Remote sensing for underwater archaeology: case studies from Greece and Eastern Mediterranean sea.

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ABSTRACT

Modern underwater remote sensing technology introduces many advantages that extend the range of conventional diving work providing the means to survey in a detailed and systematic fashion large seafloor area. There are two general approaches regarding the application of these techniques in underwater archaeology; they are being increasingly used to identify, locate and map (i) ancient and historical shipwrecks lying on the seafloor or partly buried in it and (ii) the coastal palaeogeography and thus submerged sites of archaeological interest (submerged ancient cities, settlements, ports and man-made structures). The underwater remote sensing techniques most commonly applied to underwater archaeology employ: (i) single and multi-beam echosounders (ii) side scan sonar (acousting imaging), (iii) laser line scan (optical imaging) (iv) subbottom profiler, (v) marine magnetometer and (vi) undersea vehicles. The objectives of this paper are twofold: (i) to present the results of remote sensing surveys that carried out at sites of archaeological and historical interest, in Greece (Dokos Island, ancient harbour of Kyllene and Navarino Bay whereas a historical naval Battle took place) and in Eastern Mediterranean Sea (Alexandria Egypt and Mazotos shipwreck Cyprus), and (ii) to prove the applicability of remote sensing techniques in underwater archaeology showing that a combination of these can be a very effective tool.

Keywords: subbottom profiling, side scan sonar, magnetometer, palaeogeography, shipwrecks, Dokos Isl., Navarino battle,Glarentza, Alexandria, Cyprus.

ΠΕΡΙΛΗΨΗ

Τις τελευταίες δύο δεκαετίες οι θαλάσσιες γεωφυσικές μέθοδοι έχουν αναδειχθεί σε εξαιρετικά αποτελεσματικό μέσο στη μελέτη της παράκτιας παλαιογεωγραφίας καθώς είναι εφικτό να εντοπίζουν και να αναγνωρίζουν καταβυθισμένες παλαιοακτές και γεωμορφές σχετιζόμενες με αυτές. Η επίκληση της θάλασσας και η εμφάνιση καταστροφικών φαινομένων (σεισμοί, παλιρροιακά κύματα) έχουν οδηγήσει στην καταβύθιση αρχαίων πόλεων, οικισμών και λιμενικών εγκαταστάσεων. Επιπλέον, αυτές χρησιμοποιούνται πλέον συστηματικά για τον εντοπισμό και τη μελέτη κινητών μαρτυριών (ναυάγια) της ανθρώπινης δραστηριότητας στον πυθμένα. Τα όργανα γεωφυσικής διασκόπησης του πυθμένα, που χρησιμοποιούνται για τις παραπάνω εφαρμογές είναι : (i) το μονοδεσμικό/πολυδεσμικό βυθόμετρο, (ii) ο τομογράφος υποδομής πυθμένα υψηλής διακριτικής ικανότητας, (iii) ο ηχοβολιστής πλευρικής σάρωσης, (iv) το θαλάσσιο μαγνητόμετρο, ενώ τα αποτελέσματα της γεωφυσικής διασκόπησης επιβεβαιώνονται με μεθόδους οπτικής παρατήρησης του πυθμένα (δύτες, υποβρύχια οχήματα). Στην εργασία αυτή παρουσιάζονται παραδείγματα εφαρμογής των μεθόδων θαλάσσιας γεωφυσικής διασκόπησης σε περιοχές με μεγάλο αρχαιολογικό ενδιαφέρον από τον Ελληνικό θαλάσσιο χώρο (νησίδα Δοκός, κόλπος Ναβαρίνου, αρχαίο λιμάνι Κυλλήνης) και την Ανατολική Μεσόγειο Θάλασσα (Αλεξάνδρεια Αιγύπτου, ναυάγιο Μαζωτού Κύπρου).

Λέξεις κλειδιά: Τομογραφος υποδομής πυθμένα, ηχοβολιστής πλευρικής σάρωσης, μαγνητόμετρο, παλαιογεωγραφία, ναυάγια, Αλεξάνδρεια, Δοκός, Ναβαρίνο, Γλαρέντζα, Κύπρος..

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1. INTRODUCTION

The main research challenge in underwater archaeology is to overcome the physical barrier of the water coloumn and occasionally of the loose sediments. Modern underwater remote sensing technology introduces many advantages that extend the range of conventional diving work providing the means to survey in a detailed and systematic fashion large seafloor area. The advantages of such surveys are: (i) high speed of investigation the seafloor which is time consuming and therefore can be also proven cost-effective, (ii) ability to detect buried targets, (iii) ability to detect obscure geometrical shapes on the macroscopic scale due to the broader available seabed view than that of the visual field of a diver, (vi) less environmental constrains such as for carrying out the survey (low visibility, dirty and polluted waters, strong currents), (v) precision of seafloor mapping,(vi) higher than visual resolution and (vii) reduced diving hours and unnecessary risks.

The underwater remote sensing techniques most commonly applied to underwater archaeology employ: (i) single and multi-beam echosounders (ii) side scan sonar (acousting imaging), (iii) laser line scan (optical imaging) (iv) subbottom profiler, (v) marine magnetometer and (vi) undersea vehicles.

There are two general approaches regarding the application of these techniques in underwater archaeology: They are being increasingly used to identify, locate and map (i) ancient and historical shipwrecks lying on the seafloor or partly buried in it (Ballard et al., 2000; Phaneuf et al., 2002), and (ii) the coastal palaeogeography and thus submerged sites of archaeological interest (submerged ancient cities, settlements, ports and man-made structures).

