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The Impact of Human Activities on the Erosion and Accretion of the Nile Delta Coast

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ABSTRACT

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The Nile delta has come into existence since the last ice age. Its growth was mainly the result of the deposition of sediments carried by the old branches of the Nile River under the influence of the dynamic forces in the Mediterranean. At the beginning of this century, the shoreline of the Nile delta began to experience erosion in several areas especially on the two promontories; *i.e.* the areas around the Rosetta and Damietta outlets. This erosion is in addition to that of the Burullus area which has been occurring since the 10th century. Erosion in the delta increased greatly after the construction of the High Aswan Dam in 1964 which trapped Nile sediments in Nasser Lake.

Members of the Coastal Research Institute (CRI) have studied the accretion/erosion phenomena of the Nile delta since 1971. Their research has included the examination of the available maps and continuous monitoring of about 70 hydrographic profiles a number that was increased to 80 in 1980 and 150 in 1986. A computer program was developed to analyze data collected and the erosion/accretion pattern along the Nile was delineated. As a result, it was found that for adequate monitoring and assessment of erosion/accretion phenomena the coast can be divided into nine physiographic units.

ADDITIONAL INDEX WORDS: *Control erosion, shoreline change, shore profile, marine physiography, deltaic sediments.*

INTRODUCTION

When the famous Greek historian, Herodotus, visited Egypt more than 2,000 years ago, he was so impressed by the contributions of the Nile to Egypt's development and to the continued survival of its people that he declared the country to be the gift of the Nile. Herodotus did not overstate the situation for even today the Nile continues to be the main factor that insures the livelihood of many Egyptians. Only three percent of Egypt is suitable for agriculture and that portion is along the banks of the river and in its delta. The delta was built over the centuries from the alluvium transported seaward by the river's many distributaries (Figure 1) (SAID, 1981; EL-ASKARY and FRIHY, 1986; COUTELLIER and STANLEY, 1987). These early distributaries, which silted up over time, have been replaced by the two present branches at Rosetta and Damietta (Figure 1). The central headland of Burullus was formed by the very active Sebennitic distributary about 1,000 years ago (ORLOVA and ZENKOVICH, 1974). Since that time, the headland has been subjected to erosion. Before the beginning of the 20th century and prior to the building of a number of barrages, the low Aswan Dam and irrigation control works (Figure 2) and the Nile delta's shoreline grew northward into the Mediterranean Sea. The two cities of Rosetta and Damietta, which were established hundreds of years ago at the two outlets of the Nile, were bypassed by deposited sediments and are several kilometers south of the sea shore.

Since the beginning of the 20th century deltaic deposition has decreased and serious erosion has been occurring in several locations, such as on the Rosetta and Ras El Bar promontories. This erosion increased greatly following the construction of the Aswan High Dam in 1964. In the Rosetta area, the average rate of retreat on the western and eastern sides of the promontory was as much as 147 m/yr and 48 m/yr, respectively, between 1964 and 1982. This coastal erosion caused by the loss of fluvially derived Nile sediments, land subsidence and rising sea level is now threatening large areas of low-lying northern delta areas with

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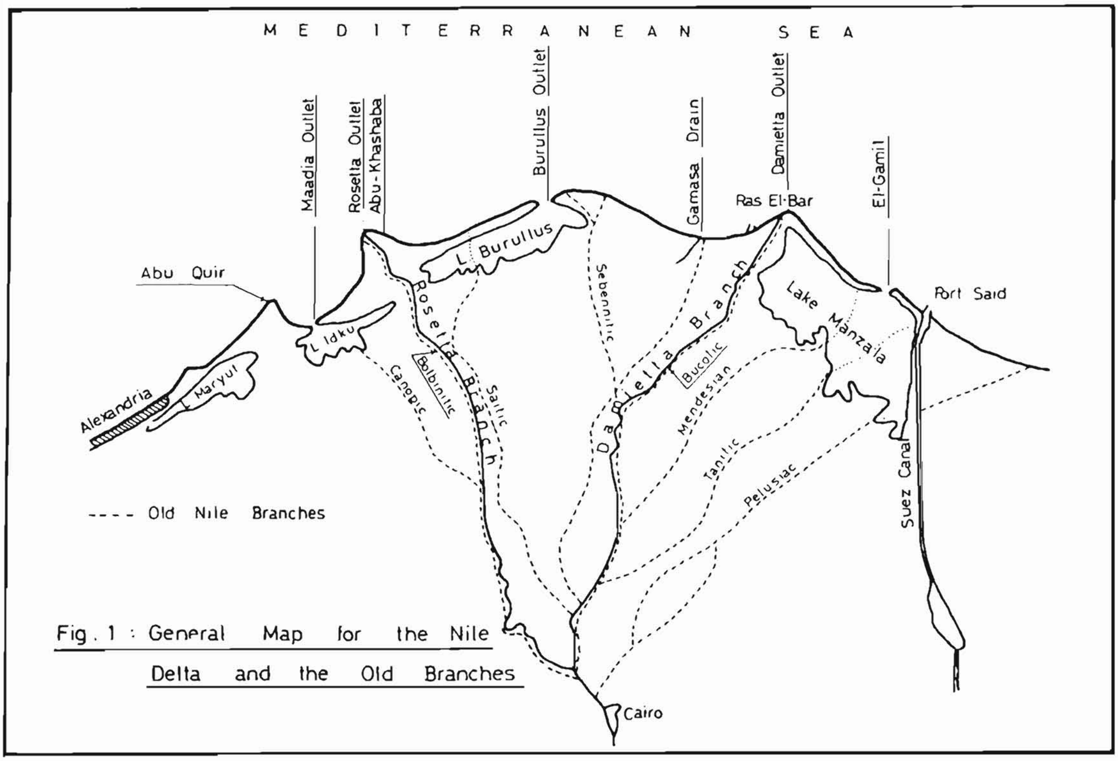

Fig. 1 : General Map for the Nile Delta and the Old Branches

Figure 1. General map for the Nile delta and the old branches.

increased salinization of ground water and incursion of salt water (STANLEY and WARNE, 1993).

Erosion is not the only problem occurring along the Mediterranean coast of Egypt. Intensive shoaling of the estuaries of the delta's northern lakes hinders fishing and navigation and also disturbs the ecosystems.

