ANNALI DI GEOFISICA, VOL. XXXVII, SUPPL. N. 5, 1994

Geoelectric and electromagnetic measurements within an organized archaeological framework: the Marzabotto example

Emanuele Bozzo, Silvia Lombardo, Fulvio Merlanti and Mauro Pavan
Dipartimento di Scienze della Terra, Università di Genova, Italy

Abstract
Geophysical prospecting was performed in the Etruscan settlement of Marzabotto, near Bologna (Italy), to find shallow anthropic structures within an almost homogeneous environment. This paper describes some results of the geoelectric and electromagnetic VLF methods used. Non-standard geoelectric devices, such as the tripotential, twin-probe and the Offset-Wenner methods, were applied. The set of results was compared to classical dipolar sections. The Offset-Wenner device was useful for detecting vertically striking structures. Conversely, the electromagnetic VLF techniques are not suitable for investigating structures with a negligible contrast of conductivity with the environment. Prospecting data generated a general pattern of anomalies and some were confirmed by excavation samples, showing walls, floors, water wells and other remains of urban structures.

Key words *geoarchaeology – applied geophysics – geoelectromagnetic*

1. Introduction

This work, which is part of a cooperative program between the authors and the Institute of Archaeology at the University of Bologna, focuses on the exploration of the Etruscan site of Marzabotto. The sector being studied is insula 2 of Region IV (fig. 1). This insula faces the north on the «plateia» that connects the city with the acropolis and to the east on the «stenopos» which separates it from Insula 1, which has already been thoroughly excavated (Sassatelli, 1989).

The Etruscan settlement of Marzabotto which developed between the VI century B.C. and the first decades of the IV century B.C. covered the Pian di Misano and the Misanello plateau, in the central valley of the Reno river near Bologna. The archaeological site is located on a river terrace which has an overall thickness of about 6 m (Cantelli, 1967). Fluvial clay and fine sand form the upper two meters of this terrace of which the remaining portion consists of medium to coarse gravel. The geological sketch of the Piano di Misano area, a cross-section through the terraces and the Etruscan settlement as well as a schematic stratigraphy of the top of a terrace are reported in fig. 2.

In this site, some problems may arise relative to the interpretation of these data since the physical characteristics of the surveyed structures are similar to those of the surrounding terrain. In fact, the walls were built with sandy pebbles, blocks of travertine and stony materi-

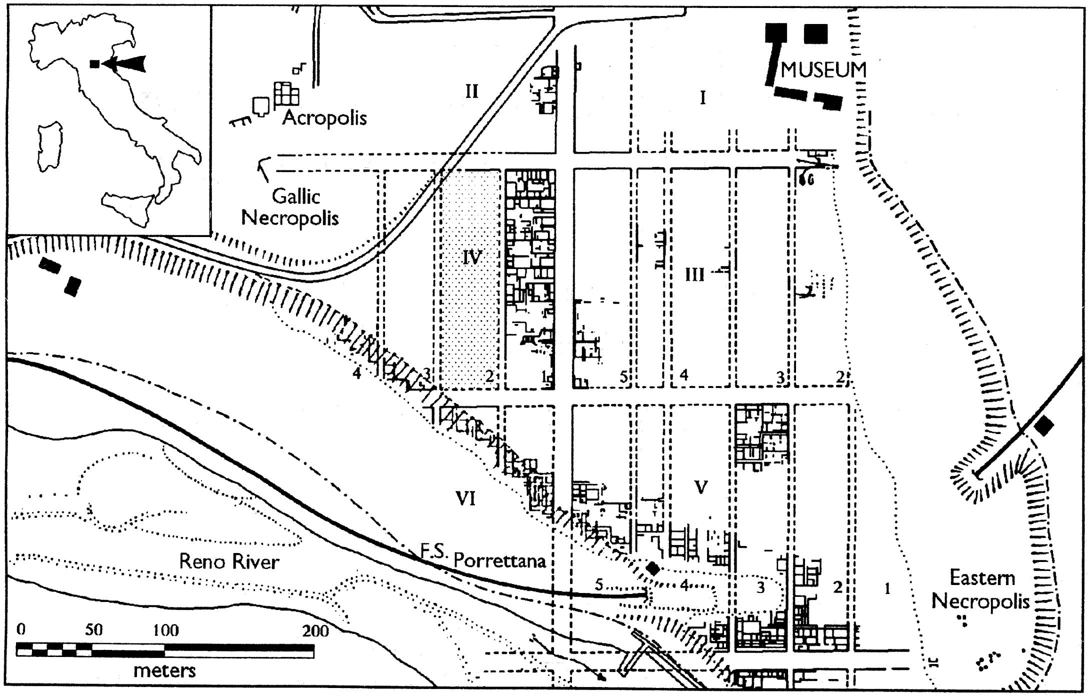

Fig. 1. Maps of the Etruscan settlement of Marzabotto. Geophysical prospecting was performed in insula 2, sector IV (hatched area).

als as the same lithologies as the sediments which currently surround them (Bozzo *et al.*, 1992a).

Figure 3 illustrates the layout of insula 2 of sector IV, with the position of the areas surveyed with geophysical techniques.

2. Geoelectric prospecting

One of the most important parameters relative to the distribution of the electrical field in the subsoil, especially when studying foundations and excavations, is the resistivity. Foundations generally have «high» resistivity while excavations may have both high and low resistivity, depending on the water content, compacting level and nature of the backfill (Carr, 1982).

The substantial stratigraphic homogeneity down to depths of a few meters where the urban part of Marzabotto is located offers good prospects for application of the geoelectric technique. Otherwise, since the medium studied consists of agricultural terrain (fig. 2) on fine river sediments and is marked by a very low average resistivity (about 20 ohm.m), it is expected that there will be a relatively small contrast between the background level and the value of the anomalies.

The dimensions of the geoelectric devices used were chosen in relation to the information relative to the sectors of the city which have already been excavated and which indicate, excluding the wells, structures within the first two meters from the ground surface.

2.1. *Resistivity: horizontal distribution*

Part of insula 2 of sector IV was covered by five 20 × 20 m blocks, each consisting of 441 measurements on a 1 m grid. A semi-automatic multiple-electrode device was used to perform measurements according to a tripotential scheme which supplies resistivity values for Wenner (alpha), dipole (beta) and mixed (gamma) devices (Acworth and Griffiths, 1985; Merlanti, 1990).

