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Abstract

The first attempts to apply geophysical methods to archaeological sites in Portugal date from the mid-sixties of the last century. Since then, geophysical methods have been used more and more frequently to help with archaeological site recognition, delineating buried structures, and help with excavating strategies. The first geophysical methods used in Portugal were geoelectrical methods followed by magnetic methods. Today these two methods are still used but the georadar and the electrical resistivity tomography methods have also been used on a routine basis whenever local conditions permit.

Four archaeological sites will be described as examples on the use of geophysical methods in Archaeology. Two of them are from roman times (the Roman Villa of Tourega in central Portugal and the Roman town of Troia in the west coast of Portugal), one is from Neolithic times (a burial mound in central Portugal) and the last one is a recent archaeological site (eighteenth century) and has to do with the location of a crypt known to exist in the garden of the Portuguese Legislature in Lisbon.

Only electrical resistivity tomography and georadar were used. The sites were chosen because in all of them there were already previously excavated areas or there were plans for future excavation. When choosing these sites the idea was to be able to compare the interpretations of the geophysical data with the results of future excavations.

Archaeological Geophysics in Portugal: Some Survey Examples

5

António Correia

Abstract

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Only electrical resistivity tomography and georadar were used. The sites were chosen because in all of them there were already previously excavated areas or there were plans for future excavation. When choosing these sites the idea was to be able to compare the interpretations of the geophysical data with the results of future excavations. AU2

5.1 Introduction

To the author's knowledge, the first geophysical methods used in archaeological prospection in Portugal date from the early sixties of the last century (dos Santos and Esteves 1966; Tite and Alldred 1965–1966). Since then many other researchers have been using different geophysical methods for detecting, delineating, and studying areas where archaeological remains are suspected to exist underground.

Geoelectrical methods were the first ones to be used in archaeological prospecting in Portugal. In the beginning of the nineties of the last century, in addition to geoelectrical methods other methods such as magnetics and georadar began to be used.

Nowadays, and following the general trend around the world, almost all geophysical methods are used to study archaeological sites. Georadar (with several antennae), electromagnetic methods, electrical resistivity tomography in two

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and three dimensions, magnetic gradiometer surveys and magnetic susceptibility surveys are routinely used in archaeology as a means of uncovering buried artefacts in sites with archaeological interest.

In this chapter four archaeological sites where geophysical methods were used are presented. The first is a Neolithic burial mound called Anta das Moitas; it is located in central Portugal near the town of Proença-a-Nova. The second site is an isolated roman villa located near the town of Évora in Central Portugal (the Roman villa of Tourega). The third site is a Roman town with a fish paste factory located near the sea and close to the town of Setubal (Roman ruins of Troia). The last site is a crypt which is located under the garden and parking lot of the Portuguese Legislature in Lisbon. All the sites that will be described in this chapter will be excavated sooner or later which means the geophysical interpretations will be compared with new information from excavation activities.

Figure 5.1 shows the locations of the four archaeological sites.

5.2 The Archaeological Sites

5.2.1 Neolithic Burial Mound of Anta das Moitas in Proença-a-Nova

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5.2.1.1 Introduction

The municipality of Proença-a-Nova, in cooperation with Emerita Ltd., has been excavating several archaeological sites near the town of Proença-a-Nova. The region is well known for the abundance of archaeological sites from the Neolithic period. One of the sites (see Fig. 5.1 for location), near the village of Moitas, is a Neolithic burial mound, known as Anta das Moitas (Fig. 5.2). The excavation in the site started in the summer of 2013 and is still progressing (Fig. 5.3); however, before excavating the site a geophysical survey using ground penetrating radar (GPR) and electrical resistivity tomography (ERT) was done as an attempt to find the location of the burial mound's chamber and its main entrance. Both ERT and GPR profiles were measured along the same directions shown in Fig. 5.2. In principle GPR would allow the identification of the slabs of schist which form the walls and the cover of the dolmen and the possible entrance, from the clay and silt that cover the structure. Since the moisture in the soil was relatively large, ERTs should also give information about depth and orientation of the schist slabs, which have higher electrical resistivity than the soil.

Since 2013 there has been an archaeology summer school funded by the municipality of Proença-a-Nova to excavate and prepare students in archaeological activities and, at the same time, improve and allow the access of the general public to the sites. All these activities are integrated in a wider study of pre-historical dolmen burial sites that is taking place in Portugal.

For those interested in seeing the area of the burial mound, the geographical coordinates in the Google Earth are: 39°43′28.50″N, 7°51′33.37″W. The average altitude of the site is 375 m a.s.l.

5.2.1.2 Method

For the Anta das Moitas archaeological site two geophysical methods were used; electrical resistivity tomography and ground penetrating radar (Fig. 5.4). Both were carried out along the profiles shown in Fig. 5.2; however, for the GPR method three parallel profiles, 0.5 m apart, were carried out along the two profiles. Both ERT and GPR profiles were 39 m long. The ERT profiles were done using a Wenner configuration with 40 stainless steel stacks 1 m apart. As can be seen in Fig. 5.2, profile 1 crosses the centre of the mound. In the figures where the ERT profiles are shown bluish colours represent low electrical resistivities and reddish colours represent high electrical resistivities.

5.2.1.3 Some Results

Figures 5.5 and 5.6 show the ERT obtained along the profiles 1 and 2. No figures are shown for the GPR profiles done; the results were inconclusive, as is explained later.

Fig. 5.1 Location of the four archaeological sites (red triangles) of this chapter. 1 refers to the burial mound in Proença-a-Nova, 2 the Roman villa of Tourega, 3 the Roman ruins of Troia, and 4 the Portuguese Legislature in Lisbon

The ERT along profile 1 (Fig. 5.5) shows that there are basically three areas, from left to right: a shallow reddish area near the limits of the profile (between 0 and 13 m, and between 28 and 38 m) which show high electrical resistivity values; a central and shallow area also with high electrical resistivities but lower than in the first area (yellow and brown colours) (between 17 and 19 m); a deeper area with bluish colours (between 8 and 17 m, and between 21 and 27 m) with relatively low electrical resistivities.

The first area in the ERT was interpreted as a zone in the mound with blocks of superficial rocky material which were visible after cleaning the first layer of the soil covering it. The second area was interpreted as the possible entrance to the chamber of the dolmen which is assumed to be full with soil and small rocks/pebbles fallen from the upper part of the ground. The third area was interpreted as finer soil (clay or silt) saturated with water.

As the excavation proceeded it was apparent that the geophysical interpretation was close to what was being uncovered (Fig. 5.3).

The ERT along profile 2 (Fig. 5.6) shows that, in geoelectrical terms, there are basically two areas: a shallow area (with reddish colours) located in the extremes of the profile (between 0 and 12 m and between 27 and 39 m) with high electrical resistivity values, which was interpreted, as in profile 1, as a zone covered with blocks of superficial rocky material; a central area (between 11 and 26 m, with bluish colours) with depths that vary between 1 and 5 m was

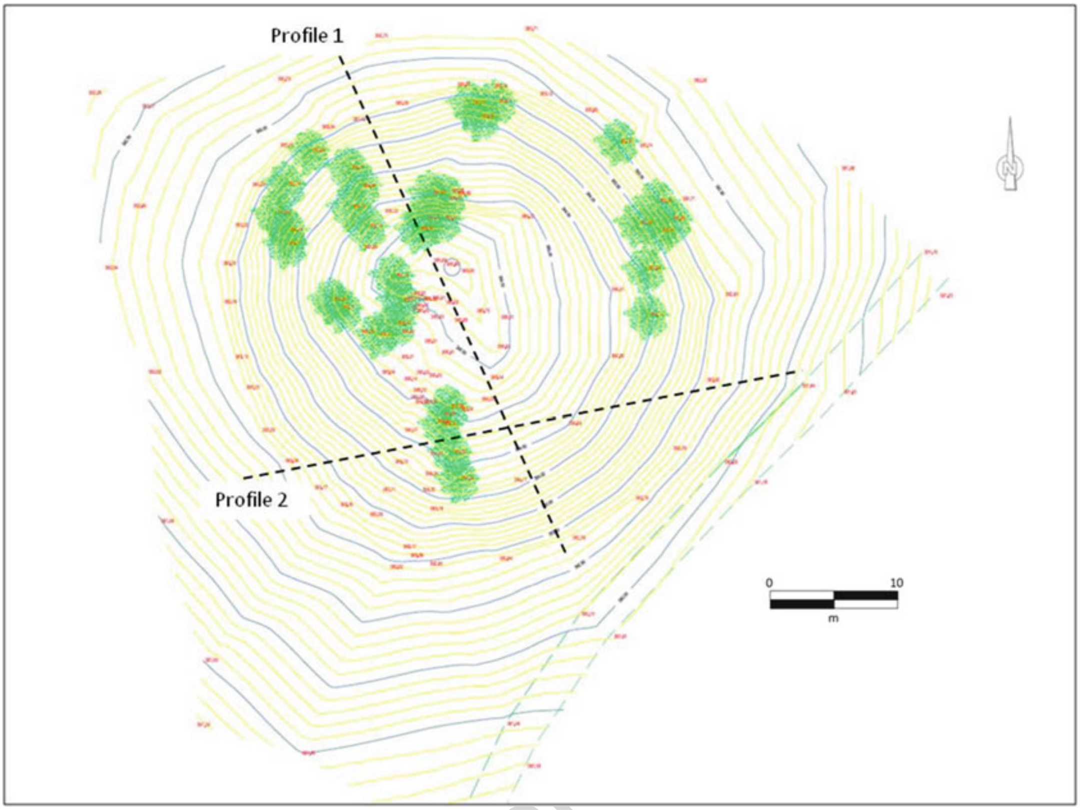

Fig. 5.2 Topographic map of the mound's area (Anta das Moitas). Profile 1 and 2 indicate the orientation of the two electrical resistivity tomography and ground penetrating radar profiles done. In green the location of trees

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interpreted as clayey or silty material that was used to fill the area around the dolmen, which was confirmed during the excavation stages.

The results from the ERT profiles and from the excavation allowed understanding as to why the GPR did not give any good results in this particular archaeological site. As a matter of fact, after starting the excavation and cleaning the first layers of soil it was seen that they covered blocks of rocks that are used to protect the filling material (clay and silt) that was used to cover the dolmen. These rocks behaved as intense diffractors of electromagnetic energy making the obtained radargrams not very useful for a geophysical interpretation of the buried structures in the ground.

5.2.1.4 Conclusions

From the two geophysical methods used up to now in the Anta das Moitas archaeological site, only the electrical resistivity tomography has shown good potential to detect and delineate the structure of the dolmen buried in the site. This contrasts with ground penetrating radar which was not very useful to detect those same structures.