The study of the accretion/erosion patterns along the delta's shoreline began in 1971. These studies included the examination of old maps of the area and the continuous monitoring of hydrographic profiles. In 1971 the number of profiles was 70 a number that was increased to 80 in 1980 and increased again to 150 in 1986. Computer programs were developed to analyze the profiles and to calculate sediment budgets.

The objective of this paper is to document the impacts that the construction of the various water regulation works in the Nile system have had on the delta's shoreline. It also examines the effect of climate change on the discharge of both water and sediment to the sea.

NILE RIVER DISCHARGE AND SEDIMENT LOAD

The Nile River, which is 6,300 km long, is the second longest river in the world. It heads in Lake Plateau on the Equator and runs to the Mediterranean Sea. It has numerous tributaries; the two major ones are the White Nile which drains Tanzania and Kenya and the Blue Nile which drains the Ethiopian highlands.

Human intervention in the flow of the Nile dates back at least to Pharaonic times (INMAN and SCOTT, 1984). Modification during recent times began with the construction of barrages some 20 km to the north of Cairo on the Damietta Branch (completed in 1840) and on the Rosetta Branch (completed in 1861). These barrages were replaced in 1939. With their construction, perennial irrigation became possible. Agriculture benefited from the increased amount of silt and clay that could be transferred to the fields. This same practice was possible through the period of further construction which included additional barrages and the Low Aswan Dam (Figure 2). However, with the construction of the High Aswan Dam in 1964 some of the benefits enjoyed earlier were eliminated because the sediment load was subsequently trapped.

Although the Low Aswan Dam and all the barrages had been provided with sluices, it was found that the dam trapped some sediment (HAMMAD *et al.*, 1979). SHARAF EL DIN (1977) calculated that 60 percent of the fresh water discharged through Aswan was used by irrigation or lost to evaporation before reaching the Mediterranean sea. Figure 3 shows the variation of water discharge at Aswan and that reaching the Mediterranean sea through the Damietta and Rosetta branches between 1860 and 1992. This curve shows that the water discharge was higher from 1860 to 1900 (110×10^9 m^3/yr) than from 1900 to 1991 (85×10^9 m^3/yr). It has been concluded that such a major change in flooding was due to monsoonal climate changes in Africa (NIELSEN, 1971; HASSAN, 1981; FAIRBRIDGE, 1984).

CRI/UNESCO/UNDP (1978), using the long term records of the Ministry of Public Works and Water Resources, conducted a study on the fluctuation of the Nile's sediment load (Figure 3). There were major differences in the sediment load before and after 1900. During the period from 1860 to 1900 suspended load was higher (200×10^6 ton/yr) than from 1900 to 1964 (160×10^6 ton/yr) (Figure 3). The measurements also showed that the highest percent of suspended load was carried during the flood season in August (Table 1).

According to QUELENNCE and KRUK (1976), SIMIKA (1970), HURST (1957), FAHMY (1974), and HAMMAD *et al.* (1979) the average annual suspended load of the Nile at Gaafra between 1902 and 1963 was 160×10^6 ton/yr (Figure 3). INMAN and SCOTT (1984), using data for the period 1861 to 1964, estimated the sediment load of the free flowing Nile as follows:

(1) Total sediment load (sand + silt + clay) ranged between 160 and 178×10^6 ton/yr.
(2) Suspended load (silt + clay) totaled 112×10^6 ton/yr. The majority of this amount was transferred to agricultural fields.
(3) Load of sand totaled $50–66 \times 10^6$ ton/yr which is equivalent to $30–40 \times 10^6$ m^3/yr. This amount went to the sea resulting in the growth of the delta northward.

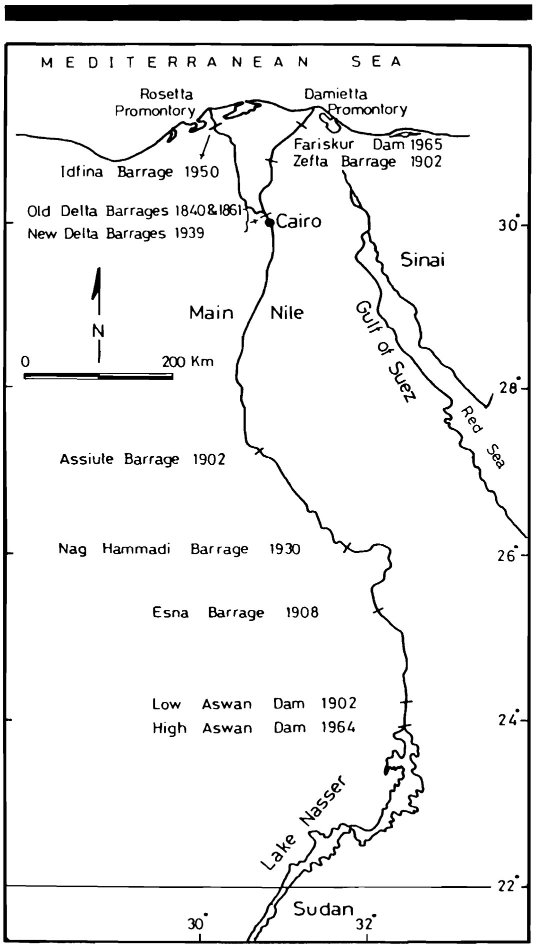

Figure 2. Regulation works and dams along the Nile River.

Since 1964, however, sediment has not been able to bypass the Aswan High Dam. The two results of this trapping of sediments behind the dam are the filling up of Lake Nasser (Figure 4) and severe erosion of the Nile delta's coast.

