Hidden Landscapes of Mediterranean Europe

Cultural and methodological biases in pre- and protohistoric landscape studies

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MINING LANDSCAPE AND MINES. INTEGRATING DIGITAL AERIAL PHOTOGRAMMETRY AND GEOPHYSICAL PROSPECTING IN GARGANO AREA (ITALY)

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Abstract
Aim of this paper is to illustrate the results of a national research project (PRIN, 2005) devoted to studying both features of a prehistoric mining landscape and underground mines not evident, or partially evident, on surface.
The context of the project is the Promontory of Gargano (South-eastern Italy), where the extraordinary availability of flint is associated with evidence for numerous extraction complexes (underground mines). According with the available data, the mines cover a time-span of almost three thousand years; among them, the most important is the Defensola A mine, the most ancient in Europe, active from roughly 5800 b.C..
Differently from other European prehistoric mining complexes, in Gargano, mines generally open onto slopes with a convex morphology, and have often produced extremely large conoidal spoil heaps outside. That have suggested a first method of investigation based on the digital aerial photogrammetry. A DGPS survey has been executed to measure both ground control points, to be used for the external orientations of the photographs, and precise positions of the main known mines. Thanks to the stereo interpretation, it was possible to recognize geological keybeds in limestones rich on flint as possible ancient entries for mines. Sometimes anthropic covers (dumps and alluvial fans), nearby that mines, have been also recognized and interpreted as evidence of the excavation activity.
A second level of investigation moves by geophysical surveys. These latter permitted to determine the internal layout of each mining structure of which only the entrance is known; Moreover, geophysical prospecting allowed to verify the presence of new mining structures in the case of one or few vertical shafts are present, generally as a part of larger mining complexes.
The archaeological features of the area suggested to perform a geophysical survey by using different methods: the resistivity and ground penetrating radar techniques. This multi-method approach permits to check the data coming from several independent measurements and increases the geometrical and physical information useful for the interpretation.

1 The geological and chronological context

The Promontory of Gargano is located in the southern part of the foreland area of Apennine-Dynaric system (Funicello et al., 1988; Patacca & Scandone, 2004) in eastern Apulia (southeastern Italy).
The geology of the area (Figure 1) is characterized by a cyclical sequence of carbonatic platform sediments (tidal and subtidal flat) and, in the eastern peripheral part, by basin carbonatic limestones that underwent a sedimentation process compensated by tectonic subsidence (Bosellini et al., 1993). From the Neogene, the area was interested by an extended and continuous raising (Doglioni et al., 1996; Gambini & Tozzi, 1996), caused from the

changed tectonics conditions in the thrusting Apennine phase. This scenario carried to the actually setting, causing, moreover, extended karst phenomena (Pieri & Ricchetti, 1999). At the top of the meso-cenozoic geologic formations of the stratigraphic sequence, the carbonatic-selciferous lithologic units of the Cretaceous-Eocene formations (particularly the carbonatic limestones so-called "Maiolica", "Scaglia" and "Peschici Limestones") outcrop.
Due to a weak tectonic deformation the flint contained within these, is often found in a no-jointed undisturbed state.

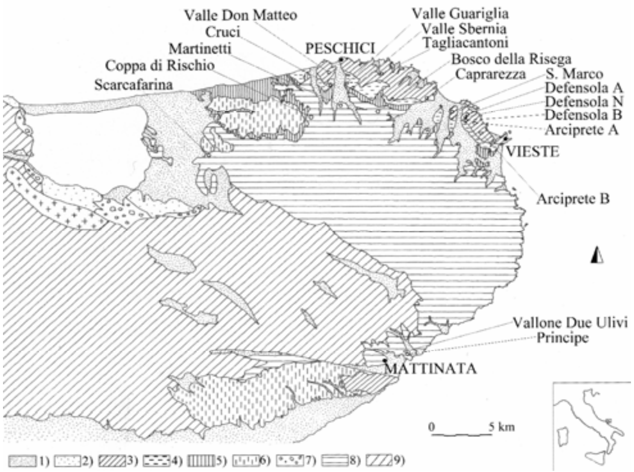

Figure 1: Geological map with showed flint mines. 1 Quaternary; 2 Mio-Pliocene; 3 M.Saraceno sequence; 4 Scaglia; 5 Scisti a Fucoidi; 6 M.Acuto e M. S.Angelo formations; 7 Breccia di Cagnano; 8 Maiolica; 9 M.Sacro sequence (geological data from Bosellini & Morsilli, 2002).

