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Beach and Nearshore Features Along the Dissipative Coastline of the Nile Delta, Egypt

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ABSTRACT

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Rhythmic beach and nearshore features along the Nile Delta coast are investigated from aerial photographs, beach profiles and field observations. Beach cusps and underwater sand bars of parallel and crescentic types, typical of tideless seas, are delineated. Aerial photographic analysis and field observations show that many beaches west of Abu Quir headland, contained long crescentic bar systems. In contrast, parallel longshore bars exist along the delta extending from east of Abu Quir to Port Said.

The parallel bar systems along the Nile Delta are generated by the dominant eastward longshore current and the associated littoral drift. The crescentic bars west of Abu Quir headland at Alexandria are associated with rip currents and negligible littoral drift. Application of the surf-scaling parameter (ϵ) indicates a fully dissipative state for the Nile Delta coast and moderate dissipation west of Abu Quir. The surf-scaling analysis and the configuration of the beaches suggested that the study area can be generally divided into two morphodynamic zones. The first zone, the delta coast has a gentle slope varying from 1:50 to 1:100, a smooth wide beach face mainly composed of quartz sand discharged from the Nile and characterized by parallel bars. The beach sand is fine to medium, mainly derived from the Nile River. The second zone is located west of the delta, along the Alexandria waterfront and the beaches further west. This zone is characterized by a relatively steep slope of 1:30, with pocket and embayed shorelines composed of biogenic sand with rocky shoals except for the western part which is of uniform alignment, with medium to coarse oolitic carbonate sand beaches dominated by crescentic bars. The oolitic grains are derived from the adjacent Pleistocene limestone ridges which run parallel to the western coast of Alexandria.

ADDITIONAL KEY WORDS: *Rhythmic beach, crescentic bars, parallel longshore bars, dissipative beaches*

INTRODUCTION

Beaches have been classified into two extreme (and opposite) states: the dissipative state and reflective state (WRIGHT, 1982; WRIGHT *et al.*, 1982; WRIGHT and SHORT, 1983 and 1984). Between these two extremes are four intermediate states, each of which possesses both dissipative and reflective elements. The dissipative state is equivalent to the 'storm' or 'winter' profile, while the reflective state is equivalent to the accreted 'summer' profile.

Dissipative and reflective beaches differ in the type of wave breaking, gradient of beach face, grain size of beach material, width of surf zone, and in the nearshore circulation. On dissipative beaches, waves break by spilling and cross a wide surf zone which has a fairly uniform and gentle slope with only subtle longshore bars. On a fully reflective beach, waves break by plunging or surging up the beach or they collapse over the step. The surf zone is narrow so that breaking is immediately followed by intense wave swash.

Published information on nearshore bars and rhythmic features along the Egyptian coast are scarce. The only previous study examining sand bars was carried out by MANOHAR (1979) on the Nile Delta. He described three longshore bars. The bar nearest to the shore is the break-point bar in 1 to 2 m water depth. The outer seaward bars are due to storms, one existing in 3 to 4 m depth and the other in 5 to 6 m depth. The inner breaker zone bar is mobile and shifts landward during summer accretional processes, joining the beach face. The two outer bars are permanent features, adjusting back and forth only slightly, consistent with the energy level of the wave climate.

On the Mediteranean coast of Israel, crescentic sand bars have been documented by STRIEM (1974), EITMAN *et al.* (1978), GOLDSMITH *et al.* (1982) and BOWMAN and GOLDSMITH (1983). CLOS-ARCEDUC (1962) reported crescentic bars

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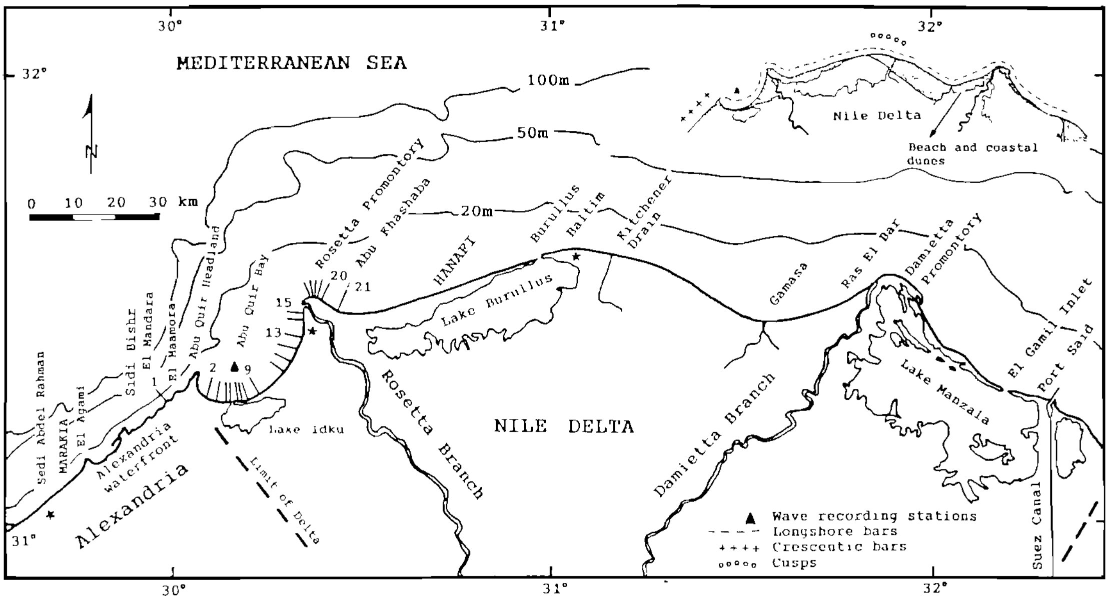

Figure 1. Study area showing the location of the wave recording station, the positions of the identified bars and rhythmic shorelines and beach profiles used in this study. Asterisks denote positions of photographs cited in the text.

along the Mediterranean coast of Algeria. The objective of this paper is to identify beach and surf zone features and their relation to the morphodynamic state along the Mediterranean coast of Egypt, including the Nile Delta.

