

Reconstruction of Archaeological Features in a Mediterranean Coastal Environment Using Non-invasive Techniques

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Abstract

Archaeological prospection and excavation of an ancient settlement is a slow, careful and consequently costly operation. In the Mediterranean region, cities were often built next to the coastline, in order to provide bases for trade along the most convenient pathway of the time – the sea. The prospection of such sites is particularly difficult and slow because these cities are now buried or have sunk into the sea. There is therefore a need for a comprehensive prospection that can delineate the areas for subsequent direct investigations. These results can also have a cultural and tourist value, even before full site excavation: this because of high resolution renderings and 3D digital representations of the subsurface. This work deals with the development and the application of an integrated methodology and visualization techniques for the 3D rendering of geophysical data of buried and submerged archaeological features in complex environments such as coastal planes. In this work, we present the results obtained from marine and ground geophysical prospection of the Phoenician, Punic and Roman town of Nora, on the South Coast of Sardinia and the Roman town of Pollentia, in the North East of the Isle of Majorca.

Keywords: *Geophysics, electrical tomography, georadar, 3D rendering, virtual reconstruction*

1 INTRODUCTION

The archaeological prospection and excavation of ancient settlements is a slow, careful and consequently costly operation. Physically uncovering a complete site (e.g., of the size of 1 hectare) requires large investments and many months of work. Enjoyment by the public is therefore almost impossible, and in many cases the site itself remains an object of specialistic study, with no direct social or economic value. It has been shown that the expected monetary value of an archaeological find (i.e. its intrinsic value times the probability of discovering it) is dramatically enhanced by the adoption of non-destructive prospection techniques, which should first be used at a large scale, in order to guide the excavation, and subsequently at a small scale, to achieve a better resolution.¹ The value of the geophysical information increases with the optimization of the

overall cost of the operations, thus making measurements and processing faster. Such a value is even larger in the absence of historical information on the site. This is the case of submarine archaeological sites, where there is a lack of information and there are only a few the instances of excavation. In land-based surveys, the most widely applied methods include magnetometry, currently mostly in walking mode, electromagnetic methods,² GPR, and electrical resistivity tomography (ERT).

¹M. Marchisio and G. Ranieri, "On the Economical Value of a Geophysical Survey of an Archaeological Site," *European Journal of Environmental and Engineering Geophysics* 5 (2000): 91–110.

²E. Brizzolari, et al., "Detection of Subsurface Magnetic Anomalies of Archaeological Interest: Computation of Tridimensional Magnetic Anomalies and Interpretation Using Bi-dimensional Cross-correlation," in *Theory and Practice of Applied Geophysics* (Wiesbaden: Vieweg Publishing, 1993) 3-16; A. Godio, et al., "Electromagnetic Survey for Archaeological Remains Detection in Urban Sites," *The Leading Edge* 19 (2000): 850-854; S. Piro, et al., "The Location of Emperor Traiano's Villa (Altopiani di Alcinazzo; Roma) Using High-resolution GPR Surveys," *Bollettino di Geofisica Teorica ed Applicata* 43 (2002): 143-155.

In the water environment, geophysical methods are mostly based on acoustic waves,¹ such as side scan Sonar,² Chirp,³ and multi-beam sonar, but other methods are also used.⁴ The application of the aforementioned techniques is today relatively frequent for the localization and characterization of ship wrecks.⁵

Applications in shallow water are limited to only a few case studies,⁶ even though there is considerable interest in this type of site, in which part of the archaeological settlement is submerged.⁷ Adequate techniques to investigate shallow water (a few meters maximum) are still not fully developed. Above all, there still no methodology that can integrate land and sea data, even though its creation via GIS is conceivable.⁸

The integration of different measuring techniques can make a site excavation more effective and inexpensive, but this can also be achieved by directly using

geophysical data to create virtual representations of reality that can be enjoyed and understood by non specialists. Over the past few years, a great deal of attention has been directed towards “virtual archaeology,”⁹ but the proposed systems are nothing else but a reconstruction of different datasets. Coiana and Ranieri proposed a geophysical reconstruction with navigation in a digital dataset, using plugging from Internet browsers.¹⁰

The main aim of the work was to develop and apply an integrated methodology aimed at 3D rendering and virtual representation of buried and submerged archaeological features in complex environments, such as coastal planes, for a user-friendly representation and wide-scale diffusion of the results.

