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INTEGRATED GEOPHYSICAL INVESTIGATION APPLIED TO THE DEFINITION OF BURIED AND OUTCROPPING TARGETS OF ARCHAEOLOGICAL RELEVANCE IN VERY SHALLOW WATER

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ABSTRACT: Passaro S. et al., *Integrated geophysical investigation applied to the definition of buried and outcropping targets of archaeological relevance in very shallow water*. (IT ISSN 0394-3356, 2009).
The results of a marine survey aimed at detecting archaeological targets in coastal areas by means the integration of different geophysical methods (multibeam bathymetry, high-resolution seismic, geoelectric and magnetism) are presented. The case study is a shipwreck recognised off the shore of Agropoli town (Salerno, southern Italy) over a sandy sea-bottom at about 5 m of water depth.
Each geophysical method has its peculiarity and detection capability depending on a wide range of factors such as: geological setting, consistency and grain size of sea-bottom sediments, burial and nature (e.g. metallic/non metallic) of the targets, water depth, etc. It is worth stressing that there is a high reduction of the ambiguities inherent in each method when a multiple approach strategy is adopted. We believe that this type of investigation may contribute to establishing a quality standard for such a category of surveys that can be adopted by local administrators and coastal managers wherever archaeological exploration is required.

RIASSUNTO. Passaro S. et al., Integrazione di metodi di prospezione geofisici per il rilievo di unità di interesse archeologico (sepolte o sommerse) in ambiente marino costiero*. (IT ISSN 0394-3356, 2009).*
In questo lavoro presentiamo il risultato di indagini effettuate con l'utilizzo di diversi metodi di geofisica marina, finalizzate alla ricerca di oggetti di interesse archeologico in mare (si intendono compresi i relitti storici o contemporanei). Rilievi morfo-batimetrici, sismo-acustici, geoelettrici e magnetometrici sono stati effettuati al largo del litorale di Agropoli (Salerno, Italia meridionale) su un relitto di nave della seconda guerra mondiale posto a circa 5 m di profondità su un fondale sabbioso. Il caso di studio ha permesso di analizzare problemi ed inconvenienti correlati alle diverse tecniche geofisiche, in relazione a variabili quali: contesto geologico, natura e granulometria dei sedimenti al fondo, grado di seppellimento dell'oggetto, costituzione (metallica/non metallica) degli oggetti o dei relitti, profondità della colonna d'acqua, etc. L'utilizzo incrociato di dati derivanti da più tecniche di acquisizione ha permesso inoltre di ridurre sensibilmente il margine di errore interpretativo sulla natura degli oggetti e/o dei relitti osservati in sito. Lo scopo del lavoro è stato quello di individuare criteri standard di riferimento che consentano scelte oggettive delle tecniche di investigazione di geofisica marina da utilizzare per il rinvenimento di relitti in zone costiere. Una buona conoscenza, infatti, dei limiti e delle possibilità di ciascun metodo può influenzare positivamente la scelta delle amministrazioni locali impegnate nello sviluppo sostenibile delle zone costiere.

Keywords:magnetics, marine geoelectrical measurements, multibeam swath bathymetry, monochannel reflection seismic.

Parole chiave: Metodo magnetico, misure geoelettriche, batimetrica multifascio, Sismica a riflessione monocanale.

1. INTRODUCTION

Sea water geophysical exploration aimed towards reidentification of targets of archaeological relevance is strongly constrained by time of data acquisition and processing. Feasibility studies in areas with potential archaeological interest are often required to be quick when the presence of a possible target has to be recognised, and this implies the use of exploration methods with a swift data response. In this regard, we have selected some standard geophysical techniques typically used in marine exploration, and tried to analyze them in regards to different aspects. Parameters that need to be considered are: geological nature of the investigated sector (volcanic or non-volcanic) provided by magnetic prospecting, textures of bottom sediments (clays, silts, sands or gravel) provided by seismic surveys, while composition and displacement of targets (buried or outcropping), depth of water column might affect the performance of all the techniques here considered.

