference compared to those collected during September.

(b) Malipuram (station 4 to 7)

The mean grain size across this beach (along different profile lines) shows an increase in Ø - values from the backshore to the foreshore during the period of study (Fig. 16 D-G). That is, the sediments of the backshore are relatively coarser than those of the foreshore. However, some inconsistencies are present,

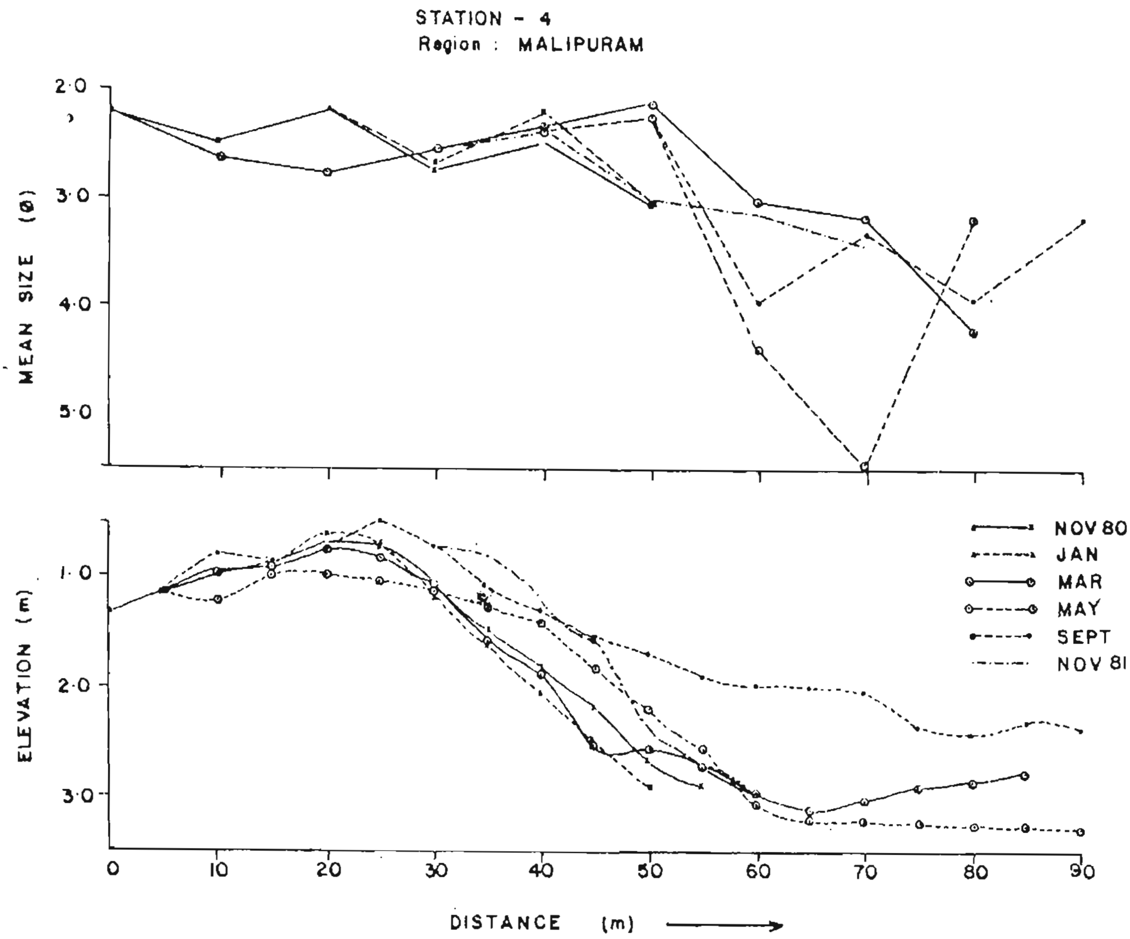

Fig. 16 D. Variation of mean grain size with elevation along the profile line at station 4

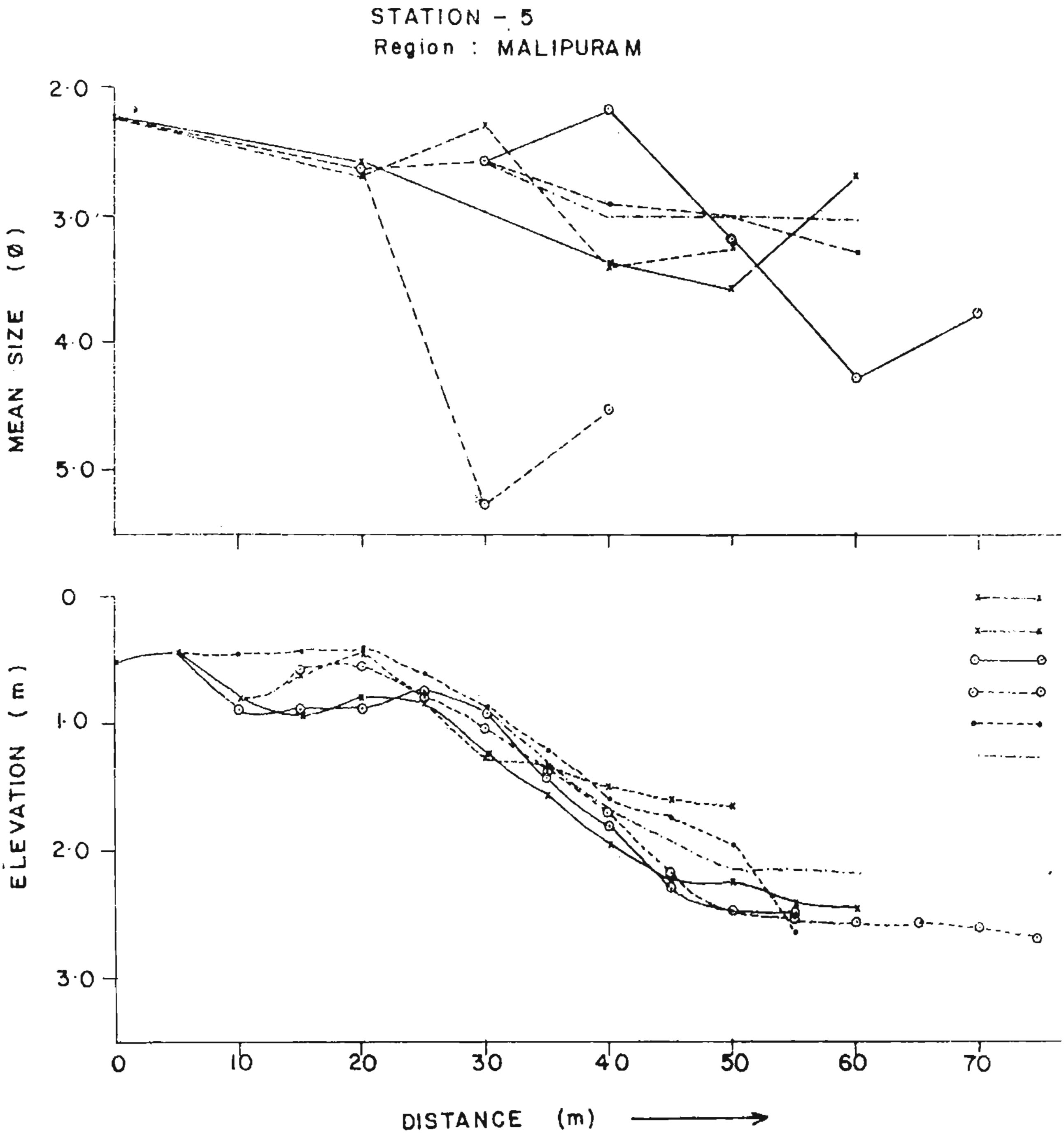

Fig. 16 E. Variation of mean grain size with elevation al
the profile line at station 5

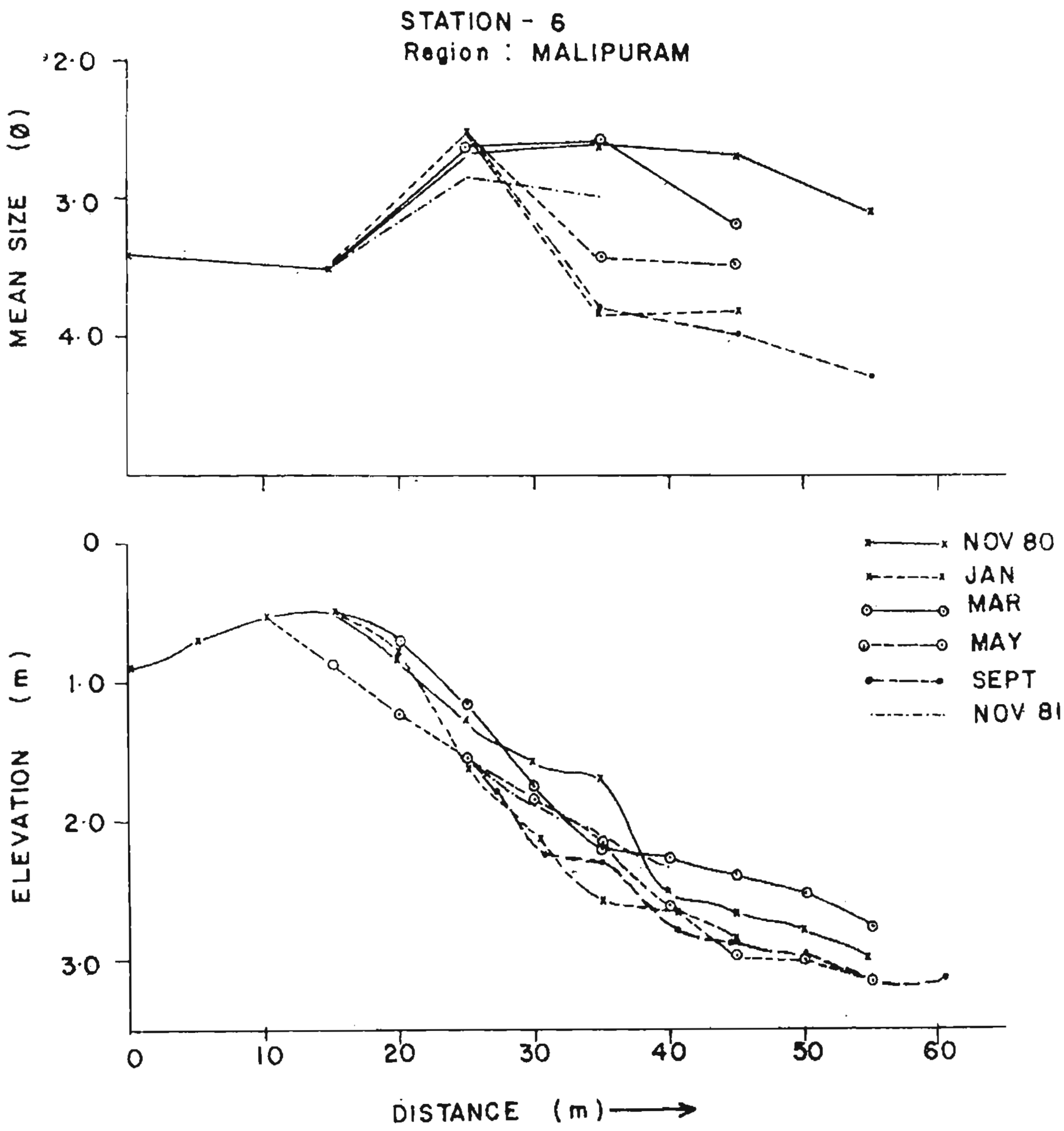

Fig. 16 F. Variation of mean grain size with elevation along the profile line at station 6

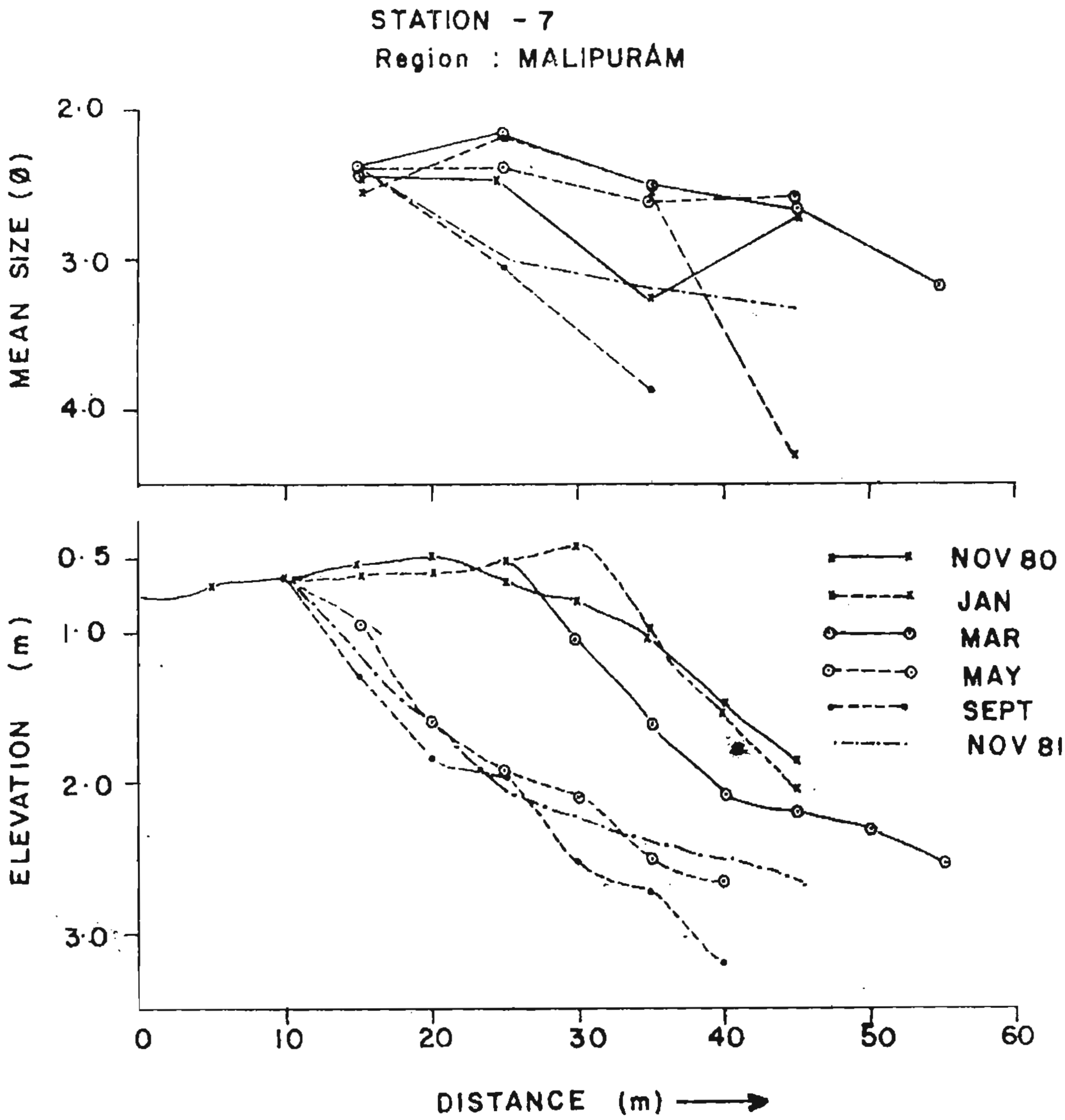

Fig. 16 G. Variation of mean grain size with elevatio along the profile line at station 7

at times, in this trend. The mean grain size (M_z) of various sediment samples range from silt to fine sand (5.5 Ø to 2.2 Ø at station 4 and 5; 4.3 Ø to 2.5 Ø at station 6 and 4.3 Ø to 2.2 Ø at station 7). Most of the sediment samples are moderately sorted except few which are very well sorted or poorly sorted. The scatter plots (Fig.17 A and B) of the mean grain size versus skewness and standard deviation for the samples from this beach failed to bring out any definite trend. Students' t test performed for these samples show that there is no significant difference in the mean grain size during different months (Table 10).

(c) Fort Cochin (station 9 to 12)

The mean grain size ranges from 4 Ø during July at station 11 to 1.3 Ø during March at station 12. In general, most of the sediment samples across the beach show relatively fine material towards the foreshore (Fig.16 H-K). The sorting values range between 0.5 and 1.0in more than 85% of the samples from this beach showing the moderately sorted nature of the beach material. Very few poorly sorted sediment samples also are encountered along this beach, but there is no well sorted sample along the beach. The scatter plots drawn for mean grain size versus skewness show a sinusoidal trend, while the

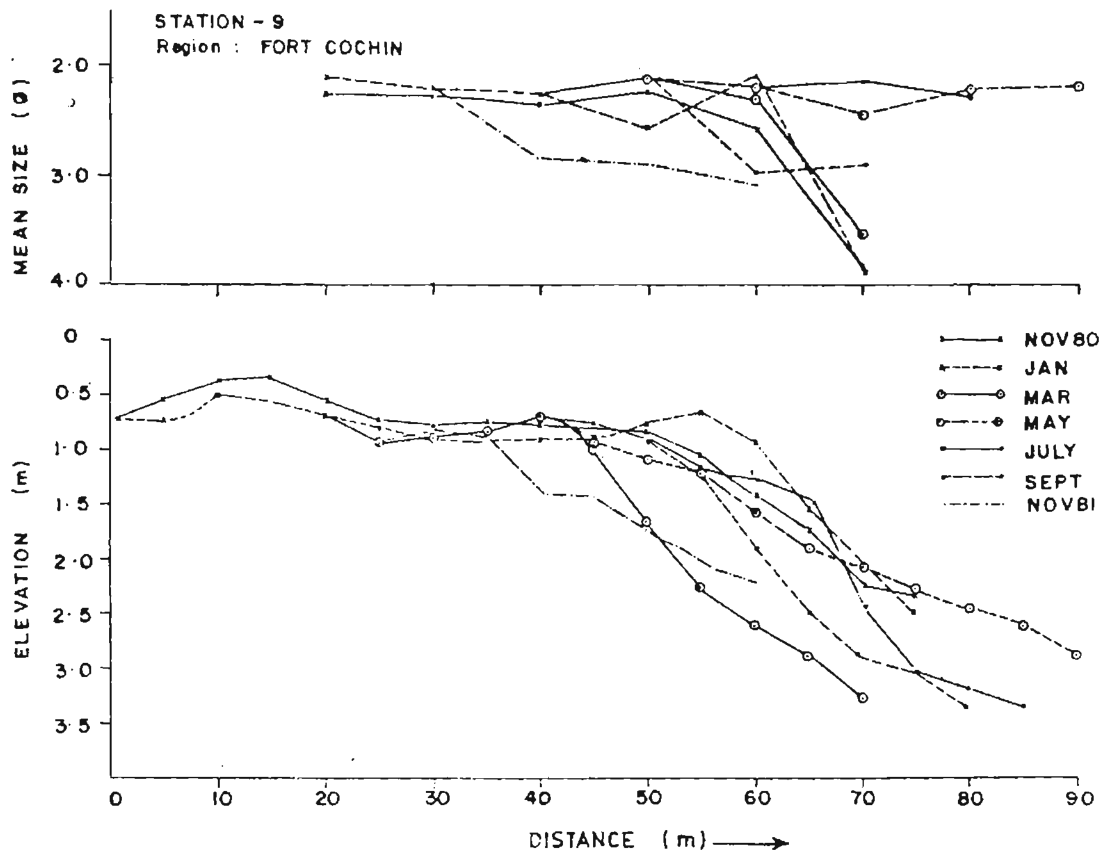

Fig. 16 H. Variation of mean grain size with elevation along the profile line at station 9

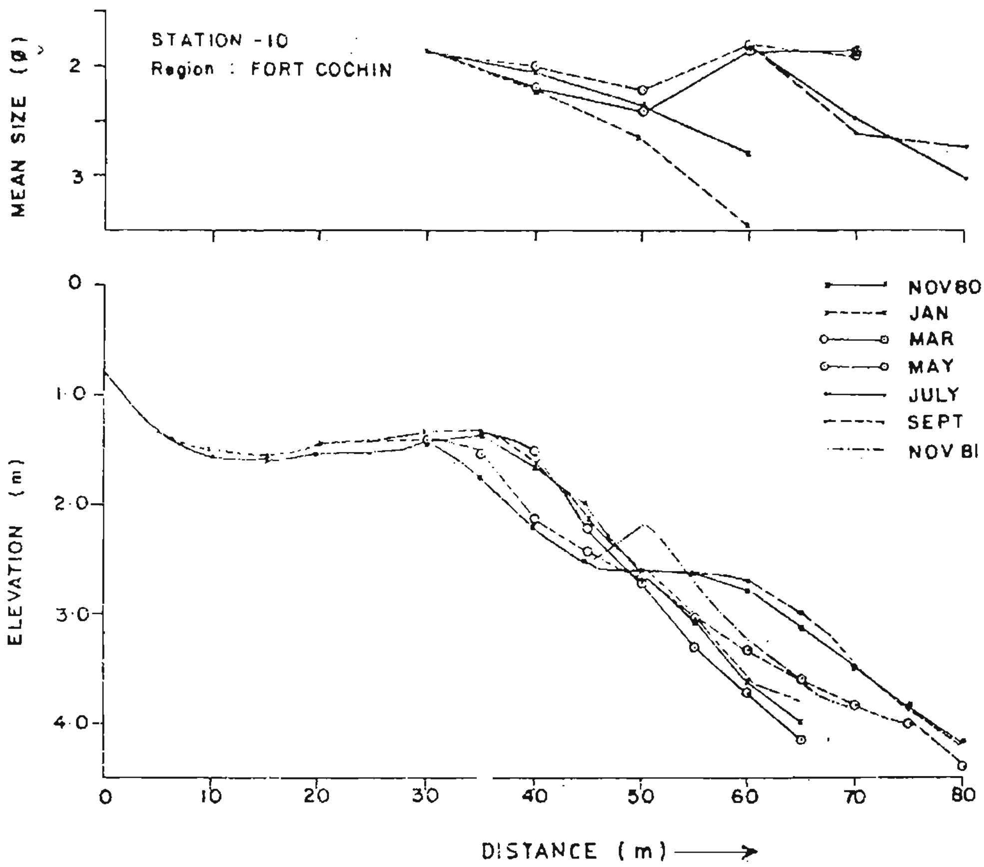

Fig. 16 I. Variation of mean grain size with elevation along the profile line at station 10

