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Geoarchaeological Interpretation of the Canopic, Largest of the Relict Nile Delta Distributaries, Egypt

Jean-Daniel Stanley†, Andrew G. Warne†*, and Gerard Schnepp‡

†Geoarchaeology-Global Change Program
E-206 NMNH
Smithsonian Institution
Washington, D.C. 20560,
U.S.A.

‡ARCOCEA International
123 route de Saint Nizier
38170 Seyssinet-Pariset,
France

ABSTRACT

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The Canopic branch, the largest relict Nile distributary, once flowed across the NW Nile delta of Egypt to the Mediterranean. This study focuses on the Canopic's evolution at the delta margin and in Abu Qir Bay seaward of the coast. Information from historic documents, integrated with data from geographical, geological, and archaeological exploration in the bay, indicates that the Canopic distributary was active from ~4000 B.C. to the end of the 1st millennium A.D. Fluvial discharge persisted through pre-Dynastic, Dynastic, Greek, Roman, Byzantine and early Arabic time. The channel flowed to two sites, Herakleion and Eastern Canopus, established by the Greeks as navigational gateways for trade in the delta and surrounding region. Eastern Canopus functioned until the mid-8th century A.D. At that time, flow in the Canopic had decreased markedly, and Nile water was diverted to the east, through the Bolbitic-Rosetta branch. By the end of the first millennium A.D., Nile water was channeled in the Rosetta and Damietta distributaries, and the Canopic branch eventually converted to a canal and drain system.

The Canopic promontory across which the branch flowed, and the 2 ancient sites located at the promontory coast near Canopic channel mouths, subsided beneath the waters of the bay after the 8th century. Submergence was a response to interaction of eustatic sea-level rise, annual floods, growth-faulting, soft-sediment deformation and other natural processes. As the Canopic promontory subsided, Abu Qir Bay attainted a marked concave-seaward shape and its shoreline shifted southward. This geoarchaeological investigation helps distinguish the long-term impact of natural events from that of increased human activity. This distinction is of practical importance for the highly populated and vulnerable delta margin that continues to experience submergence and erosion.

ADDITIONAL INDEX WORDS: *Abu Qir Bay, archaeology, avulsion, Canopic promontory, channel migration, Eastern Canopus, Herakleion, navigation, Nile floods, sea-level rise, subsidence, substrate failure, trade centers.*

INTRODUCTION

The River Nile is one of the world's best documented fluvial systems. However, there have only been few investigations of this river's lower stretch and its distributaries that once extended to, and seaward, of the Nile delta coast in Egypt. The present study integrates geographical, geological, archaeological, and historic information to define the long-term evolution of the lower Canopic branch that once flowed across the northwestern Nile delta in Egypt to the Mediterranean Sea. The Canopic, largest of the relict River Nile distributaries, discharged large volumes of sediment along the delta's coastal margin from the early to mid-Holocene. The branch remained active during the major period of human development in this delta sector, persisting through pre-Dynastic, Dynastic, Greek, Roman, Byzantine and, probably, to early Arabic time (TOUSSOUN, 1934; CHEN *et al.*, 1992).

Much of what was known about the history of the lower Nile and its Canopic and other distributary branches in the delta was summarized in the early 20th century, with the most comprehensive synthesis prepared by Egyptian Prince Omar Toussoun. This scholar reviewed changes of the Canopic, focusing primarily on about 1100 years of evolution (~600 B.C. to 500 A.D.), and based his observations largely on documents of Greek, Roman, and Arab scholars (TOUSSOUN, 1922, 1926). More recent historical reviews (BERNAND, 1970; SAID, 1993) have been formulated, at least in part, on Toussoun's sources. Geographic and geologic surveys complemented these studies and provide new information on the origin and early history of the Canopic branch and adjacent Nile delta region (EL BOUSEILY and FRIHY, 1984; CHEN *et al.*, 1992; WARNE and STANLEY, 1993; FRIHY *et al.*, 1994). Nevertheless, limitations of working only from historic or earth science perspectives have precluded summation of the Canopic branch's development through time, especially in the offshore sector.

Constraints have been accurate correlation of natural and human events in this region and evaluation of the branch's coastal evolution along the delta margin, now in waters of Abu Qir Bay (Figure 1). New light has been shed by the un-

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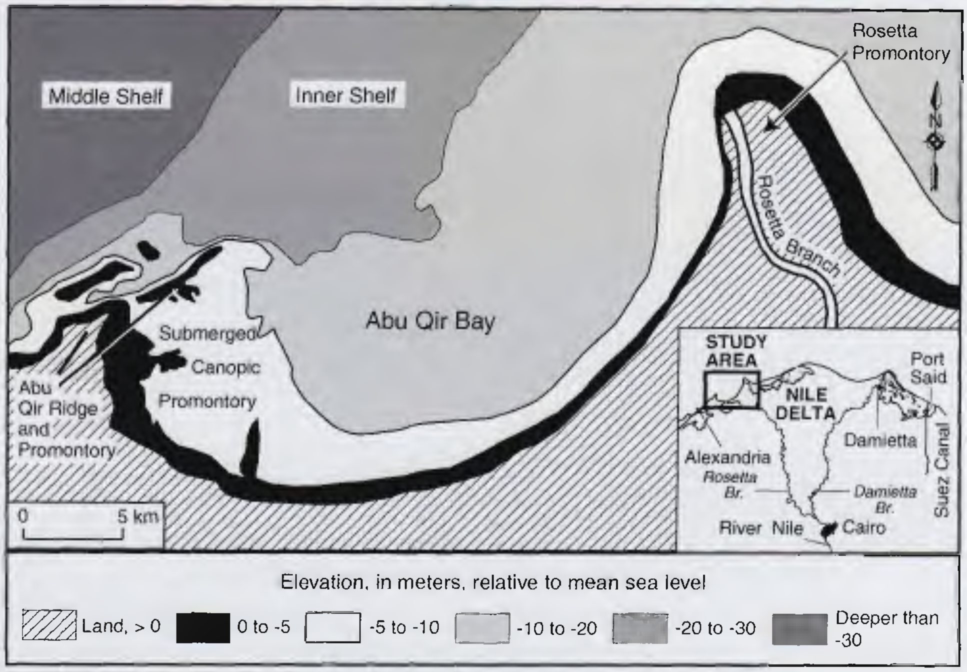

