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# The location of Emperor Traiano's villa (Altopiani di Arcinazzo - Roma) using high-resolution GPR surveys

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**Abstract -** The villa of the Roman Emperor Marco Ulpio Traiano (A.D. 98-117) was built in Arcinazzo (Italy), approximately 55 km northeast of Rome. Today, the only remains left standing at the site are the public building entrances comprising a small portion of the entire site. Over 5 hectares, adjacent to the entrance remains, were unsurveyed. As part of an ongoing study to rescue this national archaeological treasure, an extensive grid system was laid out at the site and high-resolution GPR surveys using a sub-meter profile spacings were conducted. Amplitude time slice analysis indicates that many structural foundations of the villa are still well preserved below the ground surface. Time slices below 1.5 m in one area indicate several large mushroom shaped structures enclosed within a large building over 100 meters in length. These structures are believed to be dipping pools within a larger structure believed to be the bathhouse to the villa. At a location west of the bathhouse, a large oval shaped anomaly 45 meters along its major axis was discovered. This subsurface structure is believed to be an oval garden pond or a swimming pool. Several other remnants of rectangular buildings coincident with the oval structure but much deeper were also imaged.

## 1. Introduction

Nowadays non-destructive ground-surface geophysical prospecting methods, which involve detailed physical and geometrical reconstruction of subsurface structures, are increasingly used for the investigation of archaeological sites. The integration of Ground Penetrating Radar (GPR) and other geophysical prospecting methods (magnetic and geoelectric methods) offer

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very high resolution sounding capability with detection of features of the order of a few tens of millimetres thickness at ranges of several metres (Cammarano et al., 1997, 1998; Piro et al., 2000; Carrara et al., 2001; Gaffney et al., 2002).

This work summarizes the results of the first step of a research project funded by "Soprintendenza Archeologica per il Lazio" and "Istituto per le Tecnologie Applicate ai Beni Culturali (CNR)" carried out in 1999-2000. The study site was a large expanse of open grazing land that is believed to be the site where Roman Emperor Traiano built one of several villas during his reign. One aim of the project was to determine if GPR mapping of subsurface anomalies could be used to develop a relatively complete map which could be used as a first estimate of archaeological plan of the buried villa.

The villa studied is situated on the high plateau referred to as the Altopiani di Arcinazzo (Roma). These surveys were carried out over two field seasons between 1999 and 2000. Geologic and some preliminary excavations at the villa site suggested that a GPR survey could adequately map subsurface structures down to several meters. The primary goal for doing a remote sensing survey of the site was to determine as much as possible about the location, design and purpose of any buildings that could be identified from the survey. The images obtained from the survey would have a great utility for archaeologists that are planning many years of future excavation at the site. Prior knowledge of subsurface structures from the villa would have a great importance for the archaeologist in developing an excavation strategy as well as helping to effectively manage resources assigned for the excavation.

## 2. Geological and morphological outline of the area

Geologically the site is characterised by the presence of limestone formations of Miocene age with a thickness of about 230 m. This formation is subject to karstic-erosion processes which is exemplified by the strong fracturation (Lupia Palmieri and Zuppi, 1977). The morphology of the area is strongly influenced by the tectonics, which have created a consistently NW-SE trending fracture and fault system across the region.

The most important elements of the landscape associated with the karst-erosion are the dolina, lapiez, and karren stratigraphic formations. Permeation of the area has been facilitated by the difference in height between the Altopiani area (high-plateau) and the sources of the Aniene river. In the north-east section of the villa a spring-source that is present is fed by the Aniene river and arrives at the villa through fractures of Miocene limestone basement. In this area a big rectangular cistern built in the Roman period is still present on the site.

## 3. The archaeological site

Traiano's villa near the Affilani Mountains (Lazio region) is the most inland of all the imperial villas located near Rome (Fig.1). Because the villa is situated high in the mountains suggests that it was probably used for summer holidays and for hunting expeditions.

