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Department of Civil & Environmental Engineering
Hydraulic Engineering Laboratory, Report UCB/HEL 2009-1

THE NILE RIVER DELTA COAST AND ALEXANDRIA SEAPORT, EGYPT A BRIEF OVERVIEW OF HISTORY, PROBLEMS, AND MITIGATION

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Abstract

The main objective of the International Conference on Coastal Zone Management of River Deltas and Low Land Coastlines, Alexandria, Egypt, 6-10 March 2010 is/was to bring together engineers, scientists, managers, and officials and staff of government agencies (national and local) to address outstanding problems and programs associated with erosion/ accretion/ subsidence of shores of river deltas and other low land coastal areas. The venue is on the Nile Delta, southeastern coast of the Mediterranean Sea. The Port of Alexandria, and its ancient predecessors is probably the oldest in the world. This paper gives a brief history of the venue -- the delta and the ancient and present port of Alexandria. The delta has a large population, extensive irrigation-based agriculture, and industrial/ commercial/ municipal requirements. The delta has been affected by great decreases in the delivery of water and sediment to the sea (almost a total cessation) during the past half-century. This has resulted in major changes to the delta coast, many of them adverse. Nile Delta sedimentation, coastal processes, coastal erosion and accretion have been studied extensively for the past several decades. A *Shore Protection Master Plan for the Nile Delta* has been developed. Mitigation works have been recommended, and are in various stages of implementation; they are being monitored. Many of the studies of processes, procedures, and mitigations are cited herein.

Introduction

Many problems are associated with river deltas at ocean/sea coasts, and other coastal low lands (such as atolls; "non-delta" lagoons and contiguous land): subsidence, erosion, effects of dams and reservoirs, accretion/ growth, channel shoaling and path changes, sea water intrusion. Coastal zone management, the subject of this international conference, is required to solve many of the problems, and to cope with others. The author was asked to serve as Honorary Chairman of the conference, and was pleased to accept. Both the subject and the venue are of great interest. This paper was prepared as a welcome to the Conference.

River deltas are distributed world-wide, and are of considerable variety; a sampling is: Nile River Delta in the Mediterranean Sea; Mississippi River Delta, Gulf of Mexico; Rhine/ Meuse/ Scheldt Rivers (the Zeeland Delta), North Sea; Tigris/ Euphrates Rivers (Shatt et Arab River) Delta, Persian Gulf; Indus River Delta, Arabian Sea; Ganges-Brahmaputra-Meghna Rivers Delta (the Bengal Delta system), Bay of Bengal; Mekong River Delta, South China Sea; Yangtze River Delta, East China Sea; Yellow (Huang He) River Delta, Yellow Sea/ Bo Hai Gulf; Fly River Delta, Gulf of Papua, Coral Sea; Amazon River Delta, Atlantic Ocean; Niger River Delta and the Congo Delta, Atlantic Ocean; Zambezi River Delta, Mozambique Channel, Indian Ocean; Danube River Delta, Black Sea; Volga River Delta, Caspian Sea; McKenzie River Delta, Arctic Ocean; Yukon River Delta, Bering Sea; Fraser River Delta, Strait of Georgia; Colorado River Delta, in the Gulf of Baja California. Deltas vary greatly in size; widths and shoreline lengths for many major deltas, including the Nile, are shown in Figure 1 (from Wells and Coleman, 1984). Geologic and geomorphic data of 42 deltas were compiled at the Louisiana State University Coastal Studies Institute for a NASA sponsored project (Coleman, Huh, and Braud, Jr., 2003). Fourteen of the deltas are described by Coleman, et al. (2008); one is the Nile Delta.

Most large rivers have multiple uses, which may include: navigation/ transportation (ports, cargo, movement of people); water source for agriculture (irrigation), for municipal and industrial uses, and for wetlands; cooling water for thermal-electric power plants; generation of hydro-electric power, fishing; aquaculture; bird habitats; recreation; visual (aesthetics, people like a view over water); waste disposal. Uses may be conflicting. Convenience in use is desirable. Some rivers flow through more than one country; they are "international rivers." The upstream/ downstream rights usually involve negotiated use of the water by the countries (quantity, quality, timing; shipping). The political and economic problems change with time, and may be difficult to resolve (e.g., Biswas, 1994; Mageed, 1994; Soffer, 1999).

Coastal processes of some of the deltas are fluvial-dominated and others are wave-dominated or wave- and current dominated. Effects of waves, tides, and coastal currents are important. Some deltas have problems caused by subsidence, or eustatic changes in sea level. Subsidence may be caused by tectonic movement, consolidation, wind deflation (removal of sediment by wind), weathering, mining of sediment and other material, removal of ground-water, oil and gas.

A great deal is known about how to evaluate hazards and risks; and what to do (or not do). Mitigation works and procedures may affect the quality of daily life, and the efficiency and economics of use of the region. They involve choices, tradeoffs, risk, and adaptation, either explicitly or implicitly; good judgement is required. They may be costly. Routine maintenance may be necessary in some cases; perhaps this is part of "coping with a problem." Decisions must be made and implemented using existent knowledge; but we would always like to know more, and must continue to increase and improve our knowledge of the forcings and understanding of the mix of processes at a specific site. The problems must be identified, and critical questions raised about them.

The main objective of this international conference is/was to bring together engineers, scientists, managers, and officials and staff of government agencies (national and local) to address the outstanding problems and processes associated with erosion/ accretion/ subsidence of shores of river deltas and other low land coastal areas. These are increasingly being influenced by human interference, by increasing population, and by the effects of global climate changes such as sea-level rise and perhaps increased (or decreased) storm activity. Use of water continues to increase. Often, there has been a deterioration of water quality; and there are misuses of water. Owing to the increase in the numbers of people living along the coasts, and the number of visitors to the coasts, effects of natural calamities such as tropical cyclones (hurricanes, typhoons), tsunamis, earthquakes, floods, droughts are becoming more severe; they are affecting more people. This requires the planning and implementation of mitigation works and procedures, and adaptation to hazards; including zoning and land-use management. Some redundancy may be useful. Another objective of this conference is to propose sustainable solutions (including adaptation) to minimize adverse impacts by reliable coastal zone management. Risk evaluation and public education are required, and in some cases, the development of warning systems. It is necessary to work together (cooperate) to reconcile differences, and to obtain viable solutions.

The venue of this conference is on the Nile Delta, in Alexandria, Egypt; at the west end of the delta, on the southeastern Mediterranean Sea. Alexandria was the capital of Egypt for nearly a thousand years (331 BCE - 641 CE (sic A.D.). What is probably the world's seaport with the longest history is here; and it is presently the largest seaport in Egypt. The tidal regime is microtidal, semidiurnal. The mean tide range at Alexandria is 1.1 ft, the spring range is 1.5 ft, and the Mean Tide Level is 0.6 ft (NOAA/NOS, 2008). The delta has a very long history; thousands of years. Herodotus described it and commented about it in the 5th Century BCE

The population of the delta is large, and there is a great amount of agriculture. During the past century substantial critical changes have occurred; the most important resulting from the construction and operation of dams and barrages on the Nile River. Essentially all of the water is used, or lost through evaporation and leakage. A crucial result has been the great decrease in the delivery of water and sediment to the sea. This has resulted in major changes in the delta coast, many of them adverse.

The author was fortunate to have visited the Nile Delta as a member of the United Nations Development Programme (UNDP) International Advisory Panel during 5-16 August 1983. [Note. This was a follow-up to the seminar about Nile Delta sedimentation and coastal processes held in Alexandria in 1975; and the subsequent program of coastal protection studies of the Delta's shore (UNDP/UNESCO, 1978).] There was a 5-day field trip to the coastal sites, which included meeting people involved with the problems, and visits to two laboratories. This was followed by working sessions to prepare a report (UNDP 1983), which included findings, recommendations, and terms of reference for the development of a *Shore Protection Master Plan* for the Nile Delta shoreline. The plan development and details for the shoreline extending from 30 km west of Alexandria to 30 km east of Port Said are in two progress reports and a 14-volume Final Report prepared by Tetra Tech, Inc. (1985) for the *Shore Protection Authority* (SPA), Ministry of Irrigation of Egypt. It is being implemented. The center for collection, analysis, and monitoring of field information is the *Coastal Research Institute* (CRI) in Alexandria. Many papers are available in the technical literature.

The author is more familiar with a low coastal alluvial flood plain that is in southern California, at San

Pedro Bay. It is smaller than the Nile Delta, but of major importance. Details about this complex urban coastal region, a part of the Los Angeles (Coastal) Megacity (Ewing, 2008) are given in a separate report, which is available electronically at the Water Resources Center Archives (WRCA), University of California at Berkeley, Calif. Historical knowledge of it is short; only a few centuries. [**Note.** San Pedro Bay was named for St. Peter, a 4th Century AD (sic CE) bishop in Alexandria, Egypt (Wikipedia, 2008).] There is a continuous sand beach (mostly silicate - quartz and some feldspar): Long Beach, Belmont Shore, Seal Beach, Surfside-Sunset, Bolsa Chica, Huntington Bluffs, Huntington Beach, West Newport Beach, Balboa Beach. The beaches are popular with residents and visitors (these are the nearest beaches to Disneyland). It is a world-known surfing center. The contiguous Los Angeles Port and Long Beach Port complex is the largest seaport (by volume) in the USA. The flood plain was formed by detritus deposited by the Los Angeles River, San Gabriel River, Santa Ana River, and several streams. The river courses have changed naturally over time, and also as a result of actions of humans. Dams, levees, and other river control structures have been built; sand has been mined from the river beds. This has decreased the supply of sediment to the coast. Ground subsidence has occurred owing to oil and gas removal, and ground water use (artesian and pumped wells). Floods, droughts, coastal storm wave events, earthquakes, and seawater intrusion into the ground water aquifers have occurred. Coastal structures (harbor entrances, river mouth jetties) have been built, and dredging performed in bay entrances, turning basins, marinas, and river channels. The beaches are extensively used, and many have been nourished by the addition of sand obtained from dredging navigation projects, "offshore borrow pits," or adjacent river beds. At two beaches, sand has been "backpassed" from a section of accretion to a section of recession. A coastal wetland was severely degraded by oil field activities during many decades in the previous century. It has recently been re-established in a modified form; the *Bolsa Chica Lowlands Restoration Project.* This project received the first Project Excellence Award (2008) of ASCE's COPRI (ASCE, Coasts, Oceans, Ports, and Rivers Institute, 2009).

[**Historical Notes**. 1) The first conference on coastal engineering was held at the oceanfront in Long Beach, California, in October 1950. It was organized by Morrough P. O'Brien and J.W. Johnson. Its purpose was to make available to practicing engineers and scientists the state of the art and science related to the design and planning of coastal works. It was organized by the University of California Engineering Extension. Each presentation was by invitation; written versions are in the proceedings, edited by J.W. Johnson, and published by the Council on Wave Research of The Engineering Foundation. This was followed by three other conferences in the USA. Starting with the 5th, held in Grenoble, France, they became known as the international conferences on coastal engineering (ICCE) (e.g., Wiegel and Saville, Jr., 1996). 2) What was probably the first use of wave refraction diagrams was for a study of part of the northwest section of San Pedro Bay. 3) An often used formula for estimating the rate of alongshore transport of sand was developed and used for this section of shore.]

Alexandria, Egypt; Conference Venue - A Little About Its Ancient and Modern Harbors/Ports

The venue of the 2010 International Conference on Coastal Zone Management of River Deltas and Low Land Coastlines is Alexandria, which was the capital of Egypt for nearly a thousand years (331 BCE - 641 CE). It has the largest seaport in Egypt. Information about the harbor/port at Alexandria, and its predecessors, follows: Ancient Harbor of Pharos (constructed about 1900 B.C); Alexander's Harbor (begun in 331 BCE (BC) under the direction of Alexander the Great's engineer, Dinocrat) (Savile, 1940; 1941; Forster, 1961; Wikipedia, 2008). [**Note.** Maritime archaeology (underwater archaeology) investigations using modern technologies and techniques have been underway during the past decade (e.g. Stanley, Warne, and Schnepp, 2001; 2004; Lawler, 2005); but only a few of the results are given herein.]