The occurrence of outcropping items is well detected by using morphobathymetric surveys, i.e. multibeam swath bathymetry and side scan sonar. Multibeam systems are echosounders, usually mounted on keel, made up of one hundred or more transductors, that allow te mapping of large swaths of the seafloor using acoustic reflections caused by water-sediment interface. Side scan sonar systems, typically towed, use internal roughness of materials to explore the seafloor, through the evaluation of lateral backscattering. Requirement for buried objects explorations are penetration of sediments without lack of resolution. Magnetic surveys are used when expected archaeological targets differ from surrounding materials in terms of internal magnetic susceptibility. High-resolution monochannel seismic reflection surveys use active acoustic sources (variable in shape, amplitude, frequencies) to provide a sonic section of the subsurface, where anomalies are related to local variations of acoustic impedance (i.e. the product of density and acoustic velocity). The choice of the seismic source-type could be strategic.

Marine geoelectrical methods, just like on-land measurements, use properties of materials to give different answers to an electrical impulse. Local anomalies, due to electrical resistivity contrasts, can be used to identify possible target location.

A survey using all of the above methods has been carried out over a submerged beach along the Agropoli shore (Salerno, Italy) by a research team of the Institute for Coastal and Marine Environment (IAMC) of National Research Council (CNR), supported by the "Parthenope" and “Federico II” Universities of Naples, with the aim of recognizing buried metrical objects below the sandy seabed. The survey discovered the presence of a shipwreck, that is a military vessel probably sunk during the Second World War, in the course of the Salerno landing operations.

2. GEOPHYSICAL EXPLORATION

2.1 Outcropping targets: morphobathymetric surveys (MBES)

MBES data records are usually processed with a reply of swaths, and the removal of erroneous measurements (spikes). Data are then reorganized in a MxN matrix (Digital Terrain Model, DTM), where every cell of the grid represents a depth quote. Swath bathymetry equipments are characterized by frequency-dependent vertical resolution and depth-dependent horizontal resolution (“footprint”), the dimensions of which represent a detection limit with respect to the grid cell size of DTM. The reported dataset was collected with a Seabat 8125 (Reson-Thales) echosounder/sonar system with 240 beams, 120° of Swath Coverage and a pulse frequency of 455 KHz, particularly suitable for applications in shallow waters (max 80 metres of depth).

Nadir areal footprint dimension is a function of depth and technical characteristics of the equipment. In shallow waters, high frequency MBES systems are able to map the seafloor with an adequate grid cell size, clearly showing potential targets. Fig.1 is indicative of how fast the resolution degrades with respect to the increment of cell dimensions. Where footprint dimensions are not sensibly smaller than the targets, the use of towed side scan sonar (SSS) systems is strongly recommended. Advantages related to the use of this system are evident, in the sense that SSS is considerably closer to the source with respect to MBES.

Side scan sonar is an acoustic tool used to generate image map of the seafloor and particularly suitable for outcropping target detection. Typically, the system's transducer is allocated in a towfish, which is towed through the water a few metres above the bottom. The reflected acoustic returns are processed into an image