Figure 1. General physiography of the Abu Qir Bay area, along the northwestern Nile delta, Egypt, from the Abu Qir promontory and ridge to the Rosetta promontory. The Canopic branch once flowed to the western bay sector (Figure 2). Shown are the submerged Canopic promontory, the Canopic submarine ridge that extends northeastward from the Abu Qir carbonate headland, and the Rosetta promontory.

derwater exploration of two recently discovered ancient settlements, Herakleion and Eastern Canopus, presently situated about 5 km north of the coast at water depths of 5 to 7 m in the western bay (GODDIO, 2003). These settlements, initially established by the Greeks at the mouth of the Canopic for trade purposes in Egypt, provide new insight on the branch's coastal development and significance. Particularly valuable are data on sediment substrate and natural events in this region that can now be examined in light of archaeological (CONSTANTY, 2002; GODDIO, 2004), physiographic and geophysical (SCHNEPP, 2000), and substrate stratigraphic (STANLEY *et al.*, 2001, 2004) information obtained in Abu Qir Bay where the branch once flowed. This multi-disciplinary approach applied offshore should make it possible to assess more comprehensively the evolution of the Canopic fluvial system from the time of its initiation until its demise.

GEOGRAPHIC SETTING

The present configuration of the northwestern Nile delta margin is largely the result of interaction of River Nile sediment input and accumulation along the coast and shelf, and the removal and redistribution of this material by marine processes. Seaward accretion and progradation of the delta typically prevailed when and where river accumulation rates exceeded the capacity of marine processes to rework the sediment. In contrast, subsequent erosional phases occurred when coastal processes removed more sediment than was provided by river sediment influx (STANLEY and WARNE, 1994). The arcuate Nile delta coastline that has evolved is a result of an active wave-dominated regime, where coastal currents along the northwest delta eroded and displaced eastward fluvial sediment discharged to the coast and shelf (FRIHY *et al.*, 1988; SESTINI, 1989).

The Abu Qir Bay shoreline is distinctly concave seaward, unlike the gentle convex coastline of the central and eastern Nile delta (inset, Figure 1). The coastline is about 50 km long, from the Abu Qir promontory that forms the west bay boundary to the Rosetta promontory in the east (EL ASKARY and FRIHY, 1986). Abu Qir ridge delineates the northern part of the bay; it extends seaward to the NE, from the modern tip of the Abu Qir promontory to about 5 km into the Mediterranean. The Rosetta promontory, the triangular-shaped mass of unconsolidated fluvial-deltaic sediment, protrudes seaward ~14 km to the NNW onto the inner Egyptian shelf. Landward, to the south, several environments surround the modern bay: beach, backshore sandflat and strand plain, coastal dune, brackish to fresh-water wetland (lagoon, marsh), kôm (low hill), drain and canal, and agricultural land (EL-FAYOUMY *et al.*, 1975; EL FISHAWI and EL ASKARY, 1981; FRIHY *et al.*, 1988; CHEN *et al.*, 1992; WARNE and STANLEY, 1993).

The modern bay proper can be subdivided into two distinct regions on the basis of shoreline configuration and bathymetry: the Abu Qir ridge-to-Maadia sector in the western bay, and the longer Maadia-to-Rosetta sector to the east. The seafloor in the western bay sector comprises a large, shallow triangular platform we term the Canopic promontory (Figure 1). The promontory is bound to the west by Abu Qir promontory, to the north by Abu Qir ridge, and to the east by a well-defined,

