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GEOLOGICAL OUTLINE OF THE SELINUNTE ARCHAEOLOGICAL PARK

Abstract. A stratigraphic and geomorphological study of the Selinunte archaeological site has been carried out, and a lithological map based on geological field data integrated with vertical electric soundings obtained. The aim of this work was to provide a basis for achaeological prospecting. Many useful elements were derived, together with references to previous work, for describing the geological environment of this area, which is considered of great historical and archaeological interest.

INTRODUCTION

In the Selinunte archaeological site, where several historical and archaeological field studies have been running for many years, the use of geological and geophysical methods is making a great contribution to the study of the anthropogenic layers.

This paper describes the physical and stratigraphic features of the sequence of terrains outcropping in the Selinunte area. Particular attention is paid to the extent and thickness of the calcarenitic layer on which the temples and the ancient town of the Eastern Hill and of part of the Acropolis are built.

The aim of this work is to provide the stratigraphic and morphological data needed to set up geophysical prospections for application to archaeological studies and carry them out in the selected sample areas (Brizzolari et al., 1992). In fact, the choice of the most effective methods and the interpretation of the data obtained must take into account the geological features of the studied area, besides the physical model of the structures to be identified.

FRAMEWORK OF THE AREA AND PREVIOUS STUDIES

The Selinunte archaeological area lies in the central part of the wide bend formed by the coastline between Capo Granitola and Capo San Marco, in south-western Sicily (Fig. 1). It has an area of more than 2.5 km^2 and stretches over two hills, which overlook the sea and are truncated by a small falaise.

Both the hills are oriented in the N-S direction. On the western hill is the Acropolis of Selinunte and, further north, the ancient town; on the so-called Eastern Hill, which is separated from the other by the valley of the river Cottone, the three temples denoted by E, F, G once stood (temple E was rebuilt during the 1950's).

The terrains forming the Selinunte area are similar to the Marsala Calcarenite formation, thoroughly studied by Ruggieri et al. (1977) over a vast area immediately to the west of the

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Fig. 1 — Location of the studied area.

Selinunte area. The Marsala calcarenite formation is made up of a sequence of various lithotypes (from calcarenite to clay). The sequence has been dated by the above mentioned authors back to early marine Pleistocene ("Sicilian" l.s.). In their opinion, the sedimentation environment of this sequence is circalittoral, and the sequence is transgressive over a neogenic bedrock formed of terrains up to middle Pliocene in age. The same paper states that these terrains are displaced by "two systems of faults, one stretching NW-SE and the other NE-SW, which may be attributed to a (late) early Pleistocene tectonic crisis".

The early Pleistocene sequence in this area whose biota is characterised by "northern guests" is considered in Ruggieri and Sprovieri (1977), who focused their study mainly on stratigraphy and palaeontology. The series is subdivided as follows (from bottom to top):

- Santernian (new stage), the base of which coincides with the presence of *Arctica islandica* in the platform facies, and *Chlamis septemradiata, Bulimina aetnea*, and *Muellerina problematica* in deeper facies.

- Aemilian (emended), the base of which coincides with evidence of *Hyalinea baltica.*

- Sicilian, the base of which coincides with evidence of *Globorotalia truncatulinoides.*

Ruggieri et al. (1977) consider the above mentioned stages (each of which has its precise biostratigraphic character) as the three parts of a new superstage called the Selinuntian. The three stages are of rather short duration and cannot easily be recognized outside the Mediterranean basin, although it is possible that the crisis which caused the southward migration of "northern guests" and the tectonic crisis at the end of the Selinuntian might have left traces also beyond the Mediterranean basin. According to Catalano and D'Argenio (1982), the Pleistocene formations of west Sicily are affected by a fault and fold system with three main strikes, NE-SW, NW-SE and E-W, probably representing the effect of deep structures.

In the part of Sicily where Selinunte is situated, the Quaternary terrains are characterized, as argued in Trevisan and Di Napoli (1938), by large funnel sinks caused by the solution of the underlying late Miocene gypsum. This karstic feature should be taken into account to avoid attributing failure structures on the covering terrains to tectonic events.