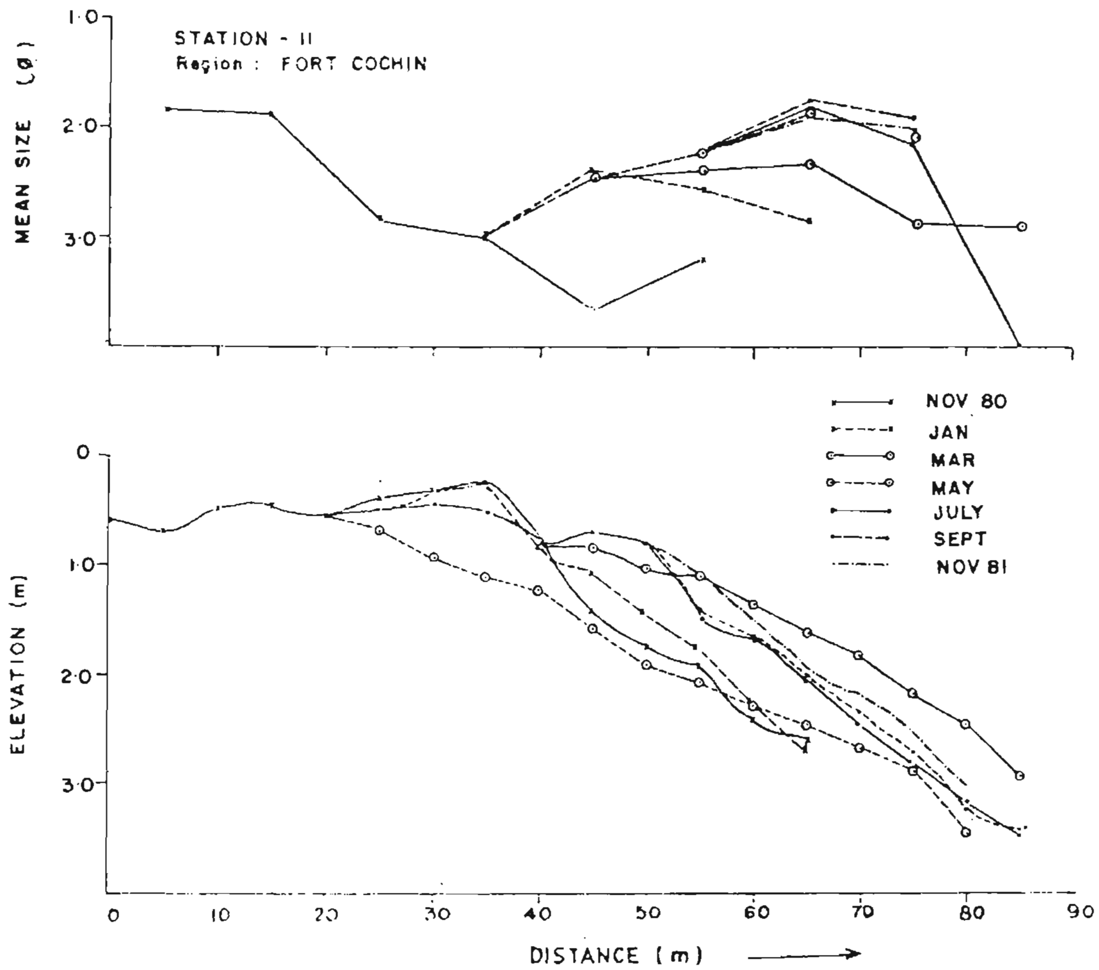

Fig. 16 J. Variation of mean grain size with elevation along the profile line at station 11

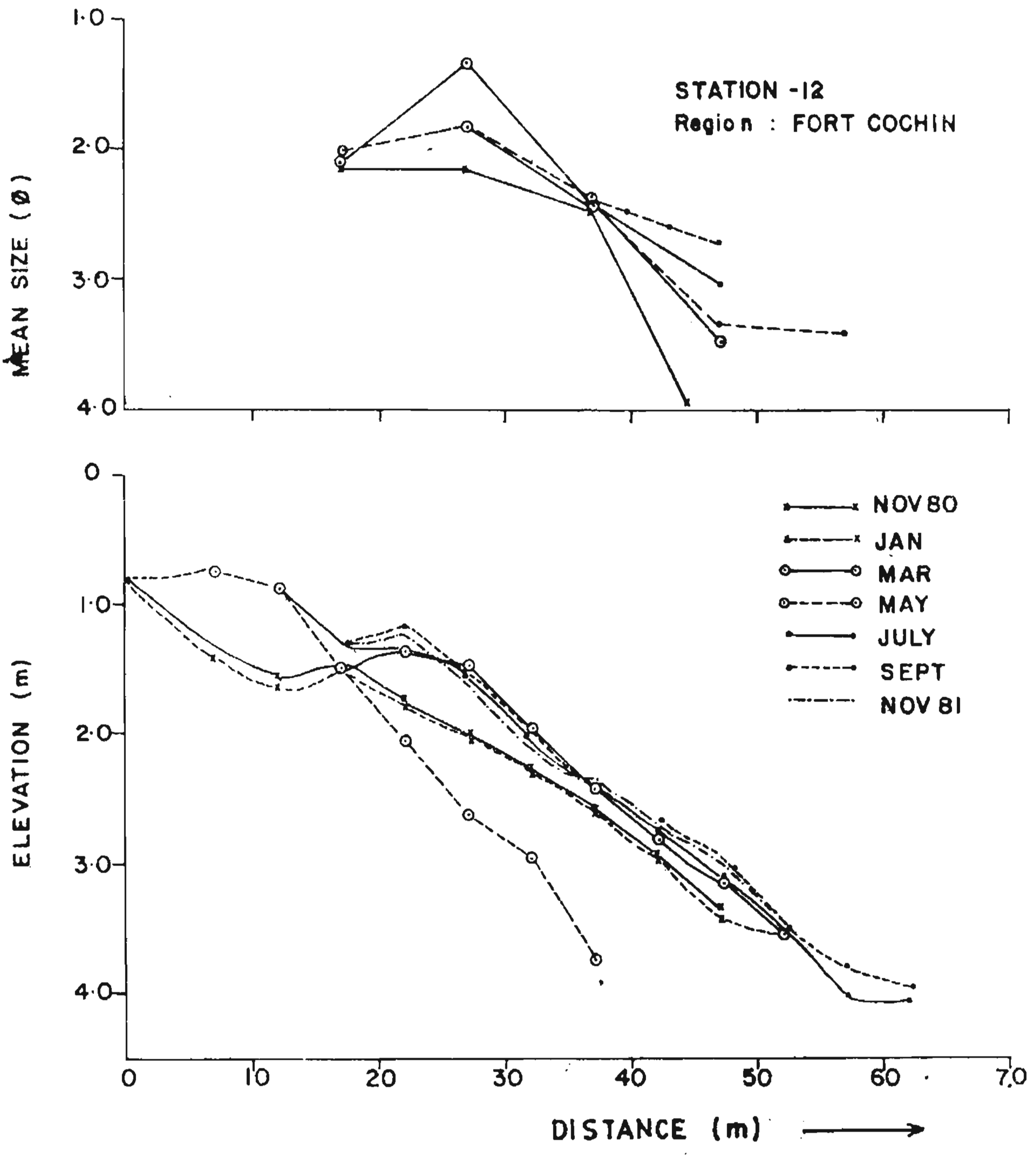

Fig. 16 K. Variation of mean grain size with elevation along the profile line at station 12

scatter plot for mean grain size versus standard deviation does not show any definite trend. The students' t test applied to the mean grain size of sediment samples along different profile lines (Table 10) suggests that there is no significant difference in the M_z values during different months except a slight difference in two samples from station 9. At station 9, mean grain size values are relatively coarser during May and July than during November. This difference is significant at 5% level.

(d) <u>Anthakaranazhi (station 13 to 16)</u>

The variation in mean grain size with respect to the position of the sample on the profile line for different months presented in Figure 16 L-O does not show any definite trend at station 13 and 15. But at stations 14 and 16, the mean grain size decreases towards foreshore with some inconsistencies. The grain size varies between 3.5 ϕ and 1.2 ϕ along the profile line at station 13, 3.5 ϕ and 1.75 ϕ at station 14, 3.3 ϕ and 1.9 ϕ at station 15 and 3.5 ϕ and 2 ϕ at station 16. Like other beaches the sediments along this beach are also moderately sorted eventhough there are few samples which are poorly sorted. At station 16, sediments remain moderately sorted during the year with standard deviation ranging between 0.5 to 0.8 ϕ. A sinusoidal trend is observed in the scatter plot between

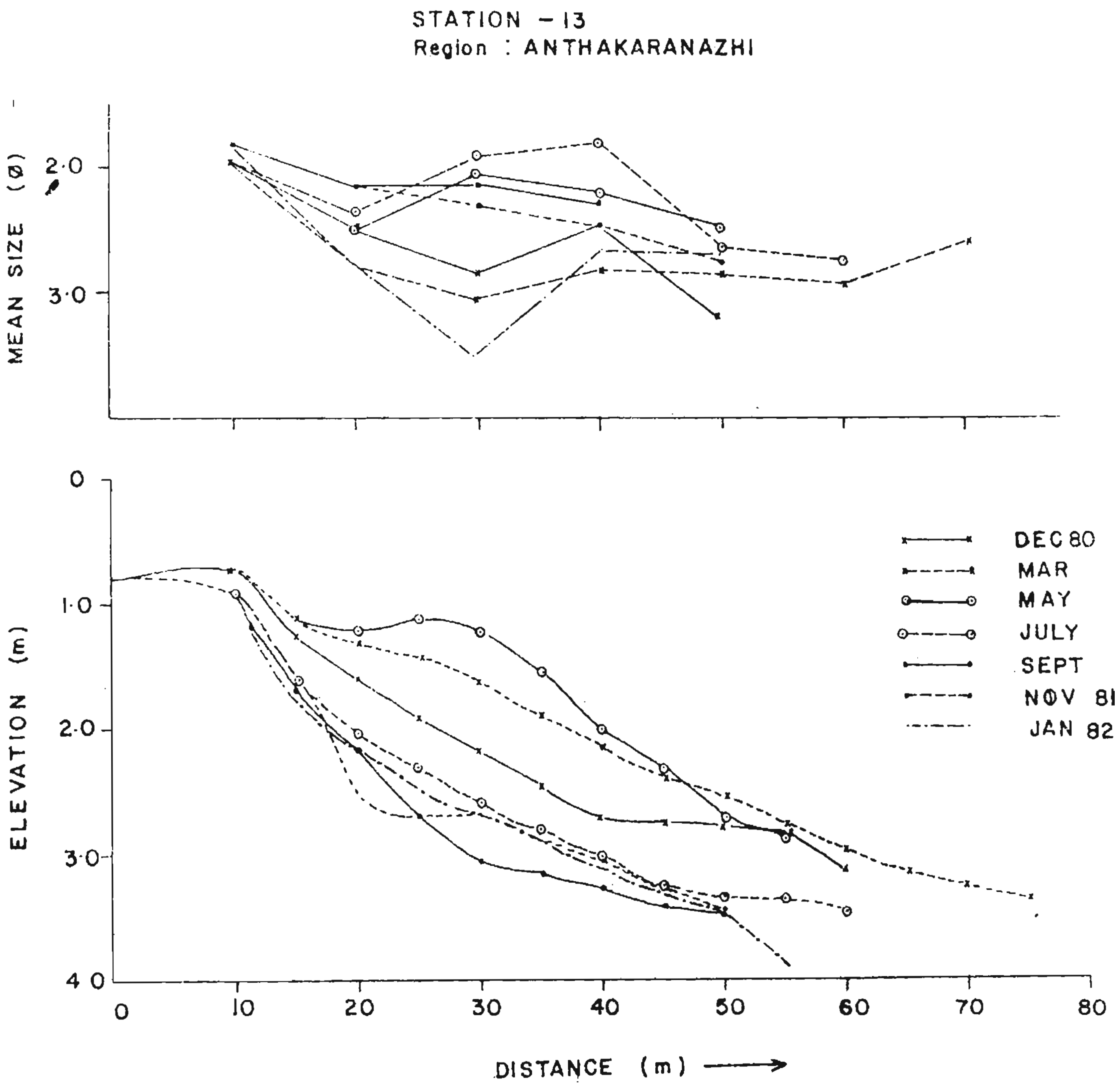

Fig. 16 L. Variation of mean grain size with elevation along the profile line at station 13

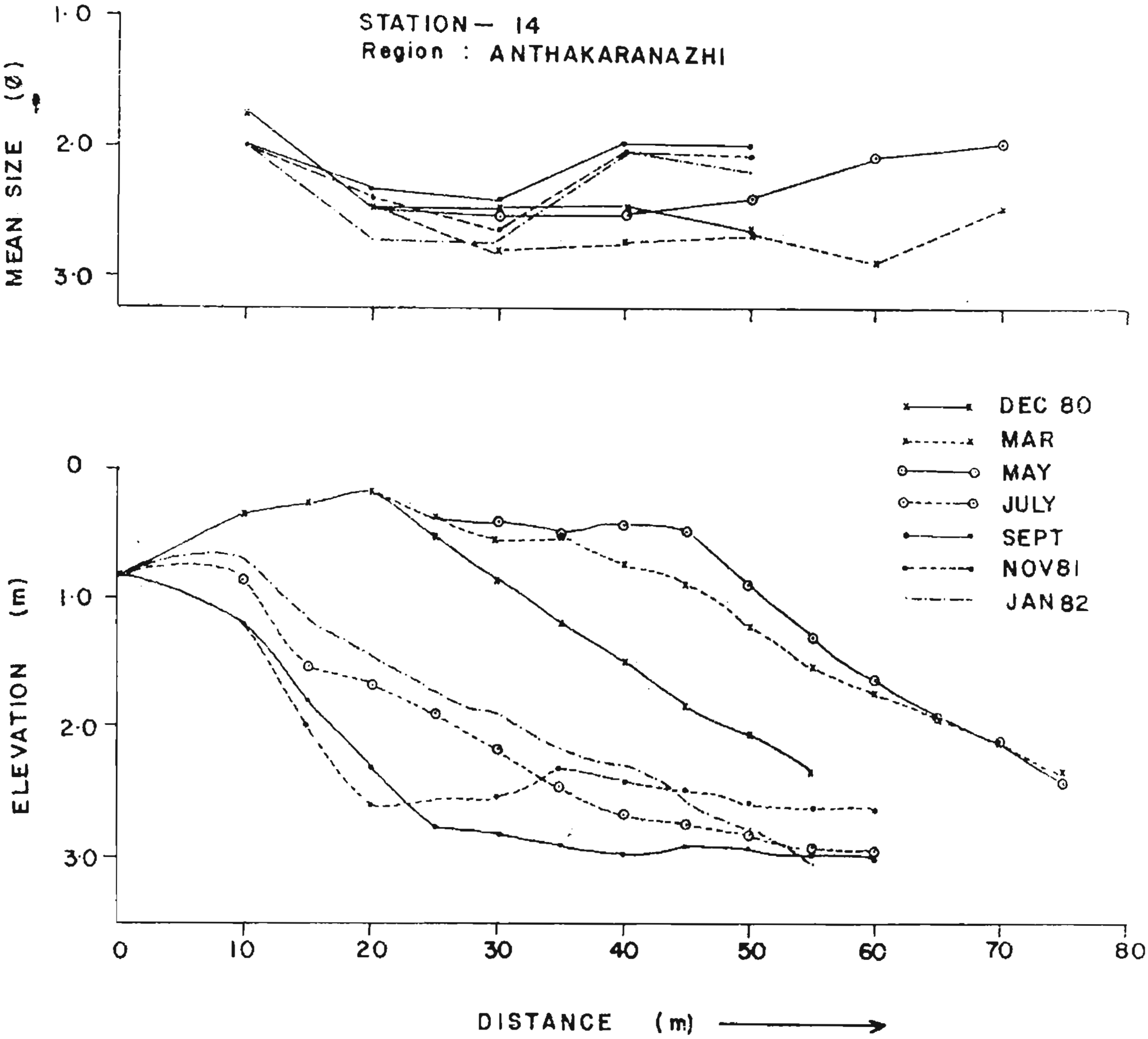

Fig. 16 M. Variation of mean grain size with elevation along the profile line at station 14

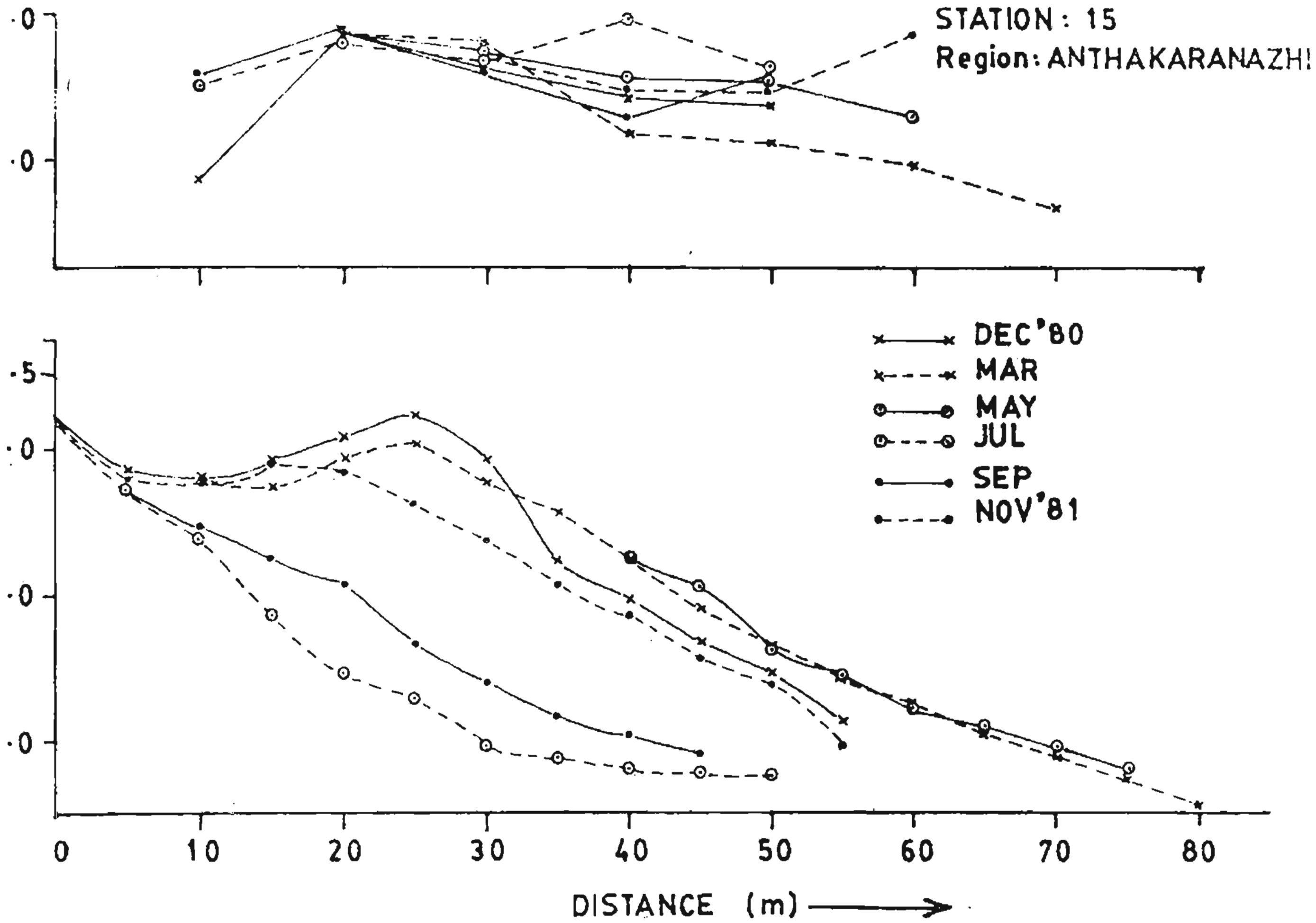

Fig. 16 N. Variation of mean grain size with elevation along the profile line at station 15

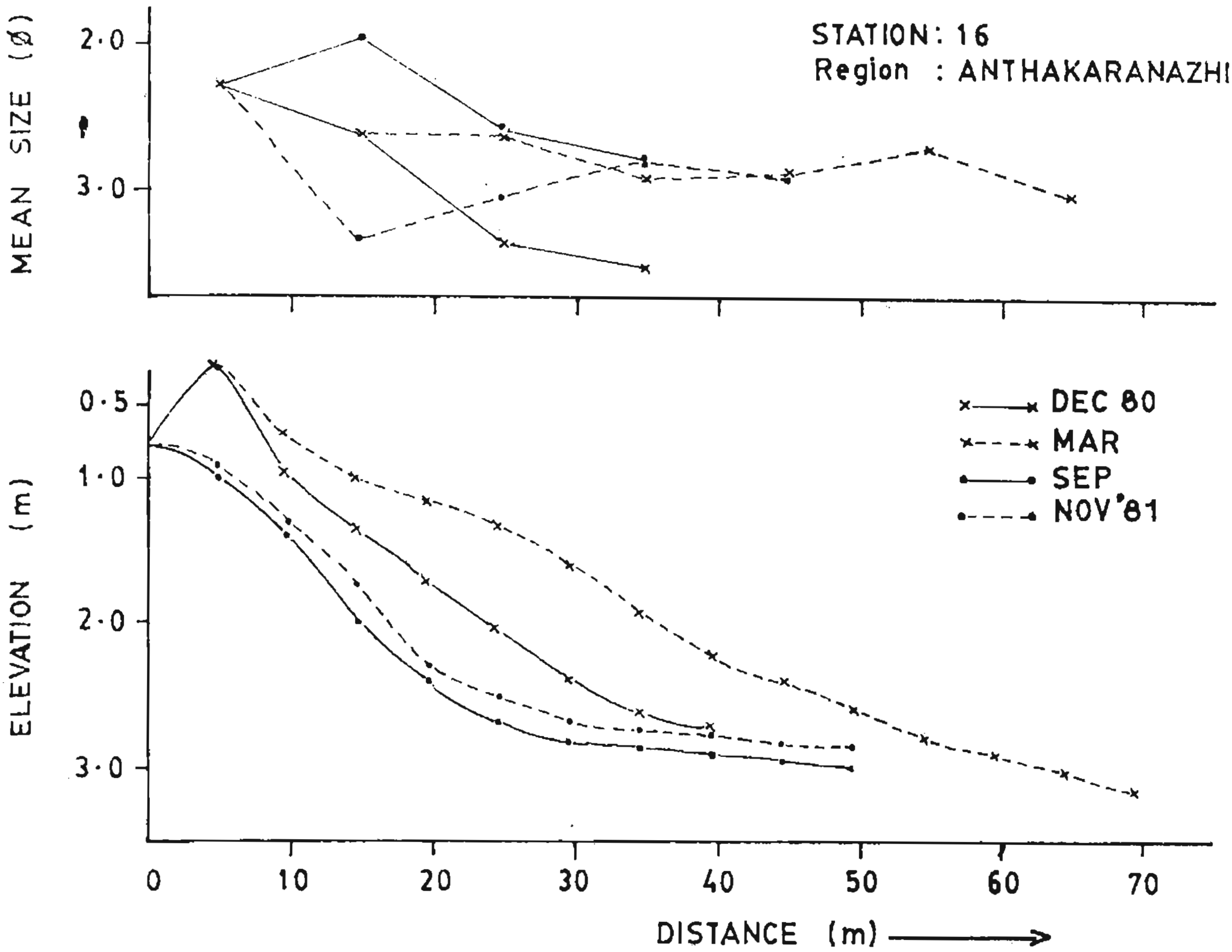

Fig. 16 O. Variation of mean grain size with elevation along the profile line at station 16

sample means and skewness. But no pattern is observed in the scatter plot of sample mean against standard deviation. The variation in grain size between months for individual station shows distinct differences only during May, July and September with the samples collected during March. The mean grain size at station 13 is found to be finer during March than during May, July and September. Except this, there is no significant difference in the mean grain size of the samples for different months.