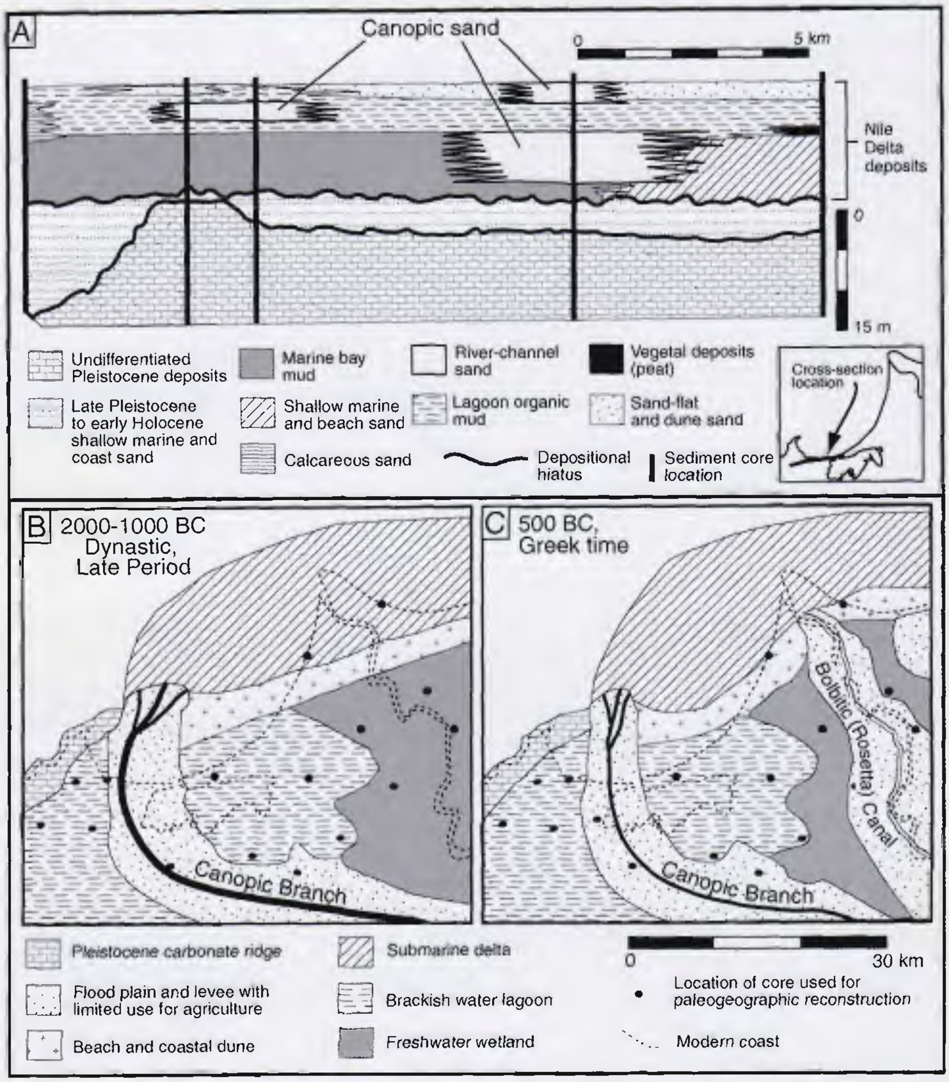

Figure 2. (A) Geological cross-section in the southern Abu Qir Bay region, showing lateral shifts of the Canopic branch through time. (B,C) Paleogeographic reconstructions at about 2000–1000 B.C., and at ~500 B.C. based on stratigraphic analysis of radiocarbon-dated sediment cores. The Canopic branch and associated subdelta lobes and small distributary channels migrated east to-west, and then back to east; the Bolbitic (and Rosetta) branch began later, its promontory forming the eastern bay margin (Figure 1). Modified from CHEN and others (1992).

linear margin that extends from the coastal town of Maadia to Abu Qir ridge. This feature extends northward a maximum of ~12 km from the southern bay shore and lies at depths that are, for the most part, less than 10 m.

The Canopic branch once flowed across the Canopic promontory to what was then its coastal margin. There, the ancient sites of Herakleion and Eastern Canopus were located near distributary mouths. Prior to its submergence, the promontory was once about 10 km wide along what is now the delta coast, and its triangular-shaped surface covered an area of ~70 km^2. The size, shape and area of the submerged platform-like feature are similar to those of the younger, subaerially-exposed Rosetta promontory formed by the Bolbitic and, later, Rosetta distributaries of the Nile (Figure 2B, C).

GEOLOGIC BACKGROUND

Subsurface investigations of the Nile delta margin initially focused on the petrology and lithofacies definition of long, continuous sediment cores (FOURTAU, 1915; ATTIA, 1954; SESTINI, 1989; STANLEY *et al.*, 1996). Radiocarbon-core dated sections have been used to document the changes in position of distributaries that once flowed across the delta plain to the coast and the delta coast configuration. These have been markedly altered since the early Holocene (8000–7000 years ago) when the modern delta began to form (STANLEY and WARNE, 1994, 1998). Chrono- and lithostratigraphic examination of the substrate serve as the basis to interpret the evolving paleogeography of the northwestern Nile delta during the long period when the Canopic branch was active (CHEN *et al.*, 1992; STANLEY and WARNE, 1993).

In addition to sediment cores recovered on land, bottom sediment grab samples and cores were collected seaward of the present coast in Abu Qir Bay (FRIHY, 1992; FRIHY *et al.*, 1994; STANLEY *et al.*, 2004). Former Canopic distributary channel patterns and coastal environments across which they once flowed have been identified with these materials. Petrologic attributes, such as texture and sand composition of dated samples indicate that the early Canopic channel, or its precursor in this area, formed about 6000 years ago (CHEN *et al.*, 1992). At that time, when sea level was much lower than at present (to ~10 m), and during much of the following five millennia, the Canopic branch discharged a large volume of sediment on the delta margin. It is this material that formed the large promontory off the coast, now submerged in the west-central part of Abu Qir Bay (Figure 1).

Lithostratigraphic analyses of Holocene core sections can be integrated with data from recently acquired high-resolution subbottom seismic profiles. Together, these indicate that unconsolidated fluvial sediment and wetland organic-rich deposits forming the Canopic promontory accumulated on a subsiding carbonate sandstone (kurkar) substrate of late Pleistocene age (Figure 2A). Closely-spaced (100 to 1000 m) seismic profiles show that the consolidated kurkar 'basement' was offset by normal faults into a horst-and-graben topography in the late Pleistocene and early Holocene. The underlying kurkar substrate was first buried by shallow marine carbonate sediment, and then by quartz-rich River Nile material during the following ~5000 years (Figure 2A). These Holocene unconsolidated delta lobe deposits thicken to 15 m east of the Abu Qir headland (STANLEY *et al.*, 2004).

Channels recorded on seismic profiles, together with fluvial sand sections recovered in cores, show that the Canopic mouth shifted periodically over a distance of as much as 5 km along the delta coast during the mid- to late Holocene (Figure 2A). Lateral migration and river mouth displacement likely occurred in a manner similar to that documented in other major delta systems, *i.e.* typically induced by avulsion and crevasse-splay processes (COLEMAN and WRIGHT, 1975; PENLAND *et al.*, 1988; TÖRNQVIST, 1994). Shifts of the distributary Canopic mouth were accompanied by displacement of their small, localized subdelta lobes and associated small channels (Figure 2B, C). As these small coastal margin channels migrated back and forth (at a frequency of ~100 years, or less), the older, abandoned subdelta lobes were eroded. Reworked lobe sediment was transported laterally along the delta margin by coastal currents and storm waves. Eventual disappearance of these delta coastal depocenters beneath the water of the bay resulted from land subsidence (isostatic lowering, fault offset, substrate failure, sediment compaction) and eustatic sea-level rise.

