PROSPECTING OF INDUSTRIAL MINERALS: A GEOPHYSICAL APPROACH

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INTRODUCTION

This work deals with the evaluation of the electrical resistivity method in identifying and characterizing industrial minerals deposits.

The ERT (Electrical Resistivity Tomography) technique is demonstratively applied to 4 different areas of the central and northern Sardinia (Italy). The research focused on hydrothermally altered pyroclastic and epiclastic deposits within the Oligo-Miocene calcalkaline volcanic sequence. Particularly a bentonite deposit near to Ozieri (N-Sardinia) was investigated by 2D and 3D ERT surveys, and potentially exploitable cineritic levels have been identified in two different sites near to Macomer and Zerfaliu (central-Sardinia). Furthermore the ERT method was tested on Messinian sedimentary clays linked to a wide alluvial system in the northern part of Nurra (NW-Sardinia).

This work aimed: 1) to define the geometry of the deposits; 2) to estimate the reserves and locate the main faults useful to decipher the ore-forming processes; 3) to evaluate the reliability of the ERT method by cross-checking the results with boreholes data.

MATERIALS AND METHODS

The construction of 2D and 3D images of the subsurface from resistivity data is commonly known as Electrical Resistivity Tomography. The ERT provides more accurate subsurface imaging compared to one-dimensional surveys (vertical electrical sounding or horizontal profiling) because the resistivity varies in both the vertical direction and the horizontal direction along the acquisition line.

In this Ph.D thesis the geoelectrical surveys were carried out by a Terrameter SAS1000 device, a single-channel georesistivimeter developed by ABEM Instruments (Sweden), based on the use of metal electrodes for galvanic coupling. The control unit Terrameter SAS1000 encloses both the energizing unit and the receiver unit and it is combined to LUND System which consists of Electrode Selector ES10-64 and multi-conductor cables (Fig. 1). The ES10-64 is a multi-channel relay matrix switch for high-resolution 2D and 3D resistivity surveys, which allows the automatic control of the electrode arrays.

Field system use a multicore cable to which 64 electrodes are connected at takeouts moulded on at predetermined equal intervals. The cable is directly connected to an ES 10-64 switching module and to stainless steel electrodes hammered in the ground. With this system, any electrodes may be switched to act as either current or potential electrodes and so within the constraints of the electrodes emplaced, any electrode arrangement can be employed (Barker *et al.*, 2001).

For inversion dataset were employed the RES2DINV (Loke, 2001) and the RES3DINV (Loke, 2004) programs which using a non-linear smoothness-constrained least-squares optimization techniques (Loke & Barker, 1996).

They automatically create the models by dividing the subsurface into rectangular blocks and choose optimum inversion parameters for the data. The optimization method tries to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of the model blocks. The model is considered to be appropriate when the calculated values and the measured ones are best fitted.