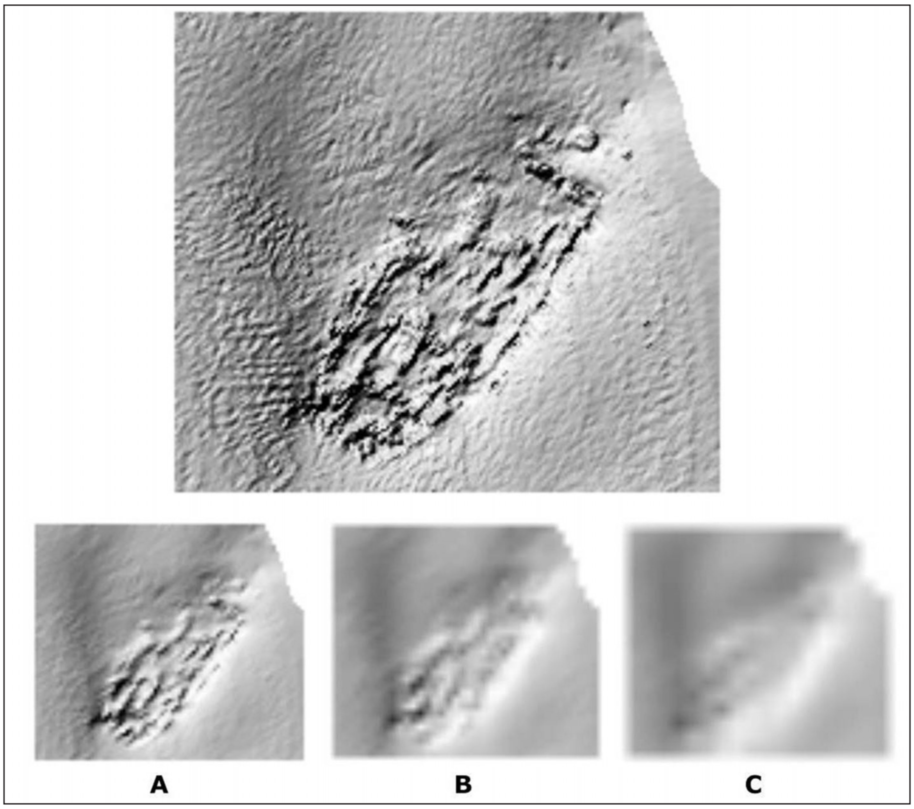

Fig. 1 - Outcropping bodies are well detected with the use of swath bathymetry. Here we show search results through a high resolution 20x20cm DTM (Digital Terrain Model) obtained with the use of Reson Seabat 8125 multibeam echosounder, and processed with the PDS2000 (Reson-Tales) software (A). This resolution is difficult to obtain, because of the intrinsic instrumental nature (the horizontal resolution is a function of depth of water column and instrumental characteristics, such as number of beams, angle wideness, etc.), but in such cases, multibeam images are equivalent to side scan sonar pictures in terms of horizontal target definition. The obtained DTM shows a perturbation in normal sedimentation, due to shipwreck outcropping, acting as an obstacle for longshore currents (Quinn, 2006). B, C and D represents the same data proposed with a grid cell size of 0.5, 1 and 2 metres, respectively. The shipwreck presence (A) is clearly identified only with highest resolution grids (dimensions are 30x10 metres).

I target di dimensioni metriche affioranti a fondo mare sono ben evidenziati dai rilievi batimetrici ottenuti con sistemi multifascio. In figura è mostrato un DTM (Digital Terrain Model) alla risoluzione di 20x20 cm, realizzato acquisendo i dati di profondità con il Reson Seabat 8125 e processando con il software PDS2000 (Reson-Tales). La risoluzione è funzione delle caratteristiche dello strumento utilizzato (numero di beam emessi, ampiezza del fascio) e della profondità d’acqua alla quale si opera. In alcuni casi si possono ottenere immagini multibeam paragonabili, come grado di definizione orizzontale, alle immagini side scan sonar. Nell’esempio in figura è visibile la perturbazione del fondale circostante il relitto, dovuta all’interferenza dell’ostacolo con le correnti lungocosta (Quinn, 2006). B, C e D mostrano l’area del relitto riproducendo lo stesso dato con tre differenti dimensioni di cella del grid (0.5, 1 e 2 m rispettivamente). La presenza del relitto (A) è chiara solo con la risoluzione massima (dimensioni della figura 30 x 10 m).

similar to an aerial photograph, which is viewed real-time on a computer monitor in the towing vessel. Typically, the side scan sonar searches a swath that is 60 to 160 feet wide at about 2 miles per hour, although other ranges can be used depending upon the size of the target.

These systems represent a fundamental key for target detection, because of their ability to evaluate roughness variations that correspond to change in materials. Side scan systems use a sonar device that emits fan-shaped pulses down toward the seafloor across a wide angle perpendicular to the path of the sensor through the water. The transducer may be towed from a surface vessel or submarine, or mounted onto the ship's hull. The acoustic intensity of reflections from the seafloor is recorded on cross-track slices. Finally, records are “mosaiced”, in order to obtain a plan view of the bottom that represents a “sonic picture” of the seafloor. This technique appears to be the most suitable for target detection of outcropping objects, although results should not be considered significantly different from multibeam data in very shallow waters.