Sea level rose at rates of ~1–2 mm per year during the period from 600 B.C. to 800 A.D. determined on the basis of dated core sections. These rates, while generally similar to those of late Holocene sea-level rise documented elsewhere for this time period (*cf.* FAIRBANKS, 1989; PIRAZOLLI, 1992), would not explain the depths on the bay floor (−5 to −7 m) where the Canopic promontory surface and submerged sites presently lie. Moreover, the configuration of the northwest Nile delta margin changed considerably during the >1000-year period when Herakleion and Eastern Canopus were occupied settlements on the coast. The overall arcuate shape of Abu Qir Bay developed as a result of rapid subsidence of the Canopic promontory, decreased Nile discharge at the mouth of the Canopic branch, and increased flow farther to the east, through the Bolbitic (later the Rosetta) branch (Figure 2).

THE CANOPIC'S LATE HISTORY ON LAND

The historic record provides valuable information to help interpret the Canopic branch's evolution at the delta coast, including the time when this major distributary became a relict feature. The Nile delta plain was described by Greek, Roman, Byzantine, and Arab scholars who identified the numerous Nile distributaries that flowed to the coast (Figure 3). It has been suggested that perhaps as many as seven fluvial channels and canals were active at one time. Herodotus and Strabo indicate that the mouth of the Canopic branch was located within what is now west-central Abu Qir Bay (Figure 3A, B). Summarizing available documents, TOUSSOUN (1922, 1926) and others indicate that the Canopic branch was the largest of the distributary channels at the time of the Greeks (as of the 7th to 6th century B.C.) and remained active until the 1st millenium A.D.

It is of note that before the 6th Century B.C., in the Dynastic Late Period, a settlement called Herakleion (N 31° 18′ 775; E 30° 7′ 670) had been established at the mouth of the Canopic branch (CONSTANTY, 2002). Initially, it was to serve as a gateway for ships sailing into and out of the northwestern Nile delta by means of the Canopic branch. Herodotus, in *The History (Book 2, 113)* states ". . . he came to Egypt . . . to what is now called the Canopic Mouth of the Nile and to the Saltpans. There was, on the shore (it is still there), a shrine of Heracles." Ships headed to Naukratis, at that time the major Greek port in Egypt (COULSON and LEONARD, 1979) built along the Canopic waterway about 55 km south of the Mediterranean shore (Figure 3A–C). It has been suggested that Herakleion, the coastal gateway, may have been positioned as much as 3 m above sea level at the time of its construction (TOUSSOUN, 1934). Meanwhile, from Roman to Byzantine time (Figures 2C, 3B–D), the Bolbitic channel to the east (later called the Rosetta) was maintained by artificial excavation. Historians indicate that the Canopic channel was radically transformed in the 5th century A.D. and flow had diminished before, or by, the time of the Arab conquest (TOUSSOUN, 1922, 1926).

It is likely that flow through the Canopic branch at Herakleion had declined in Roman and Byzantine time. Documents pertaining to Eastern Canopus (N 31° 18′ 880; E 30° 5′ 350) suggest that flow in the Canopic channel had shifted westward by ~4 km and continued in Byzantine time, until at least the early part of 7th century A.D. (BERNAND, 1970). Although flow through the channel had decreased, it is probable that the Canopic was still used for navigation after that date. New evidence from archaeological underwater exploration indicates that Eastern Canopus did not subside beneath the waves until a later date, including findings of valu-