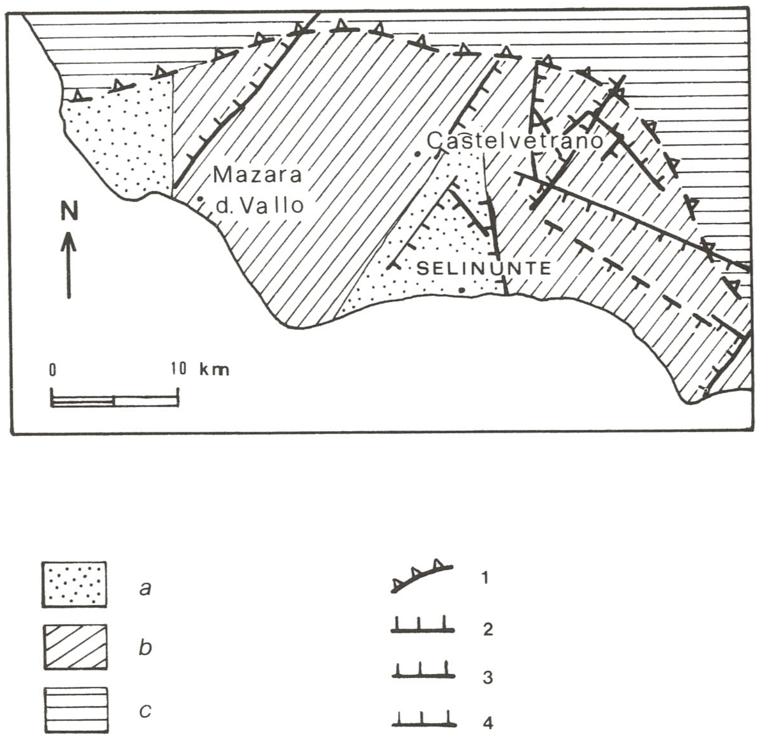

Fig. 2 — Sketch from "Neotectonic Map of Italy" (Ambrosetti et al., 1987).
Legend: a) Continuous and intense lowering in the Pliocene and in part of the early Pleistocene. Prevailing deformation by normal faults. b) Nearly continuous and moderate lowering in the Pliocene and early Pleistocene; quiescence or moderate uplift since the middle Pleistocene. Prevailing deformation by normal faults. c) Intense lowering in the Pliocene and in part of the early Pleistocene; intense uplift since early and/or middle Pleistocene. Moderate deformation mainly by folds and reverse faults and, locally, by normal faults. 1) Thrust (saw-teeth on overthrown limb). Quaternary and possibly older. 2) Normal fault (hatching on downthrown side). Quaternary and possibly older. 3) Normal fault. Pliocene and Quaternary. 4) Normal fault. Pliocene (generally middle and late) to early Pleistocene.

As shown in the Neotectonic Map of Italy (Ambrosetti et al., 1987), this area was affected by an almost continuous subsidence during Pliocene and lower Pleistocene, but, since the lower Pleistocene, has undergone a moderate uplift. The area is also characterised by deformations caused by normal faults of Pleistocene age. In particular, the Selinunte area seems to be at the center of a small graben bounded by two faults stretching NE-SW and NNW-SSE. A third fault, with NW-SE trend, closes this small structure northwards (Fig. 2).

It is worth closing this review of previous works on this area with some data on the seismicity of Sicily which may help in testing the hypothesis of a correlation between earthquakes and severe damage to the temples.

According to Guidoboni (1989), Latin and Greek sources relate that many earthquakes occurred in Sicily; the oldest described was in 426 B.C.. Information about three other events is given: around 17 A.D. an earthquake occurred in Sicily and Calabria and caused much damage; between 361 and 365 A.D., an event, or perhaps more than one, was felt throughout the Mediterranean basin: Palestina, Libia, Greece and Sicily; finally a strong earthquake was recorded in 852 A.D..

In this study, earthquakes within a 50 km radius around Selinunte before 1800 (with intensity higher or equal to V MCS degree) were also considered (Postpischl, 1985). They are listed in the Table.

In more recent times, there were two events with epicentres in the considered area, with intensities of degree VIII in 1817 and VII in 1933. In Fig. 3 the epicentre distribution of Sicilian

Table — Earthquakes located in the Geological Maps (scale 1:100,000) N° 257, 258, 265, 266, since 1000 to 1800 (Postpischl, 1985).

The serial number of the earthquake in the consulted catalogue, year and date, macroseismic intensity, references, and IGM tablet in which epicentres is located, are shown.

n.	Year	M.	D.	Int.	Ref.	Tab.		
116	1259	—	—	VII	Carrozzo et al., 1975	257	IV	NO
1354	1709	1	8	V	Baratta, 1901	257	V	NO
1520	1724	9	11	V	Baratta, 1901	266	III	NE
1552	1726	9	26	VII	Cosentino, 1982	257	IV	NO
					from			
1570	1727	5	8	VI	Carrozzo et al., 1975	266	II	NO
					to			
1628	1727	10	6	VI	Carrozzo et al., 1975	266	II	NO
series of 23 events with Int. IV-VI, all in the same Tab.								
1783	1740	3	6	V	Baratta, 1901	266	III	NO
1788	1740	6	8	VI	Carrozzo et al., 1975		id.	
1791	1740	6	13	VI-VIII	Carrozzo et al., 1975		id.	
1796	1740	6	27	VII	Baratta, 1901	266	II	NO

earthquakes is shown. In the current Seismic National Classification (Servizio Sismico, 1986), Selinunte is considered to be of the second seismic category (intermediate seismicity), but it borders on first category (intense seismicity) areas, such as the Belice Valley (Bosi et al., 1973), immediately to the northwest of Selinunte.