2.2 Buried targets: magnetic survey

Magnetically susceptible bodies can be easily detected with the use of magnetic methods (Boyce *et al*., 2004), although several problems may arise from the presence of anthropic objects such as pipelines, anchors, chains, etc.

The magnetic survey has been carried out in a 10x10 meters grid. Data acquisition was performed by using a “SeaSpy” magnetometer (Marine Magnetics Corporation), with a sensor based on the overhauser effect, with 0.2 nT of accuracy and 0.01 nT of sensitivity. The analytic signal (Nabighian, 1972; Roest *et al*., 1992) can help in the identification of the horizontal boundary and in the determination of exact location of the magnetic sources (Fig. 2). The analytic signal, *A(x,y)*, is calculated by taking the square root of the sum of the squares of each of the three directional first derivatives of the magnetic field, *T*, as follows:

$$|A(x,y)| = \left((dT/dx)^2 + (dT/dy)^2 + (dT/dz)^2 \right)^{1/2}$$

The resulting shape of the analytic signal is independent of the orientation of the magnetization of the source and is centered on the causative body. This has the effect of transforming the shape of the magnetic anomaly from any magnetic inclination to one positive body centered on the anomaly. The used function is based on the U.S.G.S. program PDEPTH (Phillips, 1997), through the calculation of the Hilbert transform. In the absence of high-frequency noise, local peaks are interpreted as corners of source, and provide a high accurate horizontal location of the magnetic sources. Buried metallic objects are clearly identified by means of magnetic surveys, but problems in data acquisition may arise over volcanic areas, particularly in deep waters.

2.3 Buried targets: high-resolution seismic survey

Typical properties of embedded objects are: 1) Small dimensions and unknown positions within large survey areas; 2) Very weak reflectors due to the attenuation of the overburden sediment material; 3) Small differences in the properties of the surrounding sediment, if the object is made of wood and filled with water.

A wide range of marine single channel seismic systems are used for high resolution prospecting. Their main differences are about the nature of the source (mainly its frequency and amplitude). Acknowledged setbacks related to the use of common linear acoustical systems are: 1) Low frequencies are required to penetrate the sediment; 2) Wide beam width with a large footprint, high reverberation level and low horizontal resolution; 3) have long and ringing transmitter signals and low vertical resolutions and 4) Small system bandwidth and low ping rates in the detection of small and weak reflectors.

High frequency seismic profilers (chirp, subbottom, etc.) are not significantly penetrative through sand, while sparker systems do not seem to be sufficiently resolutive because of the wide angle of the source