Hitherto, 18 complexes for the extraction of flint have been identified, discovered with their original entrances or following earthmoving for construction or road works. Many mines still present problems of chronological and/or cultural attribution; however, in recent years their context has been defined more precisely (Galiberti, 2005). Nine complexes have now been attributed to specific contexts; it is now possible to date the beginnings of extraction activities to the early VI millennium b.C. (Defensola A: Utc 1342 6990±80 BP, cal. 2σ 5993-5652 b.C.), coinciding with the Neolithization of south-eastern Italy; the mining phenomenon terminates at the end of the Copper Age (Defensola B: Beta 171597 4050±40 BP, cal. 2σ 2850-2820, 2670-2470 b.C.).

2 Mining typologies and methods

Generally speaking, two categories of extraction typologies can be identified in the Gargano area; these appear to be closely linked to the geological setting of the formations concerned. Nevertheless, the fact that sub-horizontal excavations in compact formations are the only type attested during the Neolithic, whereas vertical excavations and those in formations affected by tectonic activity belong exclusively to the height of the Copper Age, clearly suggests that social and cultural factors also played a part (Tarantini, 2006).

2.1 Sub-horizontal excavations

Where the formations are compact, excavation proceeded by removing individual limestone layers in their entirety. Depending on the thickness of the layers, a sufficient number of these were removed to obtain a floor-ceiling height allowing excavation to proceed. This height rarely exceeds 60 cm. This excavation method used the joins between layers as guidelines for the removal of the layers, thereby creating structures with a characteristic flat roof.
Therefore, differently from other European prehistoric mining complexes, in Gargano mines often open onto slopes with a convex morphology, and have often created large conoidal spoil fans outside (e.g. Defensola A). Therefore a first level of investigation concerns the identification of specific geological features from the digital aerial photogrammetry stereo restitution. Multitemporal aerial photos dated 1954, 1992, 1996 and 2001 have been analyzed within ERDAS^{tm} Imagine 9.1 LPS and StereoAnalyst Modules. A DGPS survey has been executed to measure both ground control points (GCP), to be used for the external orientations of the photographs, and precise positions of the main known mines.
The GPS survey has been executed by n.2 GPS Leica^{tm} 1200 receivers both in the static and in the real time differential ways; by the first, the IGM95 vertex 157701 located at Vieste whose coordinates and description card were made available by Italian Geographic Military Institute (IGMI) was utilized (Figure 2).

Figure 2: DGPS measurement at 157701 IGM95 vertex (Vieste, S.Francesco Church).

The Real Time Kinematic (RTK) way was instead carried out through GSM by connecting the rover receivers to a new reference station, properly built for the project. The survey concerned more than 80 GCP. By using the VERTO^{tm} software, the WGS coordinates were re-processed from ellipsoidal to orthometric elevation and projected to the national Gauss Boaga reference system.

By these points all the available remotely sensed data were oriented. Subsequently, thanks to their stereo interpretation it was possible to recognize geological keybeds in limestones rich on flint because they it was supposed that they can represent sites of ancient entries for mines. Rarely, anthropic covers (dumps and alluvial fans) nearby that mines have been also recognized and interpreted as evidence of the excavation activity (Figure 3).

Because mines consist of one or more communicating chambers, containing pillars of untouched rock and/or heaps of excavation debris, probably used as support structures, a second level of investigation moved by geophysical surveys, oriented to determine the internal layout of each mining structure of which only the entrance is known (e.g. Arciprete, Principe).

The depth of excavation towards the interior of the hill ranges from about ten metres in some complexes to over 100 metres in Defensola A, and follows a "chamber and pillar" layout. Their underground surface area may be as high as the 3500 m^2 currently mapped in Defensola A mine 1.

