A Ground Penetrating Radar (GPR) application for Depicting the Geoarchaeological pattern in Ancient Falasarna Harbour

FILIPPOS VALLIANATOS[1,2] , GEORGE HLOUPIS[2,3]
[1]Section of Geophysics–Geothermics, Department of Geology and Geoenvironment, National and Kapodistrian University of Athens, 15784, Athens,
GREECE
[2]Institute of Physics of the Earth's Interior and Geohazards, UNESCO Chair on Solid Earth Physics and Geohazards Risk Reduction, Hellenic Mediterranean University Research Center, 73133, Chania,
GREECE
[3]Department of Surveying and Geoinformatics Engineering, University of West Attica, Egaleo Campus, 12244 Athens,
GREECE

Abstract: In this work Ground Penetrating Radar (GPR) results achieved in the archaeological site of Ancient Falasarna Harbour in Western Crete (Greece), are presented. The survey has been performed in a site only slightly explored up to now and where has been covered by the tsunami deposits created by the AD 365 earthquake event with magnitude 8.3 located offshore of western Crete. This Ground Penetrating Radar (GPR) measurement campaign aimed to identify possible points where future localized excavation might and hopefully will be performed in the next few years. Based on the GPR findings, archaeological excavation works will be carried out in the region where the anthropogenic remains were estimated to be. This case study demonstrates and further corroborates the effectiveness and reliability of GPR for the non-invasive prospection of archaeological structures hidden in heterogeneous subsurface geoenvironment.

Key-Words: Ground Penetrating Radar; Archaeology; non-destructive testing (NDT); Crete ; Falasarna; Geoenvironment

Received: July 15, 2022. Revised: August 14, 2023. Accepted: September 26, 2023. Published: October 18, 2023.

1 Introduction

Ground Penetrating Radar (GPR) is a useful tool to study and document cultural heritage sites [1-5]. Archaeology is one of the classic fields of application of GPR prospecting [2,3], especially when localized or even extensive excavations are scheduled. However, the areas of potential interest are customarily too large for an excavation of the entire zone, which would result to be slow and expensive and might not provide the expected results and so a preventive geophysical investigation can reduce the extensions of the areas where targets of possible archaeological interest are expected, even if within the natural spatial precision and resolution limits of the technique [6].

GPR has a plethora of different applications and plays an important role in the management and preservation of cultural heritage [7]. In the scientific literature, the use of GPR to discover and map buried archaeological artefacts, to inspect ancient buildings and monuments, bridges, columns and statues, to investigate mosaics and decorations and to analyse the internal conditions of various other objects of historical value [8-12] is well documented. In the broader context of geoarchaeological research, the discovery of ancient settlements through archaeological excavations often brings up significant archaeological and geological information. The knowledge obtained during excavations provides explanations of the relationship of past societies with the evolving natural environment [7, 8]. In the case where ancient urban complexes are located in coastal areas, the discovery of structures, such as harbours, provides additional information concerning environmental processes [13,14].

Excavations are costly though and in many cases, move blindly, so the use of non-destructive geophysical methods such as ground penetrating radar (GPR) becomes a real asset. In this work, we present the application of GPR in the ancient harbour of Falasarna located in north-western coast of Crete (Fig. 1).

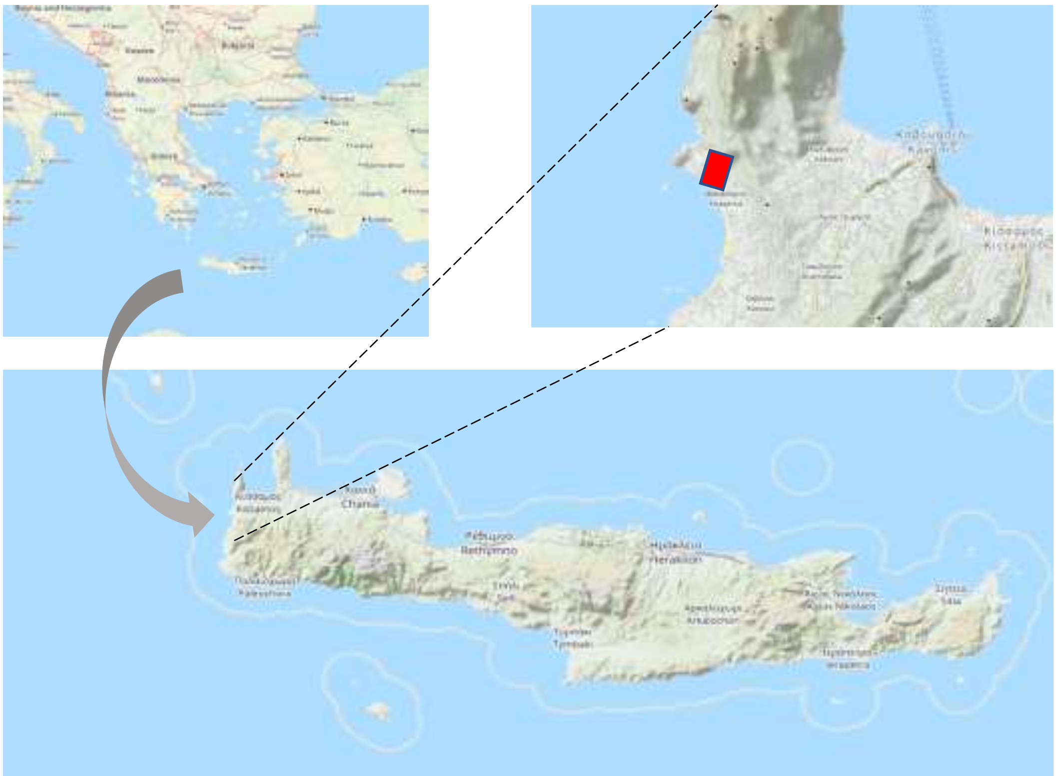


Figure 1. Map of Falasarna area. The location of GPR survey marked with red rectangle.

Ancient Falasarna is located in an area of hight tectonism in an extensional fault domain on the back of the Outer Hellenic Arc, along which the African plate is subducting under the Eurasian plate [15,16]. The Falasarna harbour area, in the past, has been affected by both relatively shallow earthquakes associated with extensional faulting and by deeper earthquakes associated with the thrust movement of the subducting plate [17,18]. The most extreme neotectonic event in historical times occurred in AD 365 with an estimated magnitude of 8.3, while the co-seismic uplift during the earthquake was about 9 m [19, 20, 21]. In the Ancient Falasarna harbour, this is mostly apparent not only from the up-and-inland displacement of the harbour jetties, but also from the late Holocene sedimentation record that includes layers of mixed deposits of sandy material and large flattened clasts, transported to the area by successive tsunamis triggered during the AD 66 and AD 365 earthquakes [22]. Even though the Ancient Falasarna archaeological site includes a series of man-made constructions, such as bridges, towers and water tanks, here we present only the results from the vicinity of the harbour.

