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# HIGH RESOLUTION GEOPHYSICAL SURVEYS TO CHARACTERISE NORBA ARCHAEOLOGICAL SITE (NORMA, CENTRAL ITALY)

## 1. Introduction

The integrated geophysical study is part of the 'Norba Project', jointly developed between the University of Campania "Luigi Vanvitelli", the Municipality of Norma (Latina) and the Institute of Heritage Science (ISPC, ex ITABC-CNR). The archaeological site of Norba is located in the Latium Region, about 90 km South of Rome, in Italy. The ancient town of Norba rises on a high plateau overlooking the Pontine plain (Fig. 1a). As stated in previous studies, the town has been founded in the archaic age and its most important period was between 450 BC and 81 BC when it was destroyed. A limited occupation may be detected in the Late Republic/Empire on the so-called Major Acropolis, and only occasionally in other areas of the city. Reoccupation during the early Medieval period was more pronounced, and centered around two temples that were then transformed into churches, but only for a short period.

The site remained uninhabited and since 1960 it has been bound by a provision of Archaeological Superintendency. This is one of the reasons for which the archaeological site is still so well preserved today. The city represents one of the best examples of urban town planning, but its plan does not follow a strict scheme. In fact, Norba's plan is articulated by minor differences in sectors and building blocks depending on the morphological configuration, despite the massive effort that was made to regularize the mountain with impressive terraces and earthen fills.

Many urban elements are still visible today as well as cisterns, wells, ambulatories, underground passages and preserved sections of Roman paving; polygonal walls, with a perimeter of over 2.5 km and several gateways such as the Porta Maggiore, are still observable. The bastion at the Porta Maggiore still stands to 13 m in height. During the last ten years, the site has undergone many studies, followed by circumscribed archaeological excavations, which allowed a regular urban layout, marked by terraces in polygonal walls, several buildings and other important archaeological features to be brought to light. The conservation of the polygonal walls and other structures has attracted to Norba, since the beginning of the 18th century, the attention of the

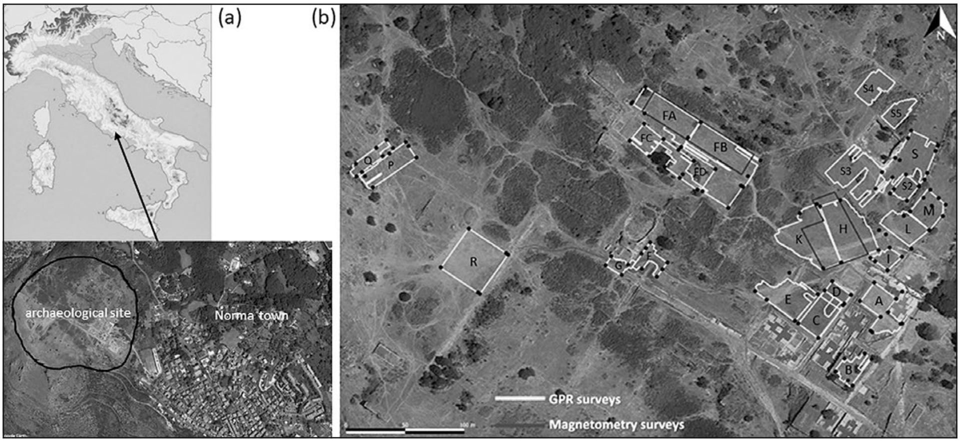


Fig. 1 – a) location of the archaeological site; b) location of the investigated area.

historians and archaeologists. Archaeological excavations were conducted by Savignoni and R. Mengarelli at the beginning of the 20th century in order to date the wall, which was earlier imagined to be Mycenaean or Pelasgian. These scholars' investigations had the great merit of bringing the walls into the Roman era; it has also been used for the experimentation of the first examples of aerophotogrammetric restitution. Thanks to the work of Latium Region and the Municipality of Norma, now the whole site is part of an archaeological park.

Geologically, the area is part of the Lepini Mountain ridge and is characterized by the presence of shallow water platform environments; the prevailing lithology outcropping in the area are Jurassic-Cretaceous dolomitic and micritic limestones.

The 'Norba Project' started in 2017 with new acquisition and processing of extensive geophysical surveys to investigate unexcavated portions of the archaeological site with the aim to enhance the knowledge of the urban plan of the ancient town. Ground Penetrating Radar (GPR) and the Gradiometric (fluxgate differential magnetic) methods have been applied to investigate this site during 2017 and 2018.

