Alexandreia Emerging – Paleogeographical reconstruction of Ptolemaic Alexandreia

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ABSTRACT

The combined interpretation of the detailed bathymetric, sub-bottom profiling and side scan sonar data acquired offshore the Eastern Harbour of Alexandria, revealed evidences for the reconstruction of the coastal geomorphology of Alexandria at the Hellenistic-Roman periods. A series of scarps obtained at sub-bottom profiles at a water depth of 8m was considered as evidence for the ancient shoreline. A lowering of the sea level at 8m is comparable with the archaeological evidences and indicates a local subsidence rate of 3.5mm/yr. The low sea level stand revealed submerged or exposed, rocky islets offshore the Pharos Lighthouse which in combination with the very narrow (in relation to the present day) entrance to the Eastern Harbour were complicating the ancient mariners. In addition, the low sea level stand revealed the Ridge A, located submerged off the Eastern Harbour, as a natural breakwater. Therefore, the tobolo of Heptastadion, the island of Pharos and the breakwater (Ridge A) had developed a natural system, almost encircling the Harbour, preventing the entrance of high waves in inshore waters and reducing the coastal erosion. The findings of the present study are consistent with the descriptions of the ancient writers. The side scan sonar data was also used in an attempt to detect ancient and historical shipwrecks on the seabed in the coastal zone offshore the entrance of the Eastern Harbour (Μέγας Λιμήν). The side scan sonar survey showed 57 targets of potential interest. The visual inspection revealed that the majority of the targets are man-made objects (ropes, cables, anchors), few of them are natural features (rocks) and one target represents an amphora cargo.

KEYWORDS

Alexandria, geophysical survey, coastal palaeogeography, relative sea level, ancient shipwreck.

1. INTRODUCTION

The sea level rise could be (i) of eustatic origin which refers to the addition/subtraction of water to/from the global ocean due to the melting/forming of continental glaciers and (ii) of isostatic origin which represents postglacial deformation of the solid earth and local isostatic factors (sediment loading, tectonic activities). Along the coastline, eustatic and isostatic components result in local relative sea levels which often show spatial variations. Furthermore short-time of rapid natural hazards such as earthquakes, tsunamis, river flood and winter storm surges additionally contribute to subsidence (Stanley and Bernasconi, 2006). Ancient settlements and harbours originally placed at or near low-lying costal margins could be partially or completely submerged due to local relative sea level rise and/or subsidence of the land.

A variety of attempts have been made to study the now-submerged coastal landscapes in areas of great archaeological interest. Almost all of these studies focus on the determination of the relatively sea level change, as it is fundamental for the ancient coastal reconstruction. Lithologic and chronostratigraphical analyses of radiocarbon-dated sediment cores collected onshore and/or offshore the low-lying coastal plain provide clear evidence of subsidence rates (Vott, 2007). Detailed archaeological surveys in underwater coastal sites using divers and/or marine remote sensing techniques such as sidescan sonar and seismic profiling reveal evidences for human presence along ancient coastlines contributing further to the coastal landscape reconstruction. More recently, the mapping of palaeoshorelines, resulting from high resolution geophysical techniques often in combination with sedimentation rate data, dated evidence from sediment cores and tectonic regime are helping to demonstrate the detail of submerged landscape that can be reconstructed (Van Andel and Lianos, 1984, Shennan et al., 2000, Papatheodorou et al., 2008a, Ferentinos et al., 2012).

In some cases, submerged and/or buried archaeological sites provide better age control than the radiocarbon dating. This is due to the fact that the organic material which is available for dating often has been reworked by sedimentary processes particularly in deltaic environments and thus is more or less meaningless for sea level reconstruction. In this context, Stanley and Toscano (2009) proposed that the subsidence rates derived from basal radiocarbon dates in sediment cores represent long-term average rates than the shorter, more-precisely and well-dated intervals derived by archaeological data.

Apart from the application of the remote sensing techniques for the reconstruction of the submerged landscape, these methods are widely used for the detection and recognition of ancient and historical shipwrecks (Papatheodorou et al., 2008b, Papatheodorou et al., 2012). Phaneuf et al. (2002) used the powerful capabilities of the U.S. Navy's nuclear research submarine NR1 in an attempt to detect and locate the submarine shipwrecks along a well-known route trade between Rome and Greece. NR1's forward looking sonar discovered a 4th century A.D. wreck resting at about 750m water depth. In this context, two deep-water archaeological surveys in the Aegean Sea conducted by Sakellariou et al (2007) led to the detection of ancient (Hellenistic) wrecks; one in the Chios-Oinousses strait at 70 m water depth, and the second, west of Kythnos island, at 495 m.

In 332-331 BC, Alexander the Great founded Alexandria which soon became a metropolis in Hellenistic and Roman periods. Detailed descriptions of ancient writers and ruins of palaces, statues, obelisks, tombs are the silent witnesses of the famous city. In distinguished position is the famous Lighthouse of Pharos which destined to be one of the seven wonders of the ancient world. Alexandria owned this vigor greatly to its port, the "Μέγας Λιμήν" (Eastern Harbour) which controlled the trade of Eastern Mediterranean in antiquity. In the coastal zone of Alexandria, almost all the coastal ancient achievements have been detected in underwater sites indicating a transgression of the sea in the last 2300yrs (Empereur, 1998, 2000, Goddio, 1998, 2000, Tzalas 2000). This suggests that part of Ptolemaic Alexandria is currently below the present sea-level and thus the coastal margin of Alexandria is one of the most promising areas of the world for archaeological studies.

The aim of this paper is twofold: (i) to reconstruct the coastal palaeogeography of Alexandria at the time of its foundation and thus to obtain the sight view of Alexander the Great the time he chooses to occupy this site and to develop there a city named by his name and (ii) to present the results of a side scan sonar survey for the detection of ancient shipwrecks in the coastal zone of Alexandria offshore the Eastern Harbour (Μέγας Λιμήν). The deductions of the present study will be based on detailed bathymetric, geomorphological and geological data collected offshore the Alexandria in conjunction with the subsidence rate derived from the submerged archaeological sites of the study area and the visual inspection of the seabed based on geophysical data.

2. COASTAL CONFIGURATION OF ALEXANDRIA DURING HELLENISTIC AND ROMAN PERIODS

Alexandria was developed over an elongated site of land limited by the Eastern Mediterranean Sea at the north and the Mariout Lake at the south (Fig. 1). There a small fishing village called Rhakotis existed and just opposite of it, a small island called Pharos. Rhakotis and the Pharos Island are cited in Homer's Odyssey, indicating that the area was familiar to ancient Greek mariners.

The construction of Alexandria led to the first change in its coastal zone. Deinokratis, the architect of Alexandria, linked the Pharos Island to the mainland by a narrow causeway-aqueduct complex, called Heptastadion (*seven stadia* long, 1300m; Fig. 1a). The Heptastadion was built on a pre-existing shallow marine topographic high and its construction separated the coastal waters of Alexandria in two parts forming two harbours; the Easter Great Harbour (Megas Limin) and the Western Harbour or Eunostos. A monumental lighthouse with a height over 100m was constructed at the eastern end of the island of Pharos and progressively became the landmark of Alexandria. The Eastern Harbour was the main port of Alexandria and by the Roman time the coastline bordering the harbour has been strongly reshaped. The palaces of city, the royal gardens and the government buildings were built along its coastline and mainly on the Cape Lochias, a promontory bordering the eastern side of the harbour.

Strabo (XVII) left a picturesque description of the survey area as it was during the period of Alexandria's prosperity under the Ptolemaic kings: "…On entering the great port (Eastern Harbour), the island and lighthouse of Pharos lie to the right while on the left are seen a cluster of rocks and Cape Lochias, with a palace standing on its summit. As the ship approaches the shore, the palaces behind Cape Lochias astonish one because of the number of dwellings they contain, the variety of constructions and the extent of their gardens…" (Morcos, 2000).

In the course of time the Eastern Harbour has been modified. The Pharos lighthouse does not exist anymore. It seems that it completely destroyed between 1303 and 1349 AD by an earthquake and at its site the Mameluke Sultan Qait Bey built a fort (Qait Bey Fort) in 1480. The Cape Lochias has been reduced in expanse to the present-day El-Silsilah promontory. The Heptastadion became wider due to the progressive silting up and loosing the original linear shape, developed to a part of the mainland of the Alexandria.

The Eastern Harbour is now a shallow and almost enclosed, elliptical basin with a width of about 2.5km from the western coastline to the El-Silsilah promontory at the east. The Western Harbour is deeper and wider than the Eastern and constitutes the main port of the modern city of Alexandria.

3. GEOLOGICAL BACKGROUND

Alexandria is positioned on a straight SW to NE-oriented low-lying coastline at the western part of the modern Nile Delta (Fig. 1b). A thin (10-40m) Holocene sequence of unconsolidated deposits covers Quaternary and Tertiary sequences of Nile Delta (Stanley and Warne, 1993). The thickness of the Holocene sequence and the depositional environment within vary considerably across the northern delta. The thickness increases eastward reaching a maximum of about 50m in the modern Manzala lagoon and a minimum (<10m) in the extreme west of the Delta, in the Alexandria and Abu-Quir regions. The fivefold thinning of the Holocene deltaic sequences from east to west indicates differential subsidence resulted in a general northeastward tilting of the Delta plain surface (Stanley and Toscano, 2009).