Currently, all available information on the Falasarna site comes from a limited area of excavations. The shape of the harbour and its surroundings is vaguely known and the rest of the ancient city probably extends inland. To detect subsurface human constructions, GPR scans were realised in selected sub-areas where surface topography denoted the existence of subsurface constructions. The smooth relief of the surficial alluvial cover of variable thicknesses permitted the efficient application of GPR.

2 The Ground Penetrating Radar (GPR) method

Ground penetrating radar (GPR) is a sensing device that uses low-power electromagnetic waves to produce high-resolution images of the subsurface and interior of objects [23, 24, 25]. A GPR typically transmits short electromagnetic pulses of energy into the structure under test, within the 100 MHz–4 GHz frequency range. When the electromagnetic waves emitted by the radar encounter a buried object or, more in general, a discontinuity of electric and magnetic properties, that happens is that reflection, refraction, transmission and scattering phenomena occurs and hence part of the energy is echoed back to the GPR sensors. By exploiting advanced data processing and imaging techniques [26], the electromagnetic signals recorded by the radar can be transformed into useful two-dimensional (2D) or three-dimensional (3D) images of near surface structures.

GPR is an active electromagnetic method. It has the ability to provide subsurface profiles grounded in vertical radar section and three dimensional view of a buried site, when is carried out a parallel investigation of more than one section [27]. In an archaeological survey it is a useful tool for the mapping of the remnants of mounds, detecting of in-filled fortifications, tracing of metallic artifacts etc. The GPR's operation is the following: the instrument emits a pulse of electromagnetic radiation in the ground [27],with nominal frequency value in the range 1–2500 MHz [28]. This pulse echoes reflections from interfaces with differing dielectric constants, either by changes at the interface between strata or between materials. To become clear, the strength of reflections of pulses depends primarily on the magnitude of change in the dielectric coefficient or conductivity at a discontinuity, unlike other methods, directly affected by the bulk magnetic susceptibility or of the resistivity contrast. These two parameters play a secondary role [28]. Afterwards, by recording the time that need the transmitted signals to travel to the tuned receiver and converting them into depth measurements, the estimation of a geoelectric depth can be achieved [27].

Ground penetrating radar can obtain very valuable results in small scale evaluations over stratified areas. By collecting data from parallel lines into a common block it is possible to produce a series of time-slice, or amplitude, maps. These can sum the data of every traverse between a selected time or depth range and they can save it as an XYZ file. This file can be further edited for the production of a plan of anomalies at these particular ranges. A limiting factor for the GPR survey can be considering possible attenuation (i.e., its signal power loss) and diffusion. That is sometimes happened due to the media resistance and their heterogeneity [28].

Thanks to its non-destructive, high-resolution imaging possibilities and its sensitivity to both conductive and dielectric subsurface structures, Ground-Penetrating Radar has become a recognized near-surface geophysical tool, commonly used in a wide variety of applications. Since its first development, the domain in which the methodology has been successfully deployed has significantly expanded from ice sounding and environmental studies to precision agriculture and infrastructure monitoring. While such expansion has been clearly supported by the evolution of technology and electronics, the operating principles have always secured GPR a predominant position among alternative inspection approaches.

3 Description of fieldwork

The survey in Ancient Falasarna Harbour took place on April 2022 after a sufficient sequence of sunny days in order to have soil sufficiently dried. The whole site was split in four discrete subareas (A to D) according to the topography and the suggestions of the Principal Archeologist based on previous evidence (Fig. 2)

For each subarea, survey lines were conducted in parallel using 1.5m intervals. The profile lines for each subarea presented in Figs.3 to 6 for the areas A, B, C and D, respectively.

Figure 2. Map of the four (A to D) subareas where GPR surveys took place.

Figure 3. Profiles of measurements made in subarea A. The start point is shown in green dot and the end point of each section is shown in red dot. The arrow indicates the scanning direction (from bottom to top – point X=0m and Y=0m corresponds to the lower right green dot)

Figure 4. Profiles of measurements made in subarea B. The start point is shown in green dot and the end point of each section is shown in red dot. The arrow indicates the scanning direction (from right to left - point X=0m and Y=0m corresponds to the upper right green dot)

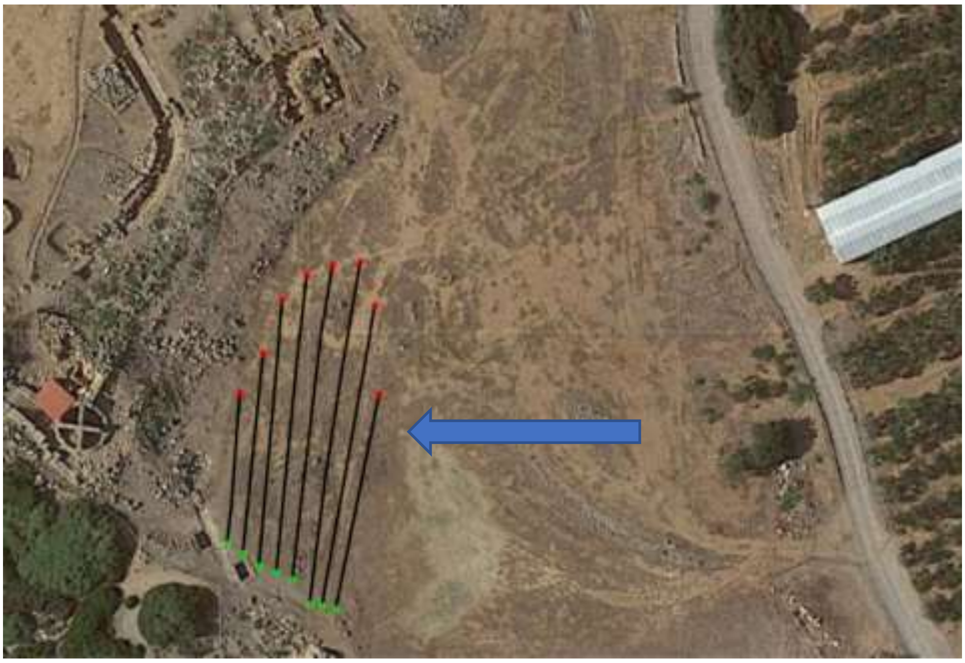


Figure 5. Profiles of measurements made in subarea C. The start point is shown in green dot and the end point of each section is shown in red dot. The arrow indicates the scanning direction (from right to left - point X=0m and Y=0m corresponds to the lower right green dot)

