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Magnetic Analysis to Determine the Permeability of a Geothermal Reservoir: Case Study of the Mt. Rajabasa Geothermal System, Lampung Selatan Indonesia

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ABSTRACT

A magnetic survey of the Mt. Rajabasa geothermal system has been conducted and the data were analyzed to determine the reservoir permeability of the study area.

Interpretation of magnetic anomalies for the Mt. Rajabasa geothermal system was carried out using the IGRF. Three dimensional modeling was used to interpret the pseudogravity anomaly.

The study shows that the demagnetized rock has good correlation with reservoir permeability. Hence, this analysis suggests that demagnetized rocks occur mainly associated with high permeability in the geothermal system.

1. INTRODUCTION

High temperature, water dominated geothermal systems hosted by Quaternary volcanic rocks are often associated with distinctive magnetic anomalies (Hochstein and Soengkono, 1997). These anomalies represent the demagnetization of reservoir rocks by the actions of thermal fluids altering ferromagnetic minerals (such as magnetite) into non-magnetic minerals (such as pyrite). Such a phenomenon is common in the Taupo Volcanic Zone, an area of Quaternary volcanism in New Zealand, where broad negative residual anomalies occur over more than ten geothermal systems (Hochstein and Soengkono, 1997b), but it has also been observed elsewhere. In the USA, for example, a ground magnetic survey over the Coso volcanic field in California recorded low anomalies associated with the geothermal prospect (Roquemore, 1984). Negative anomalies have also been observed over some Icelandic geothermal areas, such as at Reykjanes (Bjornsson et al., 1970) and Hengill (Bjornsson and Hersir, 1981). In Indonesia, an aeromagnetic survey over the Kamojang geothermal field in West Java recorded negative residual anomalies associated with hydrothermally demagnetized reservoir rocks (Soengkono et al., 1988). Hence, studies of magnetic anomalies are often useful for investigating high temperature geothermal systems hosted by Quaternary volcanic rocks (Soengkono, 2001). Since different types of volcanic rocks often have significant magnetization contrasts (differences of magnetic properties), magnetic anomalies can also be used to investigate their distribution and extent.

The main aims of this magnetic study are to investigate the gross subsurface stratigraphy of the RUW geothermal system based on the magnetic properties of the rocks and, if possible, to delineate the geothermal reservoir by modeling hydrothermally demagnetised rocks.

2. METHODS

2.1 Data Acquisition

The magnetic data used in this study were collected during a ground magnetic survey carried out by Team IGA Lampung and Laboratorium Geofisika Unila 2006. The magnetic measurements were made using a portable Flux-Gate magnetometer. For this study, a list of about 135 magnetic measurements was obtained, which includes station coordinates, magnetometer readings (total strength) and diurnal variations.

Figure 1: Magnetic anomaly over the Mt. Rajabasa geothermal system. Interval contour is 200 nT.

2.2 Reduction of Magnetic Anomalies

The contour map of the observed magnetic field of the Mt. Rajabasa geothermal system reduced for diurnal variation over the Mt. Rajabasa geothermal system is shown in Figure 1. To obtain magnetic anomalies associated with local magnetic variations of rocks, it is necessary to remove the normal geomagnetic field of the Mt. Rajabasa geothermal system from the data. The normal geomagnetic field used for the reduction was the International Geomagnetic Reference Field (IGRF) computed using the program GEOMAG (National Geophysical Data Center, 2005) for 2006 data collecting. After the reduction of magnetic anomalies a “reduced to the pole” method was used. The mathematic procedure is carried on a grid written from a contour map, similar to that of contouring procedures, from observed values (not a grid). The anomaly depends on its magnetic latitude and the corresponding variation of the dip angle of the magnetization vector in the body. The resulting magnetic anomaly is represented in Figure 1. The magnetic anomalies are shown by contours with an interval of 200 nT.

2.3 Paleomagnetism

No magnetization measurements of rocks from the Mt. Rajabasa geothermal system were available for this study. The lithology of the area consists mostly of Miocene to Pleistocene lava flows and pyroclastics. These types of rocks usually have a significant thermo remanent magnetization (TRM) because of their young age and quick cooling (Tarling, 1971).

