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Letter Section

Recent subsidence and northeast tilting of the Nile delta, Egypt

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ABSTRACT

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Sediment borings collected in the Nile delta of Egypt, many of them radiocarbon dated, indicate that the entire northern sector of this major depositional center in the eastern Mediterranean is presently subsiding. Mapping of the base of the Holocene deltaic facies, which is dated at about 8000–6500 yrs B.P., reveals that differential lowering of the northern delta plain is preferentially accentuated toward the northeast. Long-term subsidence rates at or near the coast, averaged for the mid- to upper Holocene, range from about 0.1 to 0.25 cm/yr between Alexandria and the north-central delta margin. Rates increase markedly eastward to a maximum of about 0.5 cm/yr in the Port Said–Manzala lagoon region, and this rapid lowering explains the presence of thick marine delta lobe sequences of Holocene age in cores in the northeastern delta. In contrast, only reworked remnants of Holocene marine delta lobe deposits of the earlier River nile branches which once flowed to the north and northwest are preserved seaward of the present north delta coast. Subsidence has induced marked environmental changes, particularly with respect to coastal erosion and salt water incursion. The asymmetric pattern of saline ground water, here attributed in part to the northeast tilt of the delta plain, has serious implications for agricultural development in this intensely cultivated region.

Introduction

The present study is the first systematic survey of long-term (post-mid-Holocene) subsidence trends across the entire northern Nile delta plain in Egypt. The weight of sediment sequences deposited at coasts by important rivers and concentrated as thick deltaic wedges has generally resulted in subsidence of the underlying crust (Kuenen, 1950; Coleman, 1982). In the case of the Nile delta, both faulting and compaction of deeply buried strata contributes to the sinking movement of the delta surface and contiguous continental margin (Ross and Uchupi, 1977; Said, 1981; Stanley, 1988; Sestini, 1989).

The arcuate Nile delta coast is approximately 300 km long (Fig. 1). In the study area are positioned four lagoons (from east to west, Manzala, Burullus, Idku and Maryut), extensive coastal ridges and dunes, localized salt flats, and the promontories of the two major River Nile branches (Rosetta and Damietta) that extend well into the Mediterranean (UNDP/UNESCO, 1976). The northern delta is dissected by a series of canals and drains, some of which trace earlier Nile distributary paths (Toussoun, 1922; Said, 1981).

A previous investigation focusing on the low-lying (little more than 1 m above sea level) Port Said–Suez Canal–Manzala lagoon region has shown that this northeastern delta region has been subsiding at averaged long-term rates to 0.5 cm/yr (Stanley, 1988). It has been esti-

