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Textural Facies of Recent Sediments North of Sinai, Southeastern Mediterranean, Egypt

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ABSTRACT

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Previous studies of the distribution of shelf sediments in the southeastern Mediterranean Sea have largely overlooked the sector off Sinai, East of the Nile delta. This study attempts to define more precisely the type of marginal sediments and their facies distribution in this sector of the Levantine Sea. The distribution of sediments in the study area are governed by the following: (1) the source of the sediments, (2) the topography of the area, (3) the current regime and (4) the net sediment transport. Sand is present in the innershelf area off Damietta and becomes mixed with silt in most of the innershelf zone. Silty clay forms an almost continuous belt across the slope north of Tineh bay and through the upper slope and outer shelf of the east sector of Bardawil Lagoon. Silty clay also covers the inner shelf area between Port Said and El-Tineh. Clay-mixed silt covers the inner shelf area off Damietta and Port Said. Silt forms an almost unbroken stretch across the upper slope north of Damietta and extends as far as the middle and outer shelf off Bardawil Lagoon. Most of the area sediments are of Nilotic sources; however, the non-nilotic sources from northern Sinai are also recognized.

ADDITIONAL INDEX WORDS: *Nile delta, southeastern Mediterranean, sediments distribution, Sinai, Egypt, Levantine basin.*

INTRODUCTION

Few areas of the modern world have such a rich and varied history, both geologically and archaeologically, as the lands bordering the eastern Mediterranean Sea. The principal factors in modeling the sedimentary framework of the Egyptian continental margin are the Nile River and the deposition of a sequence of evaporites during the Messinian (Ross and Uchupi, 1977).

Until the emplacement of the High Dam at Aswan in 1965, most of the sediments supplied to the southeastern Mediterranean region was transported northward by the main Nile and then across the Nile delta to the coast by its two distributaries, the Rosetta and the Damietta branches. Initially the distributaries of the Nile delta were numerous extending as far eastward as the old Pelusiac branch, which emptied into the Bay of El-Tineh. Seven branches were known in historical times, five of them had silted up. Only Damietta and Rosetta are active but have limited flow because of the construction of Aswan High Dam (Mahmoud, 1990). At present the Damietta distributary is completely blocked; hence, no more sediments are being delivered from this river's mouth (Mahmoud, 1990).

Since the sudden reduction of sand furnished by the Nile River in 1965, substantial volumes of sediments have continued to be supplied to the Mediterranean by erosion of extensive coastal sectors of the Nile delta (Stanley, 1989). According to Milliman *et al.* (1989), erosion around the mouth of the Nile River began in 1904, after construction of the Aswan Low Dam. Prior to construction of the High Dam, erosion off the Rosetta and Damietta headlands was 18 to 33 m yr^{-1}; afterwards it increased to 143–160 meters. Some of the delta shoreline is still accreting. The Nile River is the dominant sediment source for the eastern province of the Levant Basin, with secondary wind-borne deposits coming from northern Sinai (Emery and Neev, 1960; Nir, 1984). Predominant marine transport, at present, is easterly directed along the Nile delta and coast of Egypt, and on the Nile delta and Sinai shelves (Stanley, 1989).

Previous reconnaissance studies of the shelf sediments off the Nile delta were done by several authors (*e.g.*, El-wakeel and El-Sayed, 1978;

