تفسير اولية داده هاي مگنتوتلوريك منطقة ژئوترمال تراوالة ايتاليا

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چكيده

اين مقاله مدل مقاومت ويژه را با زمين شناسي ميدان ژئوترمال تراواله مورد بررسي قرار مي دهد. در اين منطقه يك مطالعة دقيق مگنتوتلوريك انجام شده است. نتايج حاصل از تفسير داده هاي مگنتوتلوريك با پريود بلند در منطقه از نظر شناسائي رساناهاي موجود در عمق بطور قابل ملاحظه اي مفيد واقع شده اند. داده هاي مگنتوتلوريك با استفاده از برنامه هاي برگردان يك بعدي و دوبعدي فرآوري و مدل سازي شده اند. مدل مقاومت ويژة بدست آمده از اين داده ها با مدل زمين شناسي در طول پروفيل هاي مگنتوتلوريك تا عمق حدود پنج كيلومتر قابل تطبيق است. تحليل اين گروه داده هاي جديد مگنتوتلوريك وجود يك منبع ژئوترمال را در منطقة مورد مطالعه تشخيص مي دهد.

واژه هاي كليدي: ميدان ژئوترمال، مگنتوتلوريك، تراواله، برگردان يك بعدي و دوبعدي، مقاومت ويژه

Preliminary Interpretation of the Magnetotelluric Data from Travale Geothermal Field in Italy

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Abstract

This paper includes a comparison of the main features of the resistivity model with the geology in exploited geothermal field of Travale, where a detailed study has been done using Magnetotelluric (MT) data. In this area, long period natural-field MT method has proved very useful for subsurface mapping purpose so that deep resistivity structures were determined properly. Using 1D and 2D inversion schemes, MT data were processed and modeled. The resistivity model obtained from the MT data is consistent with the geological model along the MT profiles down to five kilometers. Analysis of this new MT dataset suggests signatures of a deep geothermal reservoir in the area.

Key words: geothermal field; magnetotelluric; Travale; 1D and 2D inversion; resistivity

1. Introduction

Magnetotelluric (MT) method is known as the most useful exploration technique for delineating the geothermal resources since they produce strong variations in underground electrical resistivity. The depth of investigation of MT is much higher than that of other electromagnetic (EM) methods.

A supplementary goal of the current project is to evaluate the possibility of using surface EM measurements to monitor the underground heat flow alterations. This objective is followed in the frame of one- and two- dimensional (1D and 2D) interpretation to characterize the Larderello-

Travale geothermal system in Italy (Fig. 1). In this area the exploration targets are mainly located in metamorphic rocks down to 4000 m depth, having a high degree of heterogeneity and very high temperature (~400^{o}C).

MT data consists of low frequency data (300 – 0.0003 Hz) collected in September 2004. The whole field campaign was organized and led by Dr. Behrooz Oskooi (the fellow of the TRIL Programme of the Abdus Salam International Centre for Theoretical Physics) under the supervision of Dr. Adele Manzella (CNR-IGG electromagnetic laboratory).

MT processing codes from Larsen et al. (1996), Smirnov (2003), Egbert (1997) and SSMT2000 software (Phoenix Geophysics) were investigated for data sets from low frequency systems. The applicability of the programs for remote reference processing was also examined. Winglink™ developed by Geosystem, a geophysical software for MT data presentation and inversion, has been used in the interpretation stage. 1D and 2D inversions are conducted to initialize further 3D modeling.

2. Magnetotellurics concepts

MT uses the natural, time-varying electric and magnetic fields at the surface of the earth to make inferences about the earth's electrical structure which, in turn, can be related to the geology, tectonics and subsurface conditions. MT method was first introduced by Tikhonov (1950) and Cagniard (1953) and developed further by Cantwell (1960) and Vozoff (1972, 1991). Measurements of the horizontal components of the natural electromagnetic field are used to construct the full complex impedance tensor, Z, as a function of frequency,

$$Z = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix}$$

indicating the lateral and vertical variations of the subsurface electrical conductivity at a given measurement site. Impedance tensor provides information on dimensionality and strike of the conductive structures as well. Apparent resistivity, ρ_a, and phase, φ, are the desired quantities calculated through the following relations,

$$\rho_{a\,i} = \frac{1}{\mu_0 \omega} |Z_i|^2$$

$$\varphi_i = phase(Z_i) \qquad , \; i = xx, xy, yx, yy, \; DET$$

where μ_0 is the permeability of free space, ω is the angular frequency and DET denotes the determinant data.

Time series measurements collected in various frequency ranges are transformed into frequency domain, and cross power spectra are computed to estimate the impedance tensor as a function of frequency. The determinant of impedance tensor which is also called the effective impedance, Z_{DET} (Pedersen and Engels, 2005), is defined as,

$$Z_{DET} = \sqrt{Z_{xx}Z_{yy} - Z_{xy}Z_{yx}} \quad .$$

Using the effective impedance, determinant apparent resistivities and phases are computed. The advantage of using the determinant data is that it provides a useful average of the impedance for all current directions. Furthermore, no mode identifications (transverse electric, TE mode: current in parallel with the strike; or transverse magnetic, TM-mode: current perpendicular to the strike) are required, static shift corrections are not made, and the dimensionality of the data is not considered, since the effective impedance is believed to represent an average that provides robust 1D and 2D models.

3. Inversion

1D and 2D inversion of the determinant (DET) data using a code from Pedersen (2004) and a code from Siripunvaraporn and Egbert (2000), respectively, were performed. The data were calculated as apparent resistivities and phases.

3.1. One dimensional inversion

1D inversion of the determinant data (DET) was performed. The determinant provides an overview of the subsurface conductivity in a feasible sense. Based on the results of 1D inversion, a reasonable starting model and strategy could be constructed for higher order inversions of 2D.

An example of the 1D model at site F9 together with the data and calculated model responses is shown in Fig. 2. In this case processing has been done by using data from Sardinia as the remote site. A shallow conductor and a deep conductor could be resolved. For this dataset there is an acceptable level of misfit.

3.2. Two dimensional inversion

For 2D modeling purposes corresponding MT-sites were projected on 7 straight lines numbered from 1 to 7 as shown in Fig. 3. Here we focus on the 2D results of profile 1 which is more informative.

Starting with a half-space or a priori model as the initial model, for all models, convergence to a possible minimum RMS misfit was achieved after limited numbers of iterations. Root mean squared (RMS) of data misfit normalized by data error is used to control the data-fit. The resulting model, data-fit and residuals along profiles 1 is shown in Fig. 4. The residuals are simply the arithmetic difference between the observed and calculated data. In some cases there is a large misfit which most probably is due to 3D structures, since outliers in the residuals are seen quite frequently.

4. Discussion and conclusions

1D and 2D modelling of the MT data along the selected profiles has revealed remarkable confirmation of the subsurface geology by means of resistivity variations of the upper overlying Neogene cover down to the basement. The present MT study resolved the area very conductive.

The resistivity models describe the area generally conductive (0.5-300 ohmm) down to the level of 5 km.

2D inversion result of DET data along profiles 1 properly matches on the geologic cross section model (not shown in this abstract). The upper part of the crust towards the northeast consists of a relatively conductive sedimentary sequence and in the other end (towards the southwest) i.e. where the metamorphic basement formation is close to the surface, large resistivities can be observed.

The analysis of our new MT data-set suggests signatures of a deep geothermal reservoir in the area. The conductive zones recognized in the resistive basement along MT profiles can clearly be interpreted as flow of the fluids in the faults and fractures of the metamorphic rocks.

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