Sir Leopold Halliday Savile (1940; 1941), in his Presidential Address of the Institution of Civil Engineers, in London said he believed the harbor at Alexandria has the longest history of any harbor in the world. He prefaced his remarks by commenting about an even earlier port for sea-going ships (about 3,000 BCE), nearby at A-ur ("Great Door") on the Canopic Branch of the Nile River; this branch (which no longer exists) was a little to the west of the present Rosetta Branch. [**Note.** Was this the predecessor of the ancient cities of Herakleion and Eastern Canopus, now under the sea in Abu Qir Bay, which were at the mouth of the Canopic Branch? Stanley, Warne, and Schnepp (2004) said that the Canopic branch flowed into what is now the western part of Abu Qir Bay, and that it was the largest of the relict distributaries.]

Savile gives conceptual plans that show the location and arrangements of the Great Ancient Harbor of Pharos (Port of Pharos). It was westerly of the Island of Pharos (now a peninsula), and extended to the Rock of Abu Bakar. Also shown on one of the plans are the locations of Pharos Lighthouse, Alexander's Harbor, and the modern harbor/port of Alexandria. [**Note.** Plans of the harbors are also in Forster (1961).]

Savile presents ideas about the construction and arrangement of the works (breakwaters and quays) of the Port of Pharos, based on the archaeological research between 1910 and 1915 by Jondet (1916). He says "Egyptian history has no record of this harbor." Forster (1961, p. 141) refers to it as the "Prehistoric Harbour." Savile mentioned that much of the underwater portions of the breakwater was: "still in existence, and can be seen under water on a clear day."

The Port of Pharos (harbor) had two basins; an inner basin and an outer basin, with a passage between them. The outer basin was narrow and long, about 650 feet wide, formed by two long, nearly parallel breakwaters. The breakwater separating the basins extended in the nearshore from its eastern terminus located seaward of about the middle of the shoreline of the Island of Pharos, southwesterly to the Rock of Abu Bakar. It was about 8,500 feet long, and formed a very large quay. The outer breakwater was seaward of this. The South Wall and quays separated the inner basin from an open roadstead, which was between it and the mainland. Savile (p. 4) says there was a large landing-quay "... 525 feet long by 46 feet wide by 18-20 feet high, and was built of large rough-hewn blocks of limestone from the quarries at Mex on the mainland, carefully laid in courses and bonded with small aggregate and sand well tamped down. The top was paved..." Other structures were described. One was the south wall, 2,300 feet long, with the upper parts "built of large, carefully-hewn blocks ranging from 8 feet to 16 feet in length, laid with great precision. ... no cement was used, but the joints were filled with small stone." The entrance to the harbor was from the south; ships had to sail southerly and then easterly around the Rock of Abu Bakar to get to the entrance from the Mediterranean Sea.

Savile said (p.8) he believed the port's decline was probably sometime after 1,000 B.C. He commented on why he believed Alexander the Great apparently took no notice of these "wonderful works" when he founded Alexandria. Savile wrote: "The reason was that they had disappeared under the sea." He then described Jondet's hypothesis of what might have occurred. The harbor structures were built above a ridge of limestone, which was overlaid by a thin layer of clay, with a "thick layer of river silt in various stages of consolidation" on top of this. On top of this was a "stratum of hard argillaceous sand." The breakwaters and walls were built on this. Jondet hypothesized that "as the silt consolidated, its bearing value weakened and the stratum of sand which rested upon it glided down the slopes in sudden subsidence, the underlying clay acting as a sliding surface... whole portions of the works glided below water-level often without any damage to their structure." [**Note.** An e-mail of 13 Feb. 2009 from Pararas-Carayannis to RLW referred to a paper he is working on about the possibility of tsunami waves being generated in the Bohai Sea of NE China by the dissociation of gas hydrate deposits triggering mass flows of surficial sediments. He suggested that as the Alexandria area is rich in hydrates, this mechanism might have might have occurred; triggering underwater slides. As there are commercial deposits of gas in the Nile Cone, this is an interesting possibility. Also, consider the recent marine archaeological investigation of the "ruins of the ancient cities of Eastern Canopus and Herakleion" (Greek and Byzantine eras) which were discovered in water depths of 6-7 meters in Abu Qir Bay (Stanley, Goddio, and Schnepp, 2001). They wrote that their investigations "indicate that structural failure of these cities that were once positioned on the river banks, and their submergence to depths of more than 5 m at and near the Canopic mouth, are best explained by sediment failure triggered by flooding of the Nile as recently as 1,250 years ago."]

As part of the arrangements of Alexander's Harbor, a mole about 600 feet wide and 1 mile in length was built between the Island of Pharos and the mainland. The harbor was in two parts; the Great Harbor to the east, and the Harbor of Eunostos ("Haven of Happy Return") to the west. The two parts of the harbor were connected by two openings through the mole. [**Note.** Many centuries later the mole developed into a connecting spit. Forster (p. 151) says this occurred in the 9th Century CE (sic, A.D.), and referred to the mole as a bridge (others refer to it as a "causeway," or the "Heptastadion"). He also says (p. 85): "... the dyke Heptastadion, built by the Ptolemies to connect the mainland with the island of Pharos, fell into ruin and became a backbone along which a broad spit of land accreted; and so Pharos turned from an island into a peninsula - the present Ras-el-Tin."]

Bowman (1989, p. 219) gave information on the trade and commerce of Alexandria, owing largely to its port. He commented on the Great Harbor to the east and the Eunostos to the west, and said:

"These accommodated an immense volume of maritime trade with the Mediterranean world and also made Alexandria an important center of the shipbuilding industry. To the south of the city, Lake Mareotis, which itself had a harbour on its northern shore, was linked by canals to the Canopic branch of the Nile delta (sic River), giving access to the river valley.... Under Roman rule, the roads which connected the ports of the Red Sea coast to the Nile, directing goods to Coptos and then down-river to Alexandria, were developed."

[**Notes.** 1. A canal connected Eunostos and Lake Mareotis (Savile, p. 9; a map in Foster, 1961; Bowman, p. 219). 2. Papyrus was a major product manufactured here, and exported to the entire Mediterranean world. 3. Papyrus, a wetland sedge native to Egypt, grew in the Delta's freshwater marshes. The pith of the reed's stalk (stem) was used to make "paper." It was used as a writing surface by the Egyptians, Greeks, and others for centuries (e.g. Herodotus, translation by Rawlinson, 1992; Wikipedia, 2008). It was also used for other purposes.]

Originally, the Pharos structure was not a lighthouse. It was built to serve as a landmark on this flat coast to mark the entrance to the Harbor of Alexander. It was developed into a lighthouse in the 1st Century B.C., one of the Seven Wonders of the Ancient World (e.g., Wikipedia, 2008). In the 14th Century C.E. (i.e., A.D.) it was destroyed by an earthquake.

[**Historical Notes.** Cleopatra VII, the last Pharaoh of Egypt, daughter of Ptolemy XII, was born in Alexandria in 69 B.C., resided there; and committed suicide there, the traditional date being 12 August 30 B.C. (ie B.C.E.) (e.g., Wikipedia, 2008). Julius Caesar (48-45 B.C.) and Mark Antony (41-37 B.C) were in Alexandria. The Great Library of Alexandria was, of course, in Alexandria. Euclid, working in Alexandria about 300 B.C., systematized a great amount of mathematical knowledge (e.g. Bowman, 1989, p. 225). The Rosetta Stone, discovered in the port city of Rosetta (Rashid) in 1799 A.D., was created in 196 B.C. (e.g. Wikipedia, 2008).]

On 21 July 365 A.D.(sic CE), a great earthquake occurred in the island of Crete, which generated a devastating tsunami, reported from Crete and Alexandria. Galanopoulos (1969) says (referring to a 1879 paper by J.

Schmidt): "In Alexandria, after a large withdrawal of the sea, ships were carried over the buildings and left among them." Other large tsunamis may have occurred in antiquity. For example, the Santorin volcano (Thera) eruption in the Bronze Age, circa 1650 B.C. (sic BCE) (e.g., Pararas-Carayannis, 1988; 2008). In an e-mail from Pararas-Carayannis (4 Dec. 2008) to R.L. Wiegel, responding to an e-mail from RLW, he estimated that tsunami waves from a proposed mechanism at Santorin in the Bronze Age, that the larger waves at Alexandria, or the mouth of the extinct Canopic Branch of the Nile River..."would probably have been in the order of 5-6 meters, but not higher."

The transition from what is conventionally called Roman to Byzantine eras was probably about 284 A.D. (ie, C.E.). According to Lawler (2005), after the collapse of the Roman Empire: "... Alexandria faded from the historical record.... By the 8th Century C.E. the famed metropolis had faded into oblivion." Lawler adds that new data suggests "that environmental disaster played an important role in ancient Alexandria's downfall...."

Alexandria fell to the Arab Conquest in 642 A.D. (sic, CE) (e.g., Wikipedia, 2008). Alexandria was under Arab domination during the 7th - 16th centuries CE (sic A.D.).

Turkish domination (Ottoman Empire) of Alexandria was during the 16th-18th Century CE [1517-1778 CE] (Wikipedia, 2008).

Muhammad Ali (1769-1849), was appointed Ottoman Governor of Egypt in 1805 (Wali of Egypt). He began rebuilding Alexandria; 1810-1850. He built the 70 km-long Al-Mahmudiyah Canal for access to the Nile, and a railway to Cairo.

The modern harbor of Alexandria (the Western Harbor, which is the main commercial harbor/port) is located in what was the open roadstead of the Ancient Harbor of Pharos. It is protected by an extensive modern breakwater to the west of what is now a peninsula (Ras el Tin), formerly an island (Pharos). It was developed by Muhammad Ali as part of the plans for modern Alexandria (Forster, 1961). The Eastern Harbor is east of the peninsula, and is protected by a short breakwater. It was built in 1870-1874 (Forster, p. 141). Alexandria is the largest seaport of Egypt, and has been undergoing major improvements during the past several decades. For example, a new container terminal opened in November 1984 (Anon., 1984). The port is about 150 nautical miles by sea from the entrance to the Suez Canal and Port Said.

Major port facilities have been built at nearby Dekheila, 7 km west of the Western Harbor of Alexandria. It serves as an extension to Alexandria's port, with extensive container facilities (Anon, 1984). It is an industrial port. It has an iron ore terminal that opened in 1986; and a coal terminal.

The Idku LNG terminal is east of Alexandria, nearby in Abu Quir Bay, between Alexandria and the mouth of the Rosetta branch of the Nile. It accommodates LNG carriers 70,000 to 140,000 cubic meters in size, between 800 and 960 ft long, and breadths of 112-126 ft, and typical drafts of 30-38 ft. It includes a 7,900-ft trestle and loading platform sheltered by a 2,600 ft breakwater in 40 ft. of water (Jorgensen, 2003).

Nile River Delta Littoral Sediment Cell

The Nile River Delta Littoral Sediment Cell is about 650-700 km long. It starts at about Alexandria (probably Dichkeila; also spelled Dekheila), extends easterly past the Suez Canal, along the Sinai coast, and then northerly along the Israel coast to Haifa Bay at the Israel - Lebanon border. The sediment is moved easterly along the delta, and then northerly along the Mediterranean coast by waves and currents (Inman and Jenkins, 1985; Stanley, 1989; Almagor et al., 1998). Stanley (1989, p. 813) said that his and a number of previous studies by others identified the Nile River and Delta as the "...major sources of the quartz-rich sediments on coasts and shelves of the southeastern Mediterranean."

Inman and Jenkins (1985), citing several studies, say:

"The beach sands from west of Mersa Matruh for 300 km to Abu Quir headland are calcareous oolites and shell fragments. From Abu Quir Bay to Haifa Bay the beach and shelf sediments are predominantly from the Nile as shown by many studies of mineral distributions."

