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Mineralogy and Textures of Beach Sands in Relation to Erosion and Accretion Along the Rosetta Promontory of the Nile Delta, Egypt

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ABSTRACT

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The Rosetta promontory on the western coast of the Nile delta has been subjected to severe erosion. Spatial and temporal shoreline changes have been estimated from ground survey data obtained between 1971 and 1992. The data consist of 45 beach profiles along 46 km of coast. Shoreline erosion rates are higher along the promontory tip (52.9 to 102.2 m/yr). They progressively decrease with longshore distance both to the east and to the southwest. Four nodal points, two at each side of the river mouth, are areas where this erosion is reversed to accretion (1.3 to 20.4 m/yr). This accretion changes again to erosion beyond which erosion is continued (1.3 to 3.7 m/yr).

Beach-face samples were collected at each profile line and were texturally and mineralogically analyzed to relate the sediment characteristics to beach changes. The erosion/accretion pattern along the Rosetta promontory is reflected in the heavy mineral concentrations and grain size variations of beach samples. The heavy minerals are more abundant in the finer sand and are concentrated near the river mouth, reaching 80 to 92%, then systematically decrease with longshore distance, being reduced to less than 25% both to the east and to the southwest where coarser sand is accumulated along accreted zones.

Two mineral groups correspond to selective-sorting patterns: (1) Garnet and high-density opaques comprise the finest grains which tend to concentrate on the eroded promontory tip, then progressively decrease east and southwest. (2) Lower density minerals (coarsest grains), hornblende, augite and epidote are transported from eroded areas and systematically increase in percentage with distance from the river mouth both to the east and to the southwest and are deposited in the stretches of accreting shoreline; *i.e.* with the longshore transport and decreasing erosion. This means that size-density sorting is a function of the transportability. This study also emphasizes the close relationship among grain sizes of total samples, heavy mineral concentrations and heavy mineral assemblages as related to advancing and retreating shorelines.

ADDITIONAL INDEX WORDS: *Heavy minerals, beach erosion, beach accretion, Nile delta, sediment dispersal.*

INTRODUCTION

Much has been written about heavy mineral assemblages and their relationship to beach erosion and deposition on modern beaches. Heavy minerals as placer deposits or black sands have been concentrated by the natural processes of waves and currents. Investigations on the importance of beach erosion to grain-sorting processes have been documented in India (RAO, 1957), on Oregon beaches (KOMAR and WANG, 1984; LI and KOMAR, 1992), and in Egypt (FRIHY and KOMAR, 1991). With respect to the grain-sorting processes, waves and currents selectively sort and concentrate mineral grains according to their sizes, densities, and shapes (KOMAR, 1989). The processes of size-density sorting usually occur in along-coast and cross-shore directions. Wave swash on a beach may selectively concentrate fine-grained dense minerals, separating them from lighter coarse-grained minerals.

Extensive deposits of black sand are found on the Mediterranean beaches adjacent to the mouths of the Rosetta and Damietta promontories of the Nile Delta. These promontories of higher heavy mineral contents coincide with sites of intensive coastal erosion. FRIHY and KOMAR (1991) have established significant delta-wide variations in beach-sand mineralogy that correspond to patterns of shoreline erosion *versus* accretion. In their study, they have not quantitatively related heavy minerals to the annual rates of shoreline changes. Long-term shoreline changes along the Rosetta promontory based on historical and aerial photographs have been evaluated by several authors.

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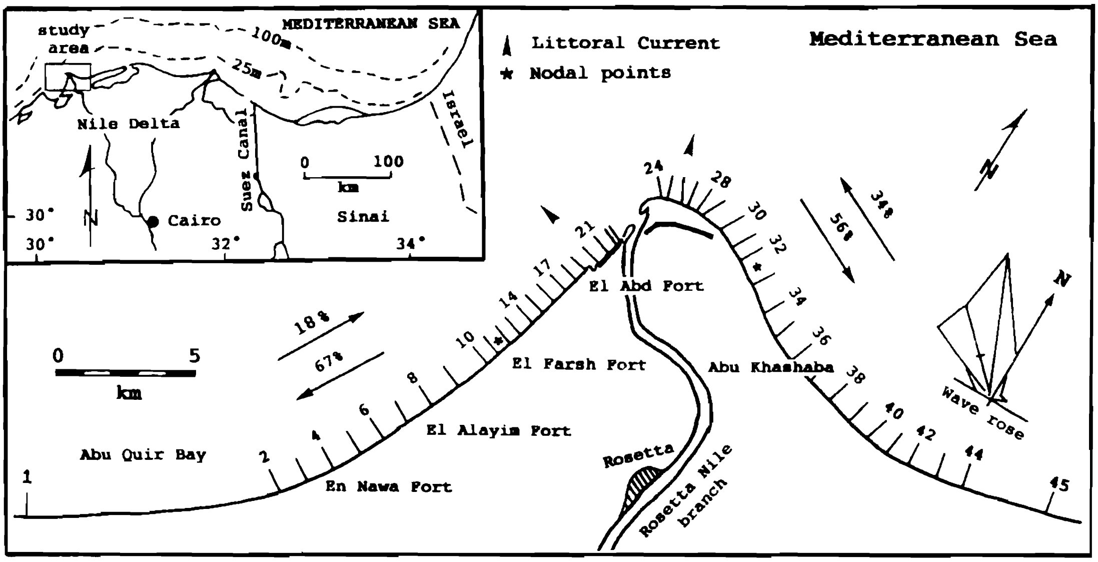

Figure 1. Map of the Rosetta promontory in the northwestern Nile Delta of Egypt. Shown are the positions of the 45 beach profile lines, and the predominant directions of waves (after NAFAA *et al.*, 1991) and littoral currents (after ABDDELA, 1987). Beach samples for heavy mineral analysis were selected at profile numbers 1, 2, 4, 6, 8, 10, 14, 18, 23, 24, 28, 32, 34, 36, 38, 40, 42, 44, and 45.

