CHAPTER 250

NILE DELTA PROFILES AND MIGRATING SAND BLANKETS

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ABSTRACT

Before construction of the various Nile River dams, the position of the Nile Delta shoreline was in equilibrium between the sediment supplied by the river and the transport of sediment along the coast. Following dam construction sediment yield from the river has virtually ceased. In the absence of sediment from the river, currents, waves and winds are actively eroding the delta. Extensive beach profiling shows that the primary locus of erosion, in excess of 10×10^6 m^3 yr, is from the Rosetta promontory. This material is carried eastward in part by wave action but predominantly by currents of the east Mediterranean gyre which sweep across the shallow delta shelf with speeds up to 100 cm/sec. Divergence of the current downcoast from Rosetta and Burullus promontories results in formation of accretionary blankets of sand that episodically impinge on the shoreline. Individual blankets of sand form 1.5 m thick covers over the residual profile in depths of 6 to 4 m, and extend for 2 to 4 km along the shore. The sand blankets move progressively downcoast at rates of 0.5 to 1 km/yr, generating series of accretion/erosion waves along the shoreline.

The erosion/accretion/erosion shoreline change is commonly 50 to 100 m and has a periodicity of 3 to 8 years. When the accretionary phase of the wave has passed downcoast, the shoreline returns to its previous form and exhibits a "residual" equilibrium profile. In its residual form, the beach profile goes through characteristic adjustments to seasonal wave climate, exhibiting an equilibrium winter profile with a pronounced bar and a summer profile when the bar tends to migrate onshore. When the nearshore is blanketed with sand during the accretionary part of the cycle, the profile is in disequilibrium with wave forcing and frequently shows several, irregularly spaced bars and troughs. Although the year to year shoreline changes associated with the accretion/erosion waves are large, 0(50 m/yr), the long-term (decadal) changes based on successive residual profiles from the erosion portion of the cycle are relatively moderate, say 0(2 m/yr).

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Findings from this study suggest that the coastal current augmented by waves may transport 10 - 20 million m^3/yr of sandy sediment, while the longshore sand transport near the shore is about 1 million m^3/yr. Thus it appears that the blankets of moving sand that episodically impinge on these relatively shallow (6 m deep) profiles are only revealing the "toe of the elephant." Additional study is needed at depths of 20 m or more to resolve this problem.

INTRODUCTION

The shoreline of the Nile Delta extends along the Mediterranean coast from near Alexandria for 200 km to the east (Figure 1). The Nile River has been the sole source of the sediment for the delta as well as for the entire Nile littoral cell that extends an additional 500 km to Akko, Israel (e.g., Inman and Jenkins 1984; Carmel et al. 1985). The sediment load from the Nile River was deposited along the submerged portion of the delta where it was sorted and transported to the east by the prevailing waves and by currents of the counterclockwise east Mediterranean gyre that commonly flows at bout 50 cm/sec over the delta. Prior to 1964, the turbid plume of the flood waters of the Nile River could be traced along the Mediterranean coast for over 700 km to the shores of Lebanon (Orin 1952; Hecht 1964).

Until 1964, the major sediment source of the littoral cell was the Nile River. Construction of the High Aswan Dam, which began filling in 1964, has resulted in a near absence of Nile River flow into the Mediterranean and a corresponding complete loss of the Nile River as a source of nutrients to coastal waters and as an active sediment source for the delta and the coastline of the Nile littoral cell. As a result, the Nile Delta is now subject to severe erosion in a number of localities.