STUDY AREA

The study area is located along the Mediterranean coast of Egypt extending along some 300 km from Sedi Abdel Rahman, 20 km west of Alexandria, to Port Said in the east (Figure 1). The entire shoreline of the delta from east of Alexandria at Abu Quir to Port Said is typically a smoothly wide arcuate coast, and the beach and backshore are composed of quartz sand. The beach sands of the Nile Delta are mostly fine grained sand (0.13–0.25 mm) with some local medium sand (0.25–0.5 mm) (El Fishawi *et al.*, 1976) and composed of quartz and feldspars with smaller amounts of heavy minerals and shell fragments. The beach sand is poor in carbonate content, being 1–3%. The shoreline is interrupted by the three main Nile promontories at Rosetta, Burullus and Damietta (Figure 1). The delta beach and its contiguous coastal flat are backed by coastal dunes or by the three large lagoons (from west to east: Idku, Burullus and Manzala) (Figure 1). Waves and currents associated with the east Mediterranean gyre are the principal driving forces that transport sediment to the east along the delta (Inman and Jenkins, 1984; Frihy *et al.*, 1991). Farther to the west, the rocky headland of Abu Quir forms the western limit of the delta.

The beach of Alexandria west of Abu Quir headland (Figure 1) consists of pocket and embayed beaches, except the newer developed part west of El Agami which is a straight wide beach. In general, beach material is composed of biogenic and oolitic sediments ranging in diameter from 0.13–1.6 mm, *i.e.*, fine to very coarse sand (El Wakeel and El Sayed, 1978). The beach sediments are derived from the eosion of the sandy limestone ridges that occur in the coastal zone. The long-term erosion rate at Alexandria is fairly small, on the order of 20 cm/year (El Wakeel and El Sayed, 1978), while erosion has exceeded 50 m/yr along the delta coast (Inman and Jenkins, 1984; Frihy *et al.*, 1991).

METHODS AND ANALYSIS

The present study is based on the analysis of two sets of vertical photo mosaics taken in 1955 (black and white) and 1983 (color), scaling 1:20,000 and 1:25,000 respectively. The study also includes field observations, analyses of beach profiles, and measured wave characteristics.

Available wave data for 1986 were recorded using the Cassette Acquisition System (CAS). A recording wave station is located off the Nile Delta at Abu Quir, situated about 18 km from shore at 6 m below mean water level and 11.5 m above the sea bed (Figure 1). The wave data are recorded 4 times per day, every 6 hours, for 34 minutes each record. The data are recorded on cassettes and analyzed by computer to obtain significant wave height (Hs), mean wave period (T) and wave direction (θ). These data are used in the application of surf-scaling parameter (ϵ) to determine the morphodynamic state of the delta coast.

WRIGHT *et al.* (1979) have established that the extremes in the beach state, dissipative beaches versus reflective, depend on a reflectivity or surf-scaling parameter:

$$\epsilon = a_i \omega_i^2 / g \tan^2 \beta \qquad (1)$$

where:

- a_i = incident wave amplitude near the point of wave breaking,
- a_i = Hb/2,
- Hb = breaking wave height,
- ω_i = $2\pi/T$; T = wave period; g = acceleration of gravity, and
- β = inshore/foreshore slope.

GUZA and INMAN (1975) indicate that the beach will be strongly reflective when $\epsilon < 1$, whereas $1 < \epsilon < 2.5$ indicates strong reflection but some dissipation, while complete dissipation occurs for $30 < \epsilon < 100$. A more comprehensive classification of dissipative and reflective beaches was given by WRIGHT and SHORT (1984) based on the surf-scaling parameter (ϵ).

The surf-scaling parameter is applied along the coastal zone from Alexandria to the Rosetta promontory, by first back refracting the measured significant wave height to calculate the wave height in deep water (Ho), then using the forward refraction techniques (DOBSON, 1967) to calculate the wave height at the breaking position. This resulted in the determination of monthly wave breaking heights for Alexandria and the delta coast for the year 1986. The results of monthly wave breaking and monthly wave periods were substituted in Equation (1) to calculate the surf-scaling parameter for prevailing waves arriving from NW. The surf-scaling parameter was computed for the inshore/foreshore slopes (β) of Alexandria (0.05–0.033) and the Nile Delta (0.01–0.02). The inshore/foreshore slopes were obtained from measured beach profiles.