4.3.2. Comparison of mean grain size at one station to another

The significance in difference in the mean grain size from one profile line to another is indicated by Table 11. Students' t test has been performed on the means of mean grain size values from each station. The following results are inferred from this table regarding the spatial variation of sediment size.

There is no significant variation in the mean grain size from one station to another along Narakkal and Malipuram beaches. The beach along Narakkal is occupied by sediments of average mean grain size 2.75 ϕ with a standard deviation of about 0.66. Malipuram beach is also occupied by the sediments of more or less same size as those at Narakkal beach except at profile line 6. Along this profile line,

TABLE 11

Values of student's t test and their significance for the difference in the mean grain size of the sediments between different stations

Stations	Narakkal		Malipuram				Fort Cochin				Anthakaranazhi			
	2	3	4	5	6	7	9	10	11	12	13	14	15	16
1	0.543 (38)	0.443 (43)	0.127 (65)	1.335 (50)	2.729** (48)	0.088 (40)	2.586* (61)	4.187** (51)	2.353* (72)	1.592 (45)	2.339* (54)	2.606* (48)	1.977 (50)	0.407 (37)
2		1.004 (45)	0.768 (67)	1.827 (52)	3.243** (50)	0.689 (42)	2.945** (63)	3.097** (53)	2.146* (74)	0.962 (47)	1.536 (56)	1.634 (50)	1.019 (52)	0.252 (39)
3			0.357 (72)	1.150 (57)	2.555* (55)	0.397 (47)	3.553** (68)	5.297** (58)	3.279** (79)	2.267* (52)	0.440 (61)	3.515** (55)	2.840** (57)	0.967 (44)
4				1.649 (79)	0.300 (77)	0.044 (69)	3.148** (90)	5.122** (80)	3.123** (101)	2.068* (74)	2.915* (83)	2.928** (77)	2.250* (79)	0.560 (66)
5					0.778 (62)	1.711 (54)	4.264** (75)	5.273** (65)	4.308** (86)	2.990** (59)	3.931** (68)	3.867** (62)	3.413** (64)	1.762 (51)
6						1.650 (52)	7.033** (73)	8.728** (63)	6.583** (84)	4.772** (57)	6.492** (66)	6.799** (60)	6.230** (62)	3.612** (49)
7							3.015** (65)	4.822** (55)	2.731** (76)	2.338* (49)	2.797** (58)	3.052** (52)	2.352* (54)	0.563 (41)
9								1.338 (76)	0.034 (97)	0.348 (70)	0.030 (79)	1.220 (73)	0.940 (75)	2.415* (62)
10									1.146 (87)	1.974 (60)	0.955 (69)	2.200* (63)	3.392** (65)	0.117 (52)
11										0.310 (81)	0.060 (90)	0.140 (84)	0.804 (86)	2.101* (73)
12											0.342 (63)	0.409 (57)	0.316 (59)	1.396 (46)
13												0.340 (66)	0.897 (68)	2.248* (55)
14													1.082 (62)	2.583* (49)
15														1.799 (51)

the sediments are relatively finer ($M_z = 3.24\ \phi$) than those along the profiles from Narakkal. But there is no significant difference between the mean grain size of the sediments from different profile lines along Malipuram beach.

The sediments along Fort-Cochin beach show significant difference in mean grain size from the sediments of Narakkal and Malipuram beaches. These sediments are relatively coarser than the sediments from Narakkal and Malipuram beaches. But the sediments along Fort Cochin beach are of almost same size from station 9 to 12 and they do not show any significant variations. The sediment samples from Anthakaranazhi beach do not show any clear trend in the differences of mean sizes from other beaches (Table 11). The beach material along certain profiles at Anthakaranazhi shows significant difference in mean grain size with the sediments from other beaches. Further, the sediments along profile lines 13 and 14 show significant variation at 5% level in mean size with the sediments from profile line 16 which are relatively finer than the sediments along other two profile lines.

The following are some of the conclusions arrived at from this study: (i) there is no spatial variation in sediment size along the beaches around Cochin when one considers a particular beach, (2) there is significant variation in the mean size of the sediments along Fort Cochin beach compared to Narakkal and Malipuram beaches, and (3) the variation of sediment size along the Anthakaranazhi beach compared to other beaches are not marked as in the case of Fort Cochin beach.

Eventhough there is no statistically significant spatial variation in sediment size along the beaches around Cochin, a close examination of Table 9 reveals certain interesting results. The mean of mean grain sizes from Narakkal indicates a decrease from station 1 to 2 in the sediment size and slight increase at station 3. This type of grain size distribution shows converging flows in the vicinity of station 2. The flows observed during June, July and August (Fig. 14 A) show northerly flows at station 3 and southerly flows at station 1. But during rest of the year, the flows are mostly towards south except the northerly flows during November and December. The mean of mean grain sizes at station 4 to 7 (Malipuram) also shows such flows directed towards station 5 and 6 from either side (Fig. 14 B). In the presence of mud banks such flows are possible.

The mean of mean sizes of sediments from Fort Cochin and Anthakaranazhi shows a decreasing tendency towards south. This clearly indicates predominant southerly flow along these beaches which is in good agreement with the observed flows (Fig. 14 C and D) and the flows identified from refraction diagrams (Fig. 15).

The composition of the beach material along the beaches around Cochin is predominantly sand with varying amounts of shell materials. But along Narakkal and Malipuram beaches, varying amounts of mud/clay material are also found during southwest monsoon season when these beaches received protection from mud banks. Most of the sediments along the beaches around Cochin are in the size class medium to fine sands and are moderately sorted. In general, coarsest grains are found along the Fort Cochin beach and finest sediments along the Malipuram beach. The coarsest sediments next to Fort Cochin are found along the Anthakaranazhi beach. As discussed in Chapter 2, the beaches at Narakkal and Malipuram are influenced by mud banks during southwest monsoon months. The calm conditions provided by these mud banks through the damping of waves produce favourable environments for sedimentation of fine sediments along the shoreline. The solitary waves propagating over the mud banks are enough to produce a foreward mass transport in the nearshore zone as suggested by Wells (1977). Thus, the very fine sediments found in abundance along the shores of Narakkal and Malipuram probably are derived from the offshore areas. Furthermore, the very weak longshore currents observed (Chapter 3) along these beaches may not be able to transport significant amounts of the fine material deposited along the shoreline. Thus the sediments do not show significant differences. Fort Cochin beach is also influenced by mud bank during southwest monsoon season; but the sediments along this beach are relatively coarser than the sediments from other two beaches which received shelter from mud bank. This may be because of two reasons (i) the mud bank observed along this beach was not so active as the mud bank observed off Narakkal and Malipuram to favour deposition of fine sediments along the shore; (2) the strong longshore currents observed along this beach (Chapter 3) prevent deposition of fine sediments along this shore.

The beach sediments generally present symmetrical distribution or negative skewness. But in this study, we encounter positive skewness in more than 50% of the samples, especially in Malipuram and Narakkal regions. Friedman (1961) also reported positive skewness for the beach sands from southern Padre Island, Texas. Mason and Folk (1958) suggested two possible processes to obtain a positively skewed distribution from a normal one: (i) addition of fine material and (2) substraction of the coarse end of a normal distribution. But along Narakkal and Malipuram beaches the first process has seemingly operated because of the presence of mud banks. The fine sediments are deposited under the calm conditions provided by mud banks instead of removing the coarse grains from the beach which requires higher wave energy. The southwestern Louisiana coast provides a good example of a shoreline in which positively skewed sands with abundant fine are common (Friedman, 1967). Thus the positively skewed sediments are possible among beach sands, provided the abundance of fines exceeds the energy available for dispersing them.

Many samples show extreme values of kurtosis in the mesakurtic to leptokurtic range. This indicates better sorting of the sediment in the central area than in the tails and it may imply that part of the sediment achieved its sorting elsewhere in a high energy environment and was then transported essentially with its size characteristics unmodified into another environment where it was mixed with another type of material (Folk and Ward, 1957).

Four scatter plots have been prepared for different beaches by coplotting mean grain size versus standard deviation and skewness (Fig. 17 A,B). No plots between mean grain size and standard deviation succeeded in showing any significant trends. This shows that for the beaches around Cochin sorting is practically independent of mean size.

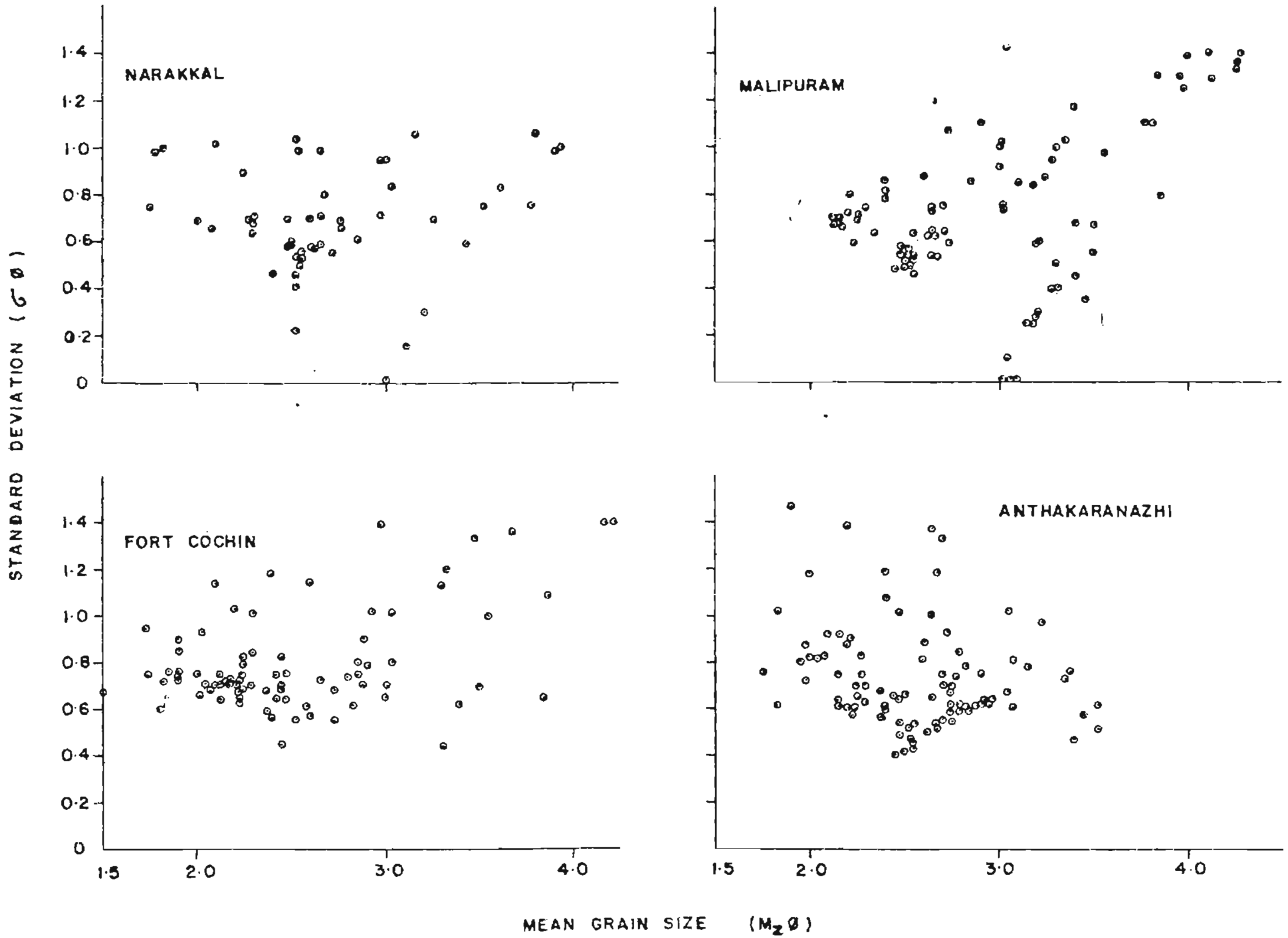

Fig. 17 A. Scatter plots of mean grain size versus standard deviation

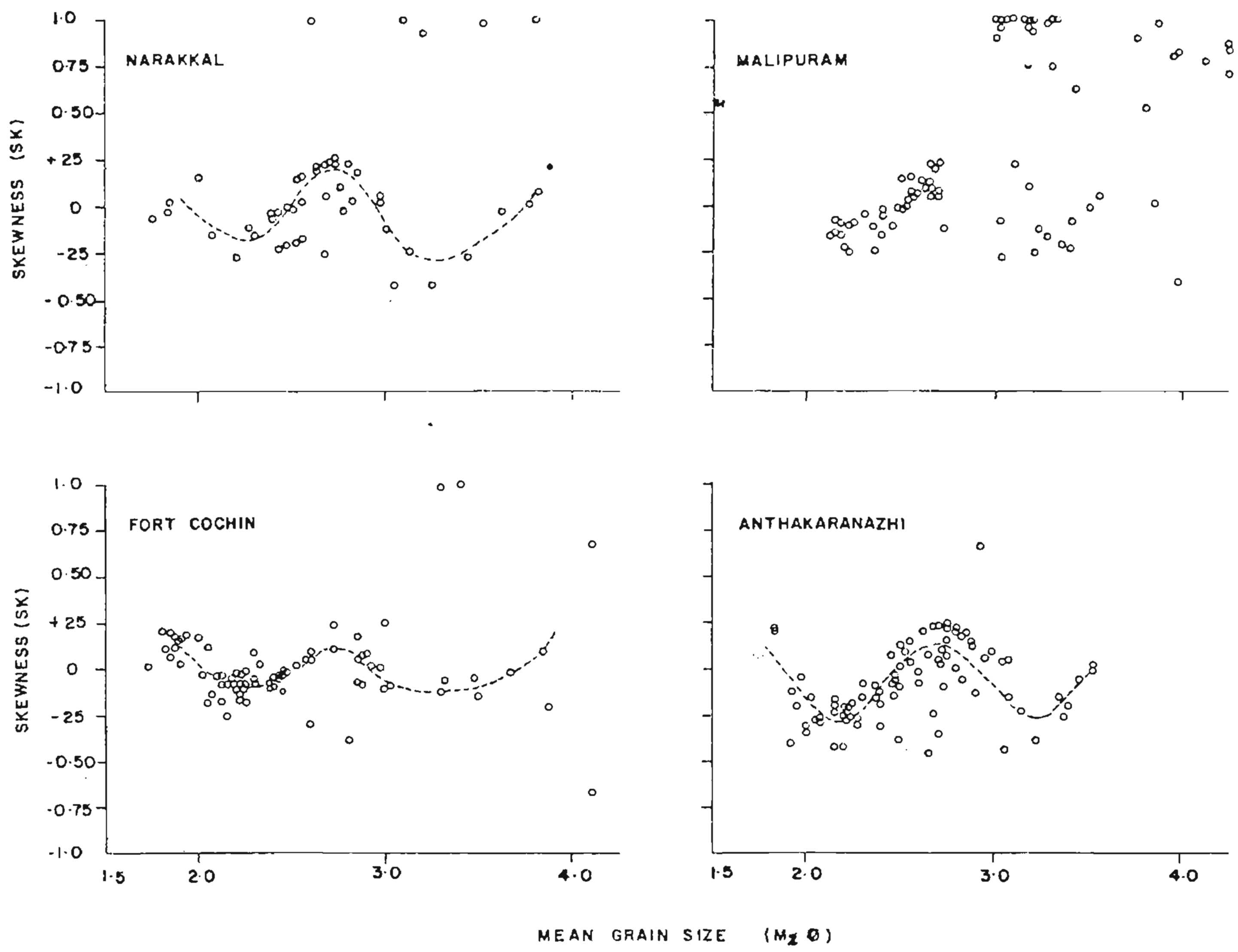

Fig. 17 B. Scatter plots of mean grain size versus skewness

the moderate sorting of the majority of the beach samples is evident in these diagrams.

The beach profiles given in Figure 16 A-O show the accretion/erosion patterns of the beaches during different months. In general, most of the erosion took place during the southwest monsoon period where along the beaches that are exposed directly to the incoming waves. But under the protection of mud banks, along certain profile lines at Narakkal and Malipuram beaches, accretion has taken place. From Figure 16, it can be found that there is a general tendency in sediment mean size to increase during phases of erosion of the beach and decrease during phases of accretion. However, some inconsistencies were also noticed. But it must be noted that these variations in mean size due to the erosional and accretional tendencies are not statistically significant during most of the months at most of the stations (Table 10).

The relative coarseness in the size of the sediments corresponding to the erosional features along the beaches is a manifestation of the increased wave activity and strong onshore winds during southwest monsoon. During this period, as indicated in Chapter 2, the waves are high and steep causing increased wave run up on the beach face. The nearshore water level also rises due to wind set up. The orbital velocities of these steep waves are high and the turbulence due to increased wave action keeps the fine particles in suspension. The prevailing onshore winds will contribute to the seaward movements inside the surf zone (King, 1972). Under such conditions, the fine material gets transported in the seaward direction or alongshore by the prevailing flows existing in the surf zone, leaving behind relatively coarse-size material on the beach face as lag deposit.

At Anthakaranazhi higher breaker heights during May to August lead to the erosion of the beach. During this period, the beach sediments are relatively coarser than during the previous months and even statistically significant at profile line 13 when compared with the samples collected dur November, which is normally an accreting month. Subsequently, with the cessation of high wave activity, low, long period wave which approach the beach bring the finer sediments on to the beach causing building up of the beach.

CHAPTER 5

LITTORAL DRIFT

5.1. INTRODUCTION

Sediments in the nearshore regions are of two types: cohesive and non-cohesive. While dealing with the mechanics of sediment transport, initiation of motion and the rate of movement must be taken into consideration. The quantity transported depends both on the properties of the sediment and on the flow parameters such as current speed and shear. This transport of sand has been found to bear close relationship with the incident wave energy flux at the breaker zone. Depending upon the above parameters, the beach sediments get transported through rolling, saltation and suspension. In general, the bed load transport forms about 75% of the total transport (Komar, 1978).

The movement of sediment within the boundaries of the surf zone under the action of waves and wave induced currents is called the 'lottoral drift'. Qualitative and quantitative estimation of the drift along the coastlines has been a topic of study for the last few decades by geologists, coastal engineers and coastal zone management personnel. The concepts of sediment transport by waves could be seen from the works of Galvin (1972) and

Horikawa (1978) who have summarized the studies of various researchers relating the longshore wave energy and longshore transport rates. Much of our knowledge on the rate of littoral drift under varying wave energy, wave steepness and angle of incidence is due to the model experiments on sand transport conducted by Saville (1950). Later on, the empirical approach of correlating the said drift rate to the longshore component of wave energy flux has been developed from field and laboratory experiments (Watts, 1953; Caldwell, 1956; Savage, 1959). This approach provided an approximate answer to the quantity of sand moving along a beach under a given set of wave conditions. The first theoretical model for longshore drift was developed by Bagnold (1963) and applied to the littoral zone by Inman and Bagnold (1963).

Experience indicates that the best way to predict longshore drift at a given site is to adopt proven values from nearby sites, or to estimate values from surveyed changes in sand volume at suitable places along the shore (Anonymous, 1977). In the absence of actual field-based estimates, the recommended procedure is to use the energy flux method (Vitale, 1980).

For the shore from Azhikode to Anthakaranazhi the method of calculating the longshore sediment drift using longshore component of wave energy has been employed under the prevailing wave conditions in the present study.

5.2. MATERIAL AND METHODS

The alongshore component of incident wave energy flux has been calculated using the data on wave climate presented in Chapter 2. Waves approaching the study area from five directions (220, 240, 260, 280 and 300° TN) with wave heights and periods falling within 0.5 and 2 m and 6 and 14 sec respectively, have been considered from the data sets for each month (Table 4; Fig. 8). It is assumed that waves from the above directions only occur on any day in any particular month. A limiting wave height of 2 m in deep water was considered to prevail at 2 m isobath because the wave heights would be depth dependant (H_b = 0.83 d); Longuet-Higgins (1972). When wave heights greater than 2 m prevail, they would break prior to reaching the 2 m isobath and secondary waves get possibly amplified due to refraction effects.

The longshore component of wave energy flux at 2 m isobath was calculated using the following equation by Johnson and Eagleson (1966) at 19 stations from Azhikode to Anthakaranazhi, and then multiplied by the percentage of occurrence of that wave:

$$E = \frac{\gamma H_o^2 C_o}{16} \cos\theta \sin\theta,$$

where γ is the specific weight of sea water, C_o is the deep water wave velocity, H_o is the deep water wave height and θ is the angle between the breaking wave and the shoreline. A positive value of E, expressed in Kg-m/m of the wave, represents a component of wave energy flux in a southerly direction and a negative value represents a component in the northerly direction.

The total longshore wave energy component at each station for a day was obtained by summation of the longshore wave energy flux for each wave type. The quantum of probable sediment transport Q has been calculated following the formula suggested by Inman and Bagnold (1963) and used by Sastry and D'Souza (1973) and Antony (1976) for the beaches along the west coast of India under similar wave conditions:

$$Q = 210.7\ E$$

where Q is the rate of littoral drift in m^3/day/m of beach and E the intensity of alongshore component of wave energy in millions of Kg-m/m of wave per day.

The beaches along the coastal segment under study are composed of sandy sediments in fine to medium size limits (Chapter 4) and facilitate the use of above equation in this area. The magnitude and direction of the net yearly longshore drift for each site were computed by algebraic addition of the littoral drifts towards south and north past each individual site for the entire twelve month period.