Previous studies have shown that the Nile Delta shoreline is bordered by a ribbon of sand, approximately 10 km-wide, extending from Rosetta promontory to near Damietta promontory (e.g., Fishawi et al. 1976; Misdorp 1977). Curiously, just west of Damietta promontory, this ribbon of sand diverges in a northeasterly direction from the coast, arching seaward from the promontory, leaving a mostly muddy offshore area from Damietta to Port Said (Figure 1). More recent studies by Murray et al. (1980; 1981) show that the Damietta promontory interacts with the east Mediterranean gyre to form a large, stationary eddy that begins at Damietta, extends offshore for up to 35 km and eastward along the coast for about 70 km. The seaward portion of the eddy is a high-speed jet over 5 km wide that forms off the promontory and flows northeasterly and then easterly with measured surface-to-bottom velocities of over 60 cm/sec. The eddy drives a field of actively migrating sand ridges easterly over a smooth mud plain. The sand belt begins in depths of 10 m, flows northeasterly, turns easterly and finally arcs southeasterly towards the coast between Port Said and Bardawil Lagoon (Coleman et al. 1981). This appears to be a major transport path and a partial sink for Nile sand.

The formation of the eddy down-current from Damietta is associated with the abrupt bend to the southeast in coastal orientation at that point. This area, including Manzala Lagoon and its barrier beaches, appears to have subsided at rates up to 0.5 cm/yr during the past 7500 years. Stanley (1988) suggests that the subsidence is associated with the Pelusium Line, a northeast-trending compressional zone bordering the Levant Basin and entering Africa along the axis of the ancient Pelusium Branch of the Nile between Port Said and Bardawil Lagoon (Neev et al. 1976).

PRESENT STUDY

This report is part of a study of the budget of sediment of the Nile littoral cell sponsored by the U.S. Agency for International Development. It is based on extensive

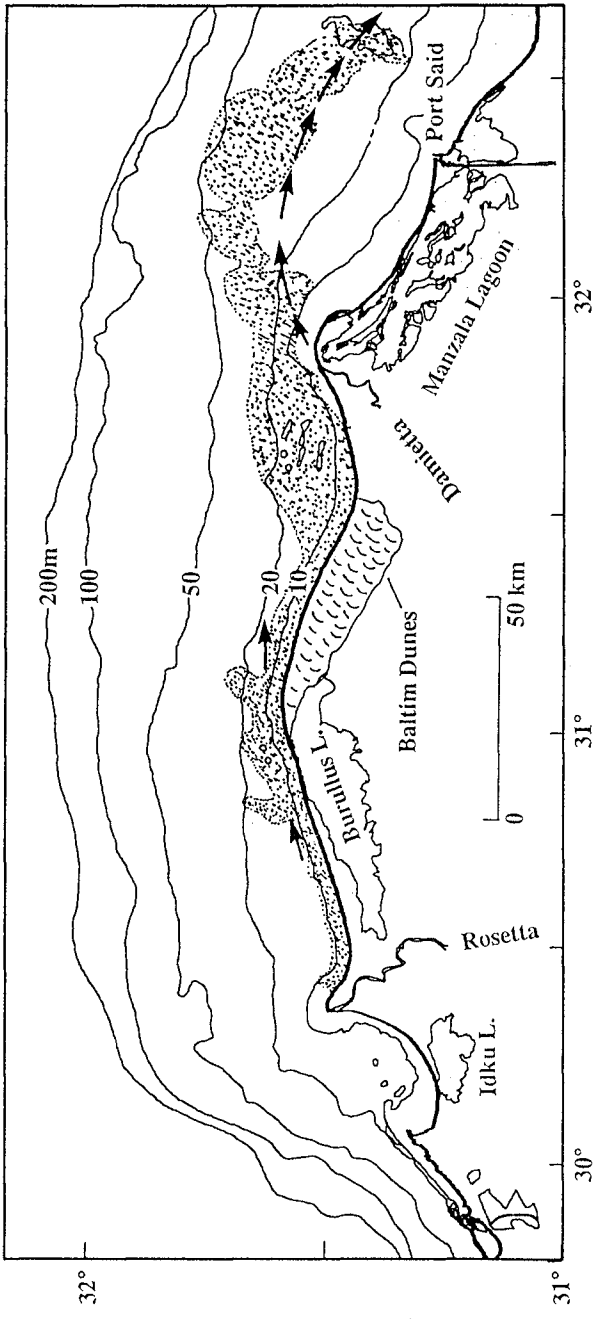

Figure 1. Bathymetry and sediment transport paths on the Nile Delta. Sandy sediment (stippled) after Fishawi et al. (1976), dunes after Sestini (1976) and Stanley et al. (1992), prevailing 25–75 cm/sec currents (central arrows) from hydrographic charts, and 50–75 cm/sec Damietta eddy current (arrows) after Murray et al. (1980).