With the ERT profiles it was possible to infer that the mound was covered by blocks of rocks which were placed on top of clay and silt, possibly to protect them from erosion. The slabs of schist that compose the walls and the cover of the dolmen chamber were also identified by the ERT profile 1.

Future geophysical surveys will concentrate on trying to discover the main entrance of the dolmen which in Iberia is normally oriented to the east. It is also expected to use magnetic methods (magnetic and gradiometer surveys) in the summer school to take place in 2017.

Fig. 5.3 Excavated area at the end of the summer of 2014. The red arrow indicates the geographical north. The blocks that constitute a protection cover for the clay and silt underneath can be seen as well as the slabs of schist that make the walls of the dolmen

Fig. 5.4 Using the GPR during the summer of 2013 along profile 2 of Fig. 5.2

This archaeological site appears to be a very interesting place to test several geophysical techniques, even more so because it will be completely excavated in the near future; this will allow comparing geophysical interpretations from several methods with the results of the excavation.

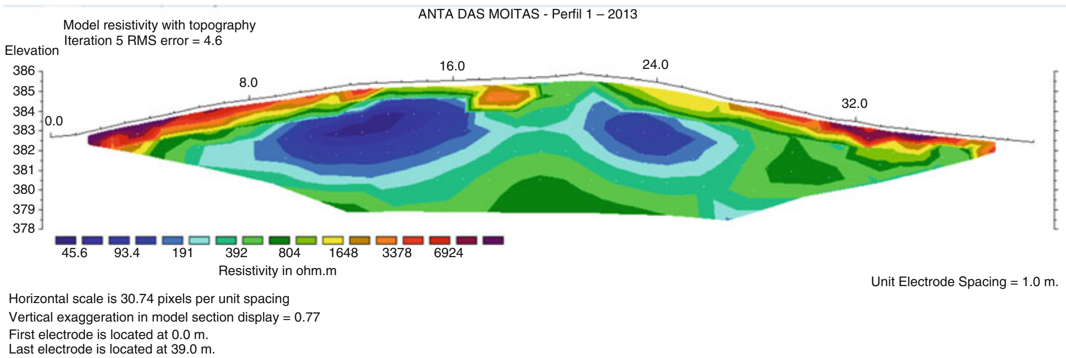

Fig. 5.5 Electrical resistivity tomography along profile 1. Bluish colours correspond to low electrical resistivities while reddish colours correspond to high electrical resistivities. See text for interpretation

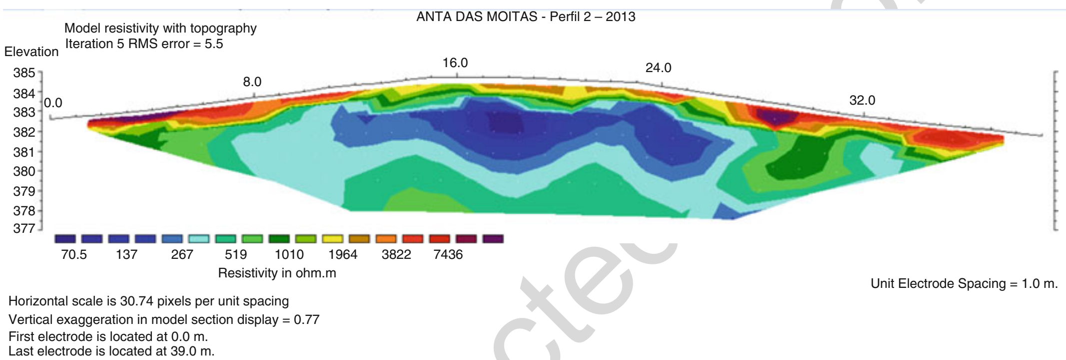

Fig. 5.6 Electrical resistivity tomography along profile 2. Bluish colours correspond to low electrical resistivities while reddish colours correspond to high electrical resistivities. See text for interpretation

5.2.2 Roman Villa of Tourega (I–IV a.D.)

5.2.2.1 Introduction

In the process of locating and mapping the most appropriate archaeological site for testing new ground penetrating radar (GPR) acquisition techniques, a subsurface survey of the surroundings of exposed structures was conducted in the Roman villa of Tourega. The villa is located about 15 km southwest of the town of Évora, in the Alentejo region in central Portugal. A bath-house structure as well as a large water tank reservoir have been previously excavated (Fig. 5.7). At this particular site only GPR methods were used with the goal of finding and delineating possible extensions of the villa complex; the main GPR target was then to identify linear archaeological structures, basically building walls.

From archaeological artefacts it was possible to infer that the villa was occupied from the first to the fourth century a.D. A funerary inscription for a roman senator, dating from the early third century a.D., suggests the villa belonged to a senatorial family for some period and the pottery found indicates a connection of Tourega to roman trade routes of the time (Vaz Pinto et al. 2004). Figure 5.8 shows an interpretation of the excavated structures.

This site was chosen for a geophysical survey using the GPR method because of the expected linear structures associated with roman buildings. Furthermore, the already excavated area could

Fig. 5.7 Picture of the remains of the Roman villa of Tourega, about 15 km southwest of the town of Évora in central Portugal

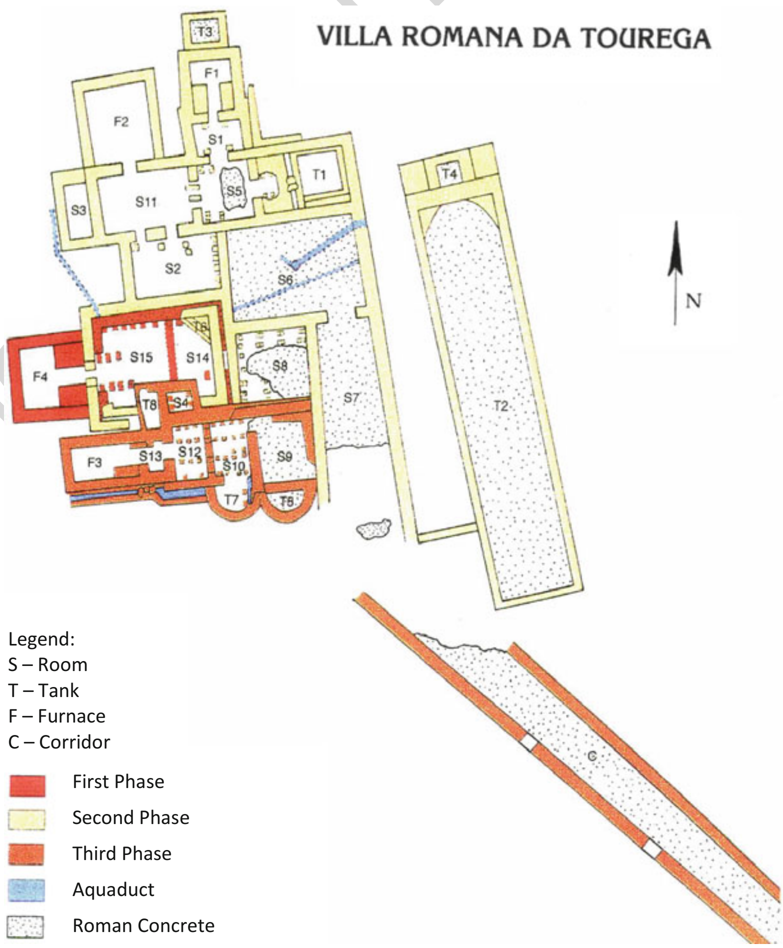

Fig. 5.8 Cartoon of the excavated portion of the site. There were three main phases of construction which are represented by a different colour

serve as guidance for type, orientation and depth of the expected structures.

For this archaeological site a summary of the results of these surveys is presented here as they contain useful information on the location and possible extension of still buried structures.

The location and depth information is of sufficient quality to be used in the planning of future excavations and in the planning of more extensive geophysical surveys with the sole objective of mapping archaeological remains.

For those interested in seeing the area of the roman villa, the geographical coordinates in the Google Earth are: 38°30′6.95″N, 8°01′41.38″W. The average altitude of the site is 199 m a.s.l.

5.2.2.2 Method

A Sensors & Software Inc. Noggin 500 MHz GPR system and a Sensors & Software Ink PulseEKKO system with bistatic 200 MHz antennae were used for the main subsurface mapping survey; however, the results obtained with the 200 MHz antennae will not be shown here. The survey was constrained to an area delimited to the North and West by the fence enclosing the archaeological site, to the East by the excavated site itself and areas of high grass and thick shrubbery, and to the South by another fence and zones of slightly more abrupt topography.

To make the acquisitions more convenient, a main grid was laid out and subdivided into several square or rectangular sub-grids. The most common line spacing used was 1 m, which is generally too coarse for 500 MHz data but was sufficient in our case for locating test areas. Three sub-grids were re-acquired using a more appropriate 0.50 m line spacing to assess the reliability and resolution degradation of the main data set. GPR lines were collected in both orthogonal directions (X and Y); the X axis approximately corresponds to the N–S direction and the Y axis approximately corresponds to the E–W direction. The radar antennae were dragged directly on the ground; data acquisition was generally complicated by the overgrown grass. A straight-line progression was difficult to achieve, and a consistent and even pacing of the profiles was hard to maintain throughout the survey. This inevitably resulted in a degraded positioning accuracy which is difficult to quantify. Overall, the 500 MHz data consist of a total line length of 2180 m in the N–S direction and 1470 m in the E–W direction, plus an additional 220 m for the slanted grid. This represents a total of 3870 m.

A maximum time window of 75 nanoseconds (ns) was used, which, based on average wave velocity, corresponds to a maximum depth of investigation of approximately 3.5 m. 200 MHz and 500 MHz common-offset and 200 rapid multi-offset data were collected for processing experiments. Processing was standard and consisted of dewowing, time-zero shift, spherical and exponential gain, bandpass filtering, and fk migration.

Figures 5.9 and 5.10 show time slices for 8 and 10 ns, respectively. A velocity of 0.12 m/ns was used.