2 CASE HISTORIES

2.1 THE OLD TOWN OF NORA, SARDINIA, ITALY

2.1.1 HISTORICAL NOTES

The old town of Nora is located on the Cape of Pula promontory, south-west of Cagliari, the capital of Sardinia (fig. 1).



Figure 1. Investigated Sites

¹D. A. Frey, “sub-bottom Survey of Porto Longo Harbour Peleponnesus, Greece,” *International Journal of Nautical Archaeology and Underwater Exploration* 1 (1972): 170–175.

²C. H. Hobbs, et al., “A Marine Archaeological Reconnaissance Survey Using Side-Scan Sonar, Jamestown, Virginia, USA,” *Journal of Coastal Research* 10 (1994): 351–359; V. S. Blake, “The Simulation of Sidescan Sonar Images,” *Archaeological Prospection* 2 (1995): 29–56.

³R. Quinn, J. M. Bull, and J. K. Dix, “Imaging Wooden Artefacts with Chirp Sources,” *Archaeological Prospection* 4 (1997): 25-35; J. M. Bull, et al., “Reflection Coefficient Calculation from Marine High Resolution Seismic Reflection (Chirp) Data and Application to an Archaeological Case Study,” *Marine Geophysical Researches* 20 (1998) 1–11.

⁴J. B. Arnold, “A Marine Archaeological Magnetometer Survey in the Galveston, Texas Area. Underwater Archaeology: The Challenge Before Us,” in *Proceedings of the Twelfth Conference on Underwater Archaeology*, edited by G. P. Watts (San Marino, CA: Fathom Eight Publication, 1981) 209-217; J. Barto Arnold III, “Magnetometer Survey of La Salle’s Ship the Belle,” *International Journal of Nautical Archaeology* 25 (3–4) (1996) 243–249.

⁵W. Forsythe, “The Shipwreck Database,” www.ulst.ac.uk/faculty/science/crg/cmases/cmases.htm (accessed: June 22, 1999).

⁶J. M. Lenham, et al., “A Marine Geophysical Survey of Strangford Lough,” *Archaeology Ireland* 11 (1998): 18–20.

⁷Y. Mart and I. Perelman, “Neotectonic Activity in Caesarea, the Mediterranean Coast of Central Israel,” *Tectonophysics* 254 (1996): 139–153.

⁸J. Breman, “Marine Archaeology Goes Underwater with GIS,” *Journal of GIS in Archaeology* (ESRI, 2003).

⁹A. Chalmers, et al., “In Site: An Interactive Visualisation System for Archaeological Sites,” in *Computer Applications and Quantitative Methods in Archaeology 1994*, Jeremy Huggett and Nick Ryan, eds., BAR International Series 600 (Oxford: Archaeopress, 1995).

¹⁰M. Coiana and G. Ranieri, “Geophysics as a Tool for Virtual Archaeology,” in *Proceedings of XXV EGS General Assembly, Nice 25-29 April 2000*.

The location is separated from the mainland by a narrow isthmus. The current morphology does not reflect the ancient situation.

The first settlements date back to the Nuragic period, as evidenced by the discovery of ceramics. The presence of the Phoenicians (VIII to VI century B.C.) is well documented with important findings of epigraphic documents and features related to the late Phoenician age.¹ In fact, the ancient town of Nora was the center of important trade routes, as demonstrated by its three ports, now mostly submerged. The town, already flourishing in the fifth century, underwent a further development in the fourth century with contact with the Italian world and especially Rome. The Roman domination began in 238 B.C. and lasted until 456 A.D., when pirate raids and Vandals invasions resulted in the rapid decay of Nora. The “coup de grace” was the Arab raids on the southern coast of Sardinia in the early VIII century. The area was then abandoned, but sporadic traces of life have been found in higher levels of the collapsed Roman buildings.