Processing of the alpha measurements with distance between electrodes $a = 1$ m is reported in fig. 4. In the N-S direction there is immediate evidence of extended resistive structures, which have a clear relation with the general urban layout of the city. Other isolated anomalies cannot be clearly referred to similar evidences. The N-S direction of the quadripole device and the interpolation criteria adopted to process the map certainly have an effect on some particular morphologies. Different inter-

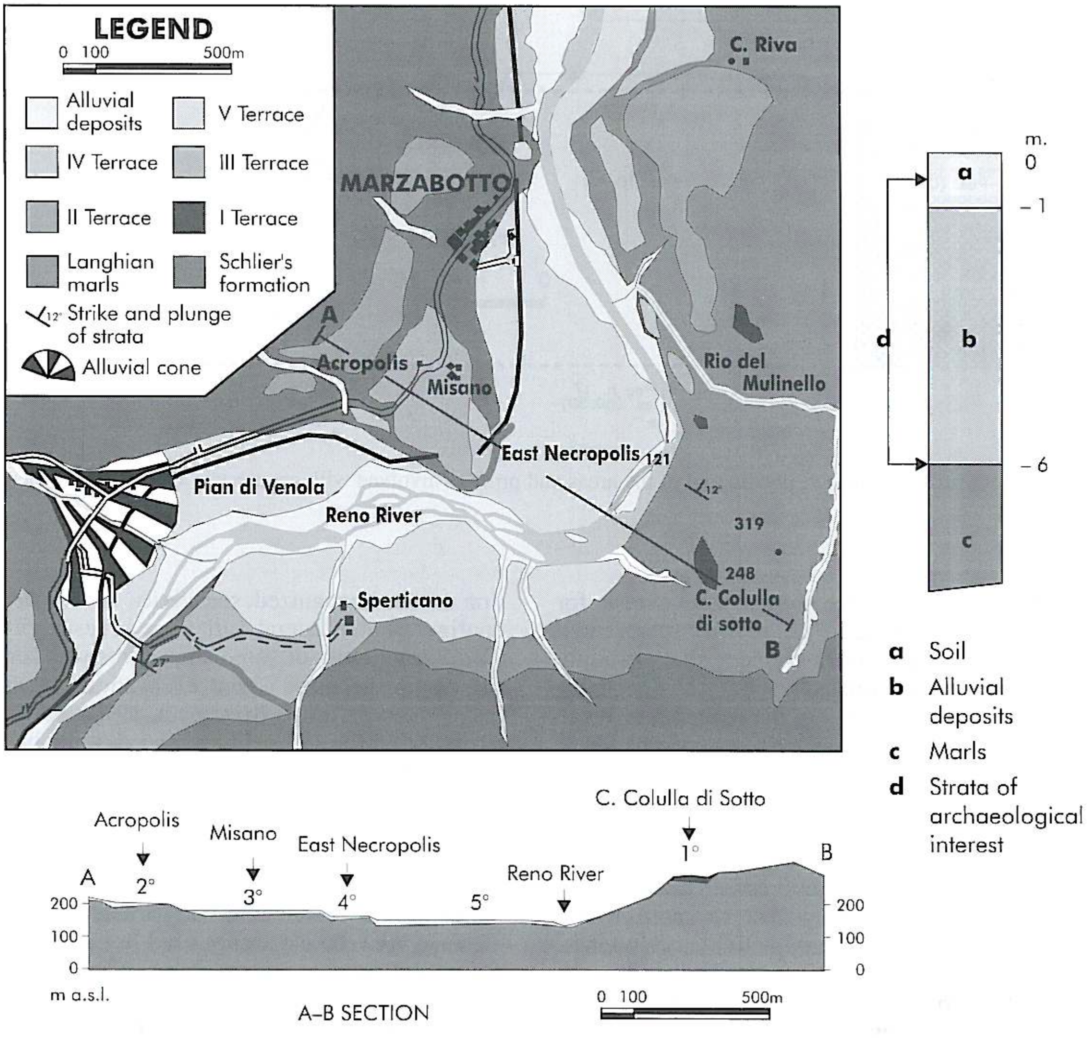

Fig. 2. Geological sketch of the area of Pian di Misano (Marzabotto); section and altimetric profile through the area of the Etruscan settlement and stratigraphic section of the III river terrace.

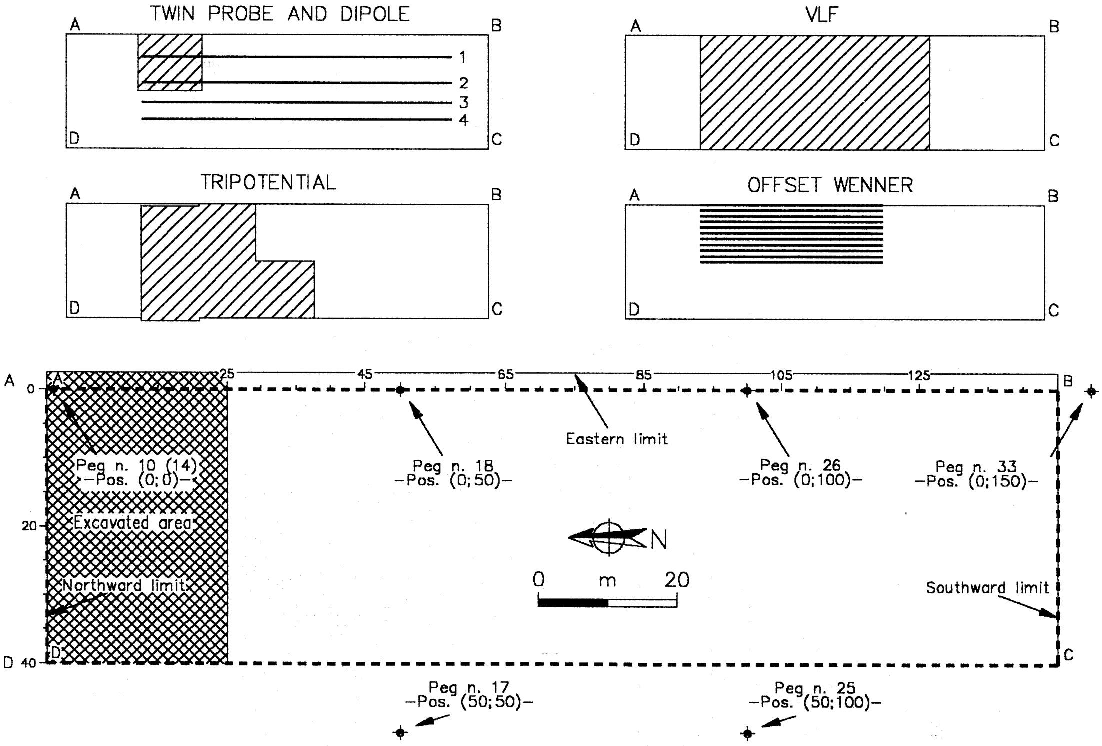

Fig. 3. Insula 2, sector IV, positioning of the areas and profiles involved with geoelectric and electromagnetic prospecting.

polation criteria have shown that, except for negligible differences, the profiles represented are reliable. The only element that certainly has been overestimated is the wavelength of the anomalies which, on the average, is twice the corresponding structures, as confirmed later in the shovel tests.

The minimum resistivity values may be generated by local variations in soil composition, which may not necessarily correspond with archaeologically interesting remains, but rather with re-handling due to more recent work, such as agricultural activities or unorganized excavations.

The map of the isoresistivity values for beta measurements (fig. 5) coincides well with what is described for the alpha configuration. The main differences involve the greater continuity of the anomalies in the E-W direction, in relation to the recognized sensitivity of the beta configuration to lateral variations in resistivity. The discontinuity of some alignments was confirmed by the most recent excavations of the insula (Sassatelli and Brizzolara, 1990) and are attributed to lines of pebbles placed at the base of reed matting walls used to separate interior rooms.