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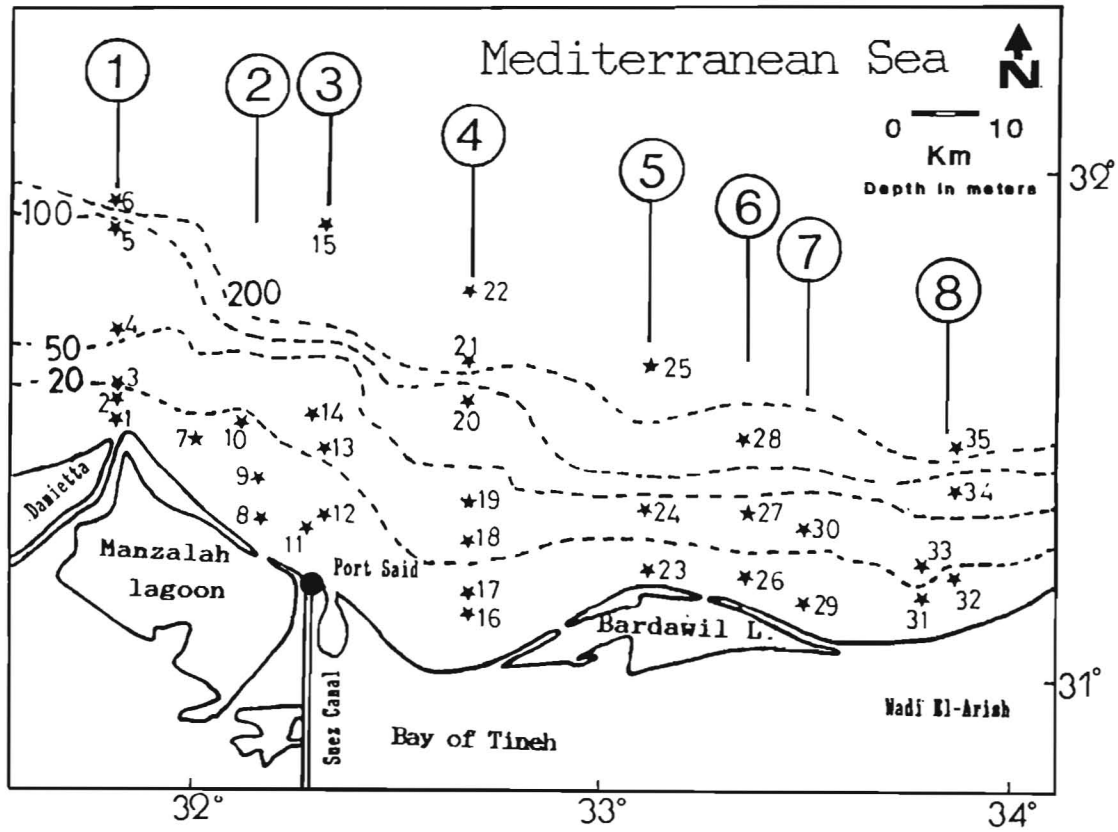

Figure 1. Area of study and stations sampled. (1) Damietta, (2) El-Gamil, (3) Port Said, (4) El-Tineh, (5) El-Bardawil I, (6)El-Bardawil II, (7) El-Bardawil III, and (8) El-Arish.

EL-WAKEEL *et al.*, 1974; SUMMERHAYES and MARKS, 1976; SUMMERHAYES *et al.*, 1978; STANLEY and WARNE, 1993). Regarding the spatial distribution and sedimentary facies off the Nile delta, EL-ASKARY and FRIHY (1986) mentioned that the near-shore facies is restricted to depths shallower than 30 m in depth, which is a delta front platform covered with fine to very fine sand and an admixture of sand and silt further seaward (offshore). Prodelta mud which is composed of silt and clay extends almost as far as the shelf edge. Scattered patches of relict, medium to coarse sand occur near the middle of the shelf. Seaward, there is a broad muddy sand zone of high organic silty clay and clay.

Most of the previous studies on the eastern sector of the Egyptian continental shelf, off Sinai, dealt with sediment transport (ALMAGOR and GARFUNKEL, 1979; GOLDSMITH and GOLIK, 1980; ROCHRLICH and GOLDSMITH, 1984; STANLEY, 1989; GOLIK, 1992), radionuclide of the sediments (YANAKI and KRONFELD, 1982) and on the sediment accumulation rate and erosion (STANLEY, 1988). EL-SABROUTI *et al.* (1988) did a sketchy study of the types of sediments covering this sector; however, the small number of the samples (16) creates several gaps in their sediment distribution map. The present study focuses on the task of filling this gap. Consequently, a thorough sedimentary facies map for the marginal area off the Sinai, east of Damietta, will be constructed.