Table 1. *Water and suspended sediment characteristics of the Nile River.*

Quantity	July	August	Sept.	Oct.	Nov.
Water, 10^9 m^3*	4.3	17.4	20.9	14.8	7.7
Suspended sediment load, % of total**	2	45	38	12	1.5

*Measured at Low Aswan Dam 1912–1947 (HURST, 1957)
**Estimated for 1903–1963 at Gaafra some 30 km to the North of Aswan Low Dam (QUELENNEC and KURK, 1976)

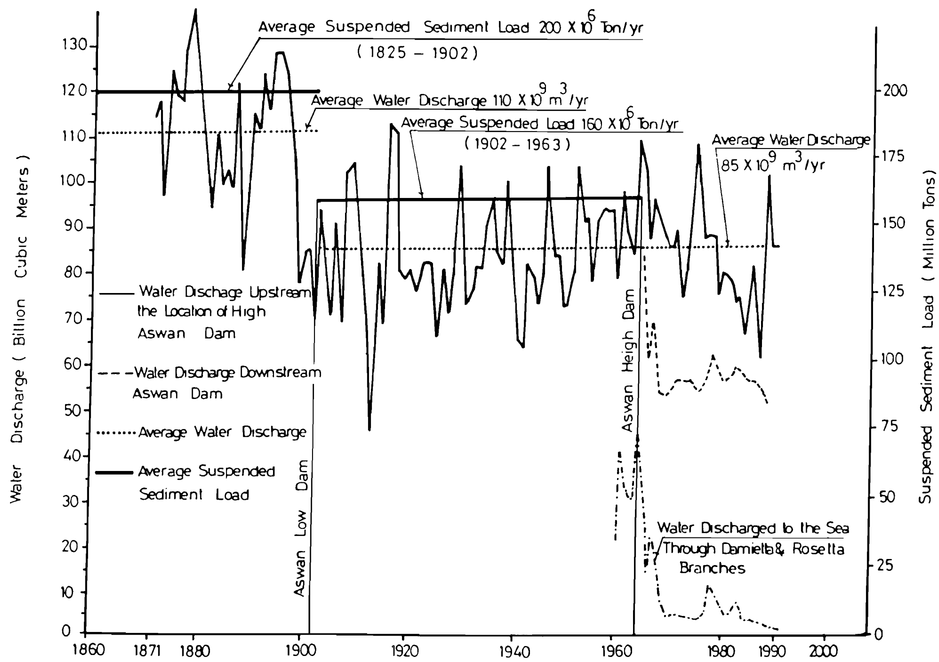

Figure 3. Variation of water discharge and suspended sediment with time.

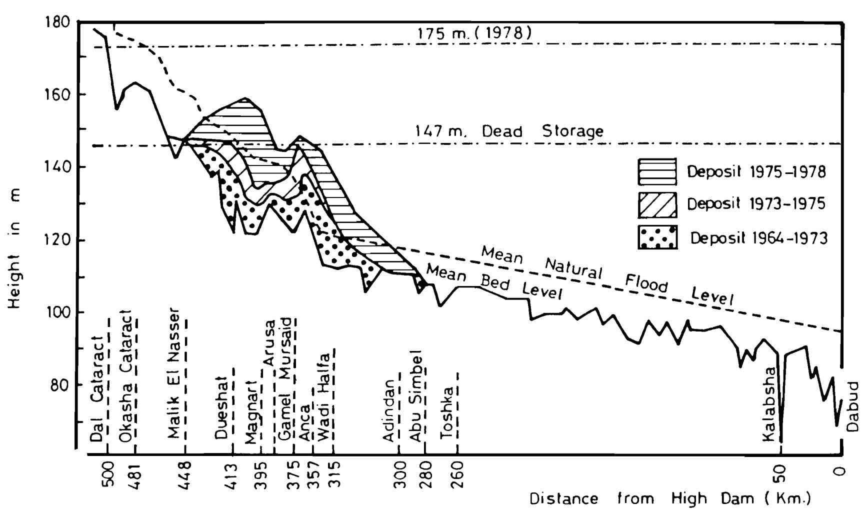

Figure 4. Sedimentation in Lake Naser upstream High Aswan Dam.

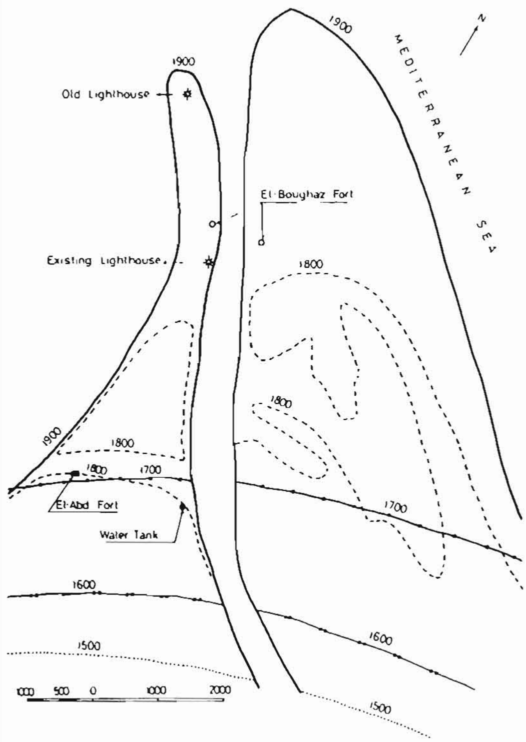

Figure 5. Shore-line advance at Rosetta Promontory (1500–1900).

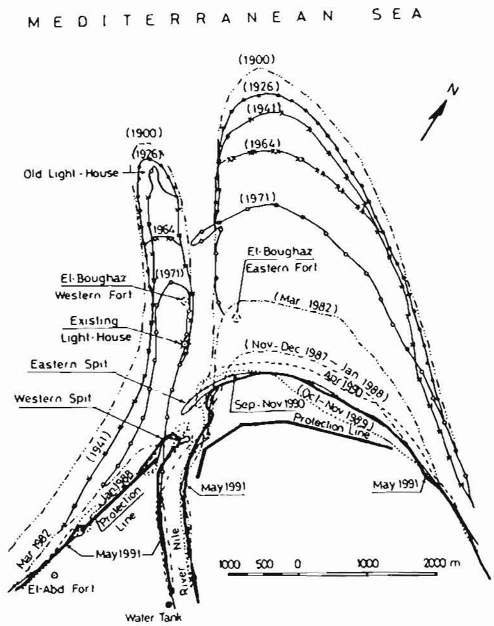

Figure 6. Retreat of Rosetta Promontory during the period from 1900 to 1991.