1.1. Shipwreck detection

Archaeologists, aided by chance discoveries by fishermen (mainly otter trawling), divers, dredging operations and marine construction but not by remote sensing surveys, have inventoried and studied several ancient shipwrecks, when these are located within conventional diving limits. Advanced remote sensing techniques, allow archaeologists to detect ancient shipwrecks in the depths of the ocean, far beyond the 50m depth boundary set by conventional diving. Over the past ten years, several projects have proven its scientific merit. A number of wrecks were detected at depths of 800 meters off the Skerki Bank in central Mediterranean Sea (Ballard et al., 2000). The “Skerki” wrecks spanning a period between the 2nd century B.C. to the 4th century A.D., document a previously unknown open-sea trade route between Carthage and Rome. Two 8th century B.C. Phoenician cargo vessels were discovered in deep waters on an open water route between Israel and Egypt. The cargoes of these vessels may be different from those of coastal crafts, providing new information about ancient trade and exchange (Ballard et al. 2000, 2002). 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 (fig 1) 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.

Despite the application of the remote sensing techniques for ancient shipwreck detection, these methods are often used for the detection and recognition of historical shipwrecks. A detailed side scan sonar survey has been carried out at the HMHS *Britannic* shipwreck site almost ninety years after the disaster for the estimation of the shipwreck condition (Papatheodorou et al., 2008a). HMHS *Britannic,* the Titanic’s sister ship, sank on just her 6th voyage while serving as a hospital-ship off the Greek island of Kea in the Aegean Sea, on November 21, 1916. The wreck was first found and explored by J-Y Cousteau in December 1975 and was relocated and surveyed in details by Dr. Robert Ballard in 1996. Side scan sonar imagery from the wreck indicates that the Britannic rests on her starboard side (fig. 2).

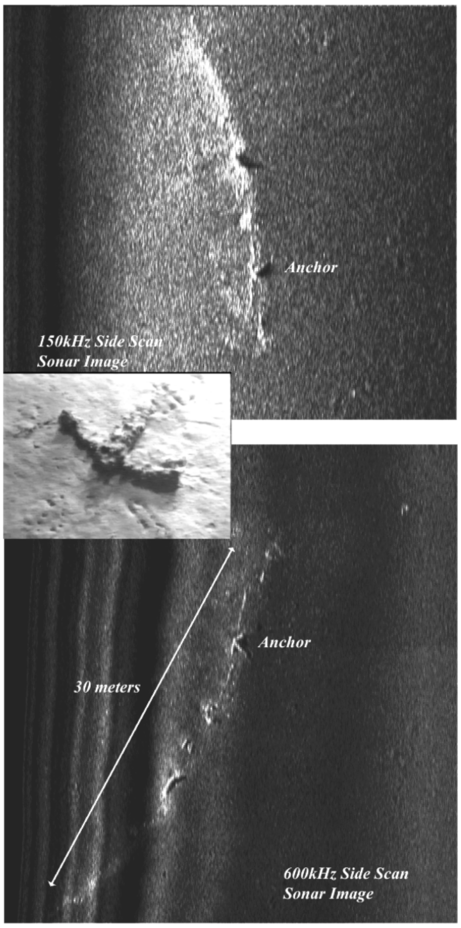

Fig.1. 150 kHz and 600 kHz side scan sonar images showing an ancient shipwreck lying on the seafloor (water depth 750 m) and the iron anchor resting atop the remains of the hull of the shipwreck. Inset digital photo showing iron anchor resting on the seafloor (Phaneuf, Ciavola, Papatheodorou and Ferentinos, 2002).

Despite the discovery of ancient and historical shipwrecks, the remote sensing techniques could be a very effective tool for the protection of the shipwrecks from disturbance effects due to *offshore construction* activities (underwater cables, harbours and marinas)(Soreide and Jasinski, 1998, Papatheodorou et al., 2001c). Papatheodorou et al., 2001c carried out a marine remote sensing survey in order to relocate a known byzantine shipwreck off Zante Island for a submarine power cables connection project. The survey showed that the primarily planned routes of the cables were crossing very close to the shipwreck site. New cable routes were carefully planned and detailed maps with special notifications of the archaeological site were produced and made available to the engineers. All the necessary precautions were taken so that the safety of the shipwreck would be ensured during the cables lying operations.

1.2.

There is increased attention in the study of the location and evolution of coastal areas of archaeological significance (port and cites) using remote sensing techniques. The evolution of shorelines is controlled by eustatic sea level changes, glacio-hydro isostatic movements and tectonic movements (Lambeck, 1996).

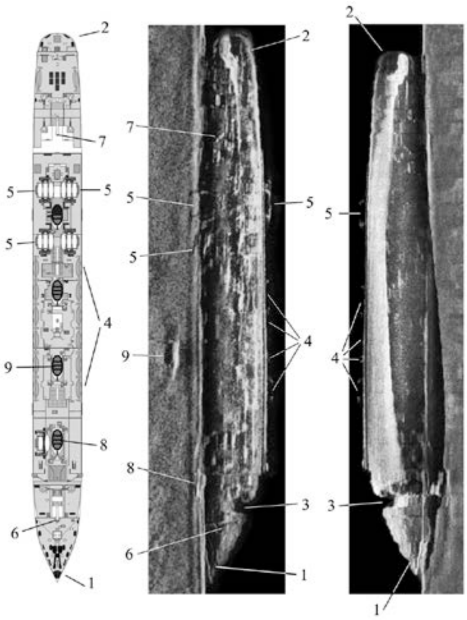

Fig. 2. A plan view diagram of the Britannic and an interpreted sonograph of the wreck. The sonograph acquired along a bow – stern direction over the deck of the wreck and shows the main structural components and superstructures of the shipwreck. (1: bow, 2: stern, 3: the massive crack in the bow, 4: Wellin type davits, 5: giant lifeboat davits, 6: fore mast, 7: rear mast, 8, 9: funnels) (Papatheodorou et al., 2008a).