5.2.2.3 Some Results and Conclusions

The most obvious result is that GPR has proved to be successful in imaging buried stone structures at the Tourega site. GPR is used fairly routinely for the prospection and study of Roman period sites in areas with well developed soils and sedimentary bedrock, mostly in Northern Europe. The success in the case of structures built directly onto granitic bedrock with relatively little soil was not assured. The Tourega results are therefore important as they demonstrate that this technique can be used very effectively in a wide variety of conditions. An abundance of buried structures can be seen in direct connection with the end of the current excavation (Figs. 5.9, 5.10 and 5.11). The corridor does seem to end at the end of the excavation; it appears to be connected to another structure that makes an angle with it. It is clear that the south fence does not mark the end of the site in this direction. There is an obvious continuation of the structures S and W of the fence. The continuation of the structures to the E of the surveyed area is not so obvious but is

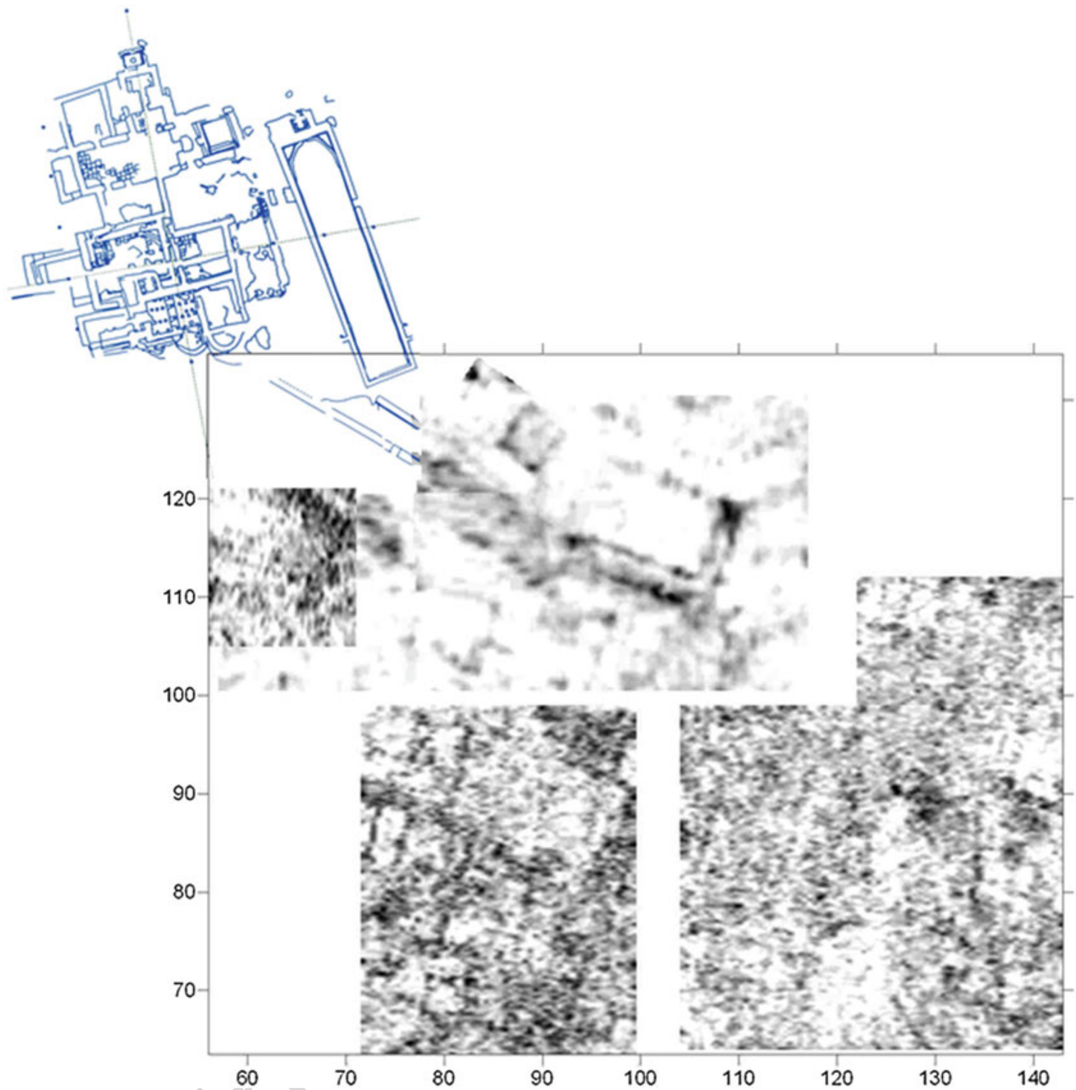

Fig. 5.9 Collage of the sketch of the excavated area and 8 ns (about 0.48 m depth) GPR slices for different areas surveyed. Distances in m. Sketch in the upper left corner indicates the location of the excavated area

likely. The results by themselves provide very clear evidence that significant structures will be found if the excavation is resumed.

5.2.3 Roman Town of Troia (I–V a.D.)

5.2.3.1 Introduction

The Roman Ruins of Troia are known since the sixteenth century. After several stages of excavation in the nineteenth and twentieth centuries it was finally established that the area near the tip of the Peninsula of Troia has been the place of a roman town with fish factories. The 25 factories identified up to now had a total of 160 tanks where fish was salted or transformed into fish paté or fish sauces (of which the *garum* was the most famous one). These products were appreciated by wealthy romans around the Roman Empire and so the town flourished from the first to the fifth century

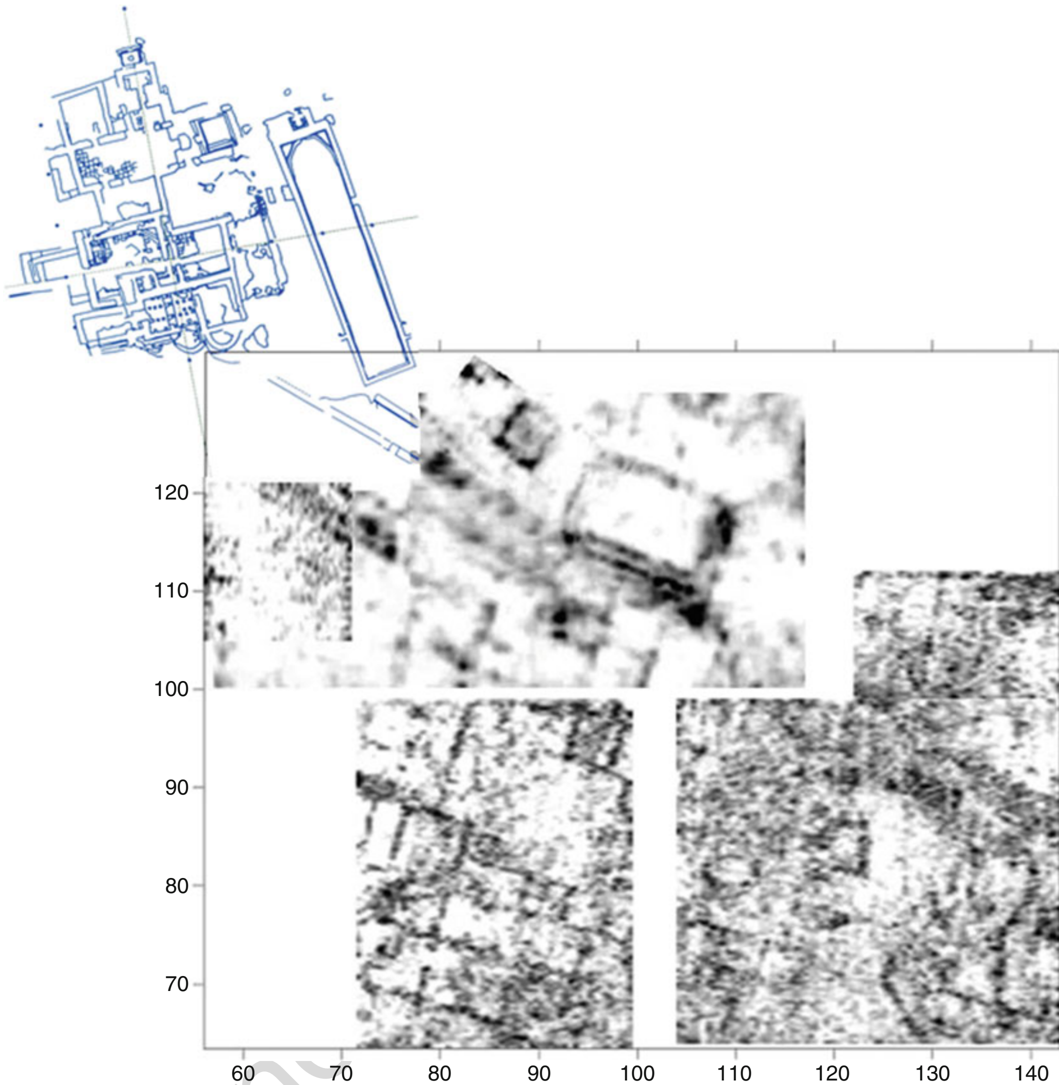

Fig. 5.10 Collage of the sketch of the excavated area and 10 ns (about 0.69 m depth) GPR slices for different areas as in Fig. 5.3. Distances in m. Sketch in the upper left corner indicates the location of the excavated area

a.D. Archaeological information indicates that fish factories finished their activity in the first half of the fifth century, and the town was completely abandoned in the sixth century. Even though a large area has been already excavated, uncovering dwellings and several necropolis, many other areas have not been excavated.

Since 2006 the roman ruins of Troia belong to the Troia Resort which, following up on a suggestion by the Geophysical Centre of the University of Évora, has allowed the surveying of areas that were not excavated yet but would be in the future. Again, the idea was to compare the results from the geophysical surveys with the structures expected to be found after excavation. An interesting aspect of this site is that all the buried structures are covered with sand, which is soaked in rain water at the surface and sea water in the deeper layers. So, in principle, there is a measurable contrast of the physical properties associated with different geophysical methods. Up to now only electrical resistivity tomography and ground