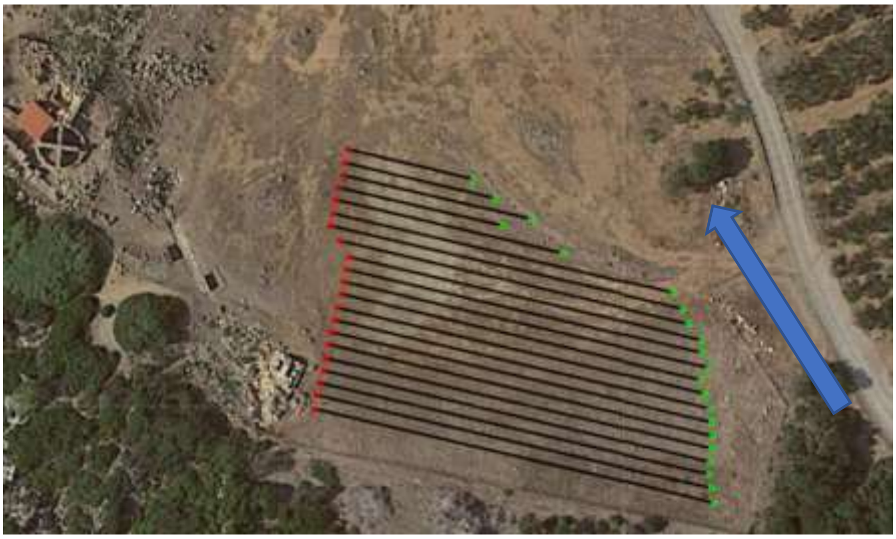


Figure 6. Profiles of measurements made in subarea D. The start point is shown in green dot and the end point of each section is shown in red dot. The arrow indicates the scanning direction (from lower right to upper left - point X=0m and Y=0m corresponds to the lower right green dot)

The GPR survey conducted using Mala (Mala Geoscience, Sweden) ProEX system (Fig. 7) in a rough terrain cart with embedded distance encoder and GNSS receiver. The antenna that used was a shielded one with centre frequency of 500MHz. Sampling rate was adjusted to 6360MHz, 512 samples, 4 stacks and antenna separation at 0.18m. With these settings the investigation depth expected to be 3.8m.

Figure 7. The GPR system that used for this survey

4 Data processing and visualization

Data processing was performed in the cloud based software MalaVision. It is a cloud based software (runs on Azure cloud solution) for the analysis and processing of GPR data that can be used from any device. It utilizes powerful distributed computing and unique artificial intelligence to help researchers to go as fast as possible from data collection to results. Apart from the typical procedures that can be found in a GPR software (filtering, analysis, interpolation, topography corrections) two distinct features are quite useful : the first one in Mala's proprietary AI algorithm for detecting hyperbolas and the second is extensive use of assisted utilities for appending annotated information to the results (mapping, photo screenshots) providing in this way a complete solution for reporting results. In addition to the above, a powerful 3D visualization subsystem is included for the purposes of 3D reconstruction of 2D results which is supported by a significant number of interpolation and weighting methods. Details are available in https://malavision.guidelinegeo.com/. The 2D raw GPR data were processed (described below) to produce radargrams ready for interpretation. However, a final presentation of the results in 3D format was selected.

The 3D format chosen is the horizontal section on the Z (depth) axis. Essentially, it is an amplitude intensity map where the points/areas that present a higher reflected trace amplitude and are therefore potential targets are depicted with a color scale. Schematically, the procedure followed is illustrated in Fig. 8.

For each area, three to five characteristic horizontal depth sections are presented. After identifying the highly reflective areas with particular geometric features, a 3D reconstruction is performed using all horizontal depth sections. With this process it is possible to have a 3D estimate of the potential target thus validating or invalidating the findings from the horizontal depth sections. The data processing followed a sequential model in a 5-step procedure as below (where in parentheses included the individual operations):

- Step 1 : Preprocessing (time zero correction, velocity analysis and depth conversions, static correction, rubber banding). Producing of B-scans
- Step 2: Basic processing (dewow, removal of background noise, gain adjust, temporal filtering)
- Step 3: advanced processing (deconvolution, thresholding)
- Step 4: 2D visualization – depth profiles (adjustments on interpolation, sensitivity, resolution limits, overlapping)
- Step 5: 3D visualization (isovalues, opacity, thresholding

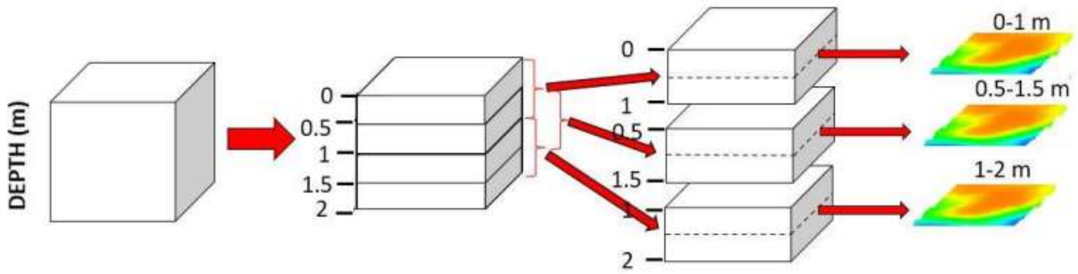


Figure 8. Flowchart of data processing for producing horizontal depth slices

5. Results and interpretation

We present the main findings in each of the subareas investigated.

Subarea A : After processing the B-scans, the horizontal sections were produced. We present the most typical of them for depths of 1.54m , 1.75m, 2.10m , 2.52m and 2.85m (Fig. 9). Areas of strong reflections are depicted in red shades, while areas with weaker reflections are shown in shades of gray.

From the horizontal sections of Fig. 9, it is evident the existence of two regions of interest marked with yellow (A1) and green (A2) circle in 2.85m slice (this also applies to the other horizontal sections).

In region A1, a pattern of intense reflection appears from the depth of 1.54 m initially, while then from the depth of 2.52 m a second one appears and remains. Both create structure with geometric features. The behavior of the non-simultaneous strong reflection with increasing depth is a strong indication of a scaled structure.