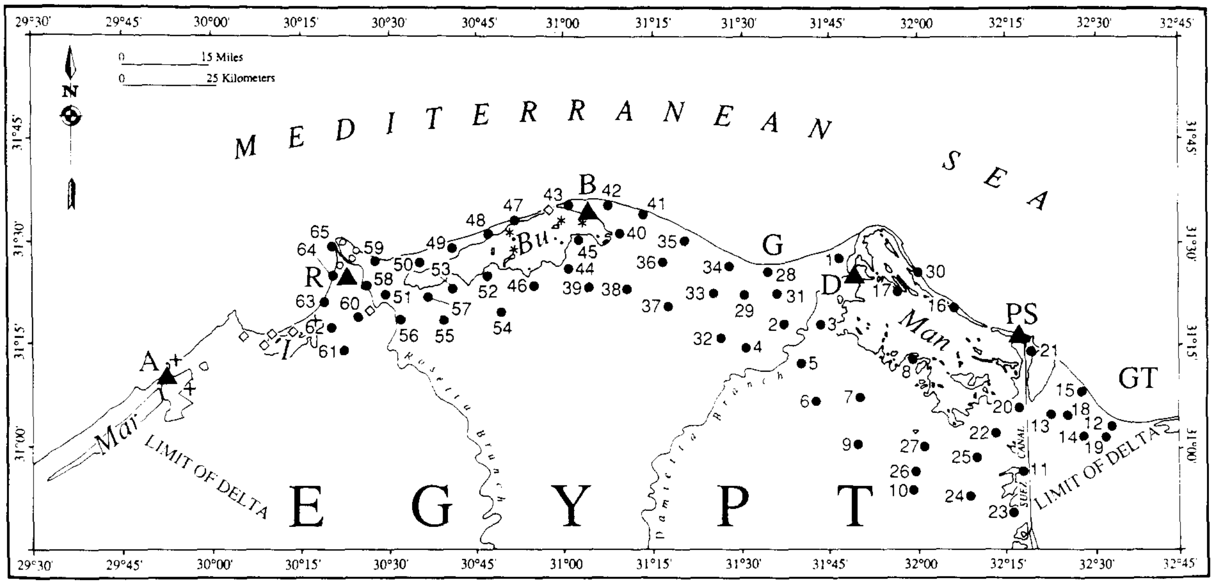

Fig. 1. Map of the northern Nile delta showing positions of sediment borings: ● Smithsonian cores S-1 to S-65 (in MEDIBA, 1990); ∗ cores in Burullus lagoon (in Anonymous, 1966); ○ cores in Rosetta promontory (in Frihy and Stanley, 1988); ◇ cores in the Idku region (in Sestini, 1989); +western delta engineering borings. *A* = Alexandria; *R* = Rosetta; *B* = Baltim; *G* = Gamasa; *D* = Damietta; *PS* = Port Said; *GT* = Gulf of Tineh. Lagoons: *Mar* = Maryut; *I* = Idku; *Bu* = Burullus; *Man* = Manzala.

mated that acting together, subsidence, eustatic sea level rise, and the now-reduced sediment supply (since closure of the High Aswan Dam in 1964) could cause a relative rise in sea level above the northeastern delta plain to about 1 m by the year 2100. This incursion would submerge much of the delta in the Manzala lagoon region to as far south as 30 km from the present coast.

To date, the aerial extent affected by this coupled land subsidence–sea level rise phenomenon has remained poorly defined. If widespread across the northern delta, it would considerably affect present and planned agricultural, irrigation, channelization, land reclamation and urban development projects in this densely populated region. A rise in sea level over such a large , low-lying region would, for example, modify the course and flow patterns of the Damietta and Rosetta branches of the Nile and associated irrigation network, and alter the depth and salinity of ground water. At present, however, most data pertain to the northeastern delta while there is only limited and poorly distributed information on subsidence rates for the north-central and northwestern delta west of the Damietta branch of the Nile.

Data base and observations

Sixty-five sediment borings, ranging in length from 10 to 60 m, were recovered from this region during four Smithsonian Institution drilling expeditions (Fig. 1): fall 1985 (cores S-1 to S-17, Coutellier and Stanley, 1987; Frihy and Stanley, 1988), spring 1987 (cores S-18 to S-30, Stanley, 1988), fall 1988 (cores S-31 to S-46, Abu-Zeid and Stanley, 1990), and fall 1989 (S-47 to S-65). Approximately 250 radiocarbon dates (using total organic carbon in most samples) for cores S-1 to S-46 are now available (together with extensive listings of compiled textural and compositional data for >1500 core samples (MEDIBA, 1990)). In addition to these borings, about 100 core lithologic logs compiled by others (Attia, 1954; Anonymous, 1966; Anonymous, 1975; El Askary and Frihy, 1986; Sestini, 1989; also, lithologic soil borings and unpublished logs from diverse engineering studies) were consulted to enhance subsurface correlation in this region. The positions of some of these borings are shown in Fig. 1.

In most borings, a basal transgressive sand unit that is about 5–20 m thick and ranges in age from about 18,000 to 8,000 yrs B.P. (Sneh et al., 1986; Coutellier and Stanley, 1987) lies below the Holocene deltaic deposits (Fig. 2). These latter comprise dark olive muds of marine prodelta and delta-front facies (MDL in Fig. 2), and of organic-rich marsh, lagoonal and fluvial origin (D in Fig. 2). Upper Holocene sands of fluvial and coastal origin also occur in the upper parts of some cores (Attia, 1954; Sneh et al., 1986; Coutellier and Stanley, 1987). The base of the Holocene mud section is time transgressive, i.e. generally ranging from about 8000 to 6500 yrs B.P. and becoming younger landward (Table 1 and Fig. 2).