LONG-TERM CHANGES

The long-term change in the shoreline of the Nile delta and the impact of human constructions on it have been studied through the analyses of old maps (CRI/UNESCO/UNDP, 1978; Egyptian Survey Department, 1964) and locally collected information (Hilaly, 1971; Khafagy and Fanos, 1981ab; Khafagy *et al.*, 1992). The first detailed and accurate survey of the coastal region was conducted during the presence of the French Expeditionary Force in 1800. The shoreline of the two promontories of Rosetta and Damietta and of the central headland at Burullus were matched with the French maps. The overlapping was possible because the positions of the fixed points, such as forts and lighthouses, were located on old maps. The main observations and conclusions drawn for the three regions form the basis of the discussion below.

ROSETTA PROMONTORY

The Rosetta Promontory was built since 500–1000 AD when water from the Canopic and Sebennitic branches was diverted naturally and artificially into an existing canal known as the Rosetta branch (CRI/UNESCO/UNDP, 1978). Advances and retreats of the shoreline between 1500 and 1991 are diagrammed in Figures 5 and 6. During this period of time, major changes in the shoreline have occurred. The eastern and western sides of the promontory advanced 11 and 8.5 km, respectively, between 1500 and 1900 (Figure 5) whereas they retreated 4.4 and 5.8 km, respectively, between 1900 and 1991 (Figure 6). The temporal variations in advance and retreat of the Rosetta Promontory are shown on Figure 7.

Erosion that began about 1900 averaged 20 m/yr until 1964 when it increased to about 120 m/yr and 240 m/yr for the east and west sides of the promontory. These changes reflect the construction of both the Low Aswan and High Aswan dams (Figure 7).

Accretion also took place to the east of the

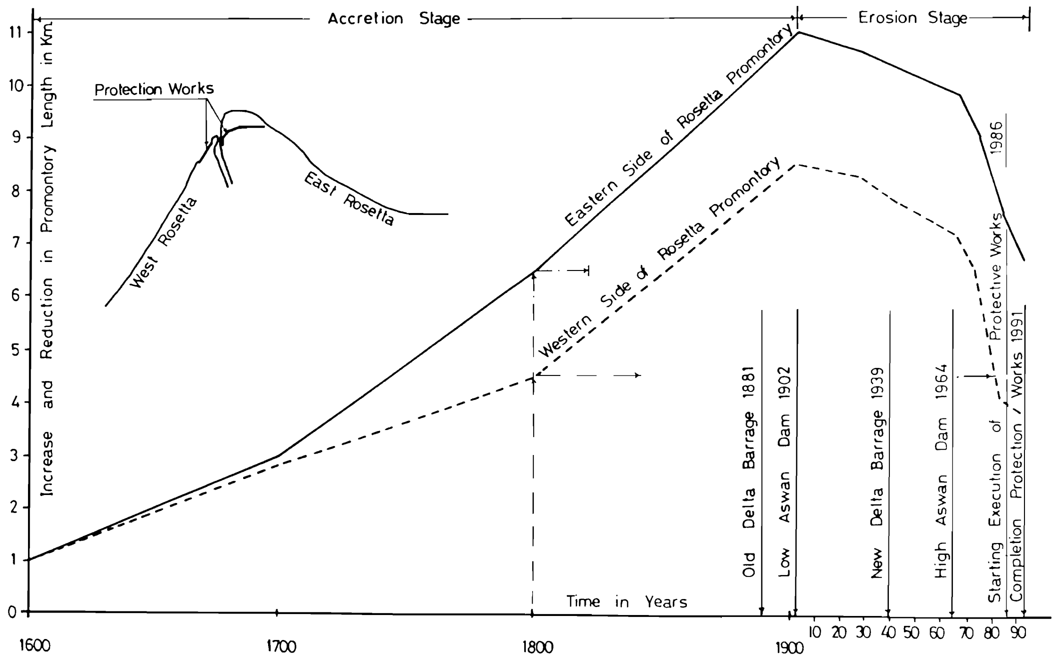

Figure 7. Increase and decrease in the length of Rosetta Promontory during 1600 to 1991.

promontory in Abu Khashaba embayment (Figure 1) and on both sides of the outlet in the form of spits (Figure 6). These structures were formed by the longshore currents that prevail in the area (FANOS, 1986).

DAMIETTA PROMONTORY

It is thought that the Damietta Branch came into existence during the 10th century AD (CRI/UNESCO/UNSP, 1978). The sediment brought to the mouth of the branch was directed to both the west and east under the combined action of the waves and currents.

The shoreline trend at this promontory for the period from 1800 to 1992 is shown in Figures 8 and 9. Changes are similar to those of the Rosetta area in that there was advance before 1900 and retreat subsequently. The average rates of advance and retreat are shown in Figure 10. The west side of the promontory, known as the Ras El Bar Peninsula, advanced at a rate of 30 m/yr between 1800 and 1900. It then retreated, at an average rate of 35 m/yr, between 1900 and 1941 when a jetty was constructed on the western side of the Branch. Although this jetty stabilized the northern part of Ras El Bar, the rest of the coast continued to be eroded although at a lesser rate of 10 m/yr. This rate was also influenced through the construction of other protective works including two groins and some detached breakwaters (FANOS and KHAFAGY, 1992).

On the east side of the promontory the rate of advance of the shoreline between 1800 and 1912 was about 20 m/yr. Between 1912 and 1973 the rate of retreat was about 40 m/yr whereas between 1973 and 1991 it was 100 m/yr. The variation in rates is a reflection of the construction of the High Aswan Dam. The accretionary pattern east of the Damietta promontory is dominated by a spit which grew because of the transport of eroded sediments toward the east by longshore currents (FANOS, 1986).