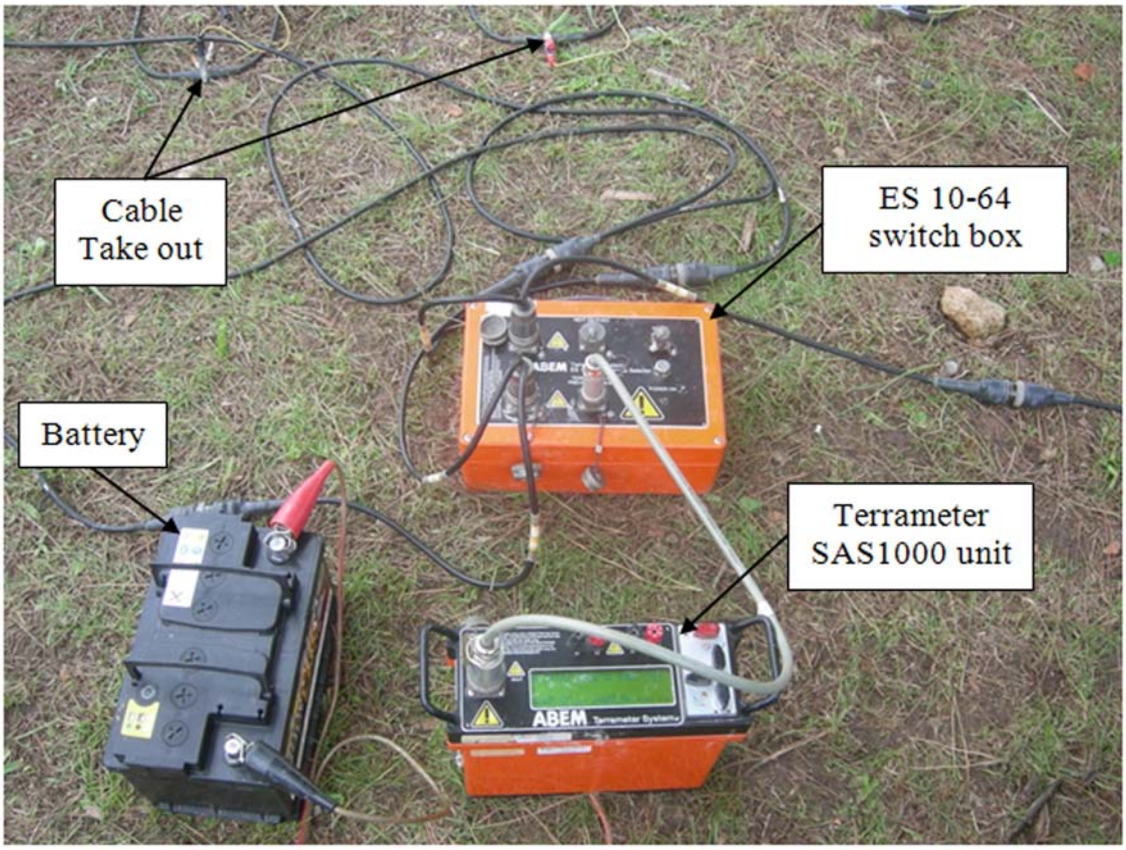

Fig. 1 - Arrangement for data acquisition with Abem Terrameter SAS1000 and Lund System.

CASE STUDIES

Site 1: Application of 2D and 3D ERT method on a bentonitic clay deposit in Northern Sardinia

The considered bentonite deposit is located about 13 km to the north-west of Ozieri (N-Sardinia) and it derives from the alteration of the pyroclastic sequences associated with the Oligo-Miocene calcalkaline volcanic cycle in correspondence of main fault systems. The first 2D electrical line, with a total length of 378 m (inter-electrode spacing 6 m), was located perpendicularly to a direct fault which controls the trend of the deposit.

The other two electrical lines, with unit length of 252 m (inter-electrode spacing 4 m), were located in correspondence of some pre-existing boreholes for evaluate the reliability of the electrical method.

The 3D ERT survey covered a rectangular surface of 189 m by 54 m. Data were collected by a series of 7 parallel 2D electrical lines positioned at 9 m intervals.

The resistivity data integrated with boreholes information have been displayed in virtual 3D space using geologic modeling software (Fig. 2).

The geoelectrical survey confirms that this methodological approach can be successfully used for mineral exploration in geological contexts where a high-conductivity contrast exists between the mineral deposits and host rocks.

A horizontal layers structure was identified consisting of: top layer (overburden), intermediate layer (conductive clayey body) and bottom layer (resistive pyroclastic bedrock).

The 3D ERT survey revealed a relatively low cost, noninvasive and rapid mean to generate 3D models for mineral reserves calculations.

The clay volumes estimated, by electrical and borehole data are very similar, hence an accurate 3D survey can conveniently replace direct borehole-based investigations.