beach profiling, sediment analysis and wave measurements. The profiling includes 70 ranges extending over the 200 km of Nile Delta shoreline (see Khafagy et al. this proceeding), about 80 % of which were measured twice annually. Measurements during the early winter quarter of the year (October-December) were initiated under a previous UNDP/UNESCO study and, as used in this study, extended over the 18-year period from 1971 to 1988. Measurements during the spring quarter (April - June) extended from 1976 to 1988. These profiles were surveyed to depths of 6 m or distances of 1 km, whichever occurred first.

Sediment sampling accompanied the profile surveying. Samples from the beach face at MSL show a mean grain size of about 250 μm from Rosetta east, coarsening to 340 μm off Burullus and returning to 250 μm in the Baltim segment. Much finer sand, 150 μm, occurs on the Manzala barrier beaches, suggesting that the longshore transport coupling between the Manzala barriers and the Burullus-Baltin area is far from direct.

Wave arrays are located on an oil platform off Abu Quir Bay and in depths of 6 m off Ras el Bar on Damietta promontory. Both are three element arrays that provide wave directional-frequency spectra (Lowe et al. 1972). The Abu Quir array became operational in 1982/83 and the Ras el Bar array in 1985 (Lowe and Inman 1984; Elwany et al. 1988). The arrays show that the predominant waves are from the northwest to west-northwest and the wave climate is characterized by $1/2 \leq H_s(m) \leq 3$ and $3 \leq T_p(s) \leq 8$, where H_s is the significant wave height and T_p is the peak spectral period.

SHORELINE CHANGES

Analysis of the 18 years of profiling along the 70 Nile Delta ranges shows that there are some sections of long-term erosion and accretion while, in other sections, the shoreline exhibits large cyclic changes with periods of 3 - 8 years, but undergoes little net long-term change. An "end-point" analysis of shoreline change over the 18 years is shown in Figure 2 together with the standard deviation of change. The end-point procedure gives

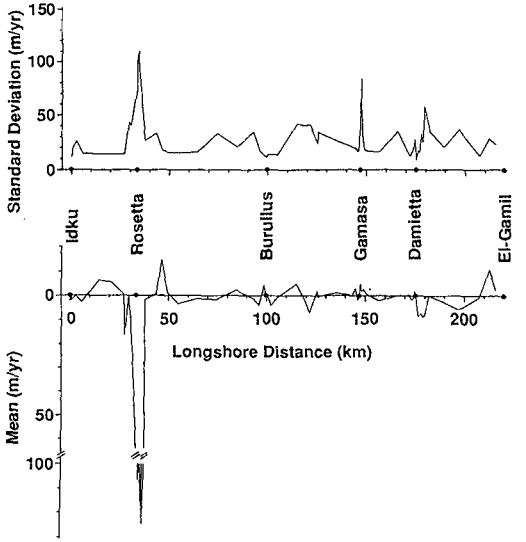

Figure 2. Mean shoreline change rate along the Nile Delta for the survey period 1971-1988 (below) and the standard deviation of the data set (above).

