PHUKET MARINE BIOLOGICAL CENTER

Phuket, Thailand

RESEARCH BULLETIN No. 37

TEMPORAL CHANGES IN SEDIMENT CHARACTERISTICS ON THE WEST COAST OF PHUKET ISLAND

by

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PUBLISHED BY THE CENTER

Phuket, 1985

TEMPORAL CHANGES IN SEDIMENT CHARACTERISTICS ON THE WEST COAST OF PHUKET ISLAND*

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ABSTRACT

Based on bimonthly samples, changes in bottom sediment characteristics have been estimated during a three-year study on the west coast of Phuket Island, Andaman Sea. A total of 540 samples, covering 54 m^2 sea bed, have been analysed and provide the first long-term study of sea beds in Thailand. The results obtained at 15 stations, ranging in depth from 10 to 30 m., show significant between-year variations in silt-clay contents of the sediments. It is concluded that fine grained deposits increase on the bottom during the period of the NE monsoon and that this material is removed from the area during the SW monsoon. Hence, the study indicates that the effect of offshore tin mining on sediment granulometrics is local and reversible since there is no build-up of fine grained sediments. The observed pattern of temporal changes is discussed in relation to turbulent currents, wind force, and direction.

The study indicates a positive relationship between the concentration of silt-clay particles in bottom sediments and the concentration of suspended solids in sea water.

* Paper presented at the 15th Pacific Science Conference, New Zealand, February 1-11, 1983.

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I. INTRODUCTION

Offshore tin mining has been practiced in shallow water around Phuket Island since the turn of this century. Initially, mining was carried out on a small scale and in very shallow water. More recently operations have been on a large scale and involve huge dredges digging through about 8 m. of sediments until the bedrock is reached. As a consequence, potential environmental impact has grown into a major controversy between miners, the tourist industry, and fishermen who fear that the mining activity will destroy the basis of their income. The concern is hinged on a potential increase in turbidity of sea water caused by resuspension of sediment from the bottom caused by dredging. Moreover, during ore processing carried out by washing on jigs onboard the dredges, the unwanted sediment is discharged into the sea. The finer particles are transported seawards and to adjacent areas by currents. Finally, the sediment particles settle on the sea bed again. The sedimentation changes the sea bed and may influence the animals living in or on the sediment.

The present work has been launched to determine whether tin mining has a permanent effect on the sediment composition, especially the concentration of silt-clay particles. The study area has been monitored during a three-year programme. The aim has been to provide the National Environmental Board (NEB) of Thailand with information needed for management of future offshore mining activities on the west coast of Phuket Island. At present, requests have been submitted to the Thai Government for offshore mining concessions in about 72 km^2 of coastal water in this area.

II. MATERIALS AND METHODS

(a) THE STUDY AREA

Phuket Island is located on the west coast of Thailand, 8°N, 98° 20′E, the Andaman Sea. In Phuket (Fig. 1) two seasons can be distinguished, namely a rainy SW monsoon from May to October, and a dry NE monsoon period from November to April. Mean annual water temperature is approximately 28°C and salinity 33 ‰ (Limpsaichol, 1981).

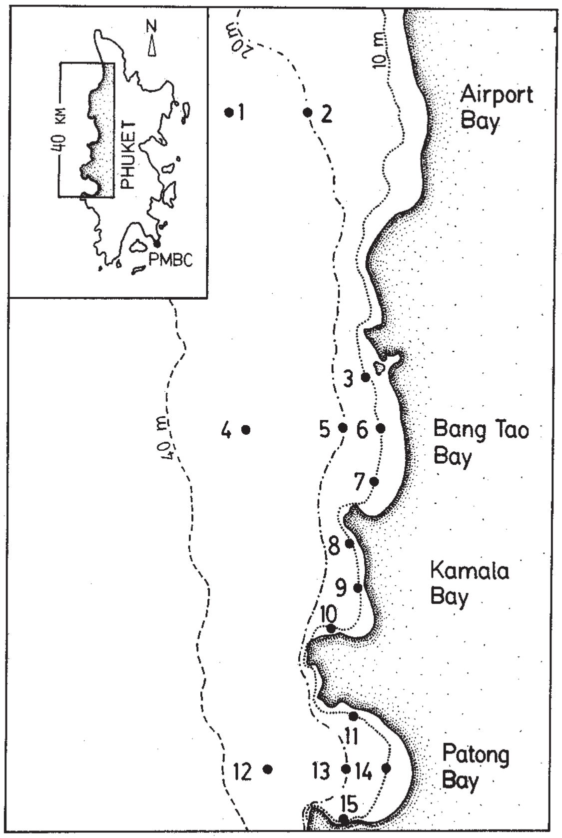

Fig. 1. The study area showing 15 stations at 10 to 30 m. depth.

Three types of current patterns can be observed in the coastal zone during the NE monsoon, namely an offshore oceanic current, a laminar tidal current and a near-shore turbulent current (Charoenlaph, 1982). It should be noted that all areas inside the 40 m. depth contour, including all protected bays, are influenced by turbulent currents (Charoenlaph, op. cit.).

Fifteen stations were studied which included Bang Tao Bay with ongoing tin dredging, and the three undredged bays: Airport, Kamala and Patong Bay(Fig.1). Depths ranged from 10 to 30 m. The linear distance from north to south of the

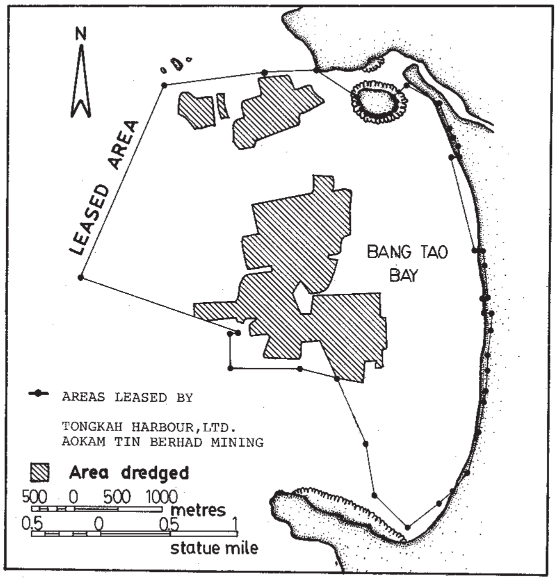

Fig. 2. Location of offshore tin mining areas in Bang Tao Bay.