However, to date, there has been no published information regarding delta-wide shoreline changes recorded from beach profiles at the Rosetta promontory. The dramatic erosion along the delta coast has generated considerable interest and research that has resulted in a number of reports and publications. Volumetric changes in beach profiles (MANOHAR, 1976; LOTFY and FRIHY, 1993), shoreline changes as recorded in historic maps (UNDP/UNESCO, 1978; FANOS *et al.*, 1991; FRIHY and KHAFAGY, 1991), and analyses of satellite images and aerial photographs (KLEMAS and ABDEL KADER, 1982; FRIHY, 1988; SMITH and ABDEL KADER, 1988; BLODGET *et al.*, 1991; FRIHY *et al.*, 1991).

The Rosetta promontory is an excellent area for studying heavy minerals *versus* beach changes since it displays both erosion and accretion. Our investigations have involved four approaches: (1) estimation of annual rates of erosion and accretion from measurements of beach profiles along the promontory coast, (2) detection of probable nodal points between zones of erosion and accretion, and thereby to determine patterns of sediment transport convergences and divergences, (3) determination of textural and mineralogical characteristics of beach samples with the objective of understanding the processes of selective sorting as the sand is transported alongshore away from the Rosetta Nile mouth, and (4) the relationship between heavy mineral suits and mean grain size of beach samples and the estimated annual rates of beach erosion and accretion along the promontory coast.

STUDY AREA

The Rosetta Nile branch is one of the two major distributaries of the Nile. The study area is located on the western part of the Nile delta, including the Rosetta promontory (Figure 1), and extends approximately along 46 km of the shoreline from 24.2 km and 21.6 km respectively from the southwest and east of the Rosetta river mouth. The shoreline consists of a sandy arcuate beach, smoothed without any natural or artificial groin or jetty interference. The modern Rosetta promontory has discharged sediment into the Mediterranean since about 7,000 years BP (SAID, 1981). This branch has developed the triangular headland Rosetta promontory trending north-northwest. Its mouth extends about 12 km into the Mediterranean Sea. The eastern side of the promontory is characterized by low-relief beach ridges and small isolated lagoons flooded by the sea in

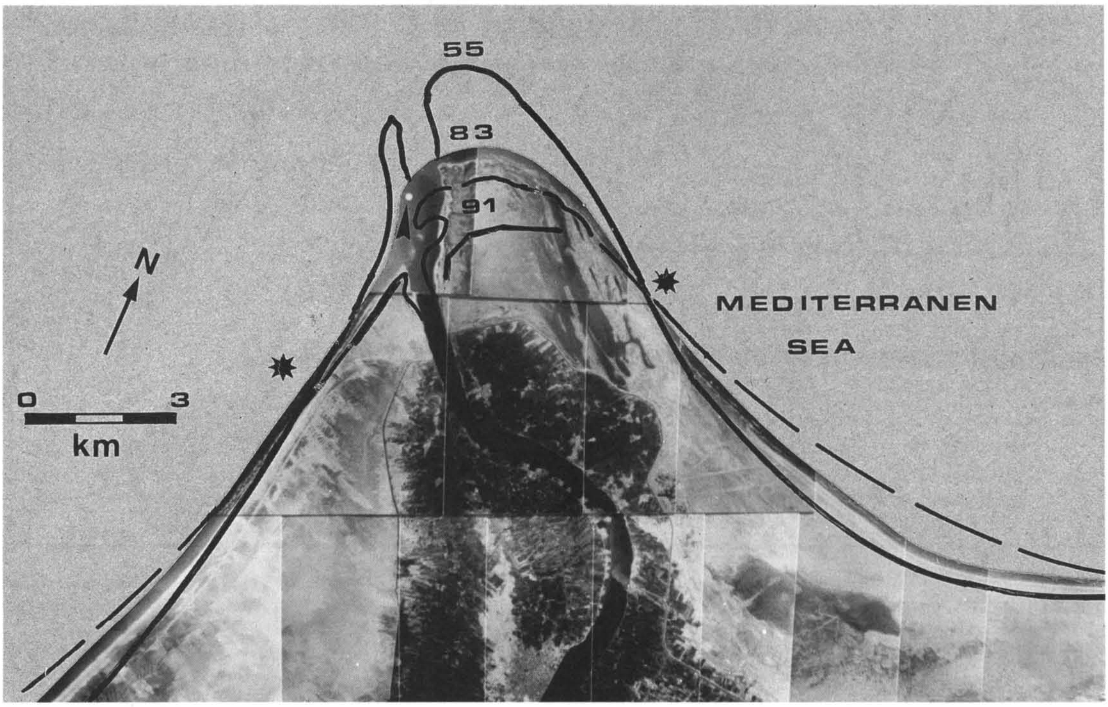

Figure 2. Aerial photograph of the Rosetta promontory taken in May 1983, with the 1955 and 1991 shoreline superimposed. The 1955 shoreline derived from aerial photography, while the 1991 from satellite image (image processing courtesy of Mamdouh Hatab). The Lighthouse as indicated by a small arrow head just north of the river mouth was built in 1954 at about 1.5 km inland. The severe erosion at the western part has isolated the Lighthouse 1.6 km offshore from the 1991 shoreline at about 5.5 m water depth. The asterisks indicate position of nodal points.

winter. Most of the cultivated land south of the backshore is low-lying, less than 1 m above mean sea level. The promontory is one of the most important areas for trade, agriculture and fishing activities in the region. In addition, the Rosetta Nile mouth suffers from a serious siltation problem resulting from the longshore and cross-shore sediment transport and a reduction in the river flow. This problem has progressed to the degree of shoaling of the Nile entrance causing navigation hazards for the fishing boats.