The sea-level rose approximately -120 meters since the LGM (18000 yrs BP) and covered former landscape of scarps, beaches, river channels, lagoons and man-made structures such as ports and human settlements.

The sea level rise was rapid but pulsating revealing a series of still-stands and consequently the formation of palaeoshorelines. In littoral environments with limited sediment supply the still-stands are imprinted as geomorphologic features, such as scarps and ridges. In the last decades the use of remote sensing techniques for the reconstruction of ancient coastal environments has become common practice because these techniques permit with high accuracy the identification and mapping of submerged palaeoshorelines located either on the seafloor or buried under unconsolidated post-glacial sediments (van Andel and Shacleton, 1982, van Andel and Lianos, 1984, Papatheodorou and Ferentinos 1997, Wiedicke, et al., 1999).

In a slightly different approach, Papatheodorou and Ferentinos (1997) studied coastal instabilities using 3.5 kHz and R.O.V, which were caused by a destructive earthquake of magnitude of 6.1R at 15/6/1995, in the Eliki fan delta (Nikoleika beach) whereas the ancient town of Eliki was situated. In 373 B.C the ancient Eliki which was located about 2.5km in land, was submerged after a strong earthquake. . The authors suggest that a similar type of liquefaction as that happened at the recent earthquake could be the failure mechanism of the destruction of ancient Eliki and this hypothesis is further supported by ancient literature (Strabo, Pauasanias).

The goals of this paper are twofold: (i) to present the results of remote sensing surveys that carried out at sites of archaeological and historical interest, in Greece (Dokos Island, and Navarino Bay whereas a historical naval Battle took place) and in Eastern Mediterranean Sea, and (ii) to prove the applicability of remote sensing techniques in underwater archaeology showing that a combination of these can be a very effective tool.

2. REMOTE SENSNIG TECHNIQUES

2.1. Multi-beam

Multibeam echosounder produces a number of sonar signals, or beams, that propagate from the sonar head in a fan, thus recording bathymetry and amplitude measurements of the surveyed seafloor area. Systematic coverage of the seabed using multibeam echosounder provides clear images of the morphology of the seabed as well as man-made targets on the seafloor. Modern high-resolution multibeam echosounder covers a relatively large area around a man-made target while resolving the true three-dimensional (3-D) shape of the object with centimetre- level resolution. Bingham et al (2010) collected multibeam data form an ancient shipwreck off the Greek island of Chios in the north-eastern Aegean Sea. The high resolution of the bathymetric data was sufficient to reveal the detailed characteristics of the wreckage and the surrounding seafloor. Individual amphoras spatially isolated from the wreckage were also identified. Furthermore, Plets et al (2011) analysed bathymetric and backscatter data derived from multibeam surveys off the north coast of Ireland for shipwreck detection, identification and shipwreck site characterization. In the context of the coastal palaeogeographical reconstruction, Westley et al (2011) also used multibeam data for mapping the submerged landscapes at the northern coast of Ireland.

2.2. Side-scan sonar

Side-scan sonar is an acoustic device which consists of a towed system of transducers ("tow-fish") connected by a cable to the terminal recording unit. The tow-fish is towed on a steady course and at a constant depth through the water, emitting sound pulses on high frequencies (100 to 800 kHz). A higher frequency gives better resolution but less range with the modern systems having capability to resolve objects of 20cm or less. The pulses are sent in two separate fan-shaped beams which are directed down to the seafloor either side of the tow- fish (fig 3a). The result is a plan view acoustic image which is usually called "sonograph" and portrays: (i) the morphology of the seafloor and (ii) the texture of the surface sediments. The detection and the recognition of objects projecting above the seafloor are based on specific acoustic criteria ("acoustic shadow"). On the other hand, the identification of texture of surface sediment surface is based on the acoustic reflectivity. The more coarse-grained the sediment, the stronger the return signal.

The main advantage of a side scan sonar system over the multibeam echosounder is the geometry of the side scan sonar's transducer in relation to a target (Brissette and Hughes Clarke, 1999). The shadows cast behind an object, proud of the sea floor, are the telltale sign that an object has just been ensonified. On contrary, the geometry of a multibeam echosounder's transducer in relation to sea floor targets results in the loss of almost all shadow-casting capability making the side scan sonar more promising for shipwreck detection(Quinn et al., 2002, Papatheodorou et al., 2008a).

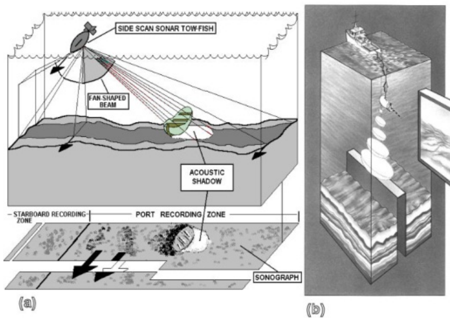

Fig. 3. 3D presentations showing a side scan sonar (together with the "acoustic shadow" criterion) and a 3.5 kHz profiling system.

2.3. Subbottom profiling system

A subbottom profiling system provides an acoustic profile of a narrow section of the subbottom beneath the path over which the device is being towed (fig 3b). The transducer produces high energy with a frequency range between 1 and 12 kHz, which is cone-shaped pulse downwards. The signals are reflected off the seafloor surface, the interfaces between strata and specific features, for example palaeo-shoreline or objects, such as archaeological findings that may be buried in the sediments. The advantage of subbottom profiling is the ability to detect buried objects and/or features of potential archaeological interest. When an acoustic wave encounters a boundary between different sediments, the wave reflects back because of the abrupt change in acoustic impedance (P.I). The strength of this reflection is governed by the reflection coefficient (Kr) (Anstey, 1981 Quin et al., 1997). In addition, the "detective ability" of a subbottom profiler is also controlled by the vertical resolution of the system which is the minimum distance between two distinguishable adjacent reflectors or objects (Plets et al., 2008).