The coastal zone of the Egypt from Arabs Gulf to Abu Quir is dominated by a series of long coast-parallel ridges (at least, eight in number) of carbonate sandstone (Stanley and Bernasconi, 2006 and references within) (Fig. 1c). Such coastal ridges are moderately to well-cemented limestone which was formed mainly of whole and broken shell, pellets and oolites along with some quartz and heavy mineral grains. These ridges are commonly called "*kurkar*" in the Eastern Mediterranean.

Two of these ridges, Ridge I and II seem that have controlled the coastal configuration in the site of Alexandria (Fig. 1c). Ridge I is located offshore and constitutes the northern margins of the two ports of Alexandria by the forming of linear, discontinuous, emerged to shallow submerged, inlets and reefs (Fig. 1c)**.**

Ridge II or El Max-Abu Sir Ridge is of late Pleistocene age (about 100.000 yrs BP; El Asmar and Wood, 2000) and forms a linear high-relief carbonate (Fig. 1c). This ridge separates the shallow brackish Mariout lagoon, at the south and the open marine shelf at the north and forms a zone of land upon which the cities of Alexandria and Abu Sir (25 km eastwards) were built.

3.1 Relative sea level and subsidence

The wider area of Nile delta has received considerable attention with regards to its sea level rise evolution. Although the study area is located on a relatively tectonically stable margin of N.E. Africa instabilities have been resulted from readjustment to downwarping of the thick sediment sequence (4000m) due to isostatic lowering, faulting and sediment compaction. The relative sea level rise seems to be the main factor for the predynastic occupation of the Nile delta. Stanley and Warne (1993) suggest that the change in sea level rather than regional climate factor is the driving force in the accumulation of Nile silt, the creation of the widespread and fertile delta plain and therefore the predynastic occupation of the Nile delta. Sea level rose rapidly (9 mm/yr) from 125 to 16 m below its present stand, between 18.000 and 8.000 years B.P. The rate of sea level rise decelerated to 1mm/yr, from about 7000 to 5000 B.C. and rose to about 12m below present stand at 6000 B.C. At the time river gradients decreased and a system of meandering Nile distributaries began to deposit large volumes of nutrient-rich sediments. By 4ka the sea level continued to rise slowly and by 2 ka sea level had risen to about 2.5m below present level. By that time, the Nile delta had began wave dominated and the population increased particularly in the Alexandria sector.

Although the general westward thinning of Holocene deltaic sequence indicates minimum rate of subsidence (<1 mm/yr) in Alexandria and Abu Qir region, archaeological and oceanographic data suggest a considerable higher rate of subsidence for the coastal area of Alexandria.

The subsidence of the coastal zone of Alexandria is well documented by short-term (oceanographical data) and long-term (archaeological data, radiocarbon-dated sediment cores) observations (Table 1). Tide-gauge data suggests that Alexandria is subsiding during the last 60 years with a rate of 2mm/year (Frihy, 1992). Greek and Roman settlements along the coastline are 5 to 8m below the present sea level (Frihy, 1992). In addition Jondet (1912, 1916, 1921), the Chief Engineer of the Department of Port and Lighthouse, discovered a line of submerged ruins of an ancient breakwater of the Western port of Alexandria at a water depth ranging between 6.5 and 8.5m below the sea-surface at 1915. Furthermore submerged ancient harbour facilities were also discovered in the Eastern Harbour at a water depth of about 6-7m (Goddio, 1998, 2000). All the above suggest that the coastal morphology of Alexandria is now markedly different from what it was 2300 BP.

4. ARCHAEOLOGICAL BACKGROUND

The Eastern Harbour of Alexandria has undergone three underwater archaeological surveys in the last fifteen years. J-Y Empereur (1998, 2000) uncovered 2500 pieces of stonework of archaeological interest, scattered over 2.5 hectares off the Qait Bey Fort (fig. 1). These include columns, bases, capitals, sphinxes, statues and some blocks of granite, which were probably parts of the great Pharos Lighthouse. The Institut Europeén d'Archaeologie Sous-marine under the direction of F.Goddio detected, located and mapped submerged harbours, jetties and dock works in the southern and southeastern sectors of the Eastern Harbour of Alexandria which are considered to be remains of ancient Antirhodos and Timonium, and submerged port facilities, probably ancient Navallia, in the western sector of the Harbour (Goddio, 1998, 2000) (fig. 1). Tzalas (2000) discovered three architectural elements weighing 4, 10 and 12 tons, which are located on the seafloor adjacent to the eastern side of El-Silsilah promontory at a water depth of 7m (fig. 1). These pieces are probably remnants of the Temple of Isis Lochias, which was located at the tip of ancient Cape Lochias. The ancient Western harbour (Evnostos) was brought to the light by G. Jondet (1912, 1916, 1921) when he discovered submerged massive harbour structures during his work on improving and expanding the modern harbour. He discovered two submerged breakwaters almost parallel to each other; (i) the inner ancient great breakwater extending 2360 m at a water depth of about 4.5m and at a distance of 300 m north to the coastline and (ii) the outer submerged ruins of the breakwaters, 200 m to the north of the inner and at water depths ranging from 6.5 to 8.5 m. J-Y Empereur (2000) discovered forty Greek and Roman ship hulls dated from 4th BC to 7th AD about 350 m to the north of the entrance of the Eastern Harbour. The most striking fact of that discovery is that the ships sank within 350m to the north of Pharos Lighthouse and at a time when the Pharos was operating.

5. MATERIAL AND METHODS

5.1. Survey area

The geophysical survey was conducted on board two zodiacs and a 10m-long vessel which were suitable modified for the needs of the survey, over an area of approximately 32.5 km^2 in the coastal zone of the city of Alexandria. The survey area extends from Qait Bey fort site where the ancient Pharos lighthouse used to stand to Stanley Bay about 4.6 km to the east of the El-Silsilah (ancient Cape Lochias) promontory and from a water depth of about 2-3 m to about 45m (Fig. 2). Numerous underwater discoveries regard the study area as one of great archaeological significance.

5.2. Instrumentation and survey design

The Laboratory of Marine Geology and Physical Oceanography of the University of Patras carried out geophysical surveys during seven campaigns from 1999 until 2006. The scientific campaigns took place in partnership with Céntre D'Etudes Alexandrines (CEA) under the directionship of J-Y Empereur, the Hellenic Institute of Ancient and Medieval Alexandrian Studies (H.I.A.M.A.S) under the direction of H. Tzalas and the Department of Underwater Archaeology of the Supreme Council of Antiquities of Egypt.

The geophysical survey was carried out using two acoustic systems: (i) a towed E.G&G side scan sonar system with an analogue corrected image graphic recorder E.G&G 260 and a dual frequency two fish E.G&G 272 TD and (ii) a high frequency 3.5 kHz subbottom profiling system consisting of a Model 5430A GeoPulse Transmitter, a Model 5210A GeoPulse Receiver, a Model 1600 EPC "S" type Graphic Recorder and an O.R.E. Model 132A/132B over-the-side four transducer array. Positioning data was obtained by a Trimble 4000 Differential Global Positioning system (DGPS) with an R.M.S. accuracy of 2m and a Magellan NAV 6500 GPS with an accuracy of about 10m. The data were collected at a boat speed of about 4 knots.

The E.G&G 260/272 TD side scan sonar is a dual frequency system operating at 100 and 500 kHz. Only the 100 kHz signal was interpreted because this frequency provides a wide spectrum of acoustic facies regarding the variety of seabed texture. The same sidescan sonar acquisition settings were used during each survey period.

A total area of 32.5 km^2 was insonified by over fifty tracklines. The majority of them were running parallel to the coastline while about twenty lanes were running vertical to the northern breakwater (Armiyan) of the Eastern Harbour of Alexandria (Fig. 2a). The water depth varied between 2 and 45m. In most tracklines, the range of each lane was 100m for each side and the lane spacing was 150m providing a 50% range overlap. The towfish was towed above the seafloor at a height ranging between 10 and 50% of the lane range.

Sixty 3.5 kHz subbottom profiler lines covering a total area of about 21 km^2 were surveyed (Fig. 2b). The seismic lines were running perpendicular to the north breakwater of the Eastern harbour having a spacing of 50 to 100m. A time base of 0.1 s and a 0.1 ms pulse length were used. The vertical resolution of the system was about 0.5 m and even in water depths less than 10m, a maximum penetration of about 4-5m was achieved.

For the detection of ancient shipwrecks, the survey was carried out into two phases. The initial phase involved systematic survey of the seabed by side scan sonar. The detection of potentially interesting targets which may represent wrecks or man-made structures, based on: (i) their reflectivity in relation to the surrounding seafloor, and (ii) their shape and size (certain geometrical patterns). No seafloor classification system has been used for the classification of the targets (e.g. TARGAN software by Fakiris and Papatheodorou, 2012). The second phase of the investigation consisted of conventional diving oriented by the results of the first phase of fieldwork. During this phase, all the targets which were detected during the first phase were systematically inspected by a French diving team (C.E.A) under the direction of Jean-Yves Empereur.

All side scan sonar and seismic data were recorded graphically but for the post-survey processing were scanned, imported and georeferenced into the ArcView environment. A detailed description of the data post-processing approaches has been presented by Chalari et al. (2008).

Similar geophysical techniques have been used in underwater archaeology in order to reconstruct the coastal palaeogeography (Van Andel and Lianos, 1984) or to detect archaeological sites in shallow and deep waters (Quinn et al., 2000, Papatheodorou et al., 2005, Sakellariou et al., 2007).