An isopach map depicting the thickness of the Holocene sequence above the basal transgressive sand unit has been derived from numerous borings (Fig. 3). This map also shows the distribution of dated proximal (coastal and lagoonal, D) deposits and of more distal open marine (delta-front and prodelta, MDL) facies relative to the present Nile delta coast between the Gulf of Tineh and Alexandria. The thickest Holocene deposits in the northern delta are almost coincident geographically with the position of Manzala lagoon and the lowlying sebkha terrain (< 1 m above mean sea level) east of the Suez Canal. Moreover, borings that contain the most complete Holocene sequence of sediment facies, including marine prodelta and delta-front muds, occur mostly to the east of the Damietta Nile branch. In this

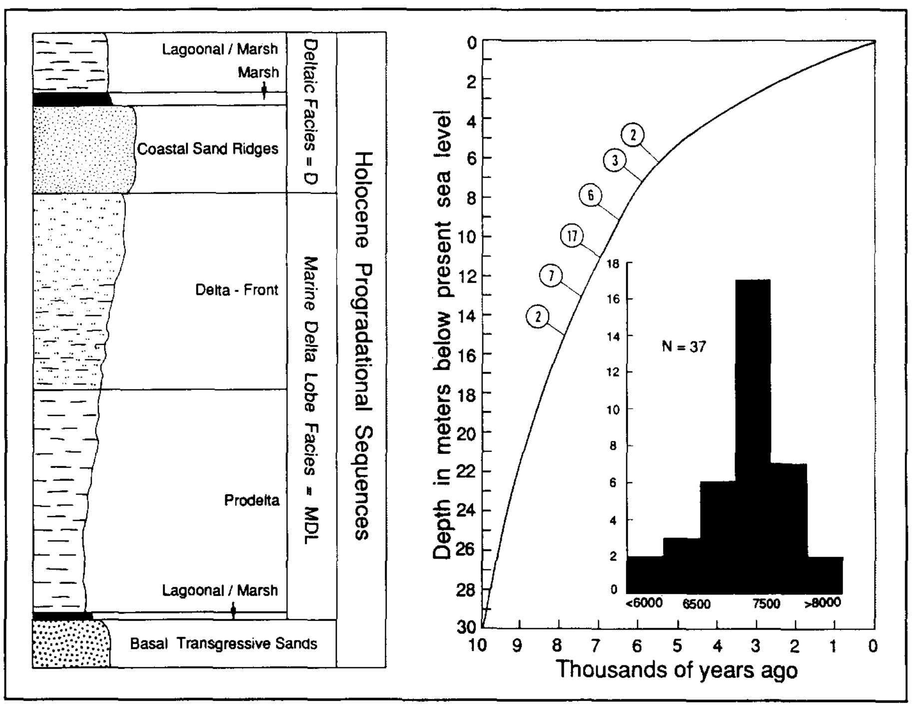

Fig. 2. Left: Generalized Holocene sequence on lithostratigraphic log showing MDL and D facies above basal transgressive sands. Right: Age of the base of the Holocene mud sequence above the transgressive sands. Histogram shows range of dates in yrs B.P., and these data are plotted on the eustatic sea level curve after Lighty et al. (1982).