The major drawback of this equipment is the relatively narrow path of investigation of a seabed and in archaeological surveys usually operates after the side scan sonar mapping.

2.4. Marine magnetometer

A marine magnetometer is a portable instrument which measures the intensity of the Earth's ambient magnetic field (fig 4a). Their

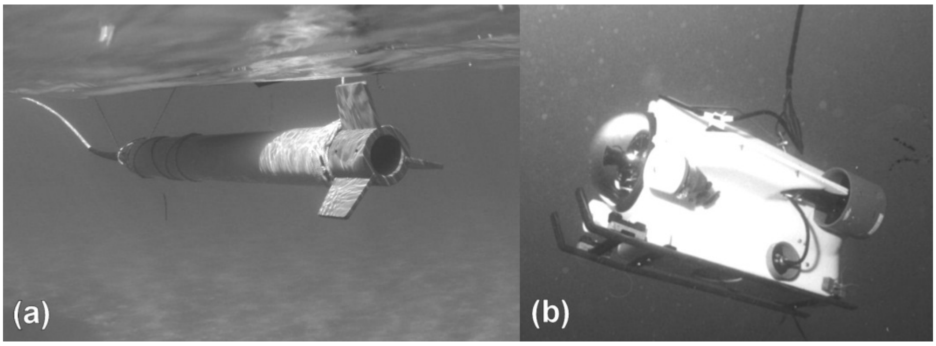

Fig. 4. The Overhauser marine magnetometer (a) and the MKII Benthos R.O.V. (b) which are owned and operated by the Laboratory of Marine Geology and Physical Oceanography.

application in geophysical prospection is founded on the principle that they can measure and record deviations from the earth's field due to the presence of ferromagnetic material. Recent development of magnetometer sensor is the Overhauser magnetometer and the caesium vapour magnetometer, which have improved detection levels compared to previous type of magnetometer sensors (proton precession). These two types of marine magnetometer are recommended for underwater archaeological surveys. Although the use of marine magnetometer for detection of steel and historical wooden shipwrecks is well established and many papers have been published (e.g. Barto Arnold III, 1996, Quinn et al., 2002, Conlin and Russell, 2006), very few surveys have been carried out on ancient shipwreck sites and submerged ancient harbour. Greene et al (1967) carried out the first, as far as we know, magnetometer survey over an ancient shipwreck, the 4 B.C. shipwreck of Kyrenia which was located at the northern coast of Cyprus. The magnetometer survey showed the existence of buried cargo which was extended from the visible wreck.

Boyce et al., 2009 carried out a marine magnetometric survey at the ruined remains of the Roman harbour of Caesarea Maritima which are located on the northwest coast of Israel. The large variations in magnetic intensity across the Roman harbour result from the presence of magnetite-rich hydraulic concrete (pozzolana) within the buried harbour foundation. Furthermore, ballast stone deposits consisting of foreign igneous and metamorphic boulders were detected due to the strong magnetic contrast between the ballast deposits and the natural seabed sediments (Boyce et al., 2009).

2.5. Undersea Vehicles

An undersea vehicle is a mobile, self-propelled, piloted or remotely controlled subsurface platform, capable of carrying sensors and tools. Three general types can be distinguished: (i) deep submersible vehicles (D.S.V's), (ii) remotely operated vehicles (R.O.V's) and (iii) autonomous underwater vehicles (A.U.V.'s).

D.S.V.'s are human-occupied, deep probes that usual travel more vertically than horizontally distances to accomplish their scientific missions. *Alvin* is the oldest D.S.V. in service and has completed the greater number of dives. It is owned and operated by Woods Hole Oceanographic Institution (WHOI). The U.S. nuclear research D.S.V. *NR1* with its tender ship Carolyn Suess participated in three major deep-water archaeology programs in Skerki Bank (Sicily Straits), off-Egypt and the Gaza strip (Ashkelon Project) and in the Ionian Sea. *NR1* has a continuously collecting high-resolution side scan sonar system (100-600 kHz), subbottom profiler system, CTD data and digital imagery from down-looking, hull-mounted digital video cameras.

R.O.V.'s are unoccupied, tethered submersibles, with umbilical cables that carry electrical power, sensor data and control commands (fig 4b). The light-work class R.O.V.'s have replaced scuba diving in most occasions and have developed to one of the principal tools of underwater archaeology. For this type of R.O.V. ship requirements are minimal. A small deck space is required and the vehicle can be deployed and recovered by hand. The MKII R.O.V., one of the most popular light-work class R.O.V.', is a small 4 thruster controlled neutral buoyant vehicle which can navigate in any direction, fitted with a high resolution video camera, small manipulator, scanning imaging sonar and a still photo camera.

A.U.V.'s are unoccupied submersibles, without tethers or umbilical cables. All power is supplied by on-board energy systems such as batteries or fuel cells and is controlled itself while accomplishing a pre-defined task. The use of an A.U.V. system is a revolutionary concept in that the user has very little, if any control over the system as it performs its task. Recently, deep-sea archaeology is the new field for scientific application of A.U.V.'s. In June 2001, an Odyssey IIc AUV, which is owned and operated by M.I.T. AUV-Lab, was deployed to Nisyros Island to search for an ancient shipwreck (Delaporta et al., 2002). Furthermore, Bingham et al (2010) conducted a remote sensing survey off the Greek island of Chios in the northeastern Aegean Sea using an autonomous underwater vehicle (AUV) built specifically for high-resolution site inspection and characterization.

