NON-DESTRUCTIVE GEOPHYSICAL SURVEYES: ARCHAEOLOGICAL FEEDBACK

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ABSTRACT:

In this work are introduced three different magnetic surveys and a geoelectric one performed in Turkey and in Apulia (southern Italy). The geophysical prospection was required by the archaeologists to guide excavation programmes and to rescue a site destined to be partially destroyed. A cesium gradiometer magnetometer and a dipole-dipole array were used for collecting data. Despite the presence of perturbing contributions all the surveys had a remarkable archaeological feedback that largely satisfied archaeologists' expectations. At the same time for the geophysicists arose the possibility to provide, in retrospect, complete information of the sources of signal (geometry, location in the space, composition, physics properties). This allowed to verify under best conditions, the results of the employed methodologies, the interpretative aspects, the techniques of elaboration and visualization of the data. Some detected anomalies were critically compared to the corresponding structures brought to the light by the following excavations.

1. INTRODUCTION

In the last 50 years geophysical techniques have been offering a relevant contribution for archeological research. The possibility to obtain quick information on buried archaeological structures in a non-destructive way constitutes a precious advantage for planning and optimizing excavations in already known sites. Moreover by opportunely integrating the information obtained with remotely sensed images, it is possible to offer a considerable help to the investigation and the location of those archaeological sites which are partially known and of those which have not been discovered yet (Ciminale and Ricchetti, 1999). Finally, in many cases, geophysical survey proved to be essential for the knowledge and the study of those areas of archaeological interest which were bound to be extensively modified or even destroyed by modern development.

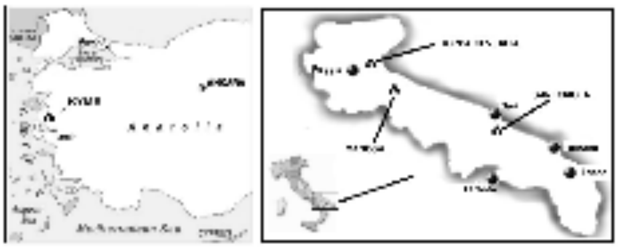


Figure 1. Location of the surveyed archaeological sites.

The four geophysical surveys discussed below, which were performed in Turkey and in Apulia (Figure 1), constitute meaningful examples of the effectiveness of the magnetic and electric methods in answering archaeologists' demands. Despite the difficult environmental conditions it was possible to locate and recognize the archaeological structures. Digital Image Processing (DIP) was used to enhance visualization (Mather, 1999) of the high resolution geophysical data making easier interpretation and identification of archaeological features.
Each survey is presented explaining the archaeological context in which it was performed and its main purpose. The characteristics of the recorded signal are analyzed using the information derived from the excavations. The comparison between the highlighted anomalies and the recovered structures has outlined the good correspondence both in their mutual position and in the likeness of their shapes.

2. THE MAGNETIC AND ELECTRIC SURVEYS

The magnetic and the d.c. electric surveys are among the most largely employed methods in archaeological research (Scollar et al., 1990).
The first one is based on the analysis of the anomalies of the earth's magnetic field, produced by the contrast of magnetization and/or of magnetic susceptibility between the bodies present in the subsoil (object of the research) and the material which englobes them. Fundamental aspect in the application of the magnetic method to the archaeological research is the high resolution with which the signal is recorded. Both the techniques of acquisition of data and instruments have been conceived to allow a survey with a very narrow sampling step in less time. The modern magnetometers are able to acquire up to 10 data s^{-1}, with a sensitivity of a picotesla (Becker, 1995). Therefore it is possible, by using proper field procedures, to detect also the highest frequencies of the magnetic signal, improving identification and location of the buried structures. However, magnetic data are very often affected by noisy contributions (due to systematic and non-systematic errors), which may degrade the magnetograms rendering the correct interpretation of the anomalies uncertain (Eder-Hinterleinter et al., 1996). It is essential for this reason to restore the real value and shape of anomalies before the interpretative phase. In favorable conditions objects of remarkable archaeological interest such as kilns, hearths, bricks, pottery, iron objects, etc…, endowed with an elevated remanent magnetization, can produce strong magnetic anomalies easily identifiable.
With the d.c. electric method it is possible to detect with high sensitivity slight differences of electric resistivity between bodies inside the subsoil. The most useful technique for archaeological aims is a combination of sounding and profiling which delineates variations in resistivity across the vertical plane through the direction of the survey. Data can be visualized as electric pseudosections obtaining an immediate transversal view of the subsoil. This allows for an easy first estimate of the