It must, however, be pointed out that the results obtained in the present study are limited to non-cohesive sediments and to reasonably well balanced wave conditions. The results provide some insight into the quantum of sediment drift along the beaches under study.

5.3. RESULTS AND DISCUSSION

The temporal and spatial variations of the alongshore component of wave energy (Table 12) show significant variations in magnitude at all the 19 stations B-T. The data for January has not been included in this table as the energy available along the shore under study has been found to be insignificant during this month for the directions and periods considered. As could be seen from this table, maximum longshore component of wave energy is

TABLE 12

Alongshore component of wave energy, E in Kg-m/m of wave per day

Station	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B	2479.68	8475.84	20545.90	5063.04	9694.08	5011.20	6799.68	12553.92	6013.44	768.96	16692.48
C	2116.80	8484.48	21997.44	5028.48	5944.32	4484.16	6013.44	2401.92	5901.12	17.28	11370.24
D	2090.88	10532.16	19198.08	2860.64	4717.44	2816.64	3533.76	1321.92	5520.96	- 267.84	10860.48
E	777.60	5702.40	17288.64	4354.56	3611.52	2064.96	2496.96	1105.92	5676.48	-1356.48	8553.60
F	1572.48	7620.48	19742.40	2384.64	4510.08	1909.44	2471.04	1581.12	4268.16	- 864.07	9028.8
G	2903.04	10100.16	19224.00	7205.76	9218.88	7810.56	9426.24	7266.24	7577.28	2669.76	10860.4
H	2885.76	10307.52	26040.96	5235.84	6549.12	5149.44	6713.28	4207.68	5762.88	466.56	11275.20
I	1961.28	8441.28	20252.16	2773.44	4060.80	1235.52	1736.64	2574.72	6030.72	-1753.92	11370.24
J	717.12	3144.96	3758.40	3611.52	-1304.64	-3127.68	-1218.24	-2998.08	-1200.96	-2427.84	8873.28
K	924.48	2522.88	10454.47	-1252.80	- 673.92	527.04	- 751.68	-1399.68	3274.56	-1598.40	9460.80
L	665.28	3283.20	11335.68	-2289.60	-1546.56	-1235.52	-2177.28	-1183.68	- 164.16	-2090.88	7551.36
M	1848.96	5495.04	14627.52	2548.80	9564.48	2980.80	3957.12	2712.96	4276.80	- 259.20	9607.68
N	1589.76	6419.52	15621.12	2626.56	5106.24	2462.40	3525.12	2522.88	4034.88	- 665.28	9892.80
O	1658.88	6039.36	16104.96	2237.76	2462.40	967.68	2782.08	1105.92	4026.24	-2039.04	1034.08
P	1641.60	6480.00	17418.24	846.72	2246.40	466.56	2021.76	656.64	4760.64	-1779.84	9469.44
Q	1356.58	5711.04	13582.08	267.84	423.36	- 397.44	293.76	3620.16	2583.36	-4173.12	8873.28
R	1416.96	4743.36	16588.80	1391.04	2410.56	699.84	2116.80	751.68	5883.84	-1477.44	8069.76
S	1460.16	5097.60	12173.76	803.52	1969.92	259.20	1736.64	155.52	4717.44	- 388.80	8069.76
T	1883.52	6143.04	18316.80	1140.48	3283.20	2047.68	3585.60	1598.40	5590.08	- 86.40	10152.00

+ southerly - northerly

during April and December. The longshore energy flux during June, July and August (southwest monsoon months) is not high compared to the non-monsoon months. This is because, during these months the wave approach is almost normal to the coast contributing more to the onshore-offshore component of wave energy rather than to the longshore component. During other months the wave approach is more oblique to the coastline contributing largely to the longshore component than to the normal component.

Waves impinging the coast from north result in a southerly longshore component while waves from south of the normal result in a northerly longshore component (Chapter 3; Fig. 15 A-E). The results show that except during November, the longshore energy component is directed towards south (Table 12). Only during November, the component reverses to northerly direction at almost all the stations. Results from wave observations indicate that more than 75% of the time the waves are favourable for southerly component of wave energy along this coast (Fig. 8).

Spatial variations in the longshore wave energy components are significant. The sudden changes in magnitude (Table 12) may not be representative of the actual energy flux conditions because, the refraction model used in the study uses static shoreline conditions and bathymetry. As soon as a concentration of wave energy in shallow water occurs, the resulting erosion leads to changes in bathymetry and reduction in the energy concentration.

5.3.1. Littoral drift between Azhikode and Vypin

During rough weather season (April - September), the littoral drift along the shoreline between B and I is uniformly southerly and shows an irregular trend in magnitude (Table 13). The volume of littoral material in transit due to wave breaking decreases from B to E with a maximum quantity of material in motion at G during rough weather season. During fair weather season also (October - March) the trend remains more or less same with lesser magnitudes. During this season, the direction of littoral drift remains southerly with high magnitude of drift at stations B and at G (about 215 m^3).

5.3.2. Littoral drift between Fort Cochin and Anthakaranazhi

Along this stretch of the coastline also the net littoral drift is towards south during both the seasons. Northerly drift is indicated during rough weather season only at station J. Between stations J and M, there is an increase in the magnitude towards south with a maximum of

TABLE 13

Littoral drift along the stretch of beach from Azhikode to Anthakaranazhi

(Littoral drift expressed in m^3 per season)

Station	April-September (rough weather)		October-March (fair weather)	
	Littoral drift at individual station	Total drift $\times 10^6$	Littoral drift at individual station	Total drift $\times 10^6$
B	377.16	5.8147	217.63	3.6987
C	289.99		176.40	
D	217.56		181.59	
E	195.61		122.33	
F	206.11		136.81	
G	380.07		215.72	
H	340.76		194.15	
I	206.44		164.66	
J	- 8.12	3.7057	57.62	3.3005
K	43.58		92.37	
L	18.35		58.44	
M	230.03		132.44	
N	201.52		134.35	
O	162.20		126.70	
P	149.42		129.98	
Q	112.39		90.66	
R	151.39		117.69	
S	108.13		119.88	
T	189.40		149.64	

230.03 m^3 at M during rough weather season and 134.35 m^3 at N during fair weather season. The total drift during both the seasons along the shoreline between Vypeen and Azhikode appears to be higher than that along the shoreline between Fort Cochin and Anthakaranazhi.

The amount of material dredged out from the Cochin harbour entrance channel can be compared with the above computed values as a cross check. The navigational channel of the Cochin harbour consists of 6.0 km of outer channel and two inner channels inside the back-water system. In order to maintain the desired navigable depths in the approach channel, about 2 million m^3 of material is dredged out every year. Of this, about 70% is derived from the approach channel (Gopinathan and Qasim, 1971). The present study shows that the littoral drift during rough weather season north of the entrance channel is southerly while it is northerly immediately south of the channel (between stations I and J). These opposing sediment drifts are likely to be carried into the channel and may be responsible for the high amount of deposition taking place in the outer channel.

The above computed drift values are to be viewed in the context of the availability of sediments, in the sand size limits in the surf zone and the adjacent beach sectors. The fine to medium sandy sediments are available only along a narrow belt parallel to the shore extending upto about 4 m isobath. Beyond this depth, upto about 140 m, silty clays or clayey silts are only available (Nair and Pylee, 1968). Thus, there may not be any supply of sand-sized sediments to the littoral zone from the offshore. Moreover, due to low terrain and gentle slopes of the coastal plain, the rivers becomes sluggish and deposit much of their sediment load on their way before reaching the coast. Also, as explained earlier (Chapter 1), whatever little sediments reach near the coast are likely to get trapped in the backwaters. Thus the only source of beach material appears to be the adjoining beaches. Another source of littoral material, in addition to updrift beaches can be the river Periyar, situated on the northern end (just north of station B) (Fig. 6). No field estimates are available on the rate of supply of sediments by this river. Thus in the absence of sediment supply in large quantities from any other external sources, the littoral flows associated with wave activity are likely to be undersaturated and give rise to erosion of existing material in the shore zone. The reported failures of the shore structures constructed along this stretch of the coast may be due to this undersaturation.

Based on analysis of bathymetric charts and survey maps, Moni (1972) has reported progression of shoreline north of Cochin with flat inshore bottom contours and recession of shoreline south of Cochin with steep and close bathymetric contours. This indicates the depositional nature of the stretch of the barrier beach north of the entrance channel of Cochin harbour. This is an anomaly in the light of the above mentioned undersaturation of the flows resulting in erosion as described. The deposition of the sediments (probably including silty clays and clays) at this locality may be because of the blockade of southerly drifting material at the entrance channel by the strong flows through the entrance channel which acts as a hydraulic barrier (Smith and Gordon, 1980). Also the sediment distribution on the beaches north and south of the entrance channel does not show any continuity in the transport of material from north to south (Chapter 4).

In the region south of Cochin, there is again another imbalance because $7 \times 10^6 \, m^3$ of sediments are not available for drifting towards south during the year. Since there is no supply of sediment to this stretch from the north, the existing material is eroded from this stretch. The eroded material may get deposited south of the area under study.

Calculations of the rate of littoral drift are based on a linear relationship between the rate of volume transport and the longshore component of wave energy flux evaluated at the breaker zone. But since most of the wave energy is expended in breaking, it is not necessarily available to transport sediments. The relation between rate of littoral transport and longshore component of wave energy flux evaluated may not, therefore, be so fundamental (Longuet-Higgins, 1972). It may be noted that the calculated rate of littoral drift may represent slightly higher values than the actual. The computed values are based only on the potential of available energy. The higher values shown in Table 13 need therefore, be viewed in the light of lack of supply of sediments from sources other than the beach. In addition, as mentioned earlier, the drift due to the energy flux occurs mostly (75%) in the form of bed-load transport (Komar, 1978). In the swash zone, the beach changes are decided mainly by the suspended mode of sediment transport. Thus about 1/4th of the computed net sediment transport of 16×10^6 m^3. yields an average drift of 70 m^3/unit width of the beach/year. The volume of sediment involved in the profile variations, as discussed in Chapter 6, amounts to 20 to 30 m^3/unit width/year at Anthakaranazhi. The former volume (70 m^3) represents the amount of material taking part in the drift process from the 2 m isobath to the point of maximum uprush on the beach face. The latter (20-30 m^3) represents the amount of material involved in the profile changes mainly above the mean low water level. Thus, the balance of 40 to 50 m^3 of the sediment may be involved in sediment movements within the surf zone under the influence of offshore flows coupled with the cellular circulations mentioned earlier in Chapter 3. The beach material getting traped in such cellular flows may get carried offshore particularly when the beaches experience severe erosion as reported by Murty (1977) while studying the morphological changes of the mainland beaches of the west coast of India. In this case the beaches are reported to be neither losing nor gaining material leading to any deleterious effects on longer time scales.

The most important factor controlling the direction of the net longshore drift is the angle at which waves strike the shoreline. From the breaker observations made at selected stations (Table 7), it is seen that more than 70% of the observations indicate breakers favourable for a southerly drift. The remaining waves facilitate onshore-offshore transport and/or northerly transport. This type of wave approach results in longshore drift towards south during most of the time. The 70% figure given above may actually be a conservative estimate, but the point is that the frequency of longshore transport towards the south exceeds that towards north as determined by the frequency percentage of deep water wave conditions also (Chapter 2).

The migration of shoreline features such as natural inlets, head lands, etc. are good indicators of longterm littoral drift patterns. From the analysis of shoreline charts, Moni (1972) reports the migration of headlands and natural inlets (eg. Azhikode inlet) towards south. Thus it could be inferred that the quantity of littoral material moving towards south exceeds by far the quantity of material moving towards north and supports the results of the present study.

In the present study, the principal quadrant of wave approach remains the same with sea and swell arriving predominantly from the west and west-northwest. Local storms of short duration and a limited amount of swells, originating from the southern Indian Ocean, reaching the area from west south-west and southwest (Murty and Varadachari, 1980) may create short periods of northward littoral drift. However, wave studies and longterm observations of the shoreline processes conclusively indicate a greater amount of southerly littoral drift. Thus it can be pointed out that the net sediment transport along the shore from Azhikode to Anthakaranazhi is from north to south.

CHAPTER 6

BEACH MORPHOLOGICAL CHANGES

6.1. INTRODUCTION

The investigations carried out by Shepard (1950), Inman (1953), Bruun (1954) and Inman and Rusnak (1956) mark the beginning of systematic studies on the dynamic and continually changing beach and nearshore environments. The processes and the factors contributing to such changes have been extensively described by Zenkovich (1967).

Long-term studies on beach erosion/accretion focus attention on sediment budget and the changes in the beach profile. The action of waves on an inclined bed of sand eventually produces a profile in equilibrium with the energy dissipation (Inman and Jeffery, 1965). Open-ocean beaches display highly dynamic foreshore and inshore topographies in response to the relatively high incident wave energy variations (Wright _et al._, 1978).

Beach profiles - two dimensional vertical sections showing variations in beach elevation perpendicular to the shoreline-have characteristic features that reflect the action of the various littoral processes. The concept of an equilibrium beach profile was introduced based on laboratory studies by Tanner (1958). An equilibrium beach profile can be defined as the nearshore area with a particular set of environmental characteristics and acted upon by a given set of driving forces (Inman and Bagnold, 1963). This concept implies that the profile ceases to vary with time when the driving forces remain constant or become steady. This, however, fails under field conditions.

A large number of factors influence the beach profiles in between measurements in response to many factors, such as waves, tides, winds, longshore and rip currents and beach sediments etc. The varying effects of these parameters acting on various beaches along the coastlines of the world have been documented (Wiegel, 1964; Zenkovich, 1967; King, 1972). Eventhough the role of these beach shaping mechanisms have been fairly well known their effects may vary considerably from one coastline to the other. Thus, in order to study the changes in the beach profiles, a careful evaluation of repeated profile measurements need be carried out at regular intervals of time at selected locations. These measurements provide a means to determine the changes in volume of sediments comprising the beach form under wide variety of environmental conditions.

The role of various beach shaping mechanisms along the beaches around Cochin have been outlined in the previous

Chapters. This Chapter deals with observed changes on the beach profiles along these beaches and their status in general.

6.2. MATERIAL AND METHODS

Beach profile measurements were made following the procedure suggested by Emery (1961). Each profile extends seaward from a permanent reference point (RP) situated far inside the backshore and unaffected by waves to the low tide mark across the beach and occasionally beyond into the breaker zone. The elevations were measured across the beach at fixed intervals (2.5 m) and at shorter intervals whenever any distinct morphological features such as beach ridges, erosional scarps, etc. were present on the beach. Maintenance of profile alignment was made by sighting two conspicuous and permanent landmarks such as electric posts. These surveys were carried out at low tide times so as to obtain maximum exposure along the profile. The measurements were made upto the nearest centimetre in the vertical.

The changes observed in the beach profile have been presented in Figures 18 A-P. From these profiles, the cross-sectional area of each profile line has been computed by integrating 10 m horizontal slices through the area bounded between the initial profile and next. These have been subsequently converted to volume (m^3) per unit width of the beach (Figures 19 A-D).

The beach profiles were measured at regular intervals of time at four beaches namely Narakkal, Malipuram, Fort Cochin and Anthakaranazhi. The details regarding the number of profiles studied at each location and the total number of surveys carried out have been indicated in Table 14.

6.3. RESULTS AND DISCUSSION

6.3.1. Results

(a) Region : Narakkal (stations 1 to 3)

The beach profiles at stations 1 and 3 showed build up from the second half of December 1980 to first half of January 1981 (Fig. 18 A and C). But the profile 2 showed considerable accretion during November 1980 to December 1980 and erosion during the second half of December 1980 to first half of January 1981 (Fig. 18 B). During February 1981 all the three profiles indicated moderate erosion which continued till April, 1981 at profile 1. Accretion was noticed at profiles 2 and 3 during March 1981 and erosion during April 1981. From

TABLE 14

Details of beach profile surveys

Profile No.	Mean beach width (m)	Width considered for Vol. computations (m)	Survey period From	Survey period To	Frequency and total No. of surveys		Net loss(-) or gain (+) of sand at the end of the survey period (m^3)
Region: Narakkal							
1	65	45	18.11.'80	31.12.'81	2/month	26	+22.90
2	50	40	18.11.'80	31.12.'81	2/month	26	+17.11
3	50	40	18.12.'80	31.12.'81	2/month	24	+ 5.37
Region: Malipuram							
4	120	50	14.11.'80	3.1.'82	2/month	26	+14.02
5	100	50	31.10.'80	3.1.'82	2/month	26	+14.69
6	90	45	31.10.'80	3.1.'82	2/month	26	-11.81
7	80	45	31.10.'80	3.1.'82	2/month	26	-44.44
8	45	30	31.10.'80	25.8.'81	2/month	17	-11.90
Region: Fort Cochin							
9	100	65	11.11.'80	5.1.'82	2/month	26	-65.42
10	90	60	11.11.'80	5.1.'82	2/month	26	-33.01
11	125	55	11.11.'80	5.1.'82	2/month	26	26.06
12	70	50	11.11.'80	5.1.'82	2/month	26	28.57
Region: Anthakaranazhi							
13	75	50	25.11.'80	8.1.'82	2/month	25	- 9.73
14	75	50	25.11.'80	8.1.'82	2/month	25	-29.63
15	80	50	25.11.'80	8.1.'82	2/month	24	+20.94
16	60	45	25.11.'80	8.1.'82	2/month	24	- 3.70

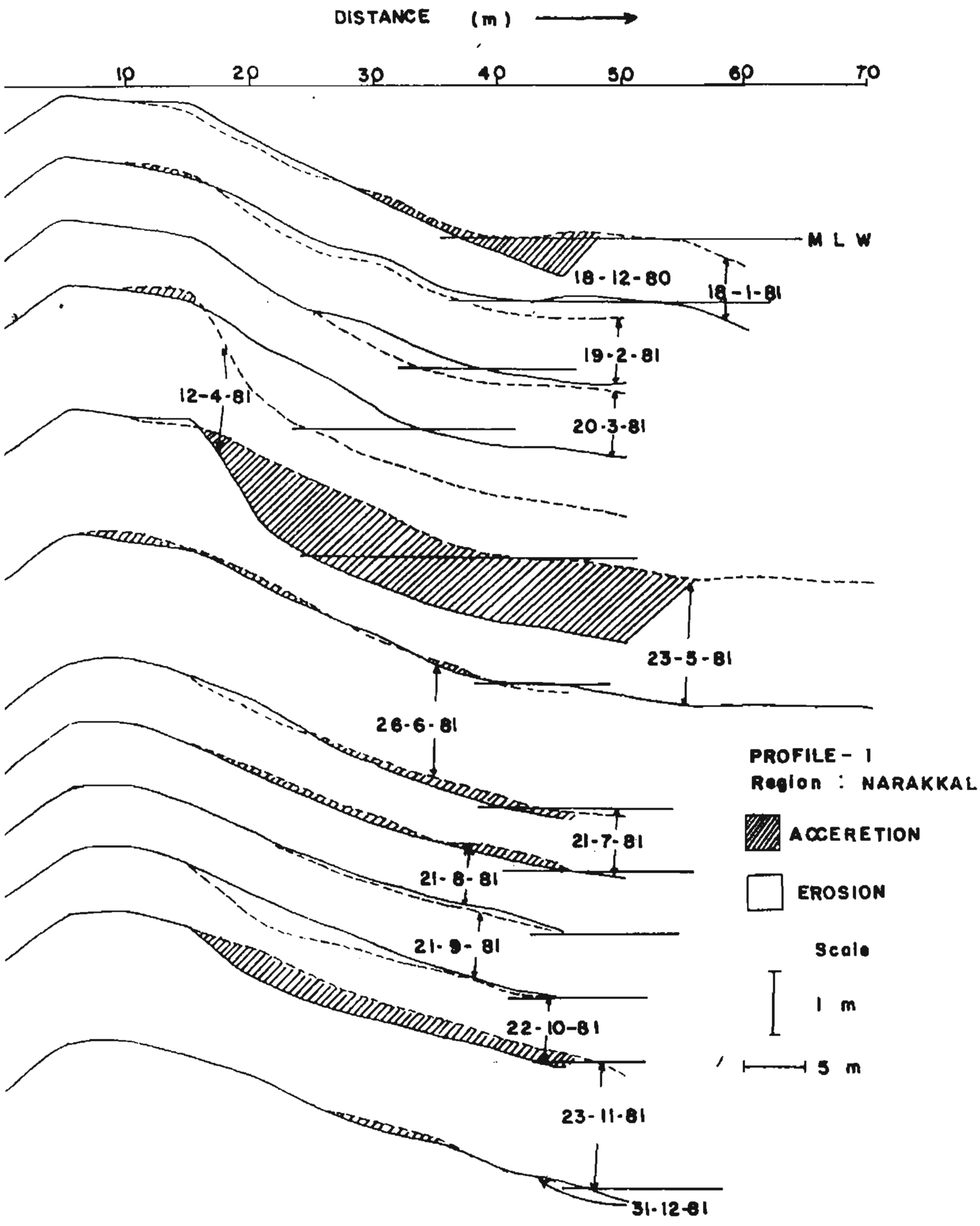

Fig. 18 A. Accretional - erosional patterns during different months along profile 1