3. CASE STUDY 1: DOKOS ISLAND

In 1975 P. Throckmorton discovered a concentration of prehistoric ceramics in the Bay Skindou at the northern part of Dokos Island (fig. 9). The Hellenic Institute of Marine Archaeology (H.I.M.A.) started detailed underwater archaeological studies in the area, under the direction of G. Papathanasopoulos (Papathanasopoulos et al., 1989-92). The study of on site discovered ceramics concentration proved that they belonged to a wreck which was dated as Early Helladic II. In 1992, the Laboratory of Marine Geology and Physical Oceanography was invited to participate in the Dokos Project carrying-out a marine remote sensing survey (Papatheodorou et al, 2008b).

The aim of the remote sensing survey was to detect and to map the submerged palaeoshorelines in order to reconstruct the palaeoenvironmental conditions which prevailed at the Skindou embayment, in the northern part of the Dokos Island, where the shipwreck was found (fig. 5) (Papatheodorou et al, 2008b). During the Dokos Project, a 3.5 kHz O.R.E. subbottom profiler and an E.G&G. side scan sonar system were utilized. A Magellan G.P.S. was used for navigation and positioning.

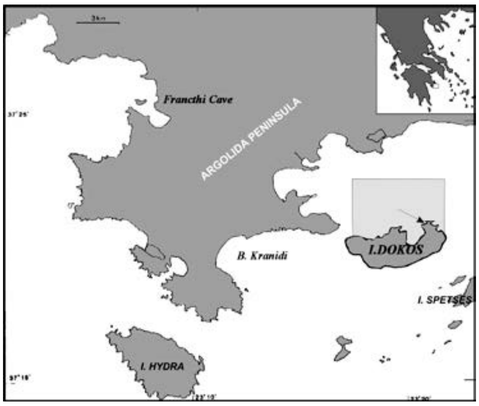

Fig. 5. General map of the Argolida Peninsula. The grey area indicates the area where the marine remote-sensing survey (Dokos Project) was carried out. The arrow indicates the position of the wreck in Skindou embayment.

The study of the 3.5 kHz profiles has shown that the sea-bottom is characterized by four different echo types, each one corresponding to different seabed material (fig. 6). Detailed examination of the profiles on the limestone bedrock surface reveals numerous small scarps which appear as sharp breaks in the overall slope gradient of the limestone surface (fig. 7). 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 sea transgression. Therefore it can be regarded as evidence of a palaeoshoreline. Taking into consideration that the sea level at the time of scarp formation corresponded to the base of the scarps, the position and the depth of the fossil sea levels can be determined to within 2 to 3m accuracy. The scarps cluster at a small number of depths below present sea level and

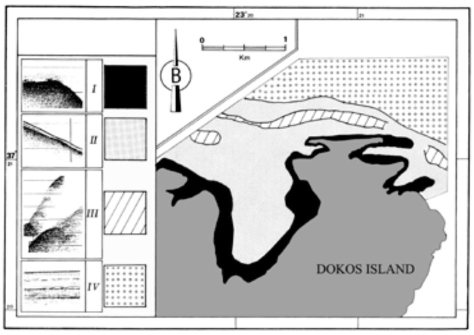

Fig. 6. Spatial distribution of the Echo Types (I-IV) identified in the studied area. In the left side of the figure representative 3.5 kHz records of Echo Types (I-IV) are shown.

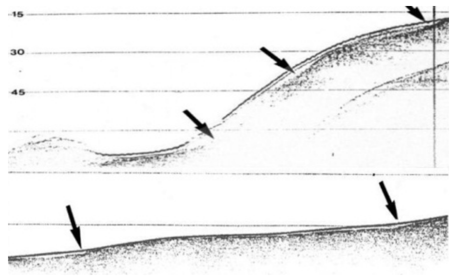

Fig.7. Selected seismic profiles offshore the Dokos island. The arrows indicate the geomorphologic features which correspond to surficial or buried traces of submerged palaeoshorelines (scarps).

assuming that eustasy was the only parameter controlling the above sea level changes then their age of formation can be determined using the sea-level change curve, constructed by Fairbanks (1989). The clusters present synchronicity with relevant markers found along the coastline of Argolis Peninsula (Van Andel and Lianos, 1984) and coincide in age with stadials prevailed at this period (Rohling et al., 1998, Geraga et al., 2000). The above suggests that the transgression of the sea at the study area was not continuous during the Late Glacial-Holocene period but was interrupted for short time intervals. This in combination with the archaeological data from the close Franchthi cave (Farrand 1989) provide a rough estimation of the areal extent during Paleolithic, Mesolithic and Neolithic periods for the northern Dokos Island (fig. 8) (Papatheodorou et al, 2008b).

The most remarkable result from the study of the coastal ancient evolution is the development of a cove at the Skindou embayment at around 6000yrs BP, when the sea was 10-11m below the present level (Papatheodorou et al, 2008b) (fig. 9). This cove providing all weather protection would have made an ideal shelter for the mariners carrying goods and moving to and fro in the area and probably provoked the establishment of the Neolithic settlement found on the island. Later, at about 4000yrs BP the rise of the

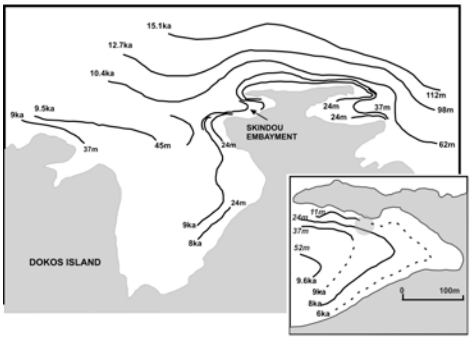

Fig. 8. Map showing the palaeoshorelines around Dokos Island and Skindou embayment between 15100yrs BP and 6000yrs BP. The grey circle indicates the location of the wreck.

