Multidisciplinary shallow underwater geophysical prospecting at Delos island

Angelos Plageras[1*], Dimitrios Oikonomou[1], Nikos Papadopoulos[1], Athanasios Argyriou[1]

1 Laboratory of Geophysical Satellite Remote Sensing and Archaeoenvironment, Institute for Mediterranean Studies, Foundation for Research and Technology, Rethymno, Greece
* Corresponding author: E-mail: plageras@geo.auth.gr

Abstract
Geophysical imaging methods have been applied to reconstruct the cultural dynamics in the two different submerged sites in Delos island. The geophysical results provided useful information for understanding the complexity of the submerged archaeological sites.

Keywords
archaeological prospection; Delos island; ERT; multisensor magnetic gradiometry; shallow marine geophysics

Introduction

The island of Delos is located at the center of the Cyclades archipelago in the Aegean Sea of Greece. It was one of the most important parts of the ancient Greek world, known as a religious site, the treasury of the Athenian Alliance, and as trading port. The island hosts temples honoring the birthplace of the twin gods Apollo and Artemis and therefore, it is rightfully considered as one of the most important archaeological sites worldwide.

The increased attention to coastal zone management contributed to the development and implementation of shallow-water mapping approaches for capturing current environmental and archaeological conditions (Simyrdanis et al. 2015, 2016; Papadopoulos 2021). The geophysical survey took place during early September of 2021 and its purpose was to map the extent of the settlement limits through offshore geophysical investigation and to locate possible archaeological relics buried below the sea bottom in two different submerged sites in the northeastern (Stadio) and northwestern (Skhardanas) bays of the island.

Methodology and instrumentation

The digital bathymetry models in both bays were completed through a combined implementation of the Ohmex SonarMite BTX single beam echo sounder and RTK-GNSS measurements to survey the deeper and the shallower parts. The bathymetry models in Stadio and Skardhanas covered ca. 21,000 m^2 and ca. 24,000 m^2 respectively.

For the survey purposes, two different geophysical techniques were used. The electrical resistivity tomography (ERT) method was used in two variations: the static mode in Stadio Bay and the dynamic mode in Skhardanas Bay. The choice of different ERT survey variants in the bays was based on the depth of the bays. Thus, the maximum depth of about 12 meters in Skhardanas was actually prohibitive to use productively the static mode, whereas the maximum 4 meters water depth in Stadio facilitated the used of static ERT mode. The multisensor magnetic gradiometry method was used in the shallow part of Stadio bay, whereas ground penetrating radar was concentrated in a small section along the coast of Skhardanas.

For the dynamic survey, a 10-channel resistivity meter was used, along with a special cable equipped with 13 graphite electrodes with one meter spacing between them. The cable was pulled using a boat along 37 predefined lines, employing the dipole-dipole array covering 10,385 m^2 of marine area. At Stadio Bay, the pole-dipole electrode configuration employing a fixed submerged cable position was used to complete the ERT survey in two