STUDY METHODS AND DATA COLLECTED

In the Selinunte area, outcrops of the rock formations are rare and the lack of natural or

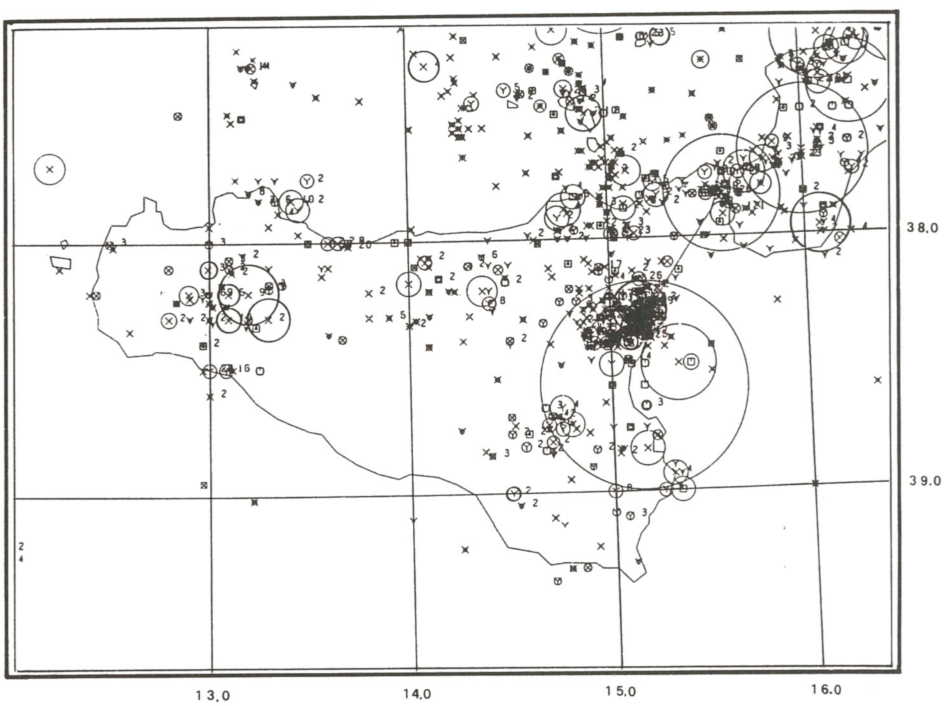

Fig. 3 — Epicentre Map of Sicilia (Postpischl, 1985). Events with intensity greater than degree IV-V MKS (local magnitude >3.5) are located. Epicentres are represented by circles, whose radii are related to earthquake intensity.

Fig. 4 — Ditch north of Eastern Hill. A heap of calcarenitic stones can be observed on the northern side of the ditch. The ditch has been excavated in clayey sands with macrofauna.

artificial cuttings, the gentle acclivity of the slopes, the thick detrital cover and the presence of a wide archaeological area, hinder surveying by traditional methods. The results hereafter discussed sum up the literature, aerial photography interpretation, field data, micropetrographic studies, and information from vertical electric soundings.

Surface geological elements

The following stratigraphic sequence, from the most recent to the oldest elements has been identified in the field survey:

- a calcarenitic layer occasionally vacuolar and macrofossil-bearing, which may also be dense and hard and in some places weathered and fractured. This layer is of variable thickness, as evidenced in particular by vertical electric soundings on the Eastern Hill (see the following sections). Cross-bedding is locally present. In thin section, a sample of the dense variety was seen to be formed of abundant quartz grains and fragments of acid magmatic rocks;

- a seldom cemented clayey sand, with calcareous concretions and macrofossils (e.g. Ostreida, Pectinida etc.) which is locally intercalated with scarcely cemented calcarenitic lenses with macrofossils;

- clay and clayey marl; micropalaeontological analyses carried out on clay samples taken from the foot of the promontory where the Acropolis is built have identified the typical lower Pleistocene association: Bulimina aetnea, Hyalinea baltica, and Globorotalia truncatulinoides.