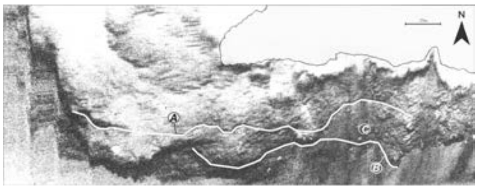

Fig. 9. Side scan sonar sonograph showing: (a) the paleoshoreline of 11-14m, (b) the paleoshoreline of 22-24m and (c) the Dokos wreck location.

sea level changed again the configuration of the shoreline, the cove submerged and the area was no longer suitable for sheltering as it was straighter and exposed to westerly winds. This change probably contributed to the sinking of the boat whose wreck was found on the seabed.

4. CASE STUDY 2: NAVARINO NAVAL BATTLE (1827)

The Navarino Bay is a natural harbour, located in front of Pylos, at the southwestern end of Peloponnesos. Navarino bay has been a settlement for ships and fleets, over the last thousands years due to its location and geometry. Significant naval battles took place there. The most recent battle happened at 1827, during the Independence War of Greeks from the Ottoman Empire. The Navarino naval lasted for a few hours and ended in a complete disaster of the Ottoman-Egyptian fleet. Almost all the lost ships were burnt and exploded above water before sinking into the sea. Only remnants of the ships survived the fire and explosions and are lying currently on the seabed of Navarino Bay. Nowdays, Navarino Bay is used as a harbor entertaining ships, mainly tankers, for refueling. Ships of this size have anchors that cause large scours on the fine grained sediments of the seabed. Moreover, the Greek tanker Irenes Serenade sunk into the bay polluting the sea with thousands tones of crude oil (fig. 10).

In 1996, the Laboratory of Marine Geology and Physical Oceanography, of the University of Patras, Greece, started a remote sensing survey in the area (Papatheodorou et al., 1999, Papatheodorou et al., 2001a, Papatheodorou et al., 2005). The aim of the survey was to investigate the environmental condition of the shipwreck

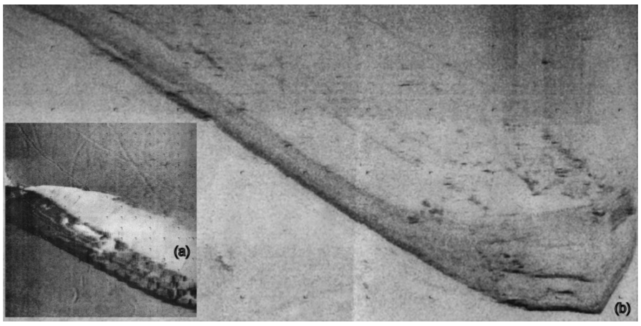

Fig. 10. Side scan sonar sonographs showing the Irenes Serenade shipwreck (a) and the bow of the shipwreck (b).

remains in relation to the use of Navarino Bay as a harbor.

The Navarino Battle survey utilized: (i) an E.G. & G. side-scan sonar system, (ii) a 3.5 kHz O.R.E. subbottom profiling system, and (iii) a small light work class eyeball R.O.V (Benthos Minirover MKII) with a single color CCD camera and a 35mm camera with flash. Positional data were provided by a Differential GPS. The most striking features recognized in the sonographs of the Navarino Bay seafloor were: (i) drag marks caused by the anchors of moored tankers (fig 11), and (ii) high reflectivity (dark colored) targets (Papatheodorou et al., 2005). 3.5 kHz profiles show that a surface veneer of 0.5-1.0m in thickness is highly disturbed by the drag action of towed anchors (fig 12).

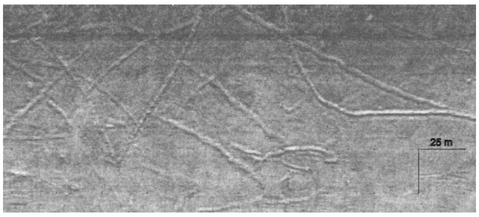

Fig. 11. Side scan sonar sonograph showing dense net (cluster) of sub parallel or intersected and superimposed marks caused by the anchors of moored tankers.

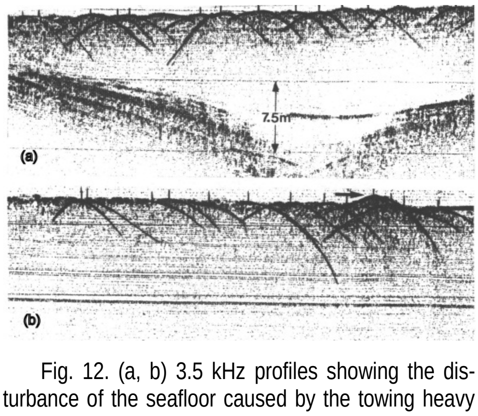

Fig. 12. (a, b) 3.5 kHz profiles showing the disturbance of the seafloor caused by the towing heavy anchors, as indicated by the hyperbolic echoes.

The area with the high frequency of scours is well correlated with the area where the Navarino Battle took place, and therefore with the aerial extent of shipwreck remains distribution, suggesting that the heavy anchors have highly disturbed the warships remains (fig 13). A small number of high reflectivity targets were detected on undisturbed seafloor between isolated anchor marks. No target was insonified on seafloor with the highest density of hyperbolae because of the

Fig. 13. Map of the Navarino Bay showing the spatial distribution of the Turkish-Egyptian fleet and the areal distribution of the degree of disturbance of the seafloor surface by the towing anchors (Papatheodorou et al 2005).

complexity of microrelief. At one particular location, a deep anchor scour intersected a well shaped target as shown in the sonograph.

Two targets were considered to be the most promising for finding wreck remains and therefore R.O.V. dives were carried out at these two sites. Systematic inspection has shown that the targets were constructed by a large number of artifacts, such as wood from the hull of the warships and small iron objects (fig 14). All artifacts had a height of about 0.5m; some were partly buried beneath the soft sediments while most of them were lying on the seafloor (fig 14). At least in one site shipwreck remains had been relocated by towing of a heavy anchor (Papatheodorou et al., 2005).