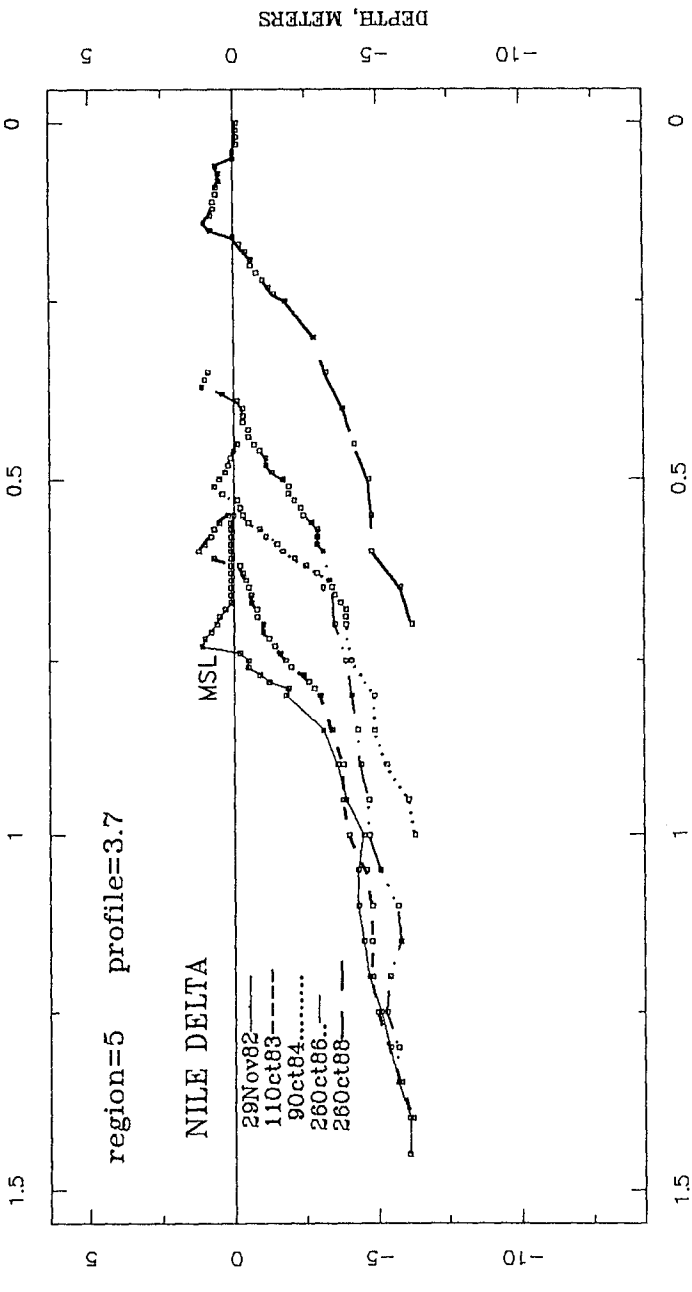

Figure 3. Shoreline retreat of 90 m/yr shown by successive surveys on Rosetta promontory.

valid information where the change in shoreline follows a continuous trend as in Figure 3, but ean give biased results when there are cyclic changes in trend, as shown in Figure 4 (e.g., Dolan et al. 1991).

Inspcetion of Figure 2 shows that thc primary loeus of erosion is from Rosetta promontory. Volume changes down to the 6 m depths surveyed give the erosion rate as 5 million m^3/yr. Since the erosion elearly extends to greater depth, and the profile is steepening as it recedes (Figure 3), a conservative estimate is about 10 million m^3/yr. This material is transported easterly along the delta coast by waves and currents. The strong eurrents, whieh may reach their near-bottom velocity maximum in depths of 10 to 30 m, are also likely eroding sediments from thcse deeper portions of the shelf.

SAND TRANSPORT

There appear to be two interrclated sand transport mechanisms with somewhat different paths along the Nile Delta coast: a *longshore* and a *coastal current* transport path. The classical longshore sand transport is most intense in and near the surf zone, and is driven by the waves and wave-induced longshore currents. Along the Nile shoreline the longshore sand transport is eastward at rates of about 1 million m^3/yr (lnman and Jenkins 1984).

A coastal current transport path of sand appears to be primarily driven by the easterly-flowing east Mediterranean gyre that attains velocities of up to 100 em/sec over the shallow shelf. This transport is undoubtedly enhaneed by wave action, partieularly during storms when 3-m-high, 8-sec-period waves can move sand in depths of 40 m. However, the sediment distribution and coastal current measurements (e.g., U.S. Hydrographic Chart 56100) suggest that this transport oceurs in a band about 5 to 10 km wide centered around depths of 10 to 15 m. Clearly this transport path is earried to mueh greater depths by the trapped jet off Damietta promontory (Figure 1). Consideration of the overall budget of sediment suggests that the eoastal eurrent system may transport sand at rates of 10 to 20 million m/yr along the coast. The coastal transport of sand along the southern California eoast, which is largely wave-driven, appears to be about 10% of the longshore transport rate (Inman and Masters 1991). Along the Nile Coast, the eoastal current transport is likely an order of magnitude larger than the longshore transport rate.