An analysis of air photographs shows dunes on the west of the Acropolis hill, which stretch from the Triscina houses to Manuzza Hill. Other dunes, although covering a smaller surface, are present on the eastern slope of the Acropolis hill. Where the detrital cover is thinner, there are clayey-sand layers easily visible due to their greater refllectivity than the other terrains. Some carbonatic outcrops are also easy to locate by their characteristic morphology resulting

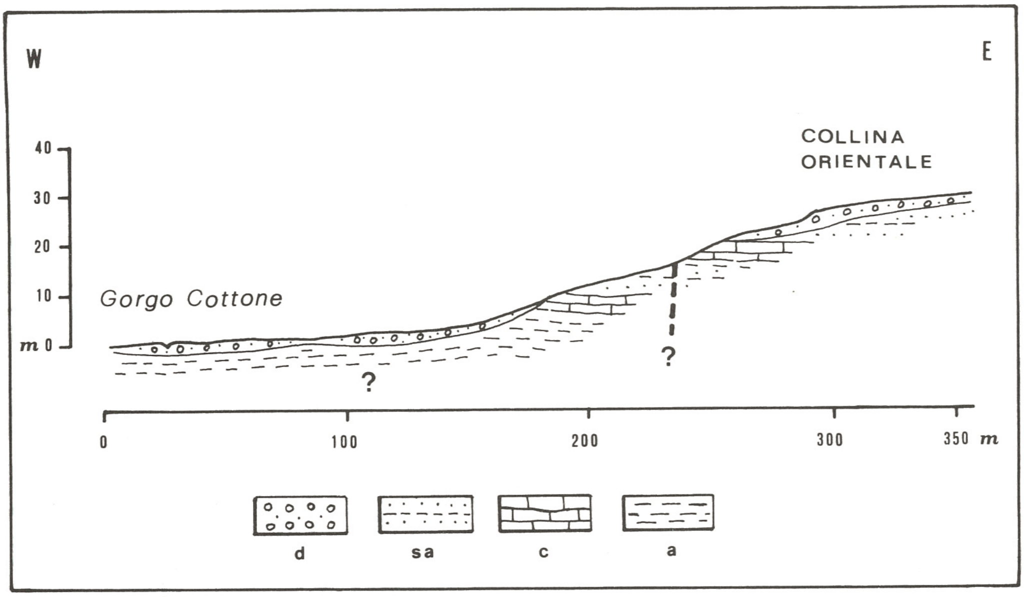

Fig. 5 — Geological sketch of an outcrop located near the cross road on the southern side of the Selinunte Archaeological Park. Legend: d=alluvial and detrital soils; sa=clayey sands; c=yellow calcarenite with macrofauna.

from their imperviousness to running water.

The geological survey showed that on the wide plain of the Eastern Hill, now cultivated with orchards, the detritic cover is characterized by a sandy-clay matrix with a certain amount of calcarenitic fragments and rounded pebbles (mainly formed of carbonatic rocks, quartzite and chert). There are also ceramic and fictile fragments. In the northern part of the hill, there are piles of calcarenitic boulders which are the remains of a very fragmented and thin calcarenitic superficial cover (Fig. 4). In this zone, along the ditch bordering the archaeological site to the north, a weakly cemented yellowish clayey sand, with abundant macrofossils outcrops.

Further southwards, in the central part of the hill, on the slope overlooking the river Cottone, there is a sequence formed of three layers of either lithoid or vacuolar whitish calcarenite, separated by two layers of clayey sand. The whole outcrop is no more than 8 m thick. The outcrop is visible almost all over the slope up to the road leading to the Acropolis. The outcropping sequence near the road is shown in the section of Fig. 5. Calcarenite is there different from that observed in the above mentioned outcrops: it is ochre in colour, friable and vacuolar; macrofossils are present. The upper layer is about 1.5 m thick. The underlying sandy layer is the same colour and contains macrofossils (Ostreida, Pectinida) and fragments of calcareous rocks. This layer is about 5 m thick. The underlying calcarenitic layers are separated by a 1 m thick layer of clayey sand, similar to the upper one. The total thickness of these three layers is less than 3 m.

In the remaining area, there are no outcrops with more than one level of calcarenite; moreover, the presence in the subsoil of more than one layer of calcarenite was also excluded on the basis of vertical electric soundings (Brizzolari et al., 1992). To explain the described outcrop two hypotheses were put forward: the occurrence of discontinuous lenses not present elsewere; or alternatively and more probably, small dislocations affect this area causing local "repetition of sequence".

The geological features of the Western Hill, where the Acropolis is built, are very similar to those of the Eastern Hill. Also in this zone, outcrops are rare and often concealed by thick detrital cover.

On the hill slopes, there is a thick heterogeneous deposit with a clayey-sand matrix, containing many relics of fictile materials testifying to ancient settlements. The sequence is very similar to that of the other area: calcarenite, clayey sand with calcarenitic intercalations and clay.

Fig. 6 — Outcrop of cross-bedded calcarenite on the northern side of the Manuzza Hill.