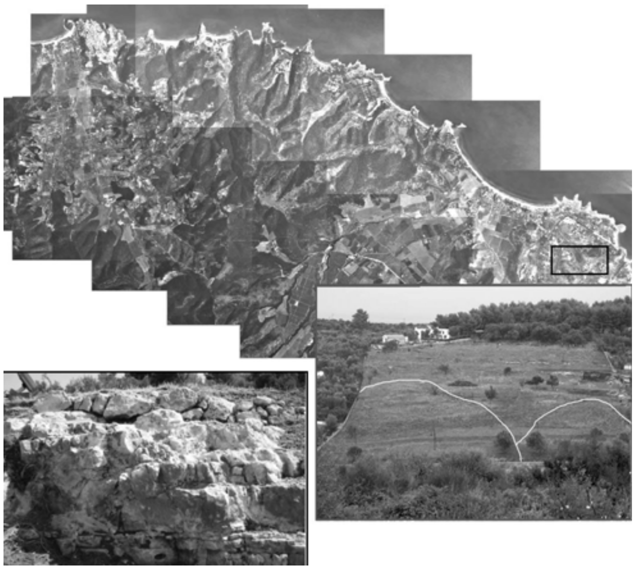

Figure 3: Keybeds in limestones and rock fans identified at Defensola A mine 2 (Vieste).

The application of non-excavation methods is recognized as an important element in mining site research (Budziszewski, 1990) and in particular the geophysical methods have been successfully used in other Neolithic mining complexes (Herbich, 1997; Leopold, 2004; Borkowski et al., 1991). The archaeological features of the area suggested to perform a geophysical survey by using different methods: the resistivity and Ground Penetrating Radar (GPR) techniques. This multi-method approach permitted to check the data coming from several independent measurements and increased the geometrical and physical information useful for the interpretations. Two dimensional apparent resistivity investigations were performed by an automatic device (Abem^{tm} Terrameter SAS 1000) that supports 64 electrodes. The Schlumberger acquisition with a high n factor[1]

[1] For a Schlumberger acquisition the n factor is defined as $n = \frac{1}{2}\left(\frac{AB}{MN} - 1\right)$ where AB and MN is the distance

was chosen because it is sensitive to both horizontal and vertical structures.
From this acquisition a pseudosection, that is a two dimensional image of the subsurface apparent resistivity variation, can be obtained. Then, computer modelling helps to interpret geoelectrical data by using inverse methods (Res2Dinv Geotomo^{tm} Software) getting images of the subsurface resistivity from the pseudosections. The two dimensional imaging of the ground is called Electrical Resistivity Tomography (ERT) and it gives information about the distribution of the resistivity in the ground (Loke, 2004). The resistivity is a physical property of materials, which not univocally describes the nature of each material; the soils and rocks resistivity strongly depends by their water content, by minerals presence and by the porosity. For this reason the same rock type could have a broad gap for resistivity values and in particular for archaeological applications all the contributions play a fundamental role.
The GPR survey was executed by using a SIR-20 - GSSI^{tm} device with an antenna of 400 MHz. GPR furnishes similar results to the ones from seismic reflection but at higher resolution (Martinez et al., 1996). GPR is most frequently used to perform 2D reflection profiles, which are acquired by keeping the two GPR antennas an equal distance apart while taking measurements at equal spacing along a traverse (Davis & Annan, 1989). The success of GPR is based on electromagnetic (EM) waves operating in the frequency range where displacement currents dominate and losses associated with conduction currents are minimal (Annan, 1996).
In compliance with earth materials that rarely have a magnetic permeability appreciably different from the unity (except for few magnetic minerals), the electromagnetic wave moves with a velocity depending on the resistivity or the dielectric constant. Consequently, for many earth materials, at high frequencies or high resistivity, the velocity of an EM wave is determined only by the relative dielectric constant. GPR data presented here are post-processed by RADAN software (GSSI^{tm}) and the results (in terms of intensity signal) are represented by contiguous wiggle trace curves.