BURULLUS HEADLAND

The Burullus headland was built by the very active Sebennetic Branch. It began eroding more than 1,000 years ago (CRI/UNESCO/UNDP, 1978) when that branch began to decrease in im-

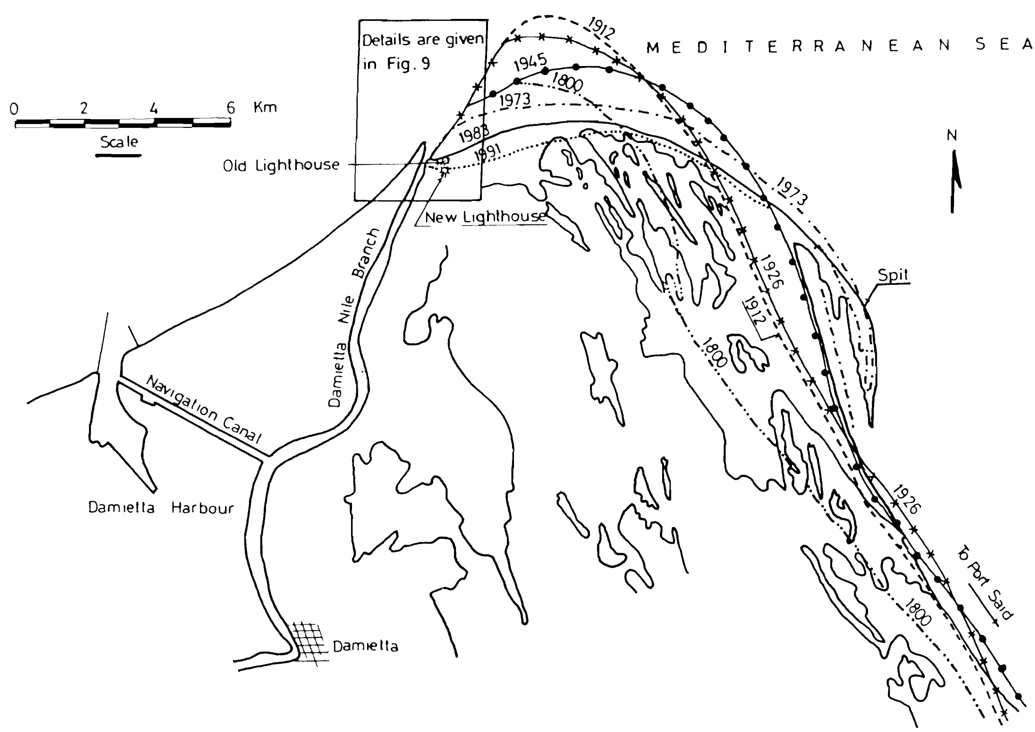

Figure 8. Evolution of the shoreline and spit formation on the eastern side of Damietta Promontory.

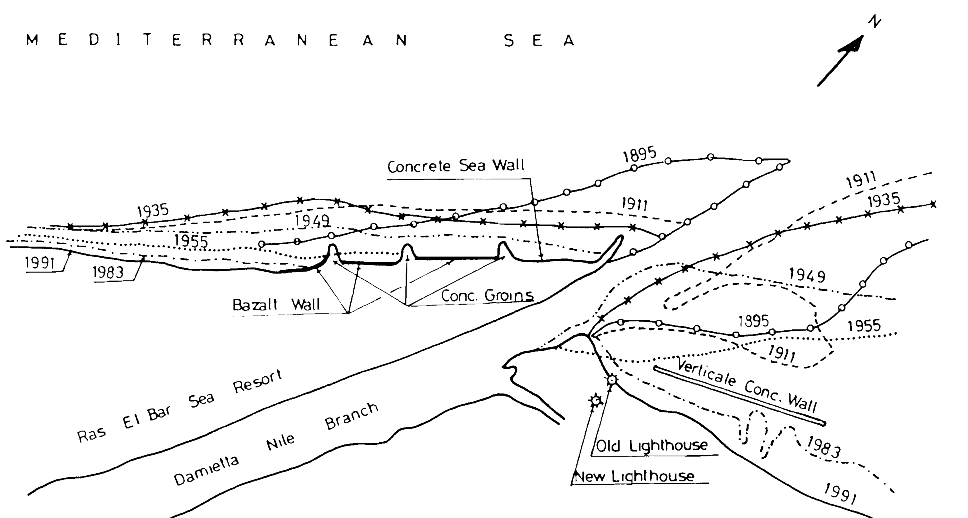

Figure 9. Shoreline changes (1895—1991) at Damietta Promontory (long-term).

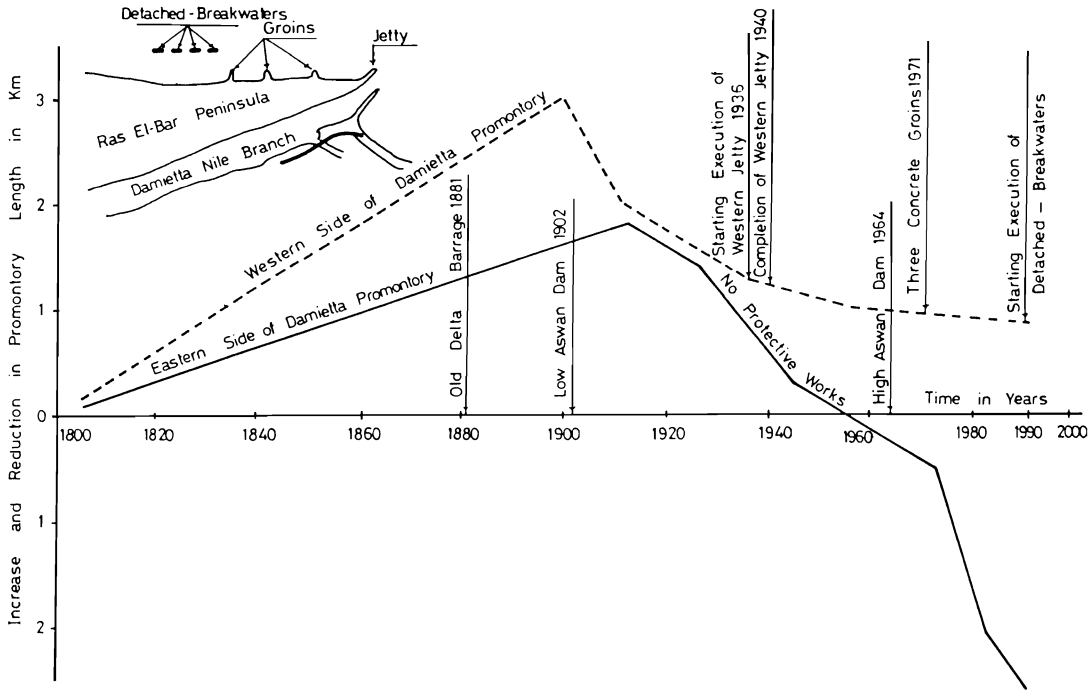

Figure 10. Increase and decrease in the length of Damietta Promontory during the period 1800 to 1991.

portance and eventually died out. Since then Burullus village was destroyed by erosion many times only to be built farther inland. The changes occurring along the coast at the Burullus outlet between 1810 and 1988 are shown in Figure 11; the erosion/accretion changes through time are shown in Figure 12.