The particular shape of the promontory of Nora led to hypothesize the location of the port in the bays that flank it. The ancient port of Nora was certainly located in the natural bay, which in 1957 was turned into a fishing harbor and located northwest of the peninsula.² Investigations in the immediately surrounding land and the waters in front of the fishing industry have led to the identification of a number of archaeological finds related to the port. This is the case of a series of structures located in the northern and eastern parts of fishing industry that are a productive sector related to port activities. In addition, a series of submerged structures have been identified along the west coast of the promontory. These are barriers breakwaters and channels, which, in addition to counterbalancing the erosive marine activity and preventing the burial of the outer port, have made entry to the port easier.³

2.1.2 THE SURVEY

We performed continuous marine resistivity profiling and sub-bottom profiler surveys to recognize the archaeological targets related to the presence of the ancient port in the lagoon close to the old town of Nora.

¹R. Zucca, s.v. “Nora” in *Miscellanea Epigrafica in onore di L. Gasperini*, G. Paci, ed., vol. 2 (Rome, 2000) 1124.

²P. Bartoloni, “L’antico porto di Nora,” *Antiqua* 13 (1979): 57–61.

³E. McNamara and W. G. St. J. Wilkes, “Underwater Exploration of the Ancient Port of Nora, Sardinia,” in *Papers of The British School of Rome* 35 (1967): 4–11.

The development of geophysical methods to survey the shallow water archaeological areas was a necessary step to overcome the economic and logistic problems of the invasive methods. It proved challenging to design a prototype of a boat that could be used in very shallow water for geophysical prospection. The requirements of the boat were: a very low draught hull which would produce very little disturbance on the surface of the water; the possibility of installing instrumentation longitudinal to the hull; the possibility of being transported; alternative propulsion.

The design and prototype are shown in figures 2 and 3. The boat was built with catamaran hulls which were linked to a plastic platform reinforced in incorporated fiberglass. A box for the monitors, hardware and piloting is located in the prow and an over-board rotor is located in the poop for the propulsion of the boat. The boat is completely dismountable and easily transportable. Its full load draught is about 0.2 m.

For continuous marine resistivity profiling, we used the Syscal Pro 10 channels, 300 W resistivity-meter by Iris Instruments, a streamer with 13 graphite electrodes, resistant to saltwater corrosion, and inter-electrode spacing of 2 m. Some floats were connected to the cable to keep the electrodes on the surface (fig. 4). We also put a weight at the end of the streamer to tighten it. We collected the bathymetry with a single beam echo sounder and georeference all the data with a Garmin GPS system. The water column thickness was between 0.5 m and 4 m with a mean resistivity value of about 0.7 ohm-m.

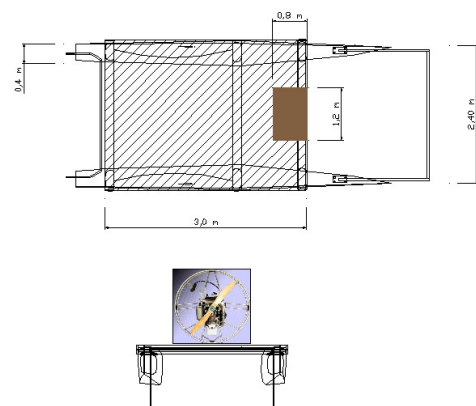


Figure 2. Boat design.



Figure 3. Boat prototype.

The resistivity meter, GPS and echo sounder were connected to a control board and to a laptop that utilized the Sysmar software by IRIS Instruments. We applied a constant voltage of 50 V, a time frequency acquisition of 250 ms and a reciprocal Wenner array with the current electrodes placed in the central part of the array and the potential electrodes separated. We acquired more than 30,000 resistivity data points in one day (fig. 5). Water-based data processing is very similar to land-based surveys, except for the separation of curved paths from the acquisition tracks.

The data processing was directed towards the creation of a 3D model of the Nora lagoon. We fixed the water conductivity and inverted the 2D resistivity sections with the RES2DINV software by Geotomo. Finally, we made a 3D rendering with the Kriging method using EVS Pro software by C-Tech. In the 3D model, we considered only higher resistivity than 0.7 ohm-m to exclude the most saturated layers.

