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High-resolution geophysical investigation at Banditaccia Necropolis (Cerveteri) by means GPR and magnetic surveys

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***Abstract* – In the search for bodies of archaeological interest at shallow depths, geophysical methods can provide useful indications. The aim of the present work, carried out in collaboration with the Archaeological Park of Cerveteri and Tarquinia, was to detect the presence of tombs/graves and/or buried structures in an unexplored area of Banditaccia Necropolis (Cerveteri and Tarquinia Archaeological Park), one of the largest ancient necropolis in the entire Mediterranean area. In the investigated area, two different non-destructive geophysical techniques have been employed: Ground-Penetrating Radar and gradiometry. The results made it possible to identify anomalies referable to probable structures of archaeological interest buried at a depth of several meters and probably attributable to tombs/graves.**
These geophysical results will preparatory to set up an archaeological excavation.

I. INTRODUCTION

The archaeological area of the Banditaccia (UNESCO site since 2004) is part of the Cerveteri and Tarquinia Archaeological Park and is located about 2 km NE of Cerveteri (province of Rome) (Figure 1a).

The site is one of the largest ancient necropolis in the entire Mediterranean area.

The necropolis, which is the ultimate example of Etruscan funerary architecture, in total covers about 400 hectares and is traversed by a burial route more than 2 km long. The site contains many thousands of burials (the part open to the public represents only 10 hectares in size and has about 400 tumuli), from the oldest from the Villanovan period (9th century B.C.) to the most "recent" from the Hellenistic period (3rd century B.C.) [1].

The necropolis belonged to the ancient city of Caere (Cerveteri), a flourishing Etruscan town that stood on a tuffaceous hill about 40 km NW from Rome and not far from the Tyrrhenian coast. The prominence of the city of Cerveteri in the history of Etruscan civilization is evidenced precisely by the monumentality of the necropolis and the enormous amount of material found both in grave goods and in excavations of the shrine and settlement areas [2]. The oldest tombs are of the pit type, with incinerations within vessels, and grave type for inhumation. From the 7th century B.C., with the prevalence of the inhumation rite, large burial mounds developed with burial chambers excavated in the tuff and decorated with motifs inspired by the forms of domestic architecture. Such monuments, belonging to high-ranking families, returned rich grave goods where the presence of materials imported from the Near East and Greece is frequent. During the 6th century B.C., the tumulus type, now of medium and small forms, was joined and gradually established by dado tombs aligned regularly along the burial routes and those with machicolations. During the 4th century B.C., the type of hypogeum consisting of a single room and with benches leaning against the walls appears to be widespread. All the monuments offer evidence of the exceptional experiences of funerary architecture in ancient Caere.

The importance of the Cerveteri Etruscan Necropolis is also due to the fact that it provides important insights into the life of the Etruscans and the structure of their houses. In fact, the tombs are built in imitation of the houses "of the living" with multiple rooms with shaped doors and windows, columns and pillars, furniture, furnishings, precious metal vessels, and objects locally produced and from the Near East and Greece.

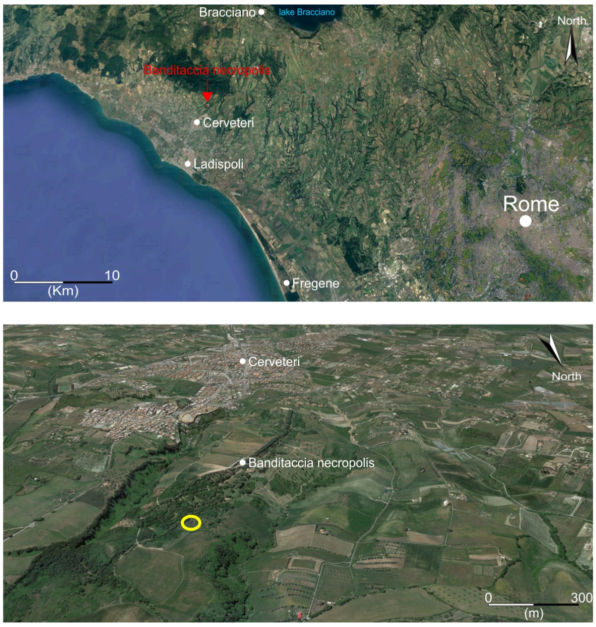

Fig. 1. Satellite imagery from Google Earth showing a) Banditaccia archaeological site and b) the explored area (yellow dot).