2.2 Vertical excavations

Vertical access to flint-bearing formations is the only option where the morphology is flat, as in large areas of central Europe. Extraction using vertical shafts is also the only option in formations which are strongly affected by tectonic activity, where it would be impossible to carry out sub-horizontal excavation safely. Less information is available about this extraction method, due in part to the difficulty of interpreting structures which are visible mainly in road sections. However, on the basis of comparison with other mining contexts (Di Lernia and Galiberti, 1993; Weisgerber, 1999), this exploitation strategy was found in the area involving digging multiple shafts, often adjacent one to another, sometimes providing access to single structures. The debris from these vertical excavations was partly used to fill shafts or structures nearby, and partly distributed over the land surface in ways only observed in road sections making difficult its recognition.
The areas covered by these complexes is difficult to determine with surface surveys. Therefore, aim of the project was both to determine by geophysical prospecting the extension of these areas and to verify the presence of new mining structures in the case in which one or few vertical shafts are present, generally as a part of larger mining complexes (e.g. Defensola B shaft, Vallone Due Ulivi).

3 Results

The results coming from three different sites, Defensola A and B, municipality of Vieste, Principe, municipality of Mattinata, investigated with resistivity and GPR techniques, are here presented.

3.1 Defensola A (mine2)

Figure 4 shows the executed resistivity and GPR profiles. At the top of the hill, three 2D electrical imaging surveys (line 1=50,4m of length, line 2=63m and line 4=94,5m) and one GPR profile (line 2=97m), placed on the terraces, were carried out. Another 2D resistivity survey was

between the current's electrodes and the voltage electrodes respectively. For these survey n=6 was used.

performed along the hill's slope (line 3=63 m), crossing the rubble fan.

The ERT and GPR results on the lines 1 and 2 show an homogenous layer of limestone rocks (ρ > 200 Ωm) up to about 3 m of depth. From this layer up to the maximal depth (about 10 m), it is possible to note another homogeneous zone with low resistivity values (ρ < 60 Ωm), probably caused by larger content of water in the porous. From these data the presence of important cavities or chambers must be excluded. The line 3 starts from the higher terrace and cuts perpendicularly the line 1, 2, the GPR profile and the fan; the ERT investigates up to 10 m of depth. Whereas the terraces shapes an horizontal surface, the same homogeneous layer of limestone with high resistivity values (ρ > 200 Ωm) is present, while lower resistivity values are registered in the lower part of the section.

In this tomography the presence of the excavation rubble is emphasized by higher resistivity values (ρ > 300 Ωm): probably the fan is placed on the top part of a wider layer of limestone and it is composed by the same material. All the data collected along the line 3 can be interpreted in the local geological framework and it is not evident any anomalous signal having reference to mining human activity.

The ERT along the line 4 shows the same resistivity setting: under a limestone layer 3 m thick (ρ > 200 Ωm), the presence of water in the porous reduces the resistivity values for the investigated section to a depth of 16 m (ρ < 60 Ωm). The only singularity in this homogeneous scenario is represented by a spot of very high resistivity (ρ > 1000 Ωm) located 15 m underground (visible at the bottom of Figure 4). This confined area is placed 56 m far away from the left boundary of the unvegetated area at a depth of 8 m from the terrace where the fan is placed.