The gamma configuration, with intermediate characteristics compared to the previous values, tend to «double» all those anomalies which have a wavelength comparable with the distance between electrodes used in the profile. Therefore, meter-sized structures, if intersected with an orthogonal profile, have two lateral maxima and one apparent minimum on the axis of the structure. Gamma measurements are mainly used for comparison purposes with beta measurements. Their ratio can be used to study

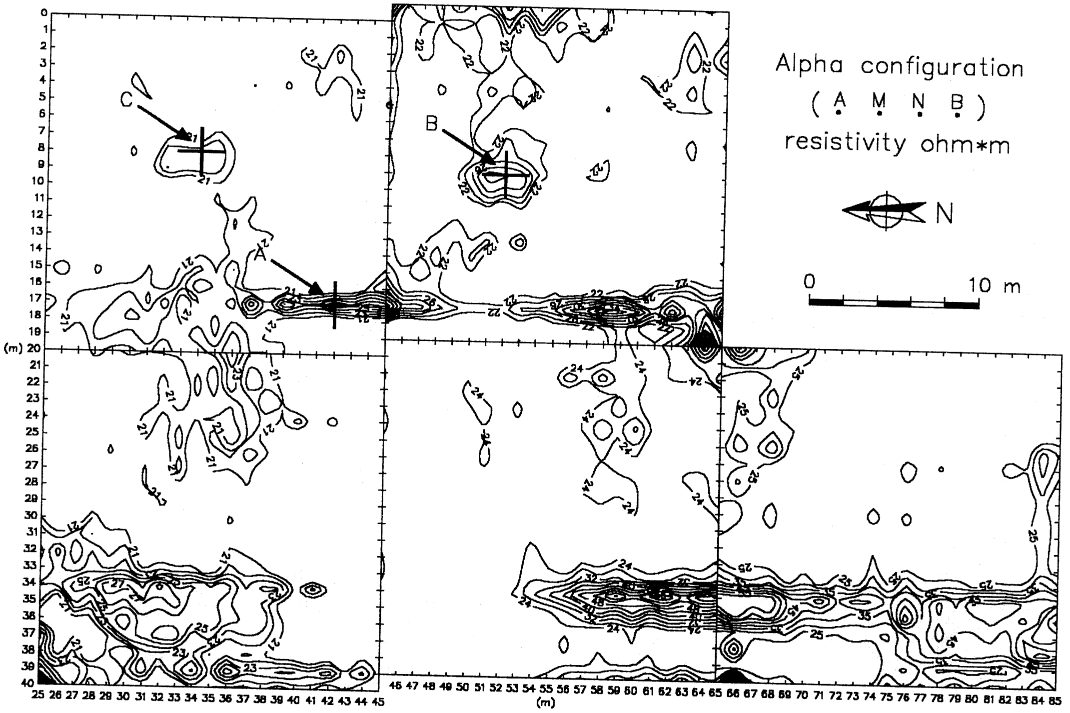

Fig. 4. Tripotential geoelectric measurements, alpha device; general overview of the five 20×20 m blocks.

the resistivity contrasts, especially along the horizontal plane. Theoretically, it can also be used to highlight vertical variations of a horizontally stratified medium (Acworth and Griffiths, 1985).

2.2. *Twin probe measurements*

This electrode configuration has been proposed mainly for archaeological research (Aspinall and Lynam, 1970), it is more similar to the more classical potential device used in geoelectric profiles (Apparao, 1991). In fact, the main feature of this configuration is the electrode system consists of only two mobile electrodes: one for the power supply and the other for measurement, while the two stationary electrodes are installed at a much greater distance than that between the first two.

Figure 6 shows the results of processing relative to the twin-probe and alpha tripotential measurements, as performed on a 20 × 20 m tessera, located in the central-eastern part of insula 2. Along with the elements already clearly detected with the alpha device, the figure also shows other anomalies in both the SE and central parts of the tessera in question. The lack of a signal (mainly in such clear terms) by the other devices may be caused by the greater surface features of the structures. The hypothesis presented is that this involves floors, or cobblestone paving, which is rather thin but has extensive lateral coverage.

2.3. *Resistivity pseudosections*

The measurements performed along a profile, with fixed dimensions of the electrode de-

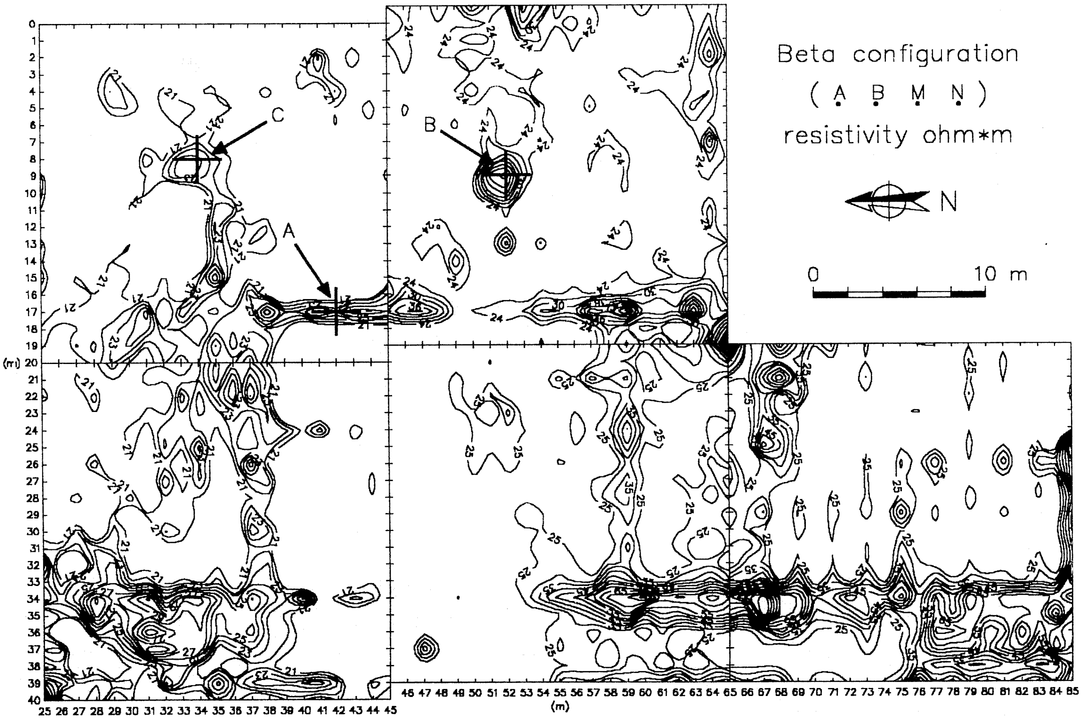

Fig. 5. Tripotential geoelectric measurements, beta device; general overview of the five 20×20 m blocks.