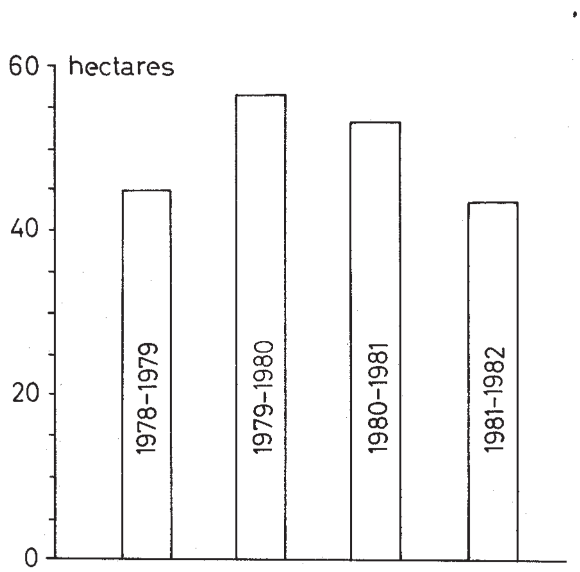

Fig. 3. Areas dredged in Bang Tao Bay during four years 1978-1982.

study area is 40 km. The bays are open with the exception of Patong Bay which is more indented and sheltered than the other bays. Two companies, Tongkah Harbour Tin Dredging Berhard Mining and Aokam Thai Mining Berhard, Ltd. dredged in Bang Tao Bay during the NE monsoon. The location of tin dredging is shown in Fig. 2. The above companies have kindly provided us with maps of the mining activities. On the basis of these maps the yearly dredging has been calculated during 1978-1982 as shown in Fig. 3.

(b) METHODS

Bimonthly sampling was carried out using a 0.1 m^2 Smith-McIntyre grab from April 1980 to June 1982. Because of rough seas during the SW monsoon, sampling in August 1980 was postponed to September 1980. Samples were not obtained in August and October 1981 due to repair of the Center's research vessel. Three grab samples were collected at each station, resulting in a total of 540 samples.

A random sample of approximately 100 g. bottom sediment was collected from each grab sample at every station during the study period. In the laboratory the sediment was dried 24 hrs at 105°C. For grain size analysis 50 g. of each dried sample was sieved 10 minutes in an automatic sieving machine provided with sieves of 2, 1, 0.5, 0.25, 0.125, and 0.063 mm. mesh size. Each grain size fraction was weighed to the nearest 0.1g. The mean values of each grain size was calculated for the 3 samples from each station and cruise and expressed as percentage of the dry weight. The median particle diameter was determined graphically from cumulative plots of the percentage distribution. The particle diameter at 50% was estimated both on a mm. and a phi scale. The sorting, expressed as the quartile deviation, was calculated according to the formula $QD_{phi} = (Q_3 - Q_2)/2$ (Holme & McIntyre, 1971).

From December 1980 to April 1982 suspended solids were determined in sea water samples collected from about 2 m. depth by use of the sea water pump of the research vessel. In June 1981, Nansen bottles were used to collect samples from mid water depth of each station. In the laboratory the 2,000 ml. sea water samples were filtered through glass microfibre filters (Whatman, GF/C). Prior to filtration the filters had been dried for 4 hrs at 105°C and weighed. After filtration the filters were dried at 105°C, weighed again, and the suspended matter calculated as mg. l^{-1}.

Representative data on wind direction and force were provided by Phuket International Airport (Fig. 1).

(c) TREATMENT OF DATA

Non-parametric tests have been carried out on data sampled in identical months during 1980-1982. The cumulative distribution function of a random variable with binominal distribution was calculated. A two-tailed test was applied to test significant differences at the 5% level.

Linear regression by least squares method has been carried out to estimate the functional relationship between two variables, and a test for the correlation coefficient (r) being zero was performed (Table of test values for the correlation coefficient).

Comparison of mean values has been made by visual comparison of empirical distributions. Assuming that the data display a normal frequency distribution, the standard deviations of the observations are a measure of the concentration of frequency about the means. A range of two standard deviations in each direction excludes 5% of the distribution (95% confidence interval). In consequence, mean values are judged as significantly different if the two standard deviation intervals do not overlap with the means.

We have desisted from further statistical treatment of data for the following reasons: The number of samples per station and cruise is low for statistical purposes and a considerable amount of variation is present in most field data. Standard deviations may be small on one occasion and very large the next time, i.e., heterogeneity of variances. Normal distribution of the data cannot always be regarded as a sufficiently good approximation.

Table 1

Median grain size in mm. Mean values of 3 samples calculated for each station and cruise during three consecutive years.

cruise	1980					1981				1982		
station	Apr.	Jun.	Sep.	Oct.	Dec.	Feb.	Apr.	Jun.	Dec.	Feb.	Apr.	Jun.
1	0.083	0.078	0.155	0.109	0.075	0.075	0.073	0.078	0.088	0.088	0.091	0.088
2	1.050	0.850	1.030	1.350	1.050	0.900	1.100	0.710	1.150	0.880	1.000	0.980
3	0.078	0.083	0.091	0.088	0.083	0.119	0.095	0.083	0.088	0.088	0.091	0.091
4	0.083	0.083	0.160	0.125	0.069	0.083	0.083	0.083	0.088	0.088	0.088	0.088
5	0.088	0.085	0.190	0.140	0.078	0.078	0.109	1.000	0.095	0.095	0.095	0.348
6	0.083	0.085	0.190	0.098	0.078	0.075	0.072	0.115	0.091	0.088	0.320	1.050
7	0.115	0.119	0.140	0.360	0.125	0.180	0.133	0.119	0.145	0.255	0.750	0.351
8	0.133	0.119	0.190	0.165	0.140	0.160	0.160	0.109	0.140	0.165	0.177	0.280
9	0.400	1.250	0.190	0.091	0.085	0.210	0.073	0.255	0.165	0.220	0.300	0.119
10	0.195	0.580	0.990	0.085	0.460	0.351	0.440	0.210	0.250	0.290	0.150	0.160
11	0.650	0.083	0.880	0.078	0.600	0.069	0.069	0.083	0.085	0.085	0.088	0.088
12	0.075	0.083	0.370	0.105	0.078	0.073	0.075	0.085	0.085	0.085	0.088	0.091
13	0.119	0.088	0.560	0.500	0.530	0.600	0.550	0.510	0.420	0.095	0.600	0.385
14	0.083	0.083	0.360	0.088	0.073	0.075	0.073	0.088	0.088	0.088	0.091	0.091
15	0.510	0.420	0.356	0.440	0.440	0.320	0.270	0.260	0.290	0.140	0.356	0.240

III. RESULTS

The results of this 3-year study is described in two sections. First, (I) the measured parameters : median diameter, quartile deviation, concentration of silt-clay in bottom sediment, suspended solids, and wind patterns are examined at individual stations and cruises. Second, (II) trends in data collected at specified depths are shown for stations grouped into 10, 20 and 30 m. depth areas and an overall picture of the west coast is compiled by grouping all stations sampled at each cruise.