Earlier studies on coastal changes at the Rosetta promontory using historical maps reveal that the promontory advanced seaward by about 9 km between 1800 to 1900. The reversal to an erosion phase began about 1900 with a subsequent shoreline retreat rate on the order of −53 to −58 m/yr (FRIHY and KHAFAGY, 1991). The shoreline changes along the promontory between 1955, 1983 and 1991 are shown in Figure 2. The reversal from prograding to retrograding phase was generally in response to a combination of several factors: (1) Reduction in the Nile discharge and sediment load to the Rosetta mouth due to the construction of water control structures along the Nile. Six barrages and three dams were built on the main Nile and its two branches. Since the building of the High Aswan Dam in 1964, sediment discharge at the Nile promontories has reduced to near zero. Subsequently, the Nile promontories have been subjected to dramatic erosion. (2) A natural reduction of Nile floods resulting from climatic changes over east Africa. (3) Waves and currents continue to move sediment alongshore, resulting in a major reorientation of the coastline as some beaches erode while others accrete.

COASTAL PROCESSES

Wave records at Abu Quir Bay were analyzed by NAFAA *et al.* (1991). The wave action is seasonal with the severest winter storms approaching from the northwest and north-northwest, producing an eastward longshore sand transport. The small component of spring and summer waves coming from the northeast causes westerly sand transport. The average and maximum wave heights measured at Abu Quir Bay are 0.75 and 4 m, (NAFAA *et al.*, 1991). Wave refraction computed by QUELENNEC and MANOHAR (1977) show an area of extensive wave divergence located off the promontory tip that results in strong longshore gradients of wave heights and breaker angles, and therefore of sand transport. Their sediment transport (Q) calculations indicate a strong eastward and southwest transport from the tip of the promontory. Longshore currents have been measured by ABDDELA (1987) during 1983 at two locations, one in the east (profile P-26) and one in the west of the mouth (profile P-20). On the eastern side of the promontory, the current direction was from the west 56% of the time, and 34% from the east; while on the western side, currents were mostly from the north 67% of the time (Figure 1). The maximum measured speed ranged from 50 to 67 cm/sec. The tides along this coast are semidurnal with a tidal range of 25 to 30 cm (MANOHAR, 1981).

BEACH PROFILING, SAMPLE COLLECTION AND ANALYSES

Repeated series of annual and semi-annual beach profiles have been surveyed from 1971 to 1992 along the Rosetta promontory, extending cross shore to about 6 m water depth from a fixed land baseline. Profile lines are perpendicular to the coastline and are spaced 0.5 to 9 km apart. The leveling (above MSL) and sounding (below MSL) data are adjusted to local measured MSL datum using fixed bench marks of known elevation located behind the beach area. Positions of these profiles are shown in Figure 1. A detailed description of the field survey program has been given by FANOS *et al.* (1991). To estimate the change in beach width, the data base of this study focuses only on the landward part of the beach-profile survey. This includes the beach width in meters measured between the shoreline at MSL and the baseline over successive surveys. Data from each profile are arranged in a one-dimensional array, where Y is the beach width in meters (▲S), and X is the date of the survey in years. These data are used to calculate the annual rate of shoreline change (R) in m/yr employing least squares techniques (Figure 3).

An attempt is also made to evaluate the relationship between the grain sorting, heavy mineral concentrations and assemblages, and transport directions. In total, 45 samples were collected from the beach face of the investigated profiles during the summer of 1991. Samples were obtained by pressing a plastic sample jar into the surface of the beach sand. This method gave a uniform sample depth of about five centimeters. In the laboratory, the bulk samples were sieved at half phi intervals to determine the texture of the total sample using standard sieves. The mean grain size was calculated from grain size data using the formula of FOLK and WARD (1957). Of the 45 samples, 19 were subjected to heavy mineral analysis. Grain size fractions rich in heavy minerals (3 and 4ϕ) were subjected to heavy mineral separation using sodium polytungstate (density 2.9 gm/cm^3) (CALLAHAN, 1987). Heavy mineral concentrations (grams of heavies/100 grams of total sample) were calculated. About 400 grains were identified and counted under a polarized microscope using standard petrographic techniques. The number percentage obtained by point counting was converted to a weight percentage according to RUBEY (1933) and YOUNG (1966), so that mineralogy of the 3–4ϕ size fractions were obtained for each sample.

RESULTS AND DISCUSSION

Annual Rates of Beach Changes

Linear regression was applied separately to the time series, 10 to 21 year sets belonging to each profile line (beach width (▲S) *versus* years). Time series of shoreline positions for twelve representative profiles are graphically presented in Figure 3. Shoreline fluctuations of some time series have varied greatly from one time period to another; *i.e.*, they are episodic rather than continuous. These cyclic changes are common on sandy beaches and are associated with episodic events such as storms or sea level rise (DOLAN *et al.*, 1991). After estimating the annual rate of shoreline retreat or advance at each profile line, these values are listed in Table 1 and geographically distributed from east to southwest along the shore (Figure 4). Nodal points, convergences and divergences can be positioned at the change or areas of transport from erosion to deposition or *vice versa* that result from the orientation changes of the shoreline.

The Rosetta promontory segments the northwestern delta coast into two sub-cells: the Abu