MATERIALS AND METHODS

Through the period from 1982–1986, several cruises were carried out using the Egyptian R/V Nour Ya Nabi to the southeastern Mediterranean off the Egyptian coast. The area surveyed (Figure 1) covers the continental shelf and part of the

Table 1. *Types of sediments in different stations sampled.*

Station	Section	Depth (m)	Sediment Type
1	Damietta	9	Sand
2	Damietta	19	Sand
3	Damietta	20	Silt
4	Damietta	64	Silt
5	Damietta	88	Sand
6	Damietta	210	Silt
7	El-Diba	17	Clayey silt
8	El-Gamil	2	Clayey silt
9	El-Gamil	9	Clayey silt
10	El-Gamil	18	Silty clay
11	El-Gamil/P. Said	12	Clayey silt
12	Port Said	15	Clayey silt
13	Port Said	27	Silty clay
14	Port Said	33	Silty clay
15	Port Said	240	Silt
16	El-Tineh	8	Silt
17	El-Tineh	11	Silt
18	El-Tineh	25	Silty clay
19	El-Tineh	33	Sand-Silt-Clay
20	El-Tineh	78	Silty sand
21	El-Tineh	235	Silt
22	El-Tineh	445	Silty clay
23	El-Bardawil I	10	Sand
24	El-Bardawil I	35	Sand-Silt-Clay
25	El-Bardawil I	300	Silty clay
26	El-Bardawil II	14	Sandy silt
27	El-Bardawil II	46	Silt
28	El-Bardawil II	179	Silty clay
29	El-Bardawil III	9	Silt
30	El-Bardawil III	30	Silty clay
31	El-Arish	14	Silty sand
32	El-Arish	16	Silty sand
33	El-Arish	31	Silty clay
34	El-Arish	58	Sandy silt
35	El-Arish	246	Sandy silt

upper continental slope of the south eastern Mediterranean Sea between 2 m and 445 m. It extends from Damietta in the west to El-Arish in the east and lies between longitudes 31°54′ and 33°45′E. Thirty five sediment samples were collected using a Petterson grab sampler with a movable upper lid that covers surface area of 65 cm by 35 cm. The samples were collected along eight profiles more or less perpendicular to the coast, namely from west to east, Damietta, El-Gamil, Port Said, El-Tineh, El-Bardawil I, El-Bardawil II, El-Bardawil III, and El-Arish. Some additional stations were collected to cover the gaps between the main sections.

Detailed granulometric analyses were made by standard sieve and pipette methods. The sediment types were given according to the method of SHEPARD (1954).

DESCRIPTION OF SEDIMENT DISTRIBUTION

Table 1 shows the different types of sediments for the stations sampled. Mud, the finer terrigenous fractions, are found in two types of occurrence (Figure 2). First, silty clay formed an almost continuous belt across the slope, north of Bay El-Tineh (depth is 445 m), through the upper slope and outer shelf of the east sector of Bardawil lagoon (depths range from 79 to 300 m) to the middle and inner shelf of the eastern sector of Bardawil, *i.e.*, Bardawil III, and as far as El-Arish (depth is about 30 m). Silty clay also covers the Port Said/El-Tineh inner shelf district (that ranges from a depth of 18 m to a depth of 33 m). The second occurrence of mud as clayey silt covers the inner shelf realm, north of Lake Manzalah and around Damietta headland (depth ranges between 2 and 15 m).

On the other hand, silt formed an almost unbroken stretch across the upper slope and the shelf north of Damietta (depths range between 20 and 210 m). This silty belt extends as far east as the middle and inner shelf off Bardawil Lagoon (Figure 2). The upper continental slope north of Port Said, below 240 m depth is also covered by this silty girdle. The continuity of this silt belt is interrupted by notable patches of sand (off Damietta at a depth of 88 m) and silty sand (in front of El-Tineh at a depth of 78 m).