6. DATA PRESENTATION

The study of the bathymetric, morphological and seismic data collected along a very dense grid of tracklines showed that the morphobathymetry of the survey area is characterized by four morphological elements (Fig. 3):

(i) a dipping rocky seafloor, surrounding the Eastern Harbour and the straight coastline of the Alexandria (eastwards of the Cape El-Silsilah), down to a water depth of about 16 m (Fig. 3). This morphological element appears more steep northern to the Eastern Harbour (and in particular off its entrance) and more wide (1.0km) easterwards, along the straight coastline (Fig. 3). Within this zone there are extensive areas of highly irregular rocky relief and small areas of smooth rocky relief. Small patches of sandy sediments are also occurred which are often rippled by the waves.

(ii) a well-shaped rocky ridge (Ridge A), 6-14m high and about 700 m in width (Fig. 3). The minimum water depth of this ridge obtained at 12m forming a narrow planar strip (Fig. 4). Ridge A is located about 1.0 km north of the Quit Bay fort where the Pharos Lighthouse used to stand and about 1.5 km north of the present-day entrance of the Eastern Harbour (Fig. 3). The Ridge A is running almost parallel to the contours and present-day shoreline and has a dominant strike direction of about ~45^{o} (Fig. 3). Sonographs display the ridge as highly reflective stripe, sharply contrasting against the low reflectivity of the surrounding seafloor, which is covered by loose sediments (Fig.5). Examination of the sonographs showed that the ridge is often composite feature made of patches or smaller strips of high reflectivity and thus have irregular and undulating boundaries (Fig.5). It should be mentioned that the boundaries configuration is also controlled by the wave-induced transportation of loose sediments (Fig.5).

(iii) two basin-like depressions of about 22m and 30 m deep, which are located between the first element and the Ridge A (Fig. 3). The two basins are separated by an elongated rocky ridge of NW-SE direction, 1.5 km long and 300-400m wide (Fig. 3). The ridge is running perpendicular to Ridge A forming a rocky T-shape feature resembling the Heptastadion-Pharos Island complex (Fig. 3). The eastern and deeper basin is covered by loose sediments of a thickness more than 10m.

(iv) the gently dipping seafloor down to a water depth of 45m which is bounded upslope by the Ridge A (Fig. 3). Within this area five individual rocky ridges of low relief were detected. The ridges are between 20 m to 650m wide and about 40 to 800m apart. These features are located between the 28m and 45m isobaths and are running parallel to Ridge A and the present day coastline.

Detailed examination of the 3.5 kHz profiles on the rocky seafloor surface around the Eastern Harbour reveals numerous small scarps which appear as sharp breaks in the overall slope gradient of the rocky surface (Fig. 6). These scarps appear to have been sculptured by the erosional power of the waves when the sea level was at a stand –still for a short period of time during the sea transgression. It can therefore be regarded as evidence of palaeoshorelines suggesting that the transgression of the sea in the coastal zone of Alexandria was not continuous during the Holocene period but was interrupted for short time intervals. The spatial distribution of the depth occurrence of each scarp shows that the scarps are not randomly distributed but rather gathered in clusters which correspond to selective water depths. The water depths in which the scarps are clustered are at 16m, 14m, 12m, 10m and 8m. The non-random distribution of the scarps with regard to depth suggests that have been correctly identified as real erosional shore features. Furthermore, the spatial distribution of the scarps has shown that the palaeoshorelines on the seafloor are continuous for long distances along the coastline. Among them, the palaeoshoreline at 8m water depth is the best-shaped and defined on the rocky seafloor around the Cape El Silsilah and the Quit Bay fort site (Fig.7).

Linear elongated targets extending perpendicular to the coastline of Alexandria and parallel to subparallel to Cape El Silsilah, were observed in water depths of 5 to 8m (Fig 8a, b). These linear, ridge-shaped targets were detected on a sandy seafloor, eastwards of the Cape El Silsilah (Fig 8a, b). They are at most 135m long (within the surveyed area) and 5-20m in width (Fig 8c). At least in one case, at a water depth of about 6m, these features appear to cross each other almost vertical (Fig 8c). Their particular acoustic pattern on sonographs (Fig. 8c) indicates that these linear targets consist of big blocks of certain shape and probably represent submerged man-made structures.

Apart from the above mentioned morphological features of the seabed, the geophysical data has shown that the seafloor of the surveyed area consists of rocky outcrops and loose sediments. The rocky outcrops are layered and covers about 60% of the surveyed area while the rest of the seafloor (40%) consists of sandy to sandy-mud sediments. The side scan sonar survey for the detection of ancient shipwrecks concentrated on the sandy seafloor since on rocky and rough seafloor it is often impossible to separate man-made targets from natural features. A total of 57 targets of potential interest were detected during the sonar survey (Fig. 9). Almost half the number (46%) of targets represents man-made objects and a small percentage (14%) of the total number corresponds to objects of historical and archaeological importance (Table 2). The visual inspection showed that most of the man made targets represent modern objects e.g. ropes, wires, fishing gear, metal pieces and tires. The targets that represent natural morphological features on the seafloor are usually isolated rocks with particular shape. The targets that correspond to objects of historical and archaeological importance are: a 2nd World War torpedo, a 19th century anchor, a shipwreck ballast and an ancient shipwreck (Fig. 10) where the divers have found an amphora cargo and a stone anchor.

7. PALAEOGEOGRAPHIC RECONSTRUCTION

The combined interpretation of the acquired bathymetric, sub-bottom and side scan sonar data revealed two main geomorphological features on the seafloor of the coastal zone of Alexandria: (i) a series of palaeoshorelines, almost parallel to each other, obtained at water depths of 16m, 14m, 12m, 10m and 8m and (ii) (ii) a ridge (Ridge A), almost parallel to the present coastline, of about 3.6 km long, located at around 1.0 km offshore, at a minimum water depth of 12 m. The development of the above features comprises the framework in the evaluation of the coastal palaeogeography of Alaxeandria in the present study.

Along the coast of Alexandria, a large number of archaeological submerged sites can be used to provide constraints on relative sea level. It should be noted that the subsidence rates for all submerged archaeological sites represent the average rate of subsidence assuming the elevation of the coastal structure was about 1m above the sea level. Thus, a 1.0m correction is added to the subsidence of each archaeological site.

The majority of the port foundations, the monuments and the artifacts of the Hellenistic and Roman periods (~2100 BP) retrieved from the Eastern Harbor, were detected at water depths between 5.0 and 6.5m below the present sea level (Goddio, 1998, page 23) indicating a sea level rate of rise of the order 2.9-3.6mm/yr, in the last 2100yrs. Similarly, the detection of two breakwaters in the West Harbour (Jondet, 1912, 1916, 1921), suggests evidences for the sea level rise. The inner ancient breakwater was detected over the Ridge I at water depth of 4.5 m and the outer at a water depth of 6.5-8.5m. However, there the rate of the sea level rise is not straightforward, since large uncertainties exist in the age of these constructions. So far, three dates have been proposed for them: (i) Thuile (1922) suggested that both these breakwaters were constructed in the Hellenistic-Roman period, (ii) El-Fakharany (1963) and Jondet (1912,16,21), based on the genealogy of Kings of Egypt, suggested that the remains are older and are dated 2686-2134BC (Old Kingdom) or 1279-1213BC (Rameses II) or 1187-1156BC (Rameses III) and (iii) Weill (1919) proposed that these constructions were build by Cretans in the Minoic period (~2000BC). Based on the above, the rate of sealevel rise could be 2.4-4.1mm/yr, 1.2-3.0 mm/yr and 1.2-2.4 mm/yr if we assumed that the breakwaters were built in the Hellenistic, the Rameses II and Minoic periods, respectively. Whatever is the correct dating for the buildings, all of the estimated sealevel rates are well correlated to the range of the relatively sea level rise, 1.6-2.9mm/yr recorded in the coastal zone of Aleaxandria, in the last 70years, by tide gauge data (Table 1).

The proposed eustatic sea level rise in the last 2500yrs is ranging between 2.5m (global sea level rise; Fairbanks, 1989) and 0-0.5m (eastern Mediterranean regions; Sivan et al., 2001, Lambeck and Purcell, 2005) which in comparison with the presence of archaeological markers at depths 4.5-8.5m illustrates a regional tectonic subsidence. Based on the archaeological evidence the rate of sealevel ranges between 2.4 and 3.4mm/yr (4.5-8.5m/2300yrs). The maximum eustatic contribution is 1mm/yr (2.5m/2500yrs) indicating that the local (subsidence) contribution is 1.4 -3.4mm/yr. According to Stanley and Bernasconi (2006) and Stanley et al (2006) the further subsidence in the coastal zone of the Eastern Harbour is related to collapses of the seafloor and associated gravity movements due to heavy harbour constructions or catastrophic events such are earthquakes and tsunamis.

For the earlier time interval, where there are not any archaeological remains, the relative sea level change would be based on the sedimentary evidences. Petrological and radiocarbon data retrieved from sediment cores indicate that Eastern Harbor flooded by seawater during the Termination 1b event, at about 8000yrs BP (Stanley and Bernasconi, 2006). The mean age for the same event all around the coastal zone of Alexandria is estimated at 7500-7000 yrs BP. If we consider that the mean thickness of the Holocene sediments in the Eastern Harbour of Aleaxandria is 12-13m (assuming not compacted sediments) and the mean depth of water is 10m, then a relative sea level rise of 23m in the last 8000yrs should be assumed. Based on the global sea level changes, the sea level rose 14m during the last 8000yrs, given a rate of rise of about 1.8 mm/yr. Based on the above, the approximate rate of relative sea level rise in the last 8000yr is about 2.9mm/yr (23m/8000yr). The eustatic contribution is 1.8 mm/yr (14m/8000yr) indicating that the local (subsidence) contribution is 1.1mm/yr. The estimated relative rate of sea level rise (2.9mm/yr) is in agreement with that proposed by Warne and Stanley (1993; 3.3mm/yr) for the same area.