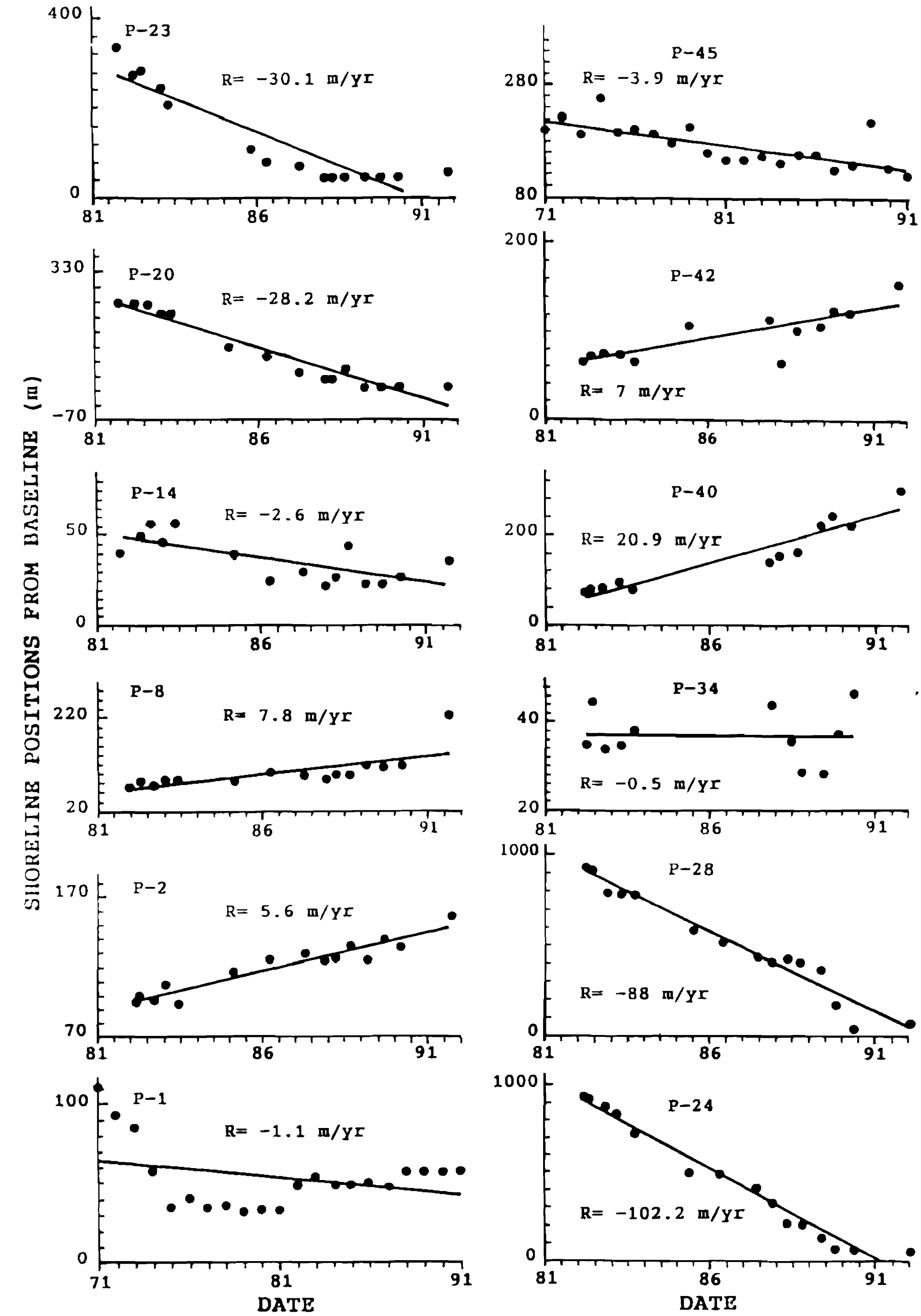

Figure 3. Time series of changing positions of shorelines for 12 representative profile lines along the Rosetta promontory cost, the locations being given in Figure 1. The annual rate of shoreline change (R) is indicated in each graph. The plotted regression line is the least-squares fit of the shoreline position data measured over the time period between 1971 to 1992. The base line is indicated by zero on the horizontal axis.

Quir sub-cell and the Rosetta sub-cell. These are parts of four sub-cells defined by FRIHY *et al.* (1991) based on multiple lines of evidence for sand movement along the Nile delta (longshore variations in beach sand mineralogy, blockage by jetties and groins, channel deflections and shoreline orientation). According to their analysis, the Abu Quir sub-cell begins from the Rosetta mouth and comprises the entire Abu Quir Bay, while the Rosetta sub-cell starts from the mouth to the east to about 20 km along the Abu Khashaba shore. The eastern most limit of Abu Quir Bay comprises the western flank of the Rosetta promontory and is a part of Abu Quir Bay sub-cell. The spacial distribution of shoreline change over the 10 to 21-year study period is shown in Figure 4B. A 7 km length of coast is eroding at an annual rate between −0.2 m/yr at profile P-12 in the southwest to −52.9 m/yr at profile P-21 in the north. The erosion is greatest at the tip, adjacent to the river mouth (−52.9 m/yr), progressively decreases alongshore to the southwest, then reverses to accretion at a nodal point between profiles P-11 and P-12, near El Farsh Fort, about 6.2 km southwest of the river mouth. This accretion occurs for about 9 km along Abu Quir Bay and has its maximum rate (9.9 m/yr) at profile P-9, then once again is followed by erosion to the southwest (−1.3 m/yr). The nodal points between erosion and accretion represent points of maximum longshore sediment transport. The alongshore patterns of erosion and accretion suggest that sand eroded from the tip is part of the accreted zone along Abu Khashaba beach in the east.

The eastern part of the Rosetta promontory is part of the Rosetta sub-cell. This littoral sub-cell encompasses the coastal zone along the eastern part of the Rosetta promontory from the river mouth to the end of Abu Khashaba beach, 20 km to the east. The regime of sediment transport in this zone is more or less similar to the Abu Quir shore with an exception of the transport direction. The first erosion segment, 8 km in length, represents the eastern flank of the Rosetta promontory. The erosion in this stretch of shoreline is extreme, being −102.2 m/yr at the eastern tip (profile P-24). This erosion decreases systematically with longshore distance, being reduced to −6.2 m/yr about 7 km from the river mouth. This erosion gives way to accretion further east to another nodal point approximately 8 km from the mouth between profiles P-32 and P-33. Similar to the shore of Abu Quir Bay, the Abu Khashaba accretion zone, 12 km shoreline length, is turned gradually to erosion in a nodal point between profiles P-44 and P-45, beyond which erosion continues for the remaining longshore distance. At this point, another littoral sub-cell (Burullus sub-cell) starts mainly covering the arcuate bulge of the central-delta region (FRIHY *et al.*, 1991). Two massive sea walls were constructed during 1989/1991 to the west and east of the Rosetta mouth to reduce the erosion impacts. However, these structures were built at inland positions, and the shoreline retreat has only recently (1992) reached the end of the eastern sea wall; therefore, their presence has not affected our measurements of shoreline erosion determined from beach profiles.