location where the present archaeological structures could be found. Actually, as over an inhomogeneous and/or anisotropic ground, the calculated resistivity will vary, data inversion will be necessary to get a real electric image of the ground (Ward, 1990). In comparison to the magnetic prospecting, the instruments necessary for a geoelectric survey are decidedly less expensive. Nevertheless time required for this kind of investigation is much longer.

2.1 Data acquisition

As regards the magnetic measures, an optical pumping magnetometer (Geometrics G858) in gradiometer configuration, was used. The sensors were set to a fixed distance equal to 1.2 m and the inferior one to 0.25 m from the ground. In general single square areas of 30X30 m^2 were surveyed. Data were acquired in the bi-directional mode along profiles 0.5 m apart with an average sampling step of one datum/0.125 m. After interpolating operations regular high resolution grid were obtained with a 0.25X0.125 m cell.
The electric profiles were performed by using a dipole-dipole array (AM=MN=NB=1m) and employing a modern computer assisted georesistivimeter (Net Sistemi EW 24/410). Each profile, 20 meters long, has a constant separation of 5 m from the others and yields a network of 105 experimental data points until a pseudo-depth of 4 m.

2.2 Data processing and visualization

In all the three magnetic surveys the row data were first visualized as 8 bit raster images to identify the presence of those unwelcome disturbances commonly known in literature with the name of spikes, stripes and zig-zag (e.g. Scollar et al., 1990; Eder-Hinterleinter et al., 1996).
Spikes are mainly due to the accidental failure of the sensors produced by thermal or mechanic shocks as well as the presence of ferrous modern material lost in the ground such as rods, wires, studs, etc.. This can cause some non systematic errors of measure shown in a magnetogram as isolated anomalies either positive or negative. For the de-spiking step a GESD method was applied to non interpolated data (Ciminale and Loddo, 2001). Spikes were identified and flagged through a statistic comparison with other neighbouring data within opportunely chosen sub areas. Once having been labeled, they were removed from the data set. Stripes predominately occur in the magnetogram when data are collected in the bi-directional mode. To reduce striping effect each line was simply set at zero mean. Positioning errors, different lengths of parallel profiles and the technical specifications of the magnetometer often cause, especially in bi-directional surveys, a strong zigzag pattern. This displacement effect has been minimized through a procedure based on the computation of the cross-correlation function between the magnetic profiles considered three at a time (Ciminale and Loddo, 2001).
After having attenuated these effects with DIP techniques, the data processing was completed through filtering operations in order to reduce the background noise present in the three surveys. Finally contrast stretching procedure helped in emphasizing the magnetic anomalies.
Electric data were simply visualized as filled contour plot. In this case it was considered not useful to apply any inversion or processing to the data because the depth of the searched structures was already known due to nearby excavations. Moreover the primary aim of the survey was the detection of the archaeological target for which a significant contrast in resistivity with the subsoil was expected.

3. RESULTS AND DISCUSSIONS

3.1 Kyme (Turkey)

Figure 2. Part of the high-resolution magnetic mosaic obtained at Kyme. The light gray features are already excavated structures.