As part of a 2022 agreement between Cerveteri and Tarquinia Archaeological Park and CNR-ISPC, an unexplored area has been identified, within the Necropolis, that, currently closed to the public, has great potential for the presence of tombs (Figure 1b). The first phase of this exploratory process consisted of the execution of a multi-methodological geophysical prospecting to characterize, in a non-destructive and cost-effective way, the stratigraphy of the subsoil and, in particular, to reveal the presence of natural and/or anthropic buried structures (such as cavities or graves), and to eventually find buried archaeological remains.

Therefore Ground Penetrating Radar (GPR) and magnetic geophysical surveys were carried out to verify the extent of the necropolis and the presence of graves. These methods allow non-invasive pre-excavation subsurface imaging, which is very important because excavation of a site can destroy essential archaeological evidences.

Geophysical prospecting will then be preparatory to set up an archaeological excavation, and then directly understand the type, shape, state of preservation, of the graves and whether these were robbed.

II. FIELD INSTRUMENTATION AND DATA ACQUISITION

Ground Penetrating Radar (GPR) is a non-invasive geophysical method for high-resolution imaging and characterization of shallow subsurface targets based on changes in the electro-magnetic properties of the materials [3]. This method has been extensively used in archaeological studies to map the spatial extent of buried cultural heritage and map shallow subsurface objects [4, 5, 6, 7, 8]. GPR utilizes the transmission of high-frequency electromagnetic waves in the subsurface and recording their reflections, due to anomalies in their propagation path, at the surface [9]. The GPR system manufactured by Geophysical Survey Systems, Inc. (SIR 3000, GSSI, Nashua, NH, USA) mounted on an in-house cart and equipped with a 270 MHz central frequency antenna and with a distance-measuring wheel encoder was used (Figure 2). This antenna was chosen to achieve a scanning depth of about 3.5 m. The survey area was investigated by 14 parallel lines spaced 1 m apart with lengths varying from about 36 m to a maximum of about 75 m for a total of 770 linear m of investigation (Figure 4a).

Fig. 2. GPR data acquisition in Banditaccia

The following acquisition parameters were selected: Scans/sec:100; Scans/Unit (m):50; Samps/Scan:512; Bits/Sample:16. The obtained data were analyzed by using a commercial software ‘‘Radan 7’’, from GSSI. The GPR processing procedure defined for this study includes the following steps: (1) static data removal, (2) time-zero correction, (3) distance normalization, (4) data filtering, (5) deconvolution and (6) migration. These processing steps are used to remove in-significant portions of the data, correct the y- and x-axes, remove unwanted noise, and improve signal-to-noise ratios.

Magnetometric method is one of the most effective investigative techniques in archaeological prospecting since it appears to be an absolutely non-destructive technique, with fast rate of data acquisition in relatively short time spans, and of high-quality spatial resolution of the gathered data [10, 11, 12, 13, 14]. Magnetic method belongs to a group of geophysical passive survey using the measurement of the natural magnetic field of the Earth and monitoring its local variations [15]. The magnetic survey was conducted with the gradient technique using a highly sensitive, fast-sampling ‘walking’ caesium atomic vapor magnetometer/gradiometer G-858AP, manufactured by Geometrics (Figure 3). The survey was performed following the same lines as the GPR acquisition.