Recently recovered long sediment cores in Eastern harbour of Alexandria revealed a variety of anthropogenic materials that date from 3000 to 2332 yrs ago, providing even higher rate of subsidence (Stanley and Toscano, 2009). The pre-Alexandrian occupational level in the Eastern Harbour of Alexandria radiocarbon dated to 3000 BP is now submerged to -13.0m beneath the present sealevel suggesting a rate of subsidence of about 4.3 mm/yr. The more extensive and younger (2000 BP) post-Alexander occupational level records a subsidence of 7.5m suggesting a rate of subsidence of about 3.7 mm/yr. It should be noted that uncertainness to the accuracy of the subsidence rate calculations could be occurred due to methodological and environmental factors. The most important uncertainness is the assumption of incremental rates of subsidence while the total subsidence may have occurred episodically during the last thousands years.

However if we assume a rate of subsidence of about 3.5mm/yr then the well-shaped and spatial-defined palaeoshoreline at the water depth of the 8m should be the coastline of the Alexandria at the time of its establishment. This proposed average subsidence rate is within the range of the subsidence rates obtained at archaeological sites in the Eastern Harbour (2.9-3.6 mm/yr) and Western Harbour (2.4-4.1 mm/yr) of Alexandria and correlates well with subsidence rates (3.7-4.3 mm/yr) based on radiocarbon dated occupational levels in the Eastern harbour (Stanley and Toscano 2009).

According to the scenario of 8m of subsidence during the last 2300 BP, the sea level stand at -8m coincides with the palaeoshoreline detected at 8m water depth and thus the spatial distribution of this palaeoshoreline is equivalent with the coastline of that time (Fig. 11). Then, the expanse of cape (Cape Lochias) where the Ptolemaic palaces used to stand was 0.721km^2 suggesting that 92% of this land is now submerged (Fig. 11). The plenty remains of port foundation, monuments and artifacts discovered during numerous underwater archaeological surveys in this area evidence the ancient geography (Goddio, 1998, 2000, Tzalas, 2000). In the present study, the detection of the linear, ridge-shaped targets (Fig. 8) easterwards of Cape El Silsilah supports further the archaeological importance of this area. The pass between the Qait Bey and the cape El-Silsilah (Cape Lochias), which is the entrance to the Eastern Harbor was more narrow (600m) in relation to now days (1700m) (Fig. 11). The expanse of Eastern Harbour (1.3km^3) was reduced up to 48% in relation to the present. Assuming that 1-4m sediments deposited in the last 2300m (Stanley and Bernasconi, 2006) then the water depth of the port was ranging between 3 and 6m. The low sea level stands had exposed small islands and rocky islets, located in particular at northeast of Cape Lochias and about 70-200m offshore. Furthermore, a rocky islet was developed inside the Eastern Harbour and most probably was equivalent with the ancient Antirodos. The above coastal geomorphology matches rather well with the descriptions of the ancient writers, such of Strabo (XVII, Geography). He wrote that the eastern side of the island Pharos (where was the glorious ancient lighthouse) was very close to Cape Lochias, suggesting that the pass to Eastern Harbour was very narrow and that dangerous rocky islets for the ancient mariners were located eastern to the Cape Lochias. Rocky islets inhibiting the entrance of the eastern harbour and an elongated inhabited island inside the Eastern Harbour are also showing in a map of 1472, presented by Jondet (1921). However, no other evidences testify the presence or the submergence of these islets in recent time, suggesting that the map of Jondet most probably was reconstructed upon the descriptions of Strabo. Nevertheless, it was the narrow pass and the presence of all these rocky islets that led to the building of the famous lighthouse, the Pharos, which was destined to be one of the seven wonders of the ancient world.

In addition, the sea level 8m below the present, at the time when Alexandria flourished (2300yrs BP), show off the Ridge A as a natural breakwater (Fig. 11). The waves in the study area are of wind origin and present a NW direction. They have an average height of 2m, reaching up 4m, at bad weathers. The wind regime in the coastal zone of Alexandria seems that is steady in the last 2300yr BP, comparing the description of Strabo and the recent measurements. At about 331yrs BC, the Ridge A having a shallow depth (4-0m) and a direction of NE-SW, almost perpendicular to that of the wind waves, was acting as a natural breakwater (Fig. 11). Thus, the “tobolo” of Heptastadion, the island of Pharos and the breakwater (Ridge A) had developed a natural system, almost encircling the Harbour, preventing the entrance of high waves in inshore waters and reducing the coastal erosion (Fig. 11). This natural structure offered to the city of Alexandria, the establishment of a safe port, the Eastern Harbour. This great advantage of the coastal zone seems that controlled the decision of Alexander the Great for the exact location in the establishment of the magnificent city. However, on the other hand, the ridge was a dangerous pass for the ancient ships putting in at Alexandria. The discovery of many Hellenistic and Roman shipwrecks between the NW part of the Ridge A and the Qait Bey fort might suggest evidence for such unfortunate stories. The ancient mariners had to follow a specific route in order to enter the port in order to avoid the Ridge A and rocky inlets.

8. ACKNOWLEDGMENTS

The authors thank Dr. J-Y Empereur, Director of Céntre D'Etudes Alexandrines (C.E.A) for his keen interest and encouragement. Thanks are also due to Mr. H. Tzalas, President of Hellenic Institute of Ancient and Medieval Alexandrian Studies (H.I.A.M.A.S) and to the Department of Underwater Archaeology of the Supreme Council of Antiquities of Egypt. Mr. A. Paleokrassas (Akti Engineering Co.) and Dr. A. Stefatos are gratefully thanked for their assistance in acquiring the data during the first three campaigns. This survey was funded by the C.E.A, the "C. Caratheodory Programme" (grant: 2460) of the University of Patras and the "Iraklitos: Fellowship for research-Environment" of the Greek Ministry of National Education and Religious Affairs.

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LIST OF TABLES

TABLE 1. The subsidence rates for certain sites of the northern margin of the Nile Delta based on oceanographic, archaeological and radiocarbon dating data

Reference	Region	Time span (yrs)	Method	Subsidence rate (mm/yr)
Frihy (1992)	Alexandria	44	Tide-gauge	2.0
Frihy (1992)	Port Said	50	Tide-gauge	2.4
Frihy (2003)	Alexandria	55	Tide-gauge	1.6
Frihy (2003)	Port Said	48	Tide-gauge	1.0
Frihy (2003)	Burullus	26	Tide-gauge	2.3
Breccia (1922)	Alexandria	3000	Archaeological data	0.8 - 1.2
Goby (1952)	Suez canal	80		1.2
Ibrahim (1963)	Delta plain	1800	Archaeological data	1.4
El Sayed (1988)	Alexandria	2000	Archaeological data	1.2
Stanley (1988)	Manzala lake	8000	radiocarbon dating	3.5 - 5.0
Stanley (1990)	Northern delta margin	8000	radiocarbon dating	0.4 - 5.0
Stanley and Warne (1993)	Northern delta margin	8000	radiocarbon dating	<1 - >4
Emery et al. (1988)	Port Said	24	Tide-gauge	4.8
Emery et al. (1988)	Alexandria	19	Tide-gauge	-0.7
El- Fishawi and Fanos (1989)	Alexandria	23	Tide-gauge	2.9
El-Fishawi and Fanos (1989)	Port Said	21	Tide-gauge	2.2
Stanley and Bernasconi (2006)	Eastern Harbour (Alexandria)	2400	Archaeological data - radiocarbon dating	2.9
Stanley et al., (2004)	Aboukir	2500	Archaeological data	2.8
Lawler (2005)	Eastern Harbour (Alexandria)	2400	Archaeological data - radiocarbon dating	3.1
Stanley and Toscano (2009)	Eastern Harbour (Alexandria)	3000 and 2332	Archaeological data - radiocarbon dating	3.7-4.3

TABLE 2. Results of the visual inspection of side scan sonar targets

Total number of targets	Man-made targets		Natural morphological features	No detection of the targets by the divers	Re-examination
	Modern	Historical - Ancient			
	Ropes, wires, tires, fishing gear	Historical anchors, WWII torpedo, ballast, amphora cargo			
57	18	8	11	14	6
100%	32%	14%	19%	25%	10%

FIGURE CAPTIONS

Figure 1

(a, b): Maps showing the location of the study area, Alexandria, Egypt. The map 1a also presents the locations of the main ancient sites in the coastal zone of Alexandria and the areas of the recent underwater archaeological surveys under the directions of J-Y Empereur (1), F.Goddio (2) and H. Tzalas (3). (c) : Map showing the eight ridges which are the main geomorphological features in the coastal margin of Alexandria.

Figure 2

Maps showing the (a) side scan sonar and (b) the 3.5 kHz tracklines of the present study in the coastal zone of Alexandria.

Figure 3

Detailed bathymetric map of the coastal zone of Alexandria based on the subbottom profiling data of the present study.

Figure 4

3.5 kHz sub-bottom seismic reflection profile showing the Ridge A.

Figure 5

Side scan sonar images showing the surface of the Ridge A.

Figure 6

3.5 kHz sub-bottom seismic reflection profiles showing the palaeoshorelines at the water depths of 12m and 8m below the present sea level. The profiles are taken from tracklines vertical to the Eastern Harbour of Alexandria.