Sand also occurred as two patches (Figure 2), one at the Damietta inner shelf area (at a depth of 9 m). The other patch presents in front of El-Bardawil opening (at a depth of 10 m). The occurrence of sand admixed with silt, *i.e.*, silty sand and sandy silt patches, are found in the extreme east off El-Arish where silty sand covers the inner shelf zone, *i.e.*, depth ranges from 14 to 16 m (Figure 2). On the other hand, sandy silt blankets the middle, outer shelf and upper slope region at depths between 58 and 246 m. Another occurrence of sandy silt is a patch on the inner shelf of El-Bardawil II at a depth of 14 m. Finally, the inner and middle shelf expanse between El-Tineh Bay (Long 32°45′E) and El-Bardawil I (Long 33°10′E) is covered by a mixture of sand silt and clay (Figure 2).

DISCUSSION

The pattern of dispersal of sediments in the southeastern Mediterranean formed during the late Eocene–Oligocene. Terrigenous detritus, pre-

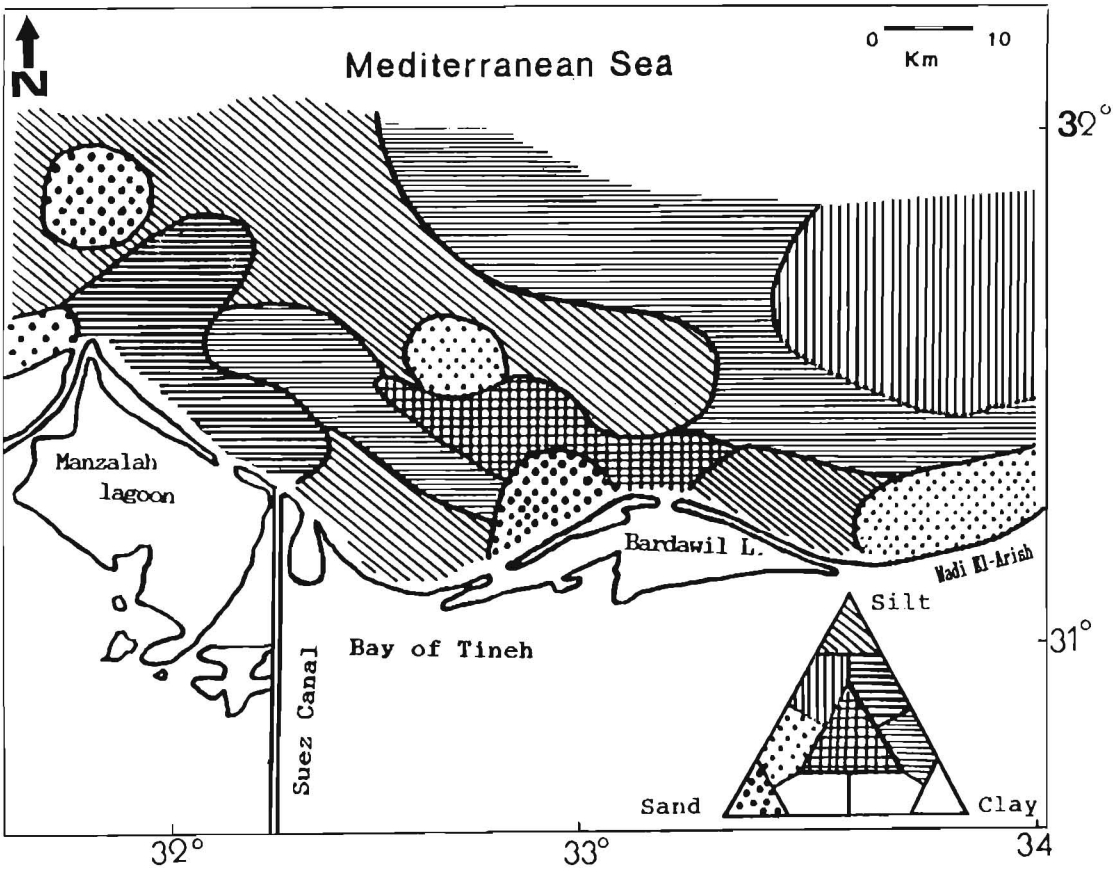

Figure 2. Areal distribution of sediments in the study area.