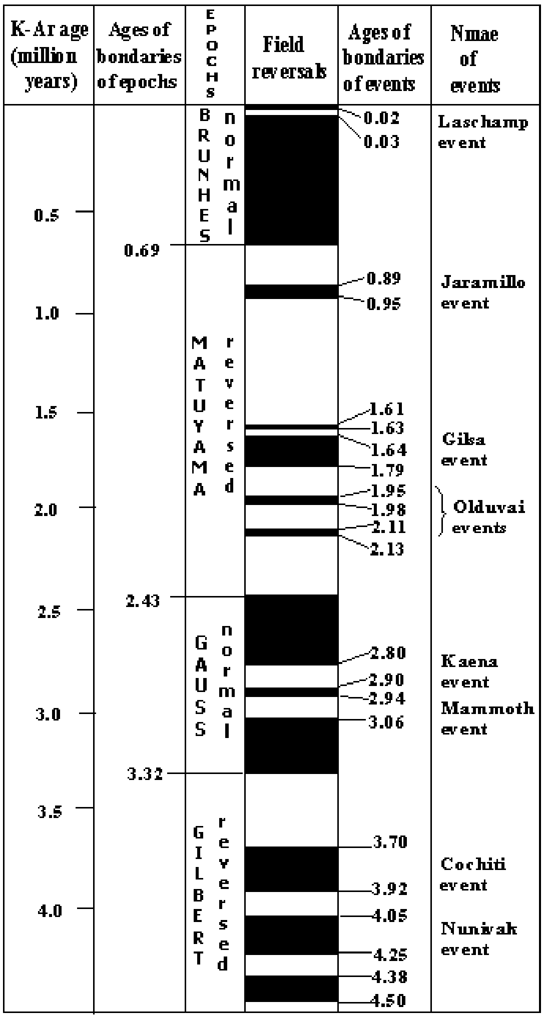

Figure 2: Geomagnetic polarity time-scale of the Cenozoic (after Duff, 1993; Suharno, 2003).

TRM is the permanent magnetization that was acquired when a rock cooled below the Curie point of magnetite (580^{o}C) (Tarling, 1971). The direction of TRM follows that of the earth's magnetic field at the time of cooling. A rock that cooled during a period when the earth's magnetic field was reversed (Figure 3) would acquire a TRM with a reversed polarity (Duff, 1993; Cande and Kent, 1995).

Magnetic anomalies are associated with the total magnetization of rocks, which is the vector sum of remanent and induced magnetizations. The induced magnetization is always parallel to the present day earth's magnetic field. Its strength is determined by the so-called magnetic susceptibility, which entirely depends on the abundance and identities of magnetic minerals in the rock. In most Quaternary volcanic rocks the strength of TRM is much greater than that of the induced magnetization (Soengkono, 1990). Thus, the total magnetization of most of the reversely magnetized young volcanic rocks would also be reversed. However, remanent magnetizations reduce in strength with time (Tarling, 1971), so the total magnetization of older volcanic rocks would be dominated by the magnetic susceptibility component and this would be aligned in the direction of the present day magnetic field.

The presence of reversely magnetized rocks can be determined by taking rock samples and measuring their magnetic polarities, or estimated using magnetic interpretation results and comparing them with the ages of the rocks (Duff, 1993). Only the latter was done in this study, since no magnetization measurements of rock samples were carried out.

In the Mt. Rajabasa geothermal system, hydrothermally demagnetized rocks probably occur in the southeastern and western part (Figure 2). Hydrothermally demagnetized rocks in the south-east, extending from summit of Mt. Rajabasa northeast around of the summit Mt. Balirang; in the western part, extend from the Balirang River, where negative magnetic anomalies are associated with surface thermal manifestations. Normally magnetized rocks may be present within Mt. Rajabasa, of the study area shown on Figure 2, where positive magnetic anomalies are not associated with any thermal activity. Most likely, the hydrothermal activity does not reach the younger rocks.