Alongshore Grain Sorting of Beach Sand

The grain size analyses performed on subsamples of unseparated light and heavy minerals provide the textures of the total samples. Table 1 lists rates of shoreline changes, grain sizes and heavy mineral percentages of the beach samples. The mean grain size for the beach samples are plotted in Figure 4C as a function of the longshore distance from the Rosetta mouth. The mean grain sizes range from 1.84ϕ (2.79 mm) to 3.1ϕ (1.17 mm), the average being 2.44ϕ (1.84 mm). The alongshore variations in the mean grain sizes show that the beach sand is finer close to the Rosetta mouth and become coarser both to the east and southwest along accreting stretches of coast. The coarsest sand occurs at about 14 to 18 km away from the river mouth. A similar pattern was found along the Columbia River mouth (BALLARD, 1964; LI and KOMAR, 1992) and in Abu Quir Bay of Egypt (EL BOUSEILY and FRIHY, 1984).

Heavy mineral percentages (Table 1) are plotted along the shore in Figure 4D. The heavy minerals are highly concentrated in beach sands close to the river (80 to 92%) where maximum erosion occurs and decreases dramatically with distance and annual values of erosion and accretion. To the east and southwest of the promontory flanks, the heavy mineral concentrations are 7 to 50%, where erosion is reversed to accretion. The decrease in percentage of the heavy minerals with longshore distance from the Rosetta mouth results from their becoming progressively diluted by the light minerals of quartz and feldspars. The sand on the beaches close to the river mouth is almost totally black, indicating high concentrations of heavy minerals. These beaches also exhibit erosional features such as erosional cliffs and

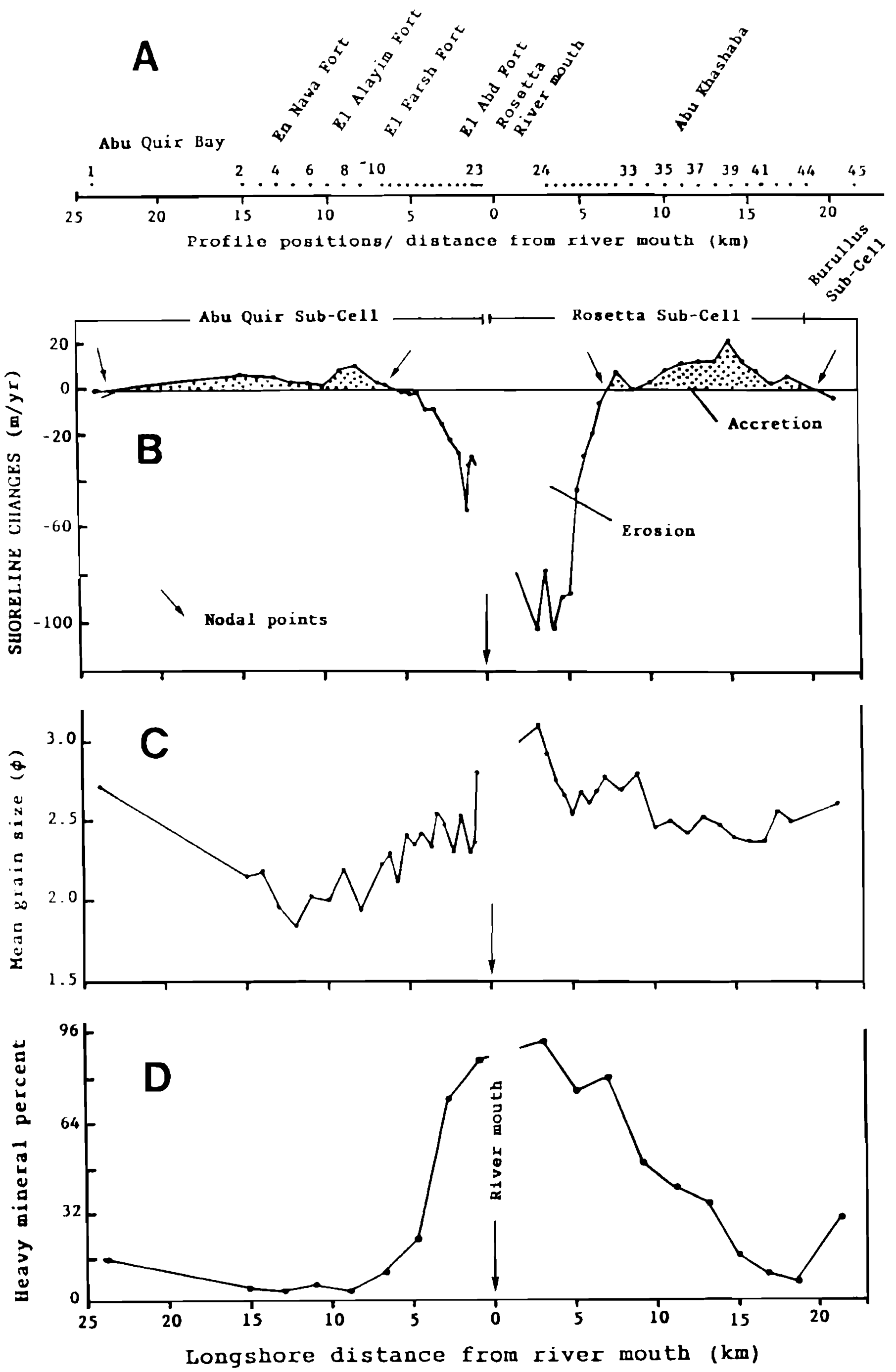

Figure 4. (A) The location of the beach profiles along the shoreline of the Rosetta promontory and coastal sites discussed in this study. The distances being relative to the mouth of the Rosetta River. (B) The alongshore erosion and accretion trends and the Nile delta sub-cells. (C) Longshore variations in mean grain size. (D) Longshore variations in heavy mineral concentrations.