Calcarenite has its maximum thickness in the Manuzza hills, to the north of the Acropolis, where it is lithoid, often vacuolar and only seldom dense. Locally it displays a cross-stratification (Fig. 6). On the slopes of the Manuzza hills to the north and, more westwards, near Case Sabato, the calcarenite outcrops are cut by old quarries (Fig. 7). Going towards the southern part of the Acropolis, the calcarenite thickness decreases until the calcarenite becomes a fragmented slab overlying a grey sandy-clay layer which is visible all along the walls of the ancient town. The walls were probably built in order to prevent earth movements and landslides.

The sequence in Fig. 8, although covered by abundant detritus of even present age, is that of the scarp delimiting the Acropolis to the south. At its bottom, a clayey marl overlies a layer of yellowish clayey sand with macrofossils and white carbonatic concretions. Upwards, there is a thick layer of cohesionless calcarenite, turning into a lithoid type in the upper part. The visible thickness of this outcrop is about 2.5 m.

The materials

Some limestone samples were collected from the Acropolis and the Eastern Hill. Petrographical analyses showed that all the lithotypes consist of "peloid" biocalcarenite with bioclastic, sometimes cross-bedding laminated, structures with various grain size and porosity.

The detritic fraction (10 to 30%) is mainly formed of clasts of volcanic quartz, from subangular to rounded, and metamorphic quartz grains, from subangular to angular. There are minor occurrences of clasts formed by:

- chert, with autigenic accretions;
- feldspars (mainly plagioclase) with rare intergrowths of slightly kaolinized K-feldspars;
- micas, mainly biotite altered into chlorite and rare muscovite;
- variously altered glauconites;

Fig. 7 — Case Sabato (NW of the Acropolis). Vertical walls, probably faces of an ancient quarry in the calcarenitic rock, are shown.

- fragments of rocks (quartzarenite with a limonitic cement, primary calcarenite and a biomicritic limestone with detrital quartz grains);

- calcite, from micritic to spatic, often of organic origin.

The biocalcarenite cement is micritic, locally spatic, and the degree of cementation varies causing great differences in porosity from one sample to another.

Micropaleontological analyses have shown the presence of incrustations of red articulated coralline algae, *Ammonia beccari*, Rotalidae, Operculina sp., *Hastigerina siphonifera*, Globigerinoides sp., Globorotalia sp., fragments of Balanus sp., Miliolidae, *Globigerina bulloides*, Bryozoa, *Elphidium crispum*, Textularia sp., and fragments of shells. Microforaminifera are in part reworked; clasts with fossil fragments are rounded to subrounded.

The diffractometric analysis showing a certain mineralogical diversification, both in the

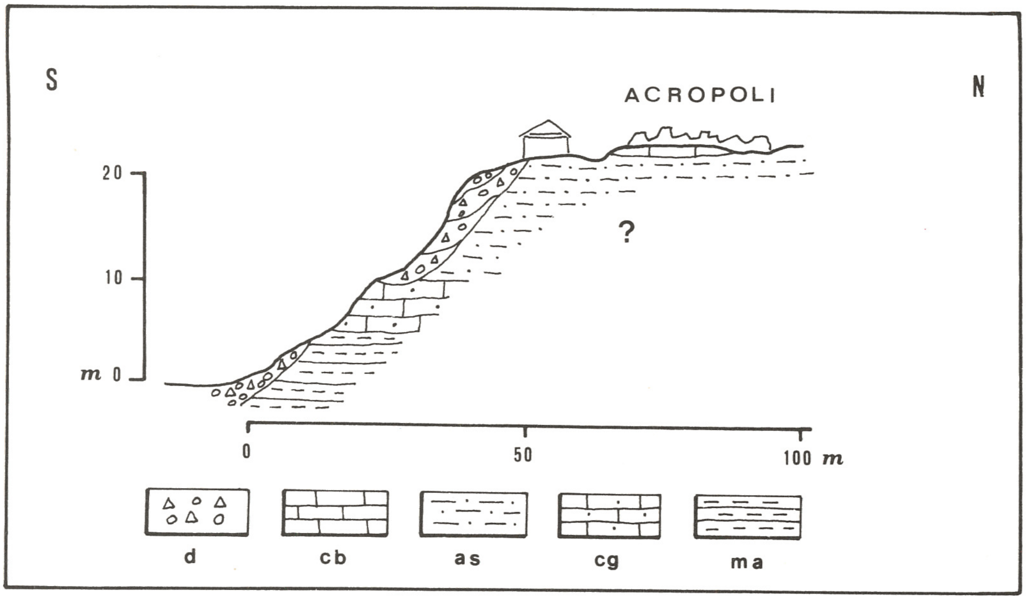

Fig. 8 — Geological sketch of the cliff that limits the Acropolis southwards. d = detritus subject to landslides; cb = whitish calcarenite; as = clayey sand; cg = yellow calcarenite with calcareous nodules and macrofauna; ma = clayey marl.

carbonatic and the terrigenous phases (some samples of clays are analyzed, too) are in good agreement with results of the petrographical analysis. Except for quartz, all the mentioned minerals, because of their small concentration, are hardly detectable diffractometrically. Only clay mineral traces were identified in all the samples.