(a) THE MEASURED PARAMETERS

(i) Median grain size

Table 1 shows mean median grain size in mm. per station and cruise. The median diameter (Md) is a relative measure showing the value where 50% of the particles are coarser, and 50% smaller than the median. The absolute variation within fractions making the 50% high and 50% low, can be substantial without influencing the calculated median diameter. However, if variation is present within fractions of sediments with identical Md the sorting characteristics of the sediments will differ.

(ii) Quartile devation

Table 2 shows mean quartile deviations (Qd) in phi units per station and cruise. Quartile deviations are measures of the degree of sorting, and they are calculated from the grain size at the 25% and 75% points on cumulative plots of the percentage dry weight against grain size. The calculated sorting classes range from rather well sorted sediments (Qd near 0.3 phi units) to poorly sorted sediments (Qd near 2.0 phi units). Most sediments were moderately to well sorted, i.e., within the range of 0.5 to 1.0 phi units. Taken together, Table 1 and 2 show cases of nearly

Table 2

Quartile deviation in phi units.
Mean values of 3 samples calculated for each station and cruise during three consecutive years.

cruise / Station	1980					1982				1981		
	Apr.	Jun.	Sep.	Oct.	Dec.	Feb.	Apr.	Jun.	Dec.	Feb.	Apr.	Jun.
1	0.35	0.4	0.57	0.58	0.45	1.47	0.5	0.4	0.32	0.3	0.27	0.3
2	0.8	0.82	0.7	0.9	0.77	0.75	0.77	1.17	0.75	0.62	0.8	0.75
3	0.42	0.4	0.35	0.35	0.45	1.27	0.87	0.27	0.27	0.27	0.25	0.27
4	0.37	0.35	0.32	0.52	0.52	0.45	0.4	0.32	0.35	0.3	0.3	0.27
5	0.57	0.32	0.75	0.57	0.85	0.55	2.05	1.02	0.37	0.35	0.32	1.22
6	0.32	0.32	0.87	0.37	0.57	0.55	0.52	0 85	0.27	0 27	0.52	2.1
7	1.45	1.5	1.25	1.57	1.55	1.47	1.27	1.0	1.6	1.65	0.82	1.77
8	0.67	1.17	1.35	0.72	0.55	0.37	0.45	1.35	0.5	0.42	0.4	0.97
9	2.25	1.0	0.72	0.35	0.52	0.77	0.47	1.25	0.57	0.6	0.55	0.87
10	095	0.82	1.05	0.32	0.67	1.75	0.77	1.2	0.77	1.27	0.7	1.0
11	0.42	0.3	0.67	0.32	0.5	0.5	0.55	0.35	0.32	0.27	0.27	0.22
12	0.35	0.3	0.35	0.42	0.32	0.5	0.47	0.32	0.3	0.27	0.27	0.27
13	1.45	4.0	0.72	0.75	0.65	0.82	0.72	0.77	0.8	0.37	0.77	1.40
14	0.35	0.3	0.35	0.32	0.45	0.42	0.5	0.3	0.27	0.25	0.27	0.25
15	0.85	0.7	0.5	0.7	1.37	0.75	0.87	0.82	0.67	0.95	0.65	0.82

identical Md but widely differing Qd, such as Sta.2 and Sta.6, April 1981 and June 1982, respectively. In both cases Md was 1.1 mm. (-0.1 phi unit) while Qd was 0.77 and 2.10 phi units, respectively. However, the normal situation is that sediments with identical Md showed only a small variation in sorting characteristics. For example, the 14 samples in Table 2 with Md = 0.083 mm. (3.6 phi units) had a sorting coefficient Qd = 0.36 ± 0.05 phi units (mean and standard deviation).

(iii) Silt-clay of sediments

The percentage silt-clay particles has been calculated separately because of the significant environmental effects associated with this fraction (Hylleberg & Riis-Vestergaard, 1984). Table 3 shows the mean values of the percentage silt-clay at each station and time of sampling. Silt-clay refers to the fraction of dry sediment passing a 0.063 mm. sieve. The error associated with the sieving procedure will mostly affect the finest fraction of the silt-clay because dry clay particles may be difficult to break up. However, we believe that comparisons between samples shown in Table 3 are meaningful because the sediments generally were sandy (see Fig.6), and did not differ markedly in composition. Sandy sediments are more easily separated into size fractions. Table 3 shows that silt-clay concentrations varied considerably within, and between years.

(iv) Suspended silt-clay particles

Silt-clay is released from land to the sea via freshwater run-off. Another source would be offshore tin mining. The fine fraction of dredged sediment is suspended from tailings dumped behind the dredges. Finally, silt-clay may become resuspended from the sea bed on account of waves and currents. Table 4 shows the amount of suspended solids (mainly silt-clay) in sea water collected on seven occasions during the survey. Very turbid water was measured occasionally in the mining area of Bang Tao Bay, st.3 & 4, April and June 1981. However, the turbidity in June

Table 3

The relative concentration of silt-clay (% d.w. of particles smaller than 0.063 mm.) of sediments. Mean values of 3 samples calculated for each station and cruise during three consecutive years.

cruise	1980					1981				1982		
Station	Apr.	Jun.	Sep.	Oct.	Dec.	Feb.	Apr.	Jun.	Dec.	Feb.	Apr.	Jun.
1	17.5	27.8	2.4	7.2	32.0	32.5	35.8	26.6	9.5	3.6	3.6	7.1
2	1.2	2.8	0.0	0.2	1.5	1.9	1.3	4.7	0.3	1.2	0.0	0.3
3	25.0	24.6	7.3	14.9	28.0	12.1	26.4	8.0	5.9	4.2	1.2	1.5
4	21.0	18.6	1.3	3.5	42.0	27.6	24.8	17.3	14.4	7.1	3.8	2.2
5	22.7	15.9	0.9	0.5	25.1	29.6	18.8	0.0	11.6	6.1	3.8	1.7
6	21.4	16.5	1.0	6.6	32.7	36.6	35.7	5.3	3.1	1.8	0.1	1.8
7	17.7	11.7	5.1	1.1	25.1	20.8	17.3	7.8	6 4	3.3	0.1	1.9
8	7.4	17.7	0.6	2.9	18.7	11.2	13.1	11.1	0.3	0.2	0.3	0.5
9	9.9	4.2	0.4	9.8	25.3	18.7	32.4	2.0	0.3	0.4	0.2	0.3
10	10.4	8.0	0.2	13.6	1.0	6.4	3.3	7.0	1.7	2.9	2.9	3.7
11	2.4	17.8	0.1	21.5	1.1	41.3	40.8	13.8	14.5	5.4	2.4	1.8
12	25.0	13.9	0.2	3.8	26.1	34.1	32.2	16.3	7.7	9.3	9.2	1.6
13	14.3	18.8	0.1	0.3	1.6	0.9	1.9	0.2	3.0	9.5	0.3	0.8
14	19.6	15.8	0.4	9.3	33.4	29.7	34.5	7.4	4.0	2.0	0.7	0.2
15	1.4	1.9	0.5	0.3	7.3	4.3	9.8	5.2	0.9	2.9	0.3	0.3