RESULTS AND DISCUSSION

Along the western coast of the delta including the Alexandria waterfront, two sets of aerial photographs taken in 1955 and 1983 and ground field observations showed that many beaches contained long crescentic bar systems (Figure 2). They have been found at El Maamora (2 km long) and El Mandara beach embayment (0.4 km long) and extending along the entire beaches west of Alexandria water front from El Agami to Marakia, covering about 25 km of coastal length. In contrast, shore parallel submerged bars exist along the delta extending from Abu Quir to Port Said (Figure 3). "Mega-cusps" with a distance between the two horns of about 100 m have been observed during calm seasons of spring and summer along El Maamora and Sidi Bishr waterfront beaches.

According to HILMY (1951), the beaches of Alexandria form one geomorphological unit, and are shaped largely by terrestrial depositional agencies and wave action. Results and observations of this study indicate that there is a difference in the morphodynamic states between the coasts of Alexandria and the Nile Delta coast. This can be noticed from their bottom and coastal morphologies, shoreline orientations, slope gradients and sediment textures. The shoreline is generally undulated and interrupted by rocky headlands forming small embayments and pocket beaches. The offshore slopes are relatively steeper in Alexandria than the rest of the Nile coast (Figure 4). This is also evident from the width of the continental shelf off the Nile Delta and Alexandria (Figure 1). The shelf (defined by the 100-meter depth contour) is much wider off the delta coast (50–90 km) and substantially narrower in front of Alexandria (25–30 km). Along most of the delta coast, waves typically break at oblique angles, generating strong easterly currents, averaging 40 to 60 cm/sec (FANOS, 1986), whereas waves approach the Alexandria coast at small angles due to its shoreline orientation, which is trending SW (Figure 1). Thus, wave crests are parallel or nearly parallel to the shoreline, producing seaward-flowing rip currents. Rip currents have been observed visually along the Alexandria coast and the western part in particular, causing serious hazards to swimmers.

Moreover, the inshore and nearshore zones of

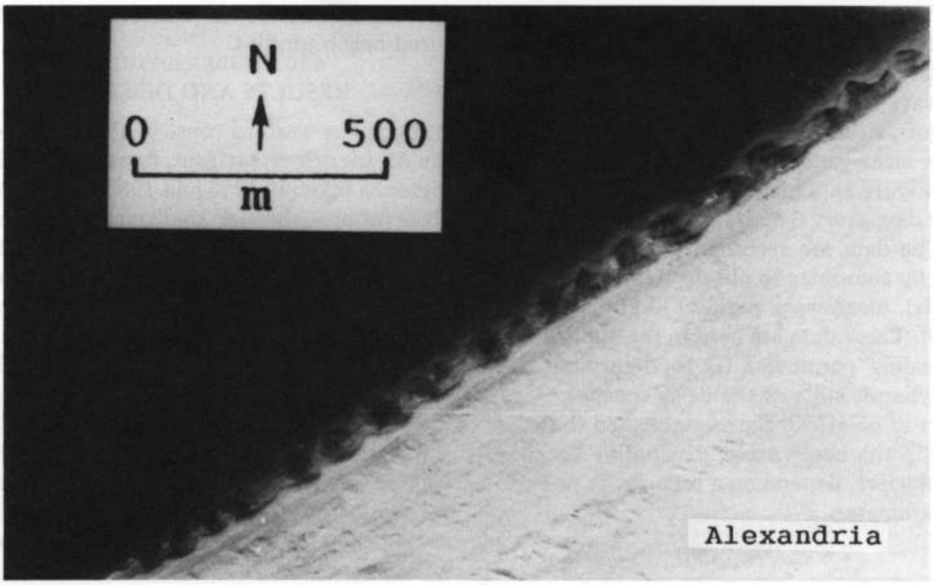

Figure 2. Vertical aerial photograph showing a well-developed crescentic bar system on the carbonate straight sand beach, 20 km west of Alexandria.

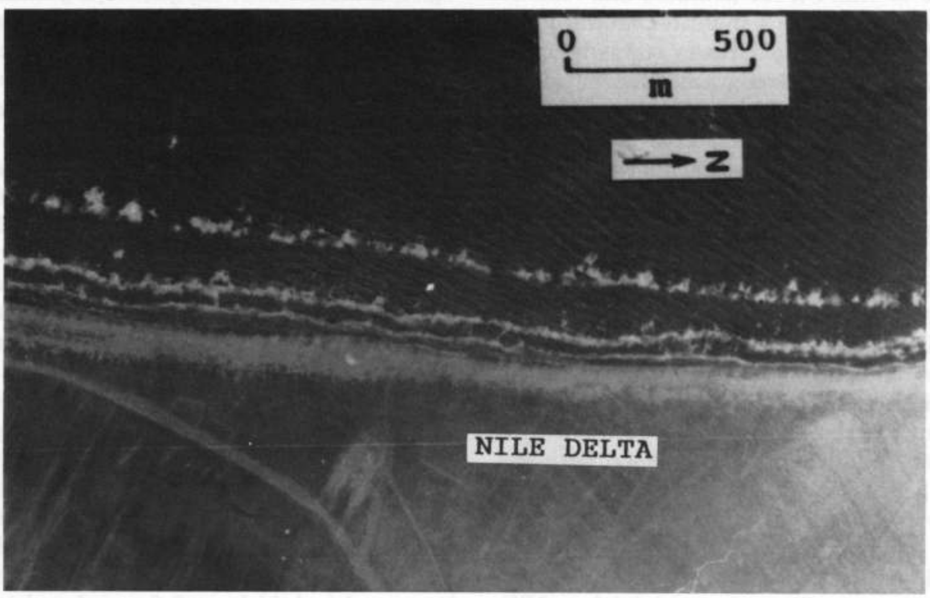

Figure 3. Vertical aerial photograph at the eastern side of Abu Quir Bay showing the three shore parallel bars as indicated by wave breaking. Note the three lines of wave breaking alignment to the shoreline.