In region A2, two patterns of intense reflection appear at the same time, varying from the depth of 1.54m up to 2.85m, showing the same behavior and intensity. This fact is (combined with their simplified geometric form) an indication of a pair of possible pillars or remains of masonry around a door.

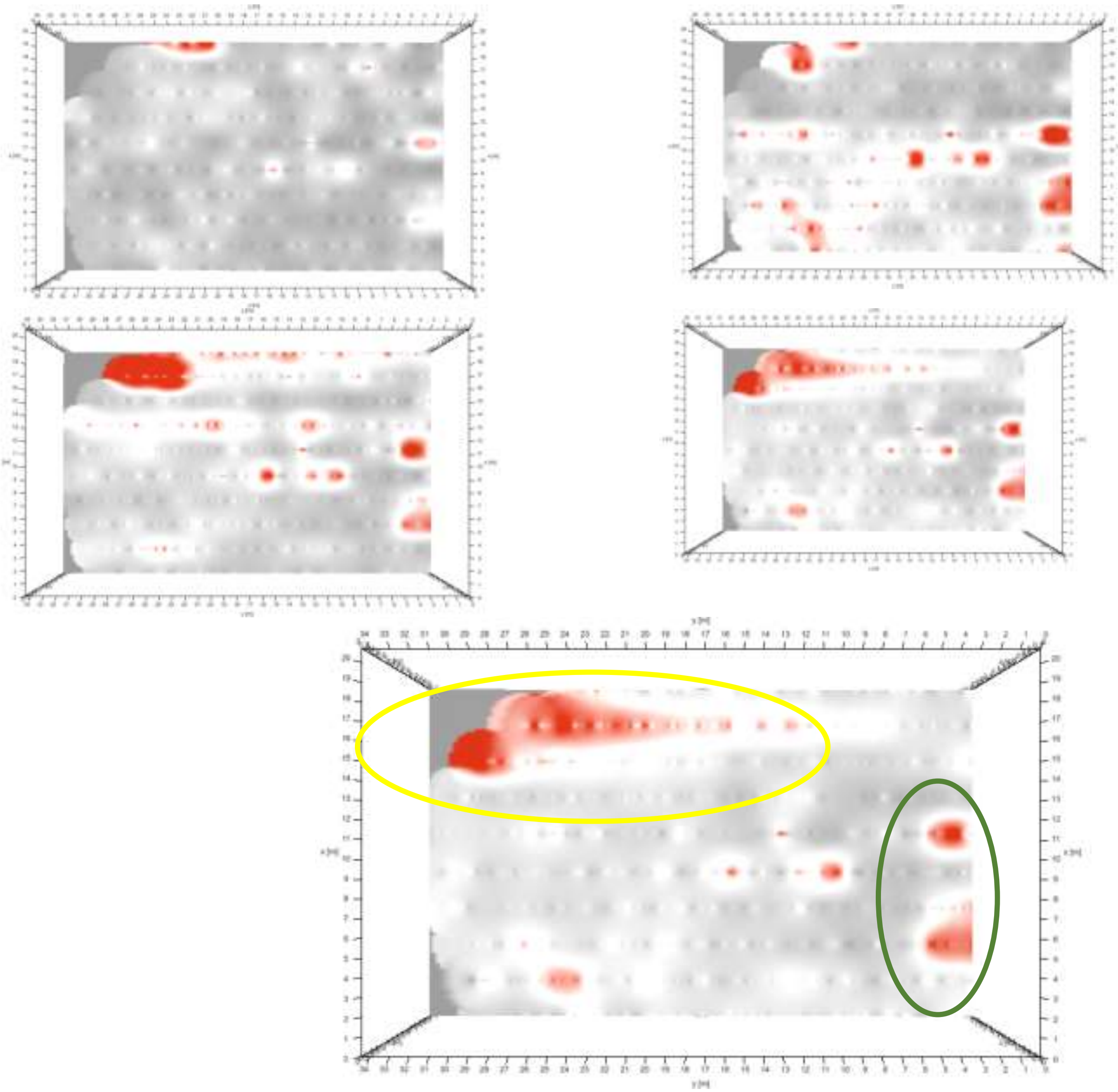


Figure 9. Horizontal depth slices for subarea A at 1.54m (top left) , 1.75m (top right), 2.10m (middle left), 2.52m (middle right) and 2.85m (bottom)

To more fully visualize the findings, the horizontal depth sections were transformed (using interpolation and smoothing) into a 3D format (Fig. 10). A threshold filter was then applied to cut off the very weak reflections and highlight the representations of the two regions A1 (Fig. 11) and A2 (Fig. 12)

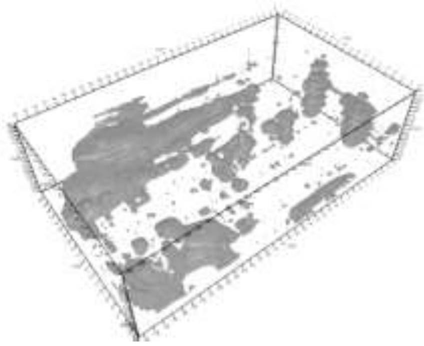


Figure 10. 3D visualization of survey results in subarea A

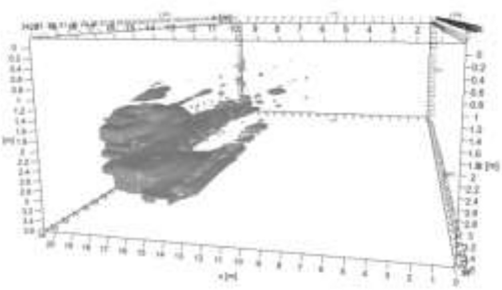


Figure 11. 3D visualization of region A1 after appropriate thresholding. A structure with geometric feature is evident

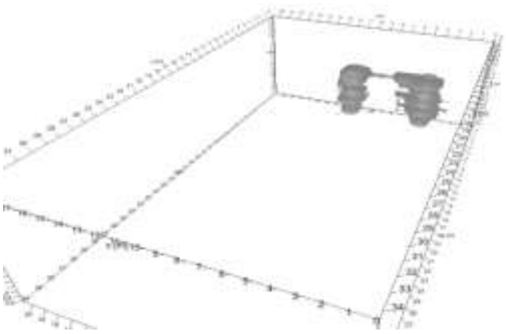


Figure 12. 3D visualization of survey results of region A2 after thresholding where a columnar structure is evident

Considering all the above, we concluded that in region A1 we have strong evidence of the remains of a stepped structure (e.g. a grandstand), while in region A2 probably columns or masonry around an opening are depicted.