Table 4

Concentration of suspended solids in sea water (mg. d.w. l^{-1}) Mean values and standard deviations of samples (n = 2) are calculated for each station and cruise, except June 1981 where only one sample was obtained per station.

cruise / Station	1980	1981				1982	
	Dec.	Feb.	Apr.	Jun.	Dec.	Feb.	Apr.
1	31.1 ± 0.4	17.7 ± 0.28	37.5 ± 1.7	51.2	16.3 ± 1.8	8.5 ± 0.7	10.1
2	32.6 ± 2.8	5.8 ± 0	32.8 ± 0.71	17.5	8.0 ± 0.2	4.8 ± 0.1	8.1 ± 0.3
3	60.9 ± 2.4	4.8 ± 1.7	223.8 ± 14.85	128.1	7.9 ± 0.6	4.2 ± 0.5	7.4 ± 0.8
4	33.1 ± 8.6	15.2 ± 6.43	347.2 ± 46.43	57.1	7.0 ± 1.1	5.5 ± 0.2	5.8 ± 0.1
5	45.0 ± 20.4	19.8 ± 0.	38.1 ± 1.94	82.4	8.9 ± 1.9	6.2 ± 0.5	6.3 ± 1.0
6	27.0 ± 0.6	19.8 ± 0.14	37.6 ± 2.83	44.2	8.9 ± 0.7	6.6 ± 1.0	5.6 ± 0.2
7	38.1 ± 0.7	16.7 ± 0	21.0 ± 1.41	141.8	12.2 ± 3.0	6.2	6.5 ± 1.1
8	29.6 ± 3.7	17.0 ± 0.35	35.0 ± 1.65	23.0	1.1 ± 0.3	5.6 ± 0.14	5.4 ± 0.2
9	28.5 ± 1.3	17.0 ± 0.49	34.5 ± 4.95	18.8	8.6 ± 2.6	6.0 ± 1.0	5.9 ± 0.2
10	34.8 ± 0.3	15.9 ± 0.99	197.2 ± 4.01	20.3	18.5 ± 1.8	5.6 ± 0.9	5.9 ± 0.4
11	27.7 ± 0.4	19.2 ± 1.84	35.2 ± 0.79	38.8	5.9 ± 0.2	5.0 ± 0.5	7.4 ± 1.8
12	28.1 ± 1.6	16.4	34.4 ± 1.62	56.0	–	6.4 ± 1.4	7.4 ± 2.5
13	28.6 ± 2.8	15.4 ± 0.92	31.2 ± 2.46	47.6	8.3 ± 0.6	6.9 ± 0.2	12.1 ± 3.3
14	27.2 ± 6.2	15.6 ± 0.21	34.1 ± 4.6	32.7	8.7 ± 2.7	4.8 ± 0.1	11.8
15	29.3 ± 1.8	16.3 ± 0.84	36.4 ± 2.2	45.2	10.4 ± 1.8	4.8 ± 0.2	6.7 ± 0.8

is not directly caused by offshore dredging. Owing to the rough sea during the SW monsoon all dredging is halted every year between mid-April and the beginning of November. Furthermore, high values of sediment load were found in April and June at Sta.12 & 15 in Patong Bay, far away from the dredges. In comparison, all concentrations of silt-clay were low in December 1981, February and April 1982 when offshore mining occurred in Bang Tao Bay. The latter finding cannot be explained as a result of between sampling differences in directions of currents since the samples were obtained at stations surrounding the dredging area (Fig.1) but the distributional pattern of suspended solids is analogous to the pattern of silt-clay in the sea bed. This relationship will be treated in section (b).

(v) Wind force and pattern

During the NE monsoon the predominant winds are easterly while they are westerly during the SW mansoon at the latitude of Phuket Island (Yesaki & Jantarapagdee, 1981). Furthermore, the average easterly wind frequency and force is weaker than the average westerly winds. The same pattern is observed with respecst to maximum wind speed shown in Fig. 4. The seasons of shifting

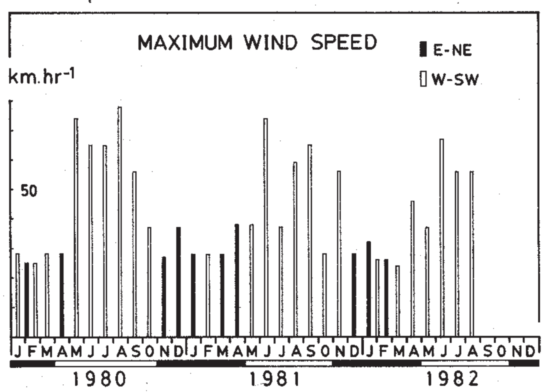

Fig. 4. Maximum wind speeds recorded at Phuket International Airport. The periods of the NE monsoon (Black bars) and the SW monsoon (white bars) aer indicated on the time axis.

monsoons are very predictable but the force and frequency of winds show considereable variances both within- and between - seasons. The former aspect is seen in Fig. 5 which depicts powerful winds prevailing for weeks, e.g., June 1980. Then the strong winds were succeeded by a long period of calm weather, and so forth

(vi) Relationship between mean and maximum wind velocities.

Days of maximum wind and direction of the winds during 1980-1982 were provided by Phuket International Airport, in addition to monthly mean wind velocities calculated over a 20-year period 1951-1970. Assuming a normal distribution of the parameters, the correlation between maximum wind as a function of mean wind velocities was calculated, using linear regression analysis. For $n = 55$, the correlation coefficient was 0.6692 and $p < 0.1$. The coeffecient of determination $r^2 = 0.4478$ shows that about half of the correlation can be explained by the analysis, i.e., maximum wind is recorded in months characterized by strong winds on average. The other half of the correlation is unexplained, among others because short bursts of high-speed winds can be measured on days with low average wind velocities. Furthermore, very powerful winds have been measured in months characterized by moderate winds. For example, in May 1980 the maximum wind speed was 74 km. $hr.^{-1}$ in the study area compared to a mean wind speed of 8.5 km. $hr.^{-1}$ for that month. The unexplained half of the variation is related to the stochastic element of nature which affects the observed variations of sediment characteristics and, thereby, becomes an important biological parameter (Hylleberg *et al.*, 1985).