Fig. 3. Magnetometric data acquisition in Banditaccia

The magnetometer consists of two sensors, operating continuously with a cycle time of 0.5 seconds and a sensitivity of 0.02 nT and separated vertically by one meter, and fastened, the lower one, at 0.30 meters from the ground surface; they are located on a staff oriented perpendicular to the ground surface and supporting the apparatus with a shoulder strap. Both sensors were controlled by a console that was integrated with a GPS antenna with real-time differential corrections. The magnetic field intensity is measured separately through two sensors: the ratio between the difference of the values obtained and the vertical distance of the two sensors provides the value of the gradient of the earth's magnetic field. Figure 4b depicts the measurement points for the magnetic total field survey. The magnetic data were processed using the MagMap2000 (Geometrics Inc.) and Matlab (Mathworks) software. The profiles were uploaded and removed inaccurate GPS coordinates. The data have been treated with the clipping function in the trace-plot mode, where the abnormal values have been detected and reduced by restricting the data with minimum and maximum values. Spike clipping is preferable prior to any further processing to improve the statistical calculation of some other processing functions. The first phase of data processing (pre-processing) consisted of a series of operations aimed at identifying and eliminating any random disturbances (for example noise spikes) and finally at creating regular grids. In the case of magnetic data, the techniques used to eliminate contributions linked to sources of no interest were non-linear de-spiking, detrending which allows the exclusion of contributions due to sources whose depth is greater than that of interest. Vertical gradientwas also computed.

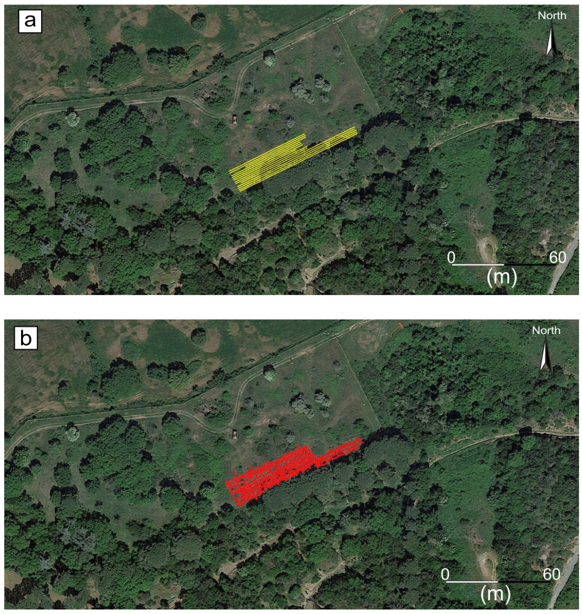

Fig. 4. Ortophoto image (from Google Earth) showing: a) GPR scanning plan consisting of 14 parallel lines, 1 m spaced. b) Magnetic lines. The surveyed area is about 725 square meters

III. RESULTS

The preliminary analysis of 2-D data is crucial to estimate the characteristics of the buried targets.

Some recorded GPR profiles, after the processing, are shown in Figure 5. These profiles show many shallow reflections: high amplitude hyperbolas, indicated by black circles (Figures 5a and 5b) are located at a depth varying from 1.25-1.5 m depth. Continuous dipping events (magenta arrows) are also present; other archaeological targets and small-size remains (white arrow) are further individuated.

A time slice GPR map (Figure 6) permits to highlight the buried archaeological targets assessing their extension, shape, and depth. For example, the slice at 150 cm depth (Figure 6c) makes it possible to highlights that the single anomaly identified on the line n.02 at 46 meters in length (Figures 5a), produces a sub circular anomaly with a diameter of about 2.5 meters. This anomaly begins to cover at about 100 cm depth (Figure 6b) and extends to about 180 cm (Figure 6d). The depth slice at 180 cm depth (Figures 6d) also allows the identification of two important anomalies zones, identified by the letters A A'.

This map particularly highlights the presence of three areas, in red, characterized by high amplitude. As evidenced by the GPR depth slice at 180 cm (Figures 6c), in the NE part of the investigated area, there is a widespread area of anomalies.

