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The deep geothermal structure of the Mid-Atlantic Ridge deduced from MT data in SW Iceland

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Abstract

Iceland is very active tectonically as it is crossed by the Mid-Atlantic Ridge and its associated rift zones and transform faults. The high-temperature geothermal systems are located within the neo-volcanic zone. A detailed comparison of the main features of the resistivity models and well data in exploited geothermal fields has shown that the resistivity structure of Iceland is mainly controlled by alteration mineralogy. In areas where the geothermal circulation and related alteration take place at depths of more than 1.5 km, the investigation depth of the DC and TEM methods is inadequate and the MT method appears to be the most suitable survey method. MT soundings were carried out to determine the deep structure between two neighboring Quaternary geothermal fields: the Hengill volcanic complex and the Brennisteinsfjoll geothermal system, both known as high-temperature systems. MT data were analyzed and modeled using 1D and 2D inversion schemes. Our model of electrical conductivity can be related to secondary mineralization from geothermal fluids. At shallow depths, the resistivity model obtained from the MT data is consistent with the general geoelectrical models of high-temperature geothermal systems in Iceland, as revealed by shallow DC and TEM surveys. The current MT results reveal the presence of an outcropping resistive layer, identified as the typical unaltered porous basalt of the upper crust. This layer is underlain by a highly conductive cap resolved as the smectite–zeolite zone. Below this cap a less conductive zone is identified as the epidote–chlorite zone. A highly conductive material has been recognized in the middle of the profile, at about 5 km depth, and has been interpreted as cooling partial melt representing the

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main heat source of the geothermal system. This conductor may be connected to the shallow structure through a vertical fault zone located close to the southern edge of the profile.

Keywords: Geothermal field; Magnetotelluric; High-temperature system; Mineralization; Iceland; Neo-volcanic zone; 1D and 2D inversion; Hengill

1. Introduction

Geothermal resources are ideal targets for electromagnetic (EM) methods since they produce strong variations in underground electrical resistivity. In thermal areas, the electrical resistivity is substantially different from and generally lower than in areas with colder subsurface temperature. The resistivity is affected by the vertically ascending, hot mineralized waters or vapours that originate from the contact between groundwater and high temperature intrusive magmas. The intrusions themselves have a very low intrinsic resistivity at temperatures above approximately 800 °C (Bartel and Jacobson, 1987). For example, the electrical resistivity of molten basaltic magma was determined at about 2 Ω m by Frischknecht (1967) in his study on Kilauea Iki lava lake. In general, the increase in the fraction of partial melts and in the partial pressure of water greatly reduces the resistivity of rocks (e.g., Lebedev and Khitarov, 1964; Wannamaker, 1986).

Resistivity in geothermal areas is also governed to a great extent by the presence of hydrothermal alteration products, since they contain clays. Clay minerals are found in natural environments ranging from surface to low-grade metamorphic and hydrothermal conditions. Systematic petrological, mineralogical, chemical and well-logging studies have been performed in recent years to investigate different hydrothermal alteration zones from the surface to great depths in geothermal fields worldwide (Kristmannsdottir, 1979; Patrier et al., 1996; Fulignati et al., 1997; Gonzalez-Partida et al., 1997, 2000; Gianelli et al., 1998; Srodon, 1999; Lackschewitz et al., 2000; Okada et al., 2000; Sener and Gevrek, 2000; Yang et al., 2000, 2001; Suharno et al., 2000; Natland and Dick, 2001). The zoning pattern is generally governed by the thermal structure, i.e., temperature is the major control on clay mineralogy. Below the unaltered and cool shallow part, the ground is characterized by alterations of smectite and zeolites, which are both electrically conductive that form at temperatures above 70 °C. At higher temperatures, chlorite (in basaltic rocks) or illite (in acidic rocks), a less conductive clay mineral, is inter-layered with smectite. The proportion of chlorite or illite increases with temperature, especially above 180 °C. At 220–240 °C the zeolites and smectite disappear and pure chlorite or illite usually appears at temperatures of more than 240 °C, together with other high-temperature alteration minerals (epidote, etc.) in the propylitic alteration assemblage.

The resulting resistivity is related to the presence of clay minerals, and can be reduced considerably when the clay minerals are broadly distributed. The most common resistivity model in the literature for geothermal areas is that shown in Fig. 1. The distribution of

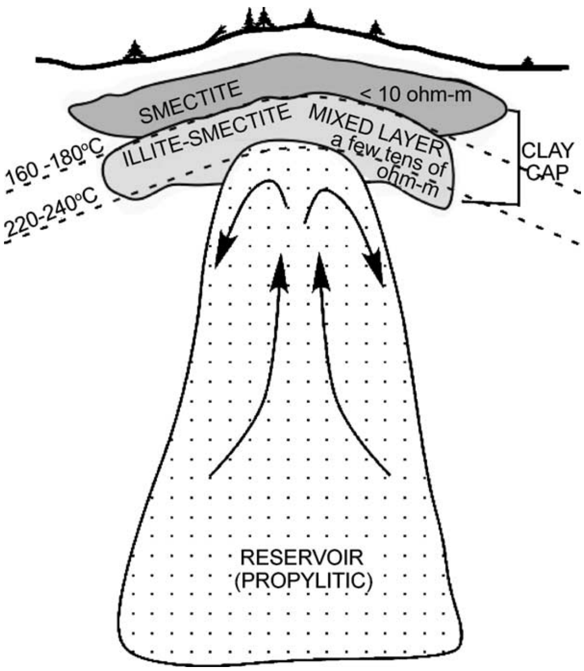

Fig. 1. Geothermal resistivity model, modified after Pellerin et al. (1996).