Subarea B :The horizontal sections (after B-scans processing) were produced. The most representatives are for depths of 0.95m , 1.08m, 1.78m , 2.50 and 3.40m (Fig. 13). In a similar was as in subarea A the areas of strong reflections are depicted in red shades, while areas with weaker reflections are shown in shades of gray.

From the presented horizontal sections in fig.13, it is evident the existence of a region of interest marked in yellow circle (also applies to the other horizontal sections with less intensity). Intense reflection appears from a depth of 0.95m initially to a depth up to 3.4m with geometric masonry features. Consistent with previous presentations, the horizontal depth sections were transformed (using interpolation and smoothing) into 3D form. A threshold filter was then applied to cut off very weak reflections. The 3D rendering of the target is shown in Fig. 14 where a longwise structure (possibly a wall) is evident

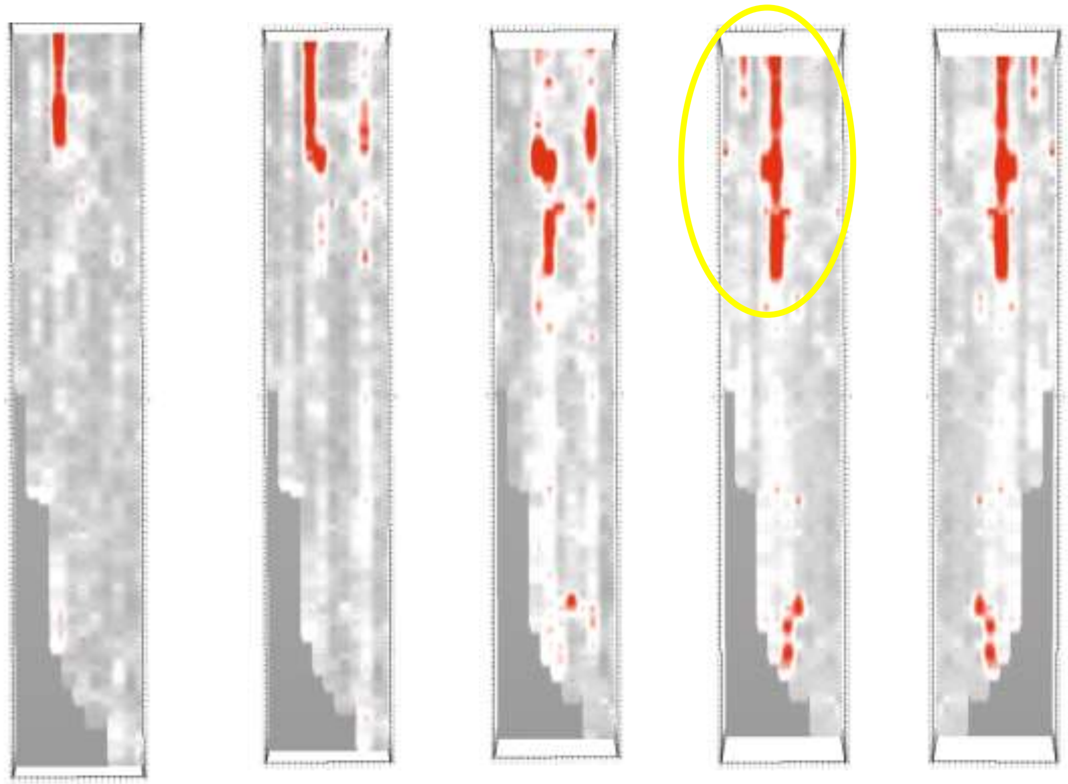
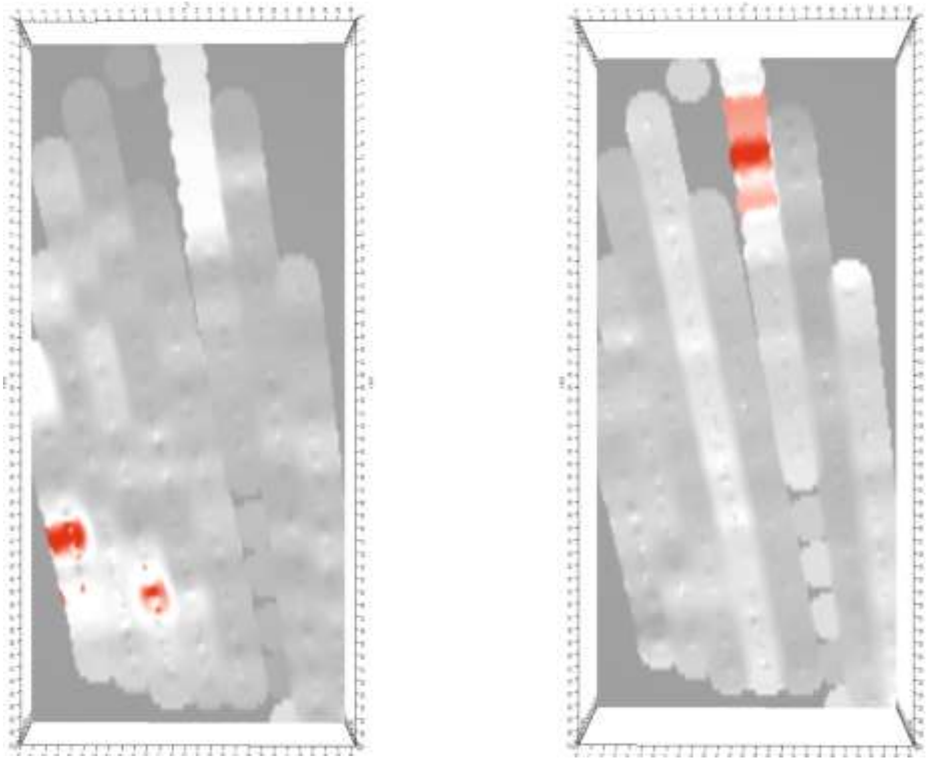
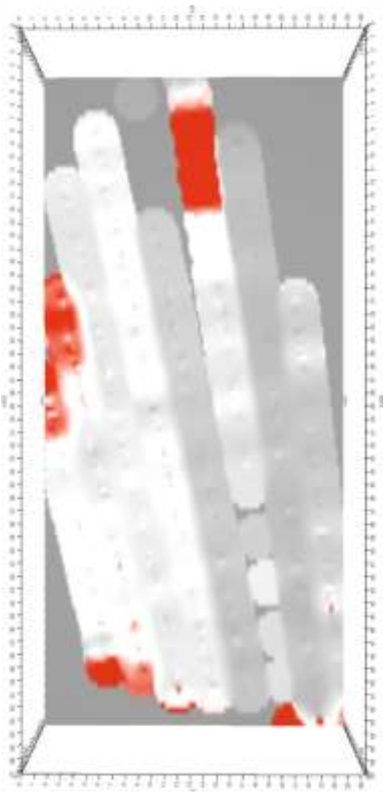


Figure 13. Horizontal depth slices for subarea B at (from left to right) of 0.95m , 1.08m, 1.78m , 2.50 and 3.40m

Subarea C: In agreement with previous results, horizontal sections of subarea C were produced. Fig. 14 present horizontal slices for 1.08m, 1.20mm, 2.51m and 2.98m. The results dictate that there is no major structure that can be identified and the discrete strong reflections may be caused by pieces of ruins at different depths.