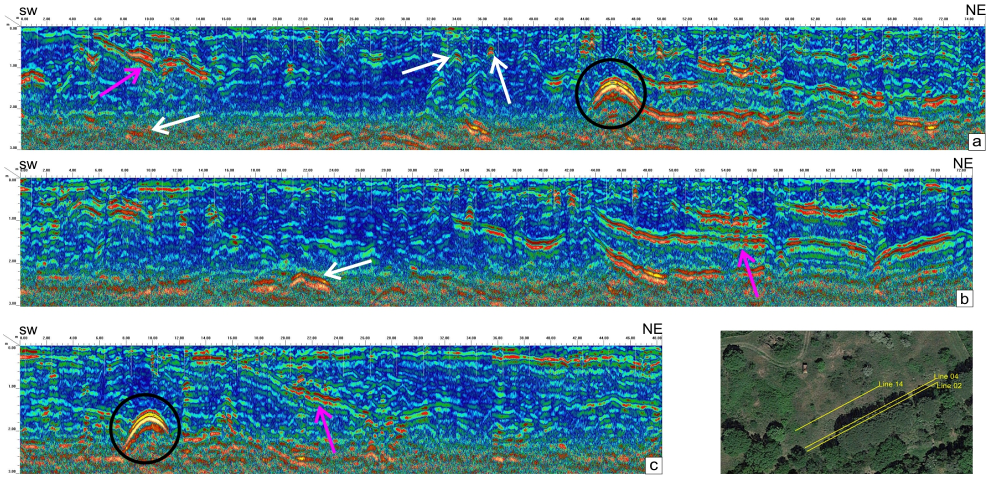

Fig. 5. Example of some GPR 2D sections. a) Line 02; b) Line 04; c) Line 14

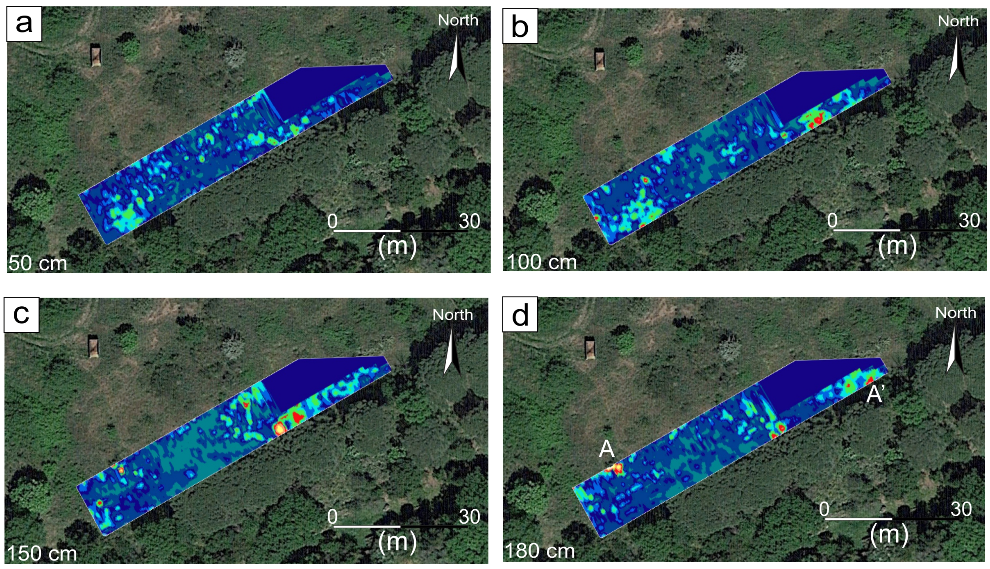

Fig. 6. GPR horizontal slice. a) 50 cm; b) 100 cm; c) 150 cm; d) 180 cm

Figure 7 shows the results of the differential magnetometer survey. Specifically, Figure 7a represents the total intensity field of the study area. This map depicts the presence of several areas of bipolar anomalies (circled in magenta). To emphasize archaeological contrast, the maximum of vertical gradient was calculated (Figure 7b).