Pronounced changes in downcoast orientation, as at Damietta promontory, produce large, standing eddies. However, more gradual changes in orientation, as off Burullus, appear to result in a downcoast eurrent divergence or spreading out and a decrease in velocity. This divergence results in a loeal deerease in the coastal sediment transport rate and the aceretion of sand. This may, in part, explain thc formation of the Damietta Banks west of Damietta promontory and the formation of the extensive Baltim dune field (Figure 1). This zone of sand accretion also appears to be a contributing factor in the formation of aecretion and erosion waves along the shoreline east of Burullus Inlet.

Accretion and Erosion Waves

Divergence of the eurrent downcoast from Rosetta and Burullus promontories results in formation of accretionary blankets of sand that episodically impinge on the shoreline. Downcoast from Burullus promontory, individual blankets of sand fonn 1 to 2 m thick covers over the residual beach profiles in depths of 4 to 6 m (Figure 5), and extend for 2 to 4 km along the shore. The sand blankets move progressively downcoast at rates of 0.5 to 1 km/yr, generating series of acerction/erosion waves that travel along the shoreline (lnman 1987). These rhythmie features are clearly visible in satellite imagery whieh shows the turbid plumes in their nearshore circulation pattern (lnman et al. 1976). Their overall shoreline aceretion to erosion patterns are shown in Figure 4 and their

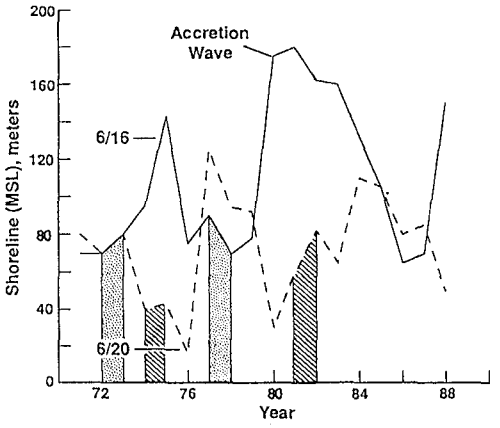

Figure 4. Accretion and erosion waves at ranges 16 and 20 km east of inlet to Burullus Lagoon. Vertical bars show initial impingement of sand blanket on profile. Compare with Figure 5.

temporal and spatial statistics listed in Table 1. The individual sand blankets impinging on the beach profile have volumes of about 2 to 5 million m^3.

The impingement of the sand blanket on the beach profile is relatively rapid, always appearing in its full thickness (~ 1.5m) between two annual surveys (Figure 5). The initial time of impingement is shown by the vertical bars in Figure 4. Thereafter the blanket gradually thins while the shoreline accretes. After several years the blanket migrates downcoast, and the shoreline erodes back to its former width.

The Residual Equilibrium Profile

When the accretionary phase of the wave has passed downcoast, the shoreline returns to its previous form and exhibits a "residual" profile. In its residual form, the beach profile goes through characteristic adjustments to seasonal wave climate, exhibiting an equilibrium winter profile with a pronounced bar and a summer profile when the bar tends to migrate onshore (Figure 6a,b). When the nearshore is blanketed with sand during the accretionary part of the cycle, the profile is in disequilibrium with wave forcing and frequently shows several, irregularly spaced bars and troughs. Although the year to year shoreline changes associated with the accretion/erosion waves are large, O(50 m/yr), the long-term (decadal) changes based on successive residual profiles from the erosion portion of the cycle are relatively moderate, say O(2 m/yr).