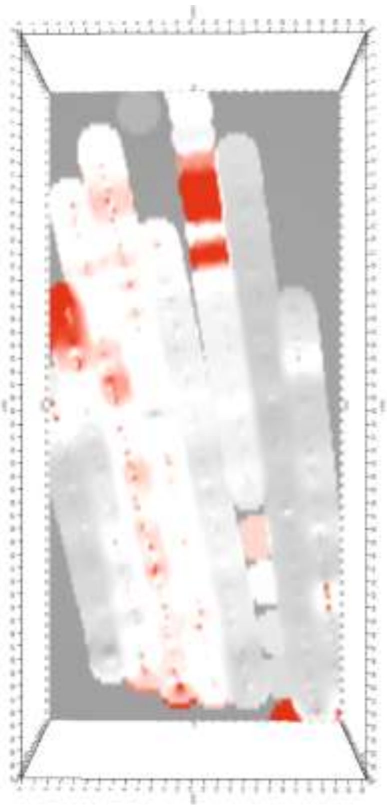
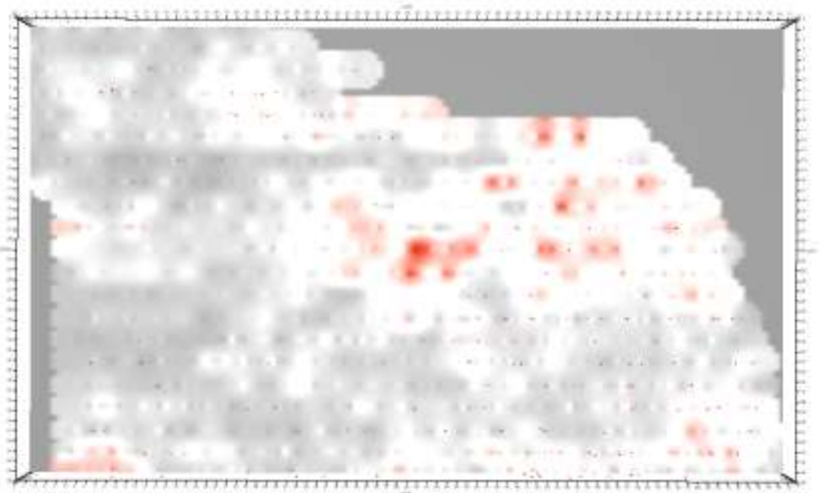


Figure 14. Horizontal depth slices for subarea C at 1.08m 9top left), 1.20mm (top right), 2.51m (bottom left) and 2.98m (bottom right).

Subarea D: After B-scan processing, as previous, horizontal slices were produced. The most representative ones are for depth 1.05m, 1.70m, 2.25m & 2.55m (Fig. 15).



