BOLLETTINO DI GEOFISICA TEORICA ED APPLICATA VOL. XXXIV, N. 134-135 - JUNE-SEPTEMBER 1992

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VERTICAL ELECTRIC SOUNDINGS AND INDUCTIVE ELECTRO-MAGNETISM USED TO INVESTIGATE THE CALCARENITIC LAYER IN THE SELINUNTE ARCHAEOLOGICAL PARK

Abstract. One of the problems that we were faced with in adopting geophysical prospecting at the Selinunte Archaeological Park was to define the calcarenitic layer on the Eastern Hill. This was done with vertical electric soundings, and measurements of superficial resistivity by means of inductive electromagnetism. The study area can be subdivided into three zones: i) to the north of the Temples area, where the calcarenite layer is probably discontinuous; ii) corresponding to the Temples, where the calcarenite is up to 6-7 m thick and has a very high resistivity; and iii) to the south of the Temples, were the thickness and resistivity of the calcarenite decrease, although the formation is still somewhat continuous. In the zone to the north of the Temples, the clayey bedrock was found at a very different depth from that to the south of the Temples. This suggests the presence of a tectonic dislocation. As a final conclusion, it seems that the presence of calcarenitic layers intercalated at various depths as proposed by the geological field survey cannot be confirmed.

INTRODUCTION

In searching for evidence of past human activity in the Selinunte Park, one of the questions to be answered is the extent and thickness of the calcarenitic cover outcropping at many places on the Eastern Hill. The calcarenite displays different lithological features from zone to zone, and its lateral continuity is very uncertain, especially in the zone north of the Temples where the test sites are located.

During a detailed geological survey of the zone, outcrops of many superposed layers of calcarenite were found along the slope from the Eastern Hill to the Cottone valley. However, the lateral continuity of such layers cannot be followed (Amadori et al., 1992).

On the basis of these data, a vertical electric sounding (VES) survey was set up to determine the limits of the Eastern Hill calcarenite. To complete the resistivity measurements in the investigated archeological areas, conductivity measurements using an inductive electromagnetic method were also taken to determine the areal distribution of the superficial electrical characteristics.

FIELD OPERATIONS

Owing to the shallow depth to be investigated, and in order to study the most superficial layers in detail, 21 VES were carried out at initial AB/2 electrode distance of 1 m, using a Schlumberger array. Ten measurements on each decade were taken to construct the field curves;

Manuscript received January 15, 1992; accepted March 20, 1992.