Table 1. *Rate of shoreline changes, mean grain size and heavy mineral percentage for the 19 beach samples collected along the Rosetta promontory. Positions of beach sample sites are shown in Figure 1.*

Prof. No.	Cum. (km)	Rate (m/yr)	Opa.	Aug.	Hor.	Epi.	Gar.	Mz (ϕ)	CH%
P-1	24.2 SW	1.3	42.59	24.65	28.00	3.19	0.62	2.71	15.00
P-2	15.2 SW	5.6	30.92	25.43	38.02	4.17	1.45	2.15	5.00
P-3	14.2 SW	5.2	—	—	—	—	—	2.18	—
P-4	13.2 SW	4.5	22.78	21.65	47.94	5.87	1.79	1.95	3.90
P-5	12.2 SW	2.6	—	—	—	—	—	1.84	—
P-6	11.2 SW	2.2	17.54	19.31	55.38	6.85	0.92	2.02	5.70
P-7	10.2 SW	1.3	—	—	—	—	—	2.00	—
P-8	9.2 SW	7.8	16.22	25.22	52.30	5.08	1.18	2.20	3.90
P-9	8.2 SW	9.9	—	—	—	—	—	1.94	—
P-10	6.9 SW	2.7	37.70	25.63	27.68	5.58	3.40	2.22	10.70
P-11	6.4 SW	1.5	—	—	—	—	—	2.30	—
P-12	5.9 SW	0.2	—	—	—	—	—	2.11	—
P-13	5.4 SW	−1.6	—	—	—	—	—	2.41	—
P-14	4.9 SW	−2.6	41.05	20.17	29.85	5.03	3.90	2.35	22.50
P-15	4.4 SW	1.4	—		—	—	—	2.43	—
P-16	3.9 SW	−9.0	—	—	—	—	—	2.35	—
P-17	3.4 SW	9.3	—	—	—	—	—	2.55	—
P-18	2.9 SW	15.7	57.53	20.39	11.19	6.89	4.00	2.47	72.90
P-19	2.4 SW	−22.6	—	—	—	—	—	2.30	—
P-20	1.9 SW	−28.2	—	—	—	—	—	2.53	—
P-21	1.4 SW	−52.9	—	—	—	—	—	2.30	—
P-22	1.2 SW	32.9	—	—		—	—	2.37	—
P-23	1.0 SW	−30.1	83.35	5.02	6.30	2.26	3.06	2.80	86.00
P-24	3.2 E	102.2	90.62	1.81	3.02	0.80	3.75	3.10	92.40
P-25	3.7 E	−77.5	—	—	—	—	—	2.93	—
P-26	4.2 E	−102.6	—	—	—	-	—	2.75	—
P-27	4.7 E	−89.7	—	—	—	—	—	2.67	—
P-28	5.2 E	88.0	88.52	2.83	3.75	0.89	4.01	2.54	75.00
P-29	5.7 E	−44.8	—	—	—	—	—	2.68	—
P-30	6.2 E	29.9	—	—	—	—	—	2.61	—
P-31	6.7 E	−19.7	-	—	—	—	—	2.69	—
P-32	7.2 E	−6.2	85.67	3.36	6.07	2.04	2.85	2.78	80.30
P-33	8.2 E	6.4	—	—	—	—	—	2.69	—
P-34	9.2 E	−0.5	81.91	6.34	7.93	1.97	1.85	2.80	50.00
P-35	10.2 E	2.1	—	—	—	—	—	2.46	—
P-36	11.2 E	7.6	77.93	7.41	10.34	1.94	2.38	2.50	40.80
P-37	12.2 E	10.8	—	—	—	—	—	2.42	—
P-38	13.2 E	12.0	24.68	31.39	35.68	6.81	1.44	2.52	35.10
P-39	14.2 E	12.0	—	—	—	—	—	2.47	—
P-40	15.1 E	20.9	20.56	31.24	42.65	4.10	1.46	2.40	16.60
P-41	16.0 E	11.4	—	-	—	—	—	2.37	—
P-42	16.9 E	7.0	16.74	30.36	46.58	5.95	0.85	2.37	9.90
P-43	17.8 E	1.7	—	—	—	—	—	2.55	—
P-44	18.7 E	5.2	20.97	29.46	42.92	6.43	0.23	2.48	7.00
P-45	21.6 E	3.7	25.13	34.17	37.13	2.83	0.74	2.60	30.10
Average			46.44	19.26	28.04	4.14	2.10	2.44	34.88
Standard deviation			28.67	11.13	18.15	2.10	1.28	0.27	31.50

Cum. = cumulative distance in km, east or southwest from the mouth of the Rosetta branch, Rate (m/yr) = Annual rate of erosion (−ve) and accretion (+ve), Opa. = opaques, Aug. = augite, Hor. = hornblende, Epi. = epidote, Gar. = garnet, Mz = mean grain size (ϕ), CH% = heavy mineral percentage.

overwash. Away from the mouth, the beach sand becomes markedly lighter in color, indicating a progressive decrease in heavy mineral content, and/or increase in tan-colored sand (quartz, feldspar, mica and shell fragments).