[**Note.** Frihy and Komar (1991) comment that the western end of Abu Quir Bay is a headland of "Tertiary limestones which form an effective barrier to (sic alongshore) sediment movements." However, Hilmy (1951) concluded that some Nile River sand was as far west as Dichkeila; perhaps this is relict.]

A study of coastal, nearshore, and onshore sediments was made by Stanley (1989). He wrote (p. 824) that his study confirms the conclusions of others that "...the bulk of sediments on the southeastern Mediterranean margin have been derived from Nilotic sources." But, he found that: "This study of the regional distribution of transparent heavy minerals indicates that mineral suites on coasts east of the Bardawil Lagoon differ increasingly from Nilotic suites in a direction away from the Nile delta." He hypothesized (p. 824) that substantial amounts of sediment are "introduced locally along the coastal path by erosion of coastal deposits...by the Wadi El-Arish on the Sinai,... and by several Israel rivers." [**Note.** A wadi is a river having intermittent flow.] In this study, use was made of the extensive work of others, and the heavy mineral analysis of samples by the Smithsonian Institution. He lists and describes an inventory of more than 300 samples and a list of published references in a table, with locations shown on a map. Values of *Ipyr index* [(frequency of pyroxenes/frequency of pyroxenes + epidotes) x 100] and *Iamph index* [(frequency of amphiboles/ frequency of amphiboles + pyroxenes) x 100] are plotted on maps.

Sand north of Haifa Bay is scarce, dominantly biogenic and mostly skeletal debris of local littoral provenance (Almagor, Gill, et al., 1998, p. 28; Rohrlich and Goldsmith, 1984).

Sediment along the Nile Delta coast is easily distinguished from the coastal sediment to the west and the coastal sediment to the east. Hilmy (1951) obtained 11 samples from the foreshore, and made mineralogy and mechanical (sieve) analyses of them. The sand from Dichkeila (just west of Alexandria) west to Mersa Matruh was almost entirely carbonate; "oolitic" in texture, white in color, highly-polished and well-rounded. He refers to this sand as "pseudo-oolites", and that it was derived from local calcareous rock. El-Wakeel and El-Sayed (1978, p. 142) say "These sands were eroded from the limestone ridges skirting the shore in this area." There were a few shell fragments, and almost no heavy minerals; the calcium carbonate content was more than 99%. Frihy has a map locating several of the limestone ridges, and describes them. Hilmy concluded from his mineralogical studies that "The sands carried by the Nile River are not distributed farther west than Dichkeila." Hilmy said the beach sands from Dichkeila to Rosetta were essentially quartz grains and an abundance of heavy minerals, transmitted to the coast by the Nile River; and common shell fragments. He described the colors of the different heavy minerals in the beach sand. He said that beach sands between the Abu Quir Headland and Rosetta mouth were relatively dark owing to enrichment of the heavy minerals. The median diameter of the sand samples ranged from 0.25 to 0.63 mm.

El-Wakeel and El-Sayed (1978) obtained sediment samples from offshore and from beaches for the reach between El-Agami (southwest of Alexandria) to about Abu Qir Headland (to the northeast); 15 were beach samples. Sediment samples were obtained by a grab sampler along profile lines across the river mouth bars at Rosetta and Damietta Headlands by staff of the Coastal Research Institute (which is in Alexandria). They comment: "Sands of the beaches between El-Anfushy and El-Maamoura vary from loose to fairly well indurated deposits of quartz, shells of recent marine organisms, and other debris. The beaches of El-Dekheila and El-Agami (west) are composed of loose, white, oolitic carbonate sands. [El-Anfushy is on Ras-el-Tin, and El-Maamoura is just west of Abu Quir Headland.] Sieve analyses were made and plotted (Frihy and Lawrence, 2004). They found the mean grain size of the Rosetta bar sediments to be medium silt to medium sand, with most samples being fine sand (0.125 to 0.250 mm). The Damietta mouth bar sediments were primarily fine and very fine sand (with some coarse silt); very little greater than 0.2 mm mean grain size. Many sediment samples were taken in 1988 and in 2000 in the nearshore and from the beach in the vicinity of the Rosetta Promontory, including Abu Qir Bay (also spelled Aboukir Bay) to the southwest and the "saddle shaped shore" Abu Khashaba to the east (Frihy, Shereet, and El Banna, 2008). They present results of the sieve analyses. The mean grain size of beach samples ranged from 0.35 to 0.45 mm for the samples taken from several km southwest of the river mouth, 0.06 to 0.2 mm in the immediate vicinity of the river mouth, 0.15 to 0.20 mm just easterly of the river mouth, and 0.3 to 0.4 mm for the reach several km west at Abu Khashaba. They commented that the coarse grained sediments had a "high accumulation of white shells and fragments." Staff of the Coastal Protection Project repeatedly took samples about every 2 km, from 4 km east of Maadia (Idku Lake outlet) to Port Said during 1973-1975 (Fishawi, Fahmy, Sestini, and Shawki, 1976). Samples were taken about once a month along portions of the shore and quarterly at other locations. Most were from the swash zone; and other samples were taken along beach profiles that extended offshore. Grain sizes from sieve analyses are in their paper; grain size is plotted versus location along the coast.

[**Note.** The Suez Canal, 192 km long, oriented N-S, connects the Mediterranean Sea and the Gulf of Suez on the Red Sea; it was constructed between 1859 and 1869. It is a "sea level" canal (no locks); but the water level in the Red Sea is higher than the southeastern Mediterranean, and sea water flows northerly through the canal (e.g. Wikipedia, 2008). The mean tide level at Port Said, Egypt is 1.6 ft, the mean range is 0.9 ft and the spring range is 1.3 ft; the mean tide level at Suez, Gulf of Suez, Egypt is 3.7 ft., the mean range is 3.8 ft. and the diurnal range is 4.7 ft. (NOAA/NOS, 2008]

Nile River Delta, Egypt

A map of the Nile River Delta, Figure 2, shows locations of present (solid lines) and historic (dashed lines) branches of the Nile. The modern Nile divides into two branches, Damietta and Rosetta, about 20 km north of Cairo. Barrages were built in each branch a little downstream of the bifurcation in the late 1800's, and were replaced by new Delta Barrages built downstream of the old ones in the late 1930's (Vaughan-Lee, 1940). Figure 3 shows the Delta coast and Nile branches in "classical times." [For a discussion of changes in the Canopic and other relic Nile River delta distributaries, see Frihy (1988); Stanley, Warne and Schnepp (2004).] Present day locations of dams and barrages in the Nile Valley and Delta are shown schematically in Figure 4 (from Abu Zeid, 1989). The irrigation scheme for the Delta is shown in Figure 5, with the locations of barrages (from UNDP/UNESCO, 1978). Details of the delta coastline with major geomorphologic units are shown in Figure 6 (from Frihy and Lawrence, 2004). In the 19th Century A.D. (sic, CE), several reaches prograded; and in the 20th Century there was retrograding. Since the end of the 19th Century and the first half of the 20th Century "...the main Nile has been controlled by several engineering constructions, including the Delta Barrages in 1881, the Low Aswan Dam in 1902, and the High Aswan Dam in 1964 (Frihy, 1988). Since 1964 essentially no sediment has been transported by the Nile River to the coast. Stanley and Warne (1993) have concluded that the Nile Delta "...is no longer an active delta but, rather, a completely wave-dominated coastal plain along the Mediterranean coast." [See also Frihy and Komar (1990).] Wave data obtained in 1977, in the form of "wave roses," are given in Frihy (1988) for each of three areas; the Rosetta Promontory, the Burullus-Baltim sector, and the Damietta Promontory. The locations of the 1955 and 1983 shorelines obtained from aerial surveys are also given; sections of shore erosion and shore accretion are indicated.

The Nile Delta extends from about just west of Alexandria (probably Dekheila; also spelled Dichkeila), easterly to about 30 km east of the Mediterranean entrance of the Suez Canal [at the location of the long defunct mouth of the ancient Pelusiac branch of the Nile] (e.g., Frihy, Shereet and El Banna, 2008).

The distance measured along the coastline is about 350 km; the "chord" length between the two ends is about 275 km [**Note.** Different values for the length of coast are given in various papers, probably depending on how the coastline is measured. The measurements above by the author, are from two topographic maps by Great Britain: War Department, General Staff, Geographical Section, Series 3930, 1933.] The delta has several sub-cells. The shoreline is gently arcuate (bow-shaped), relatively smooth, with two "slightly protruding distributary" river mouths (Coleman, 1982, p. 18). The deltaic plain area is (was) 12,512 sq. km. according to Coleman (p. 50), and 22,000 sq. km. according to Smith and Abdel-Kader (1988). It includes the Rosetta Promontory, the Burullus Headland (Promontory), and the Damietta Promontory, Figure 6. Burullus Lagoon is just inland, between the Rosetta Branch of the Nile and Burullus Headland. This section of coast is the location of the extinct Sebennitic Branch of the Nile (e.g., Arbouville and Stanley, 1991; Said, 1993). The Rosetta Promontory is at the mouth of the Rosetta Branch (Rashid) of the Nile, and the Damietta Promontory is at the mouth of the Damietta Branch (Dumyat); each branch is about 240 km long. A sand beach, about 160 km in length, is between the two mouths. [**Note.** "... canalization of Nile water dates from the early history and according to old records the present Rosetta and Damietta branches were originally artificial canals" (UNDP/UNESCO, 1978 p. xiv). Stanley and Warne (1993) say that in the Hellenistic era, "... the Damietta (Bucolic) and Rosetta (Bolbitine) channels were maintained by artificial excavation.]

The Nile Delta has a long history; thousands of years; Stanley and Warne (1994), estimate from 8,000 to 6,000 years B.P.(sic, Before Present). Herodotus in *The Histories* (Rawlinson and Bowden, 1992) wrote about it in about 450 B.C. He discussed the source(s) of the Nile's waters, and states that the Delta's "black and crumbly" alluvial soil was "brought down by the river from Ethiopia." He comments on the difference between this soil and the soil in Libya (to the west) and Arabia (to the east). Herodotus (Book 2, Ch. 17) says there were 5 mouths of the Nile River. A footnote by Rawlinson (p. 120) states this "signifies the natural branches of the Nile; and when seven are reckoned they include the two artificial ones." Herodotus (p. 124) says these two were made by excavation; the Bolbitine and Bucolic. Herodotus (Book 2, Ch. 15, p. 123) said the Delta extended along the shore "... from the Watch-tower of Perseus, as it is called, to the Pelusiac salt-pans,... and stretches inland as far as the city Cercasorus, where the Nile divides into two streams..." [**Note.** The tower was to the west of the Canopic Branch. The ancient city of Pelusium (presently Tell El Farama) and the mouth of the now defunct Pelusiac Branch was about 25 km east of the Suez Canal - see Sneh and Weissbrod, 1973).] Herodotus (p. 124) gives estimates of the size of the delta in his time, the length along the coast and distance inland from the coast to its apex near Heliopolis (which was at the edge of the desert, about where the Nile River splits into two branches). He describes the country as flat, without springs, and full of swamps. He says (p. 166): "When the Nile overflows, the country is converted into a sea, and nothing appears but the cities, which look like islands in the Egean. At this season boats no longer keep to the course of the river, but sail right across the plain."