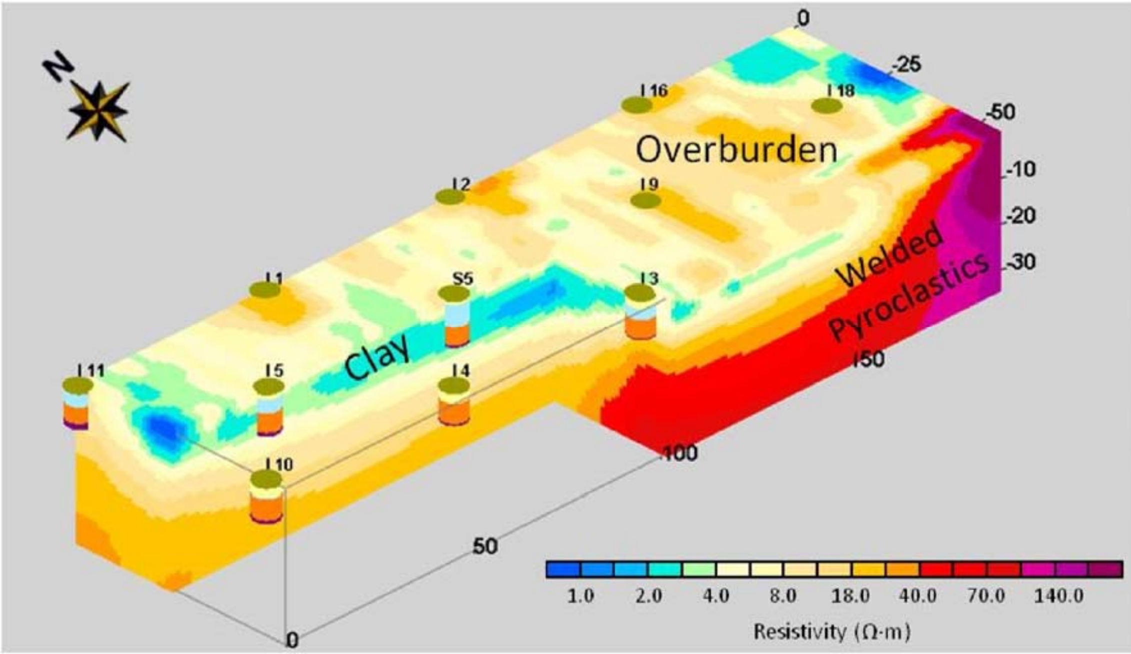

Fig. 2 -Integrated 3D ERT model along with borehole logs.

Site 2: ERT method as a guideline for prospecting volcanic ash deposits: the Zerfaliu case study

The main objective of surveys, conducted near Zerfaliu (central-western Sardinia), was to use the ERT method as a guideline to identify cinerite deposits that could potentially be exploited by mining.

Applications and therefore markets exist for both raw and popped or bloated ash products (Xia *et al.*, 2010). The choice of study area has been dictated by three fundamental factors: *i*) presence of outcropping cinerite useful for method calibration, *ii*) regional geological-stratigraphic features supporting the presence of strata of interest, *iii*) logistics conditions favorable for the implementation of possible extraction activities. The calibration profile has allowed to enclose the resistivity values attributed to the cinerite in a range between 2 and 8 **Ω**·m (Fig. 3). Then this range was used as the benchmark in interpreting the subsequent tomographies.