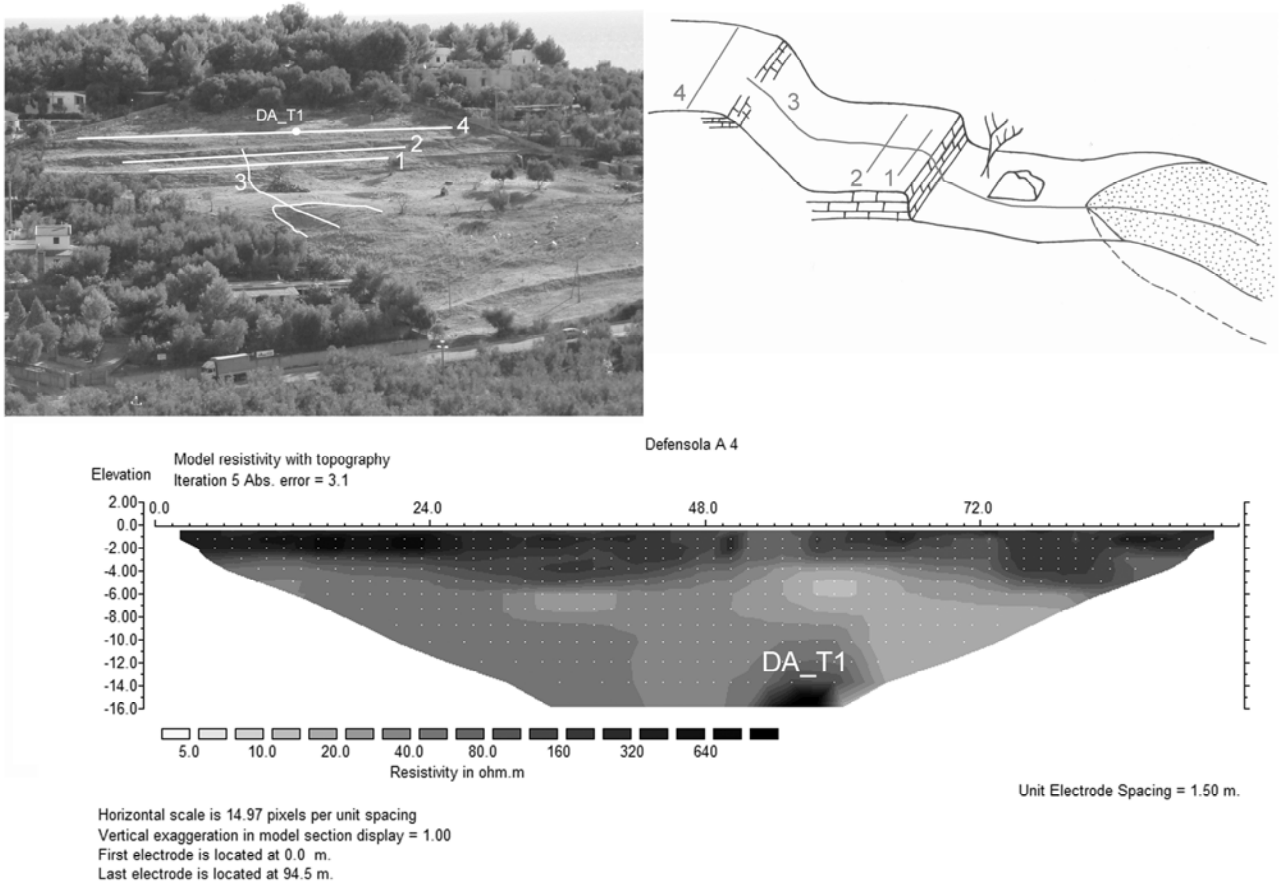

Figure 4. Defensola A. The four lines indicate the geophysical surveys. At the middle a scheme of the hill's side and of dumps fan. At the bottom the electrical tomography number 4 with the anomalous signal DA_T1 in dark grey.

3.2 Defensola B

The Defensola B site is characterized in one case by a vertical shaft and small tunnel that encloses a huge flint nodule with an estimated diameter of about 1,5 m (Figure 5). The area is fully vegetated and sometime the bush represented an hindrance for the surveys. An area of about 800 m^2 was investigated by 11 GPR profiles of different length and by 4 2D electrical imaging surveys (line 1=31,5 m, line 2=31,5 m, line 3=31,5 m, line 4=31,5 m). In all the acquisitions an homogenous (humid) soil appear clearly: in the ERT it looks like a thin layer with resistivity values lower than 100 Ωm.

The big flint nodule near the pit represented a good opportunity to test the instruments on this kind of "rare" target: it gives an impressive signal on GPR (P1) and the resistivity exceeds 10^4 Ωm (DB_T1) on ERT E1 and E4. This extremely compact rock is set in a limestone layer about 2 m thick ranged for all investigated