The Nile Delta was built during many thousands of years by sediment transported by the Nile River. Stanley and Warne (1994) say: "... using radiocarbon cores, chronostratigrapic analysis of the basil deposits in the Nile delta... confirmed that basal delta deposits from this region range in age from about 8,000 to 6,000 years B.P." It was fluvial dominated, or perhaps a combination of fluvial and waves. It is now wave-current dominated (Manohar, 1976; Frihy, 1988; Frihy and Komar, 1991; Frihy, Shereet, and El Banna, 2008). The transformation was relatively abrupt. In recent decades considerable transformation and erosion of its ocean shore has occurred; these changes are documented in many papers (e.g., Frihy and Lawrence, 2004; Mobarek, 1973). One example is a study of mineral variations of beach sand along the Nile Delta shore by Frihy and Komar (1991). They present a plot of opaques, amphiboles, and garnet+zircon versus location from Abu Quir Headland to Port Said. They found that the opaque content as percentage of the entire sample "...are greatest at the Rosetta and Damietta promontories, respectively reaching about 70% and 60% of the beach-sand composition..." and a broad peak along the central delta (i.e., east of Burullus Promontory). Also, "...stretches of delta shoreline that are eroding become concentrated in the high-density opaques and non-opaques such as zircon and rutile. Longshore transport preferentially removes the lower-density hornblende and augite as well as the quartz and feldspars and these minerals are carried alongshore to areas of accreting shorelines." They say that the accumulations of black sand on the delta coast consist mainly of the opaque minerals magnetite and ilmenite; and refer to a study by El Hinnawi (1964).

The Delta is extensively and intensively irrigated, using canals with intakes from the Rosetta and Damietta branches, or from the Nile just upstream of the Delta Barrage; see Figure 5. In *Coastal Protection Studies; Final Technical Report* (UNDP/UNESCO, 1978, pp. 138) it is said: "The drain discharges are collected by an extensive and complicated system of artificial drains which are too numerous to be fully represented in Figure [sic 5]. A great number of pumps are used in the northern part of the delta to discharge the drainage waters into the northern lakes Idku, Burullus, and Manzala, or into the sea through the main drainage collectors - the Baltim or Kitchener Drain and the Gamasa Drain."

The Coastal Protection Studies project UNDP EGY/73/063 (UNDP/UNESCO, Government of Arab Republic of Egypt) was executed in two closely connected phases: I, January 1971 to January 1975; and II, continued until January 1978. The research project was implemented by the *Academy of Scientific Research and Technology*, Egypt. In the report *Coastal Protection Studies, Project*

Findings and Recommendations, Terminal Report (UNDP/UNESCO, 1978, p. 5) the objectives were stated:

"The objectives of the first phase of the project were: to assist the Government in carrying out a comprehensive scientific study of the causes of coastal erosion in the Nile Delta area, and in the preparation of a plan for coastal protective works, including recommendations for design and construction." The objectives of the second phase of the project were: "the long-range objective of the project is the long-term protection of the shore and the coastal hinterlands and the establishment of rational management of the shore and the coastal regions. ... The project will be converted into an autonomous *Coastal Research Institute* to be responsible for the continuous surveillance of the evolution of the Nile Delta shore and the coastal hinterlands and for providing scientific and technical guidance to the master plan for the economic development of the coastal regions insofar as the protection of the shore is concerned...."

Owing to erosion of portions of the Nile Delta coast, long term studies were started in 1971 to collect data needed for a better understanding of the problems; this study lasted until 1978 (e.g., Kadib, Shak, et al., 1987). [**Note.** Kadib, Shak et al. say the *Coastal Research Institute* (CRI), in Alexandria, is the center for collection, analysis, and monitoring field information.] The aims of this project were (Mobarek, 1973):

"(1) To determine the historical formation of the Delta and forecasting future changes;
(2) Study the meteorology and the hydrodynamics of the area;
(3) hindcasting and starting a new forecasting technique for them;
(4) planning and design of protective constructions for the coast;
(5) all the above to be based on an extensive field data collection programme, mathematical models and hydraulic scale models."

It was estimated that the first phase of the project would take about three years, ending in 1974; partially funded by the U.N. Special Fund. It was planned that by that time the Institute of Coastal Studies and Protection (subsequently, the *Coastal Research Institute*) would be in full operation. Subsequently, in 1981, the *Shore Protection Authority* (SPA) was created within the Ministry of Irrigation of Egypt (UNDP, 1983; Kadib, Shak et al., 1987).

Mobarek said field and laboratory studies were carried out by the Suez Canal Research Centre for the New Damietta Harbour and the proposed Ras-El-Bar beach protection project (groins and beach nourishment). The field studies were of: wave and current recordings, littoral current measurements, sea level variations, beach profile changes, borings; and wave hindcasts were made. He gave information on preliminary studies of Ras-El-Bar, Damietta Estuary, Burullus Lake (Lagoon) Exit, Idku Lake (Lagoon) Exit.

Information about beach erosion and beach accretion between the Burullus Lake outlet easterly by the Baltim Lighthouse, the Kitchener Drain, to the Gamasa Drain area is in Anwar, Gindy, et al. (1979). The results of sieve analyses of eighty samples of sediment from the swash zone (40 samples from the eroded section and 40 from the accreted section). They found the sand in the accreted sections contained more coarse sand than in the eroded sections.

A *Seminar on Nile Delta Sedimentation* was held in Alexandria, 25-29 October 1975, organized by the Academy of Scientific Research and Technology, Egypt, the UNDP/UNESCO Project of Coastal Protection Studies, and the Dept. of Geology of Alexandria University. The 257-page proceedings were published by the Academy in April 1976. In addition to papers on coastal forcings and processes, several papers in this seminar were about the bathymetry and sediments of the Nile Cone and contiguous continental shelf. In his opening speech, Dr. Abd El Moneim Abu Azm gave background information about why studies of sedimentology of the Nile were needed, and mentioned some of the effects of the Aswan High Dam and flood gates along the Nile. He said that "The present project is certainly tied up with the construction of the Aswan High Dam, but the coastal erosion problems existed long before the effects of the closure in 1964...manifested themselves on the Nile Delta shore." He mentioned several cases; two of which were: 1) having to shift the lighthouse at Rosetta Estuary many kilometers inland because of shore erosion; and 2) in the 1950's and 1960's the erosion of foundations and crumbing of summerhouses at Ras El Bar and Baltim Sea Resort. [**Note.** A photo of the Rashid (Rosetta) Lighthouse, offshore, and damaged beach-houses in the surf, which shows that severe erosion had occurred, taken by the author on 11 Aug. 1983, is in Wiegel (1991). A similar photo by O.F. Frihy (in 1983?) is in Blodget, Taylor, and Roark (1991). The lighthouse was built on the Rosetta Promontory in 1954; it was 1 km inland by 1973; and by 1983 it was about 1-1/2 km offshore (Frihy, 1988; Blodget, Taylor and Roark, 1991).]

A two-volume report was prepared, and issued in 1978, followed by another report. The 2-vol. report is: *Coastal Protection Studies. Final Technical Report*, Vols. 1 and 2, Serial No.FMR/SC/OPS/78/230 (UNDP), Paris. Vol. 1: pp i-xix and 1-205; Introduction; Concepts; The Nile Delta; Sediment Supply; Mediterranean Sediments. Vol. 2: pp 206-483; Wave Climate in the Eastern Mediterranean; Sea Level Variations; Ocean Currents; Offshore Sediment Movement; Nearshore Morphology; Nearshore Sediment Movement; Nile Sediment System; Mediterranean Water Balance and Regime; Calculation of Ocean and Shelf Currents; Geomorphic Taxonomy of the Nile Delta. The other report is: *Coastal Protection Studies, Project Findings and Recommendations, Terminal Report*, Serial No. FMR/SC/OPS/78/218 (UNDP), Paris, 1978.

River Flows and Sediment Transport; Additional Information

Now, back to river flows and sediment transport. Commenting on Nile River flows and sediment loads, Frihy and Lawrence (2004; data obtained from reports of others) say that prior to damming of the river: "... peak flows and average sediment loads from the Rosetta and Damietta Nile branches were in the range of 100 billion cubic meters per year and 160 million tons/year, respectively... The bulk of this water discharged into the sea from July through November, carrying 19 million tons/year of sand." According to El Azm (1976): "... until the Aswan High Dam was put in operation in 1964, all flood gates along the Nile used to be operated fully during the yearly Nile floods, and studies have shown that the total amount of sediments retained behind the Nile regulatory structures or deposited over the years in the flooded basins and irrigation canals was small compared to the total amount of sediments discharged from the Nile branches and lake outlets."

In UNDP/UNESCO (1978, p. 138) it is said that owing to new water regulations (transitional period 1965-1967): "Since 1968 the Rosetta and Damietta branches have been almost completely closed during the whole year. Their corresponding tail regulators, the Edfina barrage and Faraskur earth embankment, have a by-pass outflow to the Mediterranean with a maximum discharge of less than 0.5 million cubic meters per day. The outflow is kept steady to allow for navigation and to prevent salt intrusion from the sea into the estuaries."

Frihy and Lawrence (2004, p. 927) say:

"A new water-control policy was adopted in Egypt following the construction of the Aswan High Dam, which minimized water discharge to the sea by increasing the impoundment of Nile water and sediment below Cairo. Some release of water, though, is still required during the winter months and in times of flood when the northernmost barrages at Idfina and Fraskour are partially opened to decrease the high water pressure on the barrage sluices. However, this contributes an insignificant volume of water to the sea relative to the discharge prior to 1964."

The almost complete stoppage of sediment supply to the coast by the river was due to the effects of the Aswan High Dam (closure in 1964), other dams, reservoirs, and especially the two barrages, one near the mouth of each of its two branches, Rosetta (Rashid) and Damietta (Dumyat) (e.g. Frihy and Lawrence, 2004; Stanley and Warne, 1993). Now, much of the sediment that reaches the two branches is trapped in the delta during irrigation (e.g., Stanley and Warne, 1993; Wiegel, 1992; 1996).

During the UNDP's International Advisory Panel's meeting in Egypt in 1983, the participants learned of the two barrages, one at each of the two mouths of the Nile River. They were told that no water flows into the Mediterranean Sea through either of these two barrages, except for a week or so each year to flush wastes from the river in this region. Thus, almost no sediment is transported to the littoral. It was the participants understanding that all of the water in the Nile River is either used or lost as a result of evaporation or leakage through the bottom and sides of the irrigation systems (e.g., Wiegel, 1992, 1996). The Idfina (Edfina) Barrage on the Rosetta (Rashid) Branch at Zifta was built in 1950, and the Fariskur Barrage (also spelled Faraskur, or Fraskour) on the Damietta (Dumyat) Branch was built in 1965 (Frihy and Lawrence, 2004; Abu-Zeid, 1989; UNDP/UNESCO, 1976, p. 118).

Nile Delta Shore Protection Master Plan

As mentioned previously, an International Panel of Consultants met in Egypt, 5-16 August 1983, to advise the Shore Protection Authority about the development of a Master Plan for Coastal Protection, including proposed terms of reference for studies for the preparation of the master plan. This was UNDP/UNESCO Project EGY/83/003. Details are in the report by the Panel (UNDP, 1983). The report includes the Panel's findings and recommendations; the "Terms of Reference" are Annex III (38 pp).

The *Shore Protection Master Plan* (SMPM) for the Nile Delta Shoreline development was made by Tetra Tech, Inc., for the shoreline extending from 30 km west of the City of Alexandria to 30 km east of Port Said. It was made for the *Shore Protection Authority* (SPA) of Egypt; the contract was awarded in 1984. The work was in three parts: 1) collection and analysis of relevant data to identify existing and future coastal problems and limits of needed shore protection; 2) development of shore protection alternatives with costs and economic evaluations; 3) detailed design and technical specifications for the selected shore protection schemes along the SPMP zone. Two progress reports and a 14-volume final report were prepared:

Shore Protection Master Plan for the Nile Delta Coast, Progress Report No. 1, Tetra Tech, Inc., Pasadena, CA, Dec. 1984

Shore Protection Master Plan for the Nile Delta Coast, Progress Report No. 2, Tetra Tech, Inc., Pasadena, CA, Dec. 1985

Shore Protection Master Plan for the Nile Delta Coast, Report, Tetra Tech, Inc., Pasadena, CA, Dec. 1986, 14 volumes.