Kyme, one of the most ancient cities of the Aegean coast of the Anatolia, was founded around the 1050 B.C. by people who come from the "Fricio Locrico" and assimilated the natives "Pelasgi" in the first city core (Strabone, XII, 4,3). Immediately after its foundation, Kyme became the center of trading in both the Aegean and the Eastern Mediterranean seas. Here Kyme established its most ancient colony, Cuma in Campania (Italy). Despite having already been discovered as far back as the 18th century, Kyme became an object of study, albeit sporadic, only after the second half of the 19th century. The University of Catania (Italy) has been systematically studying the archaeological site since the 1982 (Lagona, 1993). Annual excavations have brought to the light several ruins, among which the majority of the port area (IV B.C.), a theatre (I B.C. – 180 A.D.), a defence wall and a tetrastyle temple devoted to Iside (IV A.D.) and a medieval citadel (XII-XIII A.D.). Nevertheless, the most part of the site is still completely unexplored while the excavations proceed only in summer months. The contribution that the archaeologists expected from the geophysical survey, was the identification of those areas with a more probable archaeological content.
During two summers (1999-2000) 37000 m^2 were surveyed. Because of the articulated morphology and the presence of natural and artificial obstacles (threes, dried walls, cultivations, pylons, etc…) it was impossible to investigate the site with continuity. The final result is the high-resolution magnetic mosaic (Ciminale, 2003) a part of which is shown in Figure 2.
The data processing allowed to point out many anomalies with an archaeological meaning. Unfortunately the discontinuity of the survey affected the interpretation. Often in fact signals abruptly break off. Furthermore a background noise, due to the outstanding presence of potsherd and bricks spread into the

soil, rendered the identification of the useful signals more difficult. In general the anomalies have a curved or linear trend which in some cases is clearly referable to ruins of various houses. The archaeologists lingered over the elongated anomaly detected close to the theatre in the THR area. It is a rectilinear signal about 60 meters long, which appears moreover parallel to a defense wall of the IV century A.D.. The anomaly is nearly 5 meters large and its positive and negative values respectively range around ±8 nT (Figure 3a).

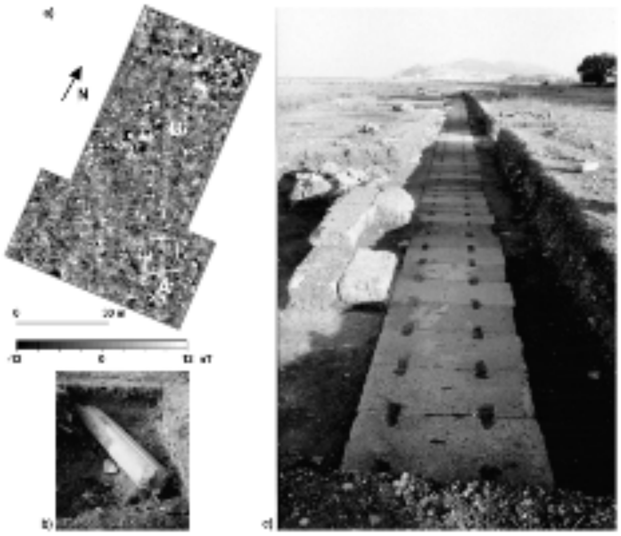


Figure 3. a) Magnetogram of the THR area. The AB anomaly extends for about 60 meters. Inside the white square area, an excavation was undertaken. b) e c) The recovered structures.

In the summer of 1999 a first excavation was performed in correspondence of this signal and a double-columned marble column was found at a depth of about 0.8 m (Figure 3b). The extension of the trench along the direction of the anomaly proved to be fruitless. Only when the excavation was widened laterally and dug deeper (1.1 m) a pavement made of blocks of grainstone (0.6X1.3X0.12 m) was discovered. The archaeologists had considered it as a basement of a long colonnade or of a portico. At present more then 50 meters of this structure has been recovered (Figure 3c).
Once having been mapped the basement showed a good correspondence in its relative position respect to the AB anomaly.

3.2 Canosa (Italy)

As it emerges from a rich tradition of studies Canusium (Canosa) had, between the IV and VI century A.D., a leading role inside the provinces of Apulia et Calabria and in general in all of southern Italy. It represented the political and administrative center being the seat both of the provincial governor and of the concilium of the Apuli et Calabri. Under the economic profile of notable importance were the agricultural activities, the transhumant breeding and handicraft productions. In Canusium moreover there was a prestigious diocese ruled by bishops often involved in important councils and in delicate diplomatic operations (Volpe et al., 2002).
Historical sources and some recoveries on the ground have suggested the presence of an episcopal complex of early Christian age (IV-VI A.D.) in the outskirts of Canosa, on the hill of S.Pietro. In the summer 2001, within a research project with the University of Foggia (Italy), a high resolution magnetic investigation was carried out.