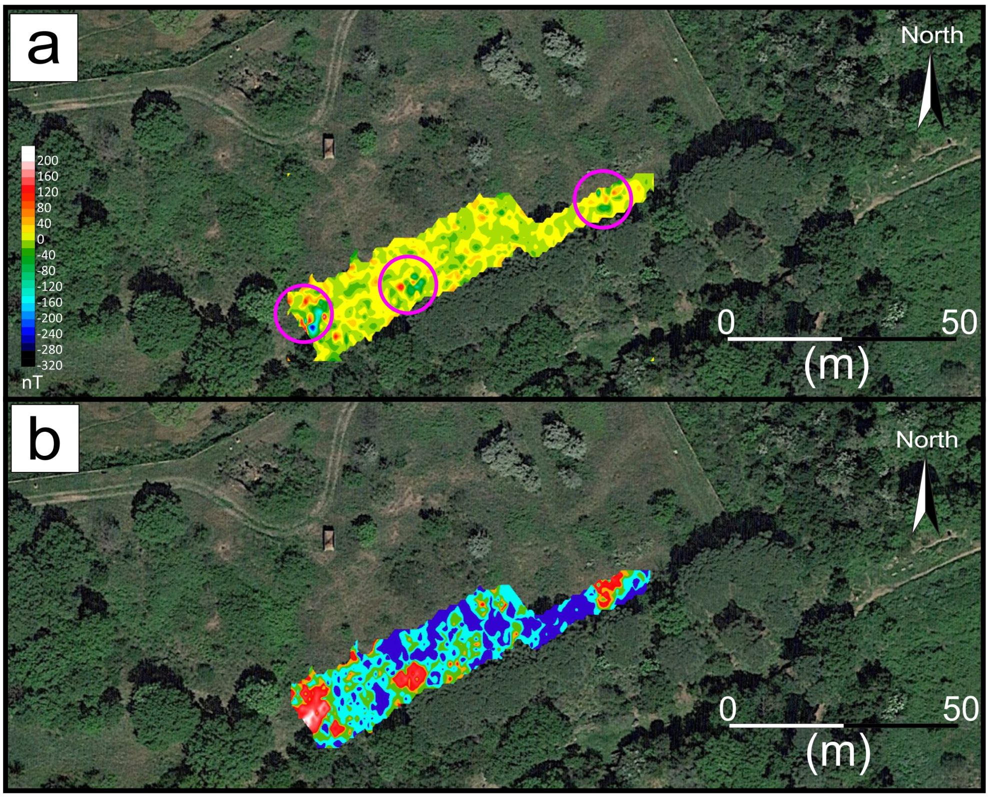

Fig. 7. Results from the cesium magnetometer survey. a) Total field intensity; b) Maximum Vertical Gradient.

IV. CONCLUSIONS

The investigations carried out in the area of the Banditaccia Necropolis have demonstrated the effectiveness of the Ground penetrating radar (GPR) and magnetometric methods as a high resolution non-destructive geophysical surveys for detection of shallow subsurface targets. The analysis of 2-D/3-D data was crucial to estimate the characteristics of the buried targets.

In 2D GPR sections the high amplitude reflections/diffractions may be associated with potential presence of tombs/graves.

The distribution of magnetic anomalies shows an extensive zone in which clusters of anomalies of varying amplitude are connected or overlapping. The main anomalies of high amplitude and with significantly increased gradient are probably due to the presence the source of tombs.

The maps obtained from the planimetric representation (time-slices) made it possible to follow the development, as depth increases, of these structures and to reconstruct their mutual geometric correlation. This allows to have a view both horizontally and vertical, of the bodies object of investigation and thus to provide useful indications to archaeologists, prior to the planning of direct excavation.

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