As the quartz is always present in all the samples, a statistical granulometric microscope analysis of the quartz grain distribution and frequency was performed (Pallante, 1991).

Seven granulometric classes were considered: <0.08 mm, 0.08-0.16 mm, 0.16-0.25 mm, 0.25-0.33 mm, 0.33-0.41 mm, 0.41-0.50 mm, 0.50-0.58 mm. No quartz was found in the upper grain size.

The results of the quartz size distribution, usually characterized by symmetrical bell shaped frequency histograms, show a general homogeneity but with a slight expansion into the coarser classes.

Calcimetric analyses gave a variable total $CaCO_3$ content, 70 to 90%, depending upon the amount of insoluble detrital portion.

A micropaleontological analysis of clays sampled at the base of the Acropolis promontory has shown the presence of three species that are typical of the early Pleistocene: *Bulimina aetnea*, *Hyalinea baltica* and *Globorotalia truncatulinoides*.

Vertical electric soundings

In order to corroborate the aerial photography interpretation and field observations, ten VES (vertical electric soundings; Fig. 10) were carried out. Of these ten, six were located on the Eastern Hill, one in the Cottone valley and three on the Acropolis. Soundings were made using a Schlumberger array, with maximum distance between current electrodes of 200 m for soundings 1 to 7, and of 120 m for soundings 8 to 10. Measurements were carried out with a Syscal R-2 instrument from BRGM. Electric power was generated with dry batteries. VES 1 and 2 were made at the centre of the same location with arrays perpendicular to one another in order to detect any lateral discontinuities.

Soundings were interpreted with a program based on the Koefoed's Steepest Descent method (1968) for the calculation of the best fit between field and theortical curves by varying the