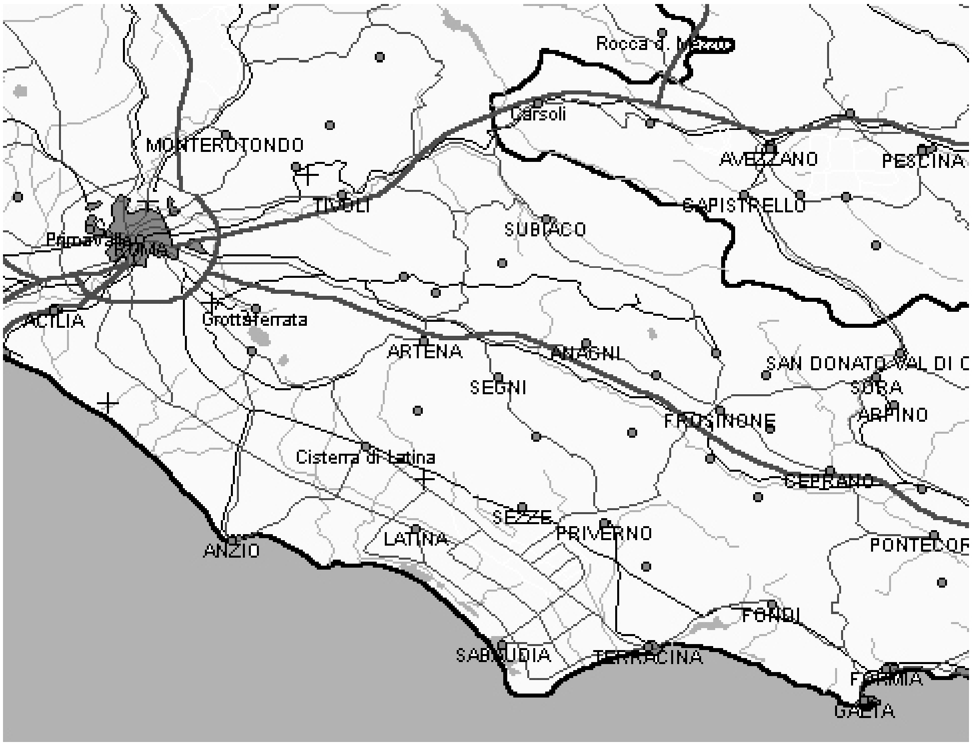


**Fig. 1** - Location map of Traiano’s villa site (Altopiani di Arcinazzo, Subiaco, Roma).

The site was ascribed to be the villa of Emperor Traiano after earlier archaeological excavations made during the 18th-19th centuries. The archaelogical site which is 55 km from Rome, could be easily reached during Roman times by the *Valeria, Sublacensis*, or the *Prenestina* roads. The buildings of the villa are located over flat spaces (*plateae*), with dimensions of about 4 - 5 hectares, and are supported by walls with counterforts and niches (Fig. 2). The lower terrace to the villa has a rectangular dimension of 105 m × 35 m, and is supported in

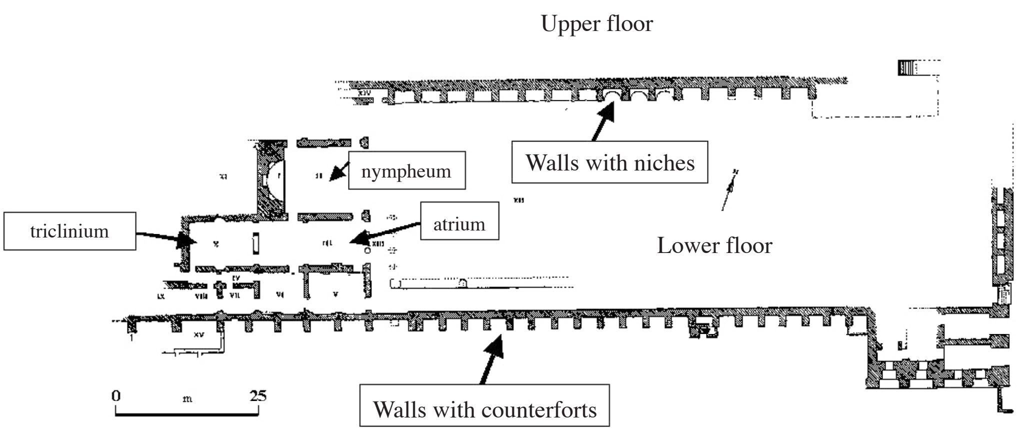


**Fig. 2** - Traiano’s villa (Altopiani di Arcinazzo) Lower flat space, plan view of the excavated structures, in the public portion of the villa (courtesy of “Soprintendenza Archeologica per il Lazio”).

the southern part by walls with counterforts and in the northern part by walls with niches. The central area of this floor was probably occupied by a garden (*Viridarium*), with an external pillared portico (Fig. 2).

On the west corner of this lower terrace there are some public buildings at the entrance to the villa (the *triclinium, atrium and nymphaeum structures*), which have undergone excavations from 1955 to 1985. The wall separated this terrace and the upper levels of the villa are supported by walls over 200 m in length.

The "Soprintendenza Archeologica per il Lazio" started in 1999 with a new archaeological project with the aim to extend the research of 1955-1985 and to rescue this very important historical monument (Fiore and Mari, 1999).

## 4. Methods

### *4.1. GPR data processing and visualization*

The increasing necessity for detailed three-dimensional resolution of the shallow depth structures makes the GPR method one of the most important remote sensing tools. The advantages of 3D surveying are documented for the case of mapping geological features (Grasmueck, 1996; Sigurdsson and Overgaard, 1998); of detecting anti-personnel mines (Zanzi and Valle, 1999); as well as for archaeological investigations, where the higher horizontal and vertical resolution is required (Malagodi et al., 1996; Conyers and Goodman, 1997; Leckebusch, 2000; Tomizawa et al., 2000). High-resolution acquisition techniques, using a sub-meter profile spacing interval, have been successfully applied in locating subsurface archaeological structures (Goodman et al., 1995; Malagodi et al., 1996; Pipan et al., 1996, 1999, 2001; Basile et al., 2000), and also to image large scale archaeological features (Archaeological Prospection 1999, 2001; Edwards et al., 2000; Kamei et al., 2000; Nishimura and Goodman, 2000; Piro et al., 2001).