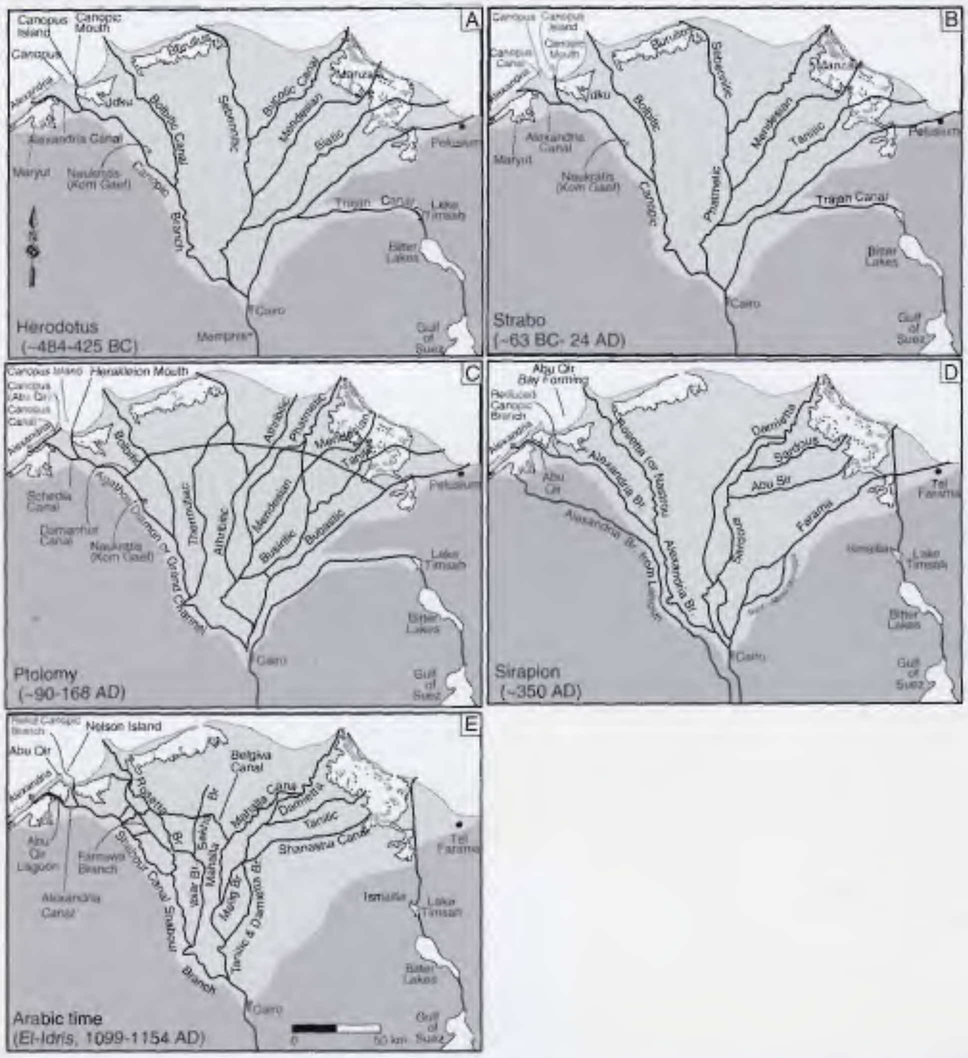

Figure 3. Generalized maps of the Nile delta showing positions of major distributary channels and canals during the times of (A) Herodotus (~484 to 425 BC), (B) Strabo (~63 BC to 24 AD), (C) Ptolomy (~90 to 168 AD), (D) Sirapion (~350 AD), and (E) El-Idris (~1099–1154 AD). Channel configurations are shown on an early 20th century base map of the delta and, hence, these maps do not record change in configuration of the coastal region. Modified from Toussoun (1926).

ables such as the youngest, well-preserved gold coins that date human occupation of Eastern Canopus to the mid-8th century A.D. (Stanley *et al.*, 2001, 2004; Constanty, 2002; Goddio, 2004).

The Canopic, however, did not completely disappear at that time. Documents dating from El-Idris in Arabic time (Figure 3E) to the post-Renaissance (UNDP/UNESCO, 1978; Said, 1981; Siliotti, 1998), indicate that water remained in the progressively modified Canopic channel. It is envisioned that some flow continued, albeit much reduced, to the coast until the beginning of the second millennium A.D.; the Bolbitic-Rosetta had become a major distributary discharging sediment at the eastern margin of Abu Qir Bay during and after the 1st millennium A.D. (Figure 4). Maps record the presence of a relict Canopic channel at least through the 18th century A.D., including those of Abraham Ortelius, 1570; Hondius, 1625 (Figure 4A), Benoît de Maillet, 1735, Richard Pococke, 1737, Jean-Baptiste Bourguignon d'Anville, 1766. Other maps compiled during this period are shown in Figure 4B–E. More recently, in the early 19th century, distinct traces of the relict Canopic are identified on more detailed maps prepared by Arrowsmith (1802, 1807), du Bois-Aymé (1813), and Jacotin (1818). By then, the branch had been transformed to an irrigation canal and drain channel system.

Traces of the Canopic branch are presently detected inland from the coast, including the southern margin of Idku lagoon, by aerial photography (UNDP/UNESCO, 1978) and satellite imagery (Abdel-Kader, 1982; IWACO, 1989). Although intensely reworked by farmers, a series of low hills (kôms) are still preserved in this northwestern delta region. Interpreted