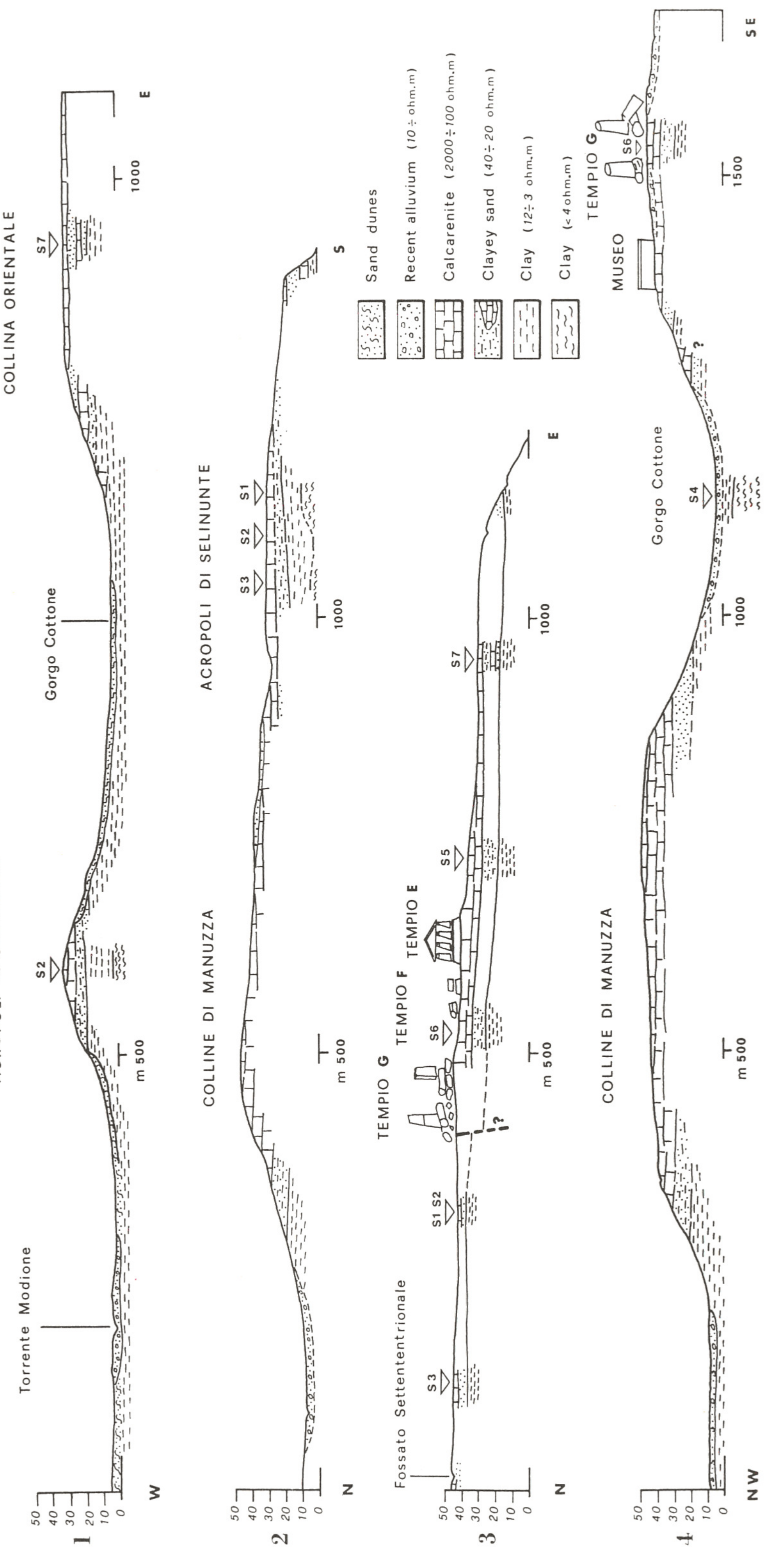

Fig. 9 — Geological profiles.

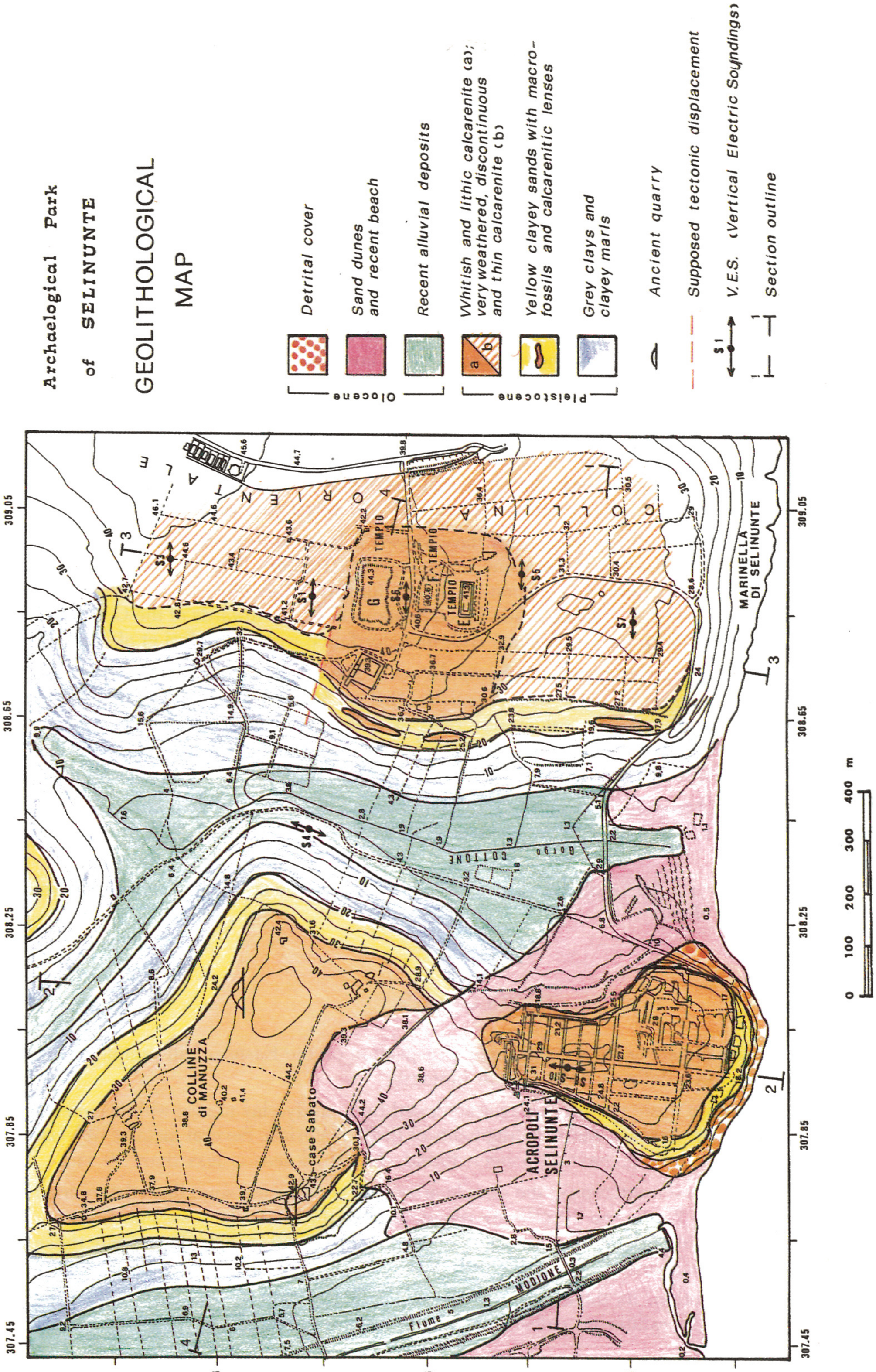

Fig. 10 — Lithological map of the Selinunte Archaeological Park.

layer resistivities and thicknesses. After a first analysis carried out sounding by sounding, interpretation was improved by comparing data from neighbouring soundings and by imposing some geological conditions based on outcrop lithology.