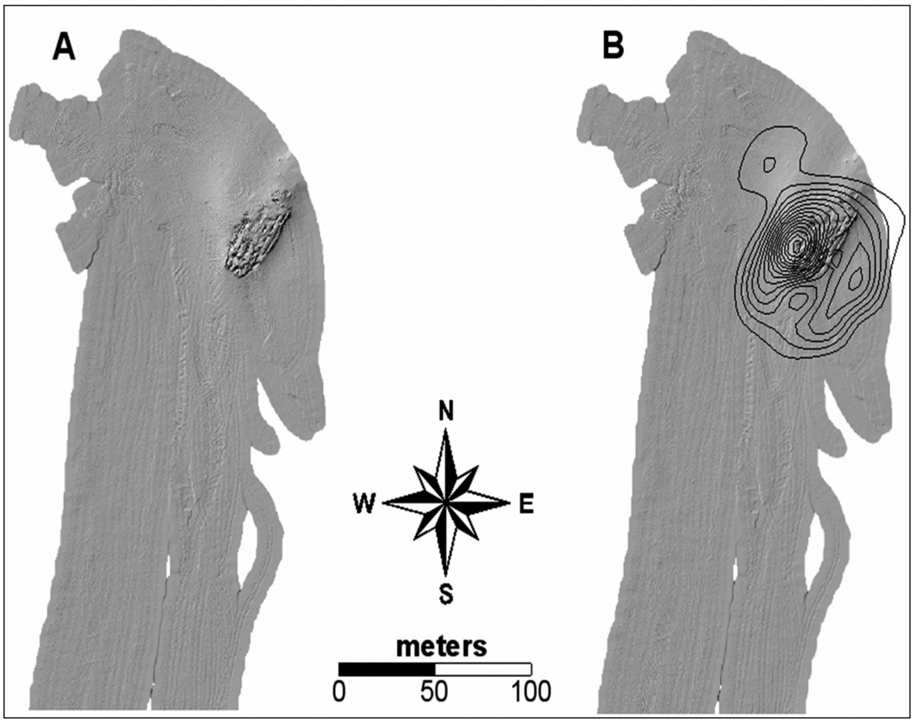

Fig. 2 - A) Shaded relief of the multibeam data (grey scaled image) with overlapped (B) the analytic signal coming from the magnetic data (contour map). Magnetic boundary are intense around the shipwreck.

A) Rilievo ombreggiato (in scala di grigio) dei dati multibeam e (B) mappa a curve di livello del segnale analitico calcolato dalle anomalie magnetiche residue del campo misurato.

beam. In this sense, boomer systems represent the best technique to ensure both penetration and resolution. The sparker, consisting of an electrode array powered by a capacitor bank of a few hundred joules, has been widely employed for studies on the continental shelf. An electromagnetic source or boomer was developed during the early 1960's (Edgerton and Hayward, 1964). Seismic energy comes from the sudden separation of an aluminium plate from a flat copper coil embedded in a hard epoxy resin. The plate is initially held against the coil. During the rapid discharge of a bank of capacitors through the coil, eddy currents are induced in the aluminium plate causing a rapid repulsion and the creation of a cavitation volume in the water. The first pressure pulse is due to the rapid outward acceleration of the aluminium plate, followed by a pulse from the implosion of the cavitation volume. Boomers (like the EG&G Uniboom) with pulse lengths of 0.1-0.2 ms have been developed for reflection profiling in water depths of a few meters. These are able to resolve reflectors less than 0.3 m apart in near-shore sediments (Simpkin and Davis,1993). Sparker and Boomer systems have different Radiation Diagrams: perfect cylindrical symmetry for Boomer and very asymmetric and with large angle in the transverse (with respect to navigation) direction for Sparker. Boomer and Uniboom, which we have used for this survey, are both energy limited to 0.5-1KJ, while Sparker is limited to 3-5kJ. Results are reported in Fig. 3.The eco signals have been acquired and post processed applying Band-Pass digital filter in order to enhance Signal/Noise ratio. This operation has been performed by mean the powerful Hardware/Software platform DSeismic. (Corradi, 2004) .

Parametric acoustic systems (like SES 1000 and SES 2000 of Innomar Technologie Gmbh of Rostock) represent a new frontier for such problems. They are particularly suitable because of the small footprint, low reverberation level and high horizontal resolution, short transmitting signals without ringing and high vertical resolutions, plus they are able to detect small and weak reflectors

2.4 Buried targets: resistivity survey

Marine geoelectrical measurements coupled with swath bathymetry represent an innovative technique for archaeological target detection in very shallow water and a valid alternative to seismic-acoustic prospection, particularly in marine sectors with sand at the seabed. Although this technique is not yet commonly used in geophysical marine exploration, the initial results of our surveys seem to be promising both for archaeological target detection and sedimentological purposes.

This method can be used to outline both conductive and resistive bodies, like metallic and wooden objects, respectively. Resistivity data acquisition was carried out using a georesistivimeter IRIS-SYSCAL PRO System, with a 2 meter horizontally spaced multielectrode marine cable, and with the use of the Sysmar software. The reciprocal Wenner array was adopted along a profile that reached a depth of about 8 m below sea level. Data inversion was obtained by using the RES2DINV algorithm (Loke and Barker, 1996; Loke and Dahlin, 2002). The occurrence of the shipwreck is strongly defined in the conductivity map showed in Fig. 4 that reports the geoelectrical tomography under a bathymetric map.

