Shallow geothermal exploration using SkyTEM data: the VIGOR experiment

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ABSTRACT

As part of planned geophysical activities within the “VIGOR Project”, aimed at assessing regional and local scale geothermal potential of four southern Italian Regions, Airborne EM survey has been carried out in Sicily, in late 2011, on two test sites (Termini and Western Sicily). After acquisition, data have been processed and modeled, providing 3D cell distribution of resistivity that has been used for detailed geological and geothermal interpretation. In particular, we describe here the results of the geological modelling of one of the two areas, constrained using resistivity data, and its geothermal interpretation focused on the detection of shallow circulation of geothermal fluids and to the reconstruction of thermal conductivity distribution at depth.

1. INTRODUCTION

Within the “VIGOR” project, aimed at assessing the geothermal potential of four regions in southern Italy (Manzella, 2013), airborne geophysical electromagnetic (AEM) data have been acquired, modeled and interpreted. The AEM survey was performed using SkyTEM system with data delivered by SkyTEM Surveys Aps, processed and inverted by Aarhus Geophysics Aps. SkyTEM is a time-domain helicopter electromagnetic system with a maximum magnetic moment of approximately 150000 A/m^2. Measurements are carried out continuously while flying. The SkyTEM system provides, after data acquisition, analysis, processing and modeling, a distribution volume of electrical resistivity, spanning an investigation depth from ground surface of few hundred meters, depending on resistivity condition.

Resistivity is an important physical parameter for geothermal investigation, since it proved to be very effective in mapping anomalies due to hydrothermal fluid circulation, which usually has high salt content and produces clayey alteration minerals. Besides, resistivity data may help in characterizing hydrogeological or tectonic features. The attempt is also to define relations between resistivity distribution, lithological units and thermal conductivity.

The AEM survey was carried out in Sicily, Italy, in the Fall 2011. The flight lines covered two areas: in the “Termini” area about 5000 km total flight lines spaced 150 m were acquired over an area of (15 x 15) km^2; in the “Western Sicily” area two different line spacing were used to cover the (30 x 50) km^2: the 1 km spacing was used for the preliminary mapping, whereas for infill areas, around the main hydrothermal springs, the flight lines had 200 m spacing.

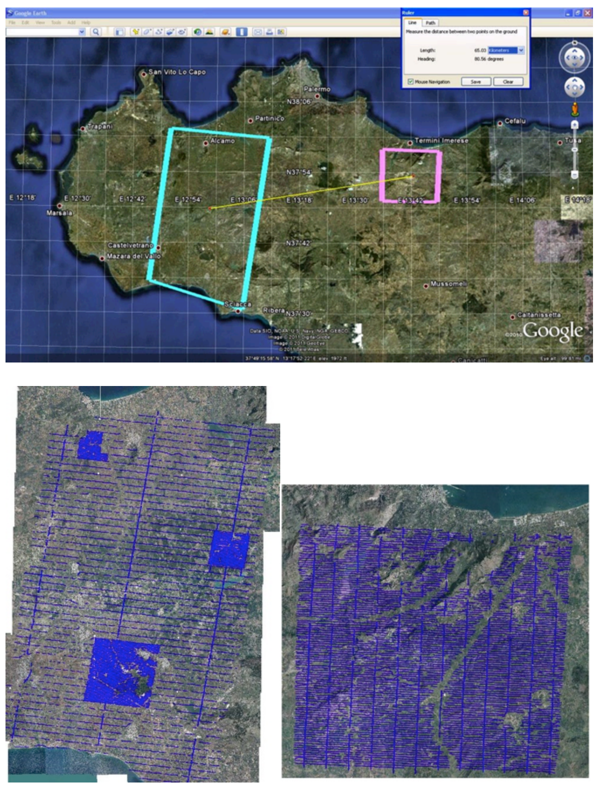

Figure 1: The two areas covered by airborne surveys: “Termini” area in pink, “western Sicily” area in blue (top). Flight lines details in the two areas (bottom). Note the infill in the “western Sicily” area, bottom left.

About 150.000 soundings were acquired in six weeks of fieldwork. The rainy and windy period made the acquisition particular slow. Data pre-processing was performed on the field.

