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Application of Time Domain Electromagnetic Method to Monitor the Shallow Resistivity of a Geothermal Field

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ABSTRACT

TDEM is an electromagnetic technique applied during the exploration stage of geothermal fields and to keep monitor its evolution during the production and maintenance stage. Its fundamental base lays in the injection of electrical current through a transmitter square loop laid on the ground which induces a magnetic field that travels through the ground layers.

Measurements of the resulting magnetic field are made in a receiving coil in the center of the loop since this is related to the resistivity of the ground rock layers. Due to its easy deployment, low electromagnetic noise susceptibility and low-cost TDEM is used to monitor the shallow resistivity instead of other techniques.

Since the prospection depths are not higher than 1000 m, TDEM is used to monitor the resistivity variations caused by the changes in the chemistry of the rock due to the interaction of geothermal fluid. This way monitor a geothermal field becomes necessary to anticipate problems that could affect the supply of fluid from the reservoir or endanger the geothermal powerhouse, surrounding buildings or houses inside the geothermal area as a result of the loss of the mechanical strength.

1. INTRODUCTION

The main target during the exploration phase of an area of geothermal interest is to define its size, structure and establish physicochemical properties, such as the type and chemical composition of the fluid, its temperature and its capacity to produce energy (enthalpy).

Geophysical exploration can be divided into three stages: reconnaissance, evaluation, and monitoring. During the operation phase of a geothermal field, some exploration methods are used to carry out field monitoring.

Electrical resistivity is a rock property that varies through time due to the dependency of factors such as temperature, hydrothermal alteration, salinity and rock porosity which also varies through time.

TDEM among other technics is usually used to monitor the behavior of a geothermal field. This technic allows to prospect at shallow depths (100 – 1000 m) and characterize the resistivity of the alteration layer resulting from the interaction of geothermal fluid and rock.

During the operation and maintenance stage of a geothermal field is necessary to maintain the mass flux, enthalpy and the chemistry of the fluid that is provided to the power plant. During this stage, the geothermal reservoir is a dynamic system that is constantly under the extraction and injection of mass. This is why is important to keep under observation the changes in this system.

2. TDEM METHOD DESCRIPTION

TDEM (Time Domain Electromagnetic) is a geophysical technique used to determine the electrical resistivity of the subsoil. Developed in Russia in the ’80s to study deep geological structures. This method is currently used to investigate the electrical parameters of the subsoil for multiple applications.

The method consists of injecting a constant current into a square transmitter loop (See Figure 1) for a specifically defined time. A rapid zero cut of this current is performed, which causes the induction of a voltage pulse for a very short time on the ground, also causing the induction of a primary magnetic field, following the Faraday-Lenz Law.

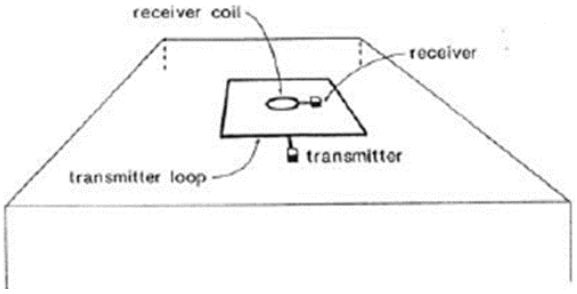

Figure 1: Center Loop TDEM Deployment. (McNeill J. D. 1994, p. 12)

This field produces an induction of secondary electric currents in the opposite direction, in the layer of the immediate subsoil to the transmitter loop, which flow in closed paths and migrate in depth and laterally, while their intensity decreases as time passes due to resistance to flow of current of these layers (See Figure 2).

Again, due to the variation of the secondary currents, a voltage, and a transient secondary magnetic field are induced, but now at a greater distance from the transmitter and greater depth. The variation of the resulting magnetic field is recorded by an internal coil in the center of the array.

The apparent resistivity is calculated based on the injected current, the area delimited by the transmitting loop and the receiving sensor, the decay time of the induced magnetic field (since the magnitude and distribution of the induced currents depend on the resistivity) and the induced potential. See equation (1).

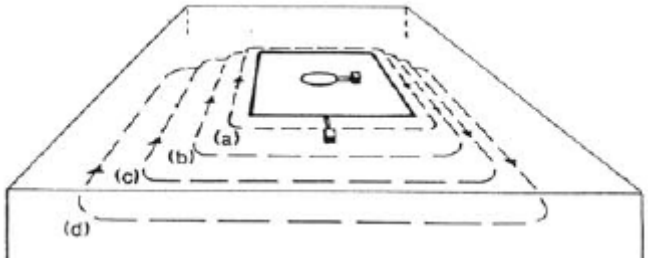

Figure 2: Transient Current Flow. (a) a Δt after the current goes off. (b)-(d) at progressively later times. (McNeill J. D. 1994, p. 12)

$$\rho_a(t) = \frac{kM^{2/3}}{e(t)^{2/3}t^{5/3}} \quad (1)$$

Where k is a constant of the electrical characteristics of the medium, M is the electrical moment that is defined by the product of the area of the transmitter loop and the current flowing through it, e (t) is the voltage in the receiver loop depending on the decay time and t is the decay time.