3. DISCUSSION AND CONCLUSIONS

On the basis of the literature the initial approach toward the choice of the most appropriate geophysical technique for marine detection of archaeological tar-

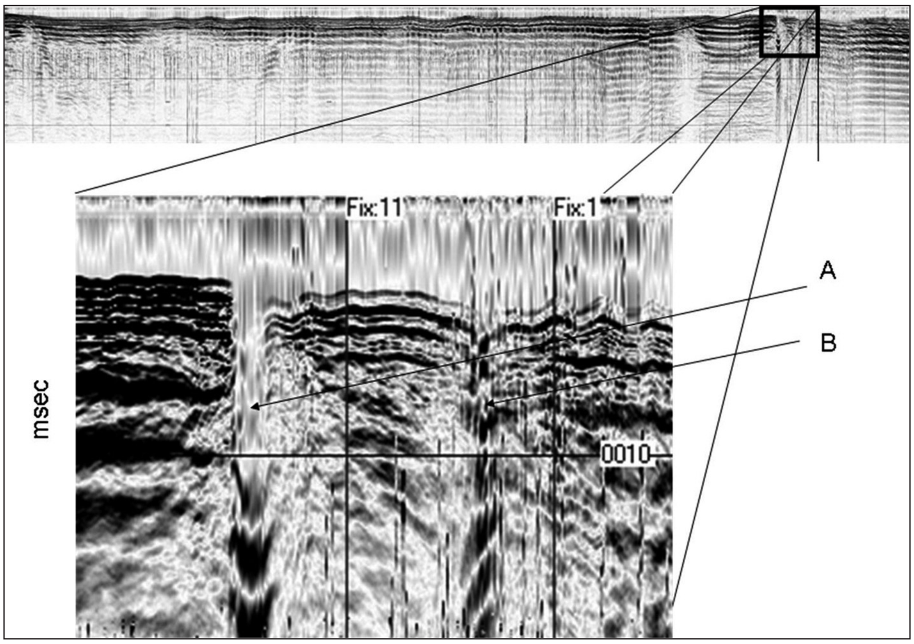

Fig. 3 - High resolution seismo-acoustic methods are difficult to use in < 5 metres of water column especially over coarse grained sediments (sands, gravels etc.). Most problems are due to strong reflectivity of coarse sediments, ringing of the seismic source, multiple or ghost reflections etc.. All these factors affect both spatial (horizontal) and vertical resolution which must be submetric in case of archaeological targets (Belfer *et al*., 1998; Papatheodorou *et al*., 2005). Results of the boomer technique in the study area: lateral changes in amplitude and phase seismic signal in correspondence of the wreck are present (A and B). Although lateral variations are clearly visible, it is difficult to relate them to the presence of archaeological bodies, but boomer data may be a valid support for other techniques.

I rilievi sismo-acustici in acque basse (>5 m) e in presenza di fondali sabbiosi e ghiaiosi sono estremamente complessi. La riflettività dei sedimenti grossolani, la riverberazione del segnale sismico-acustico, le generazione di riflessioni multiple e i segnali diretti compromettono la qualità dell'acquisizione e il grado di risoluzione (verticale e orizzontale) necessario per evidenziarei target archeologici (Belfer et al.*, 1998; Papatheodorou* et al.*, 2005). I risultati ottenuti con la sorgente Boomer evidenziano variazioni laterali dell'ampiezza e della fase del segnale sismico in corrispondenza del relitto (A e B), ma non è altrettanto chiara la relazione fra il target e il tipo di anomalia del segnale sismico da esso generato. L'utilizzo di un sistema Boomer, pertanto, è consigliabile come integrazione e supporto ad altre tecniche di prospezione.*