One of the most useful presentations of the GPR data sets collected along closely spaced parallel profiles is to display the data in horizontal maps of recorded reflection amplitudes measured across the survey grid. These maps, referred to as amplitude time slices, allow easy visualisation of the location, depth, size and shape of radar anomalies buried in the ground. The maps can be created at various reflection time levels within a data set to show radar structures at a specified time (depth) across a surveyed site. Mapping the energy in the reflected radar returns across a survey grid can help to create useful information that can sometimes mirror the general archaeological site plan result obtained from invasive excavation (Goodman et al., 1995; Malagodi et al., 1996; Conyers and Goodman, 1997).

The raw reflection data acquired by GPR is nothing more than a collection of many individual vertical traces along 2-D transepts within a grid. Each of those reflection traces or radargrams contains a series of waves that vary in amplitude depending on the amount and intensity of energy reflection that occurred at buried interfaces. When these traces are plotted sequentially in standard 2-D profiles, the specific amplitudes within individual traces that contain important reflection information are usually difficult to visualise and interpret. In areas where the stratigraphy is complex and buried features are difficult to discern, amplitude time slice analysis is one of the most efficient post processes that can be applied to the raw data to extract the 3-D shapes of buried remains (Malagodi et al., 1996; Zanzi and Valle, 1999; Piro et al., 2001).

Due to velocity changes across the area and with depth, a slice map made across a constant level time window will not represent a level slice in terms of depth in the ground. Horizontal time slices must therefore be considered to be only approximate depth slices. Without a very detailed velocity control throughout a grid, it is impossible to construct perfectly horizontal depth slices (Leckebusch, 2000).

To compute horizontal time slices, the employed software compares amplitude variations within traces that were recorded within a defined time window. When this is done, both positive and negative amplitudes of reflections are compared to the norm of all amplitudes within that window. No differentiation is made between positive or negative amplitudes in this analysis, only the magnitude of amplitude deviation from the norm. Low-amplitude variations within any one slice denote little subsurface reflection, and therefore indicate the presence of fairly homogeneous material. High amplitudes indicate significant subsurface discontinuities and in many cases detect the presence of buried features. Finally, data are interpolated and gridded on a regular mesh (Malagodi et al., 1996; Conyers and Goodman, 1997; Basile et al., 2000).

A high-to-low amplitude scale is normally presented as part of the legend of each map, but without specific units because, in GPR, absolute reflected wave amplitudes are usually arbitrary.

### *4.2. Instrument configuration and measurement parameters*

GPR surveys were performed in November 1999 and in May 2000, for a total of two weeks as a field work, in the area A-B and C indicated in Fig. 3. For the measurements a GSSI SIR $10A^+$, equipped with a 300 and 500 MHz bistatic antenna with constant offset, were employed.

Single-fold exploratory profiles were first carried out at the site with the following objectives:

- preliminary identification of the targets;
- calibration of the instrument;
- selection of the optimum frequency antenna;
- analysis of the subsurface response as a function of the orientation of the profiles.

The first GPR survey concentrated on the upper terraces of the site (A in Fig. 3), in the east portion of the area.

Adjacent profiles at the site were collected alternately in reversed and unreversed directions across the survey grids. The horizontal spacing between parallel profiles at the site was 0.5 m. Radar reflections along the transepts were recorded continuously across the ground at 80 scan $s^{-1}$; horizontal stacking was set to 4 scans. The gain control was manually adjusted to be more effective. Along each profile markers were spaced every 1 m to provide spatial reference. The