Table 1. Accretion and Erosion Waves East of Burullus Promontory[a]

Range[b]	6/11	6/16	6/20
Cycle Period[c], years	6	7	6
Mean Double Amplitude[d], meters	120	90	95
Number of Surveys[e]	15	15	17
Cycle Phase in 1978	Accretion max	Erosion max	Accretion max

[a] Data source: Cooperative Marine Technology Program for the Middle East, U.S. AID, Coastal Research Institute, Alexandria, Egypt.
[b] Profiles are from region 6 and their range (double digit number) indicates their distance in km east of Burullus Inlet
[c] Crest to crest propagation time
[d] Mean crosshore change from maximum accretion to erosion
[e] Survey period 18 years extending from 1971-1988

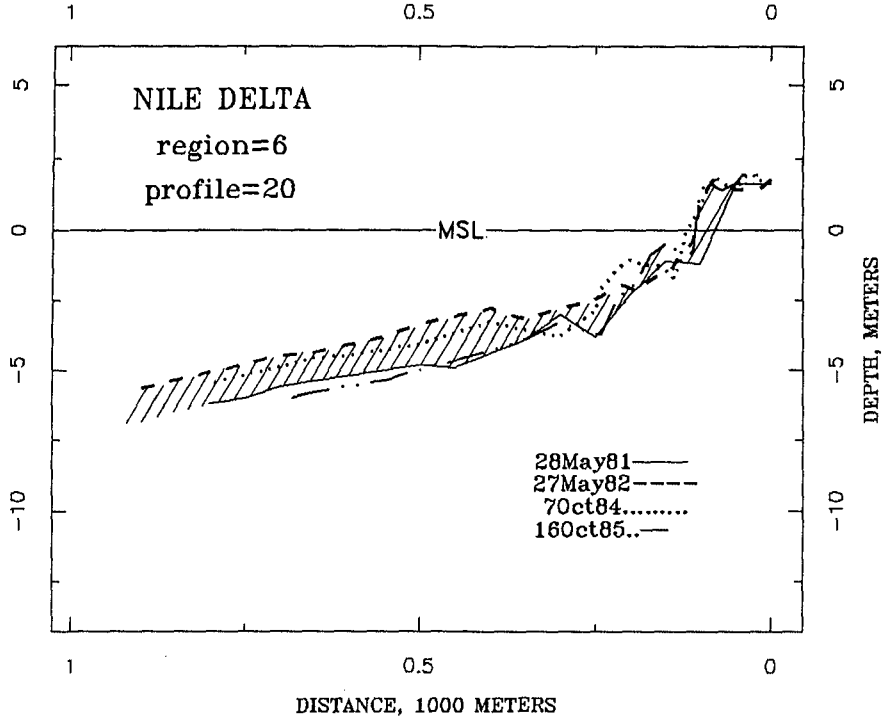

Figure 5. Comparative surveys showing impingement of 1.5 m thick blanket of sand between surveys of 1981/82 on range 20 km east of Burullus Inlet.

The best-fit form for the equilibrium profile follows that suggested by Inman et al. (in press). Their model consists of two contiguous curves, an offshore (shorerise) portion joined at the breakpoint bar with the onshore (bar-berm) portion (Figure 6). Both portions of the profile are well-fitted by parabolic curves of the form $h = Ax^m$ where h is positive

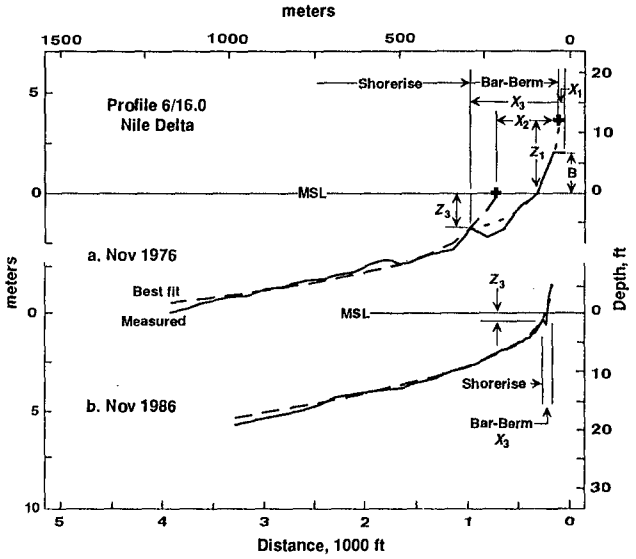

Figure 6. Profiles and definition sketch for compound parabolic curve fitting. Parameters are listed in Table 2.