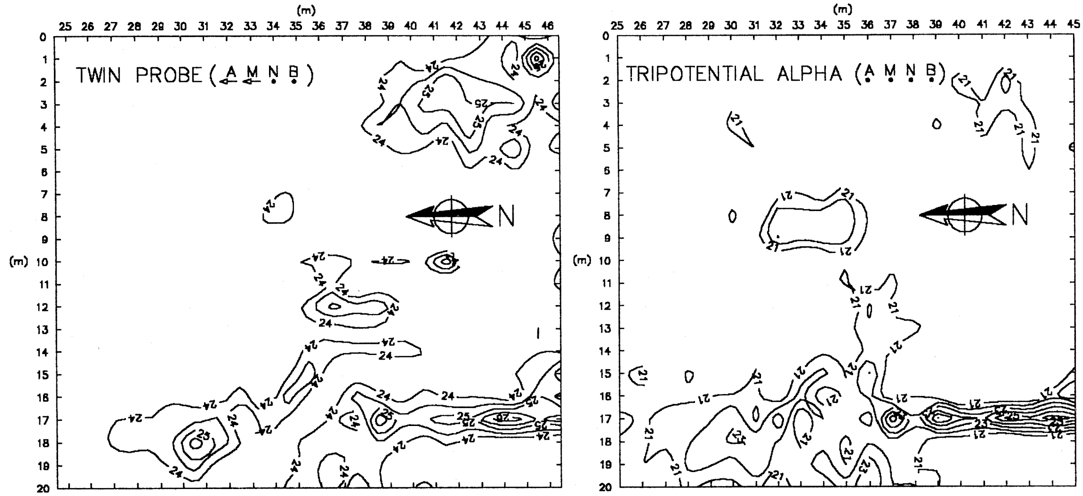

Fig. 6. Twin-probe geoelectric measurements and alpha tripotentials in a 20×20 m block.

vice (Wenner type) and those with increases of the electrode distance (VES type), may be combined to form a kind of continuous electric survey which can acquire sets of data along the same profile. The set of values is represented according to conventional schemes called «pseudosections» (Hallof, 1957).

2.3.1. Dipolar pseudosections

The dipole-dipole electrode configuration is frequently applied in geoelectric resistivity or induced polarization measurements. To represent the pseudosections, a conventional ratio: distance between dipoles/effective sounding depth = 0.42, was used (Roy and Apparao, 1971).

Dipolar prospecting was carried out with N-S oriented profiles to cover the greatest dimension of insula 2 (fig. 3). Figures 7a-d illustrate pseudosection processing along the four profiles. Linearization in the pseudosection, with a 45^o tilt, is typical of this type of representation and appears more clearly in the surface elements with rather limited lateral extension. Pseudosection processing does not include the first meter of ground, due to surface disturbances, and therefore the elements indicated can be linked to significant structures in terms of dimensions and resistivity contrast.

2.3.2. Tripotential pseudosections

The alpha, beta and gamma configurations of the tripotential device can also be used to create resistivity pseudosections. This occurs through the acquisition of measurements with gradually increasing distances between electrodes. The conversion coefficients, used to perform an approximate transformation of the distances between electrodes at the survey depth, are respectively: 0.52 for alpha, 0.42 for beta and 0.60 for gamma (Roy and Apparao, 1971).

Figure 8 reports an example of this type of pseudosection. In addition to the direct comparison between the alpha, beta and gamma resistivity values, it is also possible to analyze the development of the beta/gamma ratio, which is a good index of the variations in lateral resistivity. For an uniform half-space, this ratio is one, while for positive or negative resistivity contrasts, it is respectively less than or greater than one; this parameter also indicates the sign of the resistivity contrast.

2.4. *Offset Wenner electrical soundings*

Vertical electrical soundings (fig. 3) were performed with the Offset-Wenner (OW) technique (Barker, 1981; Merlanti, 1990). Combined with tripotential measurements, this technique can be used to control the lateral variations of the electric properties in the two half-spreads in which it is possible to subdivide any quadripole linear device.

In OW technique, each VES can be considered as two sets of values which are only partially coincident. Thus, we may define a «right» sounding and a «left» sounding for the same station center.

This OW sounding capacity can be used not only to compensate the lateral non-homogeneities (Barker, 1981), but to detail structures with a mainly vertical structure. This is confirmed by the geoelectric sections shown in fig. 9 obtained through inversion, in the E-W direction, of the curves relative to the «left» (towards the S) and «right» (towards the N) configurations (fig. 3).

The «left» section shows a very clear stratigraphy: a surface layer of about 1 m of thickness and resistivity of 20 ohm.m covers a more conductive level, with a thickness of about 2 m, probably consisting of fine river terrace sediments with a mainly silty pattern. This is followed by another river terrace level consisting of coarser sediments, with a thickness of about 3 m and a resistivity that ranges from 100 to 200 ohm.m. In this last is located the temporary water-bearing stratum which is fed during the rainy season by the supplies coming from the northwestern reliefs. At a level of − 6 m a very conductive layer corresponding to the marny formation acts as impermeable bottom of the water-bearing stratum.

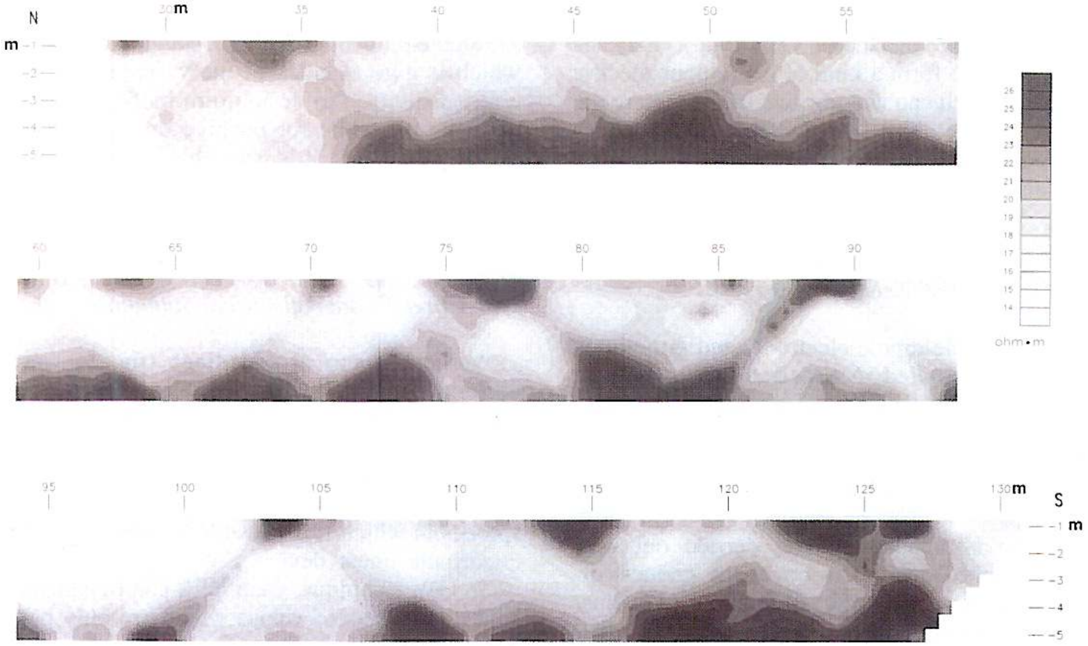

Fig. 7a. Dipolar pseudosection of apparent resistivity relative to profile 1.