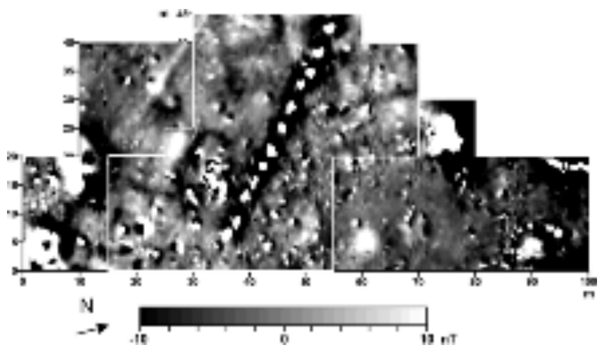


Figure 4. Magnetogram of the whole surveyed area.

The purpose of the survey was the location and the identification of the principal buried structures so to delimit the area with the greatest archaeological potentialities, optimizing in this way the excavations with a noticeable saving of time and money.
Altogether 3450 m^2 were surveyed. In Figure 4 the whole magnetogram is represented. A greater concentration of meaningful signals is immediately noted within a central zone delimited by the white contour. Many linear and curved anomalies are well recognizable. These are mostly negative with values that are around –10 nT. The minimum and maximum values of the entire area are much greater (-583 nT, 1986 nT) and connected to the intense signal formed by the regular oblique sequence of white spots absorbed in a continuous black halo. This strong superficial noise cuts sideways the whole magnetogram overlapping the weaker anomalies produced by the archaeological remains. Actually the following excavations highlighted a set of metallic anchorages, rests of a vineyard uprooted in the recent past.
In Figure 5a the most significant anomalies were outlined schematically illustrating in this way the possible shape of the correspondent sources. The archaeologists used this drawing to

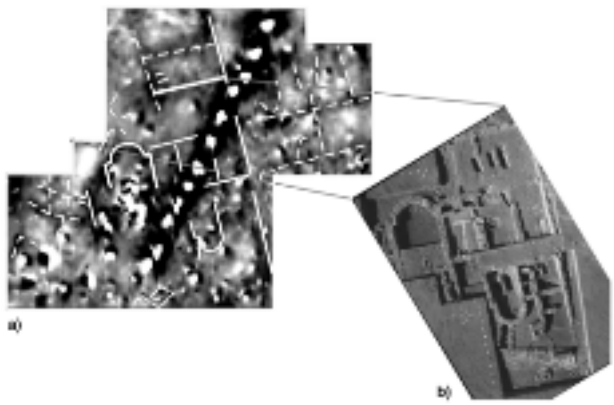


Figure 5. a) All the highlighted anomalies in the magnetogram are sketched with white lines in order to show the possible shape of the sources. b) Aerial photo of the episcopal complex revealed in the S.Pietro Hill..

plan their field work. Figure 5b shows the aerial photo of the excavations, taken from a captive balloon: all the recovered structures are well visible. They are generally made of calcareous stones. Comparing the photo with the magnetogram it can be noticed how all the magnetic features underlined inside the dug area had a satisfactory archaeological feedback. However, it is also true that many structures which are not identifiable in the magnetogram exist. This is mainly due to the complexity of the sources. In fact as shown in the aerial photo, archaeological structures are often superimposed. Besides the strong signal connected to the anchorages of the vineyard and the diffused background noise caused by the presence of sparse offending magnetic items rendered the correct visualization of the buried archaeological sources more difficult.

3.3 Santomola (Italy)

The third magnetic survey was executed in a military zone. During some channeling works a few tombs belonging to a necropolis of the V-II century B.C. were revealed. The tombs were dug inside a compact and well cemented grainstone and some of them have also a counterfosse. The thickness of the ground of coverage never overcomes 0.5 m. The archaeologists of the Archaeological Superintendence of Apulia had only a limited time to access the site and to effect systematic studies. Therefore to better define the extension of the necropolis and guide some aimed excavations a geophysical investigation was undertaken. The total surface of the surveyed area was notably influenced by the presence of metallic enclosures and a large fuel silo buried in the ground. Notwithstanding all the possible precautions, the effect of this last source of intense magnetic noise is evident in Figure 6, in the southern part of magnetogram 2.