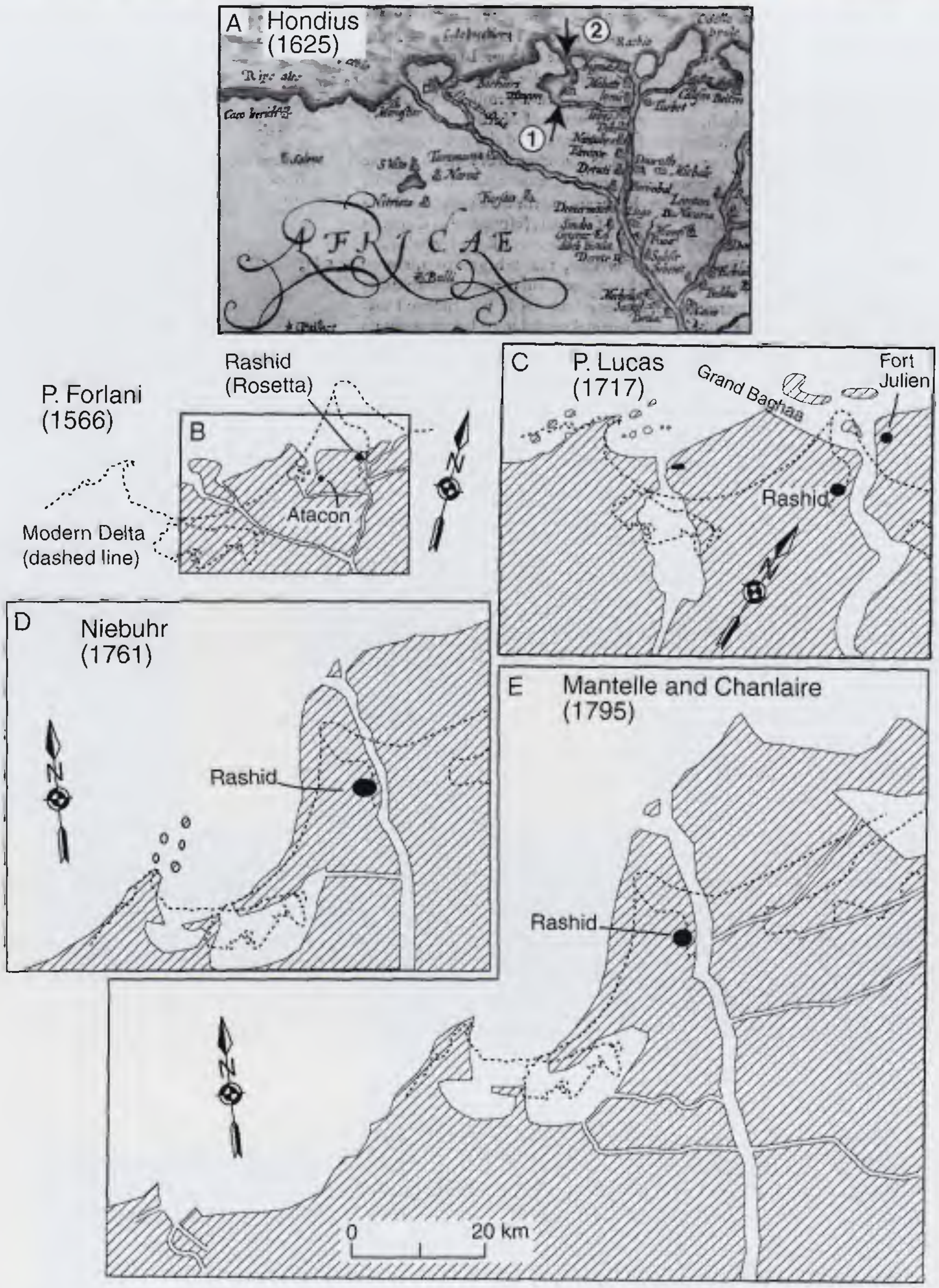

Figure 4. Maps showing the configuration of the northwest Nile delta from the mid-16th to the late 18th century A.D. (A) Enlarged portion of a map by Hondius (1625 A.D.) showing the relict Canopic channel extending to (1) Idku lagoon and (2) Mediterranean coastal outlet west of Rosetta. For C–E, the modern shoreline (dashed line) is superimposed for reference by matching the position of Abu Qir headland and town of Rashid (Rosetta) on both historic and modern maps. Because the Abu Qir peninsula was not included in historic map B, scaling and orientation of this map (relative to the modern configuration) is more conjectural. Maps B–E are compiled from data in UNDP/UNESCO (1978).

as remnant point bars related to channel migration, these features delineate late Holocene flow paths of this distributary in the northwest delta.

TRACING THE CANOPIC OFFSHORE

Investigations seaward of the NW Nile delta coast provide information essential to complement this review of the Canopic. British and Egyptian offshore bathymetric surveys made in Abu Qir Bay during the first half of the 20th century showed the presence of submerged linear features that trend SSE to NNW across the northwestern part of Abu Qir Bay (UNDP/UNESCO, 1978). These record extension of shifting Canopic branches seaward of the coast. The recent, more detailed bathymetric survey (Figure 5A), made in association with on-going geophysical, geological and archaeological exploration on the submerged Canopic promontory surface in Abu Qir Bay (SCHNEPP, 2000; GODDIO, 2004; STANLEY *et al.*, 2001, 2004), sheds new light on the Canopic's history.

The depth of the Canopic promontory is remarkably uniform, with about 80% of the surface ranging from 5.5 to 6.5 m. Physiographic anomalies include: several shallower (< 5 m), elongate (to ~2 km long) features, oriented N-S and located at the eastern promontory margin; and two rectangular to irregular-shaped depressions in the central part of the submerged promontory. Also noted are several smaller (diameter <500 m) and somewhat deeper (> 7 m) depressions, including one adjacent to Herakleion. Most significant with respect to the present study are the distinctly linear, channel-like depressions (>1 m relief) and interchannel (perhaps levee) ridges mapped along the promontory's eastern boundary (Figure 5A). These delineate a gentle eastward slope extending from a depth of ~7 m at the promontory margin to ~11 m and deeper in the central bay. On seismic profiles, these linear features are readily traced ~10 km from the present south-central bay coast, near the town of El-Maadia, to the west-central part of Abu Qir Bay. These features are now confidently interpreted as relict, partially-filled channels (STANLEY *et al.*, 2004). Sediment facies maps depicting texture and composition of modern nearshore and Abu Qir Bay floor deposits also identify the position of the former lower stretch of the more recent Canopic channel (EL BOUSEILY and FRIHY, 1984; EL FATTAH and FRIHY, 1988; FRIHY *et al.*, 1994).

More subtle, lower relief (~1 m), discontinuous channel-like features are recorded on the surface of the flat Canopic promontory proper. Two of these trend toward the ancient towns of Herakleion and Eastern Canopus (Figure 5). These features, interpreted part of the Canopic's distributary system, trend from Fort El-Hamra in the south to at least as far northward as the submerged sites (Figure 5A). It is surprising that such depressions have been preserved on the central portion of the submerged promontory since this is a relatively high-energy, shallow shelf environment. Moderate to strong bottom currents sweep the western bay erode the seafloor, and thus displace sediments laterally (FRIHY *et al.*, 1994) and smooth the promontory surface. Seismic profiles show sediment truncation, while grab and core samples record sediment reworking and depression fill (STANLEY *et al.*, 2004). Additional evidence is provided by diver excavation at the two sites in Abu Qir Bay: a surficial layer (to ~1 m thick) of reworked shelly and quartz-rich marine sand partially covers older, organic and silt-rich deltaic margin sediment (fluvial, wetland, coastal) that forms the submerged promontory substrate.

The subtle, linear SSE-NNW depressions on the promontory surface represent partially to nearly filled Canopic channels that are most likely of older Holocene age than the ones that flowed along the eastern promontory margin. We surmise that such features, extending offshore to now-submerged ancient sites, would not presently be preserved as distinct features on the Abu Qir Bay floor had the Canopic branch dried to a trickle and were no longer functioning before the 5th century A.D. as indicated by TOUSSOUN (1934) and others (R. Said, 2001, personal communication).

DISAPPEARANCE OF CANOPIC CHANNEL MOUTHS

The disappearance in Abu Qir Bay of two important human centers and coastal extension of the Canopic branch in relatively recent time is puzzling. As noted by TOUSSOUN (1934, p. 352), it is particularly surprising that what appears to have been a cataclysmic event, one occurring during an important historic period with a large population living in the region, is not mentioned in any historic document.