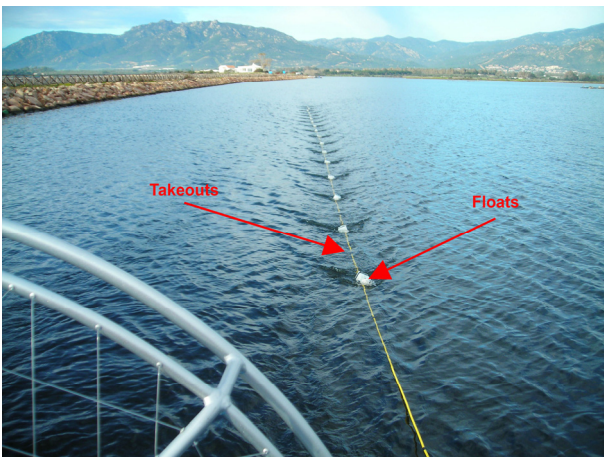


Figure 4. Streamer cable with floats.

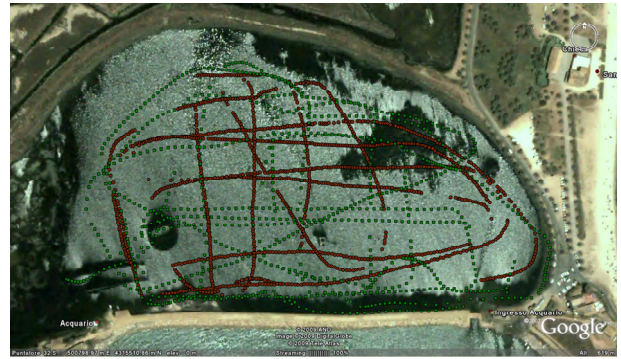


Figure 5. Electrical survey tracks.

For the sub-bottom profiler survey, we chose the secondary frequency considering the average depth of the lagoon (approximately 1.5 meters), and a desired penetration depth of about 8 meters in the sediments, we used a secondary frequency of 10 kHz. The lines were all acquired together with a GPS system mounted on board the boat. A master station that communicated to the instrument via GSM was used to correct the GPS data. A GPR survey was also carried out near the lagoon in the area of the ancient town, where an amphitheater was suspected to have been present.

2.1.3 RESULTS

The data were all excellent in terms of noise. The maximum penetration depth in the ERT data was about 5 m, and the resistivity values were between 0.2 and 10 ohm-m. We obtained very low resistivity differences (0.5 – 2 ohm-m) between most of the resistivity features and the sand layers. Resistivity features were often related to the sub-bottom profiler anomalies.

Figure 6 shows a discontinuity of the signal of the sub-bottom profiler that could be related to a buried object, which is probably anthropic, since the shape cannot be related to sedimentation processes.

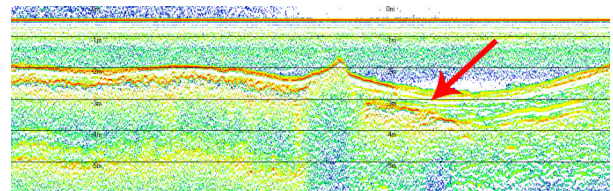


Figure 6. Sub-bottom profiler section showing the bathymetry and some objects. The distance between two vertical markers is 50 m.

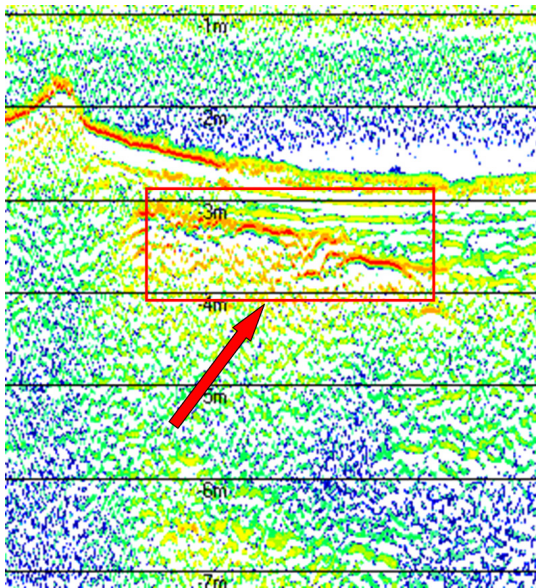


Figure 7. Deepest anomalies probably related to anthropic origin.