Erosion occurred at an average rate of 1.1 m/yr between 1810 and 1909; between 1909 and 1971 the rate was about 7 m/yr (Fig. 12). This may be due to the construction of the Low Aswan Dam in 1902. In 1971–1972 a jetty was built on the western side of the outlet and accretion began to occur at about 7 m/yr. This jetty was an effective trap until 1988 at which time the sediment drifting alongshore began to bypass the jetty and to be deposited inside the inlet. In 1990–1991 the jetty was lengthened about 150 m.

The eastern shoreline of Burullus outlet was subjected to erosion at an average rate of 2 m/yr between 1810 and 1909, a rate that increased to an average of 11 m/yr during the period from 1909 to 1935. Protective structures were added between 1936 and 1947 (Fanos and Khafagy, 1992). They culminated with the construction of a 600 m long concrete sea wall. However, erosion began again to the east of this wall and, averaging 15 m/yr between 1947 and 1964, created an embayment with a curved shoreline. In 1964 erosion had reached a band of sand dunes which slowed up the recession rate to about 10 m/yr.

SHORT TERM CHANGES

Short term change has been studied through the analyses of the profile data collected between 1981 and 1990. The profiles examined, cover the entire deltaic coast from Abu Quir to Port Said. Spacing between adjacent profiles varies between 0.5 km to 10 km (Figure 13). The profiles were surveyed twice a year: once as "Spring profiles" during April and May and once as "Autumn profiles" during September and October. The spring profiles show the result of winter storm waves whereas the autumn profiles reflect the action of summer swells.

A summary of the analysis is depicted in Fig-

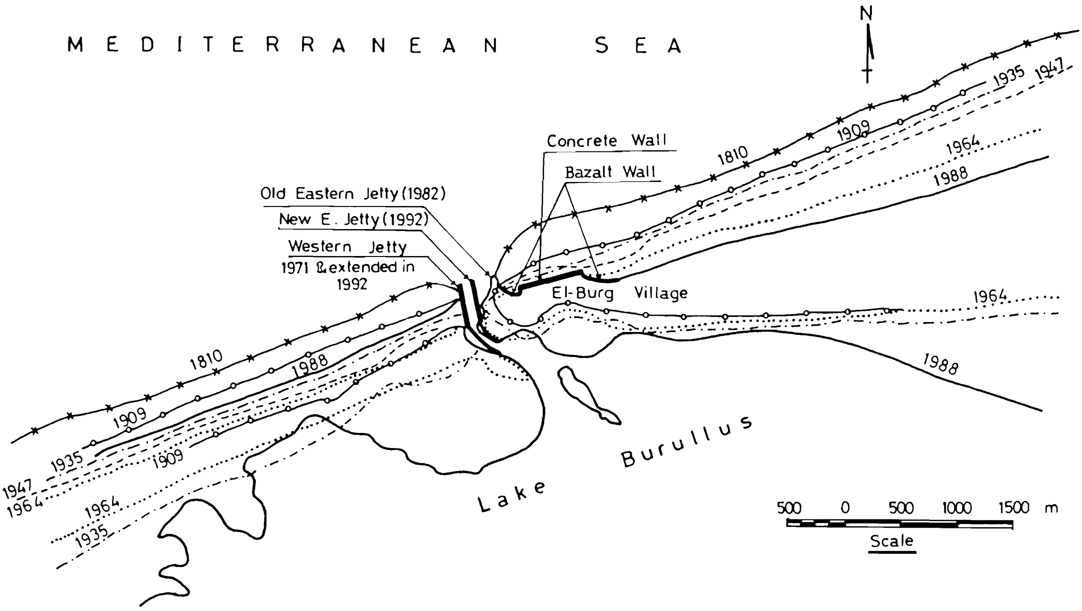

Figure 11. Shore-line changes at Burullus Headland from 1810 to 1988.

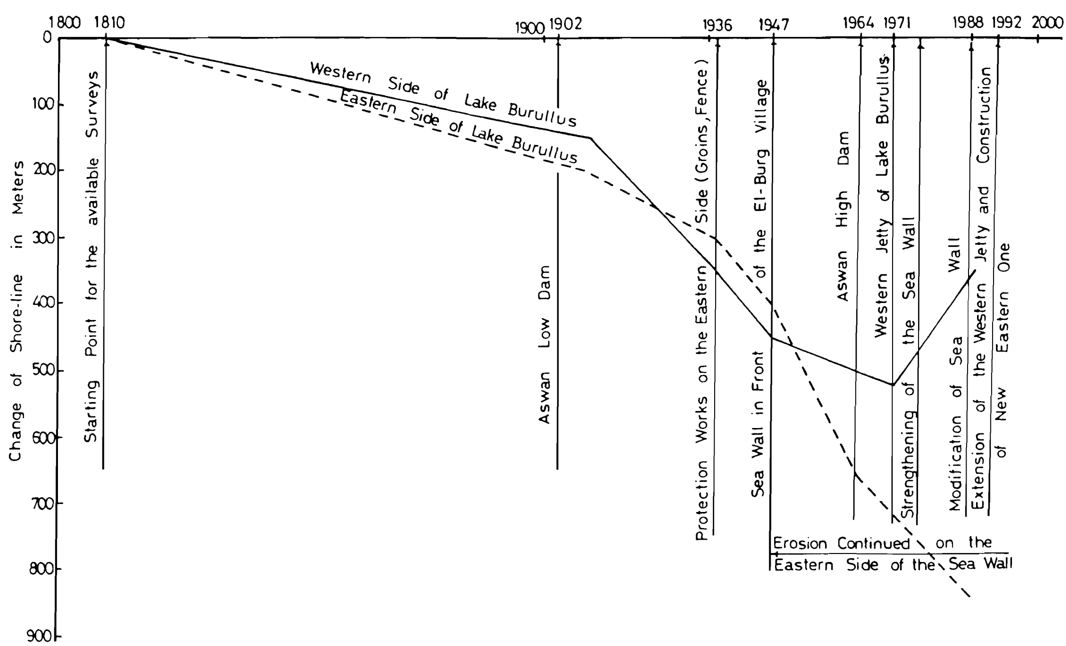

Figure 12. Erosion/accretion of shoreline at Burullus area.