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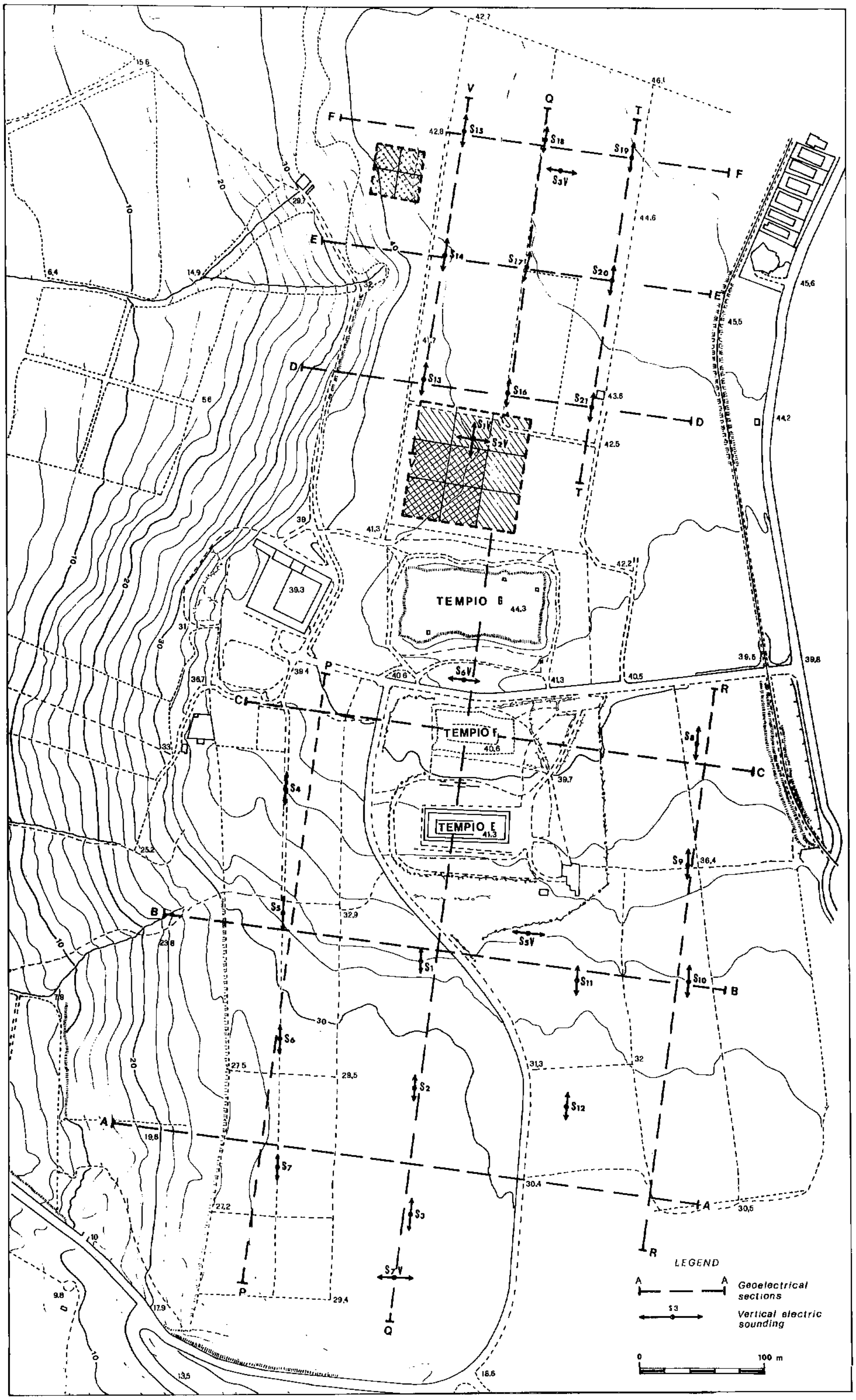
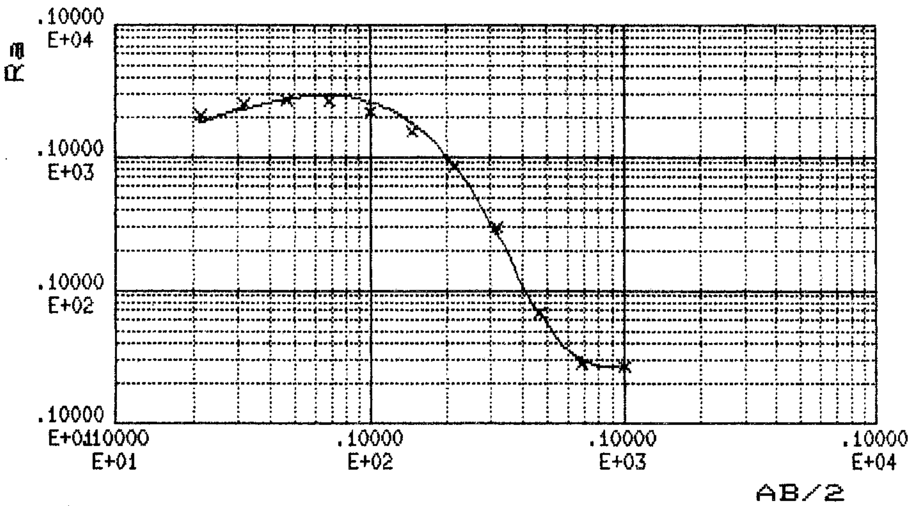


Fig. 1 — Map of Eastern Hill. Location of electric soundings is indicated (the small arrows show direction of array). EM 31 electromagnetic measurements were taken only in the darker squared areas.

SOUNDING S5

SITE SELINUNTE **DATA MAY-1991**



final model ___ ___ ___
sampled values XX

RESISTIVITY	DEPTH
118	1.2
784	3.8
25	13.8
2	

ERROR % (r.m.s.) = 9.67
MAXIMUM ERROR % = 17.08 ON THE SAMPLE 5

Fig. 2 — Example of automatic elaboration of an electric sounding.

this sampling rate seemed appropriate for an accurate field curve and for obtaining the best interpretation. The VES locations are shown in Fig. 1, as well as the previous ten VES executed in the Park area during the preliminary survey (their results are given in Amadori et al., this issue). The array direction is shown in Fig. 1 by two small arrows.

Fig. 1 also shows the position of the geoelectric sections giving the VES interpretation. It is worth noting that it was possible to locate only a limited number of soundings in the Temples area because it was difficult to find zones suitable for the array setting.

Measurements were carried out with a Syscal R-2 apparatus from BRGM using storage batteries, which were sufficient for the investigation depth.

Electromagnetic measurements were taken only in the 40×40 and 90×90 test sites, shown in Fig. 1, using a Geonics EM-31. This instrument employs the inductive electromagnetic technique for the determination of apparent soil resistivity. In homogeneous soils, the EM-31 allows an investigation depth of 6 m for a vertical position of the wire axes, and a depth of 3 m for horizontal wire axes (Mc Neill, 1980a, 1980b; Zalasiewicz et al., 1985; Frohlich et al., 1986).