The findings were summarized in a paper given at the 20th ICCE, Nov. 1986, "Shore Protection Plan for the Nile Delta Coastline," by A.L. Kadib, A.T. Shak, A.A. Mazen, and M.K. Nadar (1987), published in the conference proceedings. The authors' said the "Detailed engineering drawings and technical specifications were developed for the 13 selected shore protection projects along the SPMP zones," and that these are in the 14-volume report by Tetra Tech, Inc. (1986). Areas with specific shore protection needs were identified in this paper, and a summary of the problems listed and described in a 3-page table. A summary of the shore protective alternatives that were developed are in another table, with a few details. Two are illustrated in the paper. They list what is categorized as "first priority projects", and "second priority projects" in a 2-page summary.

Many papers have been published subsequently about what has been done, and what has happened to the coast. As an illustration, two are described below.

Damietta Harbour and Ras El Bar Beach Protection Project

The new Damietta Harbour construction started in 1982. It is 8.5 km west of the Damietta branch mouth (a small estuary), Figure 7. A 4-km long canal connects the harbor with the Damietta branch of the Nile. Damietta Port installations are within about a 11.8 sq. km. area (Wikipedia, 2008). A major facility is the very large container terminal.

The harbor entrance has two jetties (also referred to as breakwaters); the west one about 1,500-m long, and the east one about 500-m long. Accropode cast concrete armor units were used; construction between July 1982 and July 1986 (7,700 4-cu.m. units and 8,000 1.5-cu.m. units). A navigation channel, about 20 km long, and 250-300 m wide, was dredged seaward from the entrance to a water depth of about 15 m. There has been chronic shoaling, and since 1986 the channel has been maintained by periodic dredging (Frihy, Fanos, Lotfy, and Badr, 1999). The material has been placed on the downdrift beaches (which are to the east). Smith and Abdel-Kader (1988) said: "About 3 km west of Ras El Bar, at the new port of Damietta, the coastline advanced at a rate of 8 m/year between 1934 and 1973, but had no appreciable change between 1973 and 1984." Shoreline changes from about 2 km west of the harbor entrance to about 5 km east of the entrance are shown; they are from beach profile surveys (46 profile lines) made in 1992, 1997, and 1998. Wave roses and offshore current measurements are also presented, for 1997-1998. Frihy, Fanos, et al.(1999) report on an intensive program carried out to evaluate the navigation channel siltation processes: hydrographic surveys, wave measurements, alongshore current and offshore current measurements, littoral drift, and sea level variation (a tide gage was located in the harbor).

Ras El Bar is between the new harbor and the Damietta mouth. The shore at Ras El Bar, about 4 km long, is oriented NE-SW. The erosion of foundations and the crumbling of summer houses have been mentioned elsewhere herein. Mobarek (1973) described a proposed mitigation project for this region of coast. A modification of it has been implemented. The Ras El Bar beach protection project consists of beach nourishment, and a series of detached shore-parallel breakwaters. [**Notes.** Frihy and Lawrence (2004) say 8, built between 1991 and 2002; Frihy, Fanos, et al. (1992) show 5 on a sketch, and no date. The project originally was to have had groins rather than detached breakwaters; see Mobarek (1973).] The material dredged from the Damietta Harbour navigation channel has been placed on the beach at Ras El Bar; the average between 1986 and 1994 was 1.16 million cubic meters per year. The project is being monitored.

Two jetties are at the mouth of the Damietta branch of the Nile. The western one (240 m long) was built in 1941, and the eastern one (290 m long) in 1972 (Frihy and Lawrence, 2004). Substantial shoreline erosion occurred east of the mouth. A 6-km long seawall, oriented E-W, was built onshore to the east [circa 1995, but when?], starting at the east jetty; 4-7 ton dolos were used. The beach material is usually transported to the southeast, where the shoreline had advanced in the intervals 1938-1973, 1973-1978, and 1978-1984. However, there are reversals, depending on wave conditions. Frihy and Lawrence (2004) say: "The map of 2000 indicates that the area fronting the seawall at Damietta has nearly disappeared and a long straight shoreline has replaced the originally arcuate promontory tip...The seawall will now cut off the source of sediment that would otherwise continue to supply the spit."

[**Note.** In 2008, permission to build a proposed $1.4 billion fertilizer plant in Damietta was denied (Wall Street Journal, 2008).]

Rosetta Promontory; Seawalls, Groins, Shoreline Change

Rosetta Promontory, Abu Khashaba, and Abu Qir Bay are shown in the map of Figure 8; with locations of the two seawalls and the two groin fields. The promontory has suffered severe erosion (e.g., Frihy, 1988; Smith and Abdel-Kader, 1988; Frihy, Shereet and El Banna, 2008). The history of the mitigation, and monitoring of the forcings, is in a paper by Frihy, Shereet and El Banna (2008). Two seawalls were built inland (with land between them and the sea), one east (3.5 km long) of the Rosetta mouth and one west (1.5 km long) of the mouth; construction was between 1988 and 1991. They are artificial embankments covered with cast concrete dolos (4 to 7 ton). Owing to erosion, the western seawall became exposed to waves in 1990. Land can be seen in front of the eastern seawall in an aerial photo of April 1990 (Frihy, et al., 2008). By 1995 both seawalls were exposed to waves. Five (5) groins were constructed in 2003 on the eastern side of the promontory, 400 to 500 m long, spaced 800 to 900 apart. In 2005, construction was started on ten (10) short groins at the lee side of the western seawall, 80 to 150 m long, with spacing between 500 to 600 m. Beach profiles have been surveyed at 41 sites for 18 years, 1982-2000.

Additional information has been presented by Ismail and Magoon (2008). [**Note.** They show a "planned groin set of 9, rather than 10, and no date.]

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References

Abou El Azm, Abd El Moneim, "Opening Speech by Dr. Abd El Moneim Abou El Azm, President of the Academy for Scientific Research and Technology," in *Proc. of*

Seminar on Nile Delta Sedimentation Held in Alexandria, 25-29 Oct. 1975, organized by UNDP/UNESCO and Dept. Geology of Alexandria Univ., pub. by Academy of Scientific Research and Technology, Egypt, April 1976, pp 3-7

Abu-Zeid, M., "History and Future Role of Water Development and Management in Egypt," in *Land Drainage in Egypt*, eds. M.H. Amer and N.A. de Ridder, 1989, Drainage Research Institute (DRI), Cairo, Egypt, Ch. 1, pp 23-42

Almagor, G., D. Gill, and I. Perath, *Marine Sand Resources Offshore Israel*, Geological Survey of Israel, Rept. GSI/25/98, Sept. 1998, 62 pp

Anon., "Egypt Builds Up," *Port Construction International*, Vol. 1, Dec. 1984, pp 32-33

Anwar, Y.M., A.R. Gindy, M.A. El Askary, and N.M. El Fishawi, "Beach Accretion and Erosion, Burullus-Gamasa Coast, Egypt," *Marine Geology*, Letters Section, Vol. 30, 1979, pp M1-M7

Arab Republic of Egypt (A.R.E.)/UNESCO, *Coastal Erosion Studies*, Tech. Rept. No. 1, A.R.E./UNESCO Project EGY/70/581, Alexandria, Oct. 1973, 58 pp

Arbouville, Didier, and Daniel Jean Stanley, "Late Quaternary Evolution of the Burullus Lagoon Region, North-central Nile Delta, Egypt," *Marine Geology*, Vol. 1991, pp 45-66

ASCE, Coastal, Oceans, Ports, and Rivers Institute (COPRI), *Keynote: COPRI Update February 2009*, 3 pp, http://mail.google.com/mail/?ui=2&ik=522c5ael13&view=pt&searc..

Barakat, M.G., nd M. Imam, "Preliminary Note on the Occurrence of Old Indurated Sand Dunes in the District of Gamasa, Northern Nile Delta," in *Proceedings of Seminar on Nile Delta Sedimentation Held in Alexandria, 25-29 October 1975*, organized by UNDP/UNESCO Project of Coastal Protection Studies and Dept. of Geology of Alexandria Univ., Egypt, April 1976, pp 33-39

Biswas, Asit K., editor, *International Waters of the Middle East from Euphrates - Tigris to Nile*, Oxford University Press, 1994, 221 pp

Blodget, H.W., P.T. Taylor, and J.H. Roark, "Shoreline Changes Along the Rosetta - Nile Promontory: Monitoring with Satellite Observations," *Marine Geology*, Vol. 99, 1991, pp 67-77

Bowman, Alan K., *Egypt After the Pharaohs: 932 BC - AD 642, from Alexander to the Arab Conquest*, Univ. California Press, Berkeley, CA, 1986, 268 pp

Coleman, J.M., and L.D. Wright, "Modern River Deltas: Variability of Processes and Sand Bodies," in *Deltas: Models for Exploration*, 2nd Edition, ed. M.L. Broussard, Houston Geological Soc., 1975, pp 99-150

Coleman, James M., *Deltas. Processes & Models of Deposition for Exploration*, Second Edition, International Human Resources Development Corp., Boston, 1982, 124 pp

Coleman, J.M., O.K. Huh, and D. Braud, Jr., *Major World Deltas: A Perspective from Space*, Louisiana State University, Coastal Studies Institute, Research report submitted to NASA, 2003

Coleman, James M., Oscar K. Huh, and DeWitt Braud, Jr., "Wetland Loss in World Deltas," *Jour. Coastal Research*, Vol. 24, No. 1A, Jan. 2008, pp 1-14

El Azm, Abdel Moneim Abou, "Opening Speech by Dr. Abd El Moneim Abou El Azm, President of the Academy for Scientific Research and Technology," in *Proc. of Seminar on Nile Delta Sedimentology held in Alexandria, 25-29 October 1975*, pub. by Academy of Scientific Research and Technology, Egypt, April 1976, pp 3-7

El Hinnawi, E.E., "Mineralogical and Geochemical Studies on Egyptian (U.A.R.) Black Sands," *Beitrage zur Mineralogie und Petrographie*, Vol. 9, 1964, pp 519-532

El-Wakeel, Saad K., and Mahmoud Kh. El-Sayed, "The Texture, Mineralogy and Chemistry of Bottom Sediments and Beach Sands from the Alexandria Region, Egypt," *Marine Geology*, Vol. 27, No. 1/2, May 1978, pp 137-160

Ewing, Lesley, "Coastal Megacities and Hazards: Challenges and Opportunities," *Shore & Beach*, Vol. 74, No. 4, Fall 2008, pp 36-41

Fishawi, N., M. Fahmy, G. Sestini, and A. Shawki, "Grain Size of the Nile Delta Beach Sands," in *Proc. of Seminar on Nile Delta Sedimentology Held in Alexandria, 25-29 October 1975*, pub. by Academy of Scientific Research and Technology, Egypt, April 1976, pp 79-94

Forster, E.M., *Alexandria: A History and Guide*, Anchor Books, Doubleday & Co., Inc., 1961, 243 pp

Frihy, O.H., "Nile Delta Shoreline Changes: Aerial Photographic Study of a 28-year Period," *Jour. Coastal Research*, Vol 4, 1988, pp 597-606

Frihy, Omran W., and Paul D. Komar, "Patterns of Beach-sand Sorting and Shoreline Erosion on the Nile Delta," *Jour. Sedimentary Petrology*, Vol. 61, No. 4, July 1991, pp 544-550

Frihy, Omran, Alfy M. Fanos, Morad F. Lotfy, and Abd El Moniem A. Badr, "Evaluation of the Siltation Processes in the Navigation Channel of the Damietta Harbour at the Northeastern Nile Delta Coast of Egypt," in *Coastal Sediments '99: Proc. of the 4th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes, Hauppauge, Long Island, New York, June 21-23, 1999*, eds. Nicholas C. Kraus and William G.