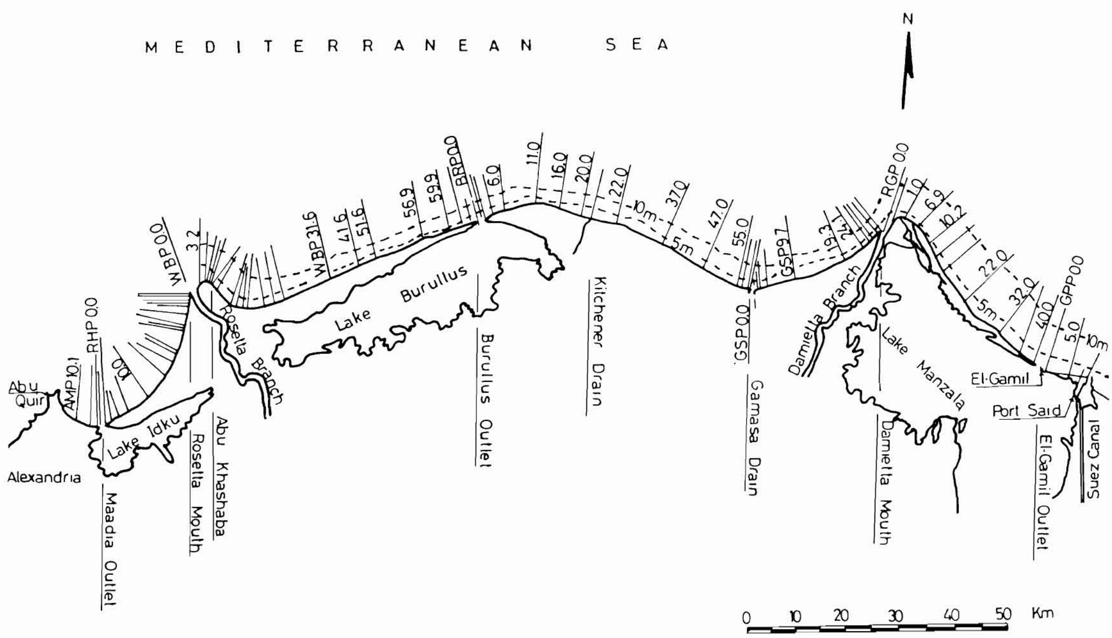

Figure 13. General layout of main profiles along the Nile delta coast.

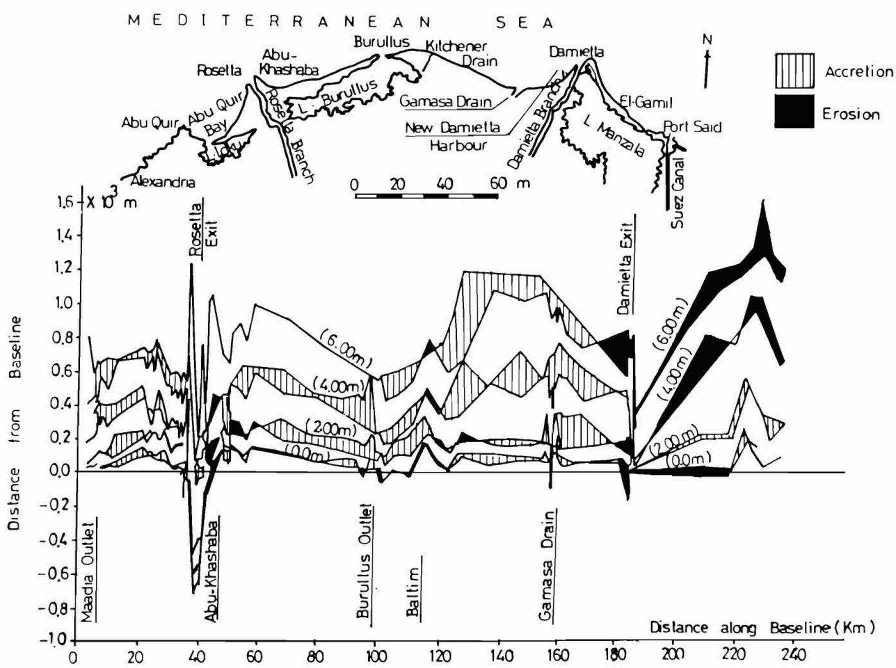

Figure 14. Changes of contour lines along the Nile delta coast.

ures 14 and 15. The full analysis is given in KHAFAGY *et al.* (1992). Between 1981 and 1990 the shoreline retreated along most of the coast, the major exceptions being for short distances between Maadia and Rosetta, at Abu Khashaba, between the Kitchener drain and New Damietta harbour, and the west of Port Said breakwater. The maximum retreat of the shoreline occurs on the Rosetta promontory where it is about 70 m/yr. In contrast it is about 5 m/yr at both the Burullus headland and Ras El Bar sea resort and about 8 m/yr to the east of the Damietta Branch. There are three regions that are subjected to erosion from the shoreline to the −6 m contour; namely the Rosetta and Damietta promontories and the Baltim Sea resort which is located 10 km east of the Burullus outlet. There is accretion at contours −2, −4, and −6 m along other areas of the delta (Figure 14).