(b) OVERALL TRENDS

(i) Sediment characteristics according to depht and locality

Median diameter: Fig. 6A shows that bottom sediments with the smallest median diameter, about 0.090 mm. = 3.5 phi units, were obtained at Sta. 1, 4, and 12 at 30 m. depth, in addition to Sta. 3 and 14 at 10 m. depth. The coarsest sediment occurred at Sta.2 with a median diameter of about 1.00 mm. = 0 phi units. Considering the high standard deviations it is obvious that the mean particle size from all other stations were not significantly different. These sediments consisted of fine to very fine sand.

Sorting: The quartile deviations show that bottom sediments were best sorted at Sta.14 and 12 at 30 m. depth, in addition to Sta. 11 and 14 at 10 m. depth. The other stations displayed moderately sorted sediments. Sta. 7 had especially heterogenous bottom material. Most stations at 10 m. depth had poorly sorted sediments apart from Sta.11 and 14 mentioned above. Variations about the means were considerable (Fig. 6B).

Silt-clay: Silt clay particles, abundant in sea beds around Phuket Island, have been formed by weathering of rocks and mainly derived from feldspar of the granitic bedrock. Fig. 6C shows that, with the exception of Sta. 2, all stations fluctuated considerably in the relative concentrations of silt-clay particles. Yet, Fig. 6 C indicates that Sta. 2, 5 and 13 at 20 m. depth were the most variable when compared to the stations along the 10 and 30 m. depth contours. Only Sat. 15 in Patong Bay differed from the other stations at 10 m. depth. However, it is obvious that there is no significant difference between the stations on account of the large variances about the means.

(ii) Suspended solids versus concentrations in the bottom.

The very turbid water measured in Bang Tao Bay in December 1980 and April 1981 (Sta. 3 & 4) is not easily attributed to offshore tin mining which occurred during this period. For example, we also found high values at Sta. 10 far away from the dredges (Kamala Bay: 197 $mg.1^{-1}$ in April 1981). Even in Patong Bay the values of 31-34 mg. 1^{-1} were high in April 1981. However, the high suspended sediment concentration there could still be due to the dredging depending on the current patterns. Normally, surface water of

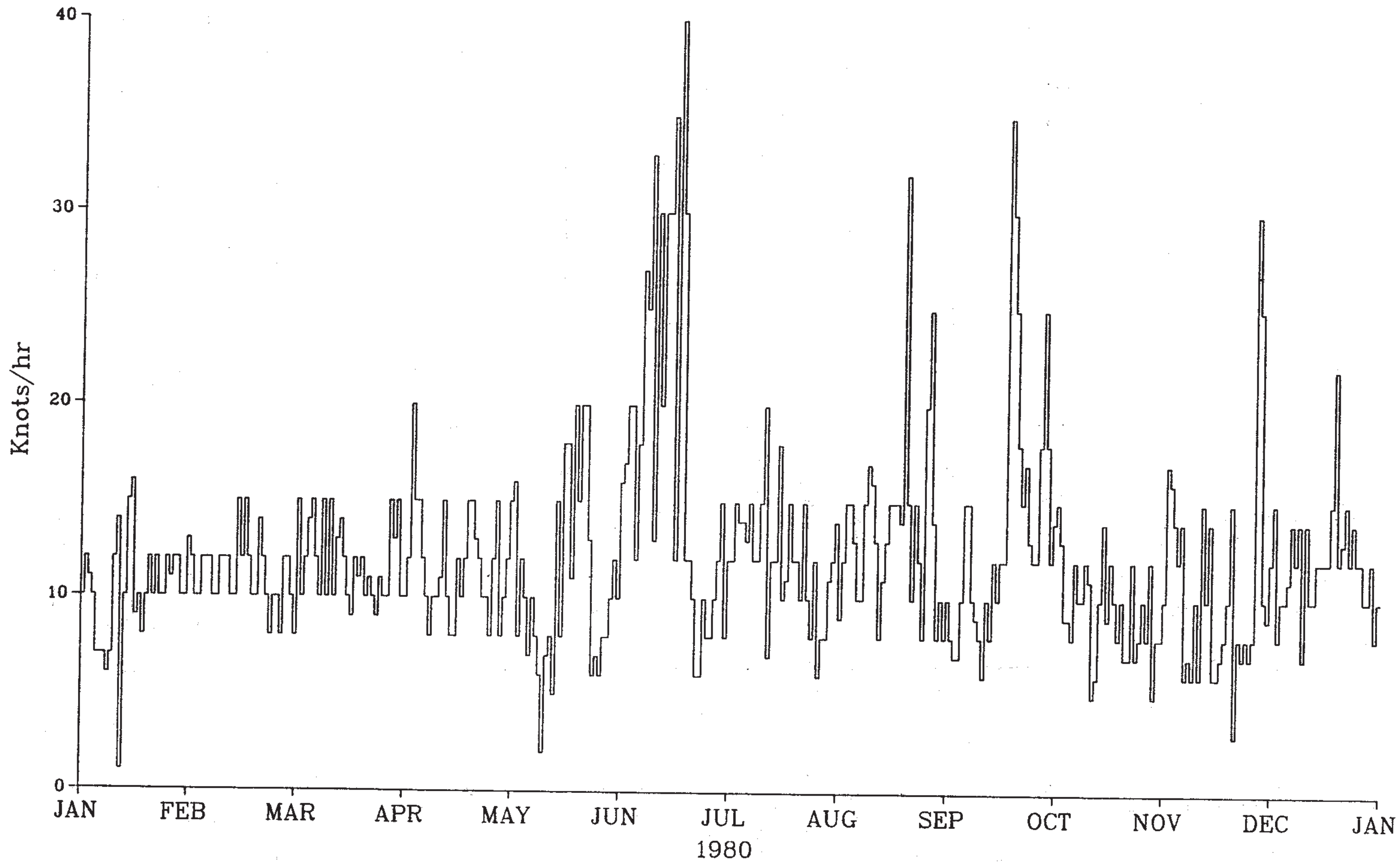

Fig. 5. Wind pattern on the west coast of Phuket Island based on daily records at Phuket International Airport near the study area.