McDougal, ASCE, 1999, Vol. 3, pp 2385-2397

Frihy, O.E., and D. Lawrence, "Evolution of the Modern Nile Delta Promontories; Development of Accretional Features During Shoreline Retreat," *Environmental Geology*, Vol. 46, 2004, pp 914-931

Frihy, Omran, Samy M. Shereet, and Mahmoud M. Banna, "Patterns of Beach Erosion and Scour Depth Along the Rosetta Promontory and Their Effect on the Existing Protection Works, Nile Delta, Egypt," *Jour. Coastal Engineering*, Vol. 24, No. 4, July 2008, pp 857-866

Galanopoulos, A.G., "Tsunamis Observed on the Coasts of Greece from Antiquity to Present Time," *Annali Di Geofisica*, Roma, Vol. XIII, N. 3-4, Lug.-Dic. 1960, pp 369-386

Great Britain, War Office, General Staff, Geographical Section, *Map, Sheet 1, Alexandria, Egypt*, 1933, scale 1:250,000, Series 3930, topographic map

Great Britain, War Office, General Staff, Geographical Section, *Map, Sheet 2, Port Said, Egypt*, 1933, scale 1:250,000, Series 3930, topographic map

Hammond, H.Y., O. Mobark, A.A. Khafagy, and S. Sidky, "A Short Note on the Sediment Regime of the River Nile," *Bull. Inst. Oceanogr. Fish Egypt*, Vol. 7, 1979, pp 314-322

Herodotus, *The Histories*, George Rawlinson (Translation) and Hugh Bowden (Introduction), Everyman's Library, J.M. Dent & Sons, Ltd., London, 1992, 748 pp

Hilmy, Mohammed E., "Beach Sands of the Mediterranean Coast of Egypt," *Jour. Sedimentary Petrology*, Vol. 21, No. 2, June 1951, pp 109-120 and plates

Inman, Douglas L., and Scott A. Jenkins, "The Nile Littoral Cell and Man's Impact of the Coastal Zone of the Southeastern Mediterranean," *Nineteenth Coastal Engineering Conference: Proc. of the Inter. Conf., Sept. 3-7, 1984, Houston, Texas*, ed. Billy L. Edge, ASCE, Vol. II, pp 1600-1617

Ismail, Nabil M., and Orville t. Magoon, *Coastal Management of Nile Delta Shoreline at Rosetta Headland*, an abstract; presented at American Shore & Beach Preservation Association (ASBPA) Annual Conference, Chicago, Illinois, October 2008

Jondet, Gaston, "Les Ports Submerges de l'Ancienne Ile de Pharos," *Memoires de l'Institut Egyptien*, Tome ix, 1916, 101 pp

Jorgensen, Mads P., "Mooring Analysis" Egypt LNG Project at Idku - Marine Facilities," in *Gerwick News*, July 2003, p. 3

Kadib, A.L., A.T. Shak, A.A. Mazen, and M.K. Nadar, "Shore Protection Plan for the Nile Delta Coastline," in *Twentieth Coastal Engineering Conference. Proceedings of the International Conference, Nov. 9-14, Taipei, Taiwan*, ed. Billy L. Edge, ASCE, 1987, Vol. III, pp 2530-2544

Khafagy, A.A., and M. Manohar, "Coastal Protection of the Nile Delta," *Nature and Resources*, Vol. 15, 1979, pp 7-13

Lawler, Andrew, "Ancient Alexandria Emerges, By Land and By Sea," *Science*, Vol. 307, No. 5713, 25 Feb., 2005, pp 1192-1194

Mageed, Yahia Abdel, "The Nile Basin: Lessons Learned from the Past," in *International Waters of the Middle East from Euphrates - Tigris to Nile*, ed. Asit K. Biswas, Oxford Univ. Press, 1994, pp

Manohar, M., I.E. Mobarek, A. Morcos, and H. Rahal, "Wave Statistics Along the Northern Coast of Egypt," in *Proc. Fourteenth Coastal Engineering Conf., June 24-28, 1974, Copenhagen, Denmark*, ed. J.W. Johnson, ASCE, 1975, Vol. 1, pp 131-147

Manohar, M., "Dynamic Factors Affecting The Nile Delta Coast," in *Proc. Seminar on Nile Delta Sedimentology Held in Alexandria, 25-29 Oct. 1974*, UNDP/UNESCO Project on Coastal Protection Studies, pub. Academy of Scientific Research and Technology, Egypt, April 1976, pp 104-129

Mobarek, Ismail E., "The Nile Delta Coastal Protection Project," in *Proceedings of the Thirteenth Coastal Engineering Conference, July 10-14, 1972, Vancouver, B.C., Canada*, ed. J.W. Johnson, ASCE, 1973, Vol. 2, Ch. 78, pp 1409-1426

Nemac, W., "Deltas - Remarks on Terminology and Classification" in *Coarse-Grained Deltas*, eds. A. Colella and David B. Prior, Inter. Assoc. of Sedimentologists, Special Pub. No. 10, Blackwell Scientific Pub., 1990, pp 3-12

NOAA/NOS, *2008 Tide Tables, Height and Low Water Prediction: Europe and West Coast of Africa, Including the Mediterranean Sea*, 204 pp, *2008 Tide Tables, Height and Low Water Predictions, Central and Western Pacific Ocean and Indian Ocean*, 466 pp, pub. by ProStar Publications, Annapolis, MD, 2007, 204 pp, approved by the U.S. Coast Guard

Pararas-Carayannis, George, "The Tsunami Generated from the Eruption; of the Volcano of Santorini in the Bronze Age," *Science of Tsunami Hazards*, Vol. 6, No. 1, 1988, pp 23-30. Also in *Natural Hazards*, Vol. 5, No. 2, March 1992, pp 115-123

Pararas-Carayannis, George, *e-mails to R.L. Wiegel*, 4 Dec. 2008, 16 Dec. 2008, 13 Feb. 2009, 21 Feb. 2001, 1 page each. http://drgeorgepc.com

Rawlinson, George (Translation) and Hugh Bowden (Introduction), *Herodotus: The Histories*, Everyman's

Library, J.M. Dent & Sons, Ltd., London, 1992, 748 pp

Rohrlich, V., and V. Goldsmith, "Sediment Transport Along the Southeast Mediterranean: A Geological Perspective," *Geo-Marine Letters*, Vol. 4, 1984, pp 99-103

Said, Rushdi, *The River Nile. Geology, Hydrology and Utilization*, Pergamon Press, 1993, 320 pp

Savile, Sir Leopold Halliday, "Presidential Address of Sir Leopold Halliday Savile," *Journal of The Institution of Civil Engineers*, No. 1, 1940-41, November 1940, pp 1-26; also "Ancient Harbours," *Antiquity*, Vol. XV, No. 50, Sept. 1941, pp 209-232

Sestini, G., "Geomorphology of the Nile Delta," in *Proc. Seminar on Nile Delta Sedimentology held in Alexandria, 25-29 Oct. 1975*, UNDP, UNESCO Project on Coastal Protection Studies, and Dept. of Geology of Alexandria, pub. by Academy of Scientific Research and Technology, Egypt, April 1976, pp 12-24

Smith, Scot E., and Adel Abdel-Kader, "Coastal Erosion Along the Egyptian Delta," *Jour. Coastal Research*, Vol. 4. No. 2, Spring 1988, pp 245-255

Sneh, A., and T. Weissbrod, "Nile Delta: The Defunct Pelusiac Branch Identified," *Science*, Vol. 180, 1973, pp 59-61

Soffer, Arnon, *Rivers of Fire. The Conflict Over Water in the Middle East*, translated by Murray Rosovsky and Nina Copaken, Rowman & Littlefield Pub., Inc., 1999, 302 pp

Stanley, Daniel Jean, "Sediment Transport on the Coast and Shelf Between the Nile Delta and Israel Margin as Determined by Heavy Minerals," *Jour. Coastal Research*, Vol. 5, No. 4, Fall 1989, pp 813-828

Stanley, Daniel Jean, and Andrew G. Warne, "Nile Delta. Recent Geological Evolution and Human Impact," *Science*, Vol. 260, No. 5108, 30 April 1993, pp 628-634

Stanley, Daniel Jean, and Andrew G. Warne, "Worldwide Initiation of Holocene Marine Deltas by Deceleration of Sea-Level Rise," *Science*, Vol. 265, No. 5169, 8 July 1994, pp 228-231

Stanley, Jean-Daniel, Andrew G. Warne, and Gerard Schnepp, "Nile Flooding Sank Two Ancient Cities," *Nature*, Vol. 412, 19 July 2001, pp 293-294

Stanley, Jean-Daniel, Andrew G. Warne, and Gerard Schnepp, "Geoarchaeological Interpretation of the Canopic, Largest of the Relic Nile Delta Distributaries, Egypt," *Jour. Coastal Research*, Vol. 20, No. 3, Summer 2004, pp 920-930

Tetra Tech, Inc., *Shore Protection Master Plan for the Nile Delta Coast, Progress Report No. 1*, Dec. 1984

Tetra Tech, Inc., *Shore Protection Master Plan for the Nile Delta Coast, Progress Report No. 2*, Dec. 1985

Tetra Tech, Inc., *Shore Protection Master Plan for the Nile Delta Coast Report*, Dec. 1986, 14 volumes

UNDP, *Project EGY/83/003 - Master Plan for Coastal Protection. First Meeting of the International Advisory Panel Inception Report, Egypt, 5-16 August 1983*, United Nations Development Programme (UNDP), 1983, 18 pp and 3 appendices, 38 pp (International Consultants Panel included J.G.H.R. Diephuis, Ismail Mobarek, Thorndike Saville, Jr., and Robert L. Wiegel; Roger Berthelot was UNDP Principal Technical Adviser)

UNDP/UNESCO, *Proceedings of Seminar on Nile Delta Sedimentology, Alexandria, Egypt, 25-29 October 1975*, organized by UNDP, UNESCO and Alexandria Univ. Dept. of Geology, published by Academy of Scientific Research and Technology, Egypt, April 1976, 257 pp

UNDP/UNESCO, *Coastal Protection Studies, Final Technical Report*, UNDP/EGY/73/063, Serial No. FMR/SC/OPS/78/230 (UNDP), prepared for the Arab Republic of Egypt by UNESCO and UNDP, Paris, 1978, Vol. 1, pp i-xix and 1-205, Vol. 2, pp 206-483

UNDP/UNESCO, *Coastal Protection Studies, Project Findings and Recommendations, Terminal Report*, Serial No. FMR/SC/OPS/78/218 (UNDP), Paris, 1978, 67 pp

Vaughan-Lee, Alec George, "The Mohammad Aly Barrages, Egypt," *Jour. Institution of Civil Engineers*, No. 4, 1940-41, Feb. 1941, pp 237-

Wall Street Journal, "Egypt Kills $1.4 Billion Deal to Build Fertilizer Facility," (Damietta), *Wall Street Journal*, 6 Aug. 2008, p. B6

Wells, J.T., and J.M. Coleman, "Deltaic Morphology and Sedimentology, with Special Reference to the Indus River Delta," in *Marine Geology and Oceanography of Arabian Sea and Coastal Pakistan*, eds. Bilal U. Haq and John D. Milliman, Van Nostrand Reinhold Co., 1984, Ch. 7, pp 86-100

Wiegel, Robert L., Photo of Rashid (Rosetta) Lighthouse, Egypt, showing the severe coastal erosion that has occurred. Note how far offshore the lighthouse is, and the damage to buildings which were in the surf at the time of the photo; by R.L. Wiegel, 11 Aug. 1983. *Shore & Beach*, Vol. 59, No. 1, Jan. 1991, p. 16

Wiegel, Robert L., "Nile Delta Eroded Prior to Construction of Dam," Letter to Editor, *Civil Engineering*, Vol. 62, No. 1, Jan. 1992, p. 30

Wiegel, Robert L., "Nile Delta Erosion," Letter to Editor, *Science*, Vol. 272, No. 5260, 19 April 1996, p. 337

Wiegel, Robert L., and Thorndike Saville, Jr., "History of Coastal Engineering in the USA," in *History and Heritage of Coastal Engineering*, ed. Nicholas C. Kraus, ASCE, 1996, pp 513-600