ELECTRIC SOUNDINGS INTERPRETATION AND RESULTS

An initial examination of the VES field curves suggests the presence of a first superficial layer with a relatively low resistivity, a second layer with higher resistivity, and a third layer showing a sudden decrease in resistivity. Thus, a 3-horizon model seems to be the simplest interpretation. As an example see sounding S5 in Fig. 2.

However, the detailed geological survey together with previous VES data (Amadori et al., this issue) show the presence of a clay-sand overlying a pure clay layer, underneath the calcarenitic cover. Therefore, a 4-horizon model is to be preferred because it takes into account an intermediate $20 \div 40$ Ωxm-layer before the slope of the curve to $2 \div 5$ Ωxm.

An initial interpretation based on the usual theoretical master curves was used as the basis for the automatic calculation program, according to the Koefoed Steepest Descent method (1968). It was in this way possible to improve the interpretation by finding the best-fit between theoretical and field curves for various values of resistivity and thickness. As an example, a theoretical curve and the apparent resistivity field values are shown in Fig. 2. It is worth noting that the field curve was sampled again by plotting decade in 6 in order to compare with the theoretical values corresponding to each of the electrode distances at which they were calculated. The computation of theoretical curves was carried out by applying O'Neill's (1975) filter with twenty coefficients, since testing showed it to be the most suitable.

These calculations gave a very small value of standard deviation (even lower than 3-4%) between field and theoretical values. Lateral congruity between nearby soundings was taken into account by giving a fixed resistivity and/or thickness to some of the layers at some points.

The sections shown in Figs. 3 and 4 referring to N-S and E-W profiles were obtained with this elaboration. From these sections, the trend of the layers both in the direction of the sections and normal to them can be obtained.

As said previously, the model with 4 superposed layers was preferred. Using also data from previous VES, it was possible to extrapolate everywhere the depth of the basal clay, which has a resistivity ranging from 2 to 5 Ωxm. Furthermore, the overlying clay-sand with more variable resistivity ($10 \div 50$ Ωxm) was generally detected everywhere.

As to the calcarenitic layer, three zones with very different thicknesses and resistivities have to be distinguished: northwards (Fig. 3 sections D, E, F), the calcarenite has a resistivity no higher than 200 Ωxm and a very small thickness (1-2 m). This suggests that the material is probably intensely altered and highly fractured. The lateral continuity shown in the sections is schematic in that the distance between the electrical soundings, and the calcarenite thinness may also indicate the presence of discontinuous lenses. On the contrary, in the Temples area (sections B, C), the resistivity (higher than 1000 Ωxm and up to 2400 Ωxm even) and the thickness (up to 6-7 m) of the calcarenite are evidence of fresh rock with lateral continuity. This matches well with the choice of area for the Temples foundation. Finally, sections A, P, Q (Fig. 3-4) display so much variability in resistivity and thickness that the calcarenitic layer is not identifiable as a continuous layer.

The N-S profiles (Fig. 4) suggest the presence of a discontinuity zone immediately to the north of the Temples area: in fact, in this area, solid calcarenite is absent, and the clayey substratum is at a much lower average depth (10 m and more) than that expected in such a small area on the basis only of depositional variations.

In the following paragraphs, we examine the possibility that VES can detect the presence of overlain calcarenitic layers intercalated with the sand-clay formation, such as the outcrops on the slope to the east of Eastern Hill. The field curves, even when thoroughly examined, do not show any hints of a more resistive layers. However, it is well known that formations which are thin and/or do not have significant resistivity differences may not be recorded on field curves.

As an example, let us consider the interpretation of sounding S5 (sited near the above mentioned outcrops) and let us refer to Fig. 2, where a layer with resistivity 25 Ωxm at depths ranging between 3.8 and 13.8 m, and thus having a thickness of 10 m is shown. Therefore, if the calcarenitic outcrops on the slope are horizontally continuous beneath Eastern Hill, they will be intercalated with the 25 Ωxm-layer.