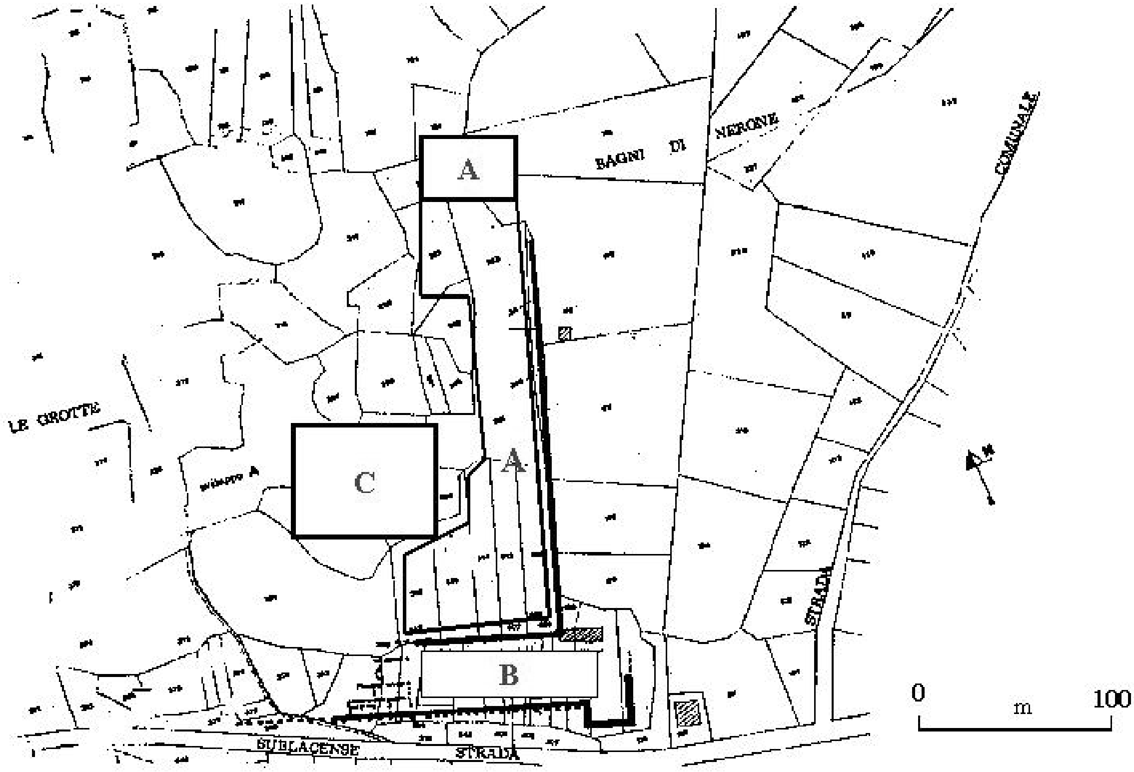


**Fig. 3** - Traiano’s villa (Altopiani di Arcinazzo). Location of the investigated areas: A, B and C.

data were later corrected for a variation in speed to a constant 30 scans per metre (or 1 scan per approximately 0.03 m).

All radar reflections within a 75 ns (two-way-travel time) time window were recorded digitally in the field as 8 bit data and 512 samples per radar scan.

The survey was carried out within a block measuring 60 m (west-east) by 220 m (south-north). This area was investigated using the 300 and 500 MHz microwave antenna. The profiles collected with the 300 MHz were similar with the higher horizontal resolution obtained with the 500 MHz antenna. In this paper we present only the results from the 500 MHz survey.

The second GPR survey was concerned with an area in the western portion of the upper terrace of the villa (C in Fig. 3). The same measuring parameters, within a 105 ns (two-way-travel time) time window were adopted. The survey was carried out within a block measuring 120 m (west-east) by 85 m (south-north).

An accurate estimation of the microwave velocity can be allowed using a CMP acquisition technique (Malagodi et al., 1996; Basile et al., 2000; Pipan et al., 2001); but on this occasion it was not possible because of some technical problems for the 100 MHz antenna in bistatic configuration. Therefore, we obtained an approximate microwave velocity of about 6 cm ns$^{-1}$ using an experimental profile carried out in correspondence of a site where the archaeologist knows the depth of a wall remains.

Finally, a GPS survey using a D-GPS Leica 520, in a differential configuration mode, was made with the aim of positioning all the investigated areas and orienting these maps with respect to the known excavated structures of the villa.

## 5. Data elaboration and presentation

Time slice analysis was applied to all the surveyed grids at the villa of Traiano. For site A, time slices were generated at 5 ns intervals, while for site C the time slices were computed at a thicker time window of 9 ns. The time slice data sets were generated by spatially averaging the squared amplitude of radar reflections in the horizontal as well as the vertical. Horizontal averaging included creating spatial averages every 0.5 m along the radar transepts. The data were gridded using a Krigging algorithm that included a search of all data within a 1.0 m radius of the desired point to be interpolated on the grid.

Filters were used to remove the background reflections and linear striations for each individual line in the survey grid. The filters were applied to the time slice data set, computing a moving window average with a filter length set by the users. The filter has a threshold amplitude setting that only allows values below these amplitudes to be included in the computation of the moving filter average. The threshold amplitude is set to a value just below the primary target signals which were strong recorded reflections from Roman walls. The moving average is subtracted from the centre value of the filter to remove the background reflections. In addition to removing striation noise along the profile directions, the filter also has the effect of removing the mosaic pattern inherent in comprehensive maps showing adjacent areas having different background geology or slightly different ground conditions. Thresholding and data transforms were used to enhance various features detected on the time-scale maps.