TABLE I

Depth in meters to the top of the uppermost Pleistocene to lowermost Holocene transgressive sands in 65 Smithsonian cores in the northern Nile delta (Fig. 1). Radiocarbon dates are of the basal Holocene muds above the transgressive sands

Core	Depth (m)	Radiocarbon date (yrs B.P.)	Core	Depth (m)	Radiocarbon date (yrs B.P.)
S-1	24	7590±130	S-34	14	6710±190
S-2	14.5	7110±70	S-35	22	7260±110
S-3	26	7180±110	S-36	15	7080±120
S-4	14.5	7020±120	S-37	13	6870±170
S-5	29	7500±110	S-38	13	7210±130
S-6	18	7790±110	S-39	3	
S-7	10	7610±90	S-40	15.5	7450±120
S-8	40	7300±110	S-41	19	>6630±250
S-9	4.5	>5140±80	S-42	23	7410±100
S-10	0		S-43	14.5	
S-11	14	6475±90	S-44	10.5	>6370±180
S-12	13.5	7280±490	S-45	13	7100±160
S-13	>30	>7150±110	S-46	9	6620±70
S-14	~5 (?)		S-47	26	
S-15	31	7430±100	S-48	15	
S-16	23.5	7700±110	S-49	15	
S-17	>43	7850±100	S-50	24	
S-18	27	7400±80	S-51	12	
S-19	9.5		S-52	12	
S-20	43	7360±90	S-53	11	
S-21	47	8140±130	S-54	10	
S-22	22	7540±70	S-55	9	
S-23	1.5		S-56	8	
S-24	1.0		S-57	12	
S-25	>14	>6210±100	S-58	16	
S-26	2.5		S-59	27	
S-27	10	6560±90	S-60	12	
S-28	23.5	7230±80	S-61	16	
S-29	9		S-62	17	
S-30	27.5	8040±250	S-63	19	
S-31	27	6880±80	S-64	20	
S-32	12	7100±130	S-65	>50	
S-33	12.5	>5500±190			

region, Holocene sediment accumulated at rates locally as high as 0.6 cm/yr (Coutellier and Stanley, 1987). Isopachs define a fault-bound rhomboidal basin with distinct NE- and NW-trending margins. It has been proposed that the rhomb-shaped feature formed as a graben during the Quaternary in association with reactivation of NE-trending faults that border the Manzala lagoon area (Stanley, 1988). Continued development of this structure during the late Pleistocene and Holocene would account for the very high subsidence rates in the northeastern delta.

Isopach contours on the outer Damietta and Rosetta promontories reveal moderately thick (>30 m) accumulations of Holocene deposits. However, along most of the coast, from west of Rosetta to Gamasa, the 20 m contour roughly parallels the coast. A distinctive trend is also denoted by the base of Holocene deposits lying between 10 and 15 m. These contours approach the coast in the north-central part of the delta, at the eastern Burullus lagoon and west of Baltim. Here the width between these two contours is about 20 km, recording a very gentle seaward gradient (1:4000). In contrast, the width between the two contours narrows to 5 km or less south of Idku and Manzala lagoons, indicating an increased seaward slope (1:1000) in the northeastern and northwestern delta.

Subsidence rates and regional tilt

In calculating subsidence rates, subsidence due to compaction (compression/dewatering) of rapidly deposited sediments should be distinguished from subsidence due to isostatic displacement and offset by faulting. Compaction has occurred in the pre-Holocene sediments as is evident by stiff, brown, alluvial mud of late Pleistocene age (Coutellier and Stanley, 1987; Abu-Zeid and Stanley, 1990) and by consolidated Tertiary deposits (Zaghloul et al., 1977). Measurements of physical properties of the Holocene muds (MEDIBA, 1990) show that at all core sites they are underconsolidated and of low strength. Furthermore, peat layers, which are particularly prone to compaction in deltaic settings (Kosters et al., 1987), account for less than 5% of the total thickness of the Holocene core sections recovered in the northern Nile delta. The comparatively low compaction values for Holocene units throughout the study area cannot explain the marked re-