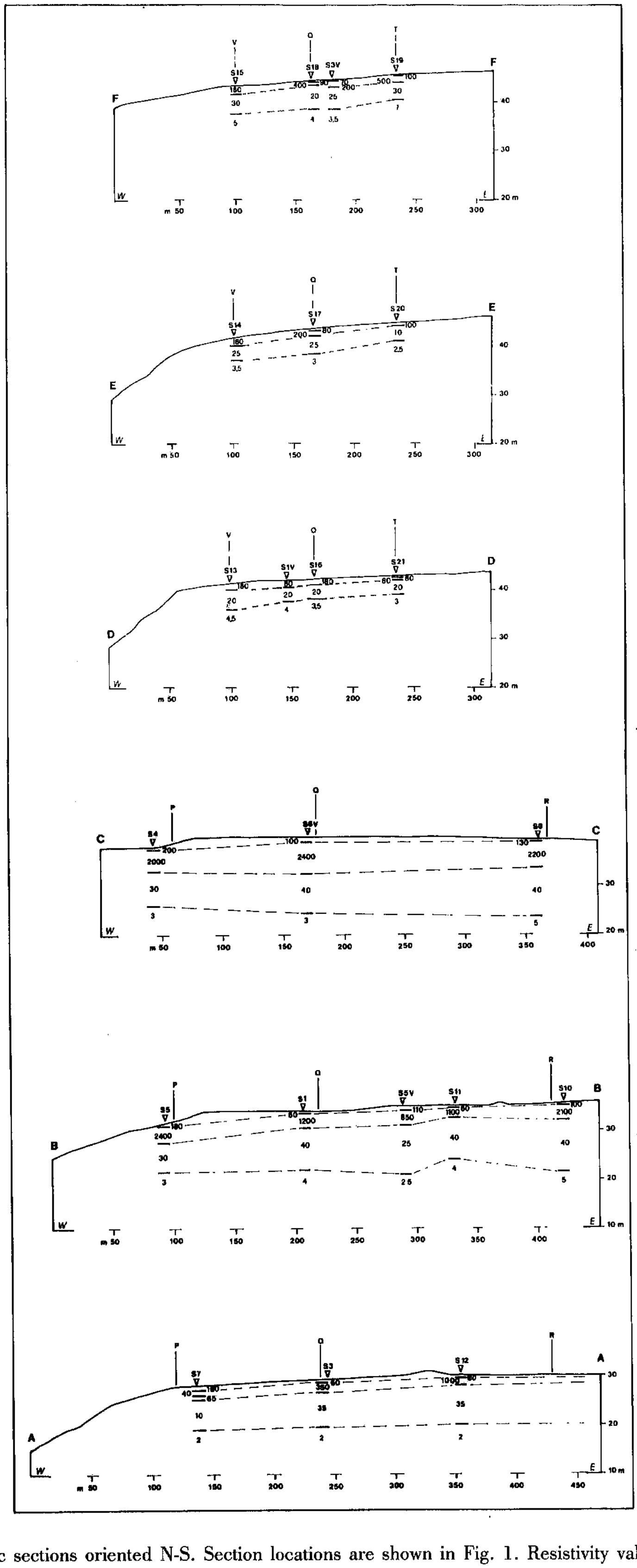


Fig. 3 — Electric sections oriented N-S. Section locations are shown in Fig. 1. Resistivity values are in Ωxm.