Among natural processes that commonly affect delta margins are world (eustatic) sea-level change and land subsidence, isostatic depression, sediment failure and compaction of substrate deposits. Interaction of two or more such phenomena could lead to submergence of subdelta lobes and their distributaries beneath the waves (COLEMAN, 1982). It is recorded that historic records and archaeological evidence now indicate that Herakleion and Eastern Canopus, located closely to Canopic branch mouths on the Canopic promontory, were occupied for a period lasting approximately 13 centuries, from the 6th century B.C. to the mid-8th century A.D. Ongoing bathymetric, geological and geophysical exploration, in conjunction with archaeological excavation by divers, show that each of the two sites covers a surface area of nearly one square kilometer and lies at water depths ranging from about 5 to 7 m. However, eustatic rise in sea level in the eastern Mediterranean since the 8th century A.D. has been less than 2 m along the Nile delta coast. Thus, subsidence of the substrate by tectonic and/or substrate sediment failure, accompanied by erosion and other processes, must account for a non-eustatic component of an additional 3 to 5 m submergence since Byzantine time. The response to important vertical lowering of land plus eustatic sea-level rise during the past 1300 years, together, would account for large rates of *relative* sea-level change. While high (to > 5 mm/yr), such rates are by no means unique on the Nile delta coastal margin (STANLEY and WARNE, 1998).

Among widely distributed valuables recovered on the bay floor, at Herakleion and Eastern Canopus, are gold and silver coins, jewelry, and statues, along with human and livestock bones. These, associated with large damaged structures, point to sudden destruction of sites that were still occupied.

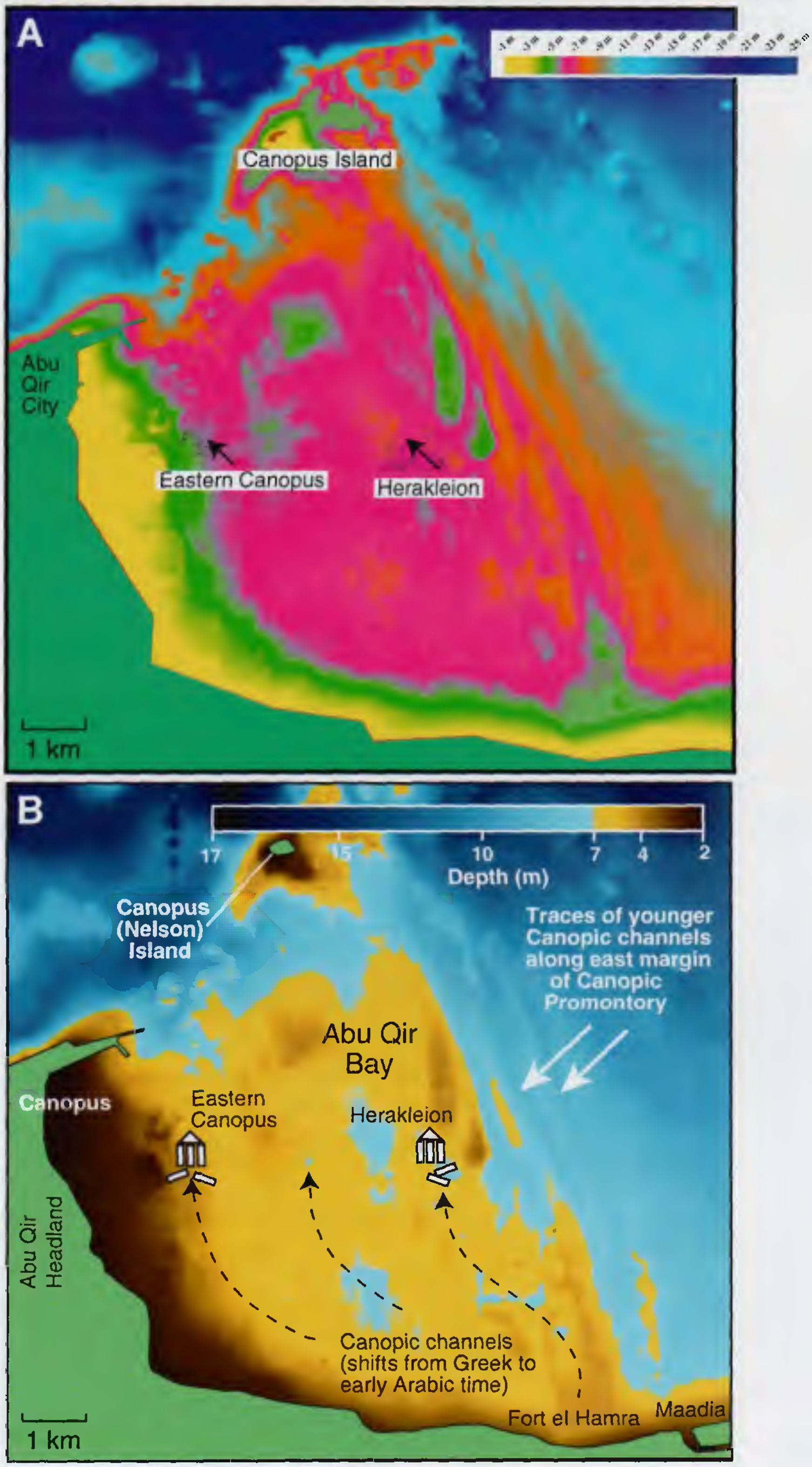

Figure 5. (A) Bathymetry of the present Abu Qir Bay seafloor and location of ancient sites of Herakleion and Eastern Canopus. The map is based on closely-spaced N-S and E-W grid lines, using a high-resolution single beam echosounder TRITECH PA500. Color shading details the submerged, low-relief Canopic promontory surface, including N-S and SE to NW trends. Shown on the promontory are well-defined highs (<5 m) and several small depressions (>7 m), including one adjacent to Herakleion. Distinct linear SSE to NNW channels at the eastern boundary of the promontory extend from

Abandonment of the two river mouth locales, located near the Canopic promontory coast, occurred respectively at about 1900 and 1300 years ago. The younger date at Eastern Canopus is established by archaeological evidence, including the youngest coins (Arabic) and Nilometer records for this specific period (POPPER, 1951), in conjunction with disrupted strata in radiocarbon-dated cores. Of note are post-depositional features in cores that include soft-sediment deformation, fluidization, and slump structures. Seismic profiles of the substrate located below the two sites at the Canopic subdelta river mouths show large sections of disturbed strata, including offset layers, tilted deposits, and mud diapirs (STANLEY et al., 2003).