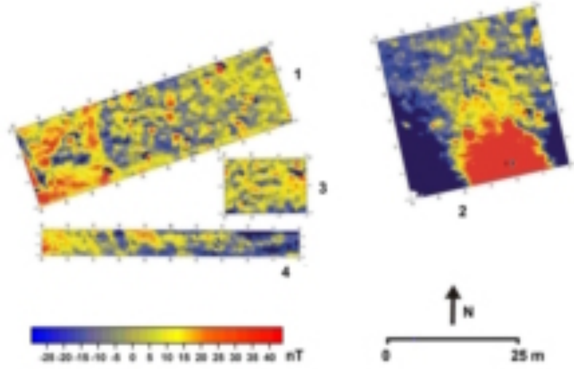


Figure 6. Surveyed area in Santomola. The strong magnetic signal visible in the magnetogram 2 represent the effect of a big fuel silo buried in the ground. The spot localized anomalies are connected to the presence of the graves.

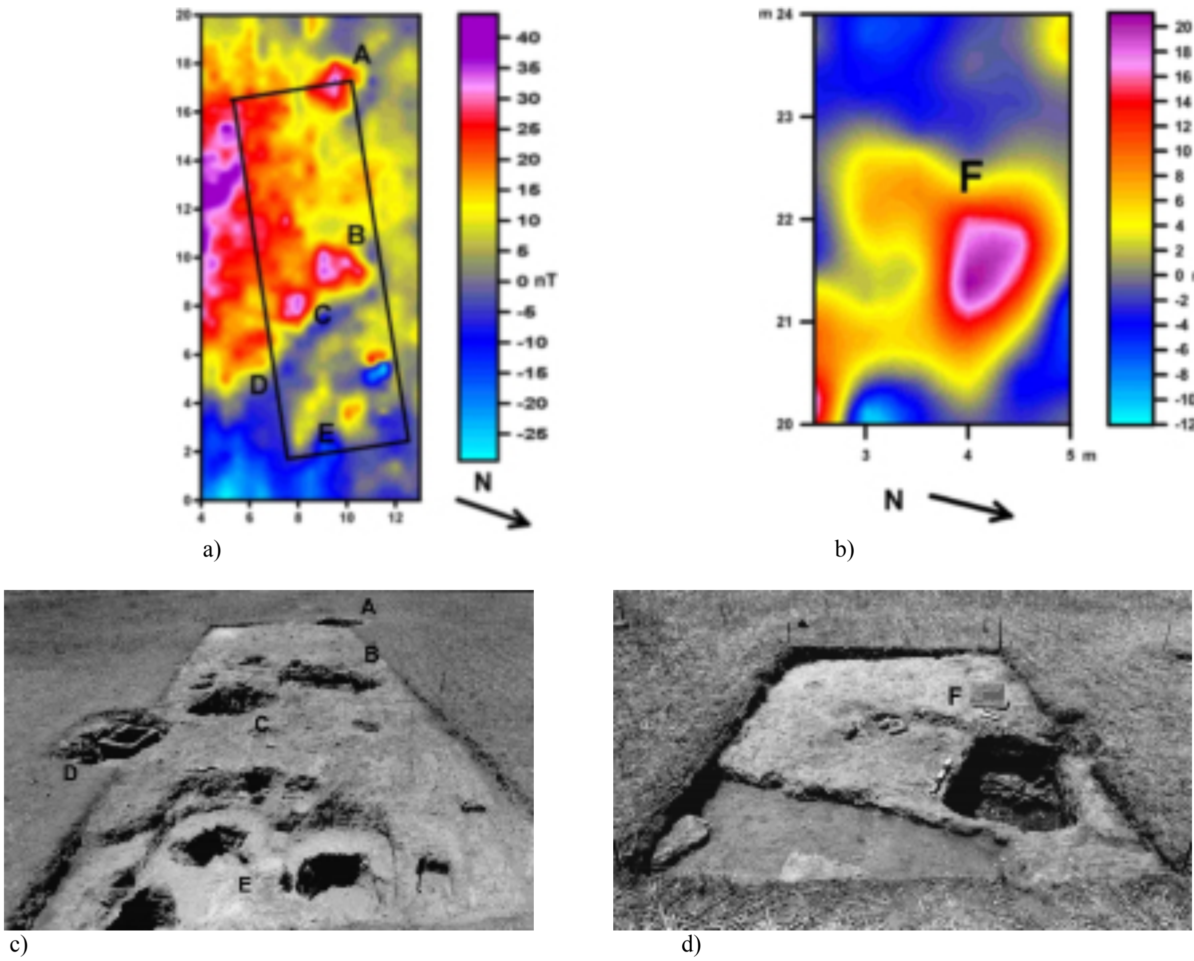
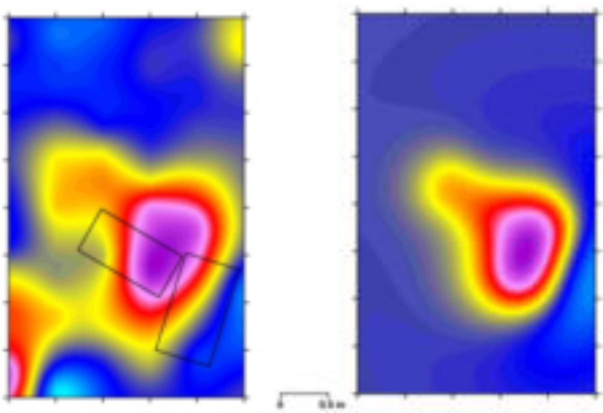