Figure 5 shows plots of the longshore variation in the weight percentages of the principal heavy minerals along the promontory beach. Two heavy mineral groups are found: one group that is associated with the high-density minerals (4 to 5

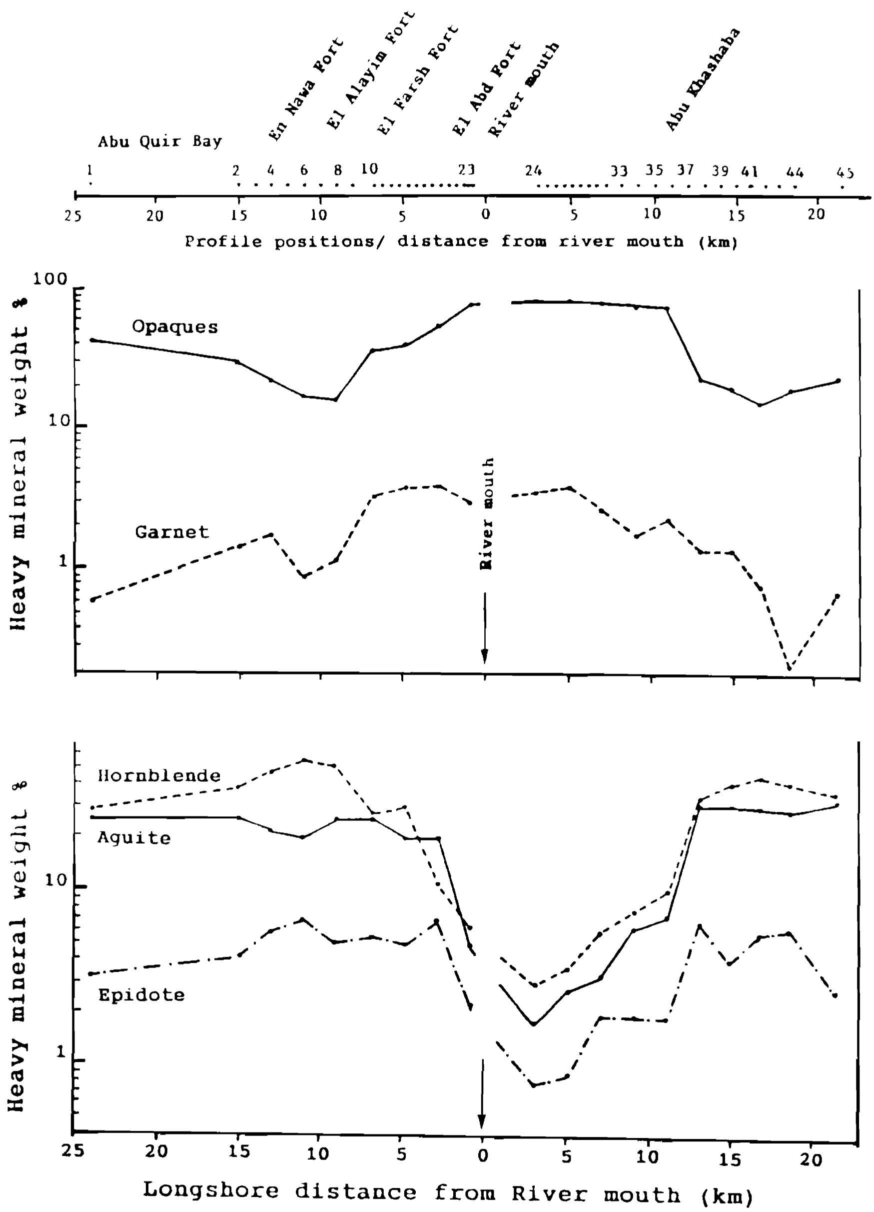

Figure 5. Alongshore variations in dominant heavy minerals within the beach samples.

gm/cm^3) and a second group with lower density minerals (3.2 to 3.45 gm/cm^3). The first group, represented by opaques and garnet, systematically decrease with distance from the river mouth, have a low concentration near the nodal points close to the accreted stretches, and then increase slightly at a point of erosion east of Abu Khashaba and southwest of En Nawa Fort (Figure 5). The longshore variations of this group are much the same as found for the total heavy-mineral group. The second group (augite, hornblende and epidote), the least dense heavy minerals, increase in the longshore direction to the east and southwest along accreted stretches. This increase continues along the eastern and south-western flanks until 12 and 16 km from the mouth, respectively, where there is a slight reduction. The trend of this group is the inverse of that for the first group. Accordingly within the heavy mineral assemblage, the opaques and garnet are the finest grained and most dense; hornblende is the coarsest grained and least dense. This is confirmed from our petrographic observations of individual heavy minerals which indicate that opaques and garnet are markedly finer in grain sizes than those augite, hornblende and epidote.

The plot of Figures 6A and D shows a reasonable correlation between the long-term rates of erosion or accretion established by our analyses of beach-profile time series, and the concentration of heavies, heavy mineral species and mean grain sizes of the beach sands. The greater the rate of erosion, the higher the concentration of heavy minerals and the finer the mean grain size of the sand. This relation demonstrates that the finest grains are concentrated in the highly eroded areas, while the coarsest grains are associated with accreted stretches. As expected, the greater the rate of shoreline erosion, the more concentrated the first mineral group (garnet and opaques) (Figure 6C). The second group (augite, hornblende, epidote) is more concentrated with increasing accretion rate (Figure 6D).

The importance of beach erosion to grain-sorting processes has been documented on other coasts; in India (RAO, 1957) and on Oregon beaches (KOMAR and WANG, 1984; LI and KOMAR, 1992). Along Abu Quir Bay, in the western part of the Nile delta, FRIHY and KOMAR (1991) have examined the grain-sorting pattern. Beaches in areas of erosion become concentrated in opaques, zircon, rutile, and garnet, while lower-density hornblende as well as light minerals are deposited in the accreting beaches. STANLEY (1989) has also used heavy mineral content of beach and shelf sands between the Nile delta and Israel to determine transport paths. His approach differs from our study in that he used ratios involving the percentages of pyroxenes, amphiboles and epidote in the sand samples, a choice of minerals that would not show the density-related selective-sorting patterns.