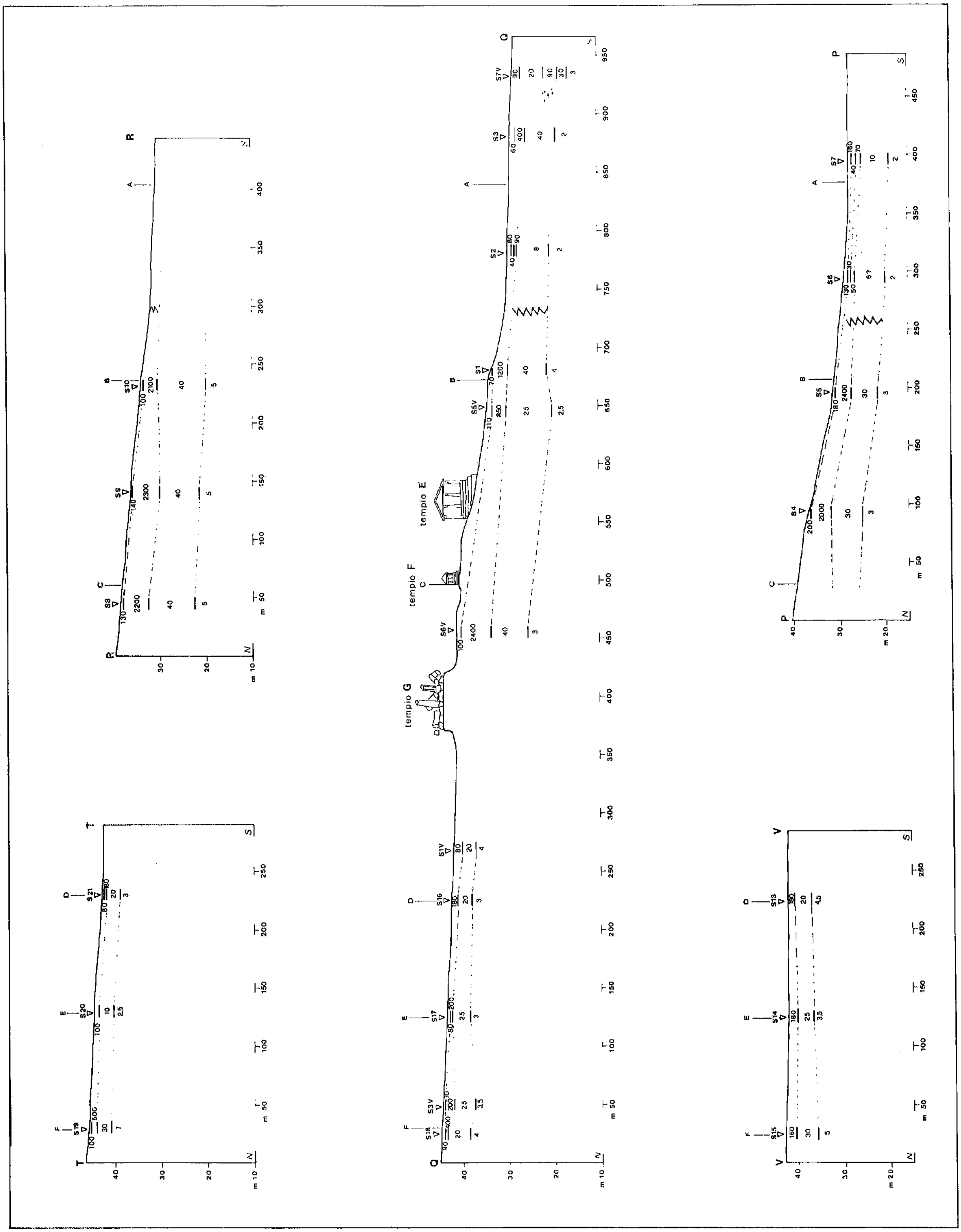
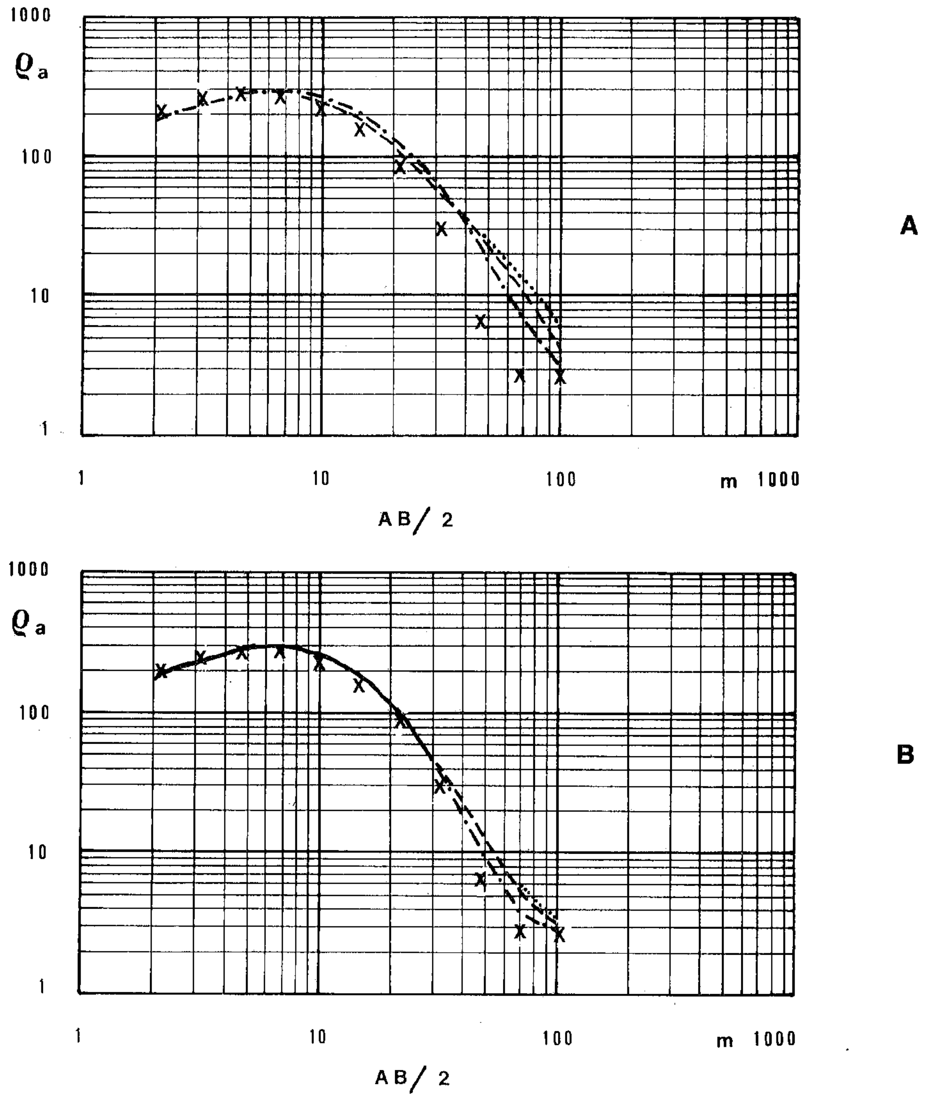


Fig. 4 — Electric sections oriented W-E. Section locations are shown in Fig. 1. Resistivity values are in Ωxm.