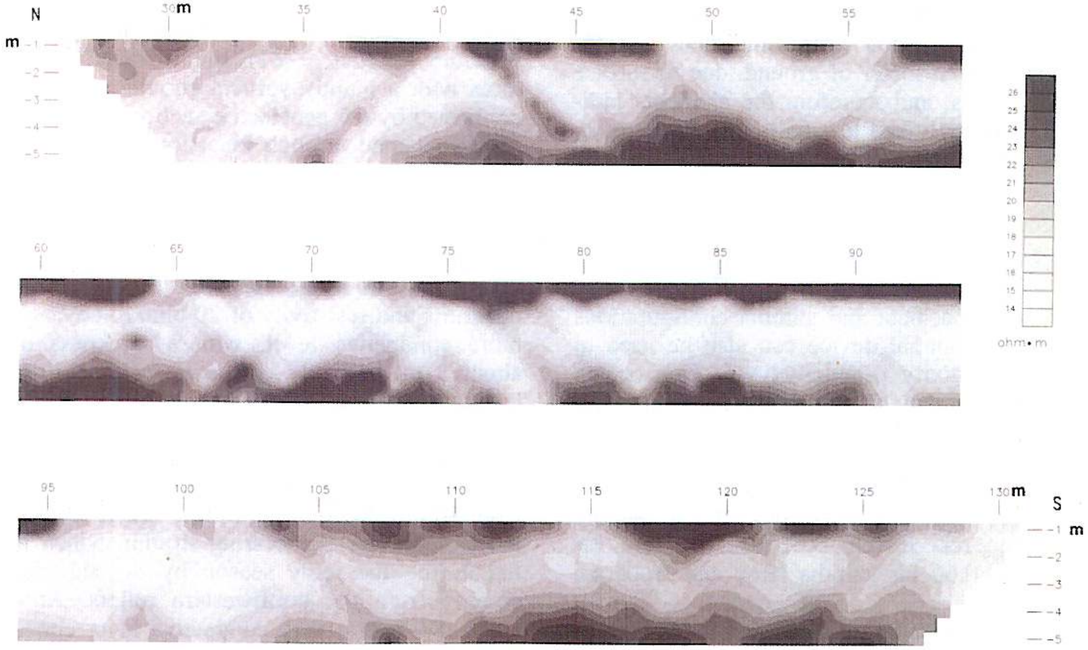

Fig. 7b. Dipolar pseudosection of apparent resistivity relative to profile 2.

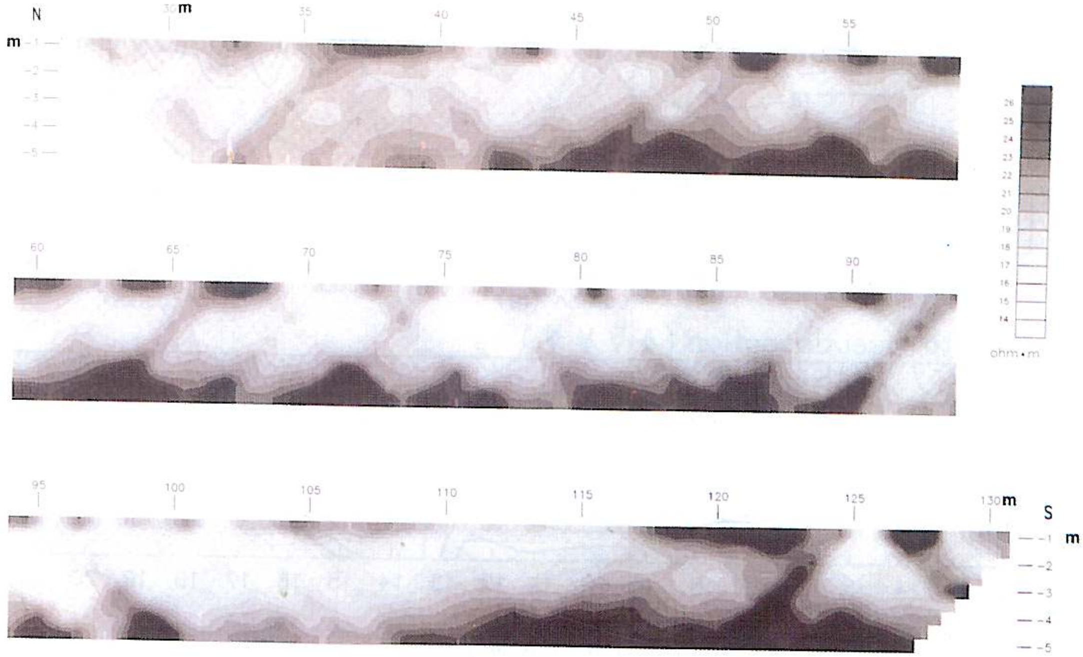

Fig. 7c. Dipolar pseudosection of apparent resistivity relative to profile 3.

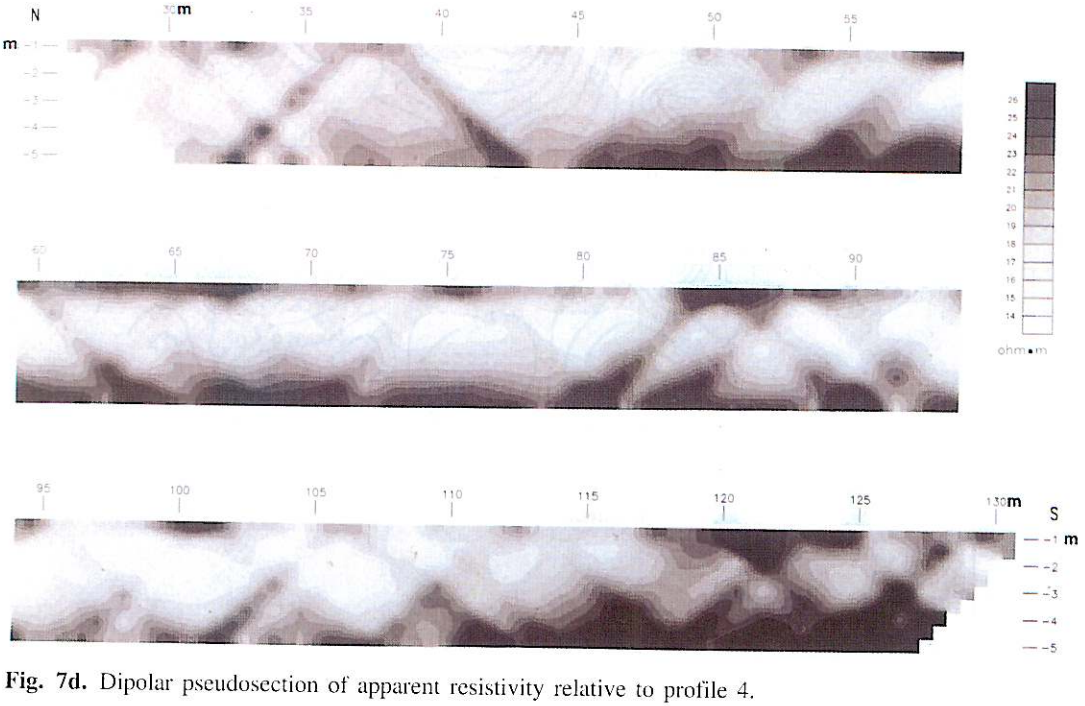

Fig. 7d. Dipolar pseudosection of apparent resistivity relative to profile 4.