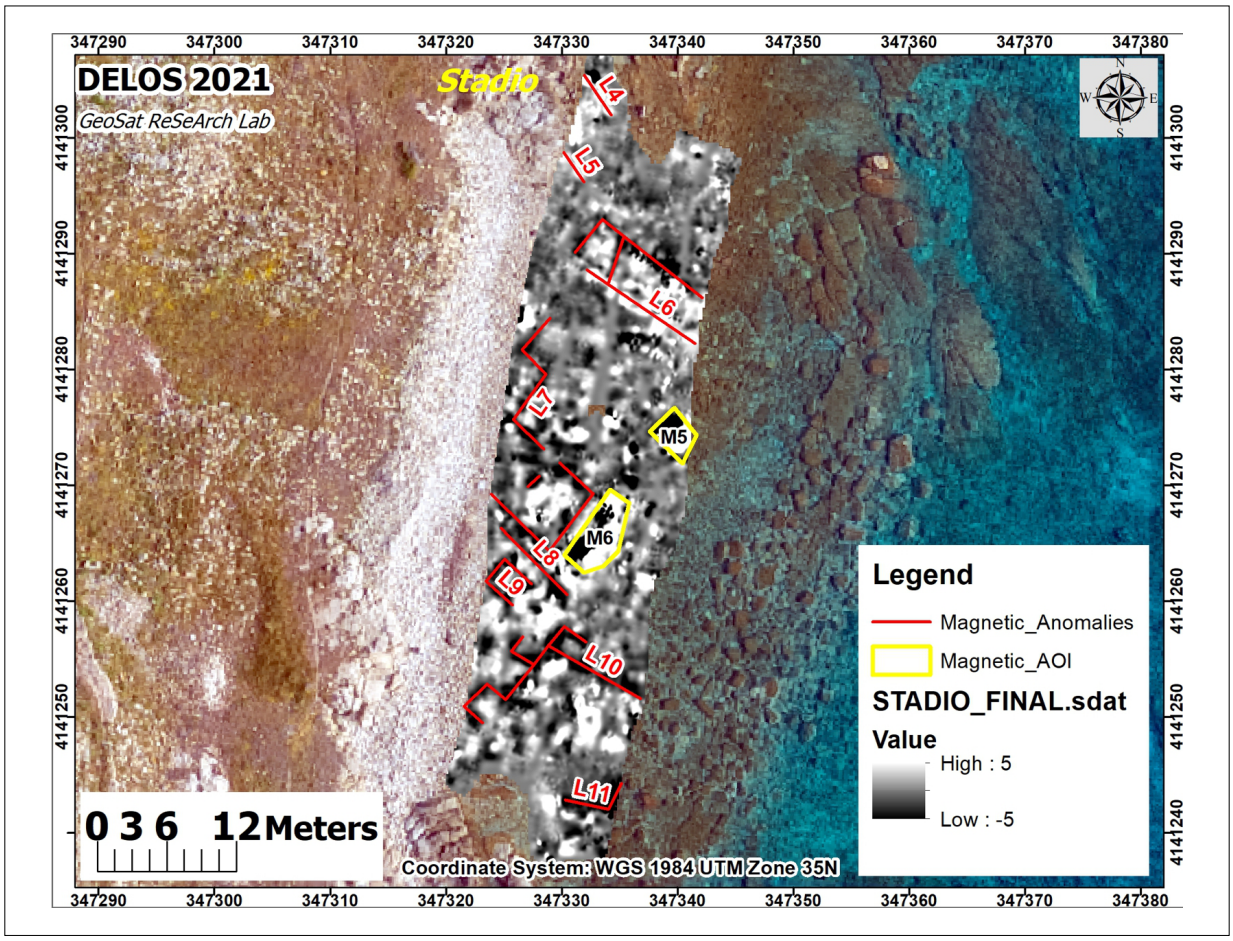

Fig. 1: Diagrammatic interpretation of the magnetic anomalies at the northern section of Stadio Bay (orthophoto: Moretti et al. 2015). Units are in nT/m. Axis units are in meters.

separate grids. The unit electrode distance along the lines was one meter and multiple combinations of N separations (distance between the current and potential dipoles) were utilized to increase the signal to noise ratio and to map the deeper stratigraphy, while the crossline distance was also set equally to one meter. The ERT survey was completed along multiple parallel transects in an effort to map the resistivity properties below the bottom of the sea within a 3D context. The tomographic data were processed with 2-D and 3-D robust inversion algorithms, incorporating the sea bottom topography and the conductivity of the sea water (Loke et al. 2020), allowing for the extraction of vertical and horizontal slices describing the resistivity variation below the sea bottom.

A multichannel magnetic gradiometer system equipped with five SENSYS FGM600 gradiometers was used to log the gradient of the vertical component of the magnetic field, covering an area of 1,443 m^2 at the very shallow part in Stadio Bay. The five magnetometers were mounted on a non-magnetic cart with 50 cm separation. and the spatial sampling resolution of the measurements along the track was about 10 cm. The whole system was mounted on a specific frame made of fiberglass for carrying the sensors, the RTK-GNSS and the electronic box.