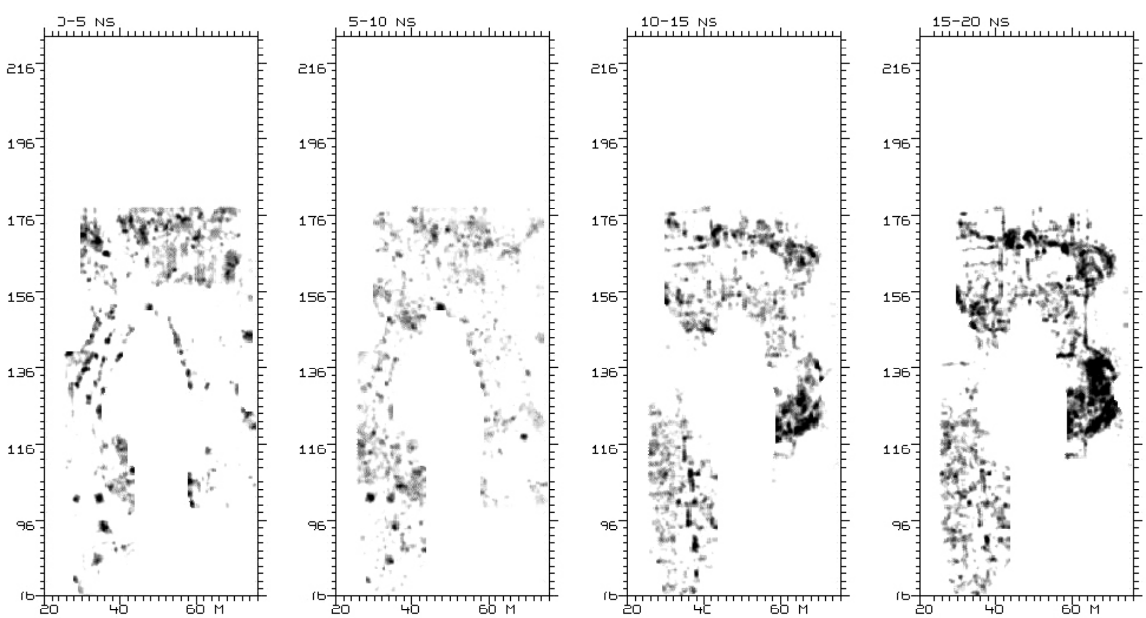


**Fig. 4** - Traiano's villa, area A. Time slices obtained in the time-window 0 – 20 ns (twt).

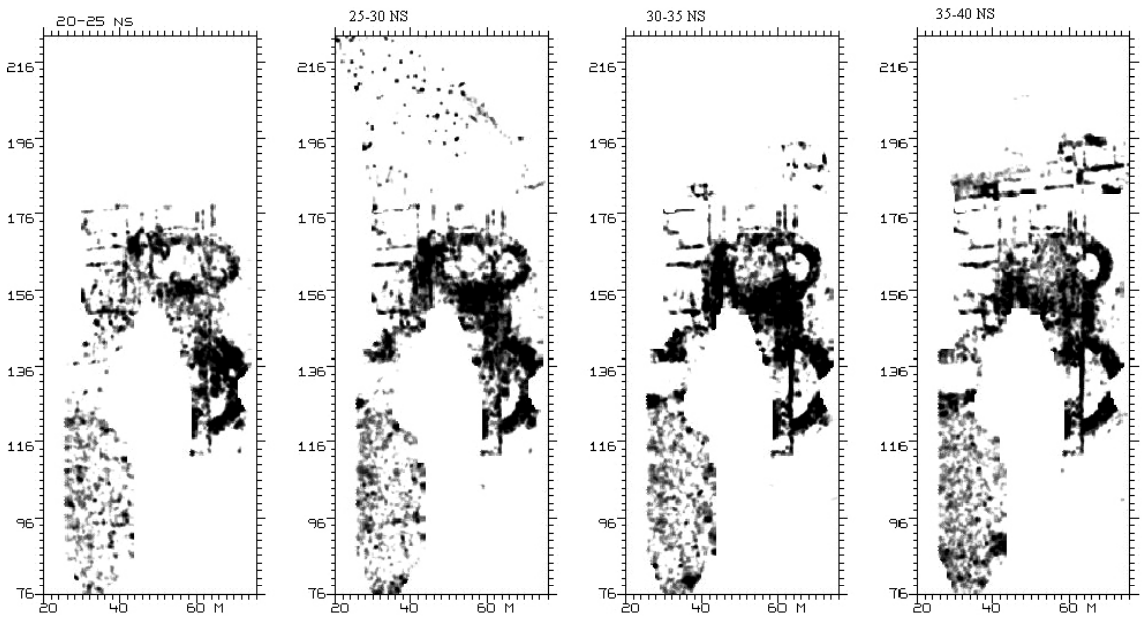


**Fig. 5** - Traiano's villa, area A. Time slices obtained in the time-window 20 – 40 ns (twt).

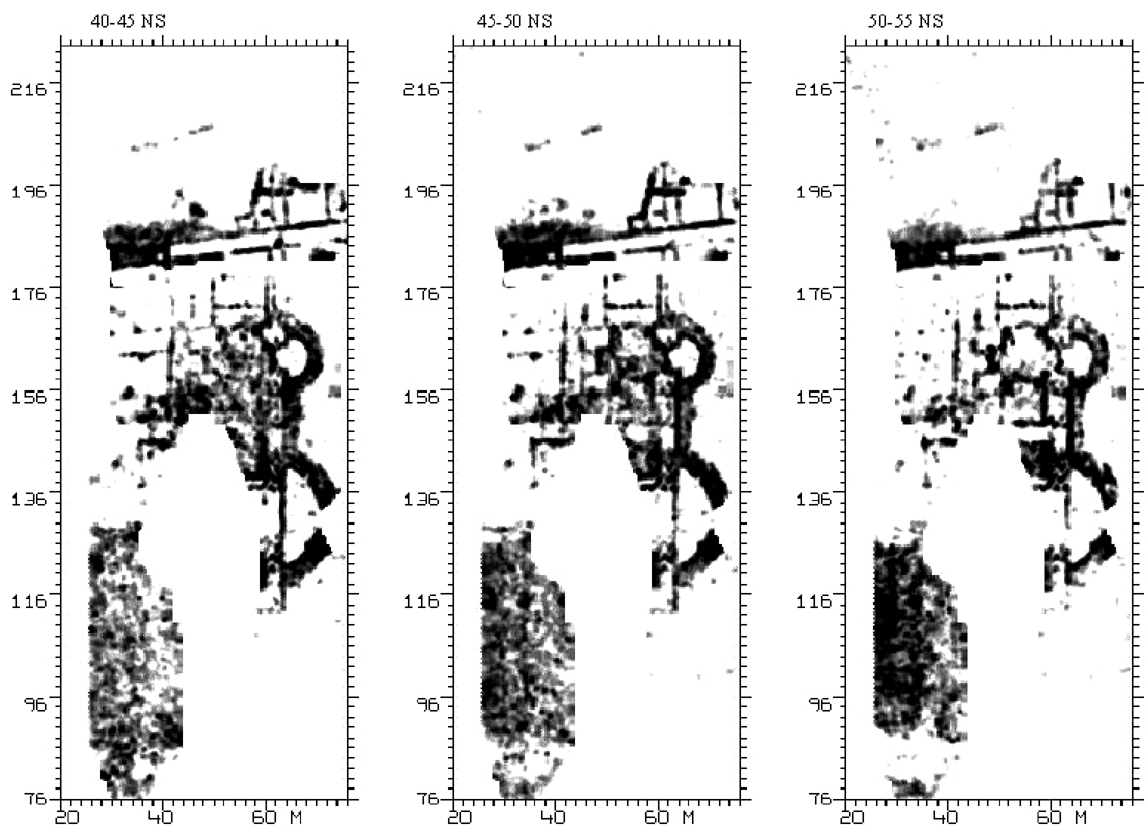


**Fig. 6** - Traiano's villa, area A. Time slices obtained in the time-window 40 – 55 ns (twt).

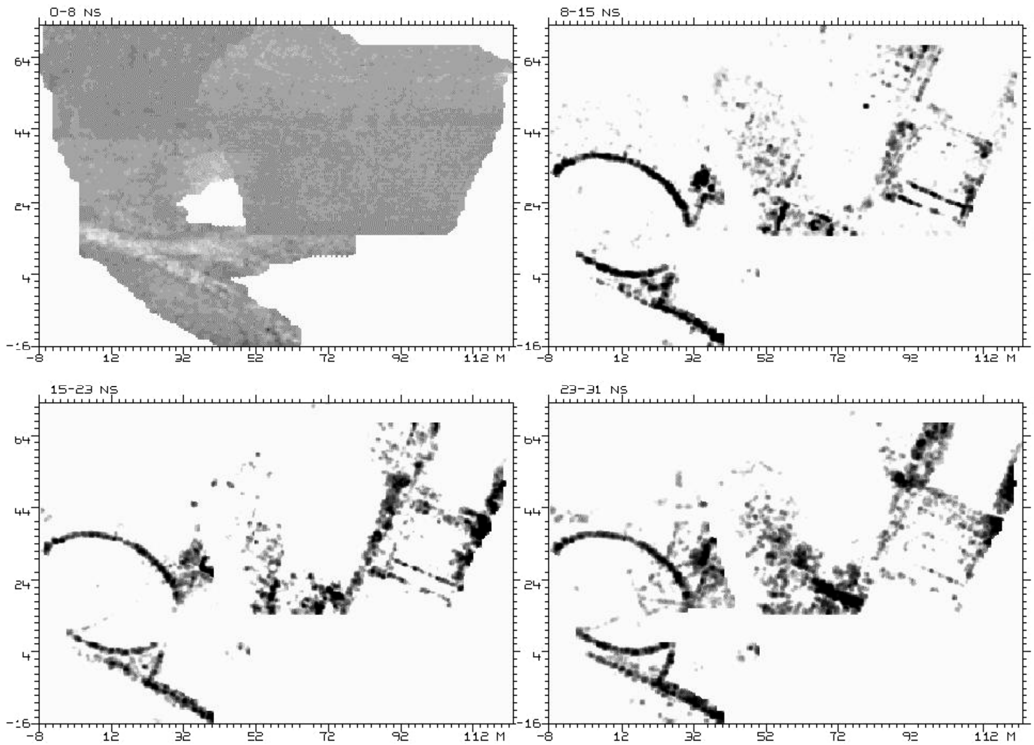