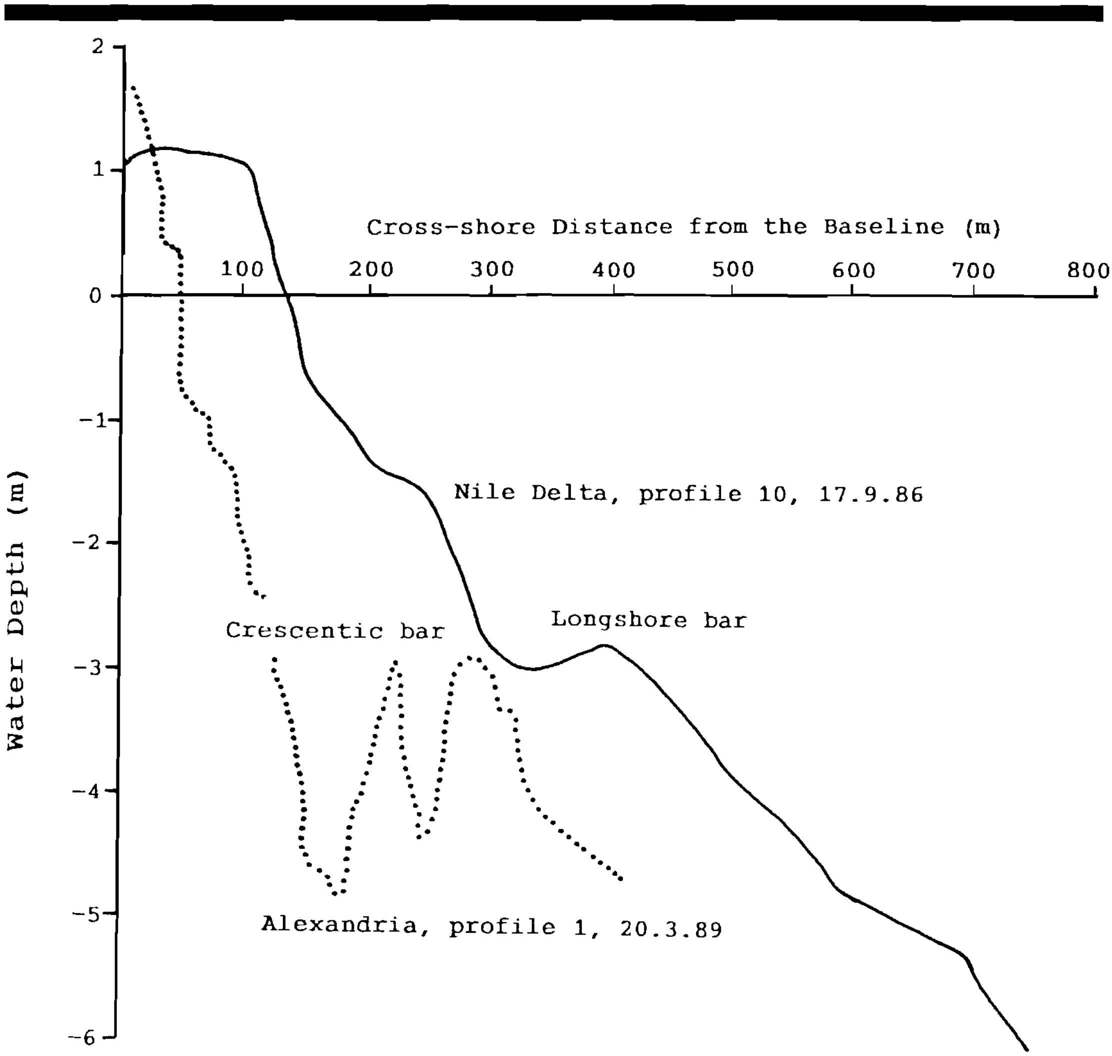

Figure 4. Beach profile configuration showing the different profile bars along profile lines; longshore bars at the Nile Delta and crescentic bar at Alexandria, see Figure 1 for profile locations.

Alexandria contain outcrops of emerged and submerged rocky islets aligning more or less parallel to the shoreline extending about 300 m into the sea. These rocks are mainly sandy limestone of Pleistocene formation and beachrock (El Sayed, 1988). Profile analysis carried out by the CRI (Coastal Research Institute) indicates that these rocks serve as wave energy dissipators in the lower parts of the active profiles causing westerly reversal in the sediment transport pattern and localized accretion and erosion. According to El Wakeel and El Sayed (1978), Alexandria beach is composed of biogenic fine to very coarse sand, varying from loose to fairly well indurated deposits of quartz, shell fragments, heavy minerals and oolitic grains. The carbonate content of the beach sand ranges from 22 to 41%. The beach sand along the Alexandria waterfront is derived primarily from the adjacent Pleistocene limestone ridges located along the western coast of Alexandria and the local rocky limestone outcrops. They are composed of oolitic and biogenic carbonate rocks (Hilmy, 1951; Anwar *et al.*, 1981; Stanley and Hamza, 1992).