Remote sensing survey at the Navarino bay showed that the central area of the bay which includes the naval remains, is “pyling” at the present by the heavy anchors. As a result, the warships remains have been highly disturbed by the towing anchors. The above suggests that the conservation of this significance cultural heritage requires a rational management plan (Papatheodorou et al., 2005).

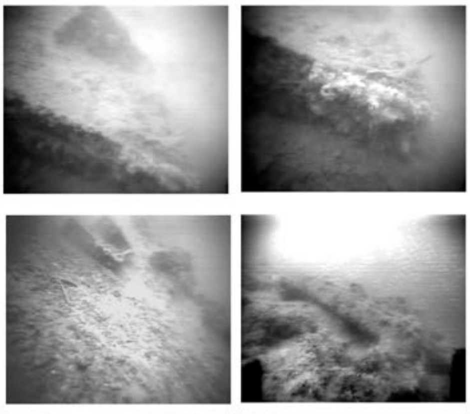

Fig. 14. Underwater photos collected by the MKII Benthos R.O.V. showing the remains of the Ottoman fleet.

5. CASE STUDY 3: COASTAL ZONE OF ALEXANDRIA

Alexandria, founded by Alexander the Great in 330 BC, was one of the most renown ports of the ancient world controlling the trade of Eastern Mediterranean during Hellenistic and Roman times (fig 15) (Tzalas, 2000). The coastal zone of Alexandria hosts the ruins of one of the seven wonders of the ancient world, the famous Pharos Lighthouse, as well as, many other ancient and historical monuments and shipwrecks. The Pharos was built between 285 and 280 BC by Ptolemy II and it was 100m high decorated with statues. The Pharos was completely destroyed between 1303 and 1349 AD by an earthquake and in its site the Mameluke sultan Ashraf Qaitbay built a fort in 1480 AD (fig 15). The majority of these pieces of Pharos fell into the sea and remained lost until Jean-Yves Empereur started mapping them, in 1994 (Empereur, 2000).

Between 1999-2000, the Laboratory of Marine Geology and Physical Oceanography in cooperation with the Hellenic Institute of Ancient and Mediaeval Alexandrian Studies (H.I.A.M.A.S) jointly with the Department of Underwater Archaeology of Alexandria, (Supreme Council of Antiquities of Egypt, S.C.A.) carried out marine remote sensing surveys in the coastal zone of Alexandria from Cape Lochias to Sidi Bais (fig 15). The survey was planned and implemented, in three periods; October 1999, April 2000 and November 2000. Moreover, between 2001 and 2006 the Laboratory in partnership with Centre d'Etudes Alexandrines (C.E.A)

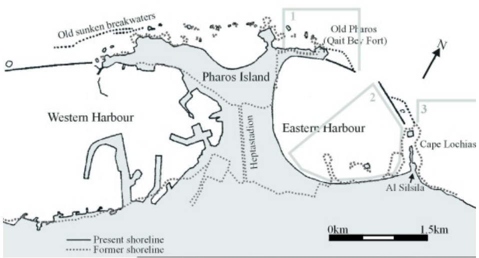

Fig. 15. Map showing the locations of the main ancient sites in the coastal zone of Alexandria and the areas of the recent underwater archaeological surveys under the directions of J-Y Empereur (1), F.Goddio (2) and H. Tzalas (3).

and S.C.A., under the directionship of J-Y Empereur carried out repetitive remote sensing surveys offshore the entrance of the Eastern Harbour (*Μέγας Λιμήν*) of Alexandria (fig 15). The objectives of these surveys were 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 detect ancient and historical shipwrecks on the seabed.

Archaeological and oceanographic data suggest that the coastal zone of Alexandria has been under subsidence for the last 2300 years. This suggests that part of Ptolemaic Alexandria is currently below the present sea-level and thus the coastal zone of Alexandria is one of the most promising areas of the world for archaeological studies.

5.1. Reconstruction of the coastal palaeogeography

The collected analogue data was processed in a GIS environment using a simple methodological scheme built specifically for the Alexandria project (Chalari et al., 2008). 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 mainly characterized by a well-shaped rocky ridge (Ridge A), 6-14m high and about 700 m in width. The minimum water depth of this ridge obtained at 12m forming a narrow planar strip (Fig. 16) (Chalari et al., 2009). 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. 16). The Ridge A is running almost parallel to the contours and present-day shoreline and has a dominant strike direction of about ~45º (Fig. 16).

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. 17) (Chalari et al., 2009) providing evidences of palaeoshorelines. Among them, the palaeo-

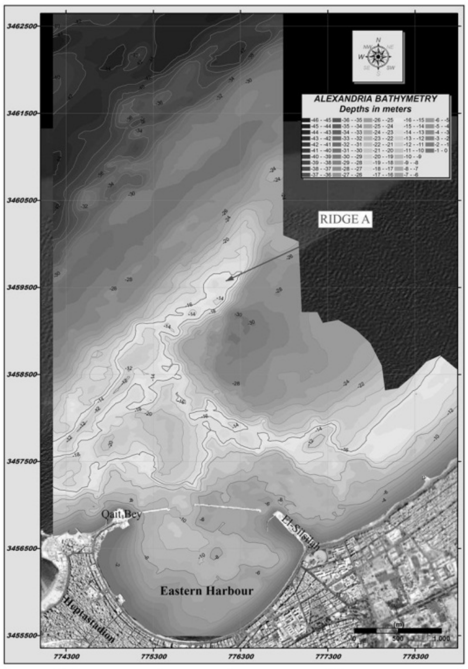

Fig. 16. Detailed bathymetric map of the coastal zone of Alexandria based on the subbottom profiling data (Chalari et al., 2009).