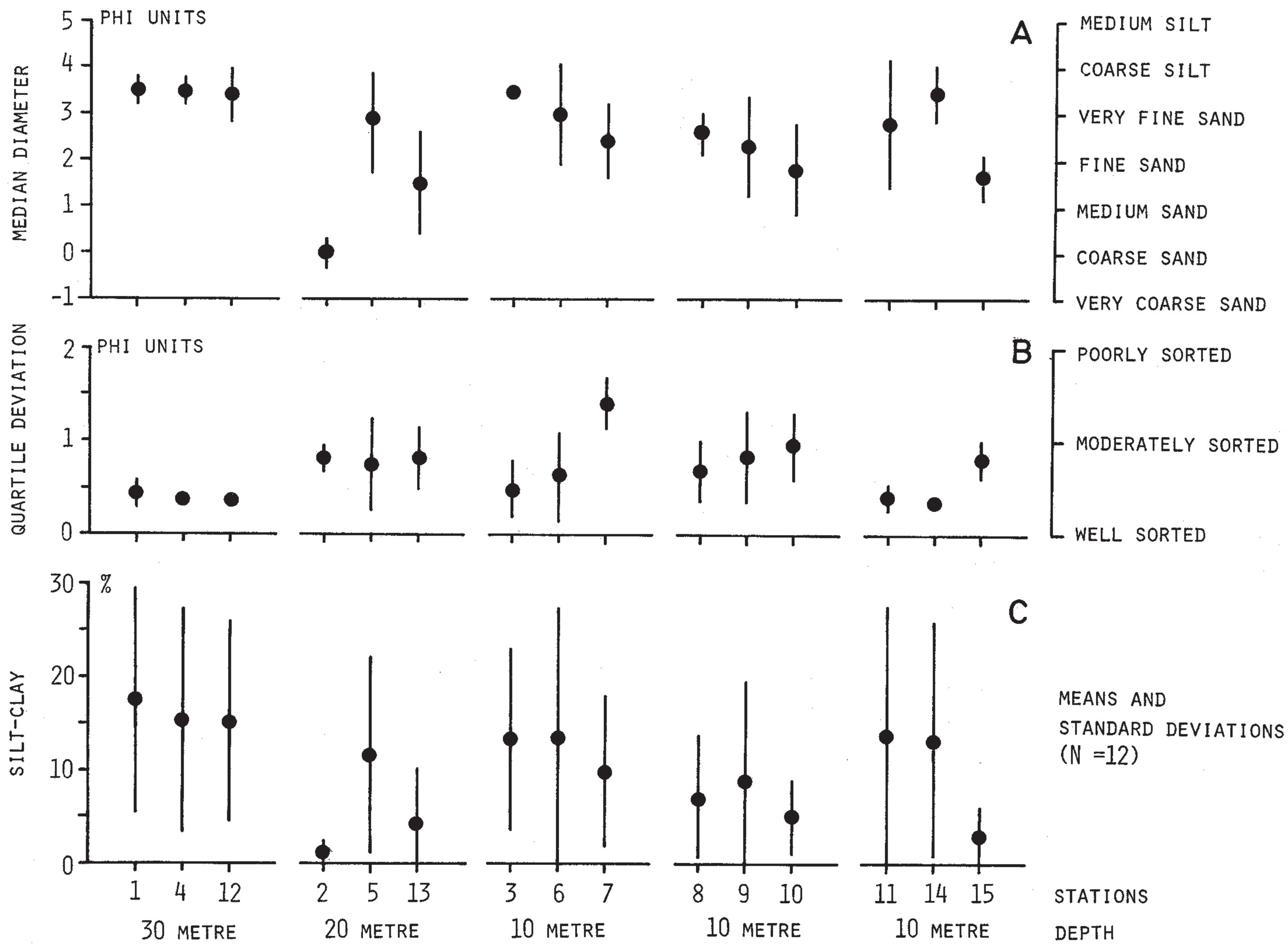

Fig. 6. Sediment characteristics : Median diameter, degree of sorting, and % silt-clay particles of dry sediment. Means and standard deviations for n = 12. Data are arranged according to depth and locality.

Table 5

Non-parametric test of pairs of data from 15 stations sampled in identical months during 1980-1982. The cumulative function of a random variable with binominal distribution is calculated and the probability P (k) of obtaining the lowest value or more extreme in a given month is shown. A two-tailed test shows no significant difference if P (k) $\geq$ 0.025 (95% confidence level, and p = 0.5). A: concentrations of silt-clay in sediments, cf. Table 3. B: concentrations of silt-clay in sea water, cf. Table 4.

	Number of stations with highest values 1980-1981	Number of stations with highest values 1981-1982	P (k)	Significance
A)				
December	12	3	0.02	S
February	14	1	0.0005	S
April	15	0	0.00003	S
June	13	2	0.004	S
B)				
December	14	0	0.00006	S
February	15	0	0.00003	S
June	15	0	0.00003	S

these coastal areas should contain less than 30 mg. l^{-1} (Limpsaichol, 1981). In Table 4 we see that such normal values were actually measured at all stations during December 1981, February and April 1982. Since tin dredging occurred at the same place in Bang Tao Bay, and at the same rate through the two periods of NE monsoons (Fig. 3) we cannot directly relate suspended silt-clay particles to offshore mining activity. However, some relationship should be expected between silt-clay in the water and silt-clay in the sediment. When the sea is calm particles settle on the bottom and they become resuspended on windy days with wave action.

The possibility of a relationship has been analysed in two ways. First, Table 5 shows a highly significant between year difference in silt-clay concentrations of the sea bed as well as in the water, when the 15 stations are compared month by month in successive years. The period December 1980 to June 1981 had high concentrations compared to the low values observed December 1981 to June 1982. Furthermore, Table 5 shows that sea water, as well as sea bed concentrations are high and low at the same time. Owing to the fact that data clump in these two groups of high and low concentrations (Fig. 7) the relationship between these parameters is bound to give a certain amount of positive correlation when silt-clay in the water is observed as a function of silt-clay in the bottom. We have graphed this relation in Fig. 8.

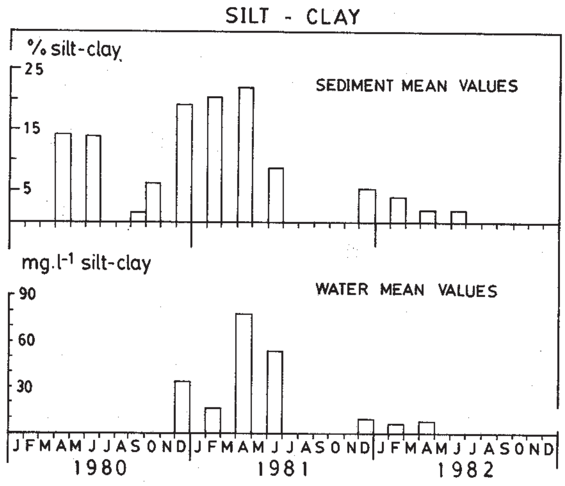

Fig. 7. Variation of silt-clay concentrations in sediment and water during the period 1980-1982. Mean values for n = 15.