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— · — · — · — · — a) depth ranging from 5.8 to 6.8 m;
— — — — — — b) depth ranging from 8.2 to 9.2 m;
· · · · · · · · · · · · · · · c) depth ranging from 10.8 to 11.8 m;
X X X X X d) field values.

Fig. 5 — Theoretical curves calculated for sounding S5 with an interposed layer 1 m thick. Two different resistivities were considered at three different depth: 5 a: layer with 700 Ωxm; 5 b: layer with 180 Ωxm. Legend: a) depth ranging from 5.8 to 6.8 m; b) depth ranging from 8.2 to 9.2 m; c) depth ranging from 10.8 to 11.8 m; d) field values.

In order to verify this possibility, apparent resistivity theoretical curves were calculated by interposing a medium of greater resistivity in the sand-clay layer. Thus, families of curves were calculated by varying both the thickness and the resistivity of the interposed medium: the thickness was taken as 1, 2 and 3 m and the resistivity as 700, 300, and 180 Ωxm, which are the values of calcarenite in the area.

The resistive layer was interposed with the sand-clay formation at different depths. For a thickness of 3 m, the layer was interposed at depths of 5.8 to 8.8 m and 8.8 to 11.8 m; for a thickness of 2 m, the layer was interposed at depths of 5.8 to 7.8 m, 7.8 to 9.8 m, and 9.8 to 11.8 m; for a 1 m thick layer, it was interposed at depths of 5.8 to 6.8 m, 8.2 to 9.2 m and 10.8 to 11.8 m.

In the case of the highest resistivity value (700 Ωxm), the calculated curves substantially differ from the S5 reference sounding curve, even for a thickness of 1 m only. The field curve and the theoretical resistivity values calculated at various depths for a thickness of 1 m are shown in Fig. 5a. It is notable how much the theoretical values always differ from the field values.

Also in the case of 300 Ωxm-resistivity, the theoretical curves still differ from the field curve, even for 1 m thickness, when the standard deviation is 25% for a layer interposed at 5.8 to 6.8 m depth.

Theoretical apparent resistivities calculated for the layer of resistivity 180 Ωxm and thickness 1 m are shown in Fig. 5b, together with the field values. The standard deviation is still 14%, even for the most superficial layer. Note also that the proposed interpretation provides a much lower standard deviation (2-3%).

Thus, unless the outcrops identified during the detailed geological field survey have a resistivity of 180 Ωxm and thickness of 1 m, they would have modified the field curves. Hence, it can be deduced that the outcrops detected on the slope of the river Cottone are not laterally continuous beneath the Eastern Hill.

INDUCTIVE ELECTROMAGNETIC RESULTS

The two 40×40 m and 90×90 m test sites were investigated using inductive electromagnetism (Fig. 1). In both areas, measurement grids of 1 m spacing were taken along S-N parallel profiles using an EM-31 apparatus. At each station, measurements were taken both in vertical (depth to 6 m) and horizontal configuration (for depth to 3 m), to acquire conductivity values (mmhos/m) (Mc Neill, 1980 a, 1980b), subsequently turned into apparent resistivity values (Figs. 6 and 7).

Fig. 6a shows the countour map of resistivity values for the vertical configuration; it is possible to see that the 40×40 area has a resistivity trend of regular decrease in the SW-NE direction, with values ranging from 18 to 31 Ωxm. The data for a shallower investigation depth (Fig. 6b: coutour map of resistivity values for horizontal configuration) gave similar results, characterised by a marked fragmentation. In this case, resistivity values range from 32 to 58 Ωxm.

In conclusion, for this area, in accordance with the results of the VES, it seems that the calcarenitic bedrock is absent and that, at depths ranging from 2 to 4 m, the soil is mainly sand-clay. The higher resistivity values of the upper level in the S-W corner of Fig. 6b may be connected with the presence of constructions (walls with square calcarenitic blocks), that outcrop in places.

Figs. 7a-b show the trend of the apparent resistivity curve in the study section of the 90×90 area, respectively for vertical and horizontal configuration of the EM-31 equipment. At first glance, homogeneous resistivity values are observed in most of the area, but the north-eastern section is characterised by a marked decrease in such values.