The coastal area up to 100 km west of the Alexandria waterfront is presently being developed

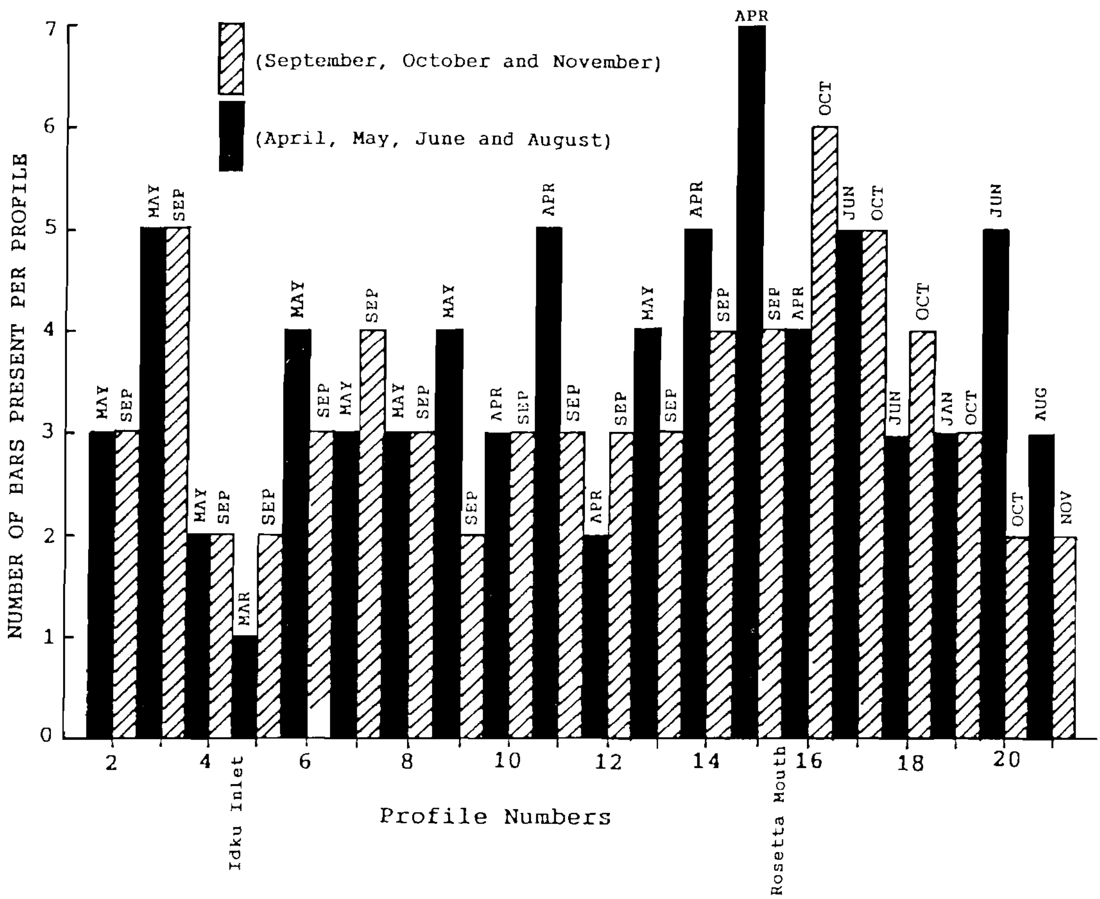

Figure 5. Number of underwater parallel type bars along Abu Quir coastal zone on the western part of the Nile Delta, established from beach profile data of 1986.

as a new resort beach. The beach is very wide with an almost straight alignment lacking irregular offshore topography. The beach is composed of oolitic carbonate sand with minor amounts of quartz grains. The carbonate content of the beach sand west of Alexandria varies between 44 and 94% (El Wakeel and El Sayed, 1978). This sand is derived from the oolitic and bioclastic sand forming a series of coastal beach-dune ridges along the shorelines to the west coast of Alexandria. (Shukri *et al.*, 1956; Butzer, 1960). The nearshore zone is characterized by crescentic sand bars extending from El Agami to 25 km to the west (Figure 2). The longshore distance between two horns is about 100 m and the maximum distance of the bars from the shoreline is about 125 m. These bars are similar to those documented at the Israeli coast by Striem (1974), Eitman *et al.* (1978), Goldsmith *et al.* (1982) and Bowman and Goldsmith (1983). As indicated from the erosion and accretion patterns resulting from the interruption of longshore sediment transport by engineering structures such as jetties and groins, the littoral drift along the west coast of Alexandria is very small as compared with the Nile Delta coast. The rate of sediment transport is presently calculated using fluorescent sand tracer at Alexandria, reaching 0.42×10^6 m^3/yr (El Fishawi, *personal communication*).

The delta coast from Abu Quir headland to Port Said exhibits longshore bars and rythmic beach features. The distance between the wave breakers of the inner, middle and outer bars and the shoreline as measured from aerial photographs and beach profile survey was found to be 25–50, 75–

Figure 6. Photograph taken from the top of the lighthouse (50 m above MSL) at Baltim beach showing mega-cusps on the Nile Delta dissipative beach. Note also the outer and inner wave breaking, indicating longshore bars.

150 and 225–450 m (Figure 4). The bars occur either singly or as a series in the nearshore zones (Figure 3). Their heights vary from 0.3 to 0.6 m. Figure 5 shows the number of parallel-type bars present in the measured beach profiles along the western part of the delta for two seasons in 1986. Since the Autumn activity is highly variable, while the Spring activity is basically steady, spring bars, formed during April, May, June and August, are much more frequent than Autumn bars (formed during September, October and November) which decrease considerably because of the less energetic waves.