Figure 7

Bathymateric map showing (i) the palaeoshoreline at the water depth of 8m below the present sea level (red line) and (ii) collection of representative 3.5kHz sub-bottom seismic reflection profiles, showing the location of the palaeoshoreline at 8m water depth (red arrows).

Figure 8

(a). Detailed bathymetric map of the coastal area easterwards the Cape El-Silsilah (ancient Cape Lochias) of Alexandria showing the present-day coastline and the Hellenistic –Roman coastline (isobath 8m; dark line). The two elongated features, vertical to the ancient coastline, are showing by arrows. (b) 3.5 kHz sub-bottom seismic reflection profile crossing vertical the two elongated features (arrows) and the depression between them filled by loose sediments. The base of the sediments (dashed line) is 4m below the seafloor. The location of the profile is showing in figure 4a. (c). Side scan sonar mosaic showing the area of the elongated features.

Figure 9

Detailed bathymetric map showing the location of targets of potential interest. Inset sonographs show representative targets.

Figure 10

Side scan sonar sonograph showing an ancient shipwreck at the coastal zone of Alexandria.

Figure 11

3-D bathymetric reconstruction of the coastal zone of Alexandria at the Hellenistic-Roman periods. The ancient coastline is assigned by the red line (see text for details).

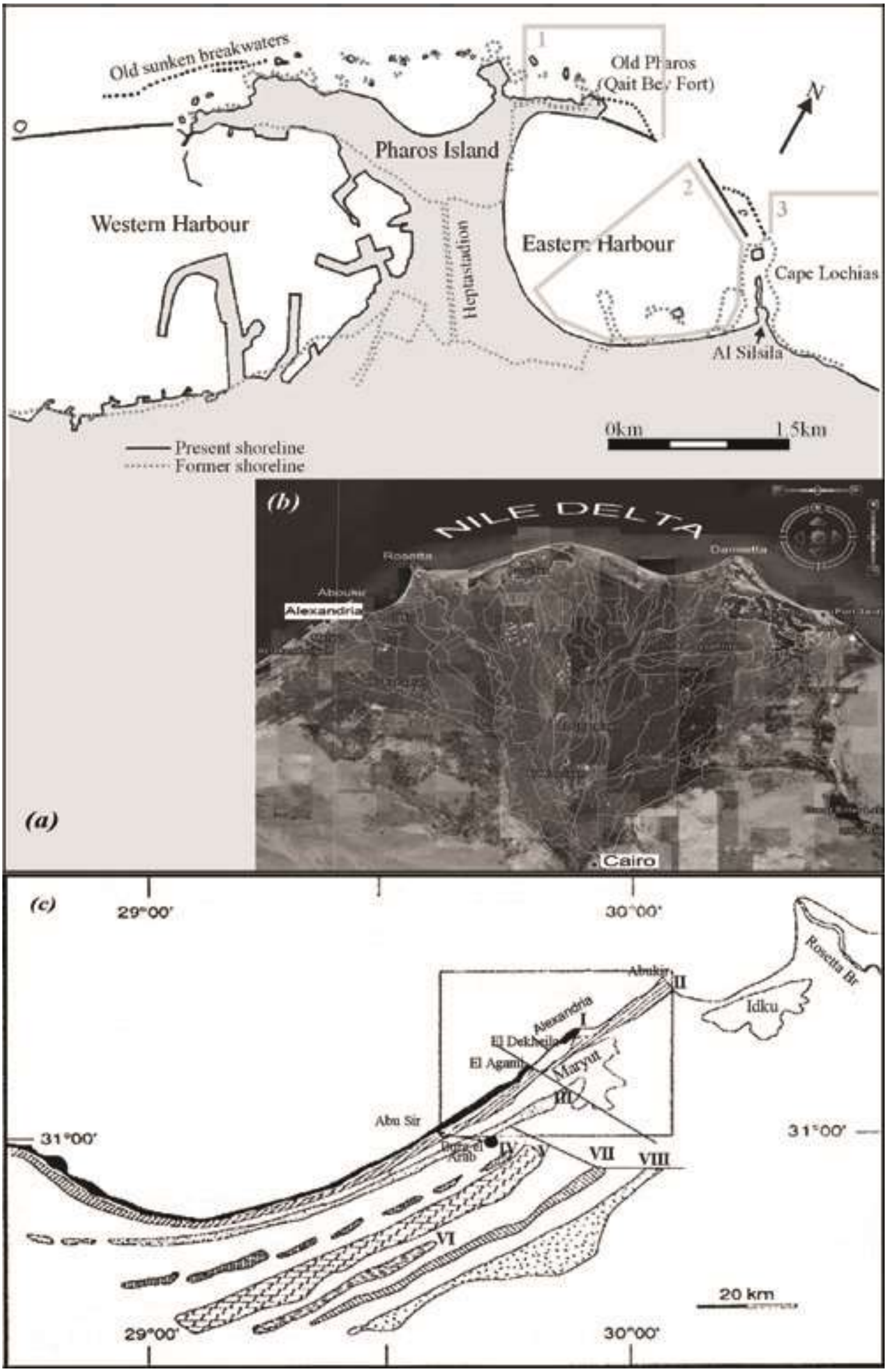
Old sunken breakwaters
Old Pharos
(Qait Bey Fort)
N
Pharos Island
Western Harbour
Heptastadion
Eastern Harbour
Cape Lochias
Al Silsila
0km
1.5km
Present shoreline
Former shoreline
(a)
(b)
NILE DELTA
Alexandria
Cairo
(c)
29°00'
30°00'
31°00'
Rosetta Br
Idku
Abukir
Alexandria
El Dekheila
El Agami
Maryut
Abu Sir
I
II
III
IV
V
VI
VII
VIII
20 km

Figure 1

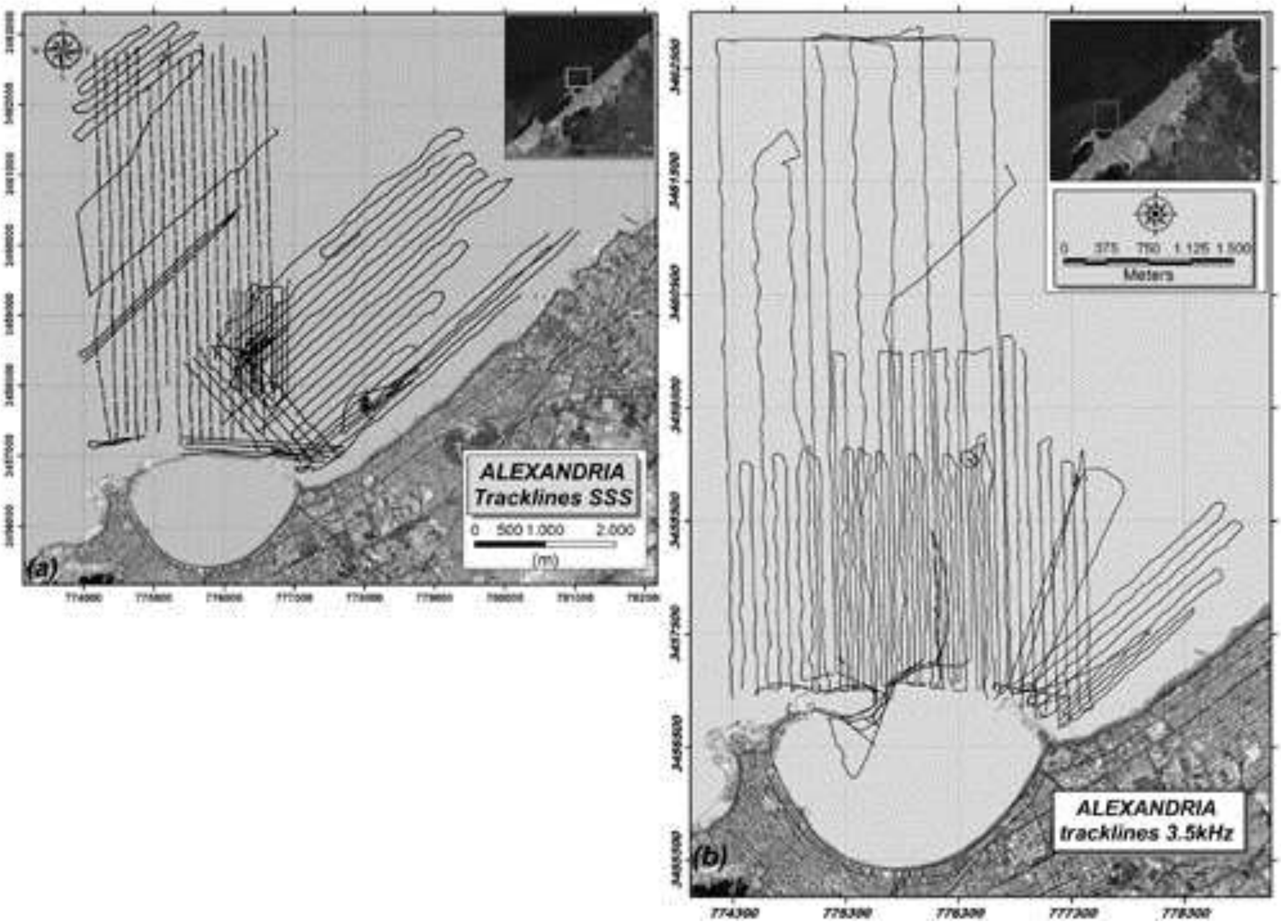
ALEXANDRIA
Tracklines SSS
(a)
ALEXANDRIA
tracklines 3.5kHz
(b)
Meters