After acquisition, data were analysed and processed. Inversions were then carried out using the quasi 3-D Spatially Constrained Inversion (SCI). Processing and modelling required 4 months. The inversion provided a wide 3D distribution of electrical resistivity with a maximum investigation depth up to few hundred meters. The geophysical results are composed by 3D cell distribution of resistivity (X,Y,Z, rho) from which resistivity slice maps and resistivity cross-section have been drawn (e.g., Fig. 2).

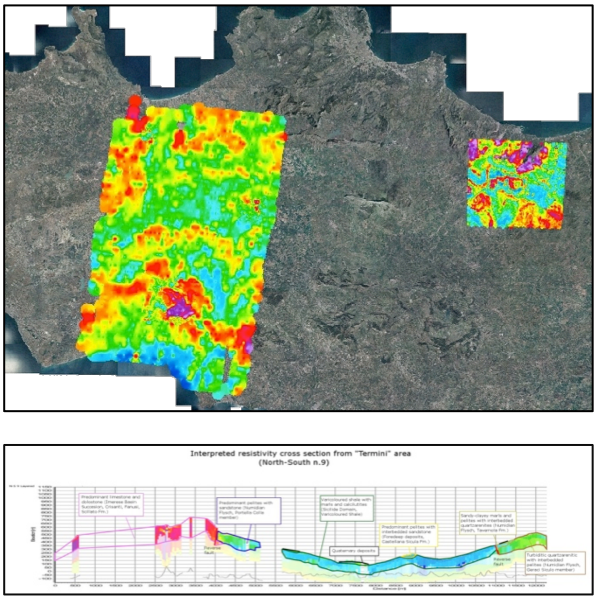

Figure 2: Surface resistivity maps in the areas (top) and a resistivity cross-section along one of the flight lines in the Termini area (bottom).

The obtained resistivity volume has then been the base for a detailed lithological and geothermal interpretation. In this paper we focus on the results obtained in the Termini area.

2. GEOLOGICAL BACKGROUND

The "Termini" test site is located in northern Sicily near "Termini Imerese" spa town, an area belonging to the Apenninic-Maghrebian Chain along the convergent plate boundary between Africa and Eurasia (Fig. 2). This segment of Sicily FTB has a very complex structural setting as a consequence of a polyphased tectonic that affected the Triassic-Pleistocene sedimentary successions.

The studied area shows a tectonic wedge made by Paleozoic to Miocene sedimentary rocks pertaining to different paleogeographic domains. The Miocene-Quaternary deposits represent the syn and post-orogenic sedimentation. The outcropping rocks belong to Triassic-Oligocene deep water carbonate "Imerese Domain", Oligo-Miocene terrigenous "Numidian Flysch units", Cretaceous-Oligocene Paleo-Thetyan "Sicilide Domain" and Neogene-Quaternary syn and post tectonic deposits.

3. GEOLOGICAL MODELLING

The 3D geological model of "TERMINI" area has been carried out using "PETREL" software (Schlumberger). The geological map and the surface resistivity were input to the model, and the lithological and geological maps were used to constrain surface condition and to understand the resistivity ranges of the different lithological units.

Resistivity distribution showed a good correlation with some of the geological structures recognized in the area (Fig. 3).

Lithological and geological maps were used to constrain surface conditions and to pick out the resistivity values of outcropping rocks, allowing the classification of main Litho-Electrical (LE) Units.