downward and x is the positive offshore coordinate (Table 2). It was found that the compound parabolic curves gave the best fit, especially when there was a longshore bar present as in Figure 6a. However, when the bars migrate onshore leaving a reasonably "smooth" profile as in Figure 6b, then a single-fit parabolic curve gives reasonable good fit as shown in Figure 7 and Table 2.

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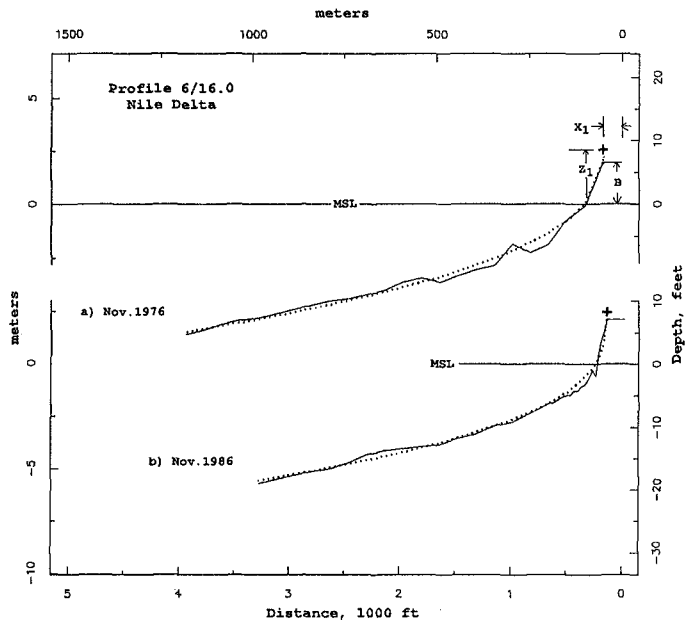

Figure 7. Profiles and single-fitted parabolic curves. Parameters defined in Figure 6 and listed in Table 2.

Table 2. Best-fit Curves of Form $h = Ax^m$ for Profile Range 6/16

Date	Bar-Berm[a]							Shorerise[a]		
	X_1	Z_1	A_1	m_1	X_3	B	Z_3	X_2	A_2	m_2
Compound-Fitted Curves										
Nov76	37	3.0	0.24	0.32	280	2.0	2.0	234	0.64	0.49
Nov86	50	2.4	0.70	0.40	40	2.0	0.7	32	0.21	0.48
Single-Fitted Curves (Berm and Shorerise)										
Nov76	48	2.7	0.63	0.38		2.0				
Nov86	40	2.4	0.74	0.35		2.0				

[a] Symbols defined in Figure 6; all dimensional units in meters.

REFERENCES

Carmel, Z., Inman, D. L., and Golik, A. (1985). "Directional wave measurement at Haifa, Israel, and sediment transport along the Nile littoral cell," *Coastal Engineering*, 9, 21–36.

Coleman, J. M., Roberts, H. H., Murray, S. P., and Salama, M. (1981). "Morphology and dynamic sedimentology of the eastern Nile delta shelf," p. 301–329 in C. A. Nittrouer (ed.), *Sedimentary Dynamics of Continental Shelves*, Elsevier, Amsterdam and New York, 449 pp.

Dolan, R., Fenster, M. S. and Holme, J. (1991). "Temporal analysis of shoreline recession and accretion," *Jour. Coastal Research*, 7(3), 723-744.

Elwany, M. H. S., Khafagy, A. A., Inman, D. L., and Fanos, A. M. (1988). "Analysis of waves from arrays at Abu Quir Ras El-bar, Egypt," p. 89-97 in *Oceanology '88*, Advances in Underwater Technology ... Society for Underwater Technology (Graham & Trotman, London), 16, 304 pp.