Wiegel, Robert L., *e-mails to Dr. George Pararas-Carayannis*, 3 Dec. 2008; 13 Feb. 2009; 20 Feb. 2009

Wikipedia, *Alexandria Port*, 1-page printout on 10/13/2008 http://en.wikipedia.org/wiki/Alexandria_Port

Wikipedia, *Damietta Port*, 1-page printout on 12/6/2008 http://en.wikipedia.org/wiki/Damietta_Port

Wikipedia, *Lighthouse of Alexandria*, 3-page printout on 10/13/2008 http://en.wikipedia.org/wiki/Lighthouse_of_Alexandria

Wikipedia, *Papyrus*, a 3-page printout on 10/10/2008 http://en.wikipedia.org/wiki/Papyrus

Wikipedia, *Rosetta Stone*, 4-page printout on 10/22/2008 http://en.wikipedia.org/wiki/Rosetta_Stone

Wikipedia, *Suez Canal*, 9-page printout on 1-/19/2008 http://en.wikipedia.org/wiki/Suez_Canal

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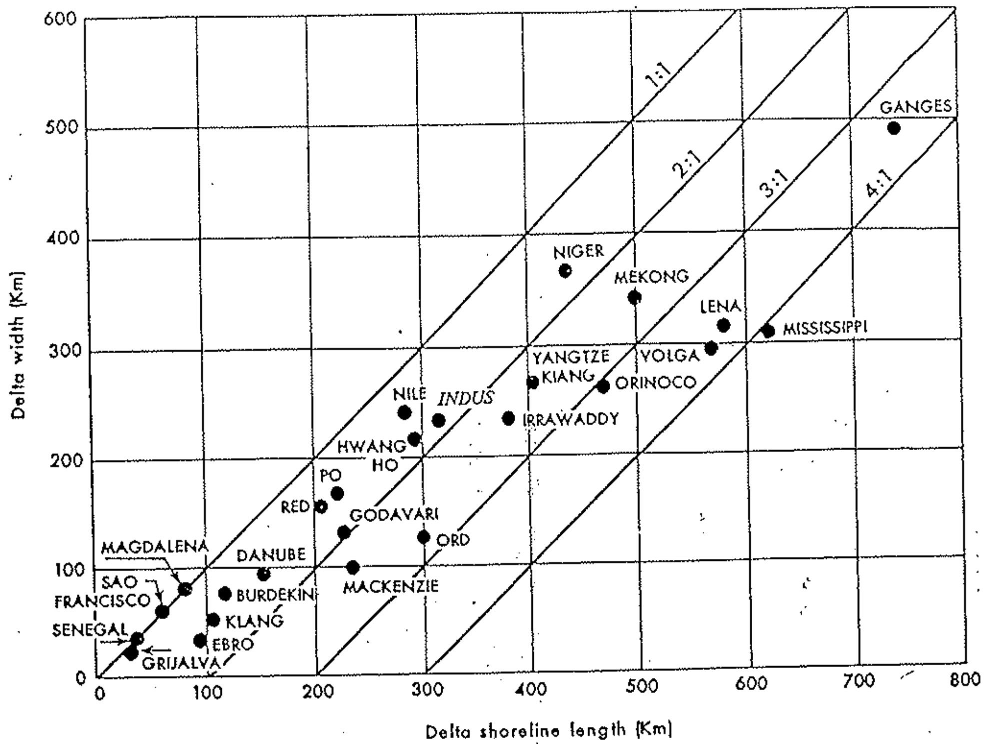

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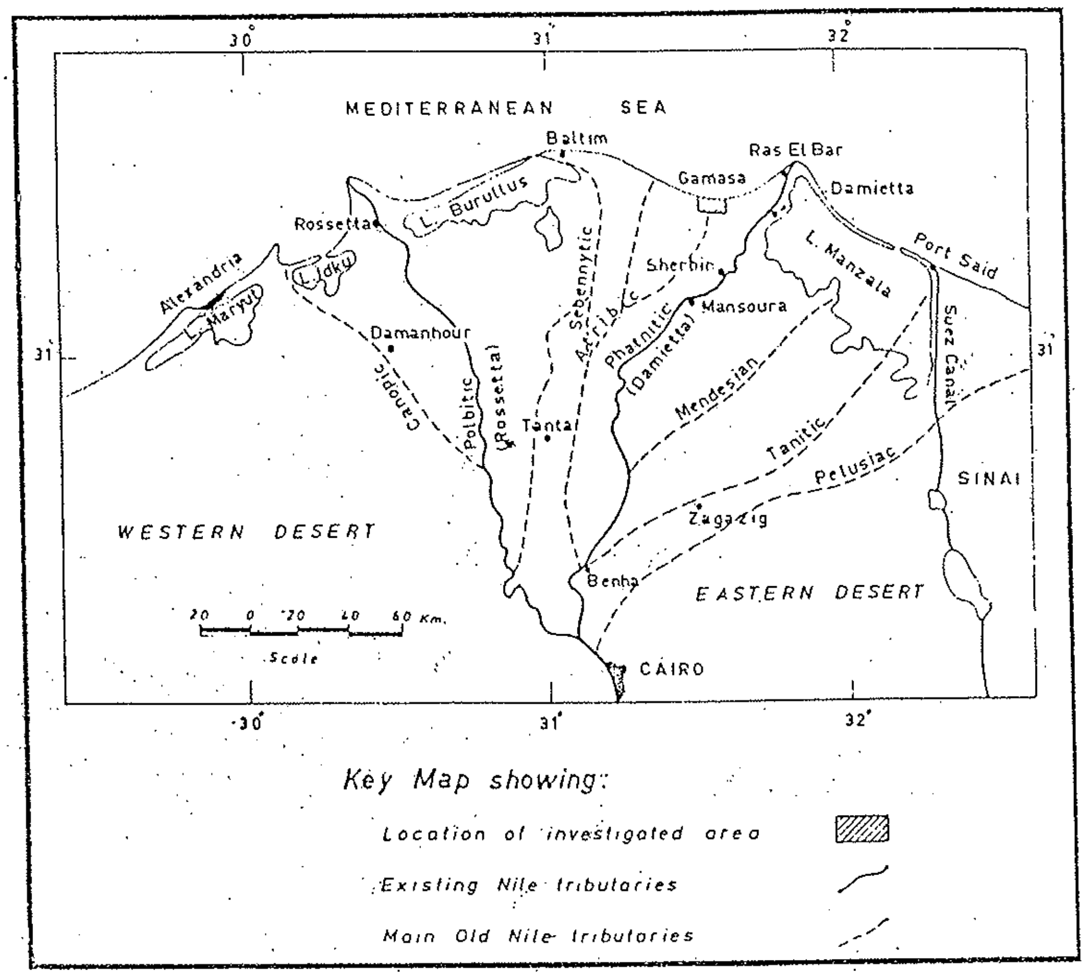

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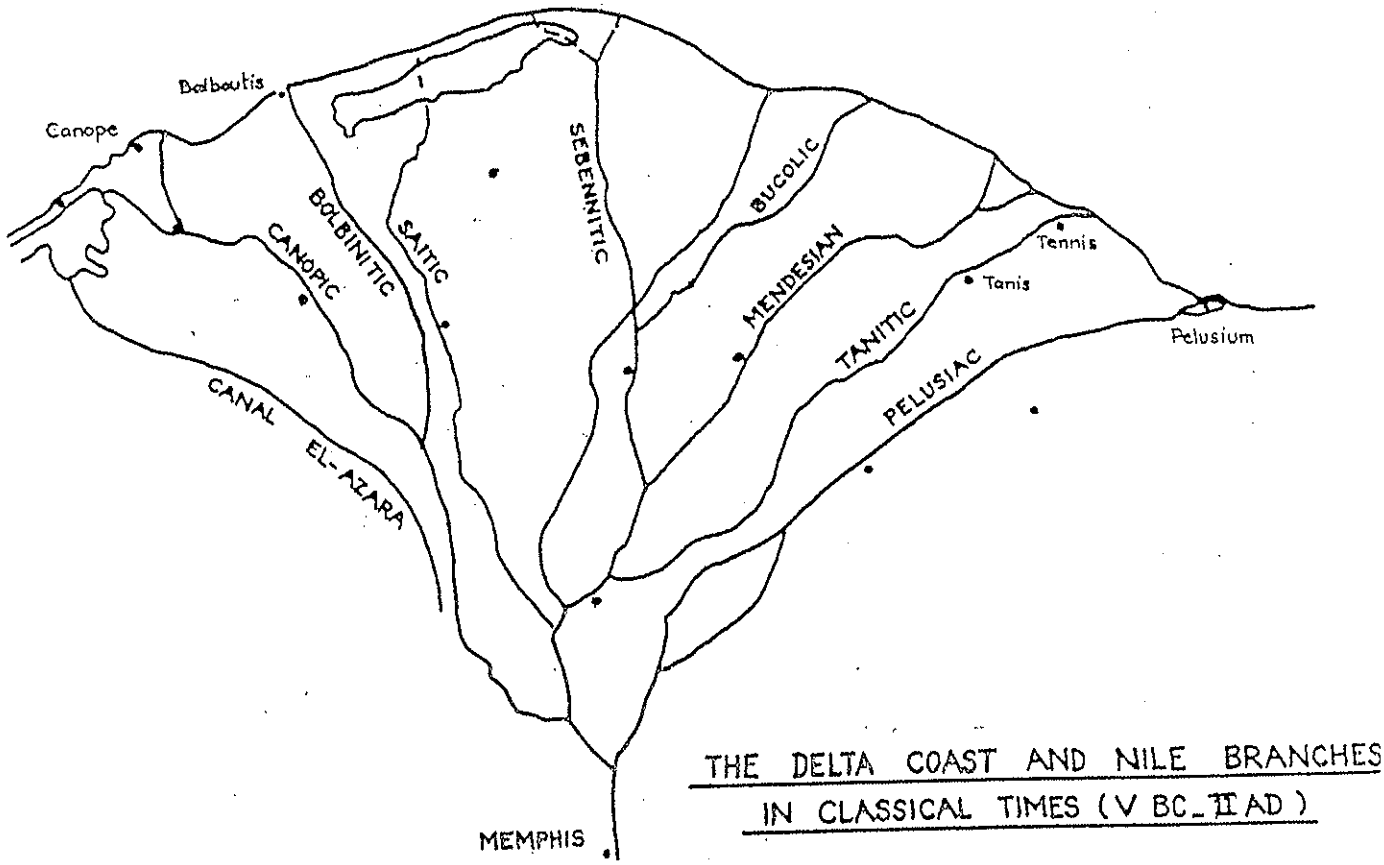

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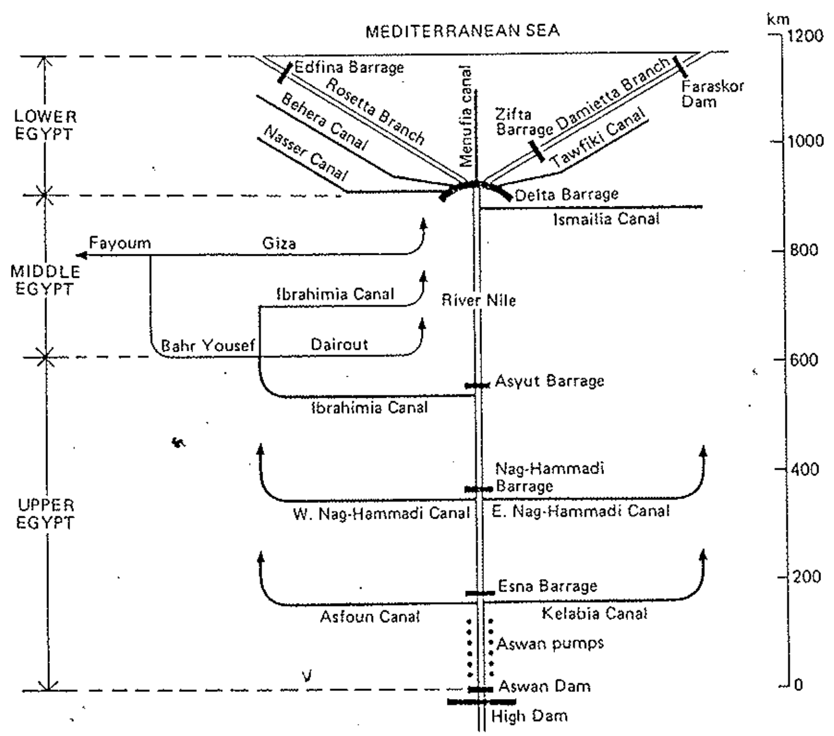