Figure 7 shows the deepest zone of the lagoon, which could be related to both anthropic and natural origin: anthropic, because it could have been an ancient shipway; natural, due to the watercourse on the surface. The dam towards the sea could have modified the sedimentation dynamics.

The sub-bottom and resistivity surveys showed a good correlation, in terms of depth and thickness of the sediment layers. Both the 2D resistivity and sub-bottom sections also showed the presence of a channel that might have been the access to the ancient port (fig. 8).

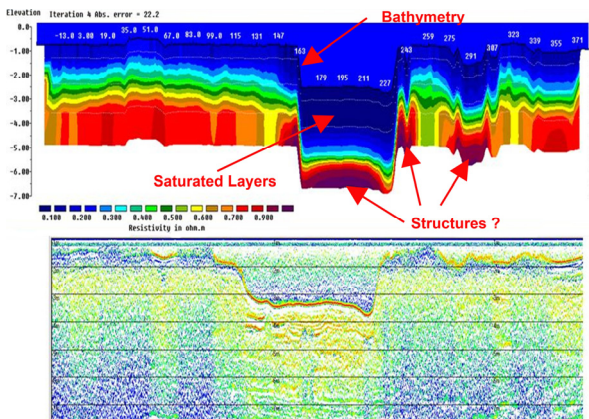


Figure 8. 2D resistivity and sub-bottom sections.

The 3D model shows a good correspondence between the identified channel and the submerged known structures along the open sea (fig. 9). A series of submerged structures have been identified along the

west coast of the promontory. These barriers, breakwaters, and channels counter the erosive marine activity and prevent the burial of the entrance of the harbor.

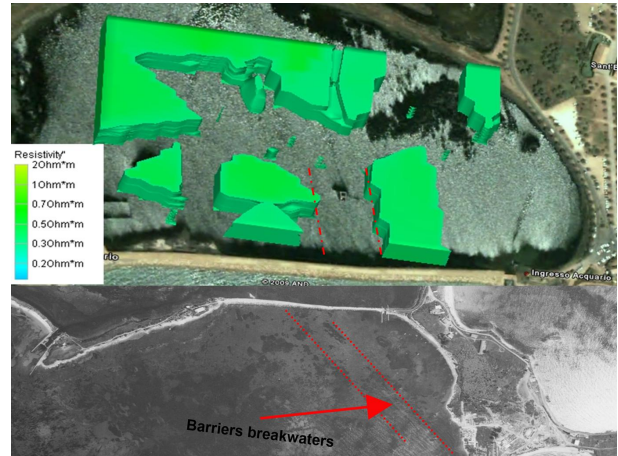


Figure 9. Resistivity 3D model of the lagoon. The model shows resistivity values higher than 0.7 ohm-m to exclude the most saturated layers.

In conclusion, continuous marine resistivity and sub-bottom profiler methods can be successfully applied in very shallow marine water environments for purposes of archaeological research.

The site conditions were challenging for GPR acquisition because of the sea water saturated ground which caused a strong attenuation of the electromagnetic signal. Figure 10 shows a depth slice with indications of the main anomalies found. The archaeologists later identified the presence of three main anomalies: an aqueduct, an ancient road, and an amphitheater. The time-slices of the GPR data were computed using a 2D linear interpolation with a 0.1 x 0.25 m grid. The subsequent excavation confirmed the reconstruction.