The results achieved through this method suggest the presence of a bedrock, with resistivity values of the order of 40-50 Ωxm down to a depth of about 3 m in almost all the investigated area. This matches well with the hypothesis of a thin highly altered calcarenitic layer overlying sand-clay soils.

In the zone characterised by low resistivity values (15 Ω xm) - NE corner of Fig. 7a - the

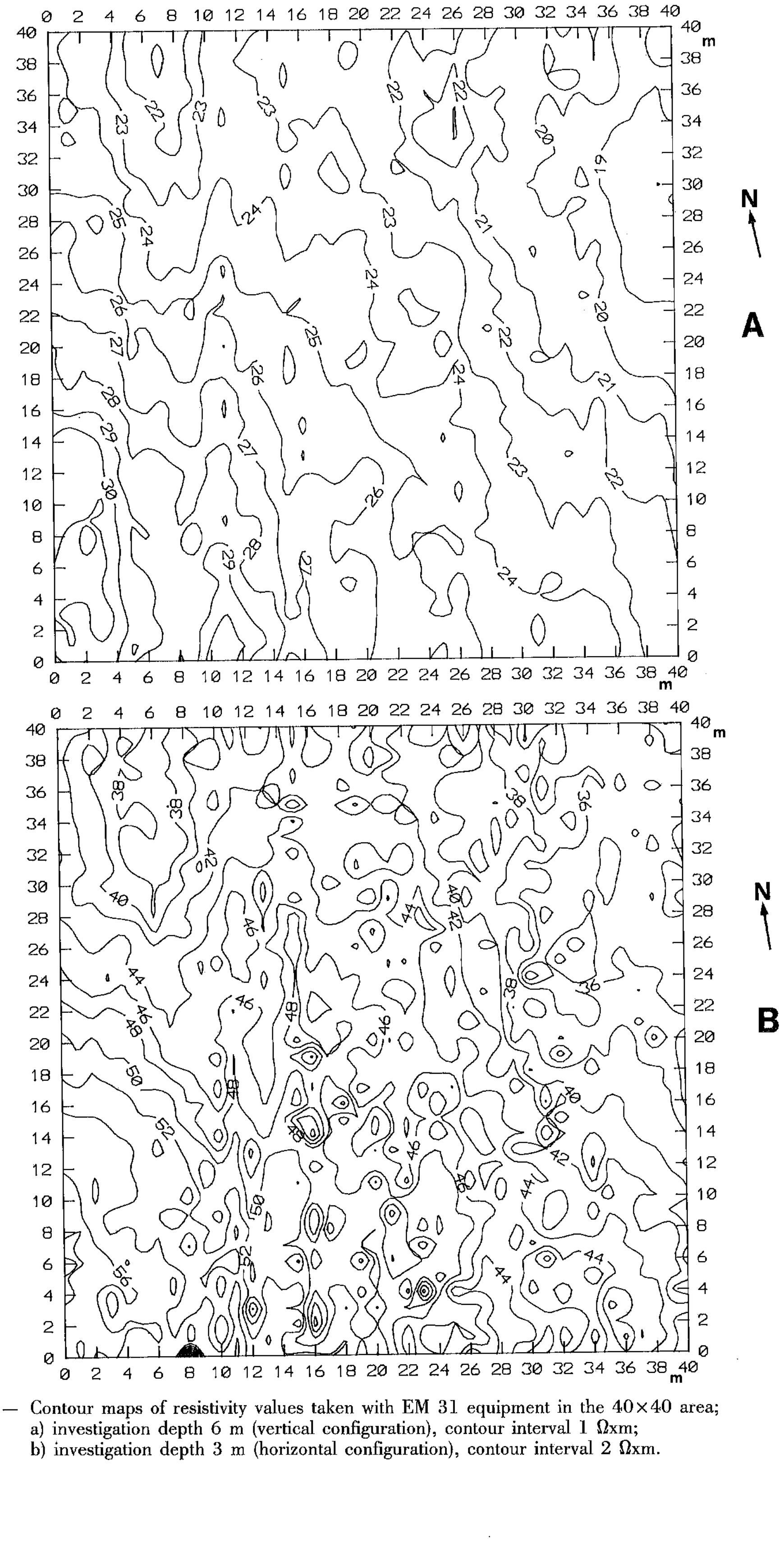

Fig. 6 — Contour maps of resistivity values taken with EM 31 equipment in the 40×40 area;
a) investigation depth 6 m (vertical configuration), contour interval 1 Ωxm;
b) investigation depth 3 m (horizontal configuration), contour interval 2 Ωxm.