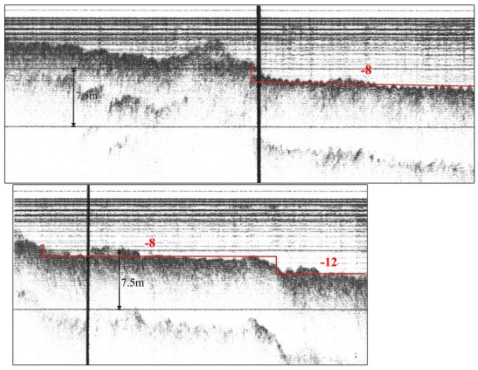

Fig. 17. 3.5 kHz sub-bottom seismic reflection profiles showing the palaeoshorelines at the water depths of 12m and 8m below the present sea level. The profiles are taken from tracklines vertical to the Eastern Harbour of Alexandria (Chalari et al., 2009).

shoreline 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. 17). 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 and probably represent submerged man-made structures (Papatheodorou et al 2001d, Chalari et al., 2009).

Based on short-term (oceanographical data) and long-term (archaeological data, radiocarbon-dated sediment cores) observations, Chalari et al (2009) suggested that a rate of subsidence of about 3.5mm/yr is a reliable value for the coastal zone of Alexandria. According to this estimation 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 (Chalari et al., 2009).

Based on the scenario of 8m of subsidence during the last 2300 BP, 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. 18). 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. 18) (Chalari et al., 2009). 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

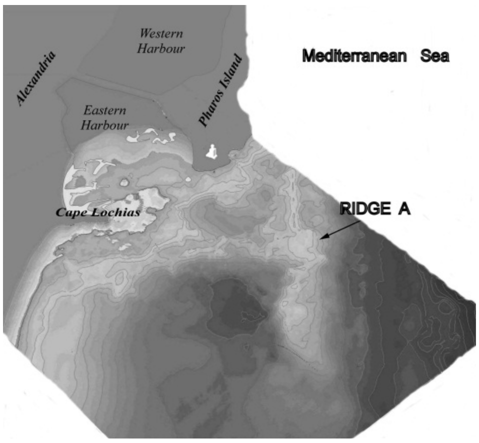

Fig. 18. 3-D bathymetric reconstruction of the coastal zone of Alexandria at the Hellenistic-Roman periods (see text for details) (Chalari et al., 2009).

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.

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. 18) (Chalari et al., 2009). 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.

5.2. Shipwreck detection

For the detection of ancient and historical shipwrecks, a detailed side scan sonar survey was carried out covering an area of 32.5 km^2. In total, 57 anomalies were detected on the sonographs and catalogued (Papatheodorou et al., 2001b, Chalari et al 2003) and then were visually inspected by the divers of the Centre d'Etudes Alexandrines.

Most of the targets (18 or 32%) were man-made objects with no archaeological or historical interest (cables, barrels, tires and iron pieces). Eight sites were identified as historical and archaeological sites, 11 targets were found to represent natural formations (isolated rocks, corals) and 20 targets did not found or must be re-examined. Of the cultural sites, two were identified as 19th century iron anchors (fig. 19a), one as ship ballast and two as amphora concentrations (fig. 19b). Detailed visual examination of these two amphora concentrations by the archaeologists-divers of C.E.A revealed an ancient shipwreck with amphora cargo and a stone anchor and few scattered amphora.

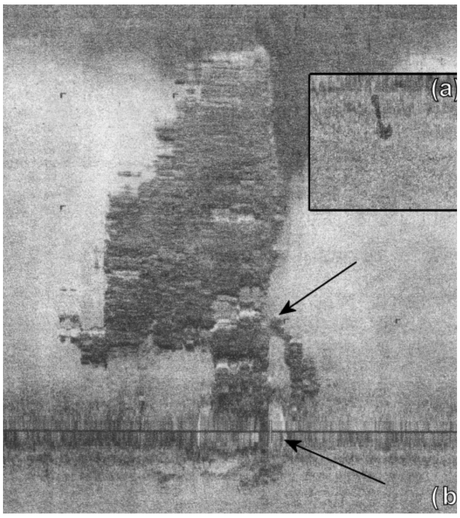

Fig. 19. Side scan sonar sonographs showing (a) a high relief target which represents an iron anchor and (b) an amphora concentration which represents an ancient shipwreck.

6. CASE STUDY 4: ANCIENT AND MEDIEVAL HARBOUR OF KYLLENE/GLARENTZA

Kyllene/Glarentza was built by the Franks in the 13th century, it developed as one of the major ports during the Crusaders' period in NW Greece.The Kyllene Harbour Project is a joint project of the Finnish Archaeological Institute at Athens and the Department of Underwater Antiquities (Ministry of Culture); it is conducted in collaboration with the Dept. of History, Archaeology and Cultural Resources Management, University of the Peloponnese and the Laboratory of Marine Geology and Physical Oceanography, Department of Geology, University of Patras. The remote sensing survey includes echosounder, side scan sonar, 3.5kHz profiler and Overhauser magnetometer and aimed in combination with high resolution topographical and underwater archaeological data to the reconstruction of the coastal zone of the famous harbour (Pakkanen et al., 2010).

7. CASE STUDY 5: MAZOTOS SHIPWRECK

In the context of applying magnetometer to ancient shipwreck sites, a very detailed geophysical survey was conducted in the 4 century B.C. Mazotos shipwreck off the southern coast of Cyprus (Demesticha, 2011). An intensive magnetometer survey carried out using Overhauser magnetometer in order to detect the buried part of the cargo Preliminary results indicate that a significant part of the wreck extends beyond the southern end of the amphora assemblage (Demesticha, 2011, Geraga et al., in preparation).

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