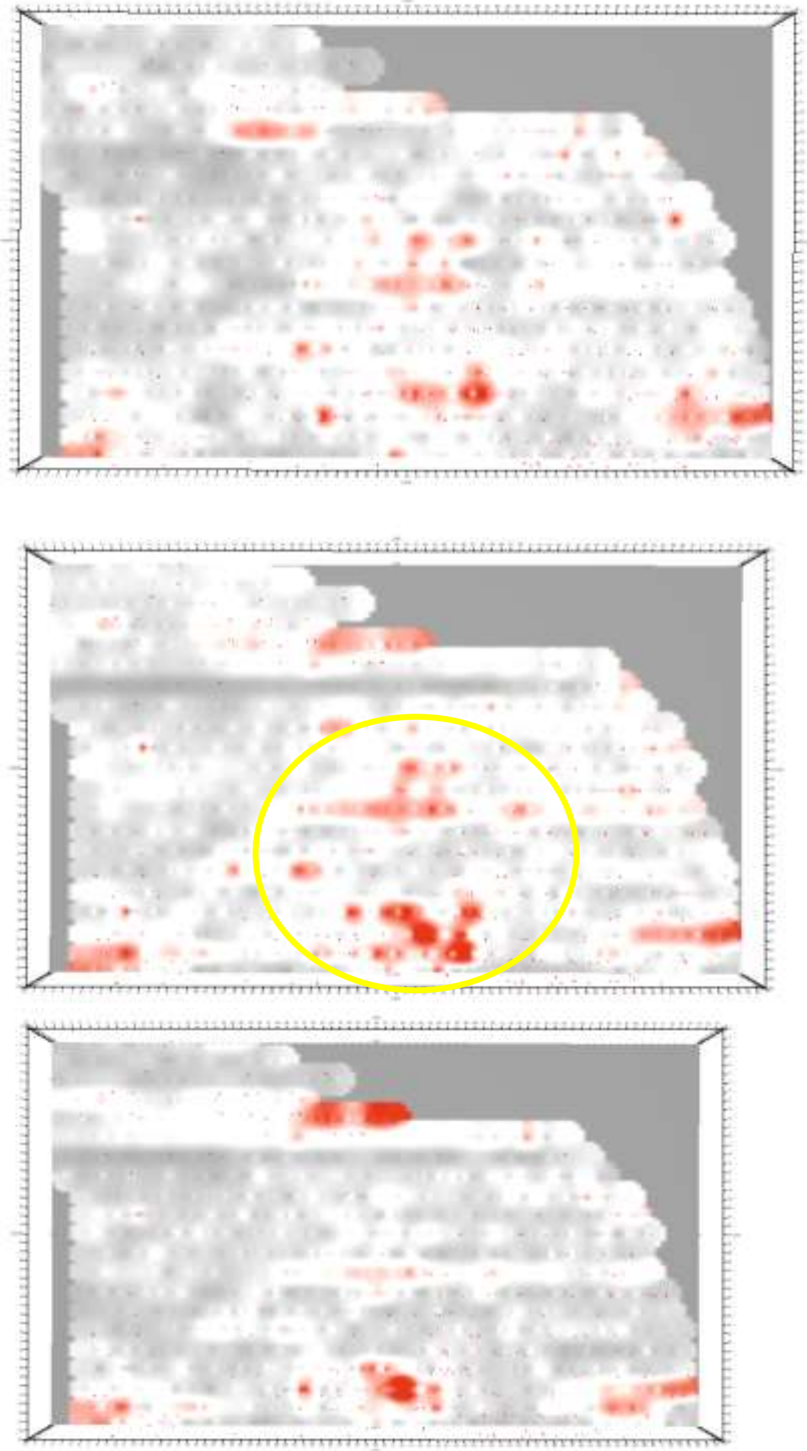


Figure 15. Horizontal depth slices for subarea D at (from top to bottom) 1.05m, 1.70m, 2.25m and 2.55m. yellow circle indicates the region of interest

From the horizontal sections of Fig. 15 , it is evident the existence of a region of interest marked in (also applies to the other horizontal sections) in yellow. Traces of construction appear with an obvious geometric characteristic, starting from the depth of 1.05 m up to the depth of 2.55 m. These are probably the remains of some structural construction due to their small height.

Consistent with previous presentations, the horizontal depth sections were transformed (using interpolation and smoothing) into 3D form. A threshold filter was then applied to cut off very weak reflections. The 3D rendering of the target is shown in Fig.16 .

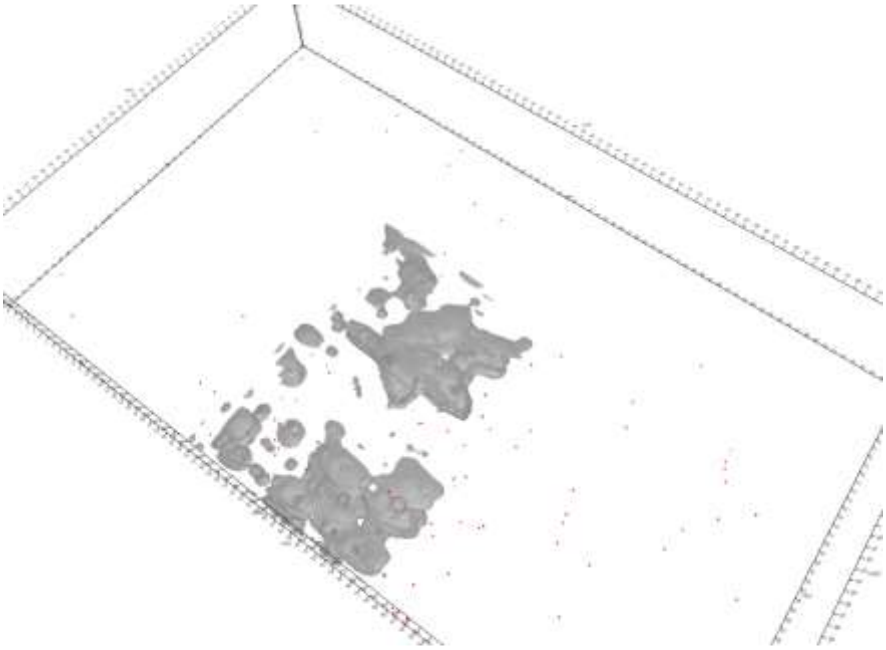


Figure 16. A 3D visualization of survey results of region of interest after thresholding where a structural construction is evident.

5. Concluding Remarks

GPR is a non-destructive, fast, low-cost and precise investigation technique that uses reflected electromagnetic (EM) waves. In modern archaeology, non-destructive geophysical site assessment methods are of great importance as they are used to provide a fast and accurate picture of subsurface conditions, prior to any excavation works. Contemporary to its archaeological applications, GPR has shown its potential for detecting stratigraphic architecture, layer boundaries and sand-body geometry. A dense grid of GPR data allows for analyses of the lateral extent of specific sediment for relatively large areas to be quickly undertaken.

In this work the results of a new case study recently carried out in Ancient Falasarna Harbour in Western Crete (Greece) are presented, demonstrating the use of GPR to obtain useful information concerning archaeological remains hidden in the heterogeneous and complex subsurface of an historical city. The main objectives of GPR profiling were to map the extent and geometrical characteristics of the subsurface human-made utilities in the Ancient Falasarna harbour area.

Our GPR-based geophysical investigations reveal new insights about the subsurface man-made structures in the Ancient Falasarna harbour, along the north-western coast of Crete where the tsunami deposits, triggered by the AD 66 and in all likelihood by the AD 385 earthquakes too. GPR data were successful in mapping the lateral extents and the extension of the ancient harbour, as well as man-made constructions throughout the archaeological site of Ancient Falasarna. These features were verified using a non-invasive geophysical investigation method such as GPR. The results will be justified applied further geophysical techniques as that of electrical resistivity tomography, resistivity mapping and magnetic measurements. Further analysis with Machine Learning techniques presents an additional challenge [29]

Acknowledgement:

We acknowledge support of this study by the project “Geophysical Exploration of Ancient Falasarna harbour”, funded by Secretariat General for the Aegean and Island Policy of the Ministry of Maritime Affairs, Islands and Fisheries. Greece.

References:

[1] Catapano, I., Gennarelli, G., Ludeno, G., Soldovieri, F. Applying ground-penetrating radar and microwave tomography data processing in cultural heritage: State of the art and future trends. *IEEE Signal Process. Mag.,* 36, 2019, pp. 53–61.

[2] Conyers, L.B. *Interpreting Ground-Penetrating Radar for Archaeology*; Routledge, Taylor and Francis Group: New York, NY, USA, 2014; p. 214.

[3] Conyers, L.B., Goodman, B. *Ground-Penetrating Radar: An Introduction for Archaeologists*; AltaMira Press: Walnut Creek, CA, USA; London, UK; New Delhi, India, 1997; p. 232.

[4] Malfitana, D., Leucci, G., Fragalà, G., Masini, N., Scardozzi, G., Cacciaguerra, G., Santagati, C., Shehi, E. The potential of integrated GPR survey and aerial photographic analysis of historic urban areas: A case study and digital reconstruction of a Late Roman villa in Durrës (Albania). *J. Archaeol. Sci.* 4, 2015, pp. 276–284.