2.4 Three Dimensional Modeling

The three dimensional program is a compilation of algorithms for inverting gravity / pseudogravity data gathered in three dimensions. This program has greater flexibility and efficiency than the basic inversion algorithms. In particular it allows larger problems to be solved through the use of wavelet transforms, and it allows geophysical constraints, in the form of upper and lower bounds on the density of each cell, to be included.

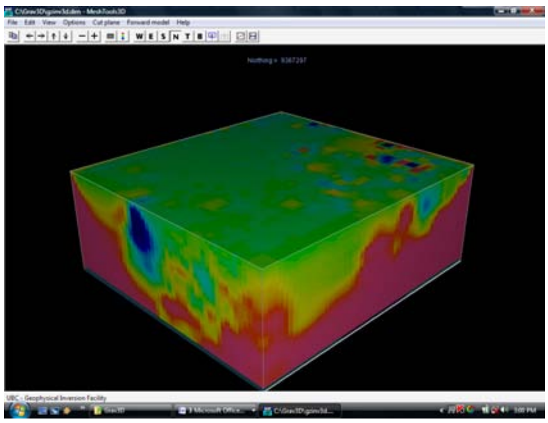

Figure 3: Three dimensional body facing north-east.

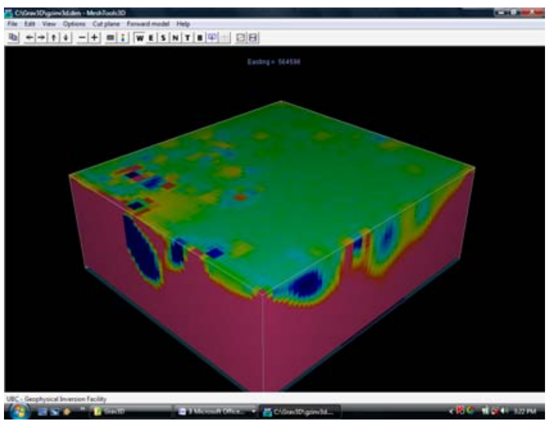

Figure 4: Three dimensional body facing south-west.

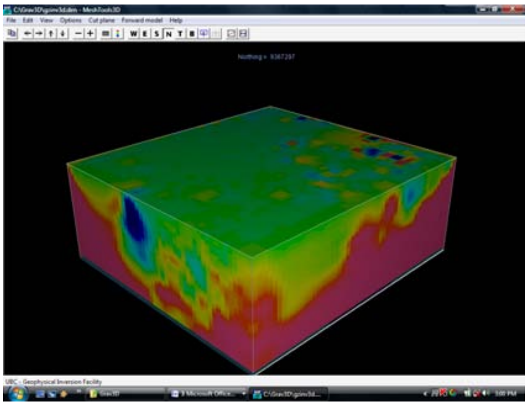

Figure 5: Three dimensional body facing north-west.

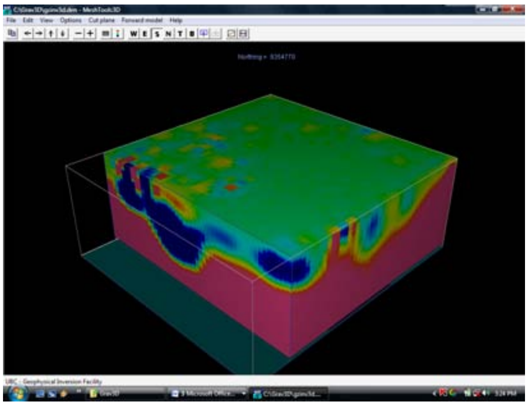

Figure 6: Three dimensional body facing to south-west, cut at Easting 571175.

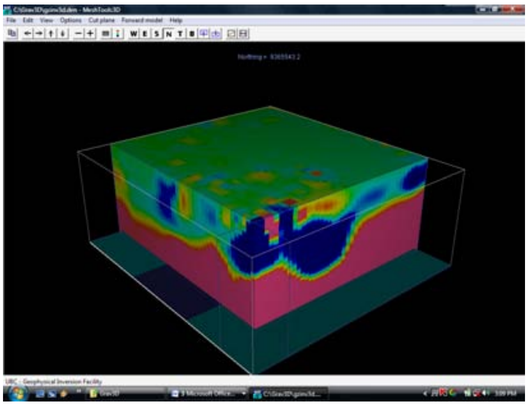

Figure 7: Three dimensional body facing to north-west.