Results

The geophysical results were rectified on the aerial photo of the site (Moretti et al. 2015). More specifically the magnetic gradiometer map in Stadio showed strong magnetic anomalies related to scattered metal fragments and the rocky outcrop on the seabed. Despite these external interferences, the magnetic results showed a number of linear and rectilinear anomalies related to submerged archaeological features in the coastal and ultra-shallow part of the bay (Fig. 1).

KIEL-UP • DOI: https://doi.org/10.38072/978-3-928794-83-1/p11

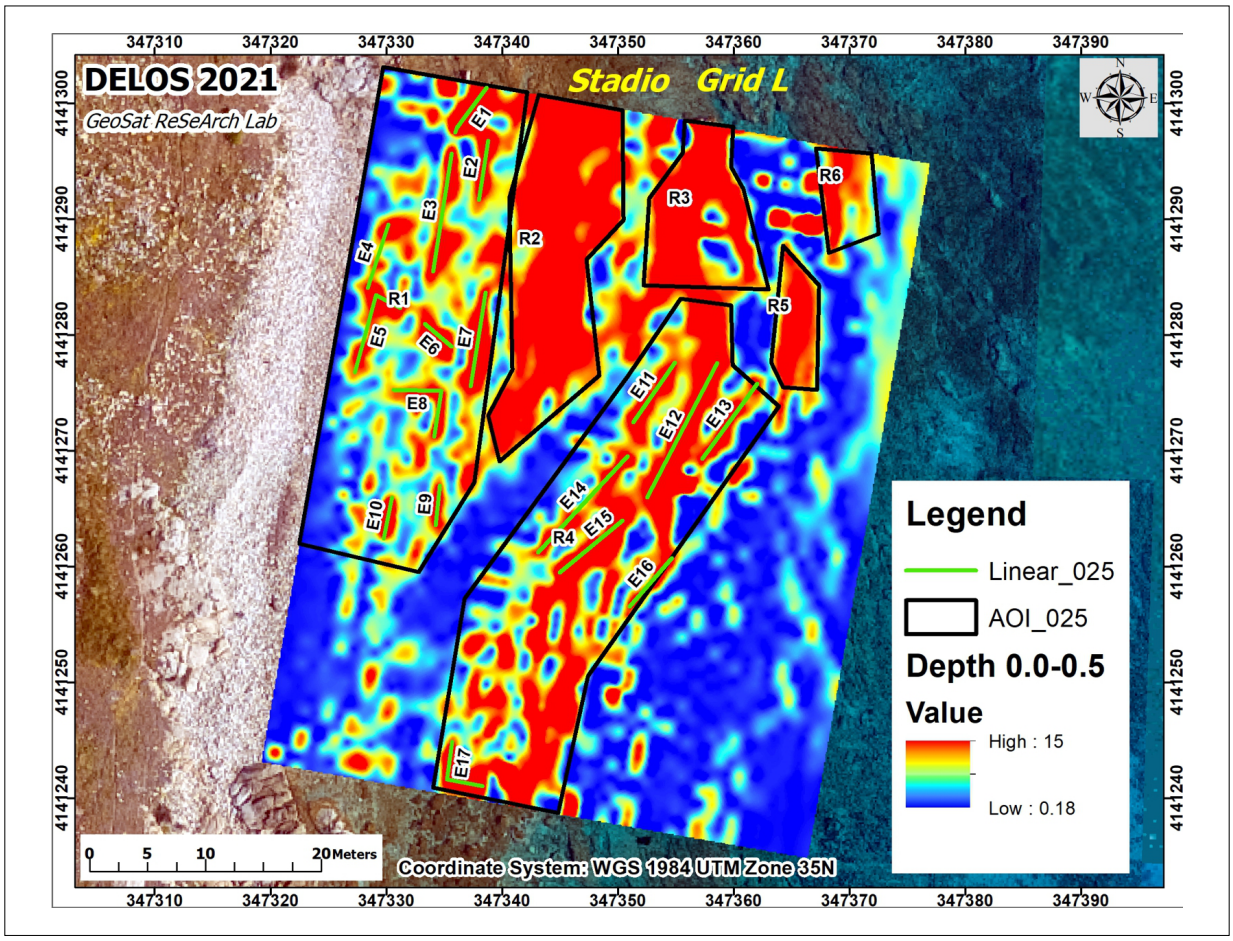

Fig. 2: ERT depth slice of the northern grid in Stadio Bay (orthophoto: Moretti et al. 2015). Indicative linear resistive anomalies (E1 –E17) are marked with green lines. Units are in Ohmm. Axis units are in meters.

The ERT depth slices in the overlapping regions show a relatively good correlation with the magnetic maps. Furthermore, ERT gives additional information on the distribution of structural remains in the deeper sections of the bay and the boundary of the settlement that is presently submerged, completing in this way the picture of the habitation pattern (Fig. 2).

Concerning the Skhardanas Bay Dynamic ERT data set, the 2D inverted lines failed to provide any information of archaeological value, since most of them were surveyed in a depth greater than 2 m. However, this data set provided valuable geological information, such as the existence of two faults in the area. On the other hand, the pseudo3D depth slices created from the ultra-shallow lines pinpointed many targets of possible archaeological interest, as well as a cultural layer that was already visible (Fig. 3).

Conclusions

The possibility of applying well-known geoinformation methods, such as ERT and magnetic gradiometry to un- (or under-) explored archaeological shallow-water contexts was very important from a methodological point of view and for the results obtained. Indeed, although the adaptation of commonly used tools to depths shallower than 2 m presented some challenges and required the creation or customization of equipment, the results support such efforts and provide useful information for understanding the complex archaeological site of Delos. The innovative aspect of this work arises from the adaptation and development of well- established and consolidated techniques (ERT and magnetic gradiometry) to a shallow water context. At the same time, this approach surely needs refinement and will benefit from inputs from different and complementary disciplines. In general, the