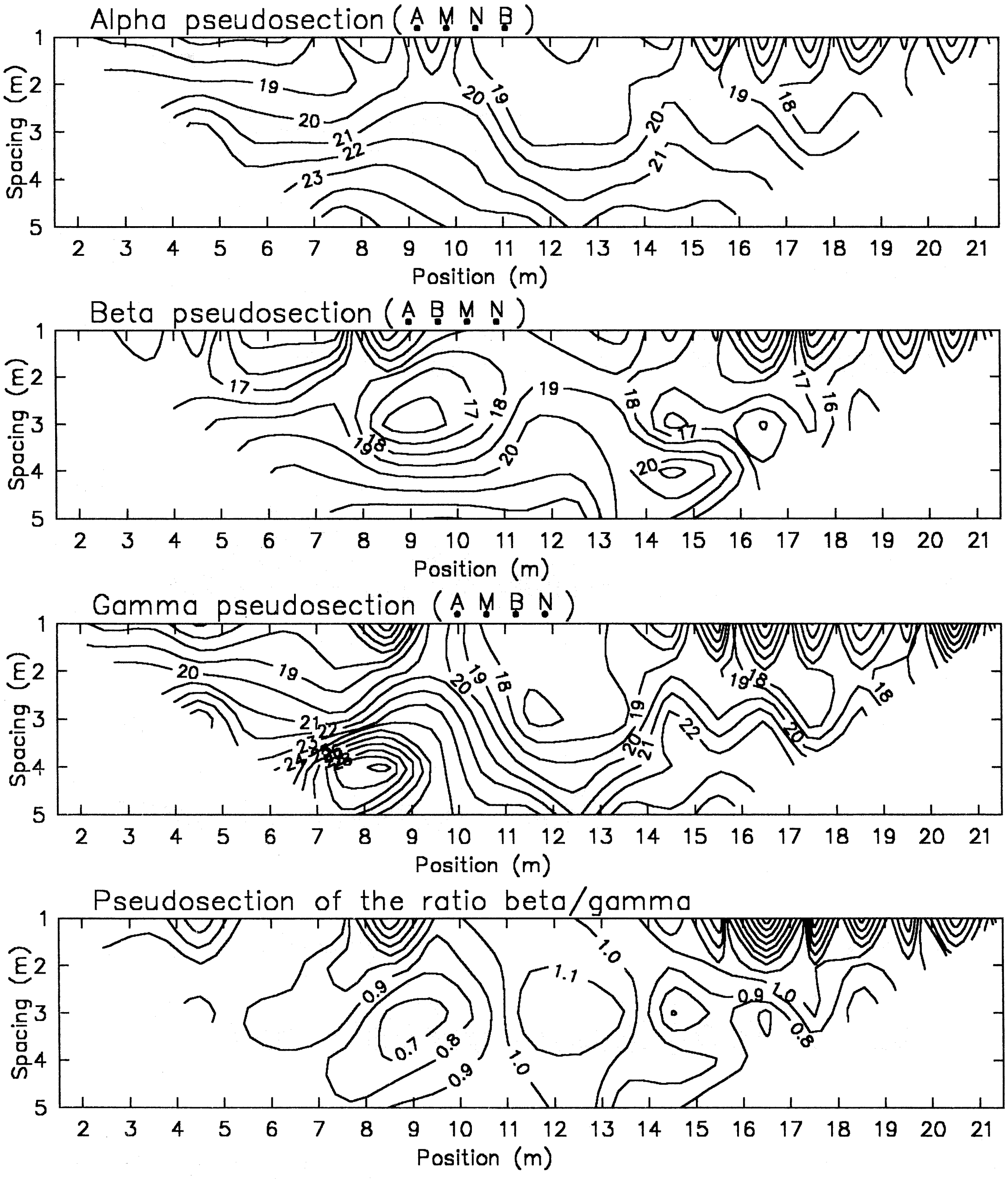

Fig. 8. Example of resistivity pseudosections obtained with the tripotential device.

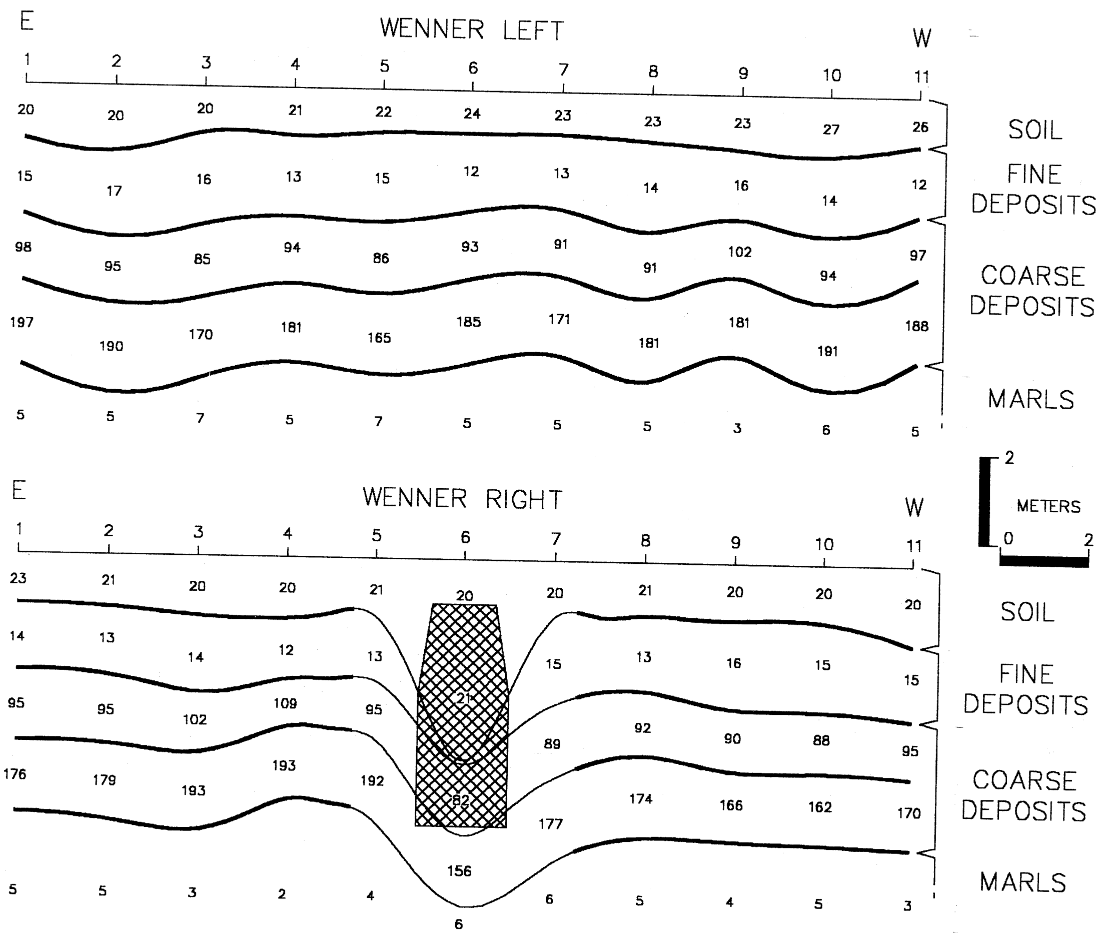

Fig. 9. Geoelectric sections processed from a set of VESs performed with the Offset-Wenner technique.

The «right» section exhibits the same situation with the only exception being the variation of the station center which is located at the 10 m coordinate.

The comparison of the VESs with the dipolar pseudosection illustrated in fig. 7a and with the alpha tripotential map shown in fig. 4, highlights the vast vertical extension of the anomaly which leads to the hypothesis that the involved structure is rather unique and attributable to a well.