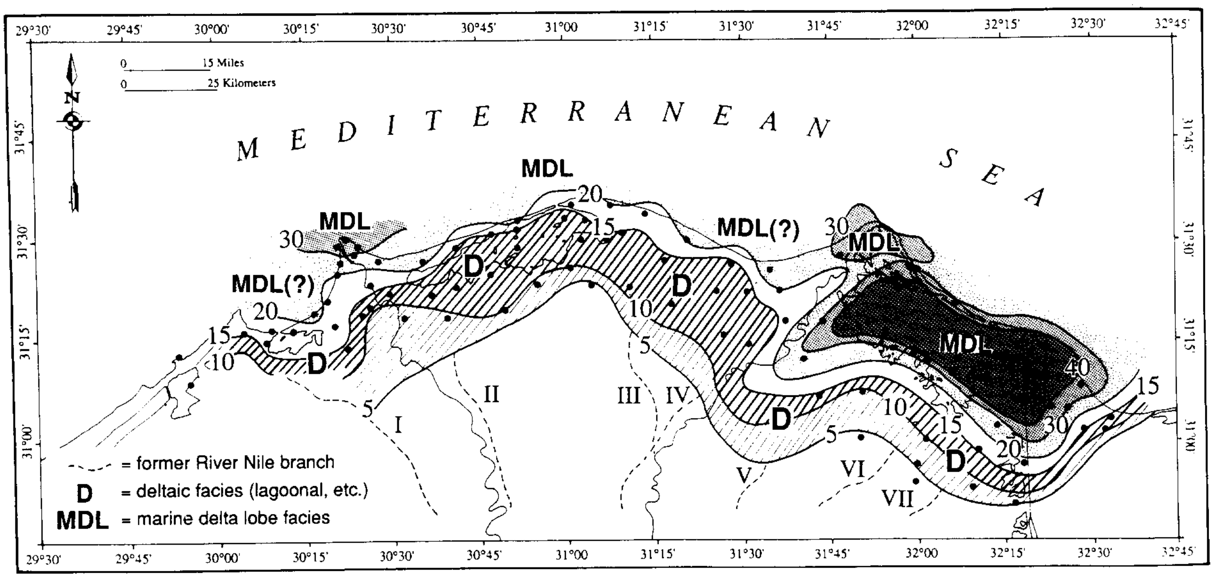

Fig. 3. Isopach map showing sediment thickness of mid-Holocene to present age lying above basal transgressive sands. D and MDL denote sediment facies depicted in Fig. 2. Contours in meters. Traces of former River Nile branches (after Toussoun, 1922, and Said, 1981): I = Canopic; II = Saitic; III = Sebennitic; IV = Bucolic; V = Mendesian; VI = Tanitic; VII = Pelusiac.

gional variations in Holocene sediment thickness mapped in Fig. 3.

Eustatic sea level change is a critical factor to consider in subsidence calculations. The radiocarbon-dated base (8000–6500 yrs B.P., Table 1) of Holocene coastal and nearshore mud sections is used here as a key stratigraphic horizon. This horizon, with a modal age range of 7500–7000 yrs B.P., is compared with depth below present mean sea level (msl) data plotted for this period on eustatic sea level curves (Fig. 2). Several such curves derived from an extensive data base (Lighty et al., 1982; Fairbanks, 1989) indicate that the basal mud horizon of this age (noted in 17 of 37 cores) accumulated when sea level was about 10–12 m below its present stand. This horizon ranges from 8000 to 6500 yrs B.P. in a larger series of cores (30 of 37) and would have formed between 9 and 13 m below present msl (Fig. 2). For calculations in this study, a date of 7500 yrs B.P. is assigned to the base of the deltaic mud facies which accumulated at a sea level stand of −12 m below present msl. These values provide conservatively low, averaged long-term subsidence rates applicable for the mid-Holocene to the present.

The lowest subsidence rates apply to a short stretch of the north-central coast in the eastern Burullus lagoon region where the Holocene section is only about 15 m thick. A lowering of the delta plain surface by about 0.04 cm/yr is calculated (15 m thickness minus 12 m lower eustatic stand equals about 3 m of measurable vertical land motion in 7500 yrs). Among much of the coast between Alexandria and Gamasa, rates are higher and range between 0.1 and 0.25 cm/yr. Comparable values were noted in the Alexandria region on the basis of tide-gauge values (El-Fishawi and Fanos, 1989) and also indirectly by measuring the depth of now-submerged Ptolemaic and Roman archaeological coastal structures (El-Sayed, 1988). Rates at the Rosetta and Damietta promontories are higher, ranging from about 0.25 to 0.35 cm/yr. Rates increase markedly east of Damietta, with values approaching 0.5 cm/yr in the Manzala lagoon–Port Said region (Stanley, 1988). It is of note that values of this magnitude are closely comparable to tide-gauge data at Port Said (0.48 cm/yr, cf. Emery et al., 1988).