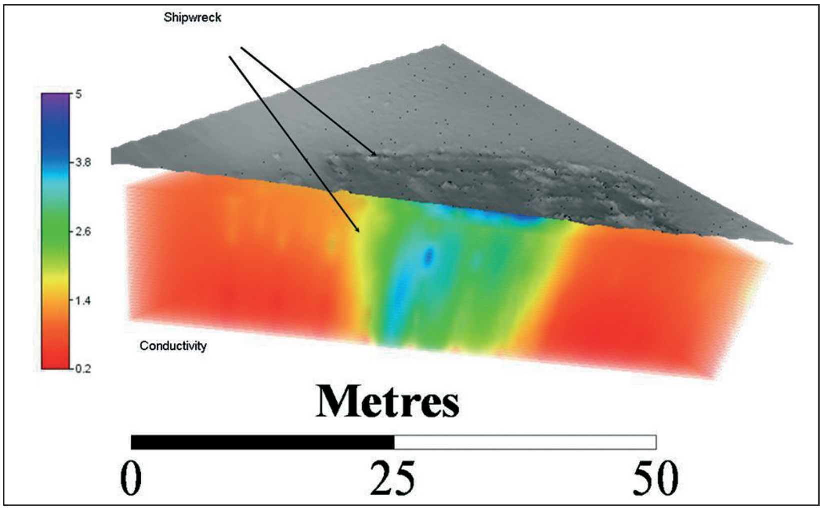

Fig. 4 - Marine geoelectrical measurements coupled with swath bathymetry represent an innovative technique for archaeological target detection in very shallow water and a valid alternative to the seismic-acoustic prospecting, particularly in marine sectors with sand at the seabed. Although this technique is not yet commonly used in geophysical marine exploration and needs more refining, preliminary results of our survey seem to be promising for both archaeological target detection and sedimentological purposes. In this picture a 3D conductivity map is represented, which clearly shows the occurrence of an anomaly in correspondence of the shipwreck (imagine on the top). This technique can be easily used in shallow water, while it might be more complicated in other cases because of limitations imposed by cable length.

L'acquisizione di dati geoelettrici in ambiente marino integrati con rilievi batimetrici di altissima risoluzione, è una metodica innovativa per l'identificazione di target archeologici in acque basse e rappresenta una possibile alternativa alle prospezioni sismo-acustiche, specialmente in presenza di fondali sabbiosi. Sebbene in letteratura manchino riferimenti a tali tecniche esplorative in mare e nonostante tali metodiche siano ancora a carattere sperimentale, i risultati preliminari delle indagini effettuate lungo il litorale di Agropoli sottolineano come tali procedure siano promettenti sia in campo archeologico che sedimentologico-stratigrafico. In figura è riportata la mappa 3D della conduttività, dove è chiaramente visibile l'anomalia generata dal relitto (immagine in alto). La geoelettrica marina è facilmente utilizzabile in contesti di acqua bassa, mentre in acque profonde il suo uso non è agevole per le limitazioni imposte dalla lunghezza del cavo richiesto.

gets can be (carefully) traced before hand. Results are summarized in Table 1 and refer to a mechanism where reciprocal exclusion may provide helpful indications about the adoption of specific surveys. Clearly, this scheme assumes a basic knowledge of the area of interest, in terms of average depths of the water column, sediments and geology of the seafloor, presence of possible anthropic targets, etc. Reliability of geophysical data is enhanced when a drilling stratigraphy is available for geophysical data calibration.

Outcropping bodies are well detected by Multibeam swath bathymetry when footprint dimension allows horizontal resolution that can be considered equivalent to side scan sonar mapping. Nonetheless, side scan sonar systems are to be considered as the essential and more reliable tool for outcropping target recovery.

In regards to buried targets, seismic sources (often used in this kind of investigation) should be chosen carefully, according to the indications provided by local sediments and water column depth. In case of fine grained sediments, such as clays or silts (e.g. lakes), the use of frequency-modulated ("chirp") or fixed frequency subbottom profilers is recommended, while in the case of coarse grained sediments, boomer or parametric systems are more appropriate. In

Table 1 - Summary of investigation methods to be used for target detection (see text for details)
Sintesi dei sistemi utilizzabili per l'identificazione di target archeologici in acque basse.