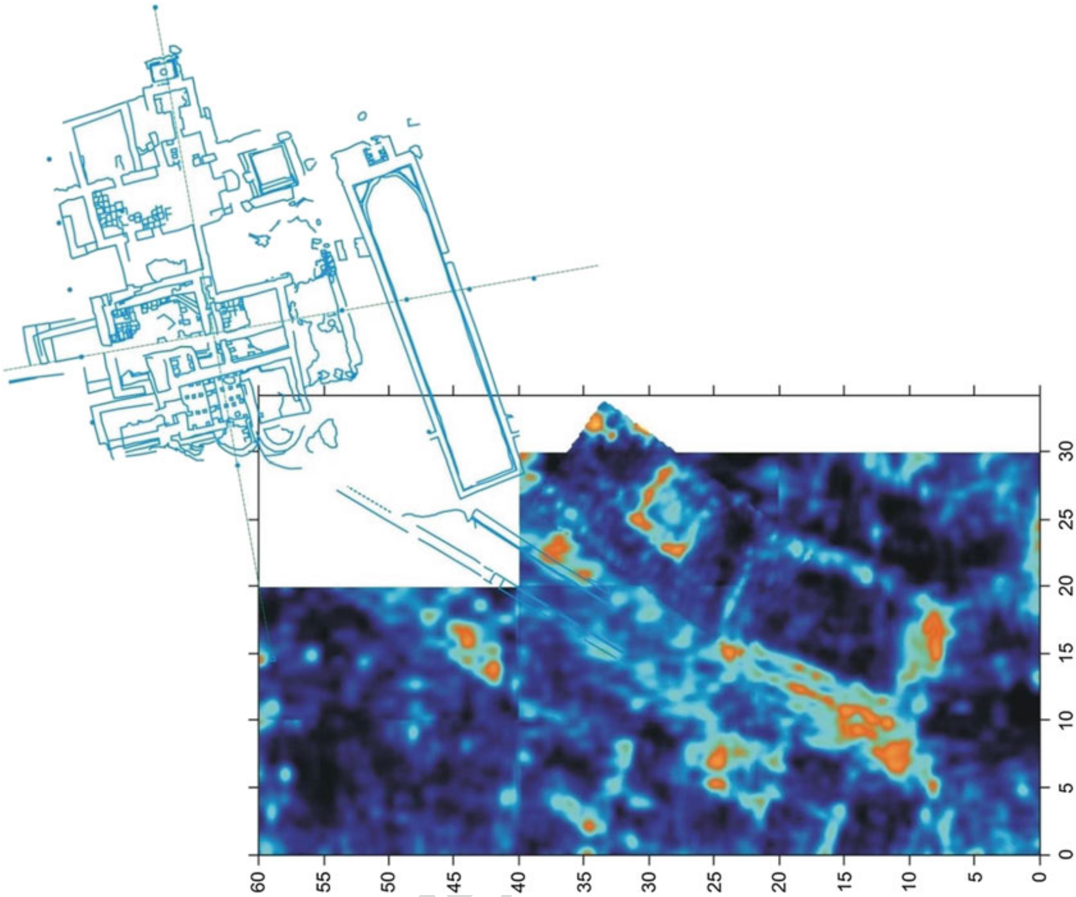

Fig. 5.11 Colour detail of Fig. 5.10. The continuation of the structures already excavated is obvious. Distances in m

penetrating radar have been used to find and delineate buried stone structures such as walls and floors.

A preliminary survey was done in June 2013 and it is expected to continue the geophysical work in the future in areas that are planned to be excavated. Figure 5.12 is a map of what is excavated in the Roman Ruins of Troia and shows three areas that were initially chosen to carry out the geophysical surveys. In the end only areas 1 and 2 were chosen to do the ERT and GPR surveys. Area 3 was not considered because of the existence of metal structures for use of pedestrians visiting the ruins.

The location of the Roman Ruins of Troia can be seen in Fig. 5.1. For those interested in seeing the area of the roman site, the geographical coordinates in the Google Earth are: 38°29′9.82″N, 8°53’5.32″W. The average altitude of the site is 3 m a.s.l.

5.2.3.2 Method

The geophysical methods used in the area of the Roman Ruins of Troia were ERT and GPR. In each of the two areas (1 and 2) chosen for the surveys (see Fig. 5.12) one electrical resistivity tomography profile and three parallel ground penetrating radar profiles were measured; the three GPR profiles were done so that the central GPR profile was coincident with the ERT profile and the other two GPR profiles were 0.5 m away from the central one to each side.

The ERT profiles were 39 m long and were carried out using a Wenner configuration with 40 stainless steel stacks 1 m apart. The GPR profiles were done using a 400 MHz antenna

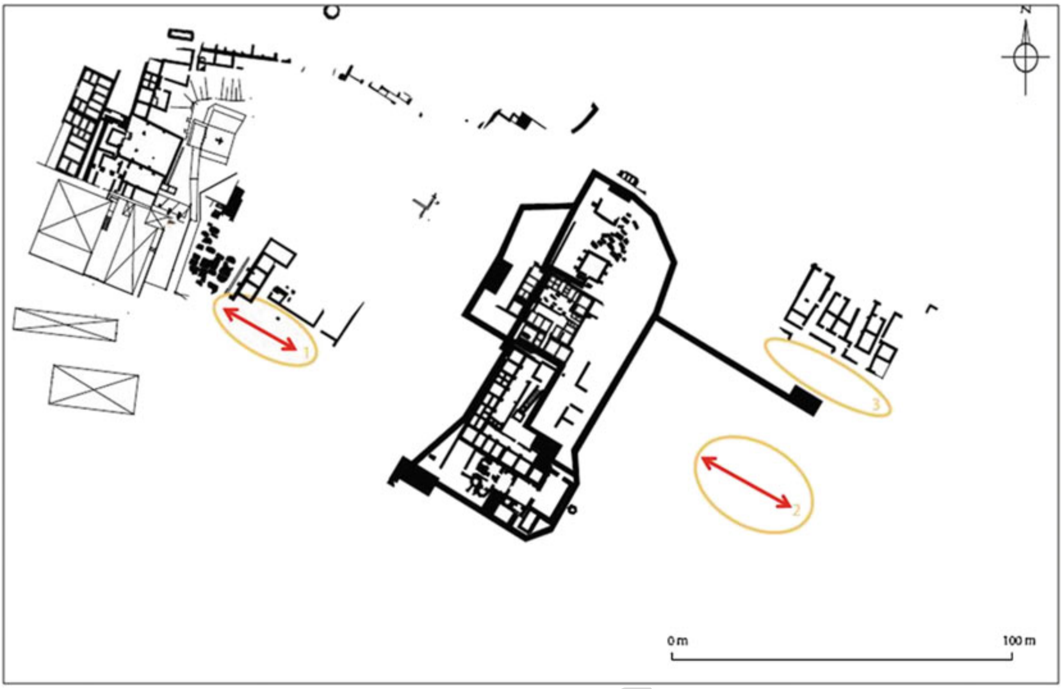

Fig. 5.12 Location of the two areas where ERT and GPR profiles were done (brown ellipses with double red arrows inside); double red arrows indicate the orientation of the ERT and GPR profiles

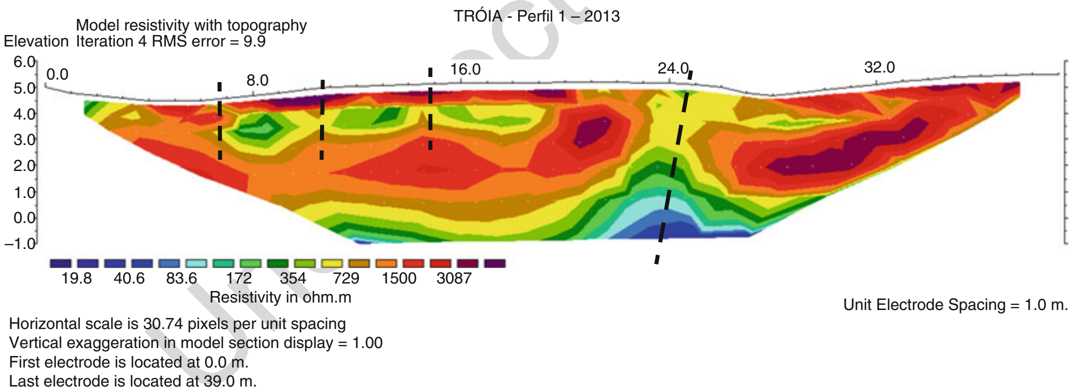

Fig. 5.13 Electrical resistivity tomography (profile 1) done in area 1 of Fig. 5.12. Reddish colours correspond to high electrical resistivity values; bluish colours correspond to low electrical resistivity values. Black dashed lines are interpretations of possible contacts between structures with different electrical resistivities

and were 40 m long in area 1 and 42 m long in area 2.

5.2.3.3 Some Results

Figures 5.13 and 5.14 show the coincident ERT and central GPR profiles done in area 1 of Fig. 5.12. Figures 5.15 and 5.16 show the coincident ERT and central GPR profiles done in area 2 of Fig. 5.12.

The ERT profile in area 1 (Fig. 5.13) indicates that ground in the area presents a compartment structure: up to 24 m there are zones with intermediate electrical resistivities (green and yellow colours) imbedded in zones of high electrical resistivity (red and orange colours). At 24/25 m there is a vertical (or sub-vertical) contact which separates two high electrical resistivity zones.

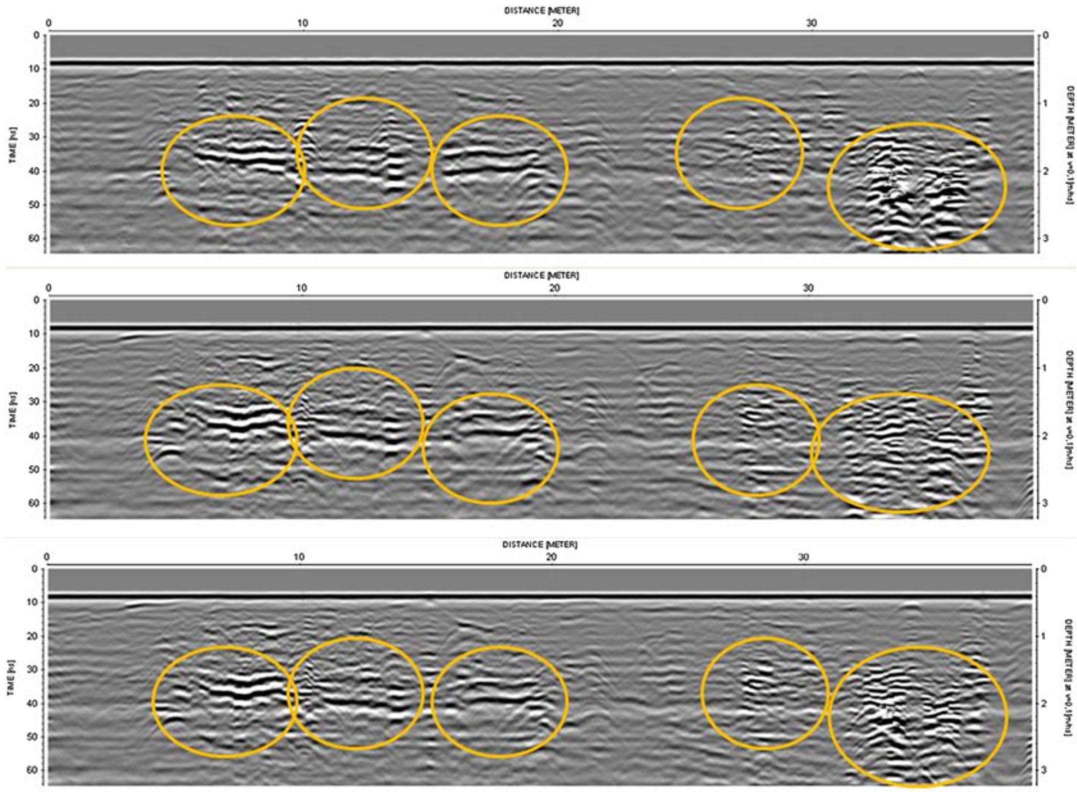

Fig. 5.14 Three radargrams done with the orientation of ERT along profile 1 of Fig. 5.12. Only the central radargram coincides with the ERT shown in Fig. 5.13. The other radargrams are located 0.5 m to the NE (upper radargram) and to the SW (lower radargram) of the central one. Yellow ellipses indicate the most prominent reflections