Due to the multiple studies that have been done with this method, it has proven to be more effective due to its results, than galvanic methods such as Schlumberger. This technique is useful for the discrimination of layers with low resistivity, high lateral resolution, can be used in urban environments, easy application and installation and reduced time in data collection for a survey of 100 to 1000 meters deep (depending on factors of terrain a survey of 100x100 meters can be carried out in approximately 1 to 3 hours).

3. SHALLOW RESISTIVITY MONITORING OF THE GEOTHERMAL RESERVOIR

Before the system begins to be modified by the effect of mass extraction for the production of electrical energy, it is necessary to establish a baseline of shallow resistivity, which will serve as a reference parameter for monitoring.

The points proposed for monitoring will have to be fixed, to ensure the reliability of the measurements over time. Also, the coverage of the monitoring points must be both inside and outside the geothermal system, to have contrast zones that highlight resistivity changes.

Many factors can alter the resistivity of the ground, so it is necessary to control the largest number of variables to ensure the repeatability of the data. The size of the arrangement and the configuration of the sampling equipment, the orientation and position regarding the arrangement of the receiving sensor, the time or season of the year to take the data (winter water alters the saturation of soil moisture by changing significantly the resistivity value), etc.

4. IMPORTANCE OF SURFACE RESISTIVITY MONITORING

The shallow studies of TDEM are useful to monitor the level of the superficial hydrothermal alteration, to observe the migration of the alteration due to the increase or decrease of the temperature.

The interaction between the rock and the fluid at a high temperature can affect in such a way that the rock modifies its mechanical properties such as porosity, density, permeability, plastic properties and can even produce microfractures in the rock which can generate greater fragility.

Monitoring is necessary to anticipate problems that could affect the supply of reservoir fluid, endanger civil works or surface installation equipment within the field or even the installation of drilling equipment due to the loss of mechanical resistance of the ground, increased the surface temperature and consequently the emanation of geothermal gases to the surface by the effect of the interaction of the geothermal fluid.

In the geothermal fields in operation different surface facilities are built. Powerhouse, access roads, geothermal platforms, offices, warehouses, etc., may be affected by the effects of hydrothermal alteration. Due to the plasticity and the ability to expand with the presence of water, alteration clays are highly problematic for civil works and that is why this monitoring takes on greater relevance.

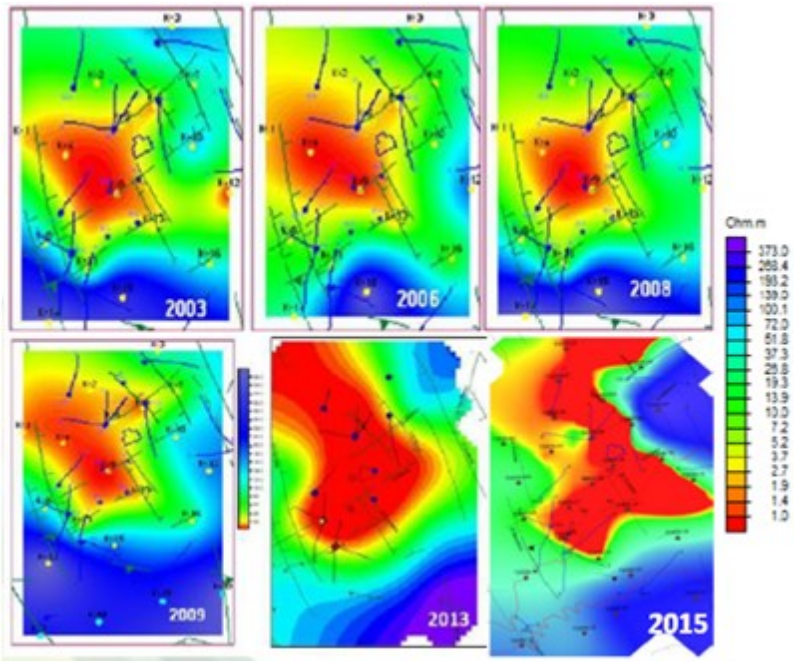

Figure 3. Resistivity maps of a geothermal field of different years at 25 m

In Figure 3, a clear decrease in shallow resistivity at 25 m can be observed from 2003 to 2015 of a geothermal field, which migrates to the SE with preferential direction to the local fault system. The decrease in resistivity may be associated with the increase in temperature and surface hydrothermal alteration, which can serve as a warning to perform mitigation measures on the surface before the rock loses its mechanical properties that may affect the stability of the ground.

CONCLUSIONS

The results confirm that TDEM method is practical, economic and perfectly reliable to monitor a geothermal field. The results of this monitoring can also be related to processes such as subsidence, loss of heat from the reservoir due to the thermal characteristics of the surface, changes in gravity, can be used to calibrate the reservoir simulations and predictive models of its behavior under a variety of extraction and injection strategies.

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