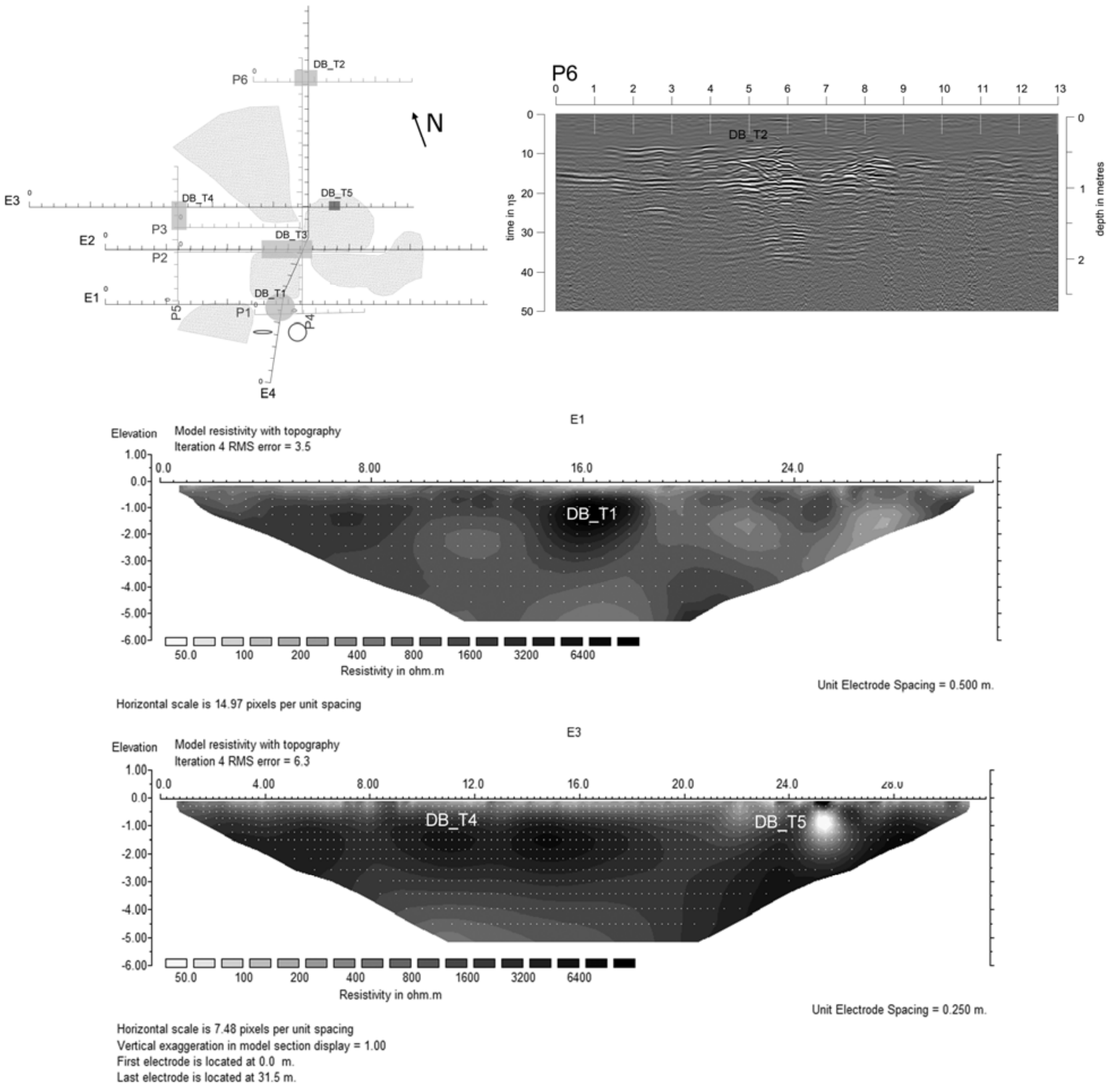

Figure 5. Defensola B. Positioning of 6 GPR and 4 ERT profiles: the light gray area represents the scrub. The DB_T1 indicates the flint stone near the mine's access. The DB_T2 is the target confirmed by two GPR profiles (P4 and P6) and the electrical tomography E4. The DB_T3 is the complex target detected by two GPR profiles (P2 and P4) and by two electrical tomographies (E2 and E4). The DB_T4 indicates the target obtained by data from P3 and P5 GPR profiles and by E3 electrical tomography. The DB_T5 is an evident anomalous signal in E3 electrical tomography.