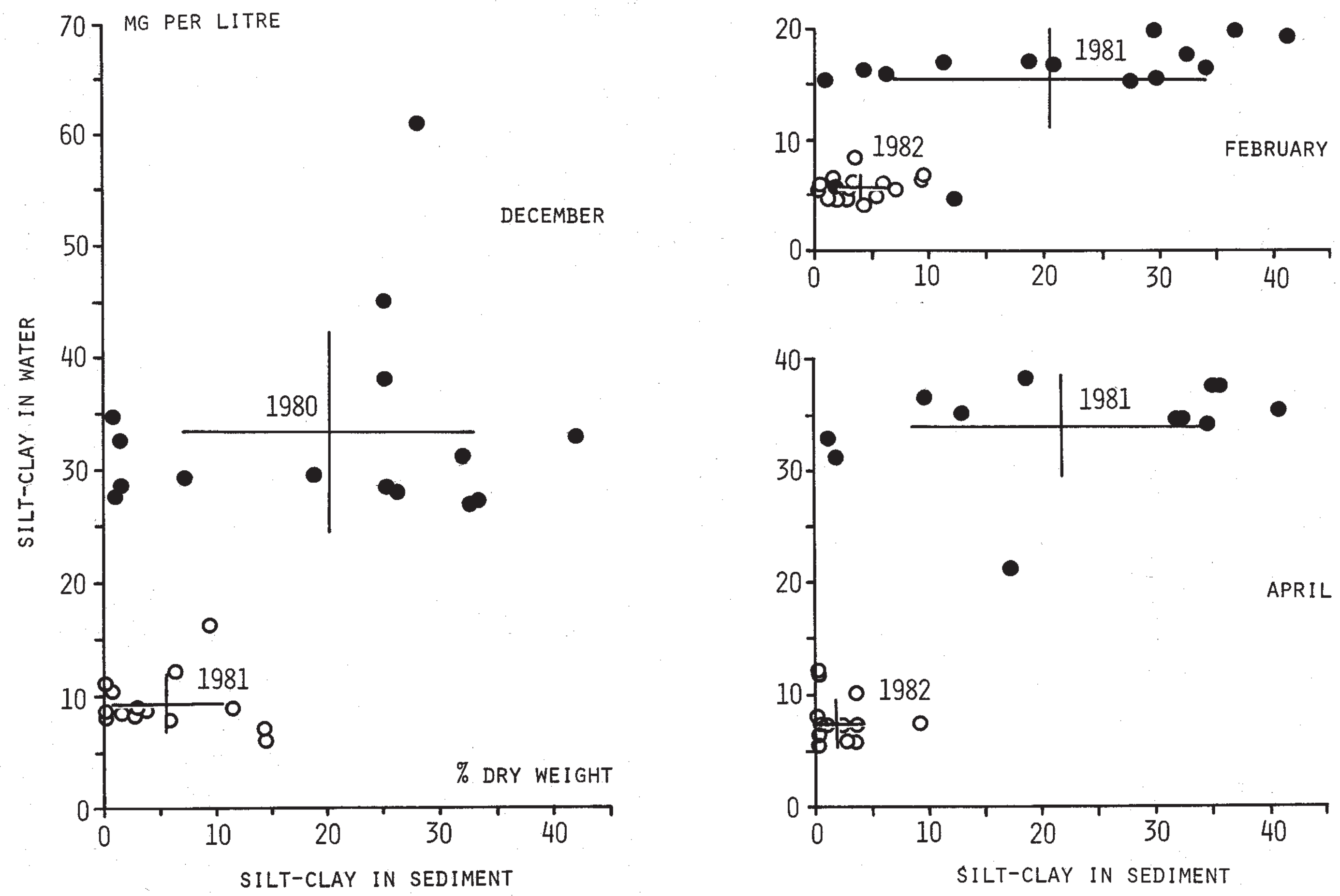

Fig. 8. Silt-clay suspended in water as a function of silt-clay in sediment at 15 stations sampled the same month in two successive years. Means and standard deviations for n = 15, except April 1981 where n = 12.

Data are according to Table 3 & 4, but the very high concentrations of suspended solids measured at Sta. 3, 4, & 10 in April 1981 have been omitted from the graph and the calculated mean and standard deviation.

By visual inspection of Fig. 8 it is seen that the relationship lacks a high degree of statistical significance on account of the marked variances. However, the repeated pattern observed in the three pairs of months indicates that a relationship does exist. Yet, more measurements are needed to reveal details of this relationship assumed to be hinged on wind direction and force.

IV. DISCUSSION

(a) Biological effects of silt-clay particles.

According to Bussarawit *et al.* (1984), Hylleberg *et al.* (1985), and Hylleberg & Nateewathana (1984) the fauna was significantly impoverished at Sta. 3 and 6 at 10 m. depth, and to some extent at Sta. 5 at 20 m. depth off the mining area in Bang Tao Bay. This downgrading of benthos is related to tin dredging but the exact cause of the impoverishment is difficult to state. We suggest that reduction of the fauna at Sta. 5 was caused by intolerable concentrations of suspended silt-clay particles while the reduction of fauna at Sta. 3 & 6 primarily took place on account of deposition which created a soft silt-clay sediment surface unsuitable as a habitat for most marine invertebrates.

Unfortunately, information about the effect of suspended loads is highly controversial, partly because of experimental difficulties, partly because a certain amount of turbidity is favourable for feeding and reproduction of invertebrates in the the marine environment (Thorson. 1964). The size and quality of suspended solids are important aspects and the water movement is of paramount importance. High suspended loads may be detrimental in low energy habitats but the same load may be without effect in a high energy environment which prevents the particles from settling (Charuchinda & Hylleberg, 1984).

Although there is abundant evidence that prolonged turbidity is harmful to aquatic life, the effects are complex. For example, adult fish like trout and salmon may survive long periods of high concentrations of suspended solids as high as 300 mg. l^{-1} in the laboratory (Wilber, 1971). However, in nature deposition of sediment reduced survival of eggs, reduced the food source, and destroyed needed shelter (Wilber, op.cit.) It is obvious that environmental turbidity is ambiguous since turbidity may no tharm adults but could be very harmful to the species, anyhow, by preventing satisfactory reproduction.