## 2. Methods

The geophysical surveys were carried out using the Ground Penetrating Radar (GPR) and the Gradiometric (fluxgate differential magnetic, MAG) methods in the area shown in Fig. 1b. In white are indicated the areas that were investigated using the GPR method; while in black


Fig. 2 – GPR time slices at the estimated depth of 0.90 m for all investigated areas.

are indicated the areas investigated with the Gradiometric method which overlaps two of the areas investigated with GPR. The Gradiometric survey was employed with the aim to compare and integrate the data sets obtained with GPR.

For the measurements, a SIR3000 GPR system (GSSI) equipped with a 400 MHz (GSSI) bistatic antenna with constant offset was employed. The horizontal spacing between parallel profiles at the site was 0.25 and 0.50 m. In the investigated areas, 1199 parallel adjacent profiles across the site were collected alternatively in forward and reverse directions, employing the GSSI cart system equipped with odometer. All radar reflections within the 90 ns (two-way-travel) time window were recorded in the field as 16-bit data and 512 samples per radar scan.

Part of the area surveyed with GPR has been investigated employing the Gradiometric method (Fig. 1b). These surfaces were divided in squares of 20×20 m and of 10×10 m where the gradient of the vertical component of the earth magnetic field was measured using a fluxgate gradiometer FM256 (GEOSCAN Research, UK) along parallel profiles with a horizontal spacing of 1 m and with a sampling interval of 0.5 m along the profile.

Furthermore, the perimeters of all selected areas have been surveyed with the use of a Differential Global Positioning System DGPS OMNISTAR 5220 HP in order to have the correct positioning and georeferencing.

## 3. Processing and results

### 3.1 *Ground Penetrating Radar data*

GPR reflection profiles were analyzed for preliminary identification of the buried features and for calibration of the instrument. Reflection data, collected along the profiles with 0.25 and 0.50 m spacing, were processed using standard techniques (Neubauer *et al.* 2002; Leckebusch 2003, 2008; Piro *et al.* 2003; Conyers 2004; Goodman *et al.* 2004; Linford 2004; Piro, Campana 2012; Goodman, Piro 2013).

The basic radargram signal processing steps included: 1) post processing pulse regaining; 2) DC drift removal; 3) data resampling; 4) band pass filtering; 5) background filter and 6) migration. With the aim of obtaining a planimetric vision of all possible anomalous bodies, the time-slice representation technique was applied using all processed profiles. All the GPR data were processed with GPR-SLICE v7.0 Ground Penetrating Radar Imaging Software (Goodman 2020).

Reflection amplitude 2D maps (time slices) were constructed within various time (and corrected to depth) windows to show the size, shape, location and depth of subsurface archaeological structures (Neubauer *et al.* 2002; Piro *et al.* 2003; Conyers 2004; Gaffney *et al.* 2004; Linford 2004; Goodman *et al.* 2008; Leckebusch 2008; Goodman, Piro 2013). These images were obtained using the spatial averaged squared wave amplitudes of radar reflections in the horizontal as well as the vertical. The squared amplitudes were averaged horizontally every 0.25 m along the reflection profiles and vertically every 3 ns along the time window (with a 10% overlapping of each slice). The resampled amplitudes were gridded using the inverse distance algorithm with a search radius of 0.75 m. Velocities of 0.10 m/ns were estimated using hyperbolae fitting in GPR-SLICE v7.0 imaging software (Goodman 2020).

The 2D GPR amplitude maps, related to the profiles collected with 400 MHz antenna have been analyzed and our attention has been focused to the following time-windows from 5 ns to 30 ns (two-way-time), corresponding to the averaged estimated depth range from 0.25 m to 1.6 m. Fig. 2, corresponding to 0.90 m in depth, shows an overview of all observed reflections due to the presence of the hypothesized archaeological structures.

Taking into account the large number of the investigated areas and all anomalies that are contained inside each area (Piro, Quilici Gigli 2018b), we focus our attention on the interpretation of anomalies contained in H and K areas. These two investigated areas (H and K)