Mega-cusp systems have been observed along the central part of the delta, in the area between 4 km east of Burullus inlet and the Kitchener drain (Figure 6). Approximately 20 well-developed mega-cusps were observed covering about 16 km in this area. The distance between two horns is about 100 to 150 m.

BARS AND WAVE CLIMATE

Since waves are the primary agent for bar development, the number of longshore bars present was correlated with significant wave heights. Based on an analysis of 20 beach profiles measured along the eastern part of Abu Quir Bay, bar crests were identified and counted through the Spring and Autumn of 1986. Descriptive wave statistics for the same year show mean wave height and wave period concentrated between 0.74 to 4.19 m and 5.6 to 10.7 sec, respectively. The monthly significant wave height (Hs) shows a consistent trend with wave period and wave breaking through 1986 (Figure 7). These three wave parameters are found to be in agreement with the monthly distribution of bar numbers in Figure 5. This indicates that bar presence was found to be closely associated with the Summer and Spring months of low and steady wave activities, and less frequent with the moderately fluctuating Autumn wave activity.

The calculated monthly surf-scaling parameter (ϵ) for the year 1986 was higher on the delta (101–627) and lower with narrow range at Alexandria (20–55) (Figure 8). On both beaches, waves broke by spilling and dissipated progressively as they crossed the wide surf zone and were very small upon reaching the beach face.

The results indicate that the beaches studied can be categorized in two morphodynamic zones with different magnitudes of dissipation. The beaches along the Nile Delta coast are fully dis-

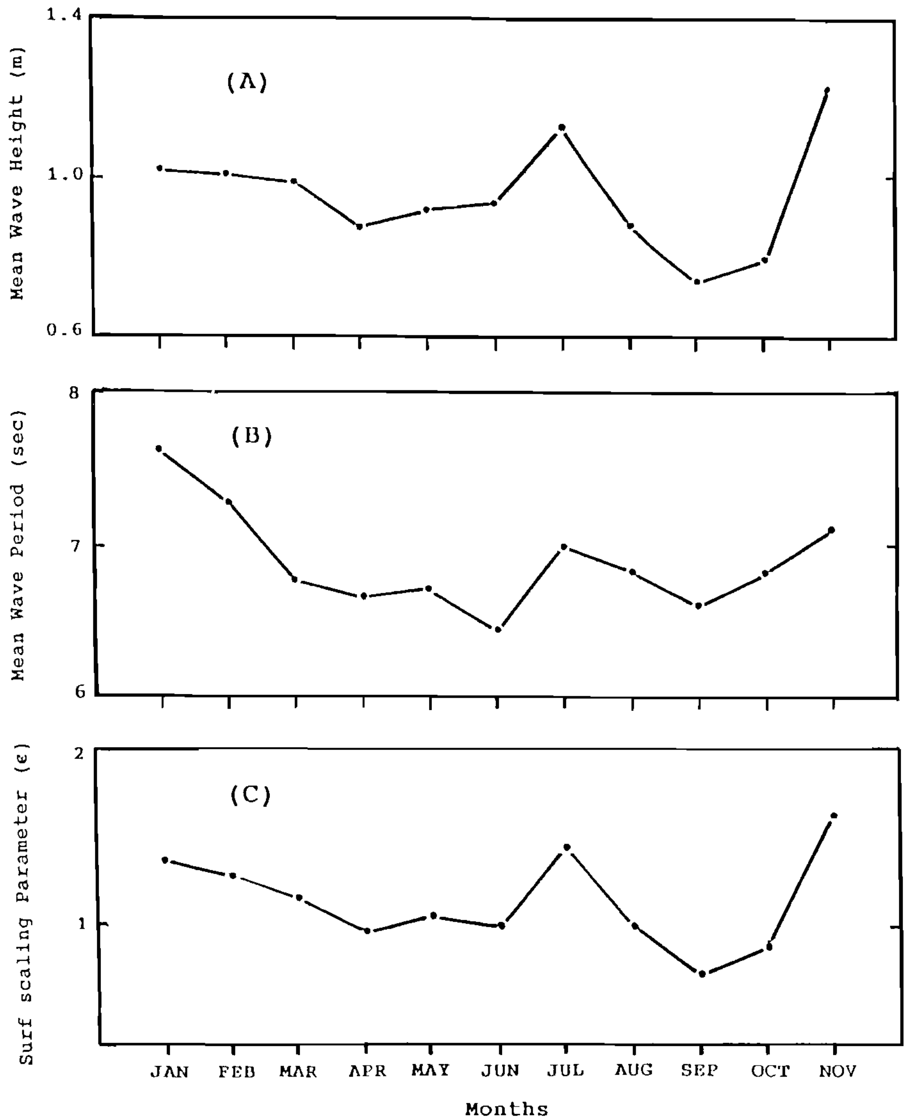

Figure 7. Wave data during 1986 (January through November): Mean monthly significant wave height (A), wave period (B), and wave breaking (C).

sipative. These beaches are wide, composed of fine to very fine sand and exhibit a very low gradient (tan β = 0.05 to 0.02). Morphodynamicaly, the Alexandria coastal segment behaves as a separate morphodynamic unit with less dissipative character than the Nile Delta coast. The major differences between these two coastal zones are summarized in Table 1.