In addition, it should be noted that in all the dipolar pseudosections there is a depth-related resistivity level which, based on the VESs, is referred to coarse sediments.

3. VLF electromagnetic prospecting

The VLF electromagnetic techniques applied to archaeological problems are still in the experimental stage. The frequent presence of conductive overburden in sites with archaeological remains, represents the main problem in applying this technique (Bozzo *et al.* 1992b,c).

The instruments used, an Eda-Vlf/Omni

model, operates in the 15-30 kHz range and converts the signals in terms of the «in-phase» and «in-quadrature» magnetic components of the resultant (expressed as a percentage compared to the main field), and of tilt of the polarization ellipse.

The VLF prospecting was performed along E-W alignments, perpendicular to the azimuth of the transmitting station (19.6 kHz, Rugby, U.K.). Then the investigation was carried out mainly to detect anomalies related to structures with N-S extension, therefore in the same direction of the main anomalies detected with the tripotential, twin-probe and dipolar devices.

The behaviour of the component in phase, which is normalized with respect to the primary field, in the sector of fig. 3, is reported in fig. 10. There is a very limited deviation of the values, except for the NW sector, where the proximity to the Porretana road creates a considerable amount of induction phenomena. If we compare this result with those from geoelectric devices, the correlations are almost insignificant and only few elements with E-W orientations seem to correspond. It may be explained with the consideration that the geoelectric measurement indicates maximum sensitivity in the first two meters of the ground, while the VLF measurement is affected by deeper and more electromagnetically differentiated levels. The analysis of the in quadrature data distribution (fig. 11) also does not provide additional significant contributions. Therefore, the information obtained from VLF electromagnetic prospecting is poorly related to the remains of the urban layout, except for those cases in which the anthropic activities (diggings for wells, for example) affect the bedrock.

4. Discussion of results

The results presented show that geophysical information contains a large number of diagnostic elements and that the integration of data coming from different techniques can eliminate any possible interpretative ambiguities. Close collaboration with archaeologists has led to useful discussions about the importance of the geophysical anomalies detected and the execution of some shovel tests. Figure 4 indicates the locations of these excavations (A, B, C), which were selected on the base of geophysical suggestions. Some details of the detected structures are reported in fig. 12.

Excavation A exhibited wall remains located at a depth of 0.7 m, with a width of 0.4 m, consisting of organized blocks of various types of stony materials.

In excavation B, part of an arched structure was unearthed, it seems to belong to the opening of a well.

Excavation C is more difficult to interpret, but the channel configuration of several stony elements resembles a system to collect rain water.

It is now possible to review several results from our prospecting activities. In figs. 4 and 5, the alpha and beta tripotential measurements not only show clear linear structures, but also areas with unstructured and irregular anomalies. This situation may be attributed to the intense agricultural activities carried out for centuries on this terrace. Sometimes the linear anomalies interrupt and sometimes are adjacent to the low resistivity areas which are generally quite extensive and with a square or rectangular shape. Their hypothetical connection with dumps, relative to different periods of city life, is considered plausible, just as their association to settling tanks for clayey materials widely used in the ceramic and earthenware industry in the Etruscan age.

Experiments performed with the twin-probe device (fig. 6) demonstrate that, without affecting identification of the main anomalies, other signals can be detected which are linked to the presence of structures in the subsoil. However, there is a certain amount of ambiguity regarding their depth. In fact, the twin-probe configuration has a greater penetration depth. Surface elements (floors) and deeper elements (foundation remains) create similar effects at the surface.

The agricultural activity, or unorganized excavations, have damaged and dispersed the materials which form the buried remains, it seems to be confirmed by the random distribution of the smaller anomalies and by the interruptions

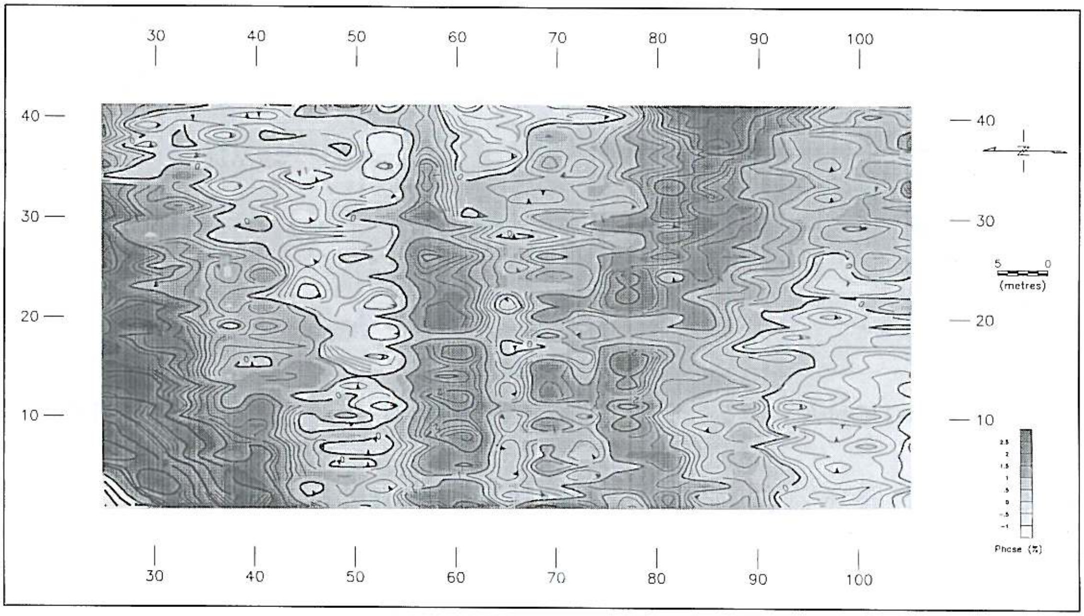

Fig. 10. VLF electromagnetic prospecting. Map of the «in phase» component (%).

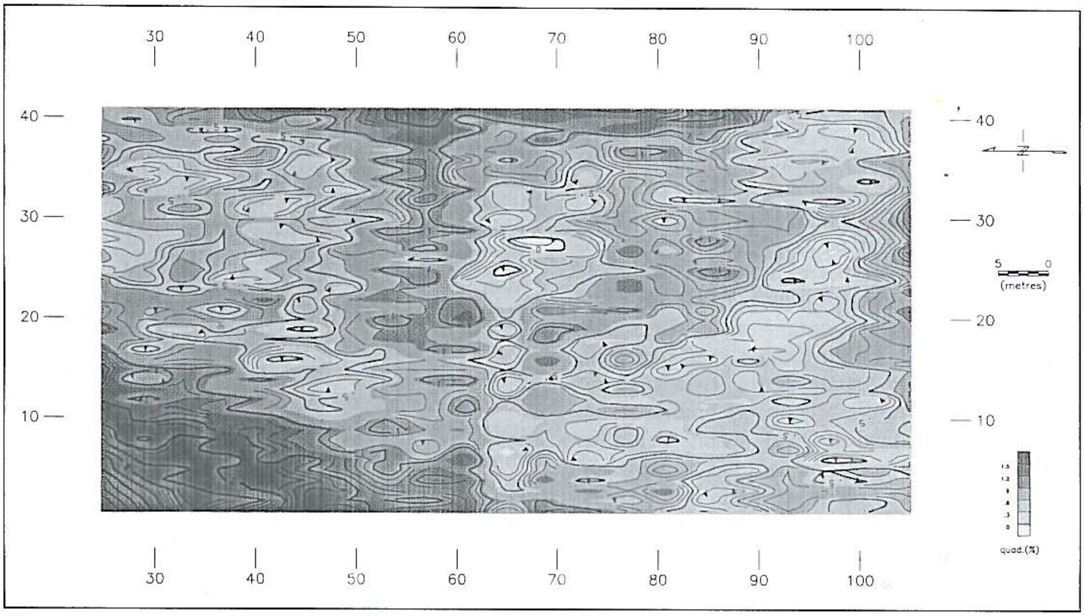

Fig. 11. VLF electromagnetic prospecting. Map of the «in quadrature» component (%).