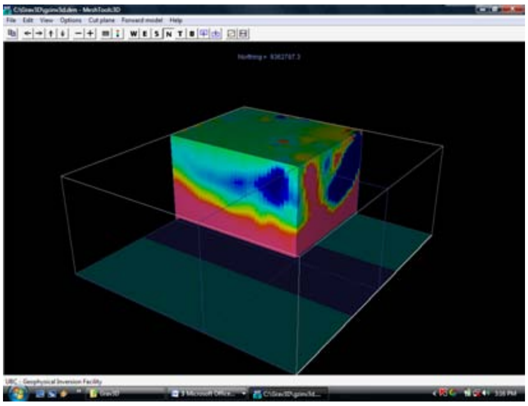

Figure 8: Three dimensional body facing to north-east, cut at E: 571175, N: 9362787

3. DISCUSSION

3.1 Qualitative Analysis of the Magnetic Anomalies

The data in Figure 1 show that negative magnetic anomalies are dominant in the Mt. Rajabasa geothermal system. Magnetic investigations over Quaternary volcanic terrain in New Zealand have shown that negative magnetic anomalies may be caused by topographic effects, hydrothermally demagnetized geothermal reservoirs, or reversely magnetized rocks (Modriniak and Studt, 1959; Hochstein and Hunt, 1970; Ignacio, 1985; Salt, 1986; van Dijck, 1988; Soengkono, 1990; Soengkono, 1993; Soengkono, 2001), particularly in Indonesia (Soengkono et al., 1988; Suharno, 2003; Suharno, 2007).

Negative magnetic anomalies caused by topographic effects are often small in amplitude and wavelength, and show some correlation with topographic contours. Those caused by hydrothermally demagnetized rocks are usually broader and often stronger than the topographic effects. Such hydrothermal demagnetization anomalies can often be recognized where they are associated with an active geothermal system. In some cases where the association with the geothermal system is less obvious, hydrothermal demagnetization anomalies may be difficult to distinguish from those caused by reversely magnetized rocks.

In the Mt. Rajabasa geothermal system, hydrothermally demagnetized rocks probably occur in the southeastern and western part (Figure 2). Hydrothermally demagnetized rocks in the south-east, extending from summit of Mt. Rajabasa northeast around of the summit Mt. Balirang; in the western part, extend from the Balirang River, where negative magnetic anomalies are associated with surface thermal manifestations. Normally magnetized rocks may be present within Mt. Rajabasa, in the study area shown on Figure 2, where positive magnetic anomalies are not associated with any thermal activity. Most likely, the hydrothermal activity does not reach the younger rocks.

3.2 Model Analysis

Figure 3, shows the three dimensional model of the study area. The body faces north-east. Figure 4, shows the three dimensional model of the study area. The body faces south-west. It shows that the permeable area (blue color) should occur in the eastern, southern and western part.

Figure 6, shows the three dimensional model facing south-west, cut at Easting 571175. It shows that the permeable area (blue color) spreads out along a line through Easting 571175.

Figure 7, shows the model of the study area facing north-west. It shows the permeable area surrounding the Kecapi and Way Balirang.

Figure 8, shows the three dimensional model facing north-east, E: 571175, N: 9362787. It shows that a permeable area (blue color) occurs around Kecubung and Pantai Wartawan.

4. SUMMARY

Data collected in the ground magnetic survey of Mt. Rajabasa conducted by Team IGA Lampung and Laboratorium Geofisika Unila 2006 was analyzed as part of this study. The results show that negative anomalies are dominant within the Mt. Rajabasa geothermal system. Qualitative interpretations were categorized into two groups. A group within the southeastern study area, around the summit of Mt. Rajabasa and Mt. Balirang appear to have negative magnetization and have probably been hydrothermally altered. The group within the western study area extends from Balirang River forward to Canggung. It also appears to have negative magnetization and to have been hydrothermally altered. The positive magnetization and areas are unaffected by hydrothermal alteration, and instances of these were found in some parts around study area.