As a rule, three layers can be well distinguished; at places, there are four layers, if the 0.5-1 m thick layer of soil is taken into consideration.

DATA INTERPRETATION

Fig. 9 shows four geological cross-sections of the investigated area which take into account information from both field surveys and electric soundings. Section 3 crossing the Eastern Hill from north to south shows that only soundings 5 and 6 - which were located near the temples - distinguished a thick highly resistive layer which can be interpreted as a dense carbonatic rock. The other soundings did not show evidence of this layer which seems to be missing. As a matter of fact, if sounding 4, which crosses terrains with a very low resistivity is excluded, in all the soundings, only the superficial layer has a relatively high resistivity (from 70 to 200 Ωxm), the thickness however always being small and never greater than 2 m. This layer may be formed, in the northern portion of the hill, by a deeply weathered and fragmented calcarenite and by a less dense layer in the southern portion of it. Thus, it may be assumed that the calcarenite layer is discontinuous here and has variable thickness and physical characteristics.

Underneath this layer, all the soundings have shown a layer with resistivity between 25 and 40 Ωxm resting on a layer with very low resistivity ($2 \div 5$ Ωxm). The first layer may be formed by a clayey sand, whereas the second may be interpreted as clay. Moreover section 3 (Fig. 9) suggests the presence of a fault, with direction about E-W, northwards of the G Temple, that has lowered the southern part of Eastern Hill, in accordance with Brizzolari et al. (1992).

The three soundings carried out on the Acropolis are in good agreement with the hypothesis of 5 layers and of a calcarenite layer with resistivity $450 \div 750$ Ωxm and thickness $3 \div 5$ m just beneath one metre of soil. The calcarenite rests on a layer with a resistivity of about 40 Ωxm attributable to the clayey-sand level which may be related to that of the Eastern Hill. The two clay layers, having a resistivity of about 10 Ωxm and 2-4 Ωxm respectively, close the sequence.

Section 2 cuts the Acropolis from north to south and shows the stratigraphic features derived from the integration of field data with the electric soundings. Sections 1 and 4 are transversal to sections 2 and 3.

The approximately 1:7,500 scale lithological map of the Selinunte area of Fig. 10 was drawn on the basis of these data.

CONCLUSIONS

With the purpose of carrying out geophysical prospection on the Eastern Hill sample areas, the following strata were defined (from top to bottom).

a) Surficial covering: these terrains are characterised by a sandy-clay matrix with fragments of carbonatic rocks, chert pebbles and rare fragments of fictile materials. Several metallic objects, related to present-day farming, have also been found. The thickness is less than 50 cm.

b) Calcarenite: this never outcrops in the sample areas. Vertical electric soundings determined that its modest (less than 2 m in the 90×90 area) and variable thickness decreases northwards. Resistivity values of altered or cohesionless calcarenite range from 65 to 170 Ωxm, while those of dense calcarenite range from 450 and 2,000 Ωxm.

c) Sandy-clay formation: its thickness is of the order of ten metres, and includes lenses of scarcely cohesive and fossiliferous calcarenite which is ochre in colour. Its resistivity ranges between 20 and 35 Ωxm.

d) Clay formation: this is the last layer determined by VES. Resistivity values are very low (less than 10 Ωxm).

The whole area to north of Temple G, where geophysical prospection is needed by the archaeologists, is flat and cultivated with orchards (at present, olive-woods; in the past also vineyards).

The field survey and the electric soundings have shown that, on the Eastern Hill, the maximum thickness of calcarenite (about 6-7 m) is recorded just below the temples. This may support the hypothesis that the temples collapsed due to an earthquake. Seismic damage amplification depends on the local seismic response, which is correlated with the lithological and structural situation. In this case, the damage caused by a moderate magnitude earthquake could be amplified by a "slab" effect related to the calcarenitic lens that overlies terrains of high plasticity such as clayey-sand and clay. Moreover, an E-W fault is postulated north of the temples area.

However, many problems remain to be solved with a more detailed analysis of the geological and tectonic situation, including satellite image interpretation, and a wider geological field survey integrated with further geophysical prospecting.

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