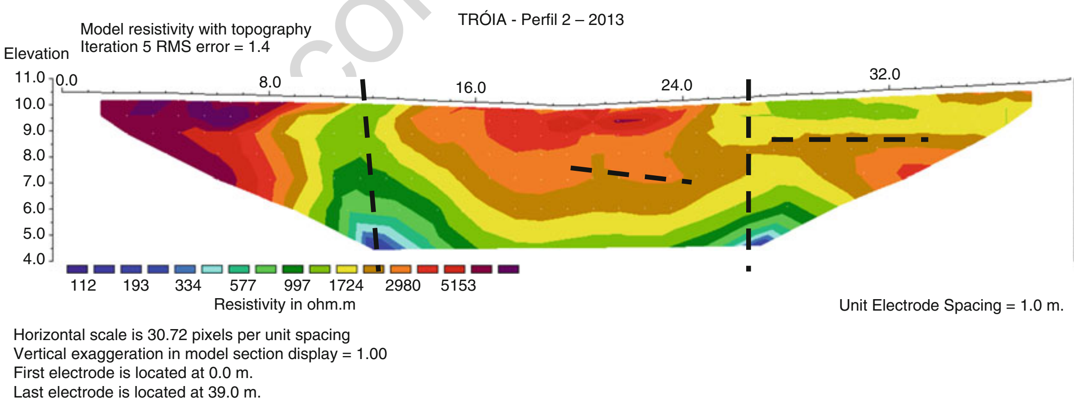

Fig. 5.15 Electrical resistivity tomography (profile 2) done in area 2 of Fig. 5.12. Reddish colours correspond to high electrical resistivity values; bluish colours correspond to low electrical resistivity values. Black dashed lines are interpretations of possible contacts between structures with different electrical resistivities

The bluish zones are probably sand with sea water because the electrical resistivities are very low. As a preliminary interpretation, the compartments (which show lower electrical resistivity values) are separated by zones of intermediate electrical resistivity values (black dashed lines in Fig. 5.13)

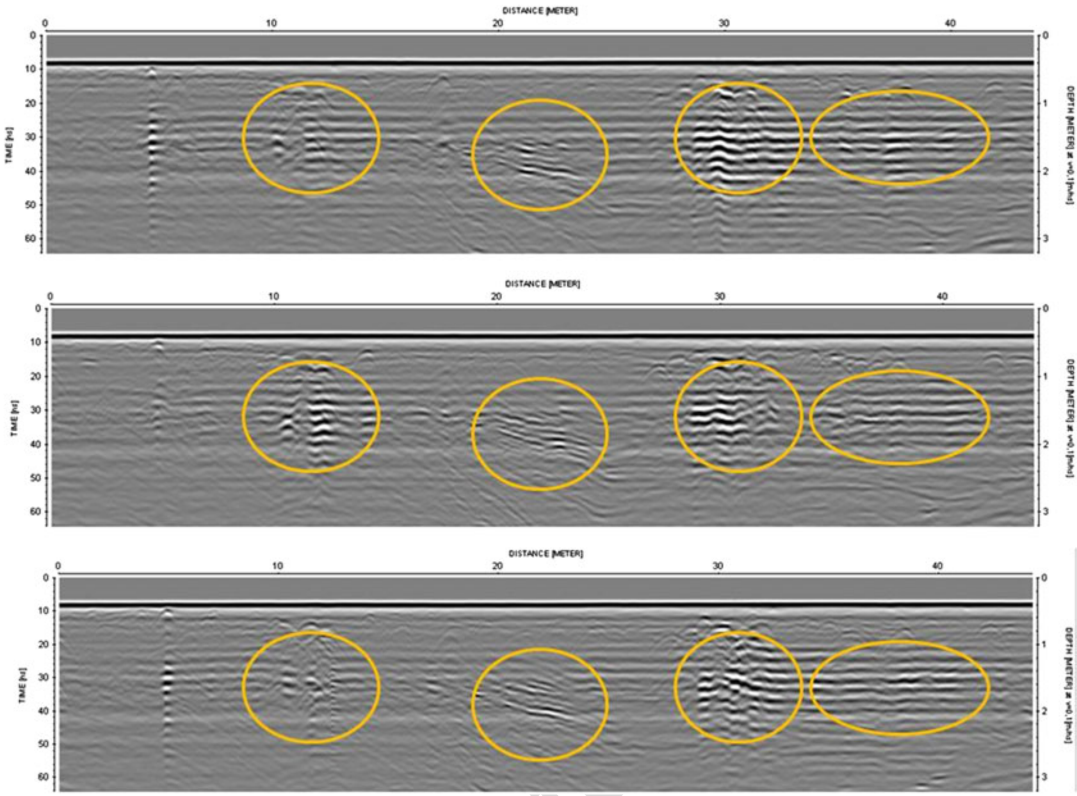

Fig. 5.16 Three radargrams done with the orientation of ERT along profile 2 of Fig. 5.12. Only the central radargram coincides with the ERT shown in Fig. 5.15. The other radargrams are located 0.5 m to the NE (upper radargram) and to the SW (lower radargram) of the central one. Yellow ellipses indicate the most prominent reflections

which are probably associated with rock walls observed in areas already excavated. The referred compartments are probably filled with rain water soaked sand and have lower electrical resistivity than the interpreted walls. For distances larger than 24/25 m, electrical resistivities are very high and show a horizontal pattern, probably indicating a large rock concentration or stone floors.

It is interesting to note that the central GPR profile (Fig. 5.14), coincident with the ERT profile in area 1, corroborates the above interpretation. In the radargram of Fig. 5.14 the most important reflections are shown inside yellow ellipses. As a matter of fact, there are many superficial electromagnetic reflections which correspond to shallow rocks from crumbled walls. However, deeper reflections also indicate the existence of compartments in the same zones as the ones interpreted in the ERT profile. It is also interesting to note that the most intense reflections of electromagnetic energy are horizontal or nearly so. Finally, in the right portion of Fig. 5.14 (after 32 m) there are strong reflections which indicate strong dielectric constant contrasts and so important buried structures are expected to be found there; this same conclusion can be inferred from the ERT profile (Fig. 5.13).

The compartment structure observed in the ERT profile (Fig. 5.13) can also be inferred in the left portion of the radargram shown in Fig. 5.14.

The ERT profile in area 2 (Fig. 5.15) is less complex than the ERT profile of area 1. The geoelectrical structure indicates three large compartments which are separated by the vertical black dashed lines. There are, however, two zones separated by two horizontal black dashed lines which probably correspond to rock/sand contacts; however, these two lines were drawn after interpreting the radargram coincident with the ERT. There is also an important vertical contact at about 11/13 m that separates two high electrical resistivity media, the left medium being less resistive than the right one.

There is another important vertical contact at about 26/27 m which also separates two geoelectrically different media; the left medium is less resistive than the right one. In this profile the possible compartments appear to be wider, as if the buried structures were wider and better defined in horizontal terms.

As happened for the ERTs done in areas 1 and 2, the central radargram obtained in area 2 (Fig. 5.16) is also less complex that the radargram obtained in area 1 (Fig. 5.14). In the former the number and intensity of electromagnetic reflections is less numerous (yellow ellipses in Fig. 5.15); there are also shallow hyperbolae probably from shallow rocks. In this radargram there are reflections at 4 m, 10/12 m, between 18 and 24 m, between 28 and 34 m, and between 35 and 42 m. Except in the case of the reflection at 4 m, (which may correspond to a buried shallow unknown object or the top of a stone wall) all other reflections are coincident with the electrical resistivity contrasts observed in the ERT profile.

In general terms it can also be said that there is a good coincidence between the electromagnetic reflections observed in the radargram in area 2 and the geoelectrical structure of the ERT for the same area; it appears that there are buried structures that were detected and delineated by both ERT and GPR. However, the number of buried structures is less in area 2 than in area 1.

5.2.3.4 Conclusions

From the two electrical resistivity tomographies and ground penetrating radar done in the two areas in the Roman Ruins of Troia, it appears to be possible to conclude that there are buried structures that have a clear geophysical signature. Their interpretation in archaeological terms is, however, more complex; one thing, though, is evident: the geophysical data obtained by ERT and GPR in areas 1 and 2 of the Roman Ruins of Troia are consistent with each other. Area 1 appears to have more buried structures and is more complex than in area 2. In this case, the utility of both ERT and GPR is evident and produced interpretable data. Excavation is thought to start again in 2017.

5.2.4 Crypt of the Marquises of Castelo Rodrigo

5.2.4.1 Introduction

The museum of the Portuguese Legislature, knowing, from newspapers dating from the twenties of the last century, that there was a crypt buried in the gardens of the Portuguese Legislature decided to try to locate it. The idea was to excavate the site and prepare it for public visits. However, before initiate excavation of the site it was decided to do a geophysical prospection in the garden and in the parking lot of the legislature building to locate the crypt. In logistics terms, the area where the geophysical surveys should be done is complex: during the working days the deputies leave the cars in the parking lot and so the space could not be used for any geophysical surveys. So, all geophysical surveys were done on Saturdays and Sundays when there were no cars in the parking lot. Besides trying to locate the crypt, it was thought as a good idea trying to locate underground tunnels, which are known to exist, that may connect the crypt, the main building and other buildings in its vicinity.

The Portuguese Legislature has is sessions in a building that is known as Sao Bento’s Palace. It is located well inside the town of Lisbon and is the building of the Portuguese Legislature since 1834. It was built as a Benedictine monastery at the end of the sixteenth century. In the seventeenth century the crypt of the marquises of Castelo Rodrigo was built in what is now the garden and parking lot of the building; its exact location was lost after several construction works inside and outside the original monastery which covered the crypt.

For those interested in seeing the area of the Portuguese Legislature, the geographical coordinates in the Google Earth are: 38°42′45.58″N, 9°9′15.95″W. The average altitude of the site is 32 m a.s.l.

5.2.4.2 Method

The geophysical methods chosen to try to locate the crypt and tunnels associated with it were electrical resistivity tomography (ERT) and ground penetrating radar (GPR) with two different antennae (400 and 200 MHz). However, the results with 200 MHz were not good and will not be shown here. The GPR surveys were done using a grid which was subdivided into several rectangular sub-grids. The line spacing used was 0.5 m. GPR lines were collected in both orthogonal directions (X and Y), the direction X coinciding with the orientation of the main outside wall of the building. The radar antennas were dragged directly on the ground. Figure 5.17 shows the area outside the building where the geophysical surveys were done as well as the six sub-areas.