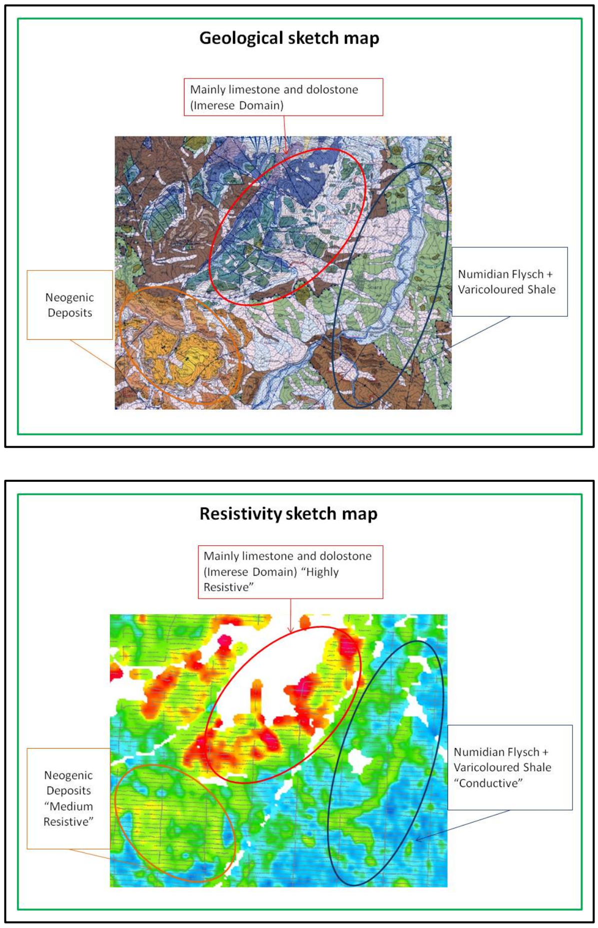

Figure 3: A detail of geological (top) and resistivity (bottom) maps showing a good correlation.

Based on resistivity volume and geological data, the LE Units have been modeled at depth greater than the achievable survey investigation depth, and 21 geological cross-sections have been built (Fig. 4).

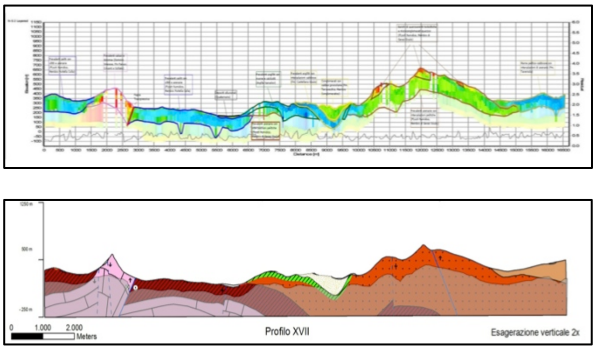

Figure 4: An example of resistivity section (top) and corresponding geological section (bottom).

These cross-sections were then interpolated by the software, to obtain a 3D model of the LE units. Faults were also inserted in the model in order to obtain a good control of the geological structure (Fig. 5).

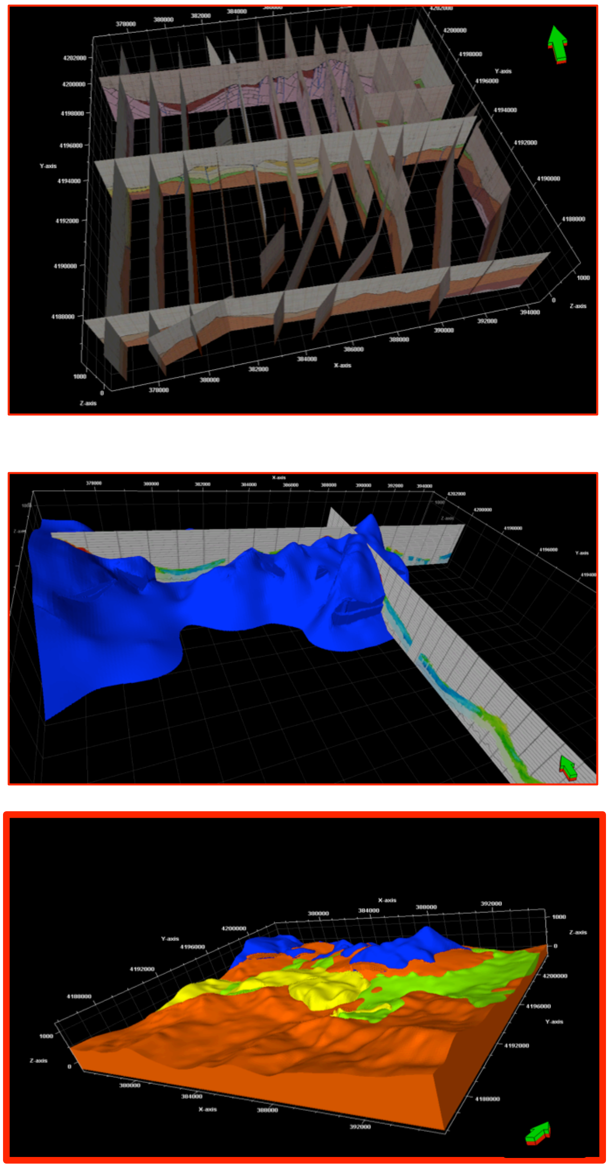

Figure 5: Geological cross-section (top) the "Imerese" unit modelling (middle) and the complete model (bottom).

