GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL STUDIES ON THE HYDROTHERMAL SYSTEM OF MENENGAI GEOTHERMAL FIELD, KENYA

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（ケニア国メネンガイ地熱地域の熱水系の地質学的，地球物理学的，地球化学的研究）

区　　分　：　甲

論 文 内 容 の 要 旨

Menengai volcano is one of the late Quaternary caldera volcanoes formed on a massive shield in the inner-trough of the Kenya rift valley, associated with a high thermal gradient resulting from shallow magmatic intrusion. While drilling of geothermal wells in Menengai area proved the existence of exploitable steam, the complexity of its geological setup has led to various technical setbacks where sited well targets turned out to be unproductive. These challenges were attributed partly to the lack of adequate knowledge to delineate the depth and lateral extent of heat sources. The aim of this study is to describe the mechanism of constraining geothermal resource of the Menengai geothermal area. This will help improve on well siting strategies which will lead to better targeting of the production zones.

The dissertation is composed of seven chapters as follows:

Chapter 1: This chapter describes the general background of studies as well as the general information about the geothermal status in Kenya and documented studies that were conducted by preceding researchers. The history and current status of geothermal development in Kenya, with a particular focus on the Menengai geothermal area, is given. Likewise, a description of the purpose, the plan and the structure of the thesis are also made.

Chapter 2: This chapter elaborates on the various characteristics that define the Menengai geothermal area beginning with a detailed review of the geology and structural setting of the area from both local and regional viewpoints. Then a description of the methodology used in the study of lineaments from Landsat images is presented. The description includes the extraction of lineaments from the satellite image, their analysis, and interpretation, and presentation of the results using a density map and rose diagrams. The last section reviews the hydrological constraints of the study area, both local and regional, and suggests six possible sources of fluid recharging the geothermal system.

Chapter 3: This chapter describes the gravity study. A comprehensive review of the gravity method both theory and applications is given then a description of gravity data and how the survey was conducted in the field is shown. Besides, some corrections that were done in the field, and others applied later to the data are also discussed. A Bouguer anomaly map is presented and the methods used to estimate the Bouguer density are discussed. An average density of 2.23×10^3 kg/m^3 was selected and deemed optimal to produce a smooth anomaly. The Bouguer anomaly shows two-fold high-density anomaly situated at the Menengai caldera and Olbanita area. A 3-D inversion model was constructed using the VOXI Earth Modelling tool and discussed in the final section of this chapter. The inversion was constrained, among others, using field lithological logs

recovered from the initial 10 deep geothermal wells drilled within the Menengai caldera. The inversion results reveal a 3-D geometry of the density structure below the Menengai caldera and Olrongai area and how the tectonic structures control the lateral extent of the density structures.

Chapter 4: This chapter gives subsurface resistivity structure of the study area using Magnetotelluric (MT) method. It gives a review of the MT method, its application in geothermal exploration and how measurements were done in the field. The data acquired suffered from distortion and static shift, and corrective measures were applied. Dimensionality analysis was carried out to determine the nature of the subsurface structures. MT inversion modeling (1-D, 2-D, and 3-D) was conducted, and the inversion results were interpreted and discussed in the last part of this chapter. The three models were able to highlight the dominant geophysical structures which appear to control hydrothermal processes within the geothermal system by depicting a typical structure of a high-enthalpy geothermal system. Two distinct resistivity features were also observed; a dike-like conductive body that cuts through the deeper resistive layer at the heart of caldera interpreted as a shallow pocket of a cooling magma, and a loop-shaped high resistive body that was observed in both the caldera and Olrongai-Olbanita areas interpreted either as cold or impervious formation.

Chapter 5: This chapter discusses the various geochemical methods that were considered and deemed essential for the present study. It begins by describing the theoretical background that forms the basis of this study, which includes isotope geochemistry and reactive transport modeling. A brief review is given on the geochemistry in geothermal exploration as well as the physico-chemical features of the geothermal system. The results of major chemical elements and isotope analysis are presented and discussed. The analysis of major chemical elements suggests that there are at least two sources: Na-dissolved CO_2 and SiO_2 end-members. The δD and $\delta^{18}O$ stable isotopes show that the Menengai geothermal waters are influenced mainly by waters of meteoric origin. The high anomaly of $^3He/^4He$ in the discharge fluids is sourced almost entirely from the upper mantle. Finally, the output of the reactive transport simulation results by using the computer code TOUGHREACT show that the secondary minerals (calcite, illite, mordenite, quartz and epidote) seem to reproduce the observed field data reasonably well.

Chapter 6: This chapter brings together the results from previous chapters and presents an integrated interpretation. This chapter presents the integrated interpretation of various methods used in this study to characterize the subsurface structures of the Menengai geothermal area. From the inversion results of gravity and MT data, the relationship in the geometry of the dense body is identified relative to the resistive body. The high-density body of Olrongai appears to mantle the resistive part while the resistive body inside the Menengai caldera seems to surround a high density structure. The resistive body is interpreted as cold or relatively impervious structures. The presence of fumarolic activities and low resistivity in the region is attributed to the rise of volcanic fluids beneath the summit of the dense body. This decrease in resistivity may have resulted from the effect of acidic waters formed by the interaction of local groundwater with rising steam and gases of volcanic origin causing intense hydrothermal alteration of the volcanic rocks at the upflow zone and fades laterally away at the outflow. The anomalous $^3He/^4He$ isotopes from the geothermal wells located on top of the dense body implies that the highly conductive zone is likely to be a cooling body of magma or a partial melt emplaced as a dike and is connected to a deeper magma chamber.

Chapter 7: This chapter presents the conclusions of the study which includes a summary of the conclusions made in preceding chapters.