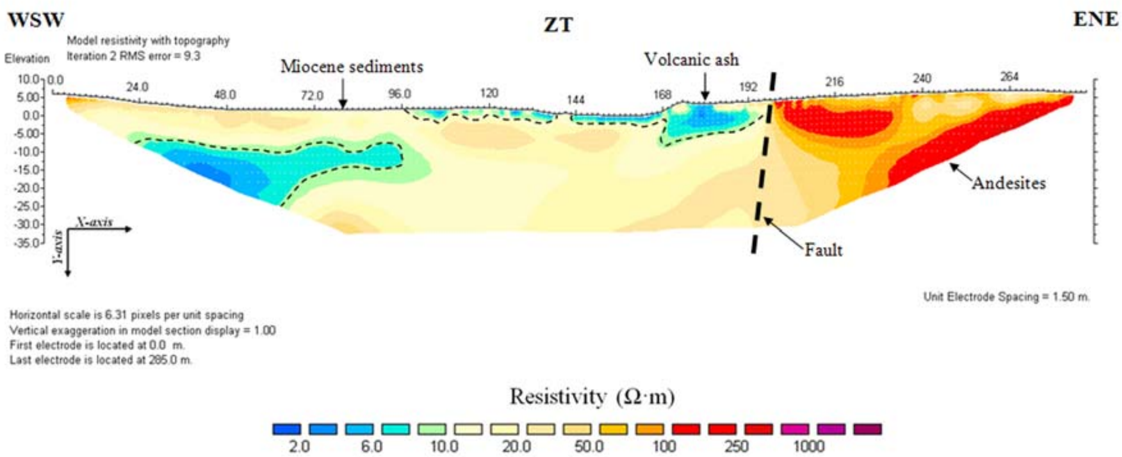

Fig. 3 - Electrical calibration profile.

The 4 ERTs, with unit length of 315 m (inter-electrode spacing of 5 m), have been examined focusing on conductive electrical anomalies that might indicate the presence of cinerite deposits. In order to ascertain the nature of these anomalies, 3 boreholes have been drilled. Two boreholes data have detected clayey levels in correspondence to conductive lenses, whereas only one borehole has successfully intercepted a cineritic level with a thickness of 50 cm, interbedded within the Miocene sedimentary succession of the area.

The surveys conducted near Zerfaliu have shown that the cinerites have meagre thicknesses making their extraction not economically viable.

In this case study the non-uniqueness of some resistivity models and the loss of resolution in the marginal portions of the images caused mistakes in interpreting phase.

Site 3: ERT method as a guideline for detecting altered volcanic ash deposits: the Macomer case study

An exploitable pumice- and ash-rich layer has been identified within a composite Oligo-Miocene volcanic succession resting on the Paleozoic basement near Macomer (central - Sardinia).

The aim of surveys was to provide information regarding the position and extension of this layer, and in particular: *i*) to define the geometry and depth of the deposit; *ii*) to locate continuous corings in order to verify the quality. The pumice-ash-rich layer examined is altered due to the action of hydrothermal fluids conveyed by the major fracture systems. Smectite and zeolite are the main phases derived from hydrothermal alteration. The heterogeneity of the material is confirmed by the broad range of resistivity values observed (2-50 Ω·m) in the calibration profile.

A set of high resolution electrical profiles have identified the contact between the coverage welded ignimbrites and the conductive volcanic ash at depth ranging from 5-10 m to 25-30 m from ground level (Fig. 4).

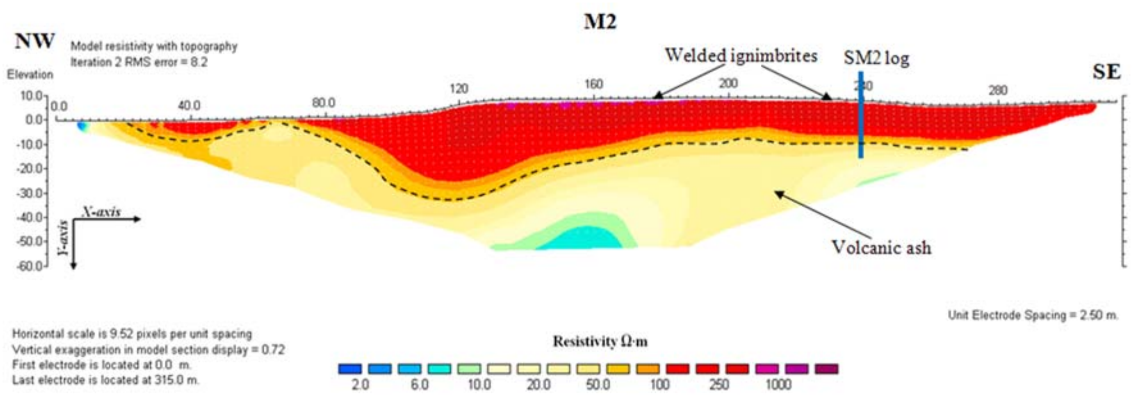

Fig. 4 - The ERT clearly distinguishes the contact between welded ignimbrites and volcanic ash.