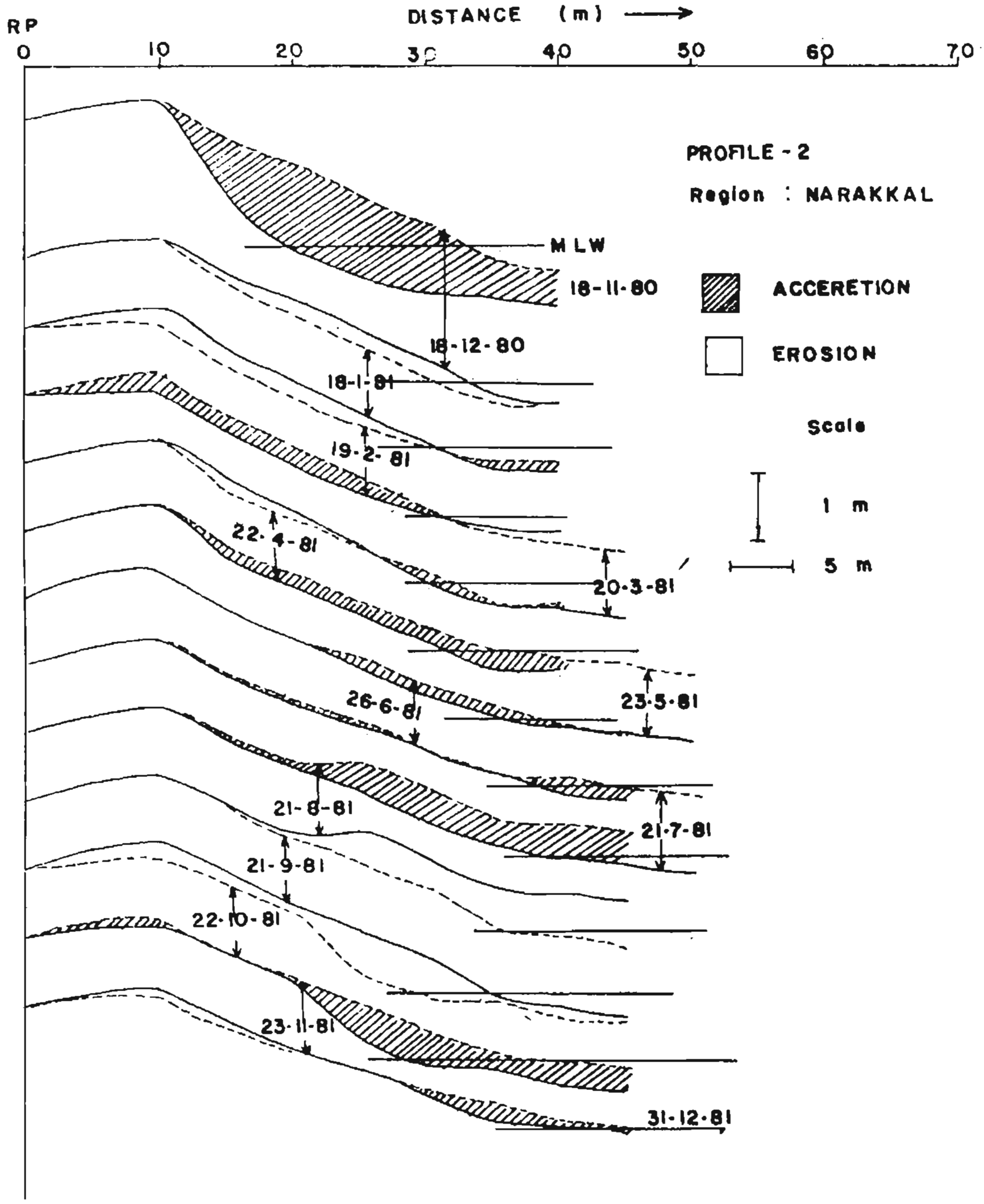

Fig. 18 B. Accretional - erosional patterns during different months along profile 2

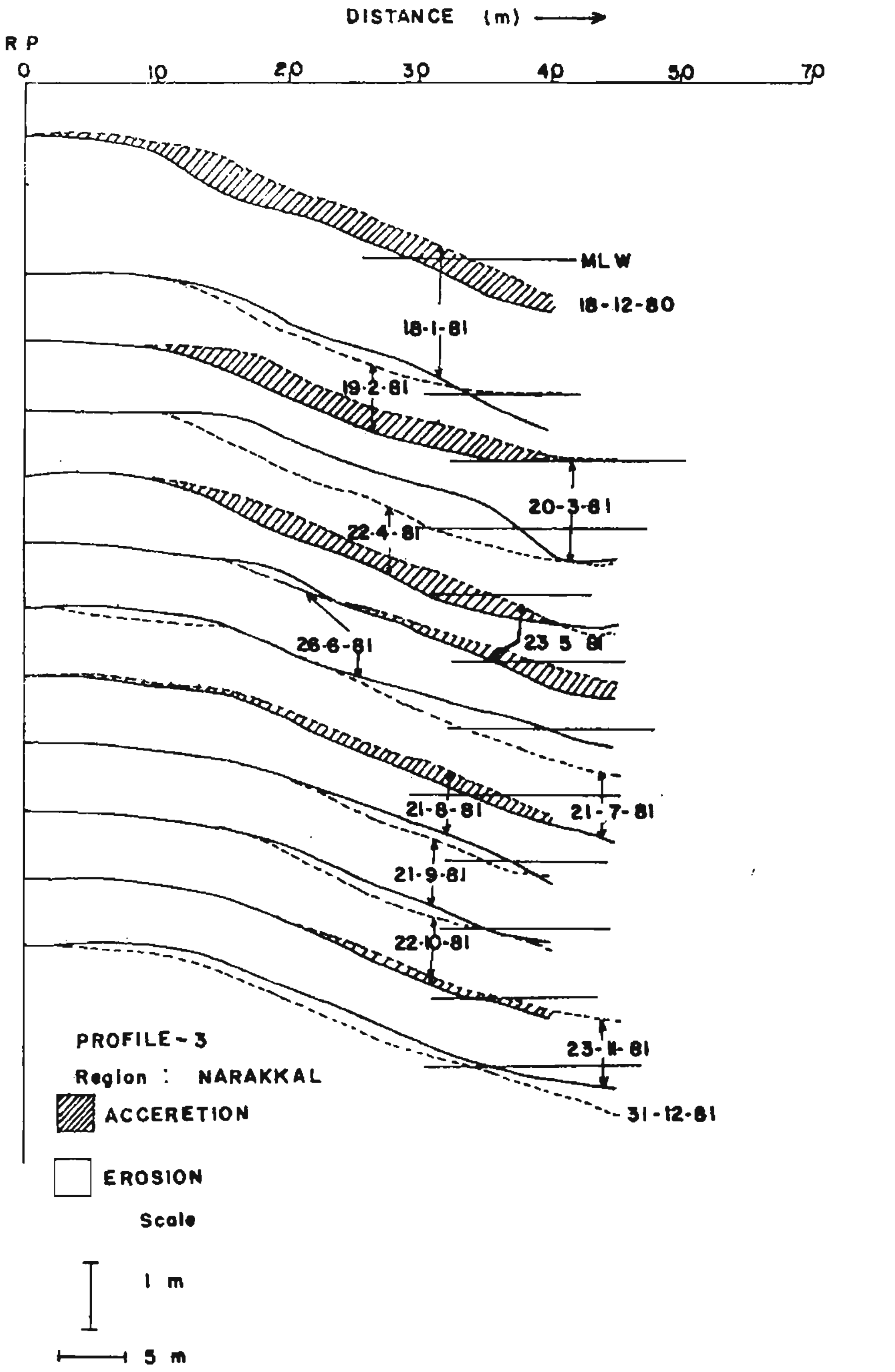

Fig. 18 C. Accretional - erosional patterns during different months along profile 3

May 1981 to August 1981 all the three profiles lines showed accretion of varying magnitudes except moderate erosion exhibited at profile 3 during July 1981. Again, all the three profile lines showed erosion during September and October 1981. During November and December 1981, all the profiles showed slight to moderate accretion except moderate erosion noticed at profile 3 during December 1981.

These figures 18 A-C show that the Narakkal beach did not undergo much changes and the profiles showed nearly stable conditions prevailing at this beach. The accretion/ erosion was mainly experienced at the foreshore during most of the surveys and no significant changes in beach topography have been observed by way of either continued accretion or erosion.

A net sand gain was recorded at all the three profile lines (Fig. 19 A; Table 14) with a maximum gain at profile line 1 (22.9 m^3) and a minimum gain at profile line 3 (5.4 m^3).

(b) Region : Malipuram (stations 4 to 8)

All the five profile lines at Malipuram beach showed an eroding tendency during October to December 1980 and during November 1981 (Fig. 18 D-H). This erosional tendency continued till the end of March 1981 at profile 4 and till the end of May 1981 at profile 7. Alternate accretion and erosion patterns with varying magnitudes were observed at profile 4 with a net gain in sand at the end of the survey. Considerable profile changes took place along this profile line during April to July 1981 which even affected the seasonal berm (Fig. 18 D).

Profile line 5 (Fig. 18 E) showed build up during early January 1981 to early February 1981. During subsequent surveys till the end of April 1981, it passed through a phase of erosion of varying magnitudes and thereafter accretion till the end of October, 1981.

The profile line 6 (Fig. 18 F) experienced continuous erosion in the upper and lower foreshore from the first week of January 1981 to the last week of September 1981, except some accretion experienced in the foreshore during February 1981. During October 1981 the lower foreshore showed build up followed by slight erosion during December 1981.

The foreshore of the profile line 7 (Fig. 18 G) showed build up during December 1980 and early week of January 1981. Thereafter it showed continuous erosion

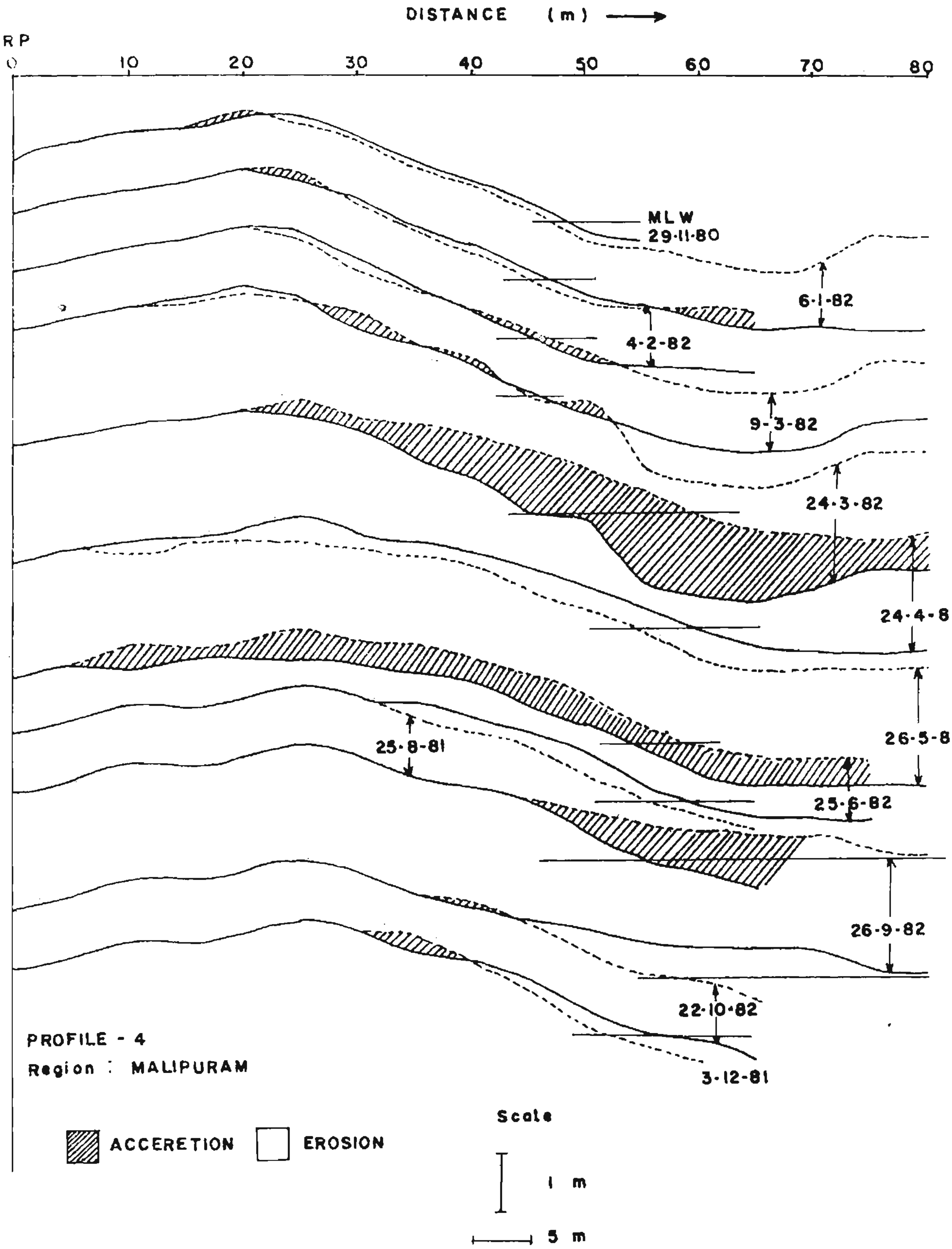

Fig. 18 D. Accretional - erosional patterns during different months along profile 4

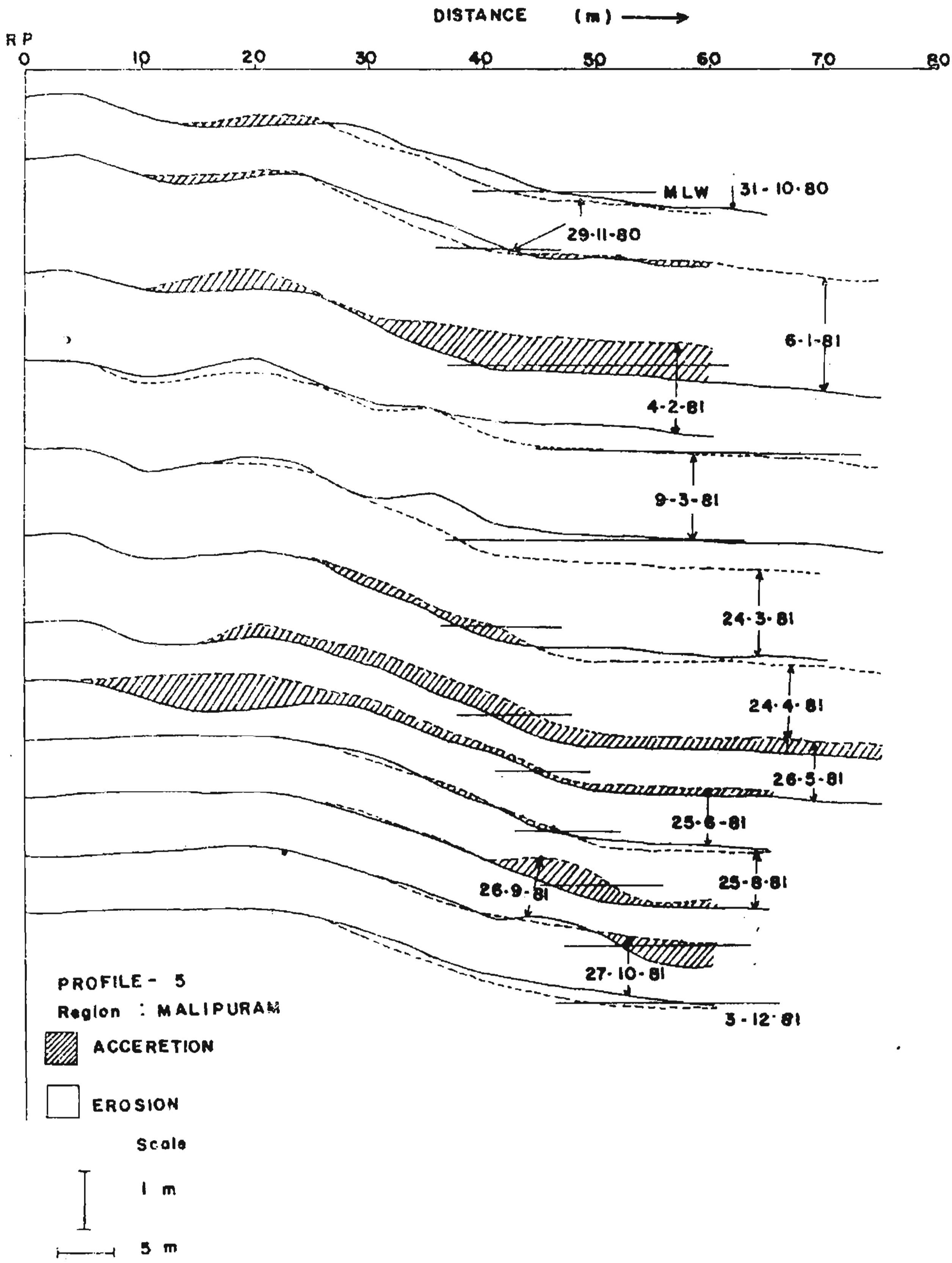

Fig. 18 E. Accretional - erosional patterns during different months along profile 5

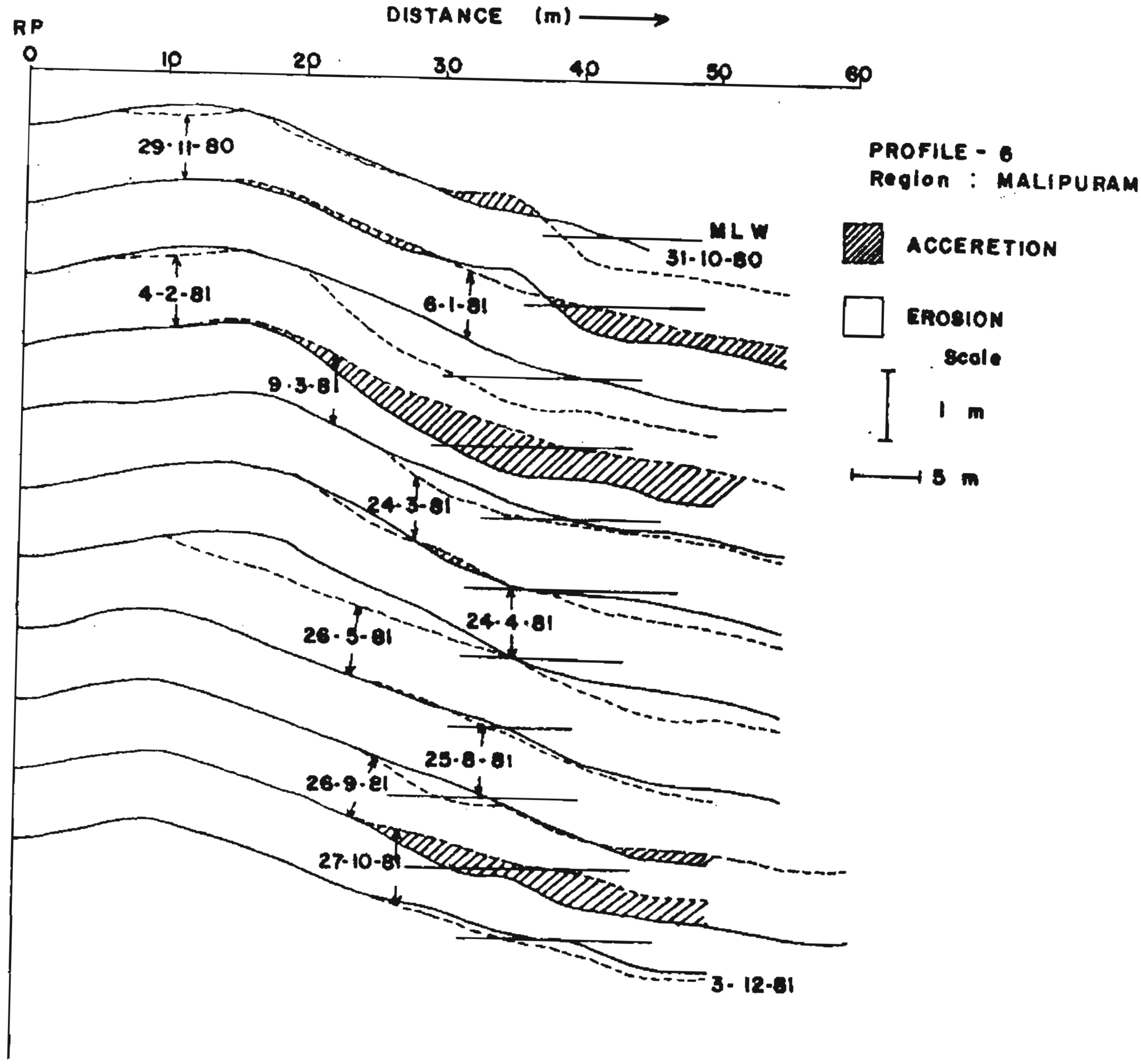

Fig. 18 F. Accretional - erosional patterns during different months along profile 6

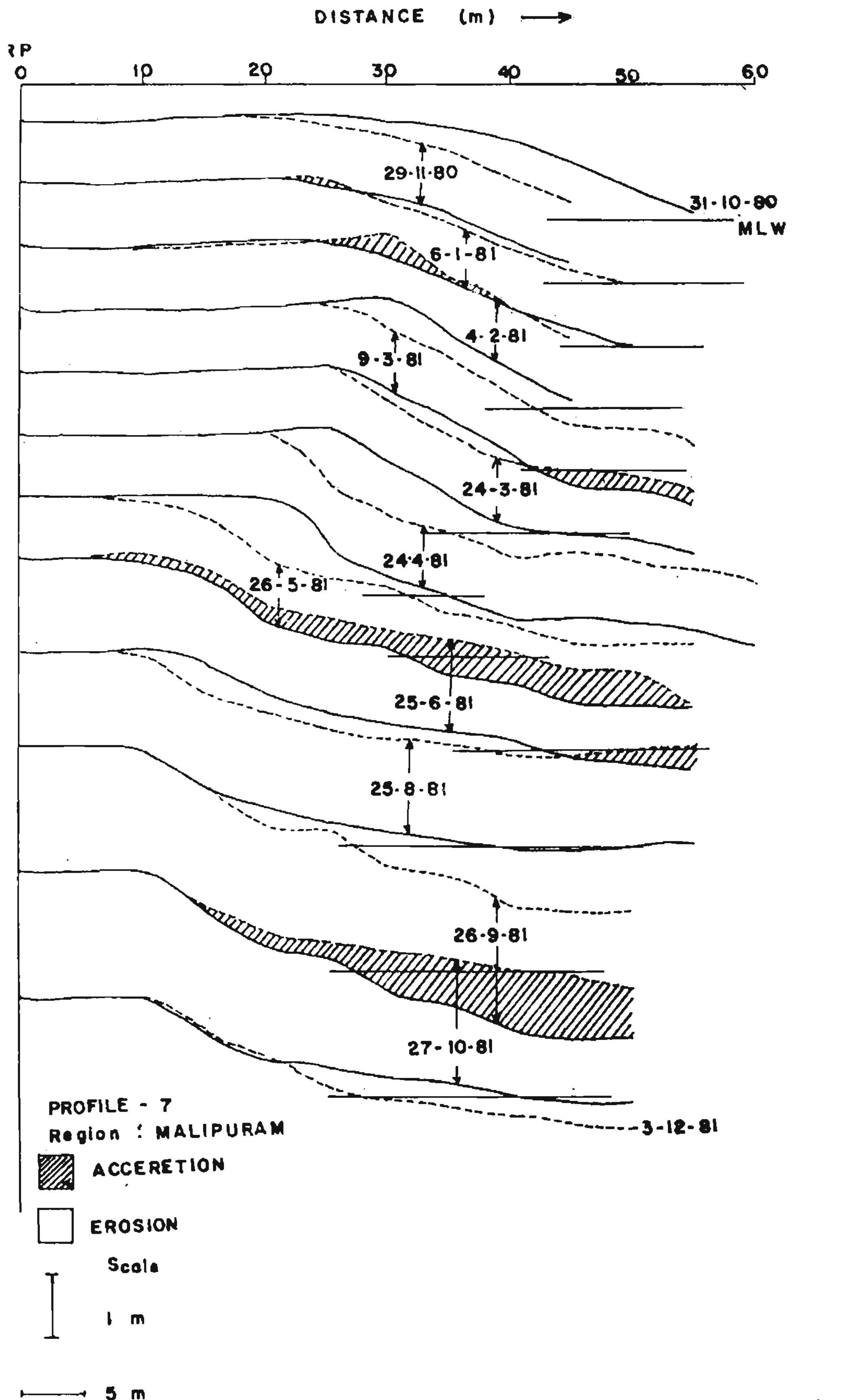

Fig. 18 G. Accretional - erosional patterns during different months along profile 7