Investigation technique	Characteristics	Use encouraged in presence of:	Use discouraged in presence of:
High resolution MBES	Frequencies (*f*): 500-250 kHz	outcropping bodies and less than 50 metres of water column depth	more than 50 metres of water column depth (use side scan sonar)
Side scan sonar	*f* of about 400-100 kHz	outcropping bodies	less than 50 metres of water column depth the use of multibeam is equivalent
Sub-bottom profiler	20 kHz > *f* > 1 kHz	fine sediments (clays or silts)	coarse sediments (sands, gravels)
Frequency modulated "Chirp" Sub-bottom profilers	20 kHz > *f* > 1 kHz	fine sediments (clays or silts)	coarse sediments (sands, gravels); poor or null penetration
Dual frequency parametric sub-bottom	35-45 khz (primary frequency) 1-10 kHz (secondary frequency)	coarse and fine sediments	
Uniboom	Frequency: 0.2-1 kHz Energy: 0.5-1 kJ	coarse sediments	fine sediments (traditional, chirp or parametric systems preferable)
Magnetic	Gradiometers or magnetometers with sensitivity of 0.1 nT	highly susceptive targets expected; clearance from magnetometer to seafloor not exceeding 20-30 m	volcanic sectors and/or highly anthropized sectors
Magnetic	Gradiometers or magnetometers	highly susceptive targets expected	Volcanic sectors and/or highly anthropized sectors
Geoelectric	5 metres step cable	investigation depth range of 0-7m	investigation depth>10m

addition, in situations of water depth of less than five metres, the adoption of geoelectrical measurements becomes preferable. Magnetic surveys may help to detect both metallic and wooden targets, especially when susceptive bodies (like anchors or armaments) are present, but may be inadequate where low signal to noise ratios are induced, especially in the presence of a volcanic (e.g. lava flows) seafloor or in industrial (e.g. harbours) settings.

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REFERENCES

Belfer I., Bruner I., Keydar S., Kravtsov A., Landa E. (1998) - *Detection of shallow objects using refracted and diffracted seismic waves*. Journal of Applied Geophysics, **38** (3), 155-168.

Belfer I., Bruner I., Keydar S., Kravtsov A., Landa E. (1998) - *Detection of shallow objects using refracted and diffracted seismic waves*; Journal of Applied Geophysics, Volume: **38**, Issue: 3, January, pp. 155-168

Boyce J., Reinhardt E.G., Raban A., Pozza M.R. (2004) - *Magnetic Survey of a Submerged Roman Harbour, Caesarea Maritima, Israel*. The International Journal of Nautical Archaeology, **33** (1), 122–136.

Corradi N., Giordano F., Giordano R. (2004) - *The application of a very High Resolution Hardware-Software (DSeismic) System for the acquisition of seismic data for the study of the Ross Sea (Antarctica) Sedimentary Deposits*, Proceedings of the Italian Association of Oceanology and limnology, pp. 115-124

Edgerton H.F., Hayward E.C. (1964) - *The Boomer sonar source for seismic profiling*. Journal of Geophysical Research, **69**, 3033-3042.

Loke M.H., Barker R.D. (1996) - *Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method*. Geophysical Prospecting **44** (1), 131–152.

Loke M.H., Dahlin T. (2002) - *A comparison of the Gauss-Newton and quasi-Newton methods in resistivity imaging inversion*. Journal of Applied Geophysics, **49** (3), 149-162.

Nabighian M.N. (1972) - *The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: Its properties and use for automated anomaly interpretation*. Geophysics, **37**, 507-517.

Papatheodorou G., Geraga M., Ferentinos G. (2005) - *The Navarino naval battle site, Greece: an integrated remote-sensing survey and a rational management approach*. The International Journal of Nautical Archaeology, **34** (1), 95-109.

Phillips J. D. (1997) - *Potential-field geophysical software for the PC, version 2.2*: U. S. Geological Survey Open-File Report 97-725, 34 p.

Quinn R. (2006) - T*he role of scour in shipwreck site formation processes and the preservation of wreck-associated scour signatures in the sedimentary record - evidence from seabed and sub-surface data*. Journal of Archaeological Science, **33**, 1419-1432.

Roest W.R., Verhoef J., Pilkinton M. (1992) - *3-D Analytic signal. Geophysics,* **57** (1), 116-125.

Simpkin P.G., Davis A. (1993) - *For seismic profiling in very shallow water, a novel receiver*, Sea Technology, **34** (9), pp. 21–28.

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