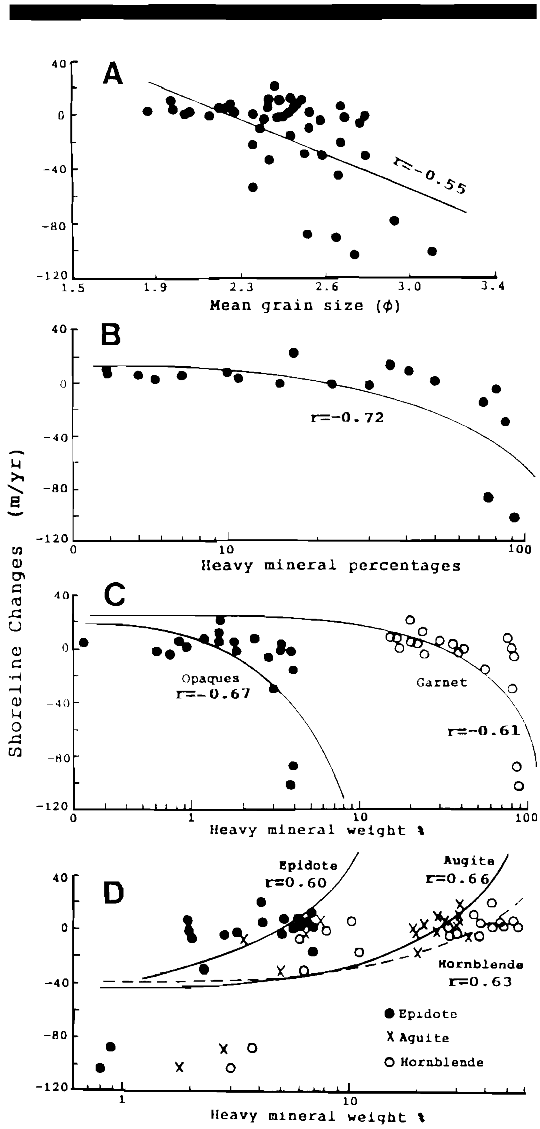

Figure 6. Relationships between mean grain size, heavy mineral concentration, dominant minerals and rates of shoreline changes (erosion and accretion). The regression lines and correlation coefficient values (r) are indicated in each graph.

Alongshore Sediment Transport

In this study, the sediment transport regime can be inferred from the established erosion and accretion pattern (Figure 4B). The pattern at the western zone along Abu Quir Bay is more or less similar to that along Abu Khashaba shore with the exception of the transport direction. Sand eroded from the shoreline adjacent to the mouth is carried southwest along the shoreline of the Abu Quir Bay and also eastward along Abu Khashaba shore. The net littoral sand transport is to the southwest along the western flank of the promontory and to the east along the eastern side. The established pattern of erosion and accretion reflect the existence of the Rosetta sub-cell at the western delta coast as identified by ORLOVA and ZENKOVICH (1974) and FRIHY *et al.* (1991). According to their analysis, the Abu Quir sub-cell begins from the river mouth to Abu Quir headland and the Rosetta sub-cell starts from the mouth to the east, to about 12 km along Abu Khashaba-Burullus coast. In this sub-cell, sand eroded from the promontory is transported to the east and west, resulting in shoreline accretion. This pattern of longshore transport corresponds to the predominant wave direction from the northwest and north-northwest measured by NAFAA *et al.* (1990) and the longshore current ABDDELA (1987). The transport pattern of erosion *versus* accretion revealed by analyses of profile time series is reflected on the pattern of the established selective grain sorting along the Rosetta promontory.

SUMMARY AND CONCLUSIONS

This study evaluates quantitatively the temporal and spatial shoreline position changes along the northwestern Nile delta of Egypt. The data consist of annual beach surveys spanning the years between 1971 to 1992 at 45 beach profile lines along 46 km of shoreline on the Rosetta promontory. These data provide an extensive data-base regarding the regional variations in shoreline positions. The shoreline history can be related to the interaction between changing shoreline, bottom topography and the direction of the incoming waves. This interaction results in a series of converging and diverging transport separated by nodal points. The longshore distributions of annual rates of shoreline change demonstrate that higher erosion occurs adjacent to the Rosetta mouth (−52.9 to −102.2 m/yr). This erosion progressively decreases both to the southwest and to the east until transport nodal points at El Farsh Fort and west of Abu Khashaba, respectively, are reached in which this erosion is replaced by accretion. Further downcoast, this accretion is reversed again to erosion. A major transport reversal occurs in front of the Rosetta mouth creating a divergent longshore sediment transport nodal zone; *i.e.*, a place where sand moves alongshore to both the east and southwest away from the mouth.

The largest retreat was calculated based on surveys prior to the recent (1991) completion of two sea walls at the Rosetta promontory. These sea walls were constructed to stabilize the tip of the Rosetta promontory and minimize the shore erosion. Recent studies by the CRI (Coastal Research Institute, Alexandria) have indicated that erosion of the promontory tip has progressively declined through the year of 1993.

Analyses of beach-sand composition and grain sizes at the profile lines have established that there is a general correspondence between sediment characteristics and the pattern of beach erosion *versus* accretion. The sediments supplied by the Rosetta Nile are subsequently sorted by grain size as well as density. The eroded areas are associated with finer-grained beach sands rich in heavy minerals (opaques and garnet)—the greater the rate of erosion the finer the beach sand and the richer its total heavy-mineral content. Inversely, the areas of shoreline accretion are characterized by coarser sands that are poor in heavy minerals (augite, hornblende and epidote) and rich in light minerals. This suggests that longshore transport preferentially removes the lower-density hornblende, augite, epidote as well as the light minerals (quartz and feldespars), and these minerals are carried alongshore to areas of accreting shorelines. The longshore variations in sand mineralogies and grain sizes confirm the eastward and southward littoral transport associated with the values of shoreline erosion and accretion. These variations are also found to be in agreement with the pattern of the wave refraction and sediment transport direction computed by QUELENNEC and MANOHAR (1977) and the predominant direction of littoral currents measured by ABDDELLA (1987). This study established that individual minerals existing in beach sands can serve as natural tracers of sand dispersal entering the study area from the Rosetta mouth. The identified erosion and accretion sands and their textures and mineral attributes serve to distinguish geographic boundaries of coastal sub-cells in this area. Moreover, the rate of shoreline change is one of the most important measurements used by coastal scientists, engineers, and coastal management planners to indicate the dynamics and hazards of the coast.

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