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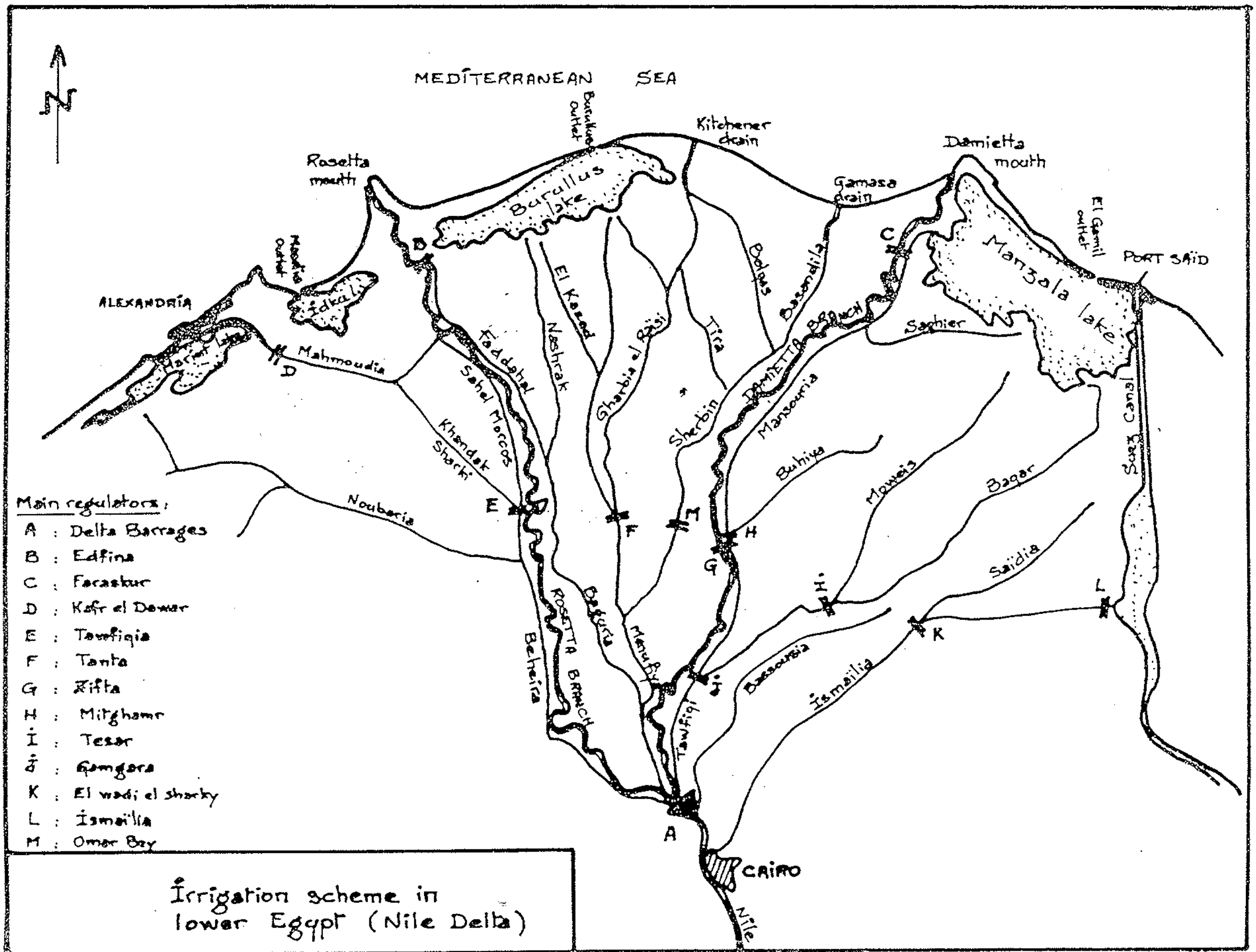

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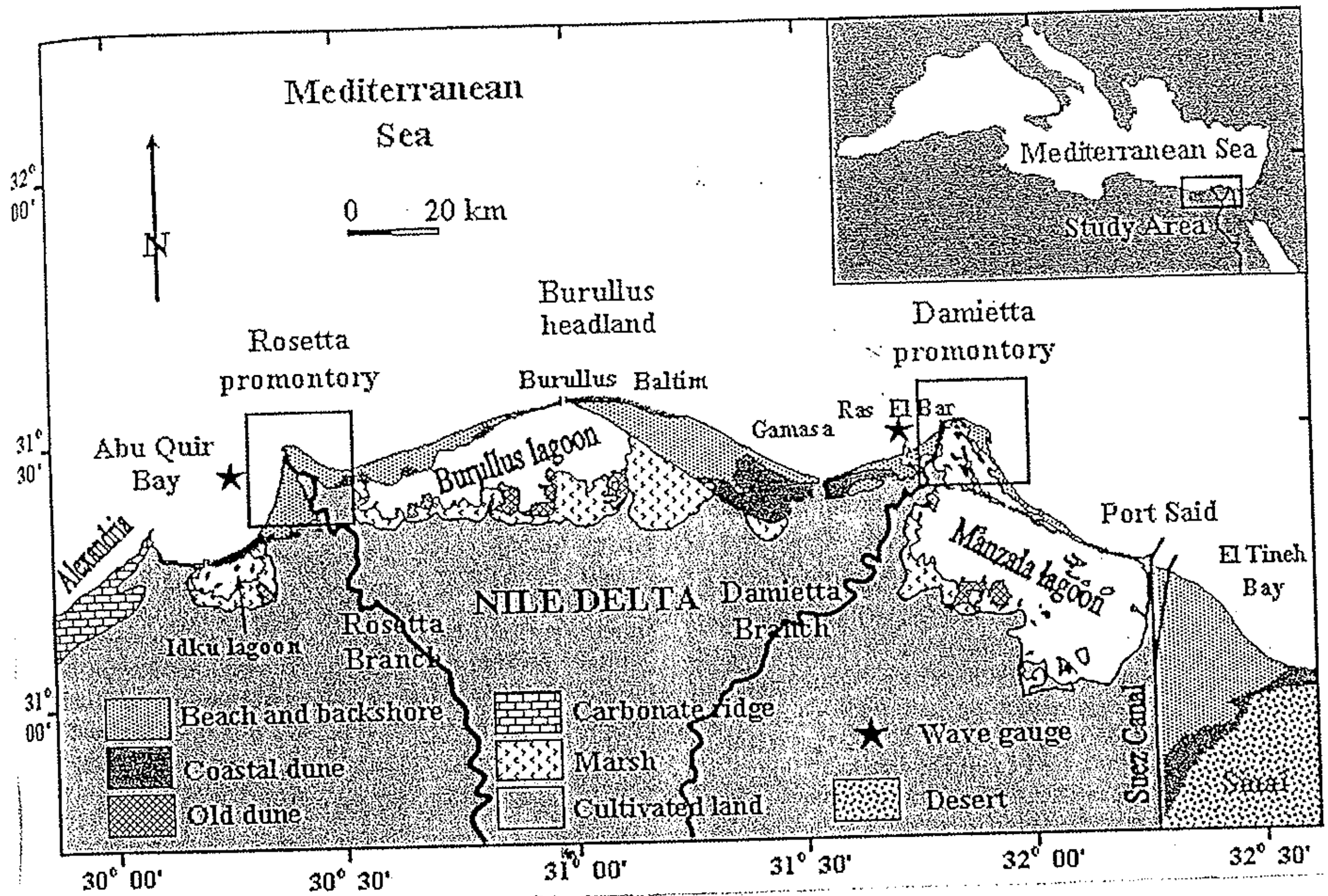

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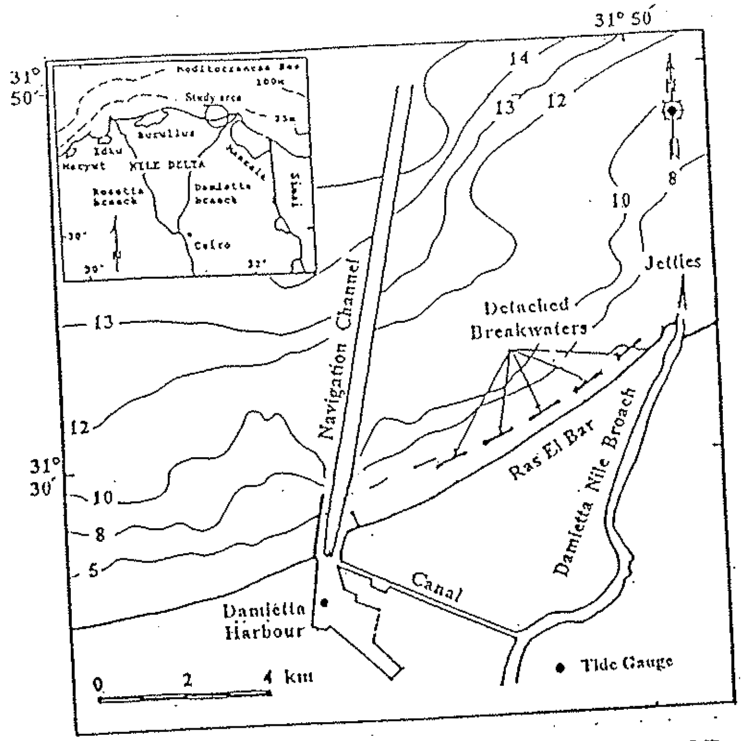

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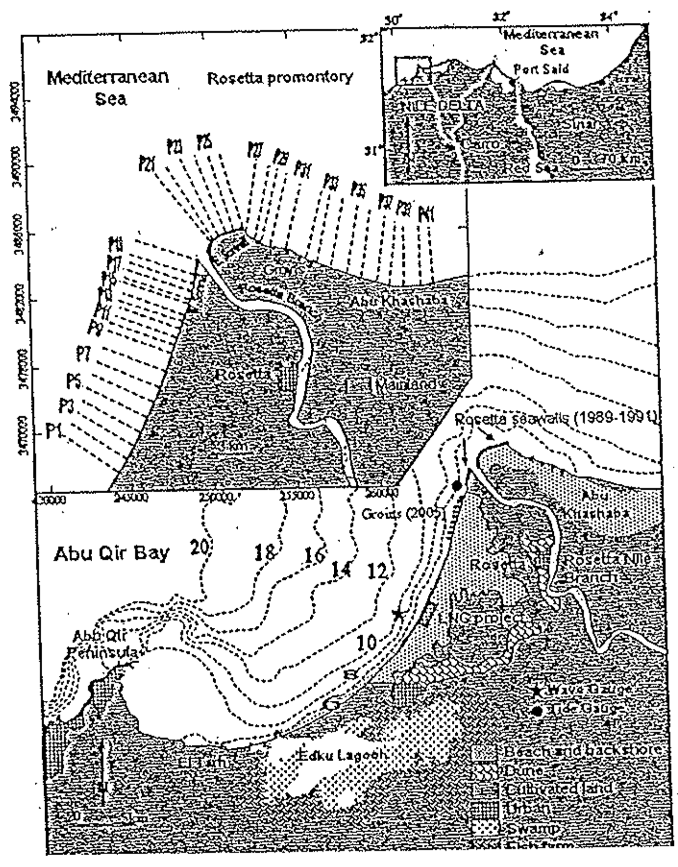

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