dominantly clay and silt, was deposited on the margins of the eastern Mediterranean during that period, the cladistics being largely derived from the African continent (ALMAGOR and GARFUNKEL, 1979). This pattern of dispersal was interrupted during the Messinian (7 to 5 Ma ago). During the early Pleiocene, sediments from the Nile, mainly silt and clay, built a large delta and submarine cone that dispersed over a large part of the southeastern Mediterranean. Some of these sediments were transported by a counter-clockwise current along the shore of the Sinai, where they accumulated to build the present coastal plain and continental margin. According to FRIHY (1990), the configuration pattern of facies assemblages of grain size distribution, faunal and floral components on the Nile Delta continental shelf, are related to former major distributary branches of the Nile and the premodern Rosetta and Damietta branches. Generally, the distribution of different sediment types in the study area is governed by: (1) the source of the sediments, (2) the topography of the area, (3) the general and local currents, and (4) the general pattern of sediments transport.

Considering the source of sediment in the investigated area, the bulk of sediments have been derived from Nilotic sources. Many authors (STANLEY, 1988, 1989; COLEMAN *et al.*, 1981; EL-SAMMAK, 1987; EL-SABROUTI and EL-SAMMAK, 1990; among others), affirm the non-Nilotic contribution east of the delta supplied by erosion of coastal cliffs and the innershelf, input from Wadis, and wind-borne deposits. The additional sources from those non-Nilotic sediments account for only a minor amount of the total sediments. The occurrence of mud between the Damietta and

El-Tineh innershelf might be related to the discharge of fine materials through lake openings and Nile branches. However, it is significant that this mud is not a direct product of the discharge from the Nile mouth; that is, muds are related to older mouths of the Nile. In general the large amount of fine fractions could possibly be of Nilotic sources, where most of the sediment discharged from the Nile mouths was silt and clay. Sand may have been in small proportion and was kept close to the shore (MISDROP and SESTINI, 1976). The occurrence of sand near Damietta promontory and north of Damietta, might be related to the older mouth of the Nile. The main location of terrigenous sand *i.e.*, north of Bardawil, appears to coincide with the older river mouth (Pelusiac branch discharging into the Bay of Tineh). This was an important axis of Nile discharging in Holocene time, where the sea level was lower than the present level and the coast was about 15–20 km to the north (MISDROP and SESTINI, 1976). Coastal sediments east of Bardawil lagoon appear to be influenced by addition of materials from Wadi El-Arish. According to STANLEY (1989), the heavy minerals on the Sinai shelf have been derived from Nile River sources, from recent lateral transport, exposure of relict littoral deposit and/or recent reworking by the offshore current of relict deposits and formations. Accordingly, sands admixed with the fine Nilotic materials off El-Arish can be interpreted as follows: (1) locally introduced sands displaced eastward, then northward, by wave induced longshore currents and then mixed with Nile sediments (STANLEY, 1989; GOLIK, 1992), and (2) by episodic input, by the Wadi El-Arish on the Sinai margin (NIR, 1984). Nevertheless, the Nile sediments on the shelf of the study area are derived from both modern sources and older sediments (Holocene and Pleistocene); where, since Holocene, the Neonile fine materials have been contributed to the Sinai shelf (ROCHRLICH and GOLDSMITH, 1984; STANLEY, 1989).