Figure 2

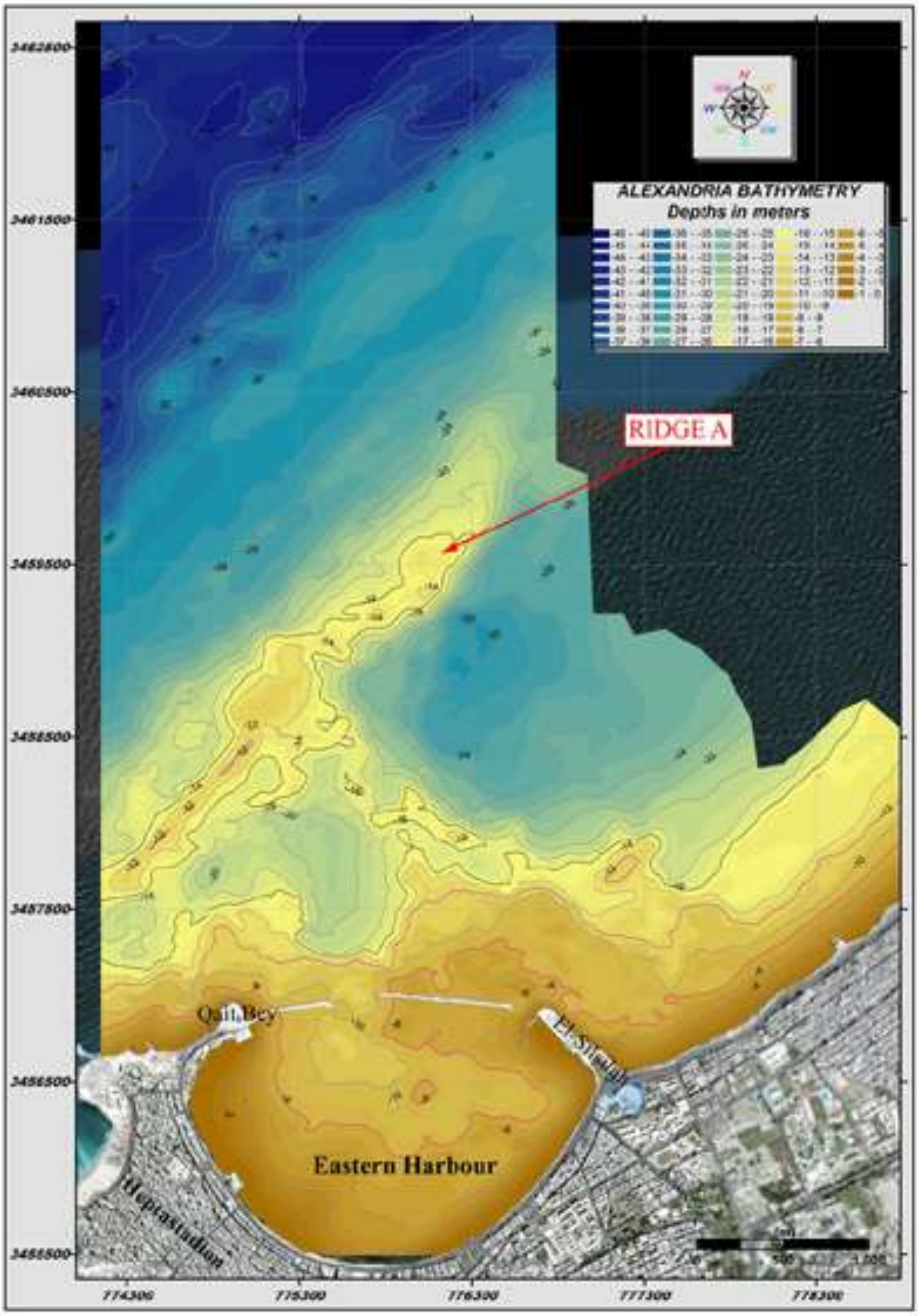
ALEXANDRIA BATHYMETRY
Depths in meters
RIDGE A
Qait Bey
El Silsila
Eastern Harbour
Heptastadion