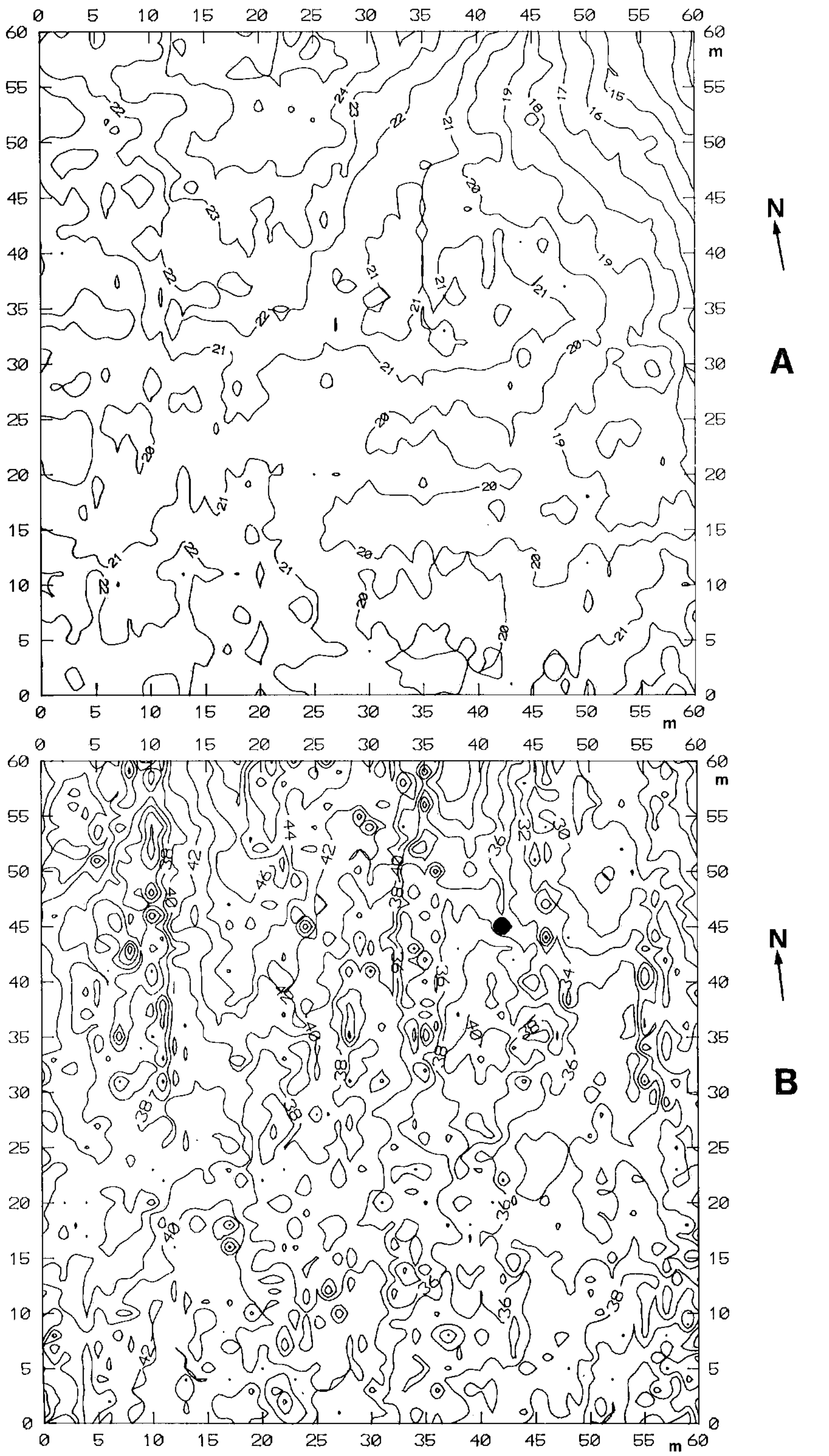

Fig. 7 — Contour map of resistivity values for the investigated part of the 90×90 area, using EM-31 equipment;
a) investigation depth 6 m (vertical configuration), contour interval 1 Ωxm;
b) investigation depth 3 m (horizontal configuration), contour interval 2 Ωxm.

absence of the most superficial calcarenitic layer is suggested. The analysis of the data obtained by means of inductive electromagnetism gave the apparent resistivity values of the soil, providing useful information on the lithological nature of the most superficial portion of the subsoil. Thus, it is an effective check on the interpretations made by traditional methods (VES), at least for the upper part.

Acknowledgements. The authors thank: Gianfranco Morelli for technical collaboration; Mario Mazza for the photographic documentation; Renato Caciagli, Mario Mazza and Gaetano Pappalardo for the topographic survey; and Mario Mascellani for the drawings in this work.

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