CONCLUSIONS

The Nile Delta coast from Alexandria to Port Said was determined to be fully dissipative based on calculations of the surf-scaling parameter (ϵ) as determined from wave statistics at Abu Quir Bay. The dissipative state was also evident from field observations and aerial photographs.

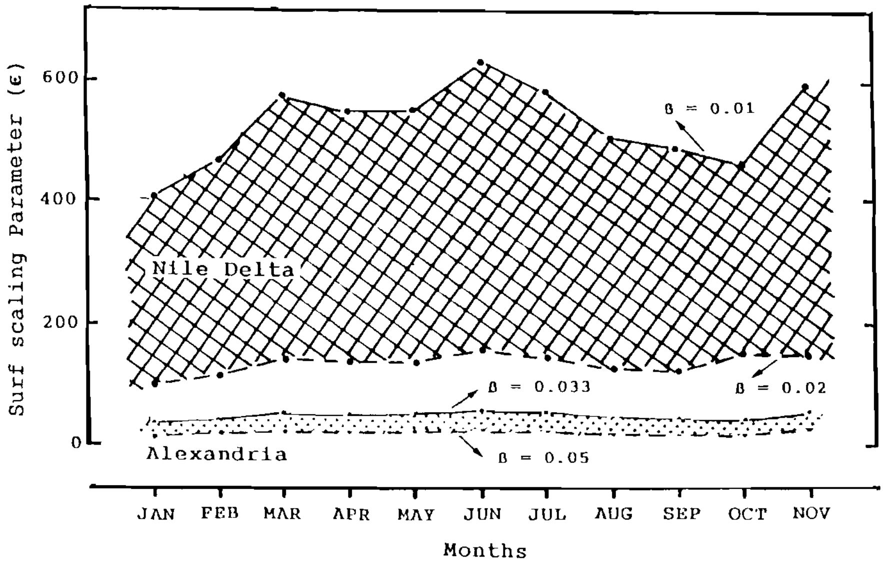

Figure 8. Monthly surf-scaling parameter (ϵ) for Alexandria and the Nile Delta coast, calculated for the inshore/foreshore slopes (β) of Alexandria (0.05–0.033) and the delta (0.02–0.01), for the NW wave direction.

The surf-scaling analysis and observations suggested that the study area can be generally divided into two morphodynamic zones. The delta coast is a gentle sloping, smooth wide beach face mainly composed of fine to very fine quartz sand. It is also characterized by a longshore bar system generated by the dominant eastward longshore current associated with littoral drift in the same direction. The second zone, which extends from the Alexandria waterfront and farther west, is composed of pocket and embayment shoreline of biogenic and oolitic sand with rocky shoals and headlands except for the western part which is straight, smoothed of wide carbonate sand beach. This stretch is characterized by crescentic bars associated with rip currents and almost or negligible littoral drift. These differences reflect the nature of coastal problems along these two stretches: the problems of rip currents that cause hazards to swimmers along the recreational beaches of Alexandria and the dramatic erosion/accretion problems along the delta. Profile analysis and wave

Table 1. *Summary of major differences between Alexandria and the Nile Delta coastal zones.*

Parameter	Alexandria	Nile Delta
Morphodynamics (surf-scaling parameter)	Moderately dissipative 20–55	Fully dissipative 101–627
Beach sediments	Biogenic, oolitic fine to very coarse sand (0.13–1.6 mm)	Deltaic quartz fine to medium sand (0.13–0.5 mm)
Carbonate content	Very high 22–94%	Very low 1–3%
Bottom slope	Slightly steep 1:20–1:30	Gentle slope 1:50–1:100
Shoreline orientation	SW-facing shoreline	EW-facing shoreline
Littoral drift	Weak to negligible 0.42 × 10^6 m^3/yr	Moderate to strong 0.4 × 10^6 m^3/yr to 3 × 10^6 m^3/yr
Rip currents	Present	Not documented
Beach cusp	Rare	More abundant
Sand bars	Crescentic	Parallel
Coastal problems	Recreational hazards due to rip currents and slight erosion	Dramatic localized erosion

data indicate that the bar/wave relationships along the delta coast are positively correlated.

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□ RESUMEN □

En la costa del Nilo, por medio de fotografías aéreas, de perfiles de playa y de observaciones de campo, se investigaron las características rítmicas de la playa y zonas costeras cercanas. En este trabajo, se describen las medialunas de la playa, las barras de arena submarinas paralelas y la del tipo crecientes. El análisis de las fotografías aéreas y las observaciones de campo muestran que muchas de las playas situadas al oeste del cabo Abu Quir, presentaban largos sistemas de barras crecientes. En contraste, las barras paralelas a lo largo de la costa se presentaban sólo en la extensión del delta desde el este de Abu Quir hasta Port Said.