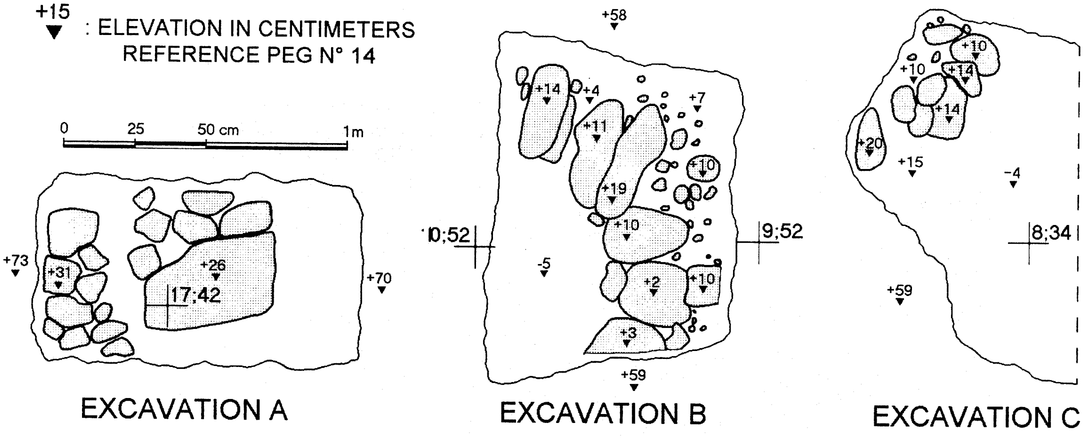

Fig. 12. Results of the shovel tests in insula 2, sector IV at Marzabotto.

in the anomalies which clearly refer to buried linear structures.

The dipolar profiles, as represented through pseudosections, provide another base for observing the distribution of electrical properties in the subsoil. In pseudosection 1 (fig. 7a) between the 32 and 35 m progressives, there is an evident high in the sublayer that is connected to a surface element. There are no significant anomalies up to the 50 m progressive where a signal appears that is similar to the previous one. Shovel tests B and C (fig. 4) have indicated the presence of structures which can be attributable to well openings.

Pseudosection 2 (fig. 7b) lies in the direction of maximum elongation (N-S) of one of the main wall structures of insula 2, which is clearly defined even along its vertical development. This structural element must represent a type of backbone in the insula configuration, and longitudinally separates the fronts of the dwelling units. The surprising continuity of the intermediate conductive level would seem to confirm this hypothesis, and thus the construction of this structure may be linked to an initial phase of the urbanization process, without having undergone any major transformations over time.

Dipolar pseudosections 3 and 4 (figs. 7c,d) describe a completely different situation. Surface structures seem to dominate the initial part of the profiles. There is limited information at any depth in the central part, almost as if to indicate a lack of dwelling elements. Instead, the bottom part presents clear anomalies which, considering their magnitude and complexity, have evident structural implications. Hypothetically, this situation may refer to a road structure or public utility plant.

The foundations, floors, channels, and other remains detected by the vertical electrical soundings have different vertical extensions, it appears, in the electrical section, as waves in the thicknesses of the layers.

Through relationships which link the skin-depth to the characteristics of the electromagnetic source and to the electrical properties of the crossed medium, the electro-stratigraphies also provide an evaluation of the survey depth that can be reached with the VLF technique. By setting a frequency of 19.6 kHz for the transmitter used and a value of about 20 ohm.m for the average resistivity of the upper part of the terrace sediments, we find that the thickness involved in VLF prospecting is about 8-10 m. Based on the direct information obtained from excavations, from the results of VESs and on the stratigraphy proposed for the area, we can conclude that this thickness includes the structural remains of the urban context and the first few meters of the archaeologically undisturbed sublayer.

REFERENCES

ACWORTH, R. I. and D.H. GRIFFITHS (1985):, Simple data processing of tripotential apparent resistivity measurements as an aid to the interpretation of subsurface structure, *Geophysical Prospecting*, **33**, 861-887.

APPARAO, A. (1991): Geoelectric profiling, *Geoexploration*, **27**, 351-389.

ASPINALL, A. and J.T. LYNAM (1970): An induced polarization instrument for the detection of near surface features, *Prospezioni Archeologiche*, **5**, 67-75.

BARKER, R.D. (1981): The offset system of electrical resistivity sounding and its use with a multicore cable, *Geophysical Prospecting*, **29**, 128-143.

BOZZO, E., F. MERLANTI and G. ROCCA (1992a): Building stones and their provenance in the etruscan township of Marzabotto near Bologna (Northern Italy), 2° Meeting of ASMOSIA, 15-20 October 1990, *Acta Archaeologica Lovaniensia*, monogr. n. 4, 105-114.

BOZZO, E., F. MERLANTI, G. RANIERI, L. SAMBUELLI and E. FINZI (1992b): EM-VLF soundings on the eastern hill of the archaeological site of Selinunte, *Bollettino Geofisica Teorica ed Applicata*, **34** (134-135), 167-180.

BOZZO, E., F. MERLANTI, S. LOMBARDO, F. GIOMI, B. TRAVERSONE and G. CANEVA (1992c): Indagini geofisiche a Poliochni, Lemnos (Egeo Settentrionale), in *Atti Scuola Italiana di Archeologia di Atene* (in press).

CANTELLI, C. (1967): Sulla costituzione geologica della zona di Marzabotto, *Studi Etruschi*, **35**, 333-388.

CARR, C. (1982): *Handbook on Soil Resistivity Surveying* (Centre for American Archaeology Press, Illinois), pp. 676.

HALLOF, P.G. (1957): *On the Interpretation of Resistivity and Induced Polarization Measurements* (Cambridge, MIT), Ph. D. thesis.

MERLANTI, F. (1990): Misure geoelettriche in corrente continua con dispositivo multielettrodico, in *Atti IX Convegno GNGTS, Roma 1990*, 489-499.

ROY, A. and A. APPARAO (1971): Depth of investigation in direct current methods, *Geophysics*, **36**, 943-959.

SASSATELLI, G. (1989): *La Città Etrusca di Marzabotto* (Grafis Ed. Bologna), pp. 92.

SASSATELLI, G. and A.M. BRIZZOLARA (1990): *I Nuovi Scavi dell'Università di Bologna nella Città Etrusca di Marzabotto* (Ed. Clueb, Bologna), pp. 47.