Figure 3

Figure 4

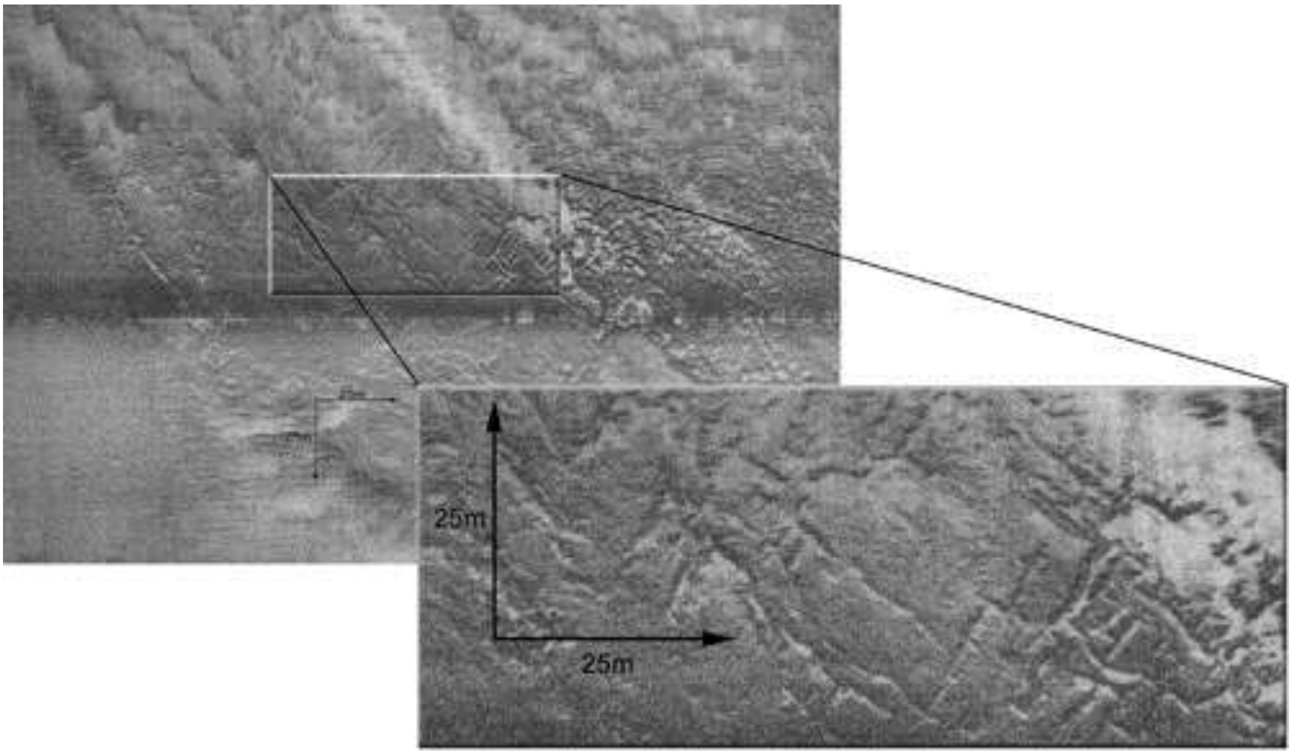

Figure 5

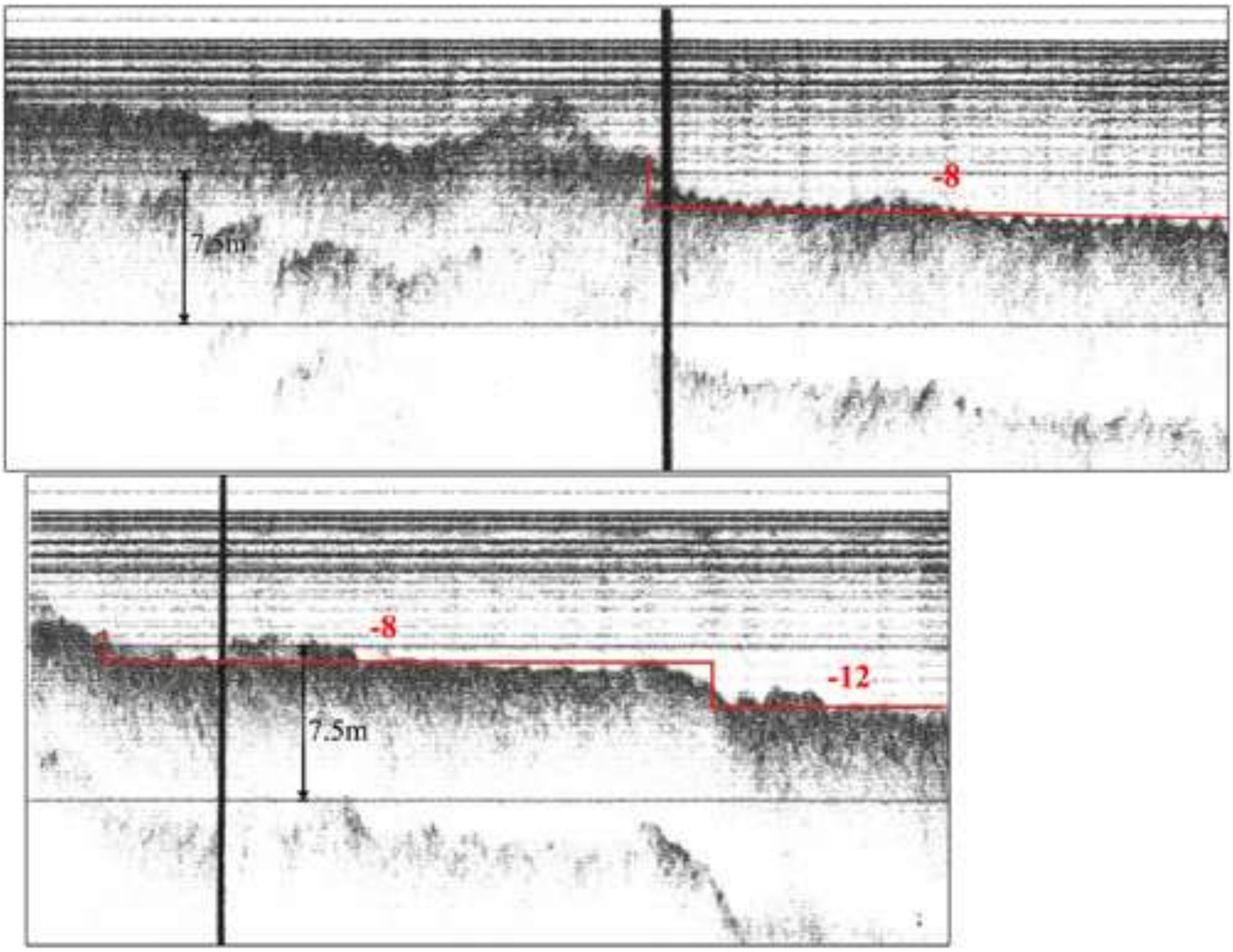

Figure 6

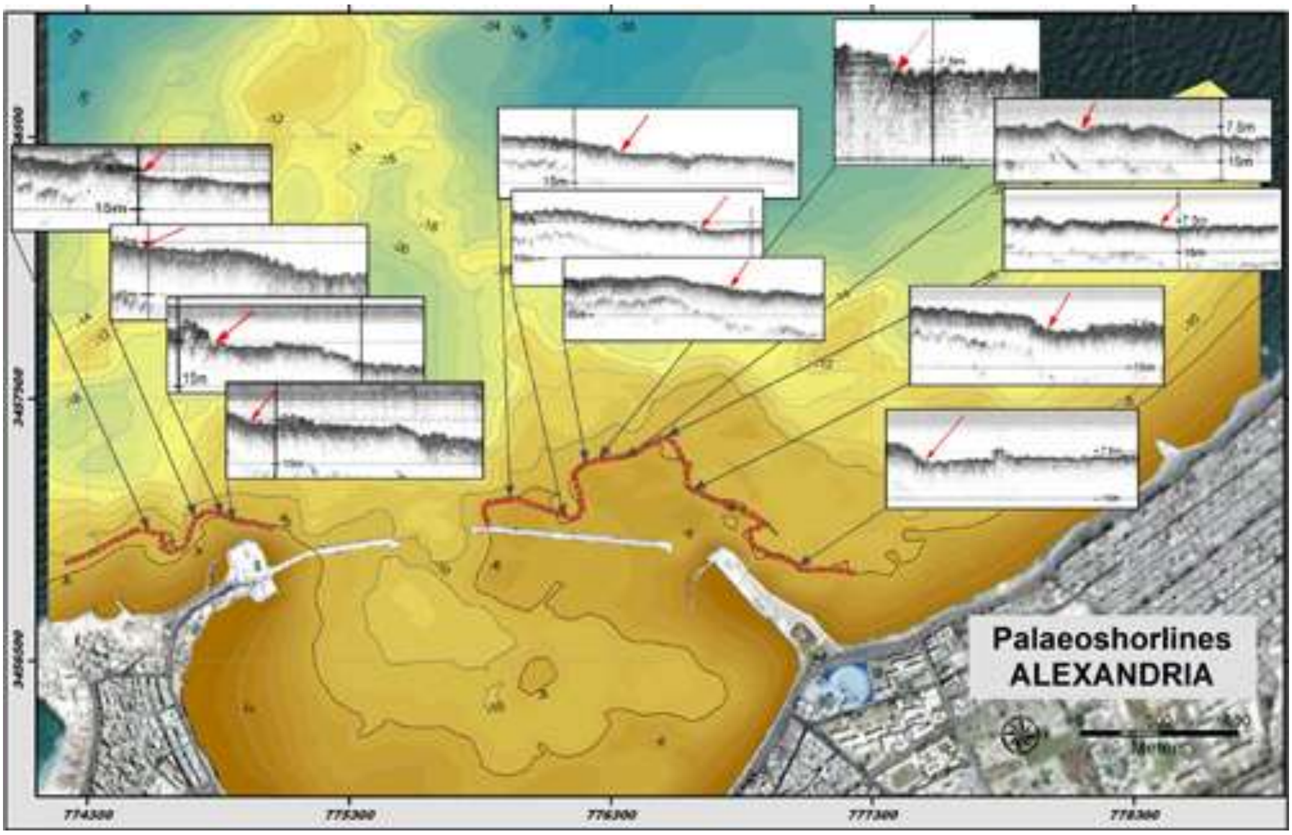

Figure 7