[5] Deiana, R.; Leucci, G.; Martorana, R. New Perspectives on Geophysics for Archaeology: A Special Issue. *Surv. Geophys.*39, 2018, pp.1035–1038.

[6] Ritter, R.S., Fiddy, M.A. Imaging from scattered fields: Limited data and degrees of freedom. In *Image Reconstruction from Incomplete Data VII*; International Society for Optics and Photonics: Bellingham, WA, USA, 2012; Volume 8500, p. 850007.

[7] Conyers, L. B., Discovery, mapping and interpretation of buried cultural resources non-invasively with ground-penetrating radar. *Journal of Geophysics and Engineering,* 8, 2011, pp. S13- S22.

[8] Persico, R., D'Amico, S. Use of Ground Penetrating Radar and standard geophysical methods to explore the subsurface. *Ground Penetrating Radar,* 1, 2018, pp. 1–37.

[9]] Bianco, C., De Giorgi, L., Giannotta, M.T., Leucci, G., Meo, F., Persico, R. The Messapic Site of Muro Leccese: New Results from Integrated Geophysical and Archaeological Surveys. *Remote Sens.* 11, 2019, pp. 1478.

[10] Conyers, L.B. *Ground-Penetrating Radar for Archaeology*; Rowman and Littlefield Publishers; Alta Mira Press: Lanham, MD, USA, 2013; p. 241.

[11] Trinks, I., Hinterleitner, A., Neubauer, W., Nau, E., Löcker, K., Wallner, M., Gabler, M., Filzwieser, R., Wilding, J., Schiel, H.; et al. Large-area high-resolution ground-penetrating radar measurements for archaeological prospection. *Archaeol. Prospect., 25,* 2018, pp. 171–195.

[12] Trinks, I., Karlsson, P., Biwall, A., Hinterleitner, A. Mapping the urban subsoil using ground penetrating radar. Challenges and potentials for archaeological prospection. *ArcheoSciences, 33,* 2009, pp. 237–240.

[13] Chianese, D., Lapenna, V., Di Salvia, S., Perrone, A., Rizzo, E. Joint geophysical measurements to investigate the Rossano of Vaglio archaeological site (Basilicata Region, Southern Italy). *Journal of Archaeological Science*, 37, 2010, pp. 2237-2244.

[14] Castaldo, R., Crocco, L., Fedi, M., Garofalo, B., Persico, R., Rossi, A., Soldovieri, F. GPR Microwave Tomography for Diagnostic Analysis of Archaeological Sites: the Case of a Highway Construction in Pontecagnano (Southern Italy). *Archaeological Prospection*, 16, 2009, pp. 203-217.

[15] Le Pichon, X., Angelier. J. The Aegean Sea. *Philosophical Transactions of the Royal Society of London,* Series A 300, 1981, pp. 357–372.

[16] Lallemant, S., Truffert, C., Jovilet, L., Henry, P., Chamot-Rooke, N., De Voogd, B. Spatial transition from compression to transition in the western Mediterranean Ridge accretionary complex. *Tectonophysics,* 234, 1984, pp. 33–52.

[17] Dominey-Howes, T. M., Dawson, A., Smith, D. Late Holocene coastal tectonics at Falasarna, western Crete: A sedimentary study. *Geological Society of London*, Special Publications 146, 1998, pp. 343–352.

[18] Scheffers, A., Scheffers, S. Tsunami deposits on the coastline of west Crete (Greece). *Earth and Planetary Science Letters,* 259, 2007, pp. 613–624.

[19] Pirazzoli, P. A., Laborel, J., Stiros, S. C. Coastal indicators of rapid uplift and subsidence: Examples from Crete and other Mediterranean sites. *Zeitschrift für Geomorphologie* NF Suppl.-Bd. 102, 1996, pp. 21–35.

[20] Stiros, S. C. The 365AD Crete earthquake and possible seismic clustering during the 4–6th centuries AD in the Eastern Mediterranean: A review of historical and archaeological data. *Journal of Structural Geology* 23, 2001, pp. 545–562.

[21] Stiros, S. C., Papageorgiou, S. Seismicity of Western Crete and the destruction of the town of Kisamos at AD 365: Archaeological evidence. *Journal of Seismology*, 5, 2001, pp. 381–397.

[22] Pirazzoli, P. A., Ausseil-Badie, J., Giresse, P., Hatzidaki, E., Arnold, M. Historical environmental changes at Phalasarna harbor, West Crete. *Geoarchaeology*, 7, 1992, pp. 371–392.

[23] Annan, A.P. Electromagnetic Principles of Ground Penetrating Radar. In *Ground Penetrating Radar: Theory and Applications*, edited by Harry M. Jol,. Elsevier, Amsterdam, 1999, pp. 3-40.

[24] Daniels, D. J. (Ed.), *Ground Penetrating Radar*, 2nd Edition. Published by the Institution of Engineering and Technology, ISBN 978-0-86341-360-5, London, UK, 2007.

[25] Goodman, D., Salvatore, P., Nishimura, Y., Schneider, K., Hongo, H., Higashi, N., Steinberg, J., Damiata, B. *GPR Archaeometry. In Ground Penetrating Radar: Theory and Applications,* edited by Harry M. Jol, pp. 479-508. Elsevier, Amsterdam, 2009.

[26] Goodman, D., Schneider, K., Piro, S., Nishimura, Y., Pantel, A. G. *Ground Penetrating Radar Advances in Subsurface Imaging for Archaeology. In Remote Sensing in Archaeology*, edited by James Wiseman and Farouk El-Baz, pp. 375-394. Springer, New York, 2007.

[27] Gaffney, V., Patterson, H., Piro, S., Goodman, D., Nishimura, Y. Multimethodological Approach to Study and Characterize Forum Novum (Vescovio, Central Italy). *Archaeological Prospection,* 11, 2004, pp. 201-212.

[28] Piro, S., Gabrielli, R. Multimethodological Approach to Investigate Chamber Tombs in the Sabine Necropolis at Colle del Forno (CNR, Rome, Italy). *Archaeological Prospection*, 16, 2009, pp.111-124.

[29] Mochurad, L., Savchyn, V., Kravchenko, O. Recognition of Explosive Devices Based on the Detectors Signal Using Machine Learning Methods. CEUR Workshop Proceedings, 3373, 2023, pp. 249– 260.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

We acknowledge support of this study by the project “Geophysical Exploration of Ancient Falasarna harbour”, funded by Secretariat General for the Aegean and Island Policy of the Ministry of Maritime Affairs, Islands and Fisheries. Greece.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.