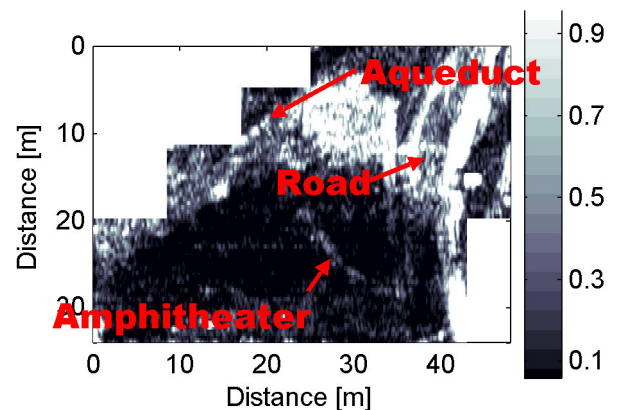


Figure 10. GPR time-slices showing normalized reflections amplitude for archaeological features detected at a depth between 50 cm and 1 m.

2.2 THE OLD TOWN OF POLLENTIA, THE ISLE OF MAJORCA, SPAIN

2.2.1 HISTORICAL NOTES

The Roman city of Pollentia (Alcúdia) (fig. 1), which is located in a strategic position on the isthmus that separates the bays of Alcúdia and Pollença in the north-eastern Mallorca, was one of the cities founded after the conquest of the Balearic Islands by Q. Cecilius Metellus in 123 B.C. However, recent investigations have demonstrated that the first Roman constructions in the area, the forum, did not occur before approximately 70 B.C.¹ After the Republican foundation, the city underwent a long historical process, with a strong refurbishment under Augustus, a series of deep transformations at the end of the second century or beginning of the third century A.D., and massive destruction by fire of different parts of the city dated at the end of the third century A.D.² The destruction did not cause the abandonment of the city by inhabitants: life continued there until the Late Roman, Vandal and Byzantine periods and to some extent into the Muslim and Christian Medieval periods. Archaeological investigations, which have been more or less continuous since the 1920's, have revealed several areas such as the forum, and residential quarters such as Sa Portella or The House of Polymnia, the theatre and several necropolises. However, the general topography of the city is still problematic. The town walls in the area of Sa Portella, dated back to the third century A.D., was the object of a pioneering geophysical investigation in 1920's. It seems that the wall enclosed the quarter of Sa Portella, but that it was not related to the possible original town walls.

A second city wall, probably of the Byzantine period, was also discovered in the forum area and, although it has been partially excavated, its full layout it is still unknown. Moreover, the strategic location of the city, where it controlled two of the most important bays of Majorca, together with some medieval documents and the results of some old excavations and chance finds during modern town planning activities, may indicate the possible presence of two ports, one towards the

north (Portus Minor) and the other main one towards the south (Portus Maior). Geophysical prospection was required in the case of Pollentia to solve some of the problems regarding the topography and extension of the city, the layout of the city walls and to investigate the location of the ports. Moreover, a progressive and systematic long-term geophysical survey was conducted in order to obtain a better understanding of the city and its remains and to help in the planning of archaeological excavations.

2.2.2 THE SURVEY

We performed GPR surveys at the Pollentia site (fig. 11). The georadar survey was carried out using the IDS RIS radar system with an antenna operating at a nominal frequency of 200 MHz. The data were acquired in single reflection mode along parallel profiles spaced 0.5 m apart. The spatial positioning of the antenna along each profile was controlled by a survey wheel device; the area coordinates were acquired using a Topcon GMS-2 GPS/GLONASS receiver. Standard data processing was applied to each single time section (B-scans) as follows: subtraction of the mean (dewow) on a time window of 5 ns, i.e. the principal period of the used antenna, in order to remove the low frequency part of the signal; subtraction average on 50 traces to remove the coherent background noise in the horizontal direction; application of divergence compensation and gain recovery for intrinsic attenuation; application of a median filter as a low pass filter in both the profile and time directions. Finally, a Kirchhoff migration was applied on 50 traces to collapse the diffraction hyperbolae. The generation of the GPR time-slices was the starting point for the standard VRML 3D data representation. The idea was to create a virtual museum using the acquired geophysical data.

The choice of the standard format was driven by the possibility of sharing data and uploading them on web-pages.

2.2.3 RESULTS

In the Pollentia site, we explored an area of about 7,000 m² and in particular an area outside the old city where the presence of the town was unknown. Time-slices were constructed every 10 ns.