Several stratigraphic and tectonic factors may be causing more rapid subsidence east of Damietta in the Manzala lagoon region. Isopachs of some Quaternary and Pliocene sections, plotted on the basis of deep petroleum borings in the delta (Said, 1981; Zaghloul et al., 1977), suggest that thick subsurface sequences of Tertiary age account for differential loading and weighting. Geophysical surveys seaward of the delta indicate that the northeastern African margin has been affected by listric faults and also a prominent NE-trending fault system. This latter, the Pelusium Line which is believed to have played a major role in formation of the southeastern Mediterranean basin, extends from the Levant directly to the Gulf of Tineh and probably into the Nile delta (Neev, 1977). It is suggested that reactivation of faults of the Pelusium or perhaps some other, yet to be defined, fault system has been responsible for continued and more rapid lowering toward the northeast in geologically recent time as well. Facies distribution patterns and the shallow depth (1–2 m) of Manzala lagoon indicate that deposition kept up with subsidence so that fluvial and marine deposits continued to accumulate on the delta margin during the Holocene.

Conclusions

This study shows that the entire northern Nile delta coastal plain is subsiding, but unevenly. The more rapid lowering of the eastern part of the delta was probably responsible for (a) the diversion and concentration of former distributary channels of the Nile (at least four major ones, IV–VII in Fig. 3) between the Damietta promontory and the Gulf of Tineh, and (b) for coalescence of their delta lobes in this region (Coutellier and Stanley, 1987). Other responses to the preferential northeastward tilting may include the increased size of lagoons from west to east (Idku, Burullus and Manzala), and development of the widest section (to 60 km) of Nile delta shelf between north of Damietta and the Gulf of Tineh.

There is indirect evidence that, during the Holocene, the north-central and northwestern delta margin that presently lies seaward of the coast on the inner and mid-shelf also subsided. Indication that lowering here was less than in the northeastern delta is provided by the absence of marine delta lobe (MDL) facies in cores collected along the coast in this region. The delta-front and more distal prodelta sequences forming delta lobes seaward of the once important N- and NW-flowing Canopic, Saitic and Sebennitic Nile branches (I–III in Fig. 3) were deposited north of the present coast. These have been considerably eroded and modified by coastal currents. The position of such remnant lobes, reworked and modified by coastal currents, is denoted by the offshore trends of surficial coarse sand (Summerhayes et al., 1978; El Askary and Frihy, 1986) and configuration of terraces on the inner and mid-shelf (UNDP/UNESCO, 1976).

Emplacement of the Aswan High Dam in 1964 has cut off a major part of the fluvial sediment supply. As a result, strong, predominantly eastward directed coastal currents are eroding some extensive sections of the Nile delta and Sinai coasts (Smith and Abdel-Kader, 1988; Stanley, 1989). Acting together, subsidence (compactional and tectonic mechanisms), eustatic sea level rise, and the reduced sediment supply could cause a relative rise in sea level of 0.6–1 m or more, depending on the specific northern coastal sector site, by the end of the next century. This study confirms that unprotected sectors of the two Nile promontories and large parts of the coast from eastern Burullus lagoon to east of Port Said will be subject to continued accelerated erosion. Those delta plain sectors in these areas without coastal protection structures will be affected by progressive inundation by the sea, encroachment by coastal dunes (such as along the Baltim–Gamasa stretch), sebkha salt pan formation (such as south and east of the Manzala lagoon), and increased ground water salinities. With regard to the latter, the present distribution of saline ground water is asymmetric and most extensive in the northeastern delta (Shata and El-Fayoumy, 1970). It is proposed here that this pattern, with its direct consequences for the intensely cultivated delta, is a function of landward incursion of the sea, preferentially from the northeast. Unless checked, migration of saline water is expected to increase toward the south and southwest.

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