Fishawi, N., Fahmy, M., Sestini, G., and Shawki, A. (1976). "Grain size of the Nile Delta beach sands," p. 79–94 in UNDP/UNESCO, *Proc. Seminar Nile Delta Sedimentology*, Academy Scientific Res. and Technol., Cairo, 257 pp.

Hecht, A. (1964). "On the turbulent diffusion of the water of the Nile floods in the Mediterranean Sea," *Sea Fisheries Research Station, Haifa, Bull.*, (36), 24 pp.

Inman, D. L. (1987). "Accretion and erosion waves on beaches," *Shore & Beach*, 55(3/4), 61–66.

Inman, D. L., Aubrey, D. G., and Pawka, S. S. (1976). "Application of nearshore processes to the Nile Delta," p. 205–255 in UNDP/UNESCO, *Proc. Seminar Nile Delta Sedimentology*, Academy Scientific Res. and Technol., Cairo, 257 pp.

Inman, D. L., Elwany, M. H. S., and Jenkins, S. A. (submitted). "Shorerise and bar-berm profiles on ocean beaches," *Jour. Geophysical Res.*

Inman, D. L., and Jenkins, S. A. (1984). "The Nile littoral cell and man's impact on the coastal zone of the southeastern Mediterranean," *Proc. 19th Conf. Coastal Engineering Conf.*, Amer. Soc. Civil Engrs., 2, 1600–1617.

Inman, D. L., and Masters, P. M. (1991). "Budget of sediment and prediction of the future state of the coast," Chap. 9 (105 pp.) in *State of the Coast Report, San Diego Region, Coast of California Storm and Tidal Waves Study*, U. S. Army Corps of Engineers, Los Angeles District, Chapters 1-10, Appen. A-Q.

Lowe, R. and Inman, D. L. (1984). "Wave parameters, Abu Quir Array, Egypt," *Univ. of California*, Scripps Inst. Oceanography, SIO Reference Series 84-32, 5 pp., tbl + fig.

Lowe, R. L., Inman, D. L., and Brush, B. M. (1972). "Simultaneous data system for instrumenting the shelf," *Proc., 13th Conf. Coastal Engineering*, Amer. Soc. Civil Engrs., 1, 95-112.

Misdorp, R. (1977). "The Nile promontories and the Nile continental shelf," p. 456–551 in UNDP/UNESCO, *Proc. Seminar Nile Delta Coastal Processes*, Academy Scientific Res. and Technol., Cairo, 624 pp.

Murray, S., Coleman, J. M., Roberts, H. H., and Salama, M. (1980). "Eddy currents and sedimcnt transport off the Damietta Nile," *Proc. 17th Coastal Engineering Conf.*, Amer. Soc. Civil Engrs., 2, 1680–99.

Murray, S., Coleman, J. M., Roberts, H. H., and Salama, M. (1981). "Accelerated currents and sediment transport of the Damietta Nile promontory," *Nature*, 293(5827), 51–54.

Neev, D., Almagor, G., Arad, A., Ginzburg, A., and Hall, J. K. (1976). "The geology of the southeastern Mediterranean," *Geological Survey of Israel Bull.*, (68), 51 pp.

Oren, O. H. (1952). "Some hydrographic features observed off the coast of Israel," *Inst. Oceanography Monaco, Bull.*, (1017), 10 pp.

Sestini, G. (1976). "Geomorphology of the Nile Delta," p. 12–24 in UNDP/UNESCO, *Proc. Seminar Nile Delta Sedimentology*, Academy Scientific Res. and Tcchnol., Cairo, 257 pp.

Stanley, D. J. (1988). "Subsidence in the northeastern Nile Delta: rapid ratcs, possible causes, and consequences," *Science*, 240, 497–500.

Stanley, D. J., Warne, A. G., Davis, H. R., Bernasconi, M. P., and Chen, Z. (1992). "Nile Delta, the late Quaternary north-central Nile Delta from Manzala to Burullas Lagoons, Egypt," *National Geographic Res. & Explor.*, 8(1), 22–51.