area. The analysis of the data coming from both methods focuses on four anomalous zones (Figure 5).
In DB_T2 a particular target placed 1 m underground producing the highest GPR signal and having a resistivity value more than 10^4 Ωm is recognizable.
This signal could be produced by a cavity even if flint nodules demonstrated very high resistivity making difficult their recognition especially when in contact with empty or partially filled tunnels.
The DB_T3 appears as a more complex target: the intense reflector registered on the cross point of GPR profile P2 and P4 is confirmed by a superficial (0,5 m) high resistivity values ($\rho >$ 3000 Ωm) exactly on the cross point between ERT survey E2 and E4: below this, ERT reveals an anomalous spot with low resistivity value ($80 < \rho < 100$ Ωm). This problematic patchwork could be interpreted in many anthropic ways, but surely it represents a purposeful geologic anomaly. The DB_T4 at about 1 m depth is a target confirmed by the GPR profile P3 and P5; its bordered shape and its high resistivity value ($\rho > 8000$ Ωm) cause ambiguity in the interpretation of the event.
By DB_T5 a peculiar target localized 1 m underground was indicated: this target produces the lowest resistivity value ($\rho < 60$ Ωm) of the whole area and it could be hardly interpreted in geological way because of its high and evident contrast with the surrounding resistivity values.

3.3 Principe

The surveys in Principe site were focused around the vertical access to an ancient mine. A square grid of 22 GPR profiles covering an area of about 400 m^2 was created. A 3D model (20 m x 20 m x 3m) representing the most important reflectors was produced (Figure 6). The pit is located between the profiles 6, 7 and 18, 19. The four 2D electrical imaging surveys investigate four sections 31 m long, that reach about 4,5 m of depth (Figure 7).
The results for both methods match and confirm the hypothesis of the archaeologist that explored the first part of the tunnel. There is a good reflector between 1,2 and 1,8 m below the surface with an orientation East-West. The resistivity models show high values ($\rho > 2000$ Ωm) whereas the section intercepts the cavity. It seems not maintaining the same depth underground when departing from the shaft: at the eastern side the depth reaches almost 2 m underground.
The geologic context is heterogeneous: the limestone is characterized by resistivity values more than 100 Ωm and it appears extremely fractured; there are areas in which the water in porous reduce the resistivity up to 10 Ωm. These geophysical surveys give an exhaustive setting of the near surface geology and the first parts of the tunnels, but they don't permit to have a complete look on the network of cavities. From the digital aerial images the trend of the tunnels revealed by geophysical prospecting do not leave any trace on the ground surface. Probably tunnels continue beyond the investigated square area but, to confirm this hypothesis, additional geophysical are necessary in the future.

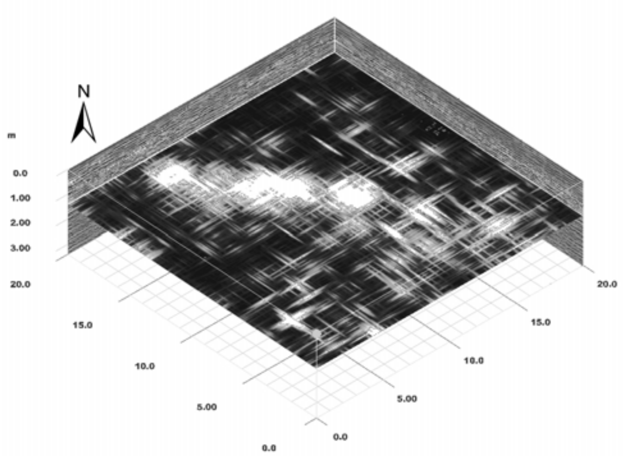

Figure 6: Mattinata; one of the GPR profiles showing a probable tunnel (white area), East-West oriented, at the depth of 1,4m.

Conclusions

This project sprang from the conviction that an understanding of the mechanisms governing the process of acquiring raw materials, often difficult to document, represents a key element in the study of the economic, social and behavioural dynamics of prehistoric societies. In order to attain this purely archaeological objective by reconstructing aspects of human activity, different methodologies, proper to the fields of archaeology, geology and applied geotechnologies have been adopted.