Three ERT profiles were done (Fig. 5.18): two of them had 39 m long crossing near the building's façade and one 59 m long in the garden parallel to the building's façade. The smallest ERTs were done using a Wenner configuration with 40 stainless steel stacks 1 m apart while the longest was done using a hybrid roll along technique.

5.2.4.3 ERT Results

Figure 5.18 shows the rear of the building of the Portuguese Legislature where the three ERTs were done on June 25 and 26, and August 6, 2011. For the three electrical resistivity tomographies (a, b, and c in Fig. 5.18) bluish colours correspond to low electrical resistivity values while reddish colours correspond to high electrical resistivity values.

ERTa in Fig. 5.18 is 39 m long and indicates that, except for a shallow thin layer (which is cobblestone), electrical resistivities are generally low; the blue spots between 1.3 and 2.9 m might correspond to pockets of clay and water from watering the garden. The orange spots between 4.0 and 6.0 m might correspond to structures associated with the crypt (such as undiscovered tunnels).

ERTb in Fig. 5.18 is also 39 m long and, in general terms, presents the same characteristics of ERTa. Electrical resistivities are, though, slightly higher than in ERTa. The blue spots are interpreted again as water from watering the building's garden. However, at 13/14 m there is high electrical resistivity pocket which might correspond to a continuation of buried structures associated with the crypt.

ERTc in Fig. 5.18 is 59 m long, was done in an area that has no cobblestone and is about 1 m higher than the other two ERTs. In general terms, ERTc presents the lowest electrical resistivities of the three electrical resistivity tomographies which have to do with the water that percolates from the soil in the garden towards the underground of the parking lot. Since the ERTs were carried out during the summer, deeper layers present lower electrical resistivity values. The stairs in marble in the middle of the ERT are well identified by high electrical resistivity values in the middle section.

So, as a conclusion, the three electrical resistivity tomography profiles were not able to show unequivocally the presence of the crypt or extensions of it.

5.2.4.4 GPR Results

Even though a few GPR surveys were done inside the building of the Portuguese Legislature, only the results obtained for the areas outside the building are shown; the GPR results inside the building were very poor because the level of noise was too high to do any processing. Figure 5.17 shows the relative positions of the six outside areas where GPR surveys was done. The GPR coverage for each area was done in such a way that a three-dimensional picture of the ground could be obtained; for that the GPR Slice software was used. For all six areas of Fig. 5.17, each GPR run was separated from the next by 0.5 m. As already said, 400 and 200 MHz antennas were

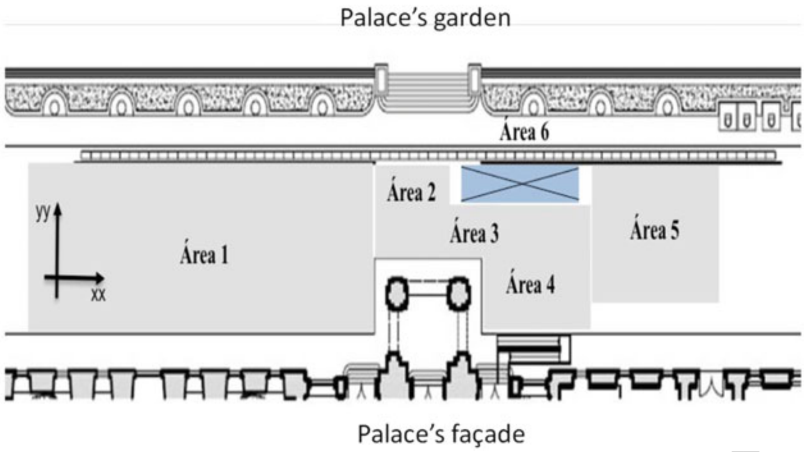

Fig. 5.17 Sketch of the area where GPR surveys were done in the parking lot of the Portuguese Legislature. The X and Y directions are defined in area 1 and were used for all other areas also shown. The lower part of the figure corresponds to the building's façade

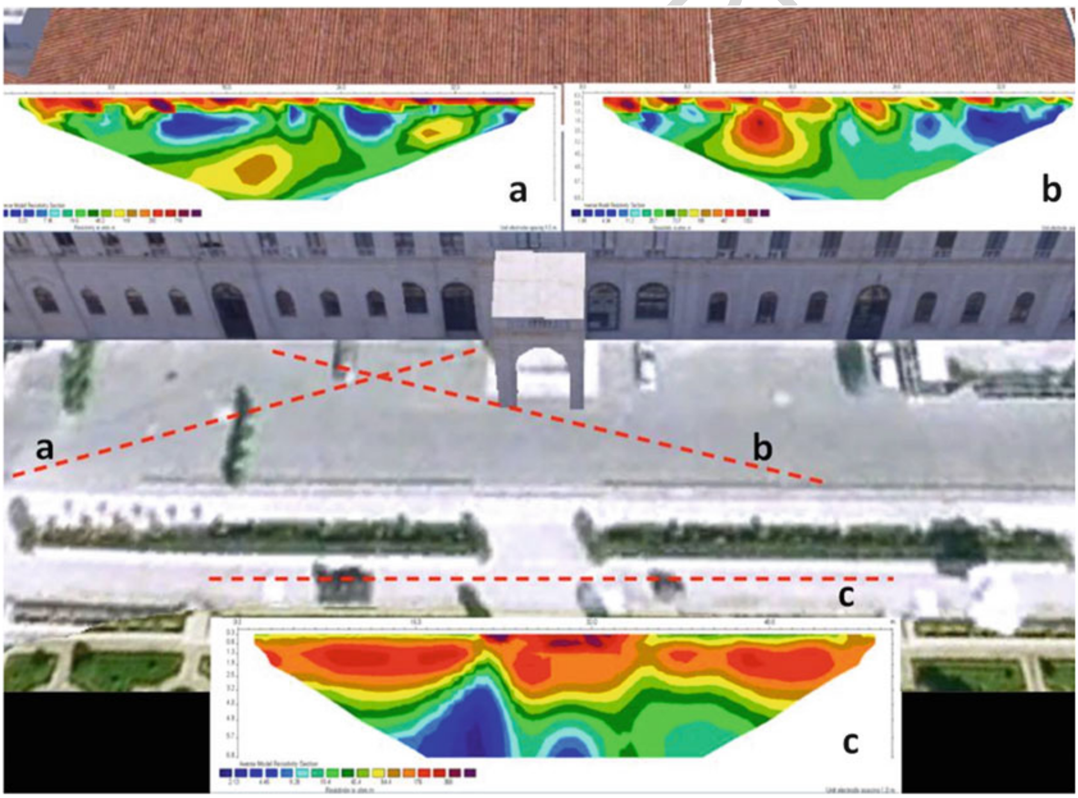

Fig. 5.18 Sketch of the area where ERTs were done (red dashed lines for orientation of ERTs a, b, and c) and ERT results in the parking lot of the Portuguese Legislature. The middle part of the figure corresponds to the building's façade and the upper part, in brown, corresponds to the building's roof

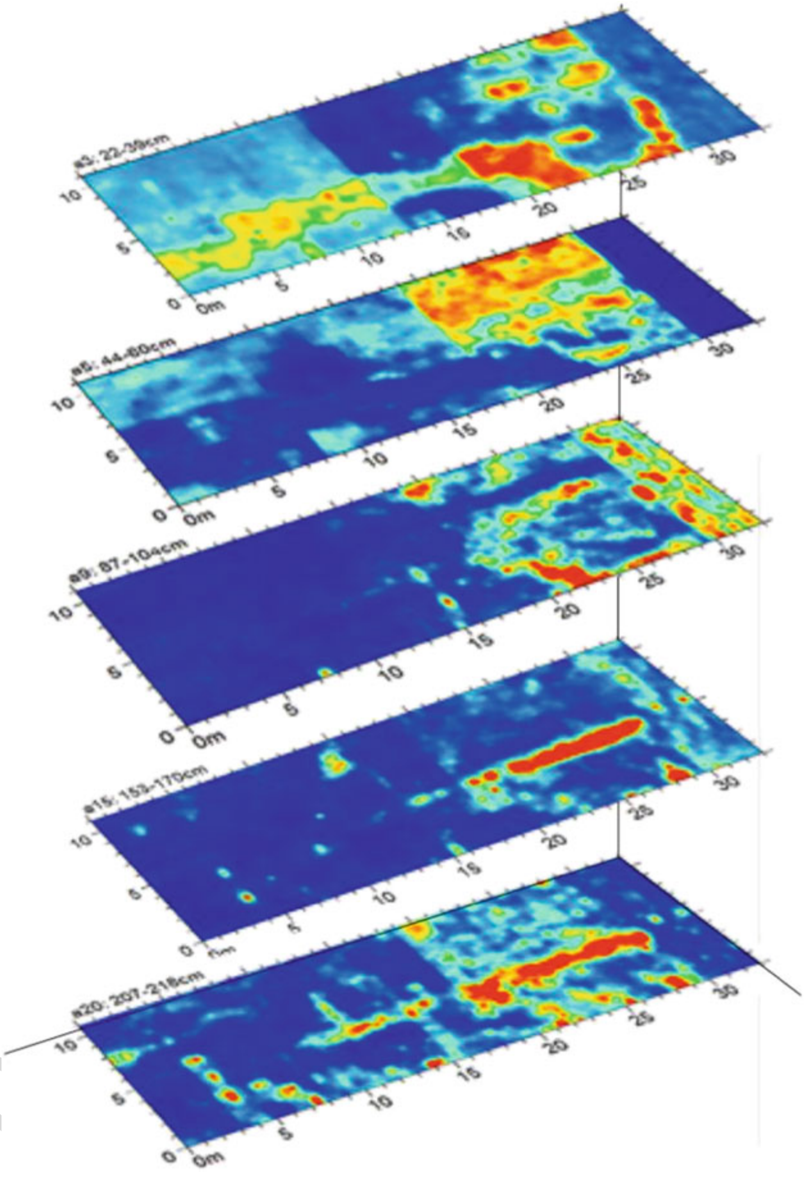

Fig. 5.19 GPR slices for Area 1 in Fig. 5.17. Slices correspond (from top to bottom) to depths of 0.22–0.39 m, 0.44–0.60 m, 0.87–1.04 m, 1.53–1.70 m, and 2.07–2.18 m

used; however, the data from 200 MHz antenna had poor quality and was not used for further processing. In Figs. 5.19, 5.20, 5.21, 5.22 and 5.23 the results obtained are shown for all areas except area 6 which was not wide enough for proper processing and interpretation. Figure 5.24 is a collage of the GPR results for the surveyed area (Areas 1–5) for 1.4–1.6 m depth.