¹M. Orfila et al., "El foro romano de Pollentia," *Archivo Español de Arqueología* 62 (1999): 99-118; M. Orfila., ed. "El Fòrum de Pollentia," *Memòries de les campanyes d'excavacions realitzades entre els anys 1996 i 1999* (Ajuntament d'Alcúdia: 2000).

²M. Orfila, et al., "Pollentia and the Cities of the Balearic Islands," in L. Abad Casal, S. Keay and S. Ramallo Asensio, eds., *Early Roman Towns in Hispania Tarraconensis, Journal of Roman Archaeology, Supplementary Series* 62 (2006): 133-145.

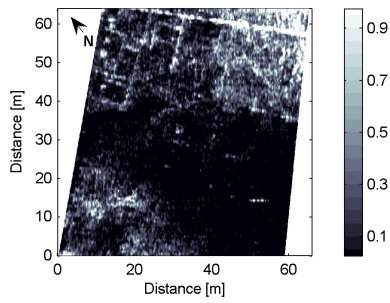


Figure 11. GPR time-slices showing normalized reflections amplitude for some detected archaeological features at 0.5 m depth.

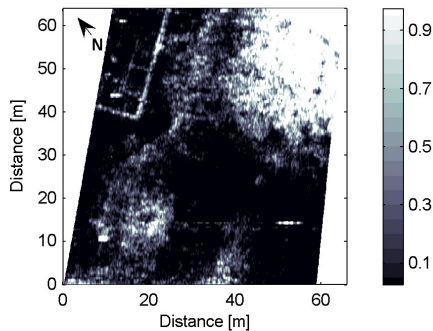


Figure 12. GPR time-slices showing normalized reflections amplitude for some detected archaeological features at 1.0 m depth.

Well organized anomalies are visible in the area (about 65 x 55 m) in the north north-east sector, at a depth between 0.5 m and 2 m (figs. 11, 12 and 13). The strong reflection anomalies in the north-east part, 1 to 2 m deep, probably refer to the calcareous bedrock.

The r2VRML software is a web application developed in the PHP language that converts the tabular data (in ASCII or XLS format) obtained from geophysical surveys into an explorable three-dimensional graphical environment. The format used for 3D data representation is VRML. Through the web interface of the software it is possible to define the numerical values of the threshold and the scale of colors to be used for the representation of the 3D model. The photographic images of the archaeological site and the 3D views are graphically elaborated and packaged in an Adobe Flash application that, with a simple and intuitive multimedia interface, allows the user to display the photographs of the site selecting the views and the 3D reconstructions

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(fig. 14), the comparison with the instrumental data and so on.

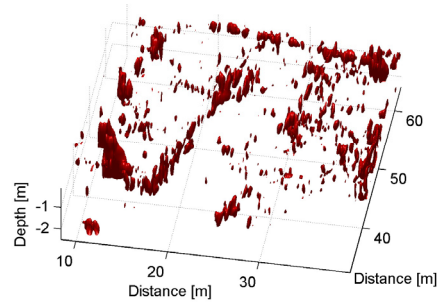


Figure 13. GPR 3D model generated by the interpolation between time-slices.

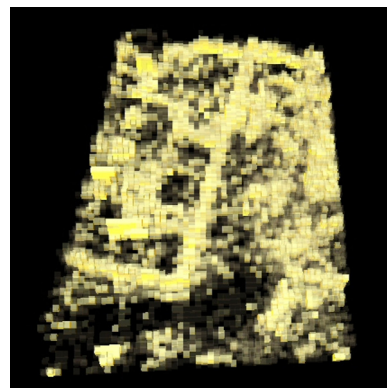


Figure 14. VRML 3D data representation.

3 FINAL REMARKS

The main objective of the work was to evaluate integrated data acquisition, processing and rendering methods in order to realize an aid for the musealisation of archaeological sites in complex environments like coastal planes.

The importance of on site data acquisition using geophysical investigation has been confirmed. The development of new technologies for geophysical data acquisition in land and water-based surveys allows high resolution information to be obtained that could be organized in a realistic 3D rendering of the main features, in order to create a virtual museum of the buried settlements.

authorization to investigate in archaeological areas and for their support. This research is part of the research programme of the Italian Ministry of Research–F.I.R.B. Project 2003.

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