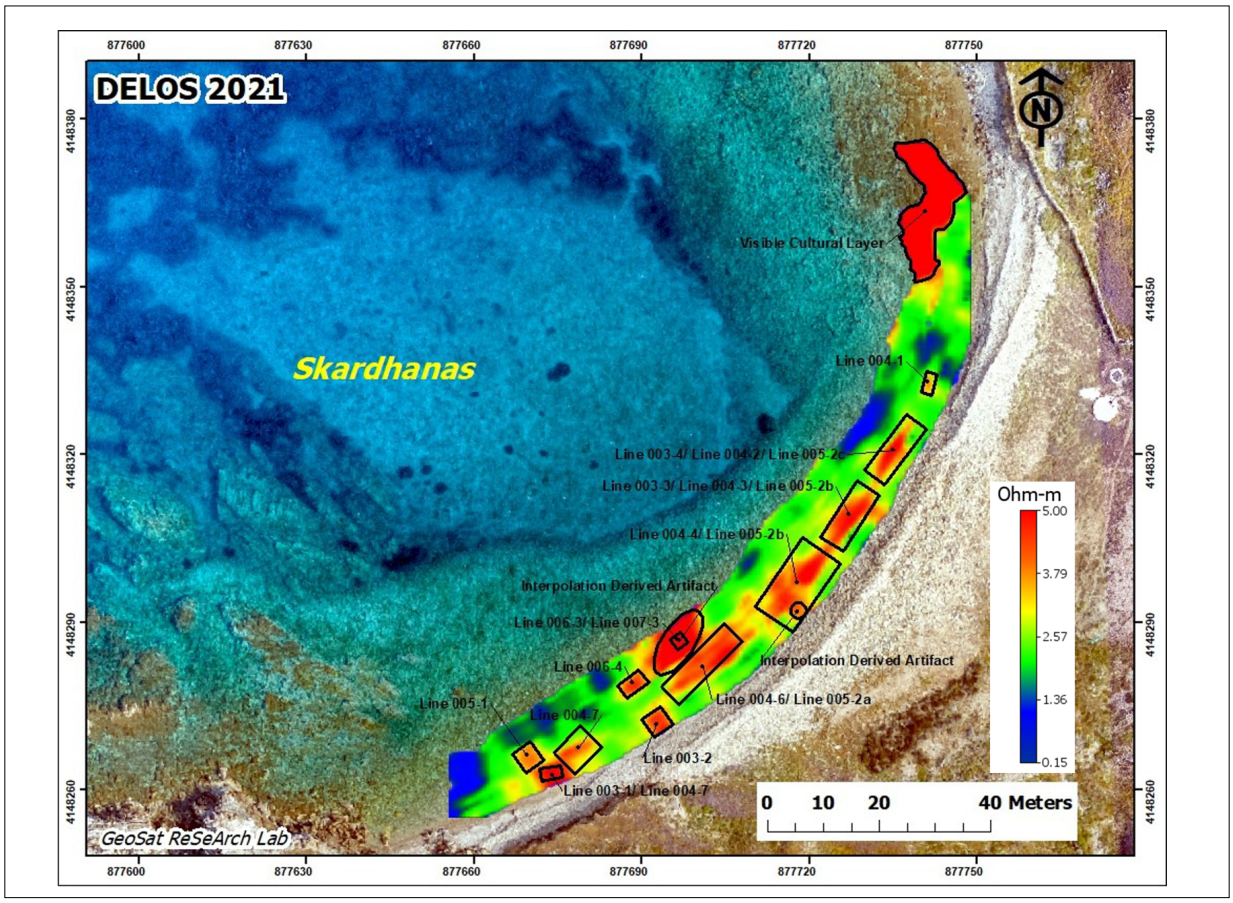

Fig. 3: Resistivity slice for depths of less than one meter below the seabed, extracted from the 3-D quasi model of the ultra-shallow dynamic ERT lines in Skardhana (orthophoto: Moretti et al. 2015). Diagrammatic interpretation of the resistive features probably related to submerged archaeological structures. Axis units are in meters.

manifold marine geophysical campaign at Delos provided promising results in the sections that were investigated. The high resolution geophysical approach was able to indicate a number of candidate targets, thus completing to a certain degree the picture for the submerged built environment of the archaeological site.

Acknowledgments

This work was financially supported by the University of Pennsylvania under the research agreement signed with the Foundation for Research and Technology Hellas. The authors would like to express their acknowledgements to Prof. Mantha Zarmakoupi, Assistant Professor in Roman Architecture at University of Pennsylvania, and Magda Athanasoula from the Ephorate of Underwater Antiquates for their support and the respective archaeological feedback.

References

Loke MH, Papadopouslos N, Wilkinson PB, Oikonomou D, Simyrdanis K, Rucker DF. The inversion of data from very large three-dimensional electrical resistivity tomography mobile surveys. Geophysical Prospecting 2020; 68:2579-2597. doi: 10.1111/1365-2478.13008.

Moretti JC, Fadin L, Fincker M, Picard V. Exploration Archeologique de Delos XLIII. Athens: Ecole Francaise d'Athenes; 2015. French.

Papadopoulos N. Shallow Offshore Geophysical Prospection of Archaeological Sites in Eastern Mediterranean. Remote Sensing 2021;13:1237. doi: 10.3390/rs13071237

Simyrdanis K, Papadopoulos N, Kim JH, Tsourlos P, Moffat I. Archaeological Investigations in the Shallow Seawater Environment with Electrical Resistivity Tomography. Journal of Near Surface Geophysics, Integrated geophysical Investigations for Archaeology 2015;13:601–611. doi: 10.3997/1873-0604.2015045

Simyrdanis K, Papadopoulos N, Cantoro G. Shallow off-shore archaeological prospection with 3-D electrical resistivity tomography: The case of Olous (modern Elounda), Greece. Remote Sensing 2016; 8:897. doi: 10.3390/rs8110897