Regarding the submarine topographic features, the sand sediments of the Damietta middle shelf might also be associated with the flat part of Gamasa terrace and Damietta bank. On the other hand, mud is the characteristic sediment of the slope (upper slope, Damietta escarpment). The spatial distribution of sediment covering the shelf between Port Said and El-Bardawil seems to be harmonized with the submarine topographical features in this section. The Port Said/El-Bardawil shelf appears to be best defined by the 33 m isobath. The inner shelf is about 46 km wide. It is composed of an inner coastal slope to a 25–27 m depth and an outer zone of shallow basins and dome sand plateaux (MAHMOUD, 1990). According to MAHMOUD (1990), three basins each about 12 km across were observed in this stretch. Between these basins there are two main banks, the Port Said Bank, north to Port Said, and the El-Bardawil bank, north of the Bay of Tineh. It is important to note that the silty sand spot north of the Bay of Tineh is concurrent with the El-Tineh basin (Long 32°40′). According to ALMAGOR and GARFUNKEL (1979), the smooth physiographic zonation of the Northern Sinai is disrupted by several regions with a more complex topography. This may explain the patchy distribution of the sediments off Sinai.

Of note, the general current in the south eastern Mediterranean is directed eastward, as a result most of the Nile sediments are deposited in a NNE direction. East of Damietta the eastern current slows down and follows two directions, ESE with a velocity of 6 cm/sec and an opposite current with a velocity of 4.6 cm/sec (MOHAMED and ANWAR, 1978), making a wide vortex. As a result, most of the fine sediments carried by the current are deposited in the area between Damietta and El-Tineh. Furthermore, distinction in the net sediment transport due to longshore currents and geostrophic current flow (STANLEY, 1989), would explain the increase of fine materials offshore. The absence of sand in the outer shelf and upper slope is partially due to the failure of coarse materials to reach the outer shelf.

According to ROCHRLICH and GOLDSMITH (1984) wave action in the Nile delta can transport no more than $1–2 \times 10^6$ tons of sediments yearly. Thus, the ocean currents could have been a major transporting agency capable of handling the large part of the finer sediment load. In the past, the Nile transported sediments toward the northwest several orders of magnitude greater than either the longshore current system or the shelf current.

The impact of damming the Nile River, increasing coastal structures and habours and the coastal protection programme, will only have a small effect on net sediments transport. These man-made modifications will affect the dynamics of nearshore processes; hence, they will modify the sum of laterally displaced sediments. In view of the abundant suspended sediment noticeable in the post-Aswan imagery and the severe erosion of the Nile delta beaches, up to hundreds of m/yr

at Rosetta and Damietta river mouths (ROCHRLICH and GOLDSMITH, 1984), it is obvious that the short term transport will continue at the same rate. STANLEY (1989) uses the difference in heavy minerals species to confirm the human impact on the southeastern Mediterranean from the damming of the Nile River. The net sediment transport along the Sinai nearshore and shelf areas will also be directly affected.

CONCLUSIONS

The present study confirms that Nilotic sediments are the main source of sediments covering the shelf of Sinai; however, the non-Nilotic sources are also recognized. The Nilotic sediments came from recent deposits covering the shelf off the delta, as well as older and relic sediments from the innershelf and formations. Topography of the area plays an important role in sediments distribution; where fine materials are associated with slopes, sands occur in the flat-bottomed areas. The regime of currents in the area allows the patchy distribution of sediments. Differences in paths of net sediment transport (GOLDSMITH and GOLIK, 1980; INMAN and JENKINS, 1984; NIR, 1984; STANLEY, 1989) may explain the progressive increase of fine materials offshore. However, the fine materials will come from the inner delta shelf, remobilized by storm waves and perhaps by currents; the sand will be supplied mainly from the eroding delta beach. The extensive volume of finer sediments on the shelf will be transported from the shelf and from anticipated erosion of the marshes and lakes to the area behind the rapidly eroding barrier island. Extensive sedimentological studies on the continental margin east of Damietta (*i.e.*, off Sinai) are necessary to determine the processes dominating the Levantine basin.

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