The thickness of the deposit exceeds 40 metres, since the maximum depth investigated (55 m) revealed conductivity values characteristic of the altered cinerites.

The resistivity tomographies have provided targets for drillings, and have reduced the number of boreholes required with consequent saving in time and costs. The boreholes have confirmed the interpretation of the tomographies. The relationship of the thicknesses of the cover materials and the thicknesses of the deposit makes this site suitable for intensive exploitation.

Site 4: Geoelectrical Prospecting for characterising the Messinian clay deposits in the Nurra region (Sardinia NW): a preliminary study

The examined sediments are alluvial deposits that have filled a palaeovalley formed after the Messinian Salinity Crisis (Pascucci *et al*., 2004). These materials represent a continuous clayey band, topped by flooding channeled mainly composed of clast-supported conglomerates with variable thickness.

These clays, for their mineralogical and chemical characteristics are extracted for use as raw materials for bricks production. In the study area there are the disused quarries of clays, some of which have been reused as solid urban waste landfill.

The electrical acquisition lines were performed with a different resolution and were localized in several areas of the palaeovalley. The Messinian clays, with resistivity values generally lower than 40 Ω·m, were discriminated by superficial conglomerates and by underlying bedrock.

The ERT models suggest that the structural setting of the area is affected by wavy and irregular bedrock, with structural highs and depressions filled by Miocene alluvial deposits.

In the eastern part of the palaeovalley, the tomographies reveal a structural high where the clays have reduced thickness of 15-20 m and are capped by 5-10 m thick conglomerates (Fig. 5).

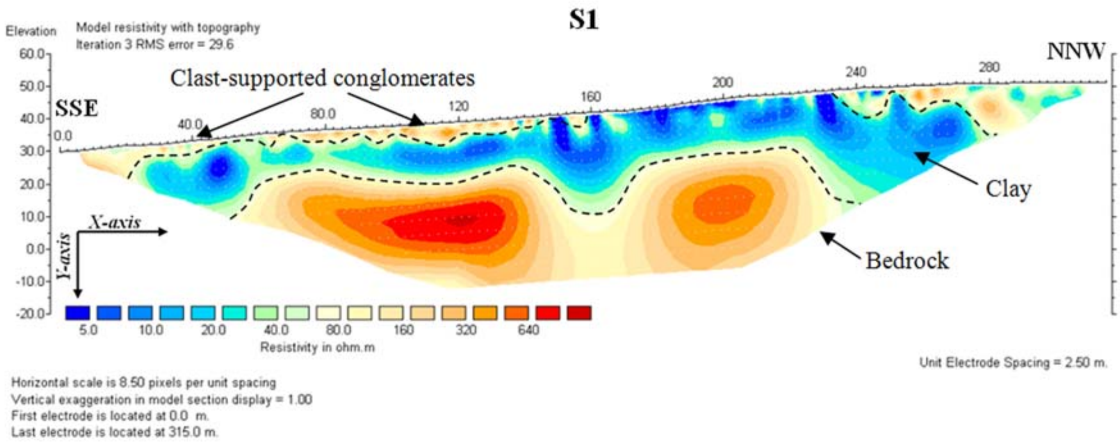

Fig. 5 - In this tomography the conductive clays are distinguished from superficial conglomerates and by underlying bedrock.

In the centre of the palaeovalley the thickness of the clays increases significantly, up to 45 m.

The westernmost tomographies, where the evaporites, limestones and redbeds crop out, were performed in order to obtain direct resistivity values on the rocks that are believed for the bedrock of the deposit elsewhere.

Even if the central part of the palaeovalley could contain meaningful clay deposits with thickness higher than 50 metres, caution must be adopted when exploitations are planned towards the palaeovalley slopes where the occurrence of conductive satured Permian redbeds can cause mistakes in interpreting the lithology of the subsurface rocks.

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