Figure 7. The black line in a) and b) represents the limit of the digs executed in the areas 1 and 2 of Figure 6. The recovered tombs are well shown in c) and d). The good correspondence between the position of the tombs and the magnetic anomalies appears very clear.

Compared to the two cases discussed above, linear or curved continuous signals are absent. The magnetograms seem to be characterized mainly by "spot" localized anomalies. For the correct interpretation of the signal the identification on field, during the data collection, of an almost outcropping grave was very helpful. Knowing its position in the surveyed area, it was possible to recognize its correspondent anomaly, named A in Figure 7a. This is a well-defined magnetic dipole normally oriented. Therefore the useful signal in the surveyed area is represented by dipolar anomalies whose maximum and minimum values vary respectively from +16 to +34 nT and from -10 nT to –5 nT. Some excavations were executed inside areas 1 and 2 of Figure 6. The limits of two trenches, for instance, are marked with a black line in Figures 7a and 7b while the tombs brought to the light are shown in the photographs of Figures 7c, 7d. The appropriate overlap of these photos with the relative magnetograms points out the good spatial correspondence and the likeness in shape between the magnetic archaeological sources and the detected anomalies.
The tombs represent the magnetic sources as the filling material of clayey composition has a greater magnetic susceptibility then the surrounding grainstone. In the light of this archaeological feedback all the spot anomalies detected especially in the magnetograms 1 and 2 can be interpreted as buried graves and the necropolis seems to be spread out all over the area.
In this study we also tried to make a synthetic model which could reproduce the observed signal. In particular the F anomaly whose sources have quite simple geometric features was chosen. They were approximated with two prismatic structures whose positions, dimensions and depth of burring were derived by measurements executed on field (Figure 8a). The only variable parameter was the intensity of magnetization; as the material filling the graves is predominately a clayey soil, a value of 0.26 A/m was assigned to it. Figure 8b shows the finally synthetic anomaly. The likeness with the experimental data is satisfactory in terms of dimension, location, shape and values.



a) b)

Figure 8. a) The black line shows on the magnetogram the layout of the prismatic structures used to approximate the sources of the F anomaly.

3.4 Coppa Nevigata (Italy)

.The settlement of Coppa Nevigata, located in the north of Apulia, offers a complete sequence of the Bronze Age and constitutes an important reference site for studying the recent prehistoric era of southern Italy. (http://antichita.let.uniroma1.it/ricerca/ric_sect.htm). Since the beginning of the last century the La Sapienza University of Rome has been carrying on a systematic study on Coppa Nevigata. It is not known yet if the first settlements of the Bronze Age were fortified whereas the following phases after the XVII century B.C. are characterized by the presence of defensive boundary wall made of over 5 meter thick dry stones. Currently the excavations have recovered more than 70 meters of it. According to the framework of this kind of prehistoric settlement, archaeologists initially supposed that a defensive ditch strengthened with stone-made coverings should have existed and surrounded the inhabited area just outside the boundary walls.