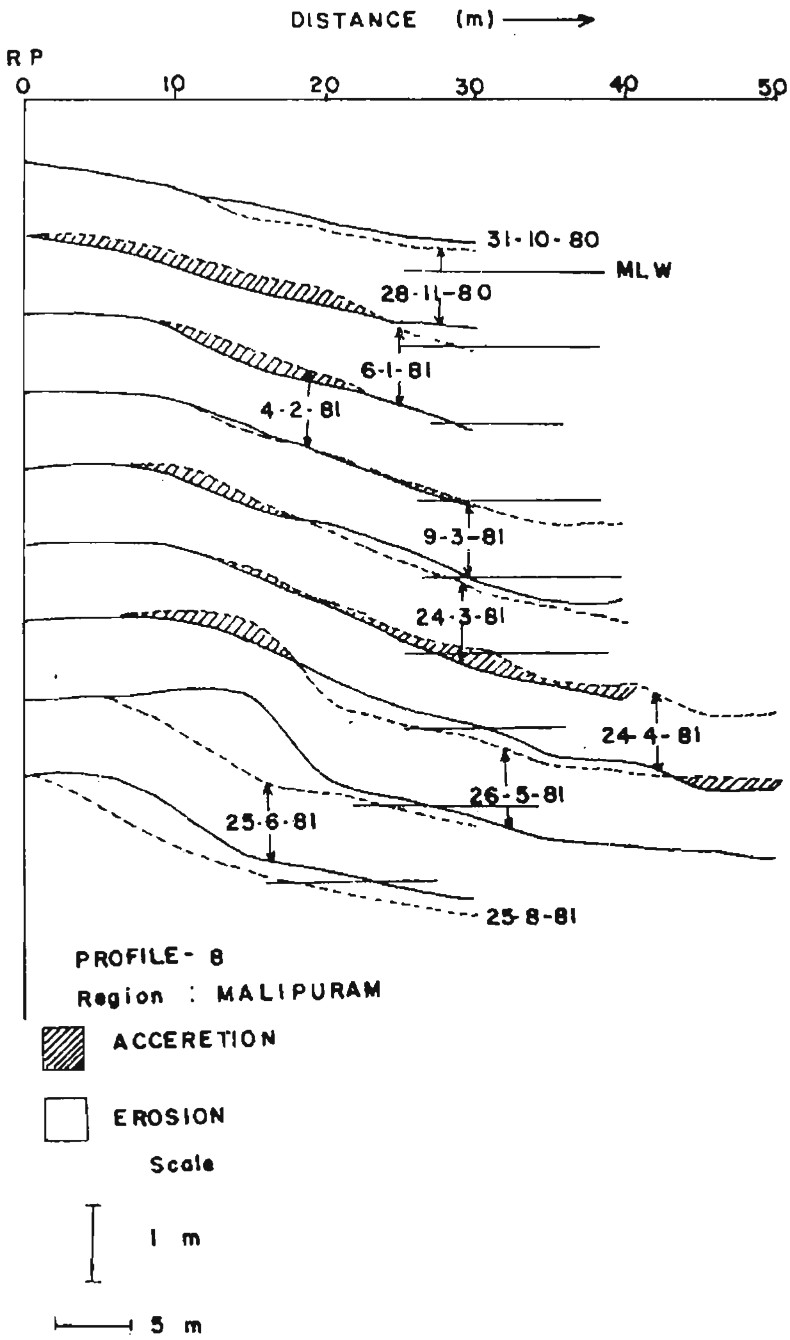

Fig. 18 H. Accretional - erosional patterns during different months along profile 8

till the end of September 1981 except slight accretion during June 1981. During October this profile showed considerable accretion along the foreshore and erosion during November, 1981.

At station 8 (Fig. 18 H) the profile survey has been carried out only upto the last week of August 1981. From the last week of November 1980 to the last week of March 1981 the profile showed slight to moderate rates of accretion. But during the months of May to August 1981 erosion was observed.

The width of the beach was maximum at the northern side (120 m at profile line 4) and gradually decreased towards south (45 m at profile line 8) (Table 14). The volume of sand eroded/accreted from the beach has been showed in Figure 19 B which shows a net accretion at profile lines 4 and 5 and erosion at profile lines 6, 7 and 8.

(c) Region : Fort Cochin (stations 9 to 12)

The profile lines 9 and 10 (Fig. 18 I and J) showed slight erosion at the upper foreshore and accretion at the lower foreshore during December 1980. But during January and February 1981 both the profiles showed accretion at upper foreshore and considerable erosion at lower foreshore. This trend continued till the end of April at profile 10, but profile line 9 exhibited erosion at the upper foreshore and accretion at lower foreshore till the end of May. Again during June 1981, the profile 9 showed accretion in the upper foreshore and erosion in the lower foreshore. But during this period the profile 10 showed erosion on the upper foreshore and accretion on the lower foreshore. Thereafter, erosion in the lower foreshore could be noticed along both the profiles continuously till early January 1982 with slight accretion in the upper foreshore during different months. However, accretion was noticed at profile 9 during December 1981 and at profile 10 during September 1981. As it could be seen from Figure 18 I, at profile line 9, the steepness of the beach face increased followed by a decrease in the width of the beach during the period of study.

Profile 11 showed accreting tendency especially in the foreshore, from November 1980 to end of May 1981 (Fig. 18 K). Later on, this profile experienced slight erosion in the lower foreshore till the end of October 1981, excepting the slight accretion experienced during August. Thereafter, the profile accreted slightly till early January 1982.

Profile 12 (Fig. 18 L) showed build up during December 1980 and slight erosion during January 1981.

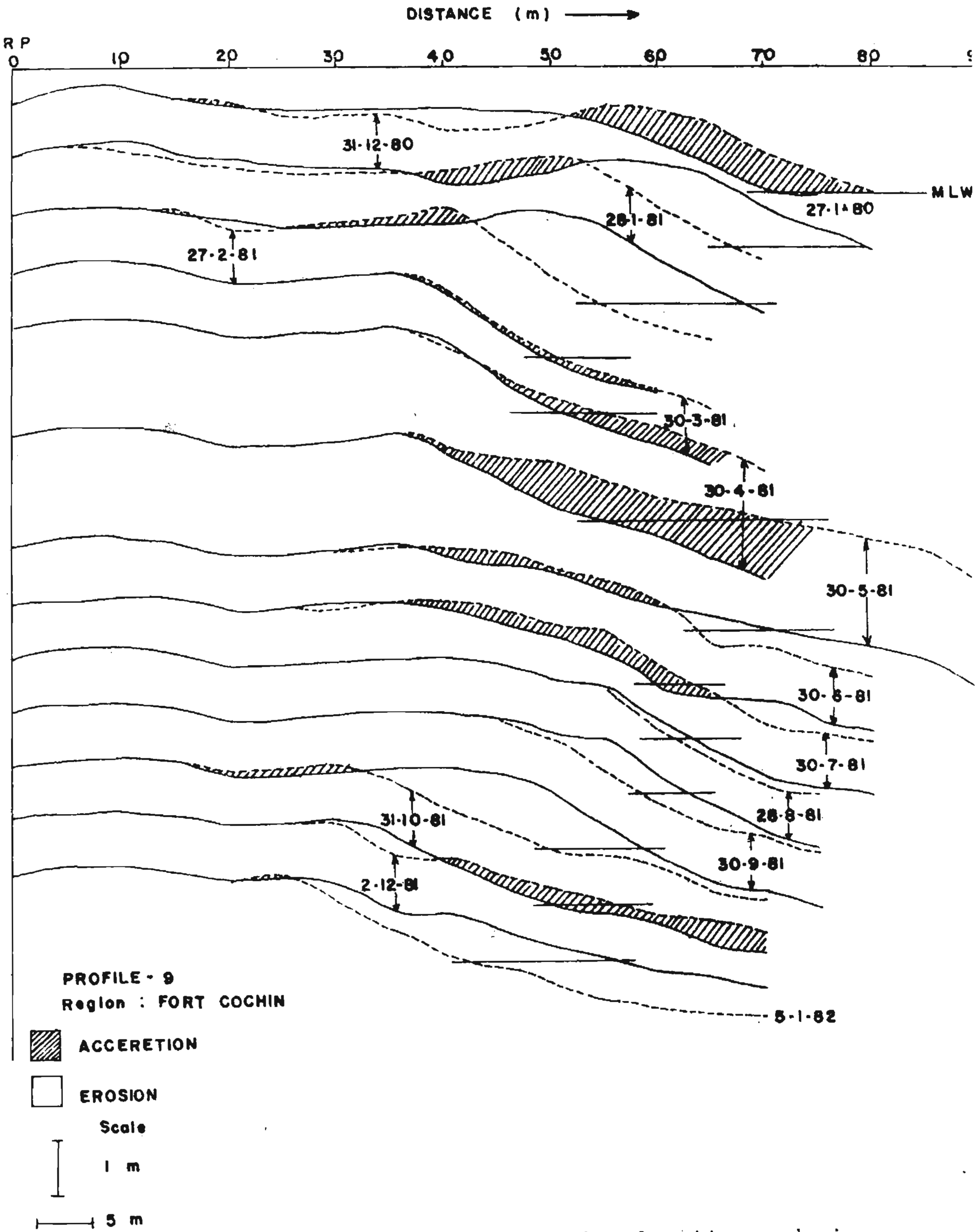

Fig. 18 I. Accretional - erosional patterns during different months along profile 9

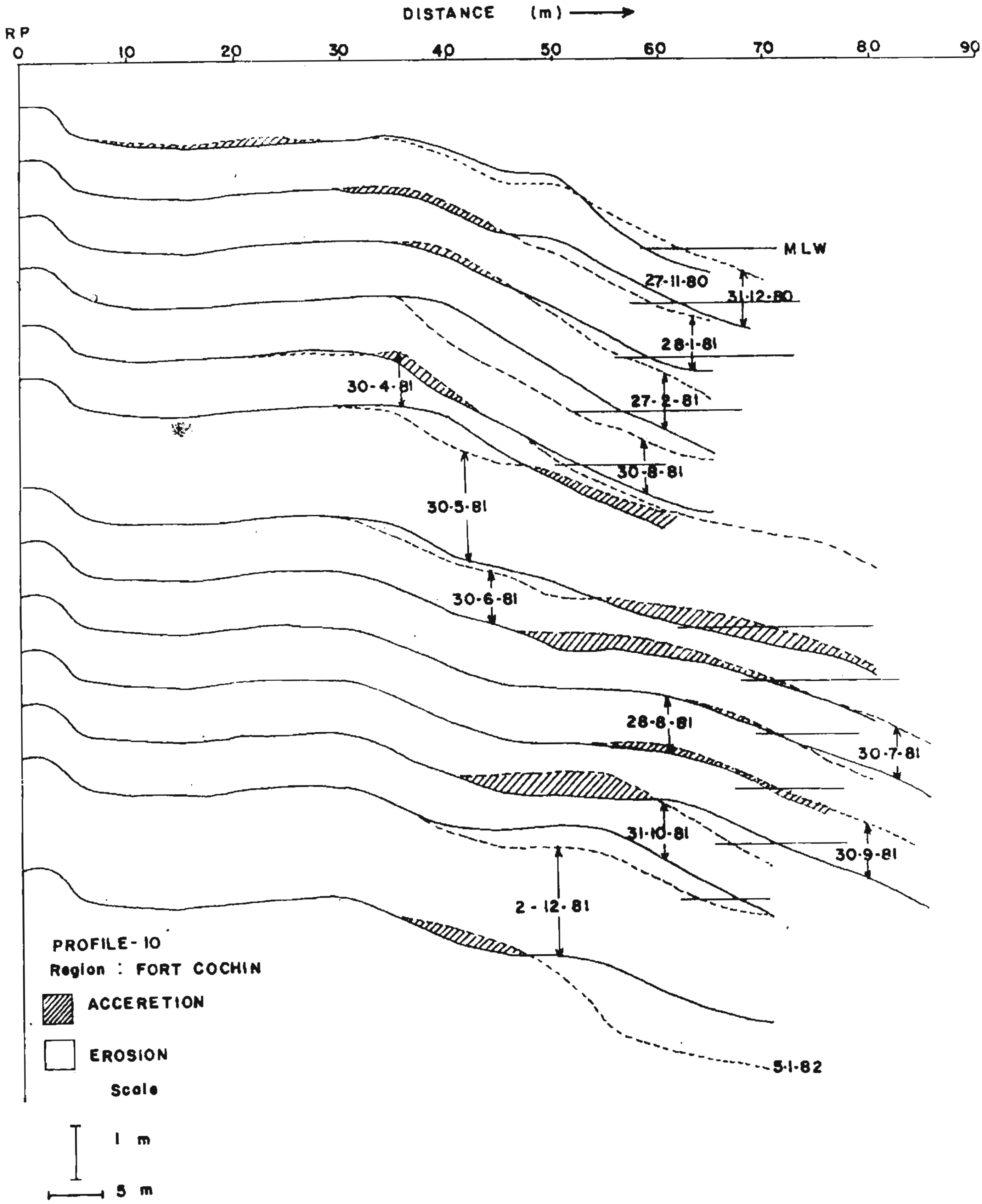

Fig. 18 J. Accretional - erosional patterns during different months along profile 10

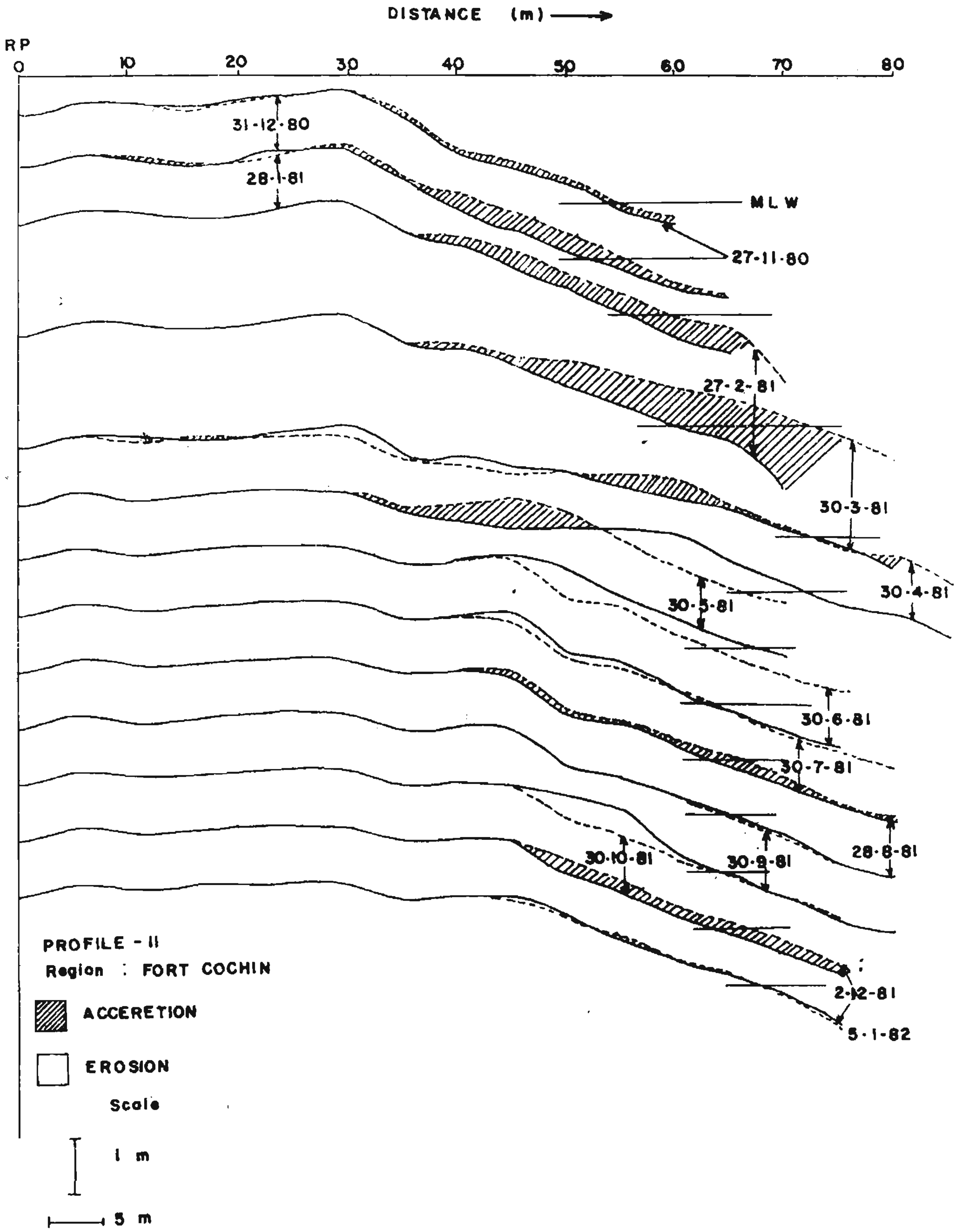

Fig. 18 K. Accretional - erosional patterns during different months along profile 11

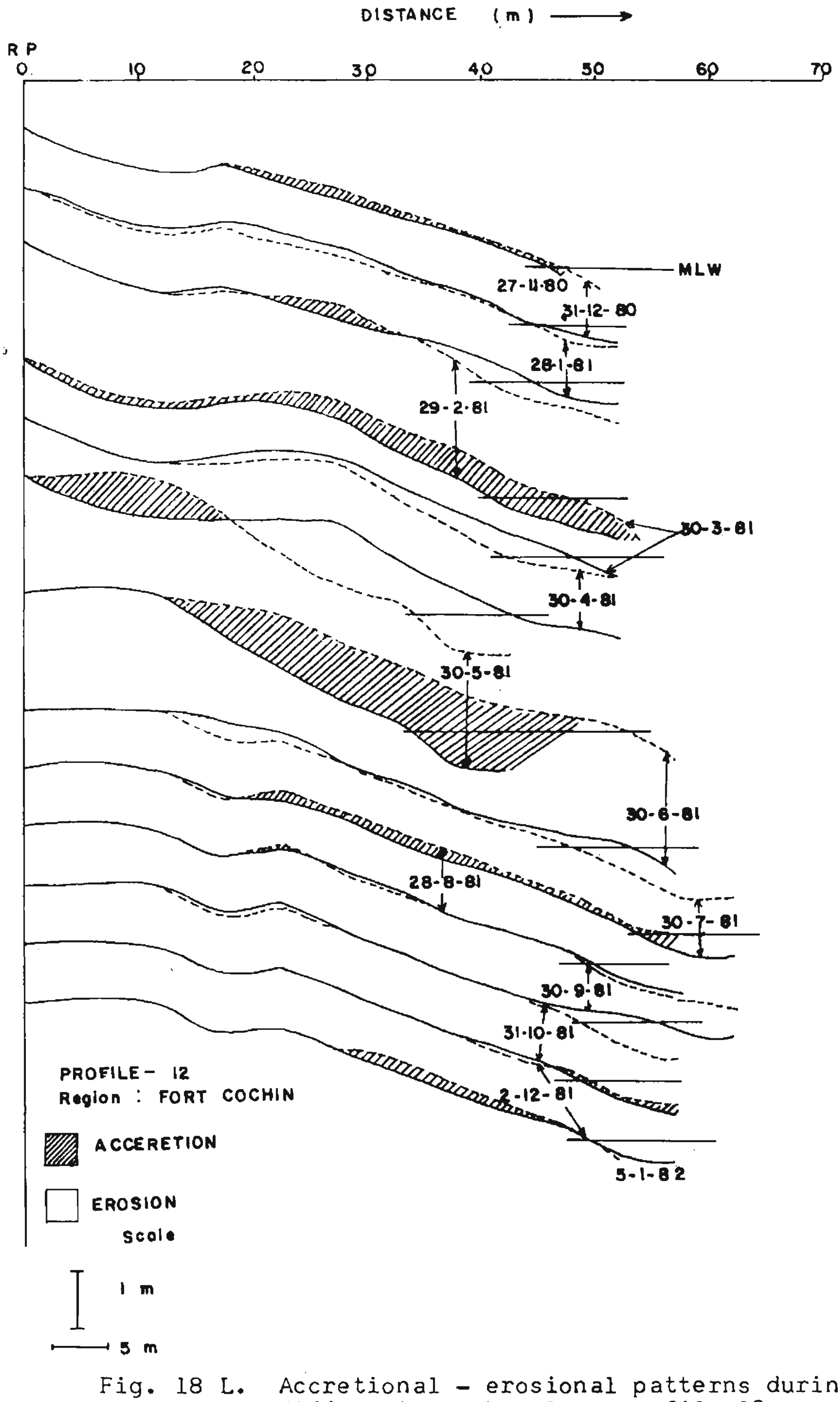

Fig. 18 L. Accretional - erosional patterns during different months along profile 12

During February also the erosion continued in the lower foreshore while the upper foreshore showed a build up. This feature was noticed during May 1981 also with increase in magnitude. Moderate accretion could be noticed during March and moderate erosion during April all along the beach face. During June 1981, considerable amount of deposition could be noticed on the lower foreshore. Slight erosion was experienced along the profile line during July and slight accretion during August 1981. Later on, this profile showed only very slight erosion/accretion till early January 1982.

During the entire period of the profile surveys, the profile lines 9 and 10 indicated a net loss of 65 m^3 and 33.0 m^3 of beach material respectively. During this period, the profile lines 11 and 12 showed an increase in net volume of material by 26 m^3 and 28.6 m^3 respectively (Fig. 19 C).

(d) <u>Region : Anthakaranazhi (station 13 to 16)</u>

The profiles at Anthakaranazhi (Fig. 18 M-P) showed more or less regular pattern in accretion and erosion of beach face unlike the profiles at Narakkal, Malipuram and Fort Cochin. The profiles 13 and 14 showed build up from November 1980 to early March 1981 followed by accretion in the upper foreshore and erosion in the lower foreshore during March, 1981 at profile line 13 and the reverse of this at profile line 14 during March. Again during April, both the profiles showed building up. From May onwards, both the profiles started getting eroded till the end of August 1981. Accretion started from September onwards and continued till early December 1981. During December again the beach face eroded moderately.