5.2.4.5 Conclusions

To try to find the location of the crypt of the marquises of Castelo Rodrigo two methods were

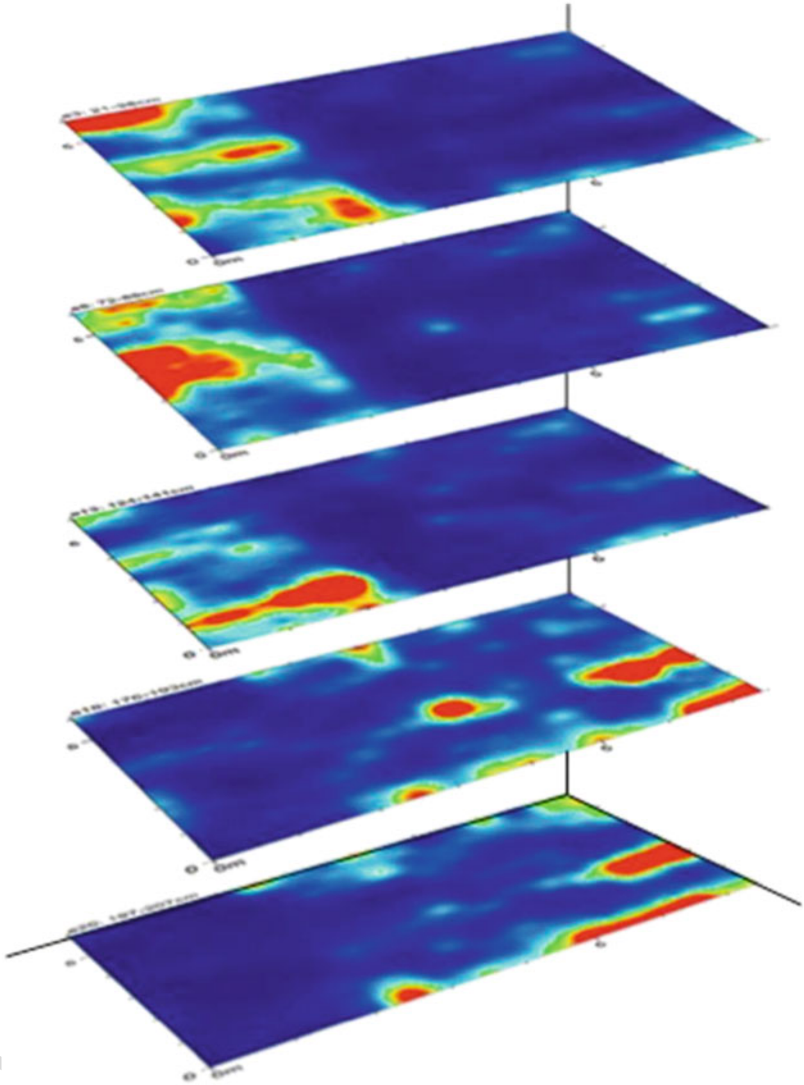

Fig. 5.20 GPR slices for Area 2 in Fig. 5.17. Slices correspond (from top to bottom) to depths of 0.22–0.39 m, 0.44–0.60 m, 0.87–1.04 m, 1.53–1.70 m, and 2.07–2.18 m

used: ground penetrating radar and electrical resistivity tomography. The former was effective in finding structures associated with the crypt; the same cannot be said about electrical resistivity tomography. ERT profiles were only able to detect strong contrasts of moisture in the ground related with watering activities in the palace's garden. During the field work a dome filled with soil and rocks was found (Fig. 5.25) near the area where the geophysical surveys were being done (Fig. 5.26).

Acknowledgments The short examples of application of geophysical methods to archaeology in Portugal, presented in this chapter, could not have been done without the cooperation of several colleagues and researchers from different institutions. The author would like to acknowledge and thank the participation in the field work, the discussions, and the authorisations to use the collected data in this publication to Inês Vaz Pinto (Troia Resort), Teresa Parra da Silva and Joaquim Soares (Museum of Portuguese Legislature), João Caninas (Emerita Ltd.), Isabel Gaspar (Municipality of Proença-a-Nova), and Brooke Berard and Jean-Michel Maillol (University of Calgary). All the equipment used during the field work belongs to the Geophysical Centre of the University of Évora (now Institute of Earth Sciences, Portugal) and the

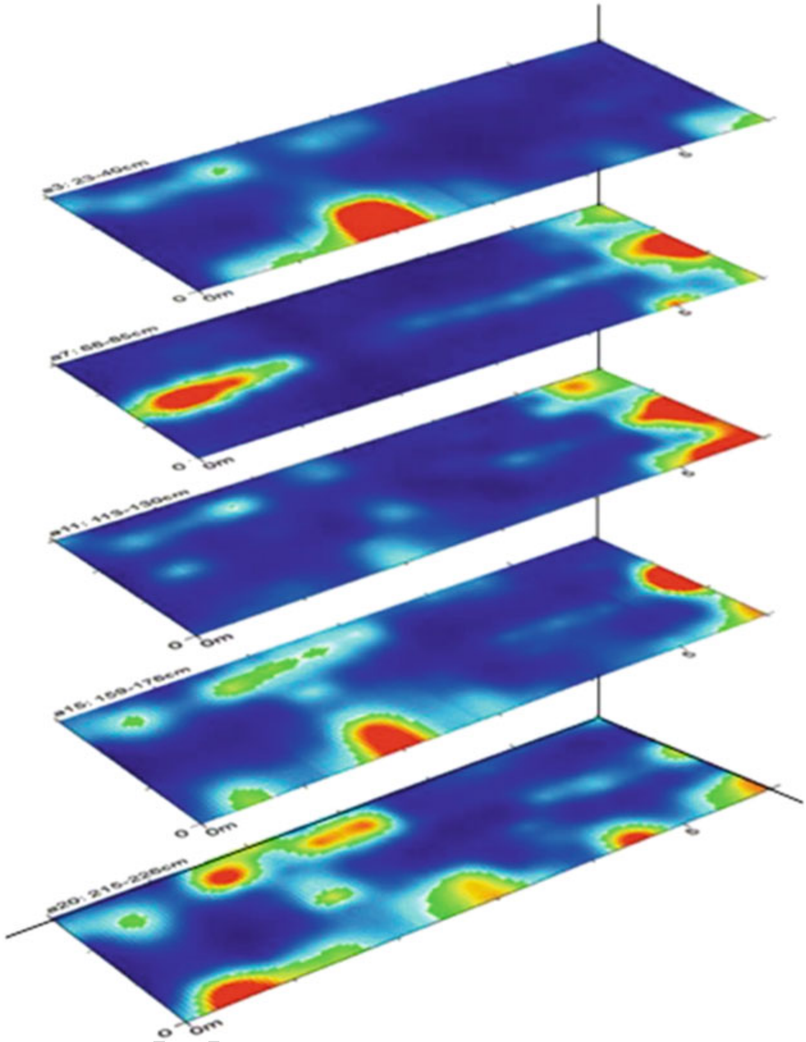

Fig. 5.21 GPR slices for Area 3 in Fig. 5.17. Slices correspond (from top to bottom) to depths of 0.22–0.39 m, 0.44–0.60 m, 0.87–1.04 m, 1.53–1.70 m, and 2.07–2.18 m

Department of Geology and Geophysics of the University of Calgary (Canada).

References

dos Santos MF, Esteves JM (1966) Possibilidade de aplicação do método da resistividade eléctrica na prospecção arqueológica. Ethnos V:313–335

Tite SM, Alldred JC (1965–1966) Aplicação de métodos científicos de prospecção em estações arqueológicas portuguesas. Trabalhos de Antropologia e Etnologia XX (1–2):147–160

Vaz Pinto I, Viegas C, Dias F (2004) Terra sigillata and amphorae from the Roman villa at Tourega (Evora, Portugal). In: Pasquinucci M, Weski T (eds) Close encounters: sea- and riverborne trasde, ports and hinterlands, ship construction and navigation in antiquity, the middle ages and modern times, British Reports, vol S1283, p 11

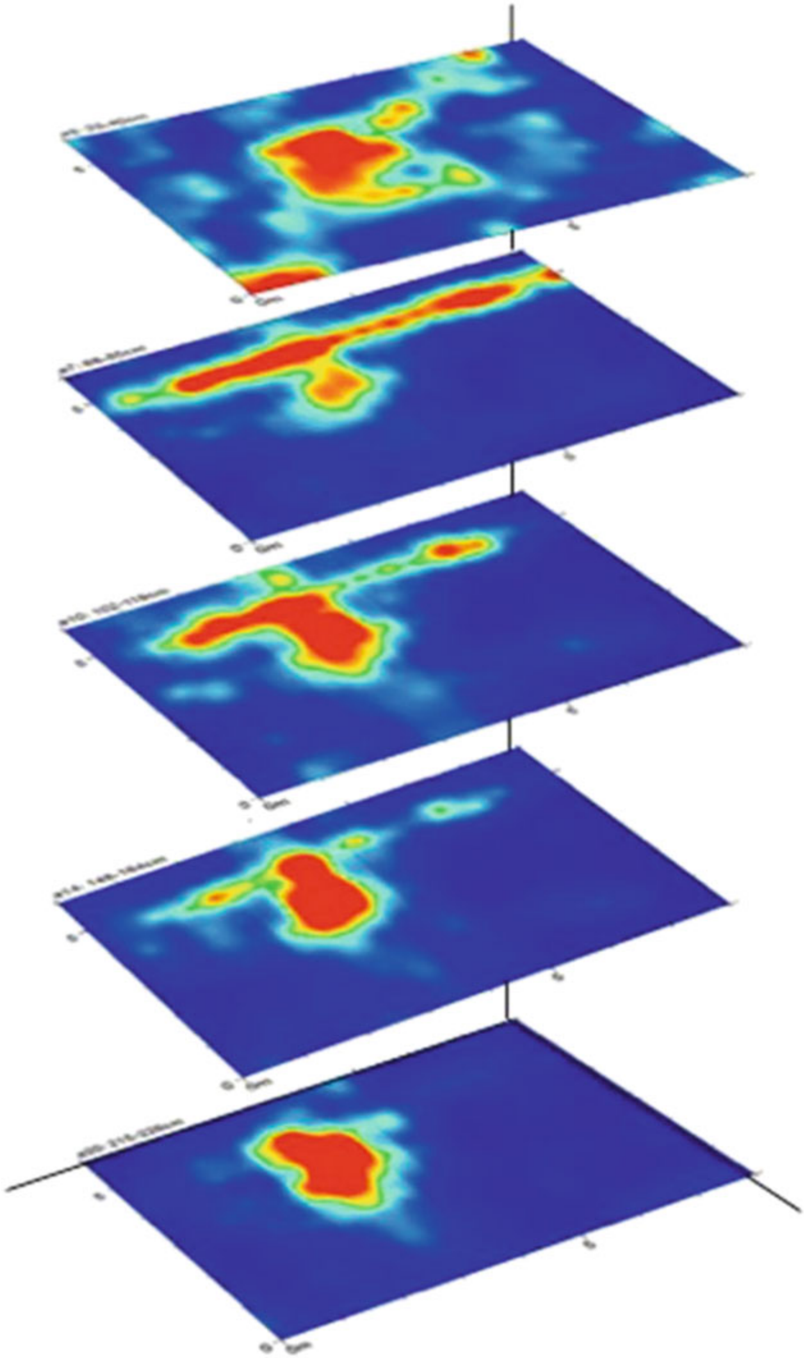

Fig. 5.22 GPR slices for Area 4 in Fig. 5.17. Slices correspond (from top to bottom) to depths of 0.22–0.39 m, 0.44–0.60 m, 0.87–1.04 m, 1.53–1.70 m, and 2.07–2.18 m