The obtained 3D model of LE Units has a cell grid of 25 meters horizontal spacing.

3. GEOTHERMAL INTERPRETATION

The detailed interpretative modelling was the occasion of recognizing resistivity anomalies within carbonate units, which host the regional hydrothermal reservoir. Some anomalies have been defined and are now under investigation to understand if they are due to shallow hydrothermal fluid circulation or other reasons, such as the presence of conductive components, e.g., clays.

The litho-electrical 3D model is also under investigation to verify how it can represent a viable way to image heat exchange properties at shallow depth. If we succeed in defining the relations between electrical resistivity, lithology, thermal conductivity and hydrogeological bodies, we would obtain a way to define, at depth, the main parameters (thermal properties and fluid distribution) for defining shallow geothermal potential in detail.

By comparison of thermal conductivity and surface resistivity, some meaningful correlation between these two datasets/physical parameters were found, for example for limestone-dolostone (Fig. 6).

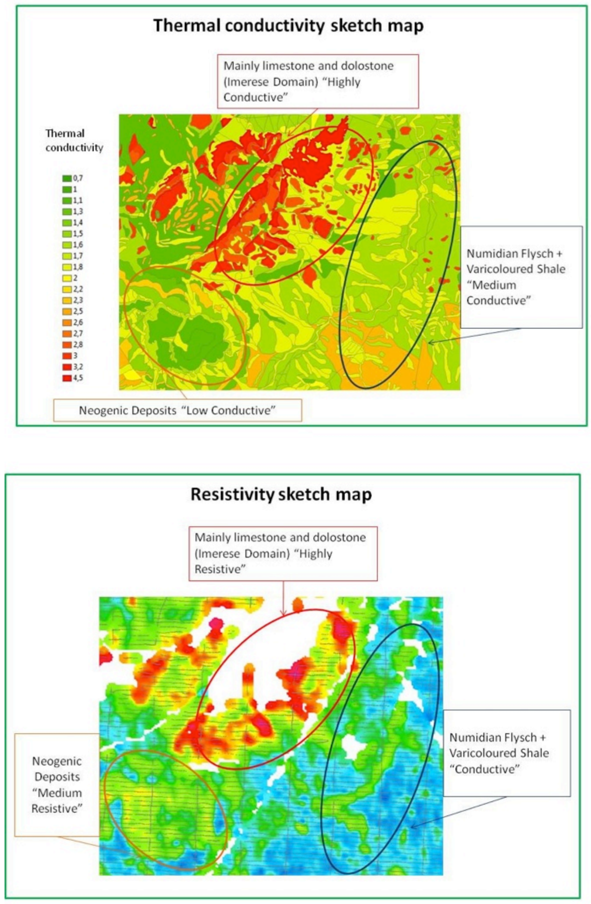

Figure 6: A detail of thermal conductivity (top) and resistivity (bottom) maps showing a good correlation.

It will be necessary to verify these correlations with more data over other domains, and taking into account the variation of thermal conductivity in rocks, an issue that is being studied in detail by Di Sipio et al. (2013) in the frame of VIGOR project. However, for units that can be mapped with resistivity and show strong contrast of thermal conductivity, resistivity will help to constrain the thermal conductivity distribution at depth, therefore contributing to a detailed mapping of heat exchange at depth, to be used for low enthalpy geothermal system planning.

3. CONCLUSIONS

A detailed 3D modelling was performed in an area of about 250 km^2 in Sicily, taking into account surface geology and extensively using the volume resistivity distribution obtained by airborne geophysical electromagnetic data. The study is considering the possibility of using AEM data for detecting geothermal fluid shallow circulation and mapping thermal conductivity in 3D. A good correlation has been found in some sectors, and a more detailed check is under development.

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