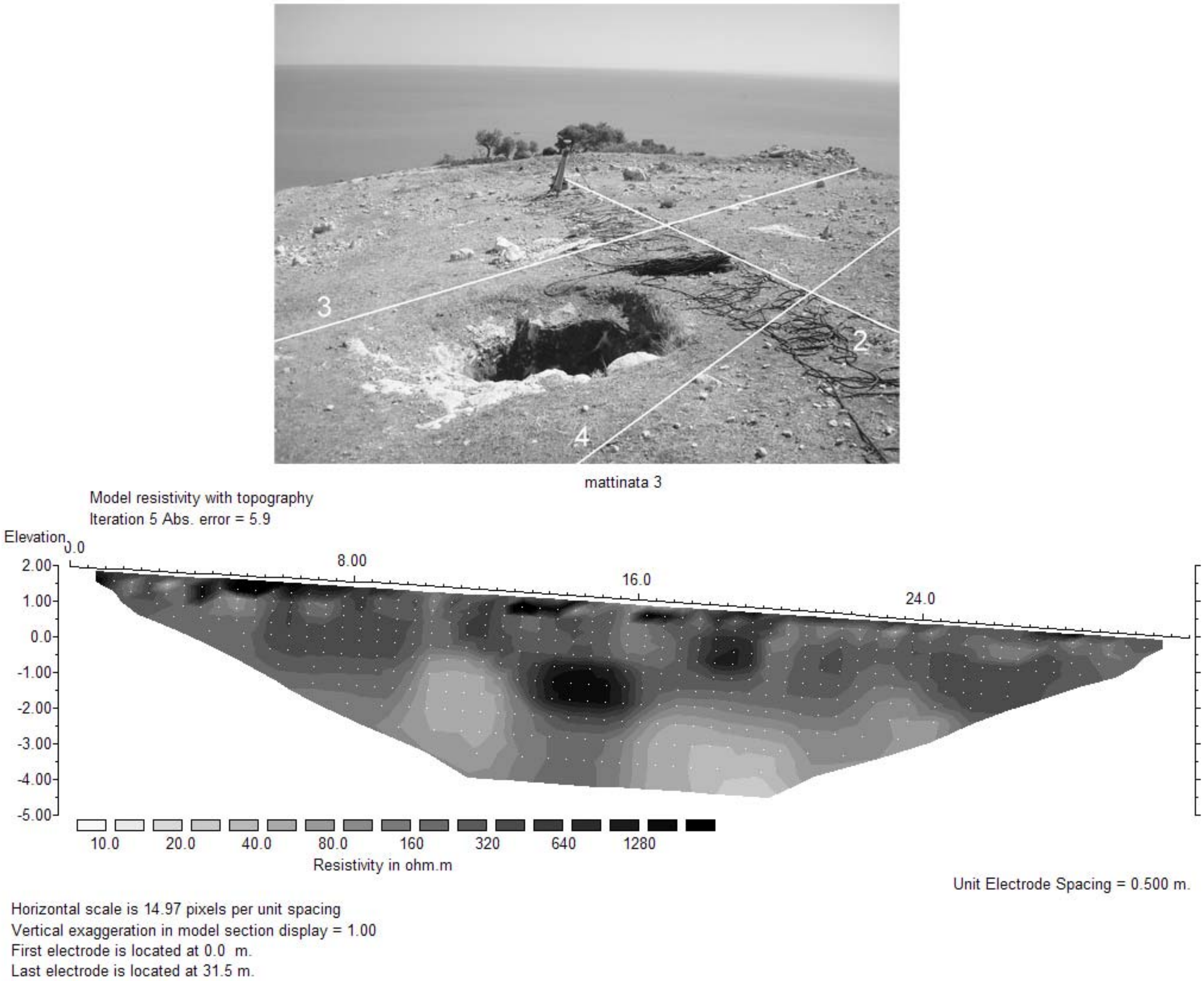

Figure 7. Principe site. The vertical access to an ancient mine with the lines 2, 3 and 4. At the bottom, the third electrical tomography with the evident signal of the tunnel departing from the pit.

The use of an integrated approach of this type in itself represented an inner objective of the research project, in this case of methodological nature. The results from aerial digital photogrammetry and geophysical prospecting demonstrated that only through an interdisciplinary approach of this type, which in this case has been tested ex novo, it is possible to attain the primary objective. The described applied technologies allowed to improve the knowledge on both a geomorphological level to identify new sites, and on the level of individual complexes (geophysical studies were used to determine their extent), the archaeological aspects of which are under investigation.

Nevertheless, many ambiguities in the interpretation of the data, especially for the geophysical approach, are still there; many times, high resistivity values left the doubt to be interpreted as cavity, natural or kart. Targets producing the lowest resistivity value could be hardly explained by the geological setting because they are evidently in contrast with the surrounding resistivity values. For these, additional fieldwork and archaeological studies are necessary.

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