An evaluation of potential triggers of sediment failure must take into account that the Nile in its valley and delta was periodically subject to unusually large fluctuations of river flow as a response to important climatic fluctuations (POPPER, 1951; ADAMSON *et al.,* 1980; HASSAN, 1981; SAID, 1993). Annual variation of the annual peak Nile flood by as little as 1 m could mean the difference between famine (flood stage too low) and widespread destruction of the lower delta and coast (flood stage too high). For example, at the end of the Old Kingdom and 1st Intermediate Period (about 2250–1950 B.C.), unusually low annual discharge and flood levels caused famine and political disorder. Such periods of drought and of major floods long continued to devastate population centers located along major distributary channels in the delta plain (SAID, 1993). Using all available data, including combined archaeological and historical information, it can be shown that a documented higher-than-average Nile flood at 741 or 742 A.D. was the major trigger for failure of the low-lying substrate on which the Eastern Canopus site and remnant Canopic branch were still located. Shortly after the time of Arab conquest, the promontory was further submerged by floods and vertical land displacement. In little more than 1000 years, the coastline regressed to its present position, about 5 km to the south and 2 km to the west of the ancient site (STANLEY *et al.,* 2003).

Tectonically-induced events during the past two millennia may also have caused listric faulting, liquifaction, and sediment slumping leading to local and vertical offset and substrate failure in Abu Qir Bay. We do not rule out the possibility of some earthquake tremors and tsunamis initiated in the more tectonically-active sectors of the eastern Mediterranean (GUIDOBONI, 1994). A well-documented example is the large earthquake-triggered tsunami that caused extensive damage to Alexandria in 365 A.D. Thus, positioned just above sea level on an unstable, water-saturated sediment substrate, Nile flooding, associated soft-sediment deformation and, additionally, earthquake and tsunami may have influenced the integrity of Herakleion and Eastern Canopus. To date, however, the record of liquefaction and fluidized sediment is localized specifically at the Canopic mouths, and not widely distributed across the Abu Qir Bay. This indicates that the impact of seismic events was as geographically limited as that of Nile flooding.

The effects of human activity such artificial channel modification (canalization, deepening, deviation) may also have had some influence in periodic lateral shifts of the Canopic subdelta mouths in the delta margin setting. Moreover, emplacement of large, heavy stone structures, such as the temples and massive walls at Herakleion and Eastern Canopus, would have had some local impact. These were constructed directly on water-saturated, organic-rich marsh and coastal sediments of Canopic subdelta promontories. Consequently, these structures contributed to substrate failure and were highly prone to damage (STANLEY *et al.,* 2004).

In time, natural processes and human activities would have rendered Herakleion and Eastern Canopus progressively more vulnerable to annual floods of the River Nile. Most destructive were those events reaching a level of 1 m or more above average high flood stage. High floods induced sudden breaks (crevasse splays) along the channels and their natural levees that lay only just above sea level. It is to be expected that the Greeks, Romans, Byzantines, and perhaps those that followed after the time of the Arab conquest, having positioned their sites on the soft, clayey silt of the Canopic mouth substrates, were increasingly subject to destructive environmentally-related problems. Positioned little above mean sea level, the inhabitants were periodically forced to rebuild and, at times, abandon part of their town especially after a larger than average flood event. This scenario would also explain large-scale population shifts from Herakleion to Eastern Canopus, and perhaps to other sites along the coastal margin yet to be discovered in the bay.

CONCLUSIONS

The data from geographical, geological and archaeological exploration, integrated with information from historic documents, indicate that the Canopic distributary was active for a period lasting at least 5000 years, from about 4000 B.C. to well into the first millennium A.D. Settlements at Herakleion and Eastern Canopus, once positioned at distributary mouths of the Canopic along the Nile delta coast, were submerged in Abu Qir Bay by the mid-8th century A.D. By then, the western and central bay received a markedly decreased input of Canopic fluvial sediment, but remained subject to continued land subsidence and sea-level rise and increased coastal erosion. In time, smaller Canopic distributary mouths and human-occupied sites north of the present coast disappeared as a response to ravages of annual floods, growth-faulting, and soft-sediment deformation processes that induced important lowering of the substrate.

By early Arabic time, much of the Canopic channel system had been converted into an artificial canal and drain system,

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southern coast northward to the Abu Qir ridge. (B) Dashed lines denote partially-filled channels that once extended from Fort Hamra at the coast, across the promontory, to now-submerged ancient sites. Herakleion (submerged during and after the 1st century A.D.) and Eastern Canopus (submerged in the mid-8th century) are studied by underwater archaeological exploration, in conjunction with geological and geophysical surveys.

as progressively more Nile water and sediment were discharged to the coast farther to the east by the Bolbitic-Rosetta system. Abu Qir Bay attained its arcuate-concave-seaward shape as the Canopic promontory was submerged, the shoreline shifted southward, and the Bolbitic-Rosetta promontory accreted seaward. By the end of the 1st millennium A.D., the Nile fluvial system was essentially reduced to two primary channels, the artificially maintained Rosetta branch and the Damietta distributary. Submergence of the northwest delta margin has continued to the present, resulting in the progressive lowering of some coastal towns and increasing problems of salinization.

This geoarchaeological investigation serves to distinguish, over the long-term, the impact of natural events from that of human activity that continues to modify the Nile delta coastal margin. The multi-disciplinary approach is a promising tool to help formulate viable protection measures needed for this increasingly populated and vulnerable region.

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