In most filter-feeders clogging of the filters will reduce feeding rates if turbidity becomes too great. In oysters quantities as low as 100 mg. l^{-1} resulted in 57% reduction of pumping rate (Loosanof & Tommers, 1948). The effect of suspended solids is also pronounced on eggs and larvae of oysters, though as much as 1 or 2 g. silt l^{-1} is needed to cause 100% mortality (Loosanof, 1965).

(b) Dynamics of silt-clay particles.

The present study has shown variations in % silt-clay of bottom sediments of unexpected orders of magnitude as shown in Fig. 7. Since the main purpose of this study was to study the effects of offshore tin mining, the observed silt-clay concentrations should be compared to available information from areas dredged in Bang Tao Bay. Fig. 3 shows areas dredged during four dredging seasons. Based on the bar October 1980 - April 1981, an area of approximately 530,000 m^2 was dredged that season. Assuming that the average depth of digging was 8 m. sediment a volume of 4.2×10^6 m^3 sediment passed the dredges that year. In an environmental impact report (TESCO, 1982) it was estimated that about 4% of this sediment was released to the water as suspended silt-clay which could settle outside the immediate dredging area. This gives a figure of about 170,000 m^3 silt-clay during a dredging season. In turn this calculated release can be compared to bottom sediment values of the present study. On average the grab used by us digs to a depth of 15 cm., that is, 0.015 m^3 sediment is sampled per m^2 sea bed. The average silt-clay concentration was 20% in February 1981, that is, 0.003 m^3 silt-clay per m^2 bottom to a depth of 15 cm. If we assume that this concentration has built up since August 1980 (see Fig. 7) and that the main source of input of particles should be from offshore mining, we can calculate that an increase in the top layer of sea bed from 0 to 20% would be possible in an area of approximately 56 km^2. However, this calculation is based on several assumptions which may or may not be true, but it should be noted that the area of 56 km^2 is the area contained within a circle having a radius of about 4 km., or the area where the present study indicates that silt-clay affected density and biomass of benthos (Hylleberg *et al.*, 1985). It is possible to some extent to relate changes in the fauna of Bang Tao Bay to release of silt-clay from dredges but more studies of sedimentation are needed before statements can be made regarding Patong Bay, far away from the dredges. In order to account for the considerable amounts of silt-clay being deposited and resuspended on the west coast of Phuket Island it is necessary to consider not only release from dredges, but also transport from the east coast to the west coast of Phuket Island by currents, transport within the west coast, run-off from land, and on-land tin mining. Run-off from land is probably not important since build up of silt-clay in the sea bed took place during the dry season. Hence, transport by currents is the most likely explanation for the observed changes.

(c) Monsoon associated effects

We suggest that between-year variation in build up and disappearance of silt-clay was caused by differences in wind direction and force, in turn influencing the currents, the erosion and sedimentation pattern. In the present part we will only consider the maximum wind velocities shown in Fig.4. The beginning of the dry season 1979-1980 is not shown but October, November, December 1979 had maximum wind speeds from E-NE, ranging from 28-56 km. hr^{-1}. Consequently, the beginning this dry season was normal, i.e., do-

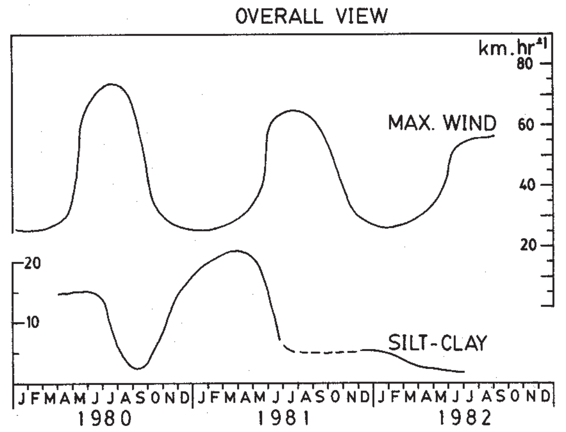

Fig. 9 Comparison of the patterns of maximum wind speed and the percentage silt-clay of sediments during 1980-1982.

minated by easterly winds. The rest of this dry season from January to April 1980 also had some weak, westerly winds. During the wet monsoon very strong winds came from W-NW from May to August but not so frequent. September had more and strong winds while October, marking the end of the wet monsoon, had less and not so strong wind. If we compare 1980 with the following years we observe a pronounced between-year variation. Of course, this should be expected. The unexpected finding was that maximum wind speed and silt-clay concentrations in bottom sediments apparently were related. From the original histograms Fig. 4 & 7 we have drawn smooth curves, shown in Fig.9, in order to facilitate comparison of winds and silt-clay concentrations. For the year 1980, just described in terms of wind, we observe that build-up of silt-clay was not as high as the following year 1981. Furthermore, the percentage silt-clay decreased later in 1980 than in 1981. If we again compare with the wind pattern we find that the dry season, November 1980 to April 1981, had winds from E-NE, except for the NW wind in February 1981. Continuing with the dry season November 1981 to April 1982, we observe a marked difference compared with the previous two years. Winds from E-NE dominated only during December 1981 to February 1982, and the wet monsoon had many days with strong winds from W-NW during June, July and August 1982.

V. CONCLUSIONS

Since the data were not collected in order to evaluate the above relationship we have desisted from statistical treatment of data, according to arguments previously given in Materials and Methods. The analysis is qualitative and on this background we can only suggest the following sequence of events. When the dry monsoon was dominated by a long period of winds from E-NE, and the transitional months October and May were dominated by weak winds from W-SW, much silt-clay accumulated in sediments on the west coast (October 1980-May 1981). When the dry monsoon exhibited a short period of E-NE winds there was only a small build-up of silt-clay (December 1981-March 1982). During the wet monsoon frequent and strong winds from W-NW resuspended silt-clay from sediments and carried the particles away from the inner shelf of the west coast. The latter statement agrees with Frerichs (1970) who found that the whole Mergui platform was characterized by very slow rates of sedimentation. The sea beds consisted of sandy, coarse grained sediments. The area off the west coast of Thailand had especially low rates of deposition.

ACKNOWLEDGEMENTS

We thank former Director Urupun Boonprakob and the present Director Boonlert Phasuk, PMBC, for help in many ways. The crew of research vessel Pramong 8 gave willing hands during the cruises. We also thank the technicians who assisted in the field and the laboratory. Our colleagues Mr. Prawin Limpsaichol and Mrs. Arna Nateewathana contributed with the analyses of suspended solids. Besides this gratefully acknowledged help we are indebted to Dr. Barbara Brown, Mr. Fred Dobbs, Dr. Volker Loesche, and Dr. Hans Siegismund for stimulating comments to an early draft of this paper.

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(Manuscript received February, 1984)