This magnetic study has shown that hydrothermally demagnetized rocks are widespread in the studied area, which suggests that the Mt. Rajabasa geothermal system is a single, large system. At shallow depth, the hydrothermally demagnetized rocks are unaltered normally magnetized rocks from a larger zone of hydrothermal demagnetization surrounding the Mt. Rajabasa, Kalianda, Lampung Selatan.

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6. REFERENCES

Bjornsson, S., Arnorsson, S., and Tomsson, J., 1970, Exploration of the Reykjanes Thermal Brine Area: Geothermics, v.2:2, p.1640-1650.

Bjornsson, A., and Hersir, G., 1981, Geophysi-cal reconnaissance study of the Hengill high-temperature area, SW-Iceland: Geothermal Resources Council Transactions, v.5, p.55-58.

Cande, S. C., and Kent, D.V., 1995, Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic: Journal of Geophysical Research, v. 100, p. 6093-6095.

Duff, P. M. D., 1993, Holmes' Principle of Physical Geology, Chapman & Hall, 791 p.

Hochstein, M. P., and Hunt, T. M., 1970, Seismic, gravity and magnetic studies: Broadlands geothermal field: Geothermics, v. 2, p. 333-346.

Hochstein, M. P., and Soengkono, S., 1997, Magnetic anomalies associated with high temperature reservoirs in the Taupo volcanic zone (NewZealand): Geothermics, v. 26, p. 1-24.

Ignacio, C. P., 1985, Geophysical study of the Atiamuri and Ohakuri geothermal systems (Taupo Volcanic Zone) [MSc thesis]: the University of Auckland.

Modriniak, N., and Studt, F. E., 1959, Geological Structure and volcanism of Taupo-Tarawera district: NZ Journal of Geology and Geophysics, v. 2, p. 654-684.

National Geophysical Data Centre, 2005, GEOMAG Computer Program and the 1990 Coefficients for IGRF Model, World Data Centre-A for Solid Earth Geophysics, NOAA, E/GCI, 325 Broadway, Boulder, CO 80304, USA.

Roquemore, G. R., 1984, Ground magnetic survey in the Coso Range, California: Journal Geophysics Research, v. 89, p. 3309-3314.

Salt, D. M., 1986, Aeromagnetic survey of Okataina volcaic centre and study of magnetometer noise characteristics [MSc thesis]: the University of Auckland.

Soengkono, S., Hochstein, M. P., and Suranto, 1988, Magnetic anomalies over the Kamojang geothermal field (West Java, Indonesia): Proceedings 10th New Zealand Geothermal Workshop 1988, p. 139-142.

Soengkono, S., 1990, Geophysical study of the Western Volcanic Zone [PhD thesis]: the University of Auckland.

Soengkono, S., 1993, Interpretation of aeromagnetic data over the Orakeikorako geothermal field, Central North Island, New Zealand: Proceedings 15th New Zealand Geothermal Workshop, p. 207-212.

Soengkono, S., 2001, Interpretation of magnetic anomalies over the Waimangu geothermal area, Taupo volcanic zone, New Zealand: Geothermics, v. 30, p. 443-459.

Soengkono, S., Hochstein, M. P., and Suranto, 1988, Magnetic anomalies over the Kamojang geothermal field (West Java, Indonesia): Proceedings 10th New Zealand Geothermal Workshop 1988, p. 139-142.

Suharno, 2003. Geophysical, Geological and Paleohydrological Studies of the Rendingan-Ulubelu-Waypanas (RUW) geothermal system, Lampung, Indonesia. [Ph.D Thesis]: of the University of Auckland.

Suharno and Soengkono, S., 2007. Magnetic Characteristics of the Rendingan-Ulubelu-Waypanas (RUW) Geothermal System, Lampung Indonesia. Seminar Internasional JCG, Bali 2007.

Van Dijck, M. F., 1988, Interpretation of airborne magnetic anomalies over selected geothermal systems in the Maroa-Taupo area [MSc thesis]: of the University of Auckland.