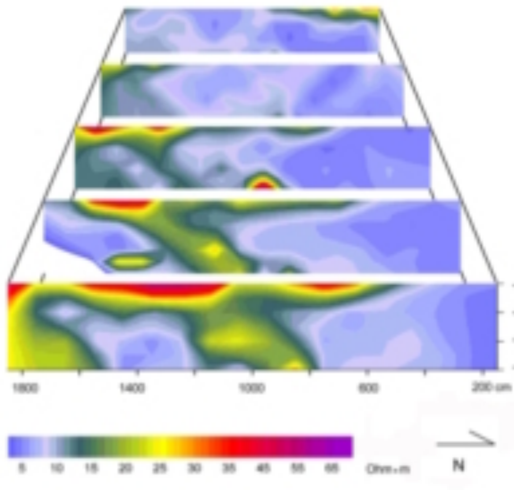


Figure 9. The five pseudosections arranged according to their relative position point out the curved trend of the detected anomalies and of their sources.

In 2000 a d.c. electric survey was performed to verify this hypothesis. A detailed stratigraphic column of the ground resulting from a shallow drilling in a nearby area, suggested the presence of readable contrast of resistivity between the calcareous stones which the archaeological structures could be made of and the surrounding material. The dipole-dipole pseudosection technique was considered the most appropriate method to detect the ditch. Five profiles, 18 m long were executed along parallel lines 5 m apart. Their locations, according to archaeologists' suggestions, were chosen to intersect the probable lay-out of the ditch.
The obtained pseudosections are visualized in Figure 9. The computed apparent resistivity varies in the range of [3, 77] Ωxm. On the central-left part of the Cp0 pseudosection an area with two sloping high-resistivity anomalies enclosing a conductive one is well visible. This signal is still present in the other pseudosections but it tends to disappear gradually. This result may be explained by the fact that the buried sources connected to these anomalies follows the curve of the defence wall. An excavation close to the Cp0 pseudosection subsequently brought to the light a stone made artifact (in correspondence to the first high resistivity value) characterized by a visible slope (Figure 10a). This artifact (XIV B.C.) was realized by an oblique cut made in the ground where a mixture of soils and stones was afterwards laid upon. Archaeologists also discovered (Figure 10b) another stone covering (the second high resistivity value) realized two centuries later and separated from the preceding one by a filling of earth (the embedded conductive feature).

a)

b)

Figure 10. a) Location of the Cp0 profile respect to the excavations. b) Lateral view of the recovered structures showing the two stone made coverings separated by a filling of earth.

As regards the right part of the pseudosections it is worth noting the lack of resistivity anomalies which could be connected to the presence of a further stone covering delimiting the other side of the supposed ditch. This outcome made the archaeologists conclude that the ditch was strengthened only on the side close to the boundary wall. In fact the possibility that the ditch could be longer than 18m and therefore its external wall located outside the surveyed area is considered to be extremely unlikely.

4. CONCLUSIONS

The geophysical surveys have successfully provided important information to the archaeological research in four different situations. Summarizing the obtained results it is worth pointing out schematically the following aspects:

- all the highlighted anomalies had a full archaeological feedback
- both the position and the shape of the signals have shown a good correspondence to those of the sources
- the structures brought to the light by the excavations are mostly made of calcareous material and were hosted by a clayey soil
- environmental noises of various origins were present particularly regarding the magnetic surveys

Definitely, geophysical surveys both magnetic and electric has proven to be quite an effective tool in locating buried archaeological structures and guiding excavations with a great saving of money and time.
The often unlikely environmental conditions and the presence of weak sources of signal (calcareous material could be considered almost inert by the magnetic point of view) affected negatively the survey. Nevertheless using proper field procedures to collect data and good processing techniques it is possible to obtain the maximum content of information. Finally high resolution magnetic and electric images are fundamental in order to recognize the structures even from the shape of their anomalies.

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