**Fig. 7** - Traiano's villa, area C. Time slices obtained in the time-window 0 – 31 ns (twt).

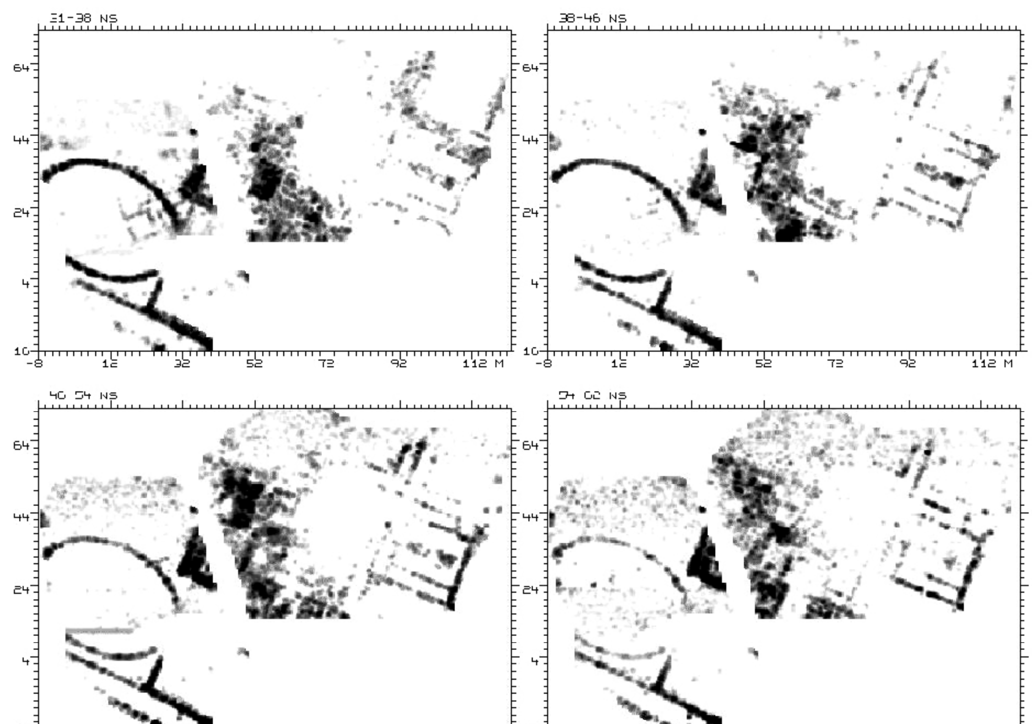


**Fig. 8** - Traiano's villa, area C. Time slices obtained in the time-window 31 – 62 ns (twt).

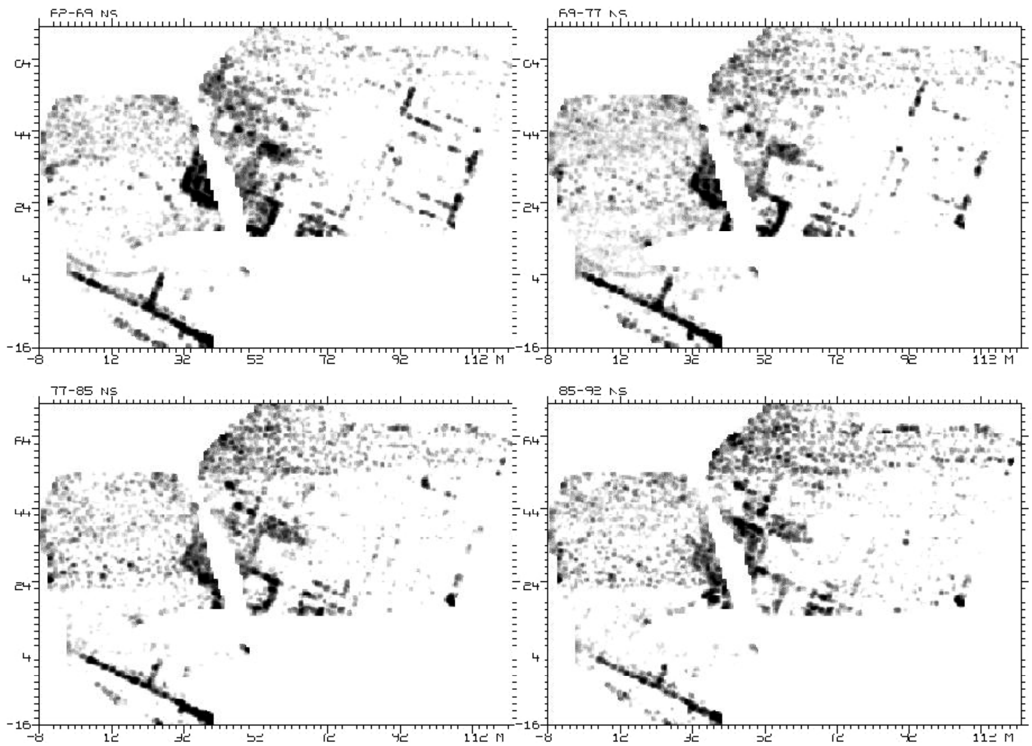

**Fig. 9** - Traiano's villa, area C. Time slices obtained in the time-window 62 – 92 ns (twt).

In Figs. 4 to 6 several time slices (10-15, 25-30 and 50-55 ns) are shown for the upper terrace to the villa. On the 10-15 ns time slice map (estimated depth 0.3-0.45 m) many anomaly structures are visible. The clearest results were obtained at the 25-30 ns (0.70-0.90 m in depth) to the 50-55 ns (1.5 ÷ 1.7 m in depth) slices, in which the location of many walls, having different shapes, sizes and orientation could be clearly imaged. This area is characterised by the presence of various rooms, halls, associated with the private areas of the villa. Several mushroom shaped anomalies are seen which are believed to be dipping pools in the bathhouse.