The profile lines 15 and 16 also showed more or less same trend in the erosion-accretion pattern of the beach during the year, except slight erosion that took place at the profile line 16 during December 1980. During December 1981, profile 15 (Fig. 18 O) showed build up while the remaining three profiles (Fig. 18 M,N and P) showed erosion. The build up started along the profiles 15 and 16 earlier to the other two profiles.

During the period of large scale erosion (May - July), mild foreshore slopes prevailed while steep slopes were encountered in the upper reaches as a consequence to erosion that took place along all the profiles. Thus, it appears that the material eroded from the upper reaches of the

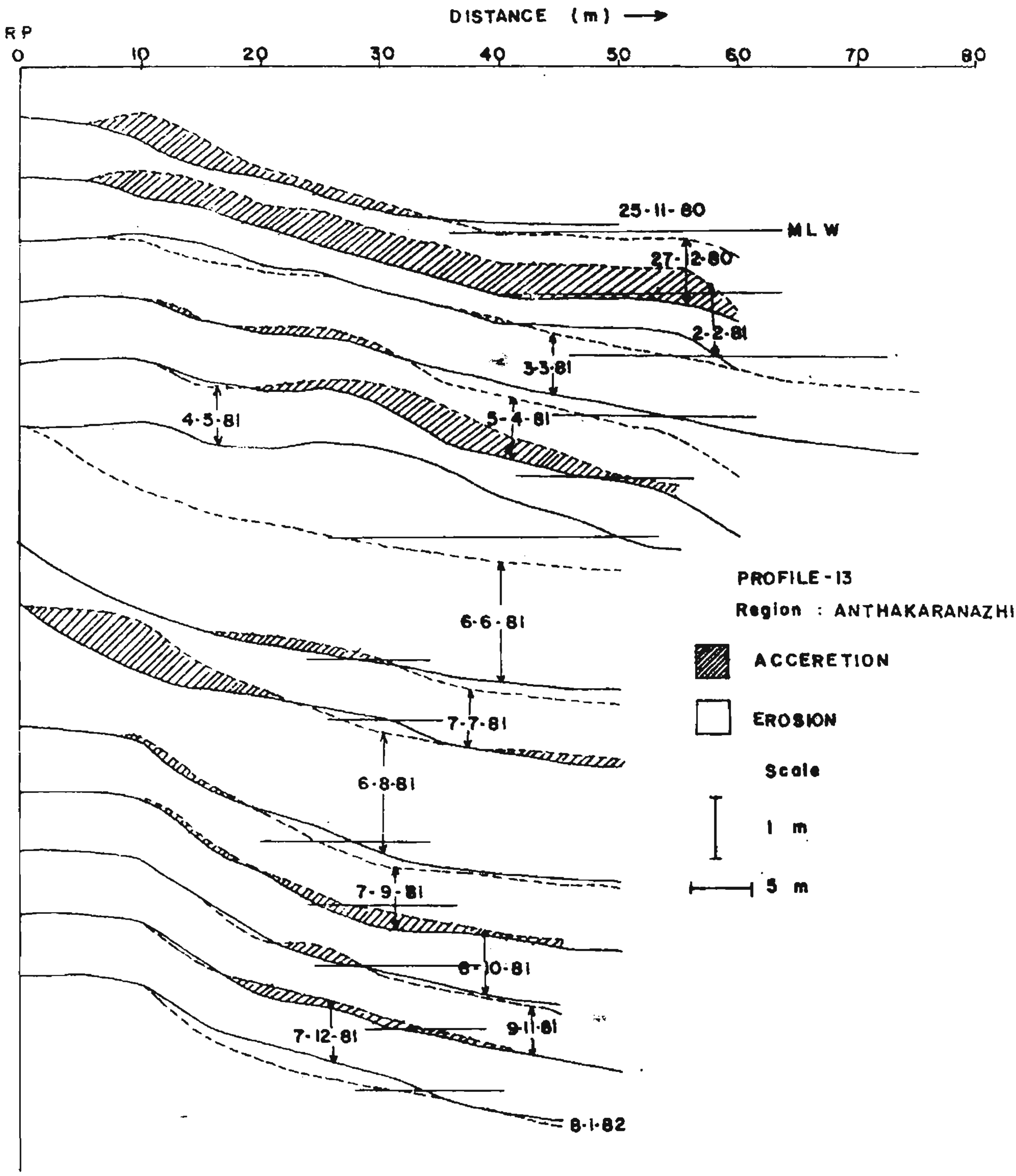

Fig. 18 M. Accretional - erosional patterns during different months along profile 13

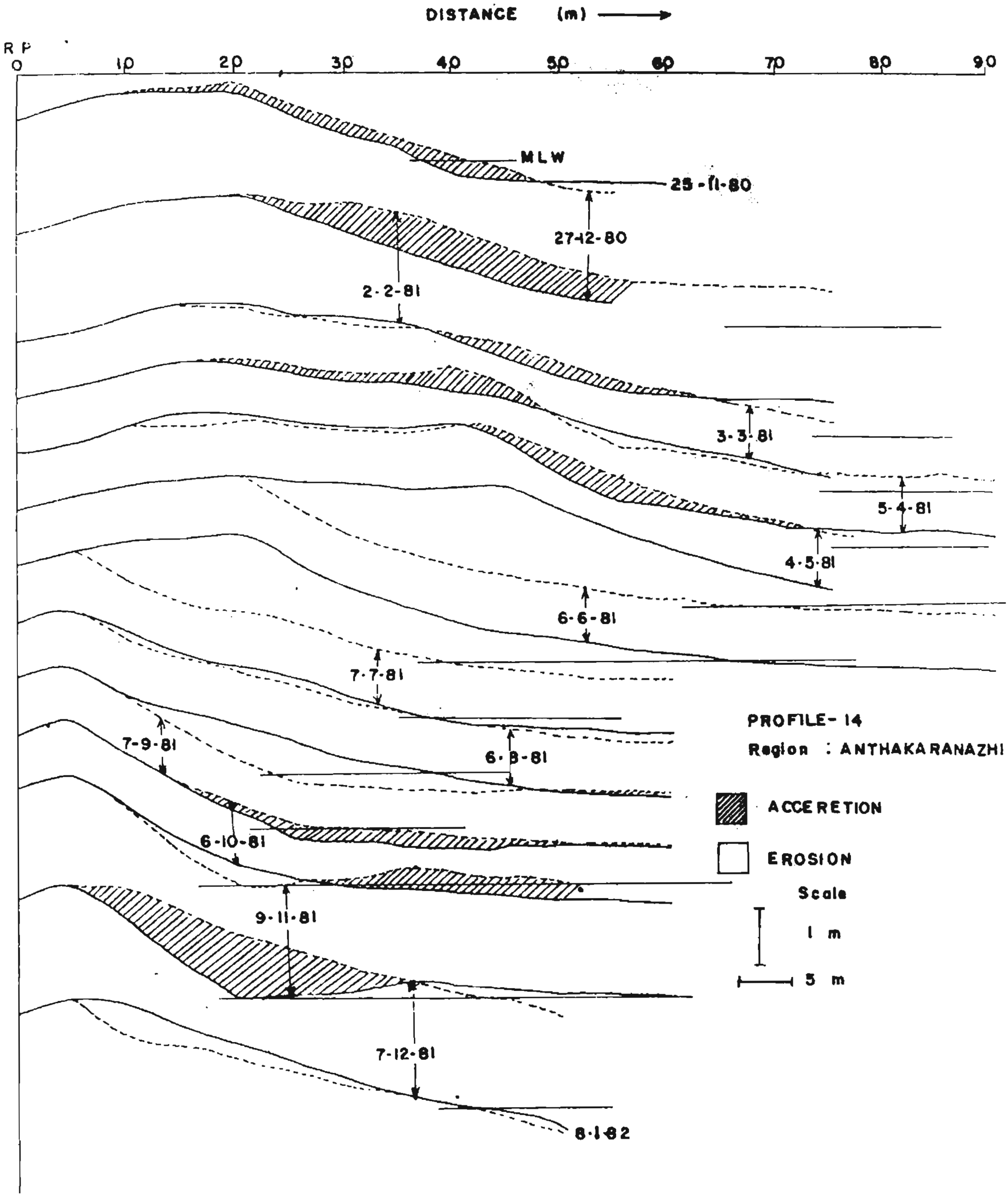

Fig. 18 N. Accretional - erosional patterns during different months along profile 14

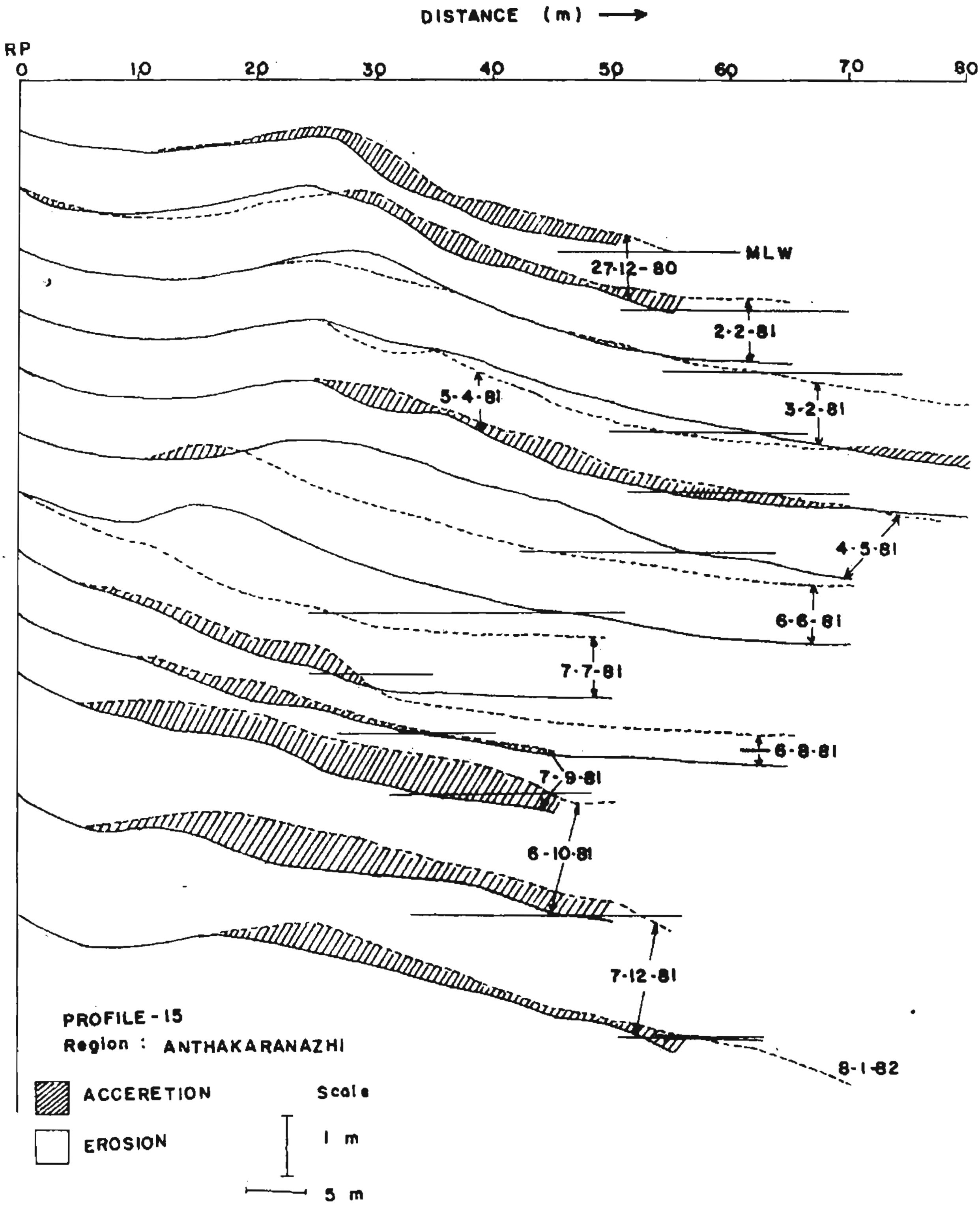

Fig. 18 O. Accretional - erosional patterns during different months along profile 15

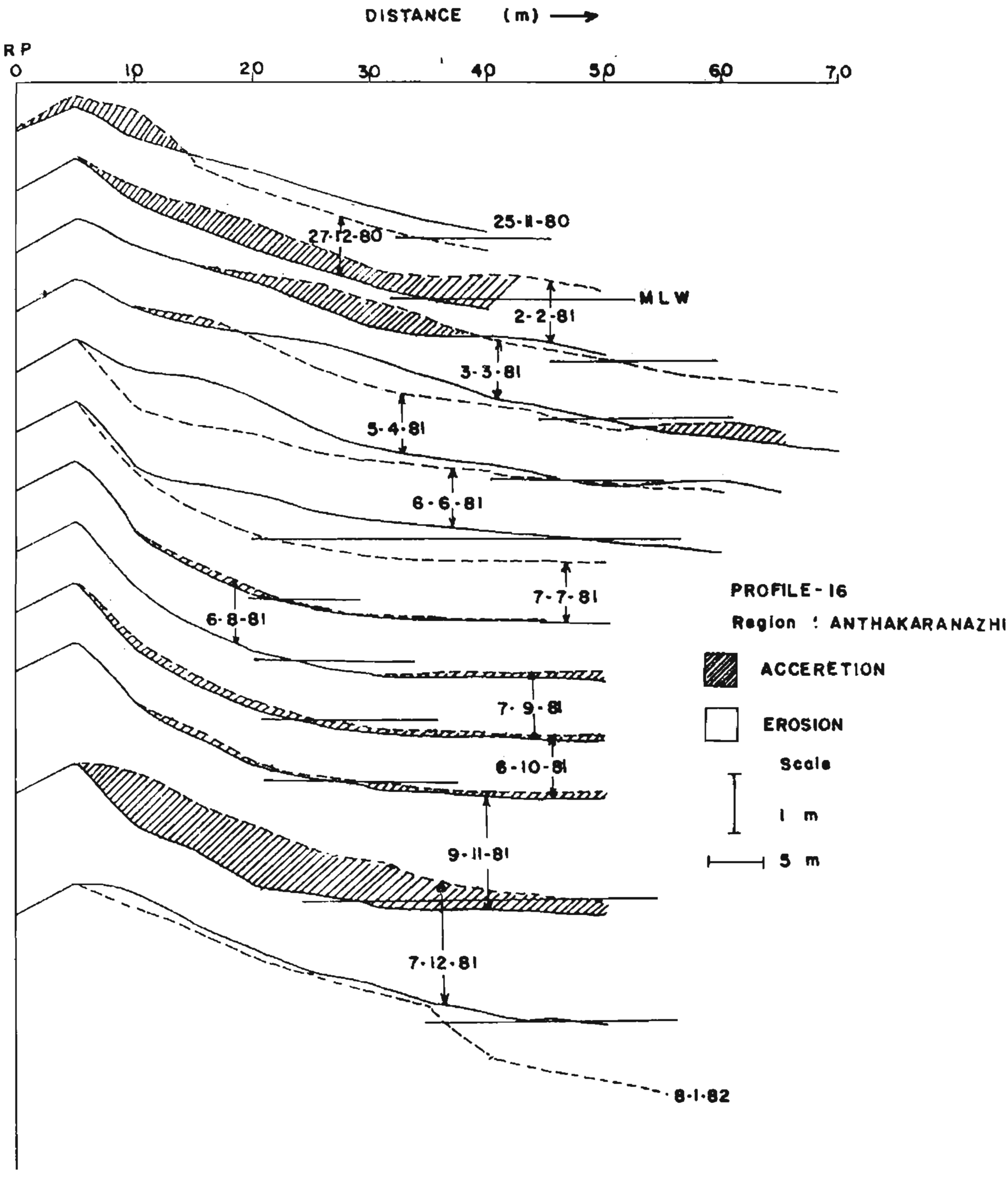

Fig. 18 P. Accretional - erosional patterns during different months along profile 16

beach face was transported to the lower foreshore and inshore areas to form a bar parallel to beach. Higher breaker activity over the submerged bar could be observed during the field work during this season. The total cumulative volume changes with time for each of the four profile lines amount to a net loss along profiles 13,14 and 16 and net gain along profile 15 (Fig. 19 D). From the volume calculations, it is clear that most of the material which got eroded during southwest monsoon period was deposited during the fair weather season. But net erosion could be noticed along this beach.

The above results show that, in general, the beaches at all the locations investigated experienced erosion and accretion with varying magnitudes. At Narakkal and Malipuram the beaches were under the influence of active mud bank during the southwest monsoon period with subaerial mud deposits in the nearshore areas during most of the period of study. Though not so active as at other locations, at Fort Cochin also, the presence of mud bank was experienced through highly turbid muddy water in the nearshore areas and unusual calmness during June - August. Along these beaches most of the profiles experienced accretion during southwest monsoon period. However, erosional tendencies were noticed at certain stations. At Malipuram, the profiles 4 and 5 experienced deposition while profiles 6 to 8 experienced erosion

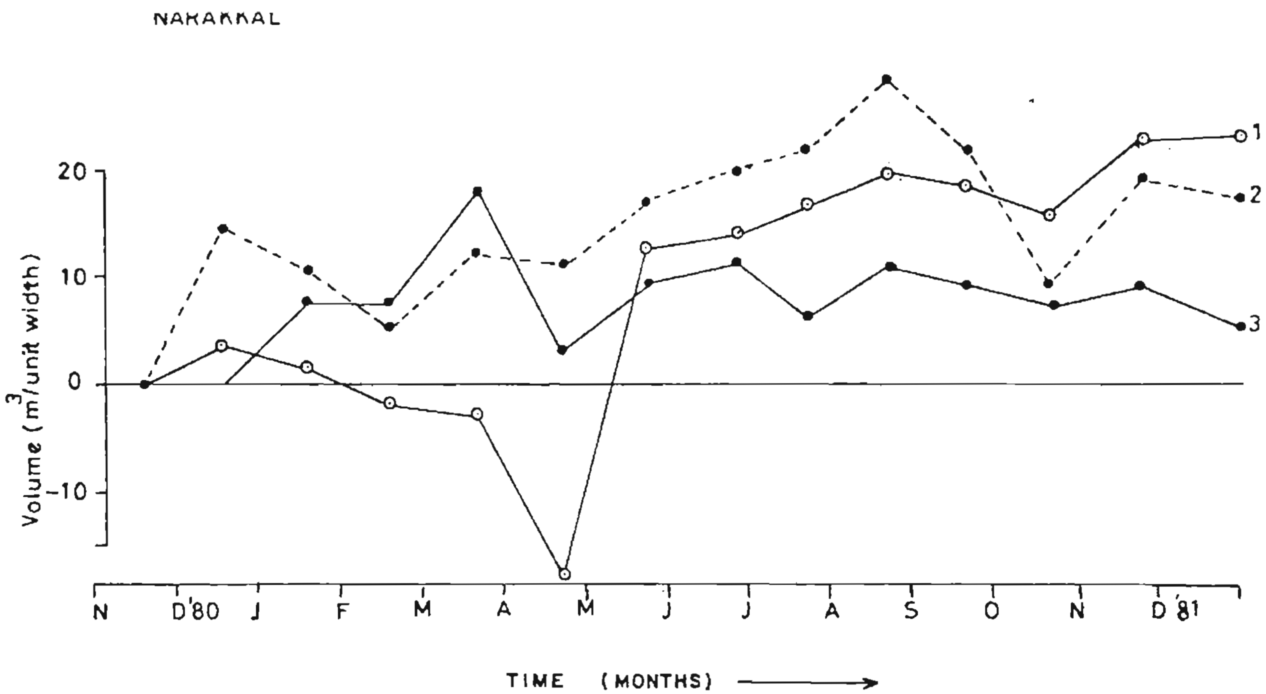

Fig. 19 A. The net volumetric changes of the profiles at Narakkal with respect to the initial profile

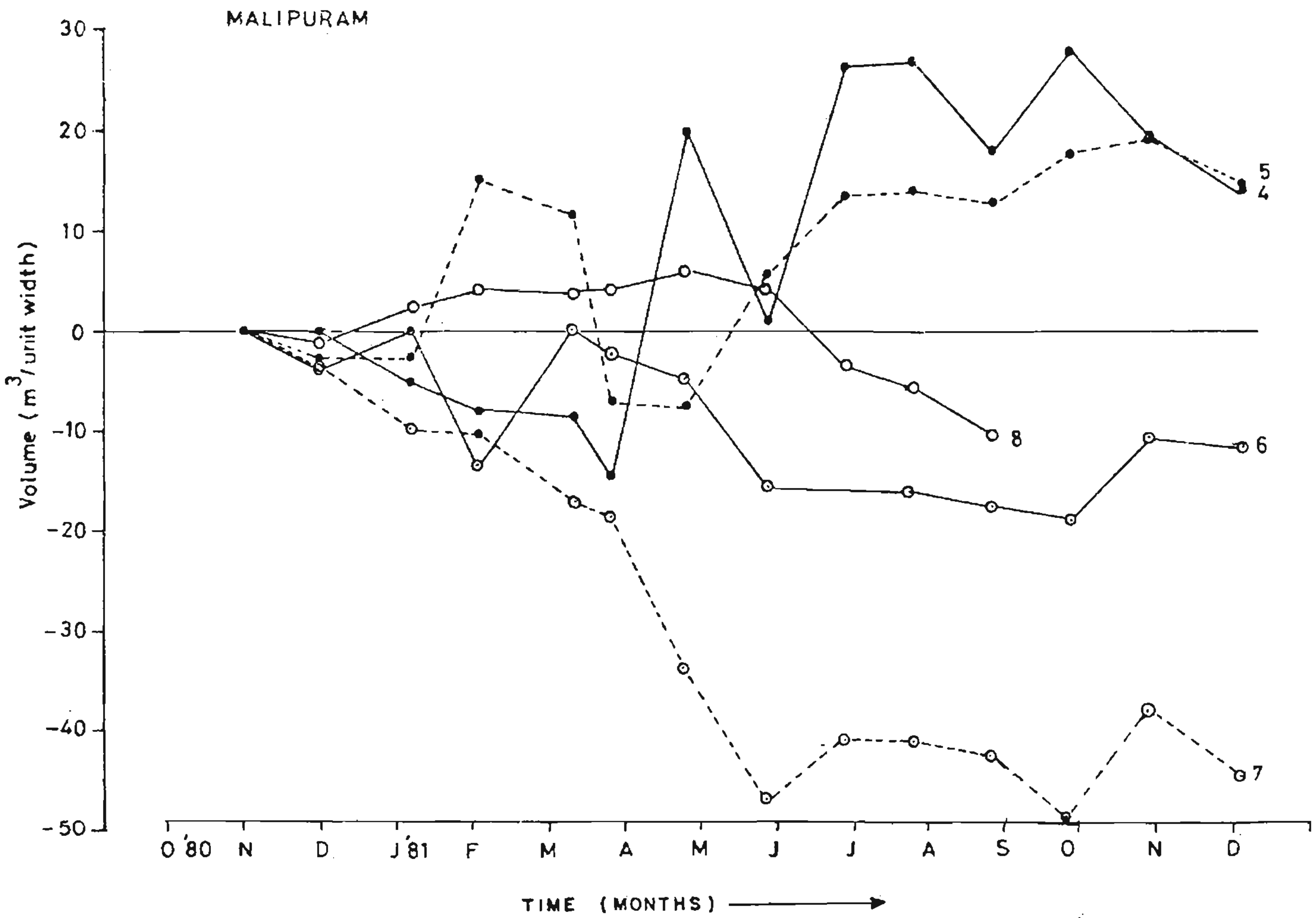

Fig. 19 B. The net volumetric changes of the profiles at Malipuram with respect to the initial profile