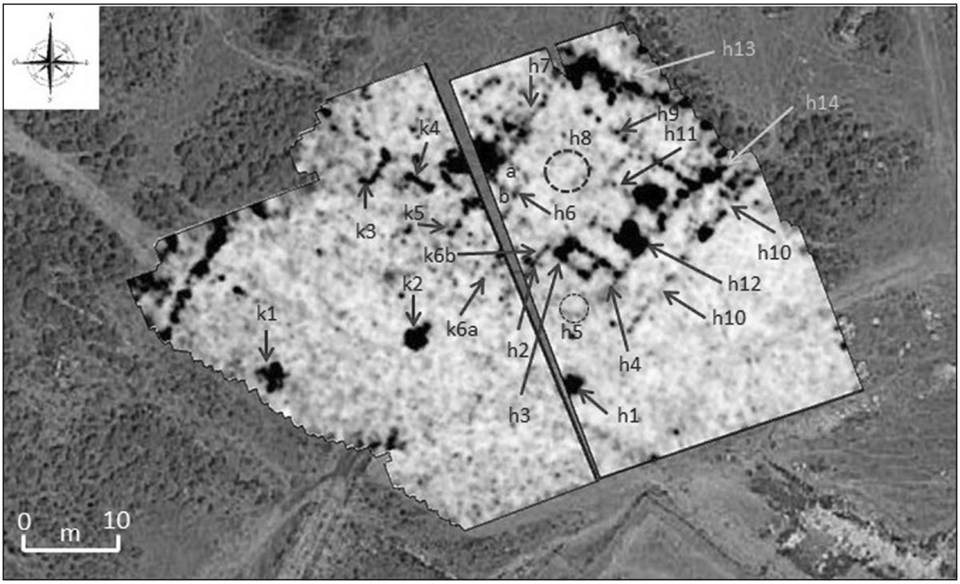


Fig. 3 – GPR time slices at the estimated depth of 0.90 m of H and K areas. The arrows, letters and numbers indicate the observed anomalies.

characterized by interesting anomalies and used as an example of the interpretation method, are presented and described in the following Fig. 3. An analysis of these slices shows that the investigated areas are characterized by the presence of reflections produced from many buried architectural features that are likely walls with different dimensions, cistern and some linear segments of ancient roads.

Fig. 3 shows the anomalies located at the estimated depth of 0.90 m individuated in the area H and K. These areas have been selected to verify the continuation of the street that enters through Porta Maggiore and to confirm the presence of a street with NE-SW direction. The observed anomalies confirm the route of the road to the East of the quadrangular reservoir, that the prospections follow for 25 m in length. The distance between h10 and h14 anomalies indicates a width of 4.3 m. The k6 anomalies show the entrance of a *domus* with a length of 6.3 m and a width of 3.8 m. These dimensions are compatible with those of *domus* like the X. The anomalies k5 and h7 indicate the perimeter of the *domus* on the western side with an overall length of about 23 m and on the eastern side a length of about 18.2 m.

The anomaly h9 can be referred to the back side of the *domus*. Inside there is a series of rooms arranged on a large central space with an average dimension of 113 mq that we recognize which *atrium*. The anomaly h8, in consideration of its dimensions, vertical development till 3 m in depth and a diameter of 4 m, is proposed as a cistern. Overall this interpretation returns the presence of a *domus* with an open entrance along the street that enters from Porta Maggiore and its eastern side arranged along one of its crossroad. The same method of analysis has been employed to interpret all anomalies present in all investigated areas.

### 3.2 *Fluxgate Differential Magnetic data*

Localization of ancient remains of anthropic origin having high susceptibility contrast against the hosting material is without doubt a magnetic task (Scollar *et al.* 1990; Godio, Piro 2005; Piro *et al.* 1998, 2007; Becker 2009). Significant contrast can also be generated by lacking masses as are cavities or structures with low susceptibility contrast. The gradient array facilitates the detection of shallow and small features. The magnetic data were processed with GEOPLOT 3.0 software (GEOSCAN Research). After de-spiking, filtering and rearranging processes, the data were combined in contour maps of the gradient of the vertical component of total magnetic field (Fig. 4). The contour map representing the results of the magnetic method is characterized by the presence of many dipolar anomalies, in the range -300, +300 nT/m, that can be related to the presence of few localized noised bodies and a portion of walls.

The most significant magnetic result is related to the presence of clear dipolar anomalies, characterized by a prevalence of the positive component of the dipole (Fig. 4), probably due to the presence of small metallic objects in the ground. In the area H and K the intense negative nucleus of the dipolar anomalies can be likely ascribed to a buried structure showing negative susceptibility contrast with respect to the surrounding material. This is particular true in the case of an empty cavity or in the case of walls made with materials with lower susceptibility value respect to the surrounding material.

The magnetic data is currently being processed using the normalized bi-dimensional cross-correlation technique in order to enhance the S/N ratio and to better define the spatial location and orientation of the possible targets (Piro *et al.* 1998). This method is a measure of the similarity between the raw data and calculated synthetic anomalies.

With the aim to have a better understanding of the subsurface, qualitative and quantitative integration methods have been employed in few investigated areas. For the integration process the following


Fig. 4 – Contour map of the gradient of the vertical component Z of the earth magnetic field. Range -300 -+300 nT/m.

techniques have been applied: map overlays and RGB colour composites (graphical integration), binary data analysis and cluster analysis (discrete data integration) and data sum, data product and principal component analysis (continuous data integration) (Piro *et al.* 2018). The results obtained employing the quantitative continuous integration techniques are presented in Fig. 5. The analysis of these figures shows that with the continuous integration techniques as the sum of the normalized different data sets and the PCA it is possible to enhance the capability to locate the searched archaeological structures.

## 4. Conclusions

Employing geophysical methods to investigate unexcavated areas of Norba site allowed us to recognize features which are compatible with the information given by the archaeologists in terms of architecture and structure type. The detailed analysis of the results obtained

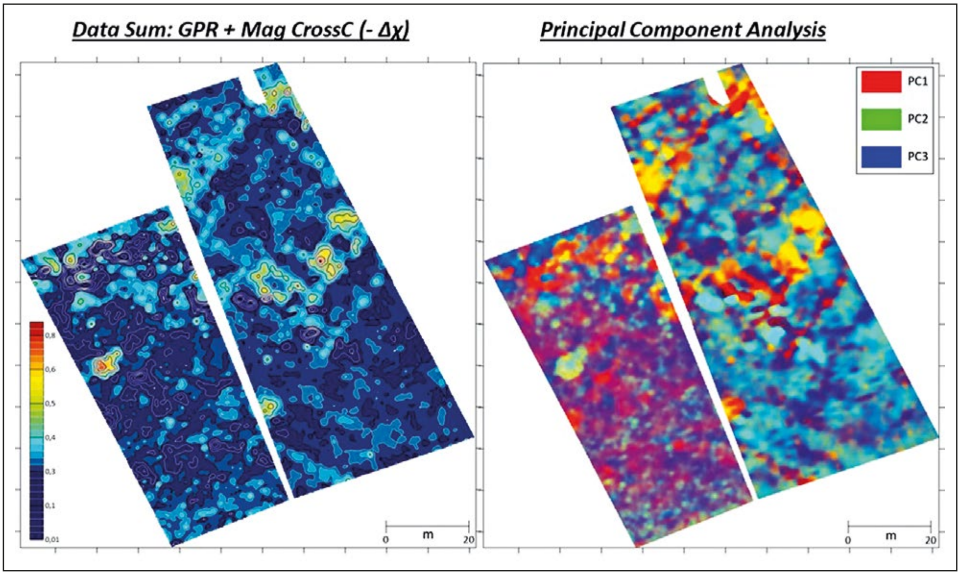


Fig. 5 – Norba, area H-K. Contour maps of the quantitative continuous integration data.

employing GPR surveys, allowed us to recognize the organization of the sectors of the town. Taking into account the environmental conditions and the characteristics of the searched structures, the intrinsic high resolution of the employed methods has allowed the identification and recognition of weak anomalies in the internal part of the buildings.

The integration of different geophysical methods and data analysis has provided an enhancement of different types of data, new analysis and visualization capabilities for future interpretations of archaeological and geophysical features at different investigated area. As expected the integration of different geophysical data sets allow us a high potential to improve the knowledge of the subsurface. As known a single geophysical method might reveal only a portion of the searched buried building. Integrated geophysical data sets may show relationships between the different physical parameters and their contrast between the searched bodies and the surrounding subsoil.

Discrete integrating methods allow application of statistical algorithms to a significant number of geophysical data sets. Continuous data integrating methods generally produce a new data set. This is characterized by the simultaneous presence of all anomalies individuated by the different geophysical methods. In these fused data sets, the anomalous conditions, frequently much less visible in a single data set, can be pointed and analysed. This project is still in progress and new field integrated surveys are planned for the next future.

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## ABSTRACT

The site of Norba is located in the Latium Region, about 90 km S of Rome, Italy. The city is one of the best example of urban town planning, with a regular layout dating back to antiquity. Over the years, many studies and archaeological excavations have brought to light important remains of several buildings, which are still very well preserved. To enhance the knowledge of the unexcavated portions of the archaeological site and to locate the position of the unknown and hypothesized buried structures, extensive geophysical surveys employing the Ground Penetrating Radar (GPR) and Gradiometric methods were planned and conducted between 2017 and 2018. For the measurements, a GPR system SIR3000 (GSSI), equipped with a 400 MHz bistatic antenna with constant offset, was used to survey 27 different sectors close to few excavated areas. Taking into account the environmental conditions of the site and the nature of the buried structures, some areas were surveyed with a spacing interval between parallel profiles of 0.25 m while other areas were investigated with a spatial interval between closed parallel profiles of 0.50 m. Furthermore, fluxgate differential magnetic (Gradiometric) surveys were carried out using the geoscan FM256 in two areas, overlapping the GPR areas. In order to have a better understanding of the subsurface, methods of qualitative and quantitative integration of the results have been employed: maps overlays and RGB color composites (graphical integration), binary data analysis and cluster analysis (discrete data integration), and data sum, data product and principal component analysis (continuous data integration). The results obtained from the geophysical surveys were interpreted together with the archaeologists to define the meaning of the structures identified and to enhance the knowledge of the ancient town's layout and mapping.