Los sistemas de barras paralelas a lo largo del Delta del Nilo han sido generados por las corrientes que circulan sensiblemente paralelas a lo largo de la costa, que provienen del este y se hallan asociadas con la deriva litoral. Las barras crecientesdel oeste del cabo de Abu Quir en Alejandría, están asociadas con las corrientes de rompiente y con una deriva litoral de poca importancia. La aplicación del parámetro de escala de la rompiente ( ) indica un estado totalmente disipativo para la costa del Delta del Nilo y una moderada disipación al oeste de Abu Quir. El análisis de este parámetro de escala y la configuración de las playas sugieren que el área de estudio, morfodinámicamente, puede ser dividida en dos zonas. En la primera zona, la costa del delta presenta una pendiente suave, variando desde 1:50 a 1:100, un frente de playa ancho y suave, compuesto principalmente por arenas de cuarzo descargadas desde el Nilo y caracterizado por barras paraleas. La granulometría de la playa va de fina a media, y proviene fundamentalmente del Río Nilo. La segunda zona se halla localizada al oeste del Delta, a lo largo del frente de Alejandría y las playas del oeste. Esta zona está caracterizada por una pendiente relativamente fuerte 1:30, con playas pequeñas y costas con formas de bahías compuestas por arenas con material biogénico con fondos rocosos, excepto en la parte oeste la cual posee un alineamiento uniforme, con playas arenosas carbonáticas dominadas por barras crecientes y con granulometrías que van de medio a grueso. Los granos oolíticos son derivados de los bancos adyacentes limosos, del Pleistoceno, con rumbos paralelos a la costa oeste de Alejandría. — *Néstor W. Lanfredi, UNLP-CIC La Plata, Argentina.*

□ RESUMÉ □

A partir des photos aériennes, des profils de plage et des observations de terrain on a recherché les formes rythmiques de la plage et de la proche plage sous marine de la côte du delta du Nil. On a identifié des croissants de plage et des barres sous marines de type parallèle et en croissant, formes typiques des mers sans marée. L'analyse des photographies aériennes et les observations de terrain montrent que de nombreuses plages situées à l'ouest du promontoire d'Abu Quir portent un système à longues barres en croissant. Par contraste, il existe des barres parallèles à la côte entre Abu Quir et Port Said.

Ce système de barres est engendré par le courant parallèle à la côte dirigé vers l'est, et la dérive littorale qui lui est associé. Les barres en croissant entre le promontoire d'Abu Quir et Alexandrie sont associées à des courants de refente et à une dérive littorale négligeable. L'application du paramètre d' "échelle d'énergie au déferlement" indique que la côte du delta du Nil est de type "à dissipation" et, à l'ouest d'Abu Quir, de type "à dissipation modérée". L'analyse de l'échelle d'énergie au déferlement et la configuration des plages suggèrent que la zone étudiée peut être divisée en deux aires morphodynamiques: la première est la côte du delta, caractérisée par une pente faible comprise enre 1/50 et 1/100, une plage sous marine large et uniforme, composée de sables quartzeux déposés par le Nil et caractérisée par des barres parallèles. Le sable de plage est fin à moyen et provient surtout du Nil. La seconde zone est située à l'ouest du delta, le long du front d'Alexandrie et les plages plus à l'ouest. Cette zone est caractérisée par une pente assez forte 1/30, avec un littoral de baies et de mini plages composé de sables biogènes et de hauts fonds rocheux sauf dans la partie ouest qui est uniformément alignée. Il y a une dominance de sables oolithiques calcaires dominés par des barres en croissant. Ces sables proviennent des cordons de calcaire pléistocène adjacents qui s'étendent parallèlement à la côte à l'ouest d'Alexandrie. — *Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montrouge, France.*

□ ZUSAMMENFASSUNG □

An der Küste des Nildeltas wurden rhythmische Strand- und Vorstrandphänomene mit Hilfe von Luftaufnahmen, Strandprofilen und Feldbeobachtungen untersucht. Dabei wurden Strandhörner, Sandbarren und sichelförmige Sandkörper kartiert, wie sie typisch für gezeitenlose Meere sind. Luftaufnahmen und Feldbeobachtungen belegen, daß viele Strände westlich des Abu Quir-Vorsprunges lange sichelförmige Barren aufweisen. Im Gegensatz dazu existieren lange küstenparallele Barren entlang der Deltalinie östlich Abu Quir bis Port Said.

Das System paralleler Barren am Nildelta wird verursacht durch ostgerichtete longshore drift und einen entsprechenden küstenparallelen Materialversatz. Dagegen werden die sichelförmigen Barren westlich Abu Quir verursacht durch Reißströme und einen zu vernachlässigenden küstenparallelen Transport. Wendet man Parameter der Brandungsgrößen an, so ergeben sich größere Streuungen für das gesamte Delta, geringere für den Bereich westlich Abu Quir. Unter diesen Gesichtspunkten läßt sich die Region in zwei morphodynamische Abschnitte gliedern: der erste, die normale Deltaküste, ist sehr flach mit Gradienten zwischen 1:50 und 1:100. Der Strand besteht im wesentlichen aus Quarzsand aus dem Nil, und parallele Barren herrschen vor. Die Korngrößen sind fein bis mittel. Der zweite Abschnitt liegt westlich des Deltas bei Alexandria und erstreckt sich von dort gegen Westen. Hier sind die Strandböschungen relativ steil (1:30), kleingebuchtete Küstenlinien mit eingebuchteten Stränden aus biogenen Sanden treten zwischen felsigen Untiefen auf, wohingegen der westliche Teil geradliniger ist und mittel- bis grobkörnige oolithische Karbonatsande sowie sichelförmige Barren aufweist. Die oolithischen Sande stammen aus begleitenden pleistozänen Kalksteinwällen, die parallel zur Küste westlich von Alexandria verlaufen. *Dieter Kelletat, Essen, Germany.*