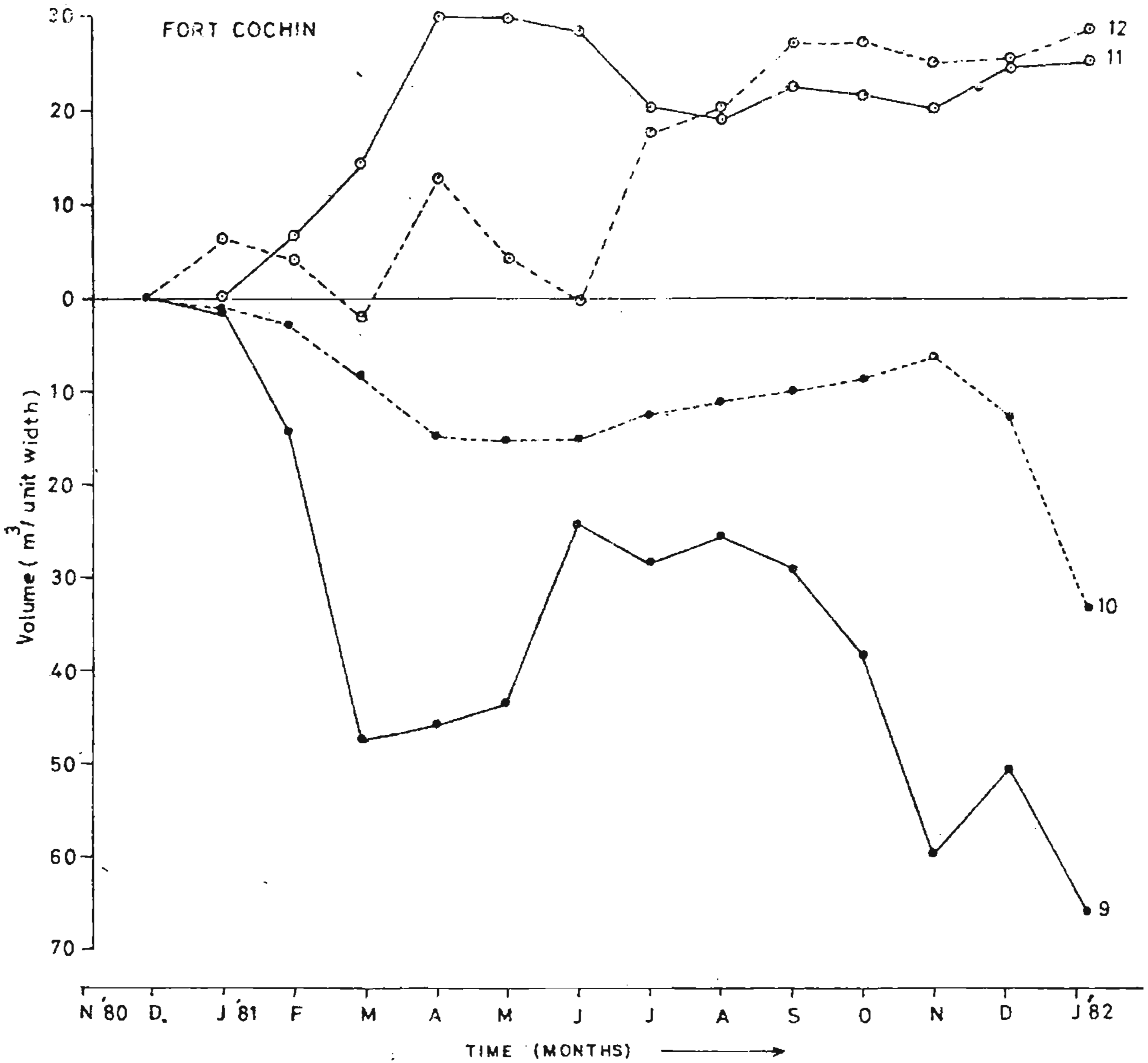

Fig. 19 C. The net volumetric changes of the profiles at Fort Cochin with respect to the initial profile

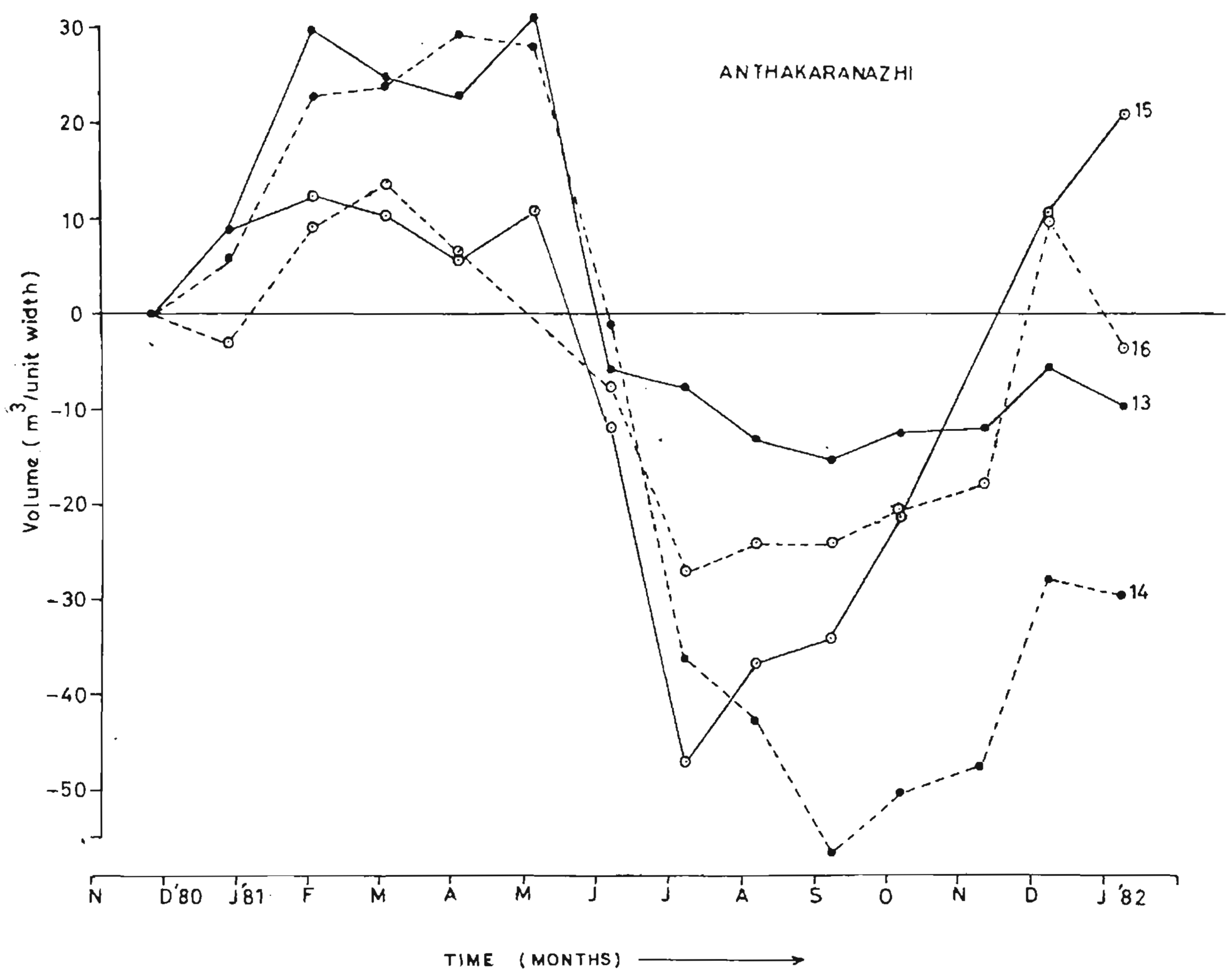

Fig. 19 D. The net volumetric changes of the profiles at Anthakaranazhi with respect to the initial profile

in spite of the protection provided by mud bank. Unlike these beaches, the beach at Anthakaranazhi (free from natural protection) showed more or less cyclic nature in the accretional and erosional tendencies.

6.3.2. Discussion

The beaches under study have undergone significant changes during the period of study. The beaches free from any natural protection mechanisms presented cyclic changes showing erosion during the southwest monsoon season and accretion during rest of the year. The beaches receiving protection from mud banks of varying activity during the southwest monsoon period, do not show any well defined cyclicity. The mud banks influence the eroding and accreting tendency of the nearby beaches.

The cyclicity in beach morphological changes will be analysed in relation to the various environmental parameters operating along the coast in the following paragraphs:

During southwest monsoon period, the winds from 260° - 290° present a growing phase with speeds increasing from 2 m/sec to about 15 m/sec (Hastenrath and Lamb, 1978). This change contributes to a rise in the water level due to wind set-up (Van Dorn, 1953) in the nearshore regions during this period and brings larger areas of the beach face in contact with nearshore waters.

The wave characteristics (Chapter 2) also undergo changes corresponding to these changing winds. During the fair weather season, for more than 90% of the time, the wave heights are less than 0.8 m but during the southwest monsoon season the wave heights are conspicuously more and for about 20% of the time they exceed 3.2 m with 5.4 m being the recorded maximum (Dattatri, 1973). But the wave period seems to be less during the southwest monsoon compared to other months. Such high waves with low periods normally give rise to steep waves conducive to rapid erosion of the beaches. Moreover the strong, steady onshore winds generate fully arisen local seas. These short period waves interacting with the incoming waves give rise to confused state of the seas comprising short-crested waves which are asymmetric in their form due to the pressure and friction of wind acting on the back of the waves and the drag upon the front face (Longuet-Higgins, 1969). These steep waves are associated with complicated water particle motions, vortex formations and macro-turbulence.

The abrupt increase, in wave heights leads to removal of beach material from the beach. The material thus removed gets deposited in the inshore regions due to the predominant offshore flows (Collins and Chesnutt, 1975). The deposition in the inshore regions leads to the formation of flat nearshore bottom. As a consequence, the width of the surf zone increases. This flat beach face will, in turn, cause the waves to break further away from the beach. Eventhough a considerable amount of wave energy would be lost through initial breaking the portion of energy remaining would get dissipated through multiple breaking occurring over a wide surf zone before the final uprush affects the upper regions of the beach with lesser energy.

In addition, the increased wave activity during the southwest monsoon season, produces considerable wave set-up which is about 5 times greater than during other seasons (Murty, 1977). As a consequence, the increased wave run-up increases the intersticial water content over larger areas of the beach. The wave set-up coupled with rise in the nearshore water level brought about by the local wind set-up leads to increased run-up on the beach foreshore with greater volumes of water than otherwise (Battjes, 1974).

Associated with the changes in the beach topography, the mean grain size of beach sediments also show slight changes with relatively coarser material during periods of erosion and relatively finer materials during periods of accretion (Chapter 4).

From September/October onwards, the beaches experience deposition. During this period, the percentage of occurrence of low period waves show a decrease (Chapter 2) compared to the southwest monsoon season. The wave heights also show a similar decrease. This increase in low swells of higher periods (relatively less steep) contributes to the deposition of the sediments on the beaches.

Eventhough, these are the processes likely to take place all along the coast in general, the presence of mud banks alter the wave characteristics locally and affect the accretional/erosional features.

At Narakkal, Malipuram and Fort Cochin the beach profile studies do not indicate any well-defined trend in the erosional/accretional tendencies. The profile lines along these beaches are characterized by a high degree of variability exhibited on a number of occasions. Most of the profile lines show large differences in monthly volume changes. Nevertheless, arguments can be made for an accreting tendency on these beaches that are protected by active mud banks.

During the period April to September, mud bank was observed along the shores at Malipuram and Narakkal. The accretion at the beach profile lines 1 to 5 is closely related to the occurrence of mud bank. The longshore currents observed at these beaches indicate alternating and weak flows (Fig. 14). The mud banks cause considerable attenuation of wave energy and decrease in wave height. Often, these waves never reach the shoreline and favour sedimentation of fine-grained material. The effect of non-linear shallow water waves over soft muddy bottom is to produce a net drift of sediments in the direction of wave travel (Wells _et al._, 1978). The subaerial exposure of these muds increases their relative resistance as they get dewatered. Once their density increases to 1.20-1.25 gm/cm^3, due to dewatering the shear strength of the muds may be sufficient to withstand normal wave attack (Wells and Roberts, 1980). This explains the growth of beach in areas protected by mud banks and the onshore migration of mud deposits observed during the field study (see the photographs of mud deposits off the profile lines 4 and 5) (Fig. 20). Murty _et al._ (1980) have reported such an anomalous growth of beach at

Fig. 20. Photographs of the mud deposits along profiles 4 and 5 during August 1981

due to the strong littoral currents observed along this beach in addition to strong outflows from the Cochin harbour during this period. These strong, undersaturated flows lead to a net loss of sediment, about 65 m^3 from profile line 9 and 33 m^3 from profile 10 during the period from November 1980 to January 1982. On the other hand the profile lines 11 and 12 appear to be gaining sand.

The Anthakaranazhi beach also has been subjected to erosion for a long time. Wave refraction studies have clearly indicated this as a zone vulnerable to erosion (Chapter 2). During monsoon months the predominant waves approach from directions 260^o - 280^o TN with periods ranging from 6 to 10 sec. The refraction diagrams show concentration of wave energy along this stretch of the beach with varying intensities. The beach showed erosion of considerable magnitude during the southwest monsoon season and accretion of relatively low magnitude during the fair weather season. During southwest monsoon months, relatively high waves have been observed breaking on the offshore bar with near-normal approach to the beach. This normal wave approach may cause cellular circulation patterns (Sonu, 1972) leading to offshore transport of material. The sediments eroded from the portions above mean low water level probably got deposited offshore in the form of an offshore bar. Here, the profiles could not be extended over these offshore bars, and so, the estimation of the amount of sand transported offshore has not been possible. As seen from the figure, this deposit gradually migrated up the beach face by October/November. From these features it appears that the major variations in the Anthakaranazhi beach profiles could only be due to the onshore-offshore transports of sediments. Offshore bars act as temporary storage areas for sediments which get deposited on the beach under favourable wave conditions. In addition, the alongshore flows alternating in their direction and varying in their magnitude with changing wave field (Figs 14 and 15) contribute to the deposition and erosion of material in the form of up-coast deposition and down-coast erosion. This feature has been qualified by the volumetric computations made from the profiles. The profile lines 13 and 14 lost about 10 m^3 and 30 m^3 of sediment respectively per unit width of the beach while profile line 15 gained about 21 m^3 and profile line 16 lost about 3 m^3 of sediment during the period of study. These values are fairly in agreement with those reported by Murty (1977) under similar environmental conditions at a location situated about 35 km south of this station. The sand accumulation at profile 15 may be due to the interruption of the littoral flow provided by the exposure of an old damaged groyne during June when the beach in general experienced considerable erosion.

It may be noted that the beaches at various profile locations from 1 to 16 responded in strikingly different manner to apparently similar beach shaping mechanisms the beaches have been subjected to. According to Goldsmith and Colonell (1970) the non-uniform wave energy in the littoral zone could be responsible for the above. Similar variations in profiles have been reported on Virginia beach (Goldsmith *et al.*, 1977). Sonu (1966) has reported profiles resembling the accepted summer and winter types barely hundred metres apart on the same section of beach at Cape Hatteras, North Carolina.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Stability of beaches is controlled by the interaction of various physical parameters such as winds, waves, currents, tides and the nature and constituents of the beaches. The results of studies carried out by the author on the dynamical effects of these environmental parameters on the shoreline processes along the beaches around Cochin are presented in this thesis. The section of the coast investigated is about 57 km of shore from Azhikode to Anthakaranazhi situated on the central Kerala coast. Four regions namely Narakkal, Malipuram, Fort Cochin and Anthakaranazhi were chosen for detailed study.

After discussing the physiography, coastal and nearshore sediments and the climatic conditions along the Kerala coast, a brief history of the shoreline changes and the coastal protection structures along the coast have been presented in the introductory Chapter. A brief review of the earlier works on littoral processes along this coast has also been presented in this Chapter.

Waves provide the primary source of energy for the nearshore processes. The deep water wave characteristics and their monthly variations have been obtained from the analysis of available data and presented as wave roses in

Chapter 2. It has been found that during fair weather season low, long period swells are predominant while the southwest monsoon season is characterized by the predominance of high and steep low period waves. During both the seasons, the predominant direction of approach of deep water waves ranges from W to WNW.

The nearshore wave characteristics have been evaluated by stydying the refraction of these waves as they propagate towards the shore. The wave refraction studies indicated greater amplification of the waves as they propagate ashore particularly from the southerly quadrants compared to those from the northerly quadrants. Wave energy concentration at certain locations (eg., stations B,I,O; Fig. 10; Chapter 2) independent of the periods and directions of approach has also been identified from these studies.

Though the nearshore wave height distributions, as calculated at 2 m isobath, indicate wave heights greater than 1.66 m (H = 0.83 x 2 m), for the computation of energy flux this height has been treated as the maximum height. Waves higher than this limiting value have been assumed to break further offshore as a result of increased instabilities.

While making a comparative study of the predicted wave heights at 2 m isobath with the observed field data on breakers, the presence of large-scale anomalies have been found. These anomalies are due to the sheltering effect of the nearshore mud deposits termed as 'mud banks' which are active during the southwest monsoon season. The computations on the probable attenuation of incoming wave energy, due to either the increased kinematic viscosity of the nearshore waters or the behaviour of the bottom sediments similar to that of fluid-muds, showed that 100% attenuation of wave energy occurs over a distance of 4 km when $\nu = 1.0\ cm^2/sec$ and that increased attenuation of energy takes place with increase in the wave height. This total attenuation of the incoming energy, as waves propagate through the mud bank areas, has been found to help considerable deposition of nearshore sediments on the lee side of the banks.

The directions of longshore currents from Azhikode to Anthakaranazhi obtained from the wave refraction diagrams have been presented in Chapter 3. The results indicate a net southerly longshore current generated due to the oblique incidence of waves along the coast for all the predominant directions of approach. The nearshore flow pattern, as identified from the alongshore gradients in wave heights, indicates alternate converging and diverging littoral flows. Combining both the forcing mechanisms - oblique incidence of waves and alongshore gradients in wave height - meandering flows directed towards south during most of the time along the coast under study have been identified. The field measurements of longshore currents using floats also provided corroborative results. Very weak flows were recorded along the beaches protected by mud banks with an indication of return flows over the banks.

The results of the studies on the temporal and spatial variations of the characteristics of beach material have been presented in Chapter 4. The sediments of these beaches in general fall in the medium to fine sand-size limits and reflect a low energy environment. These sediments, though show changes in response to the incoming wave energies, by way of relatively coarser material being associated with erosional profiles and finer material associated with depositional profiles, have been found to undergo recycling. The alongshore advection of the sediments has been restricted by the presence of opposing littoral flows partly under the influence of mud banks and to some extent by the presence of groynes.

The longshore drift of beach material along the shore under study has been computed based on the longshore component of wave energy (Chapter 5). The total quantum of sediment in transit has been estimated to be 9.5×10^6 m^3

during rough weather season and 7 x 10^6 m^3 during fair weather season. These values have been discussed in relation to the availability of sediments along this stretch of the beach. The wave-induced littoral flows are likely to be undersaturated and may give rise to erosion of existing material in the shore zone.

The evaluation of the littoral drift over the whole period of study indicates a net quantity of about 16.5 x 10^6 m^3 directed towards south. However, considering the fact that about 70 to 80% of the actual sediment transport occurs in the form of bed load, the available low wave energy flux and the absence of supply of sediments in the sand-size limits from sources other than the beaches themselves, the quantity of littoral drift mentioned above may be an over estimate. This should be viewed in the light of 20 to 30% of sediment transport in suspended form. The magnitude of littoral drift has been found to be varying considerably from location to location. In general, the magnitude of volume changes computed from the beach topographic studies were comparable with the volume of sediments subjected to littoral drift in the form of suspended load along the beaches that are directly exposed to incoming waves.

The erosional and depositional tendencies of the beaches have been estimated through beach profile surveys

(Chapter 6). The beaches exposed to wave action presented cyclic changes showing erosion during southwest monsoon season and accretion during rest of the year. The beaches receiving protection from mud banks did not show any well defined cyclicity. This cyclicity in beach morphological changes has been analysed in relation to various environmental parameters operating along the coast. The erosion taking place along most of the profile lines appears to be due to the undersaturated littoral flows rather than the high wave activity. The studies do not indicate high stability of beaches around Cochin. Compared to other beaches, Narakkal beach shows near-stable conditions. The beach at Anthakaranazhi, eventhough presented cyclicity in erosion and accretion, recorded a net loss during the period of study. In general, the shores protected by mud banks showed net gain of beach material.

The beaches along the shore from Azhikode to Anthakaranazhi are comparatively low energy environments and the erosion, though considerable, takes place for a short period during the year coinciding with the wind and wave climates of the southwest monsoon season. To combat beach erosion seawalls have been constructed along most of the beaches of Kerala, including those studied in the present work. The studies do not provide any evidence to suggest that the seawalls have helped either in achieving stability or in facilitating growth of existing beaches. To prevent or reduce the temporary erosional tendency of the beaches of Kerala, one may opt for temporary type of shore protection methods, such as floating breakwaters, to reduce the incoming wave energy rather than constructing permanent and expensive structures like seawalls which may have greater adverse effects on the adjoining beaches.

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