The volume of sediment transported along the delta's shoreline in and beyond the breaker zone was composed from the profile data. Cumulative volumes are depicted in Figure 15b. A steeper upward slope indicates accelerated accretion whereas a more gentle slope shows that accretion is less than it was in the previous zone. A downward slope signifies erosion. The total volume of sediment moving along the shoreline between the shore and the −6 m contour is shown in Figure 15c. The conclusions are:

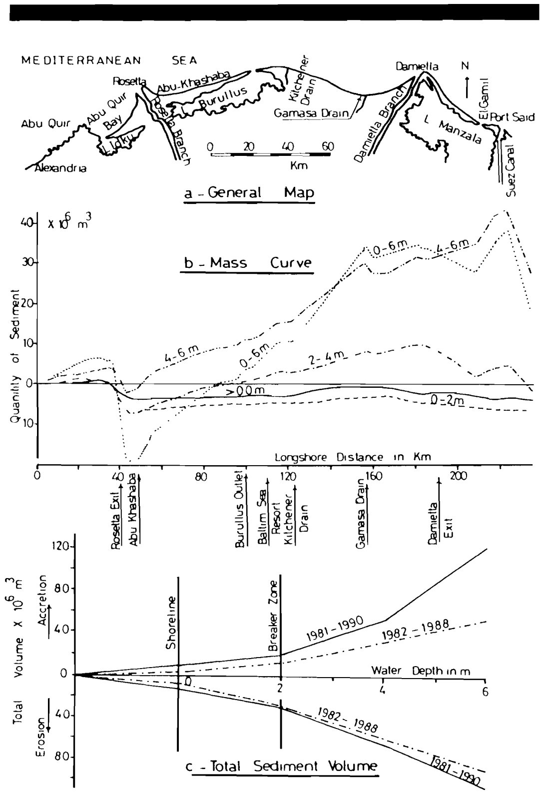

Figure 15. Mass curve total sediment volume from profile data along the Nile delta coast during the period from 1981 to 1990.

(1) Volumetric changes appear to be independent of time. For example the volume change during the mentioned period of time is not equal to the volume change per year multiplied by the number of years.
(2) Gross volume change (accretion + erosion), which amounted to 235 × 10^6 m^3 in ten years, is far larger than the net volume change (accretion-erosion), which amounted to 13 × 10^6 m^3 during the same period of time.
(3) In the breaker zone erosion predominates over accretion.
(4) The net volume of sediment moving along the full length of the sediment is coming from or lost to depths beyond −6 m. This conclusion argues for expanding the profiles seaward to the so-called closure depth.
(5) Profile changes do not follow definite patterns except at the Rosetta and Damietta promontories and to the east of the Burullus outlet where progressive erosion occurs.
(6) Analysis of the spring profiles shows that erosion along the shoreline occurs as a result of the high waves of winter whereas it shows that there is a redistribution of sediment with accretion occurring during the summer swell season.

NEARSHORE PHYSIOGRAPHIC UNITS

The seasonal characteristics of beach profile changes suggest a number of physiographic units (Figure 16) including: (1) Abu Quir Bay from the Madiaa outlet to 6 km south of Rosetta outlet is an independent unit although its northern end acts as a sink for the erosive part of the Rosetta promontory. (2) The Rosetta promontory, about 15 km long, on both sides, is a separate unit that serves as a source region for adjacent areas. (3) The Abu Khashaba zone acts as a sink for material eroded from the Rosetta promontory. (4) The section from 40 km east of Abu Khashaba to the Burullus outlet is a unit where the shore alter-

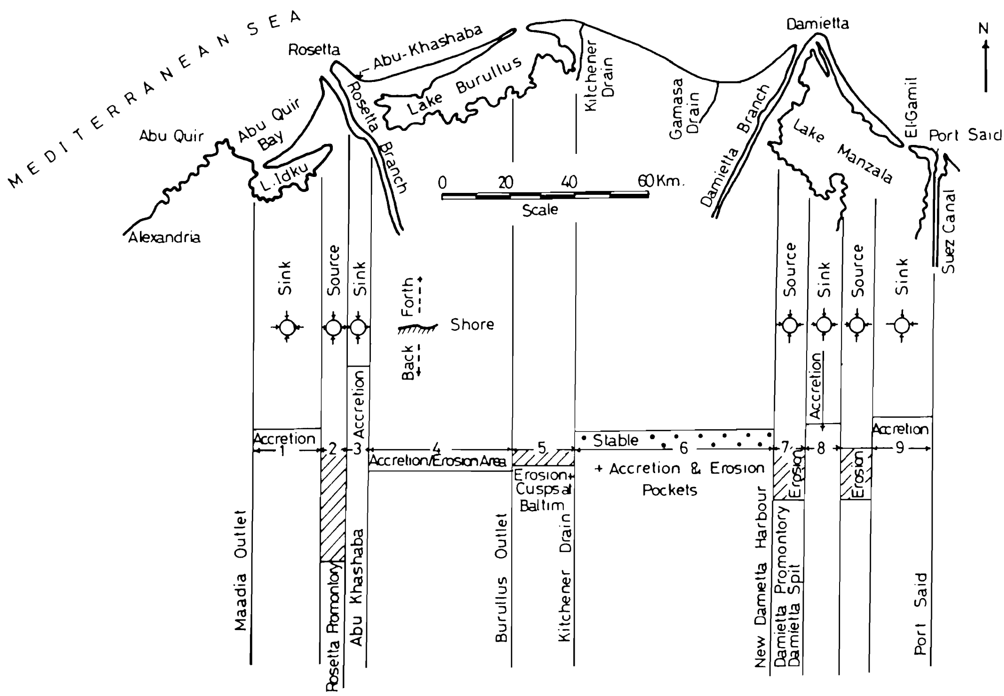

Figure 16. Diagram showing the physiographic units.

nates between accretion and erosion. (5) From the Burullus outlet to Kitchener drain, erosion dominates although a cusp is forming at Baltim Sea resort. (6) The section from Kitchener drain to the western breakwater of the new Damietta Harbour is nearly stable, although there are a few pockets of erosion and accretion. (7) Both sides of the Damietta promontory are erosive. (8) The zone from the Damietta spit for a distance of 15 km to the east is a sink for the material eroded from the promontory. It also serves as a source for the 10 km stretch to the east. (9) The section further east appears to be an independent unit and serves as the major source of sediment for the Port Said breakwater and channel entrance.

SUMMARY AND CONCLUSIONS

This study shows that the advance and retreat of the Nile delta shoreline, about 240 km from west of Abu Quir to Port Said, correlates closely with the quantity of sediment discharged to the sea, a condition affected by the construction of irrigation control structures and dams on the Nile River. This phenomenon has been affected by the climatic changes that have occurred in east Africa. It has been found that major changes prevailed prior and subsequent to 1900. Before 1900, water and sediment discharge was not impeded by artificial structures and were high. After control structures were added to the system, lesser amounts of water and sediment reached the sea and coastal erosion and retreat became common.

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