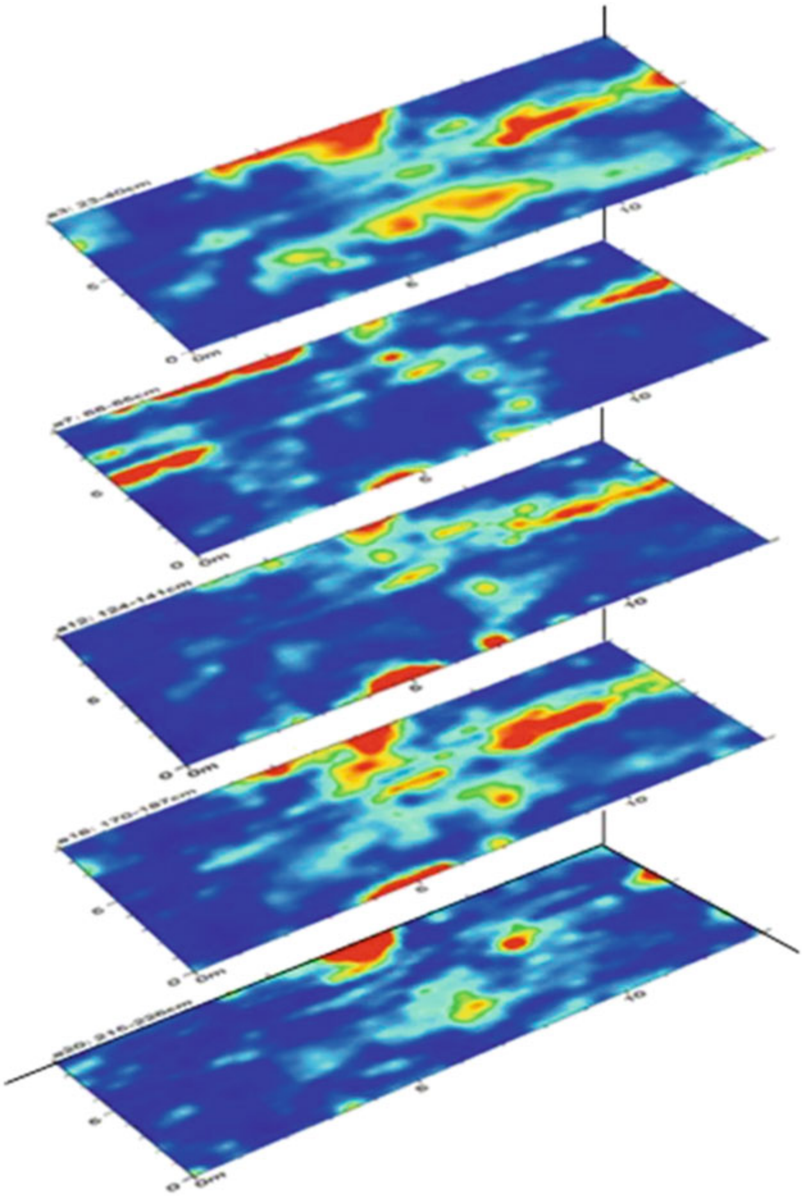

Fig. 5.23 GPR slices for Area 5 in Fig. 5.17. Slices correspond (from top to bottom) to depths of 0.22–0.39 m, 0.44–0.60 m, 0.87–1.04 m, 1.53–1.70 m, and 2.07–2.18 m

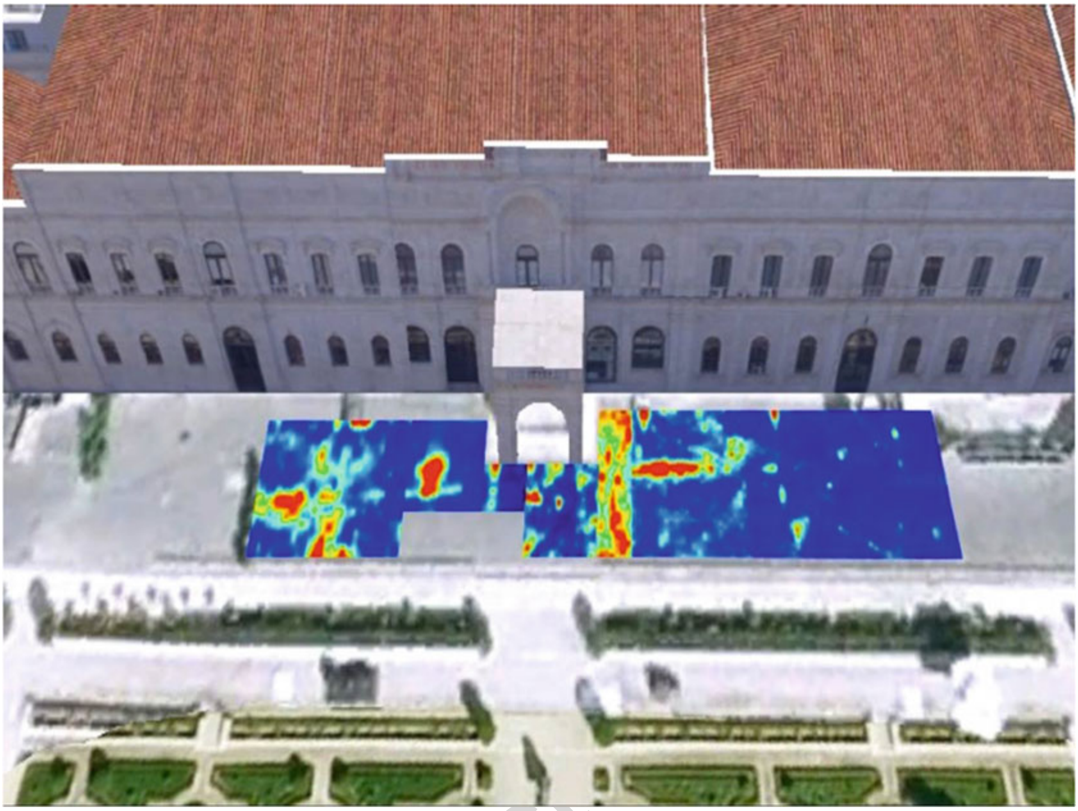

Fig. 5.24 Collage of the GPR results for the surveyed area (Areas 1–5) for 1.4–1.6 m depth

Fig. 5.25 Picture of the structure (ceiling/tunnel?) found during construction work in the area of the geophysical survey. The structure is filled with sand, rocks, and dirt. The dimension of the structure can be appreciated by comparing its size with the upper part of the ladder in the right portion of the picture

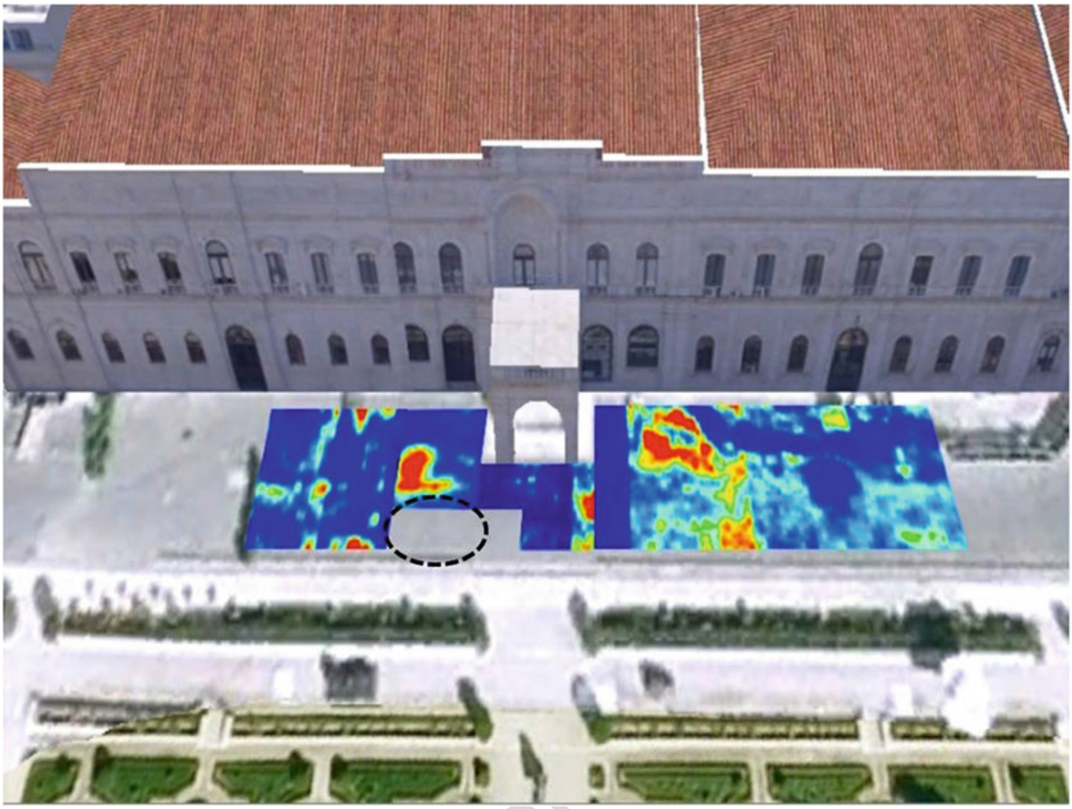

Fig. 5.26 Collage of the GPR results for the surveyed area (Areas 1–5), similar to Fig. 5.24 but for 0.5–0.7 m depth. The black ellipse indicates the location of the structure shown in Fig. 5.25

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