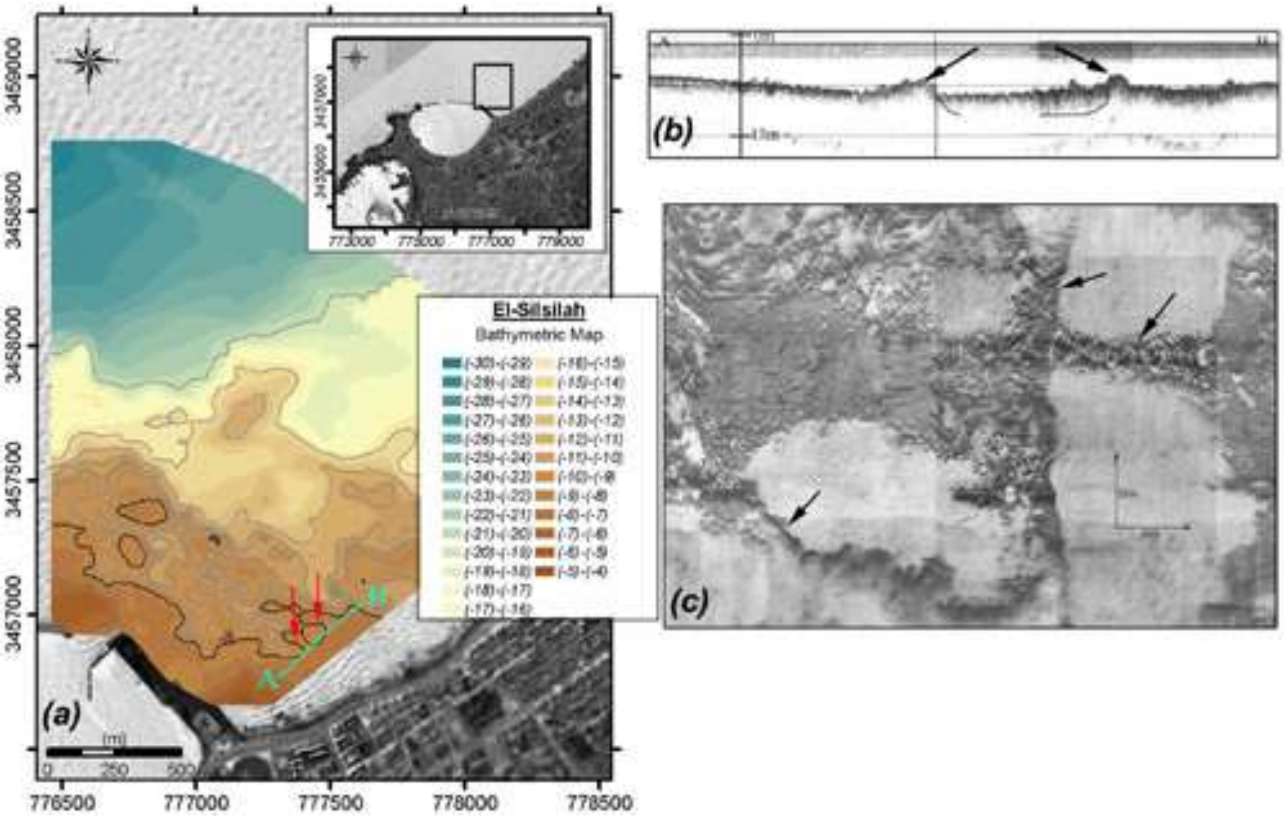

Figure 8

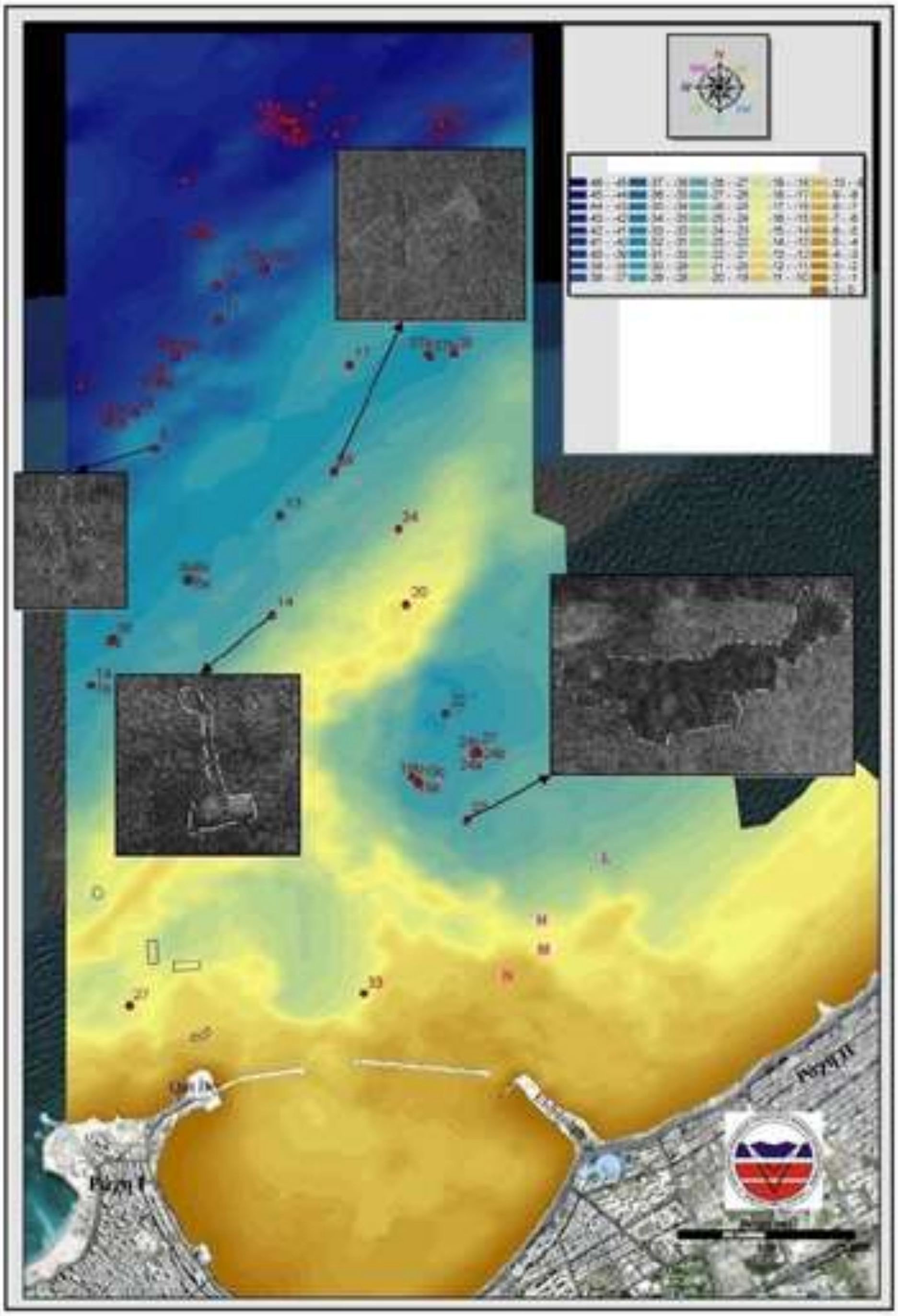

Figure 9

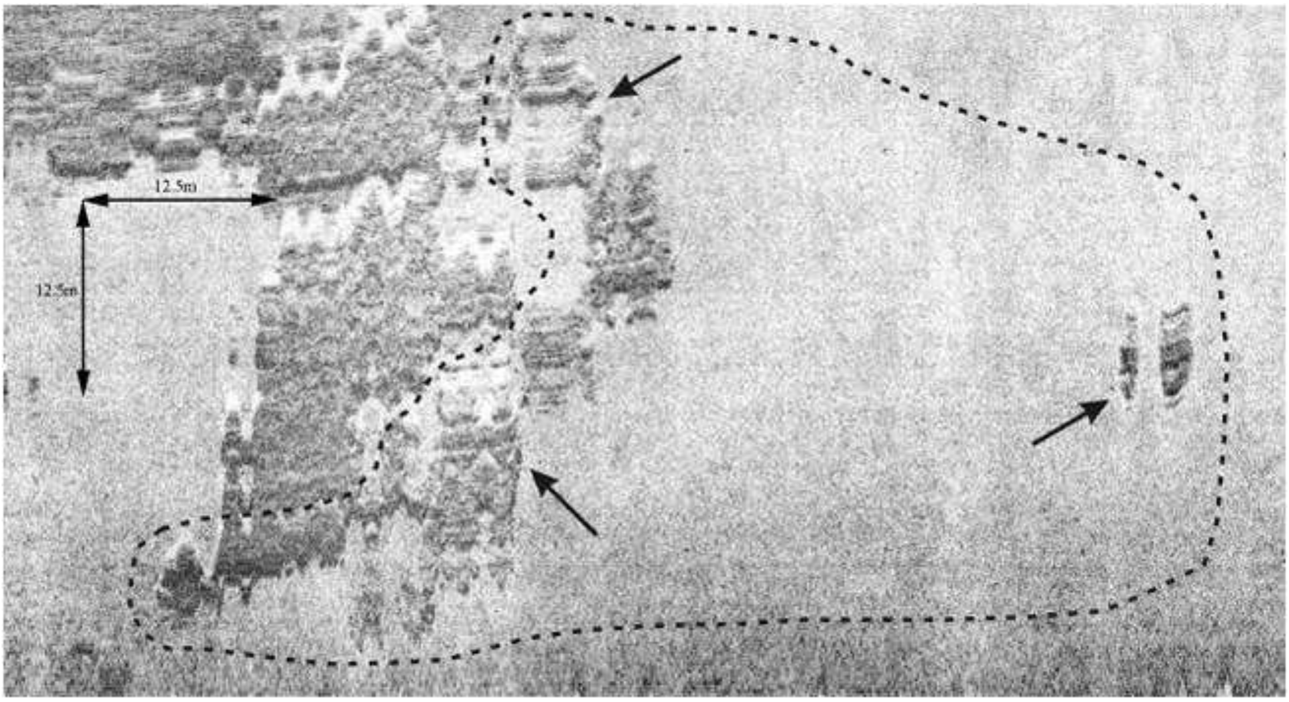

Figure 10

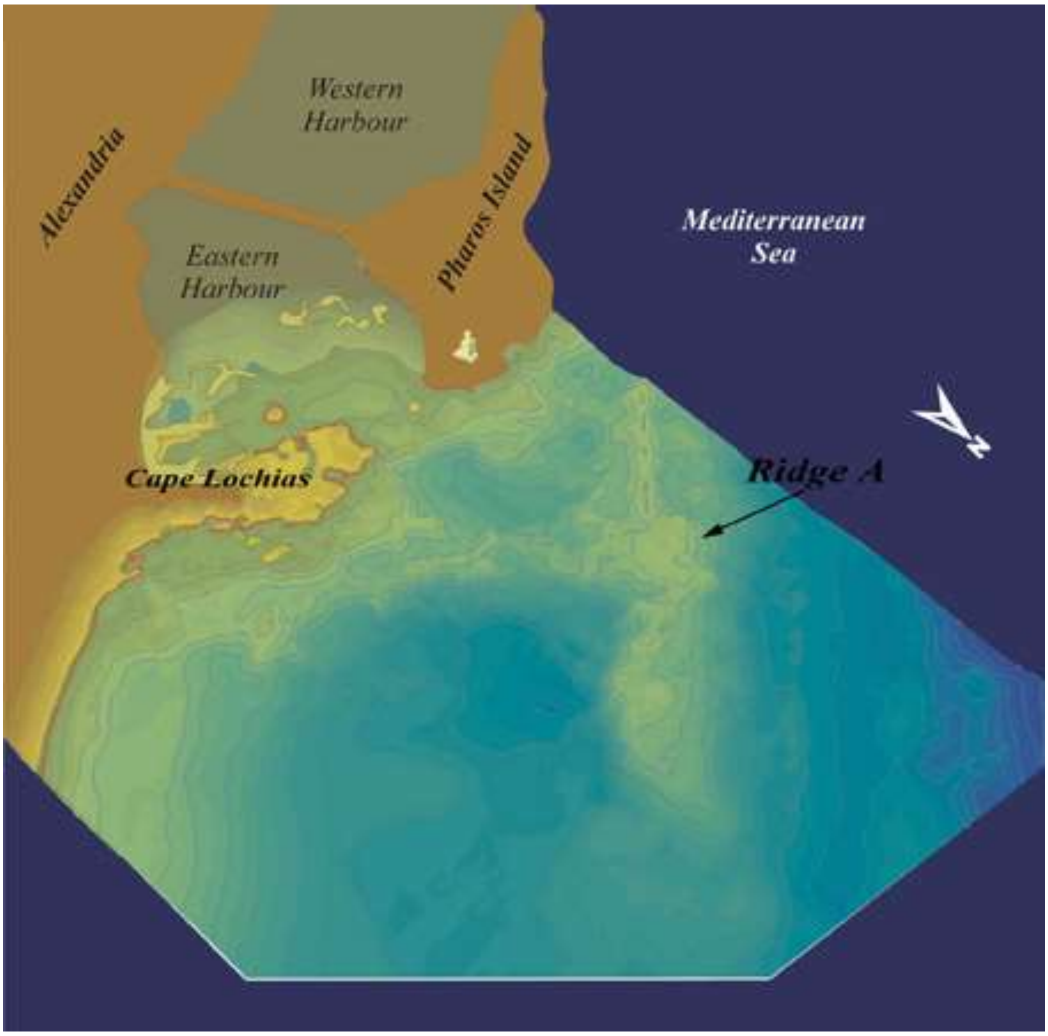

Figure 11