Figs. 7 to 9 show time slices of the western section of the upper terrace of the villa. On the slice 8-15 ns (0.25-0.45 m in depth) the area is characterised by the presence of two particular structures. The westernmost features show an oval shaped structure. It is not clearly known at this time what it is, however, archaeologists suspect that this structure may be a fish or garden pond, or possibly a swimming pool. Below this structure, square shaped rooms become visible. The large structure on the easternmost side of this area shows a very big complex characterised by large rectangular rooms and corridors.

Fig. 10 shows the results of the GPR survey mapped with the known results from archaeological excavations of the villa. The results contained in this figure have helped the archaeologists to understand the preliminary design of the individual structures, and to make a preliminary correlation between the layout of various buildings and their function within the villa complex .

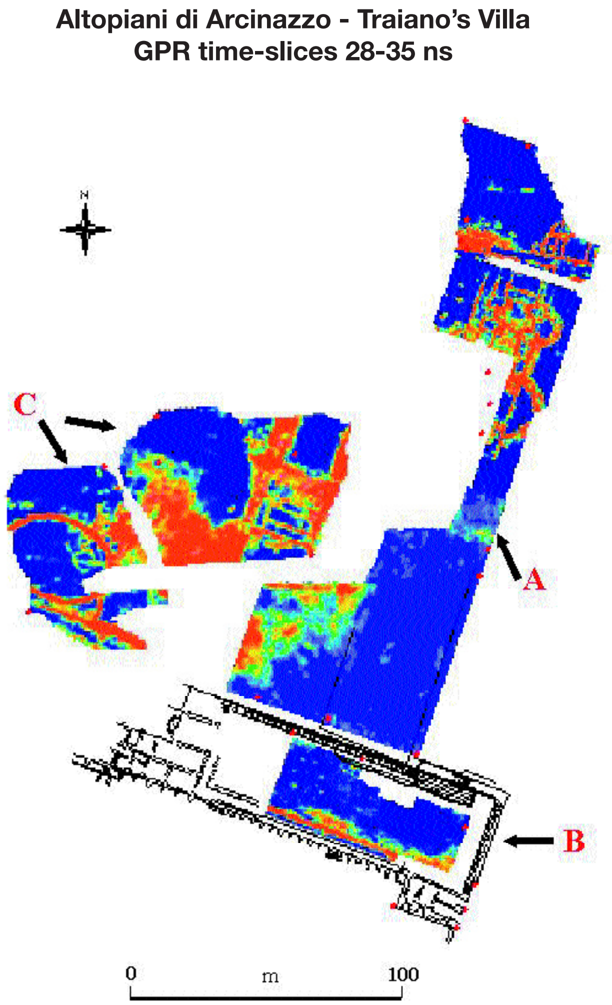


**Fig. 10** - Traiano's villa. Planimetric vision of all individualized archaeological features, located and oriented with respect to the known excavated portion of the villa. The letters A, B and C indicate the investigated areas of Fig. 3.

## 8. Conclusions

The results from this GPR survey provided subsurface radar images of Traiano's villa. Using the results from time slice analysis the archaeologists have interpreted the structures in the eastern portion of the surveyed areas, to be related to private *domus* or *palatium* of the villa. A group of quadrangular rooms, connected with each other and crossed by corridors, and semi-circular rooms were located with great accuracy and resolution. These semi-circular or mushroom shaped reflections are interpreted as thermal rooms (*balnea*) or dipping pools. In the western portion of the area, an elliptical shaped structure was interpreted by the archaeologists as being possibly a garden pond. Below this structure other squared rooms with smaller dimensions are visible.

The results of this study show that GPR is very effective in mapping wall-remains and floors of an archaeological structure. The location, depth, size and general structure of the buried buildings were effectively estimated from non-destructive remote sensing with a ground-penetrating radar system.

The archaeologists of the Soprintendenza have helped us, with their knowledge of the characteristics of the expected structures, in determining the processing parameters and visual format of the final output to enhance the features of interest.

This project is still in progress with the aim of applying the integrated approach using other geophysical techniques as magnetic and geoelectric methods. The employment of these techniques will provide information to characterise the individuated structures physically and geometrically. Finally, the reconstruction of a 3D GPR image of the sought diffracting or reflecting structures could be obtained